



**ORAU TEAM
Dose Reconstruction
Project for NIOSH**

Oak Ridge Associated Universities | NV5|Dade Moeller | MJW Technical Services

DOE Review Release 05/05/2020

Site Profile for The Carborundum Company ORAUT-TKBS-0061 Rev. 00
Effective Date: 04/23/2020
Supersedes: None

Subject Expert(s): Mutty M. Sharfi, Joseph Guido, Thomas Tomes, and Richard J. Traub

| | | | |
|--------------------------|--|-------------------|-------------------|
| Document Owner Approval: | <u>Signature on File</u> Mutty M. Sharfi, Document Owner | Approval Date: | <u>04/21/2020</u> |
| Concurrence: | <u>Signature on File</u> John M. Byrne, Objective 1 Manager | Concurrence Date: | <u>04/21/2020</u> |
| Concurrence: | <u>Signature on File</u> Scott R. Siebert, Objective 3 Manager | Concurrence Date: | <u>04/21/2020</u> |
| Concurrence: | <u>Vickie S. Short Signature on File for</u> Kate Kimpan, Project Director | Concurrence Date: | <u>04/21/2020</u> |
| Approval: | <u>Signature on File</u> Timothy D. Taulbee, Associate Director for Science | Approval Date: | <u>04/23/2020</u> |

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

New Total Rewrite Revision Page Change

PUBLICATION RECORD

| EFFECTIVE DATE | REVISION NUMBER | DESCRIPTION |
|----------------|-----------------|---|
| 04/23/2020 | 00 | New technical basis document initiated for The Carborundum Company, Niagara Falls, New York. Incorporates formal internal and NIOSH review comments. Training required: As determined by the Objective Manager. Initiated by Mutty M. Sharfi. |

TRADEMARK INFORMATION

Carborundum® and Hexoloy® are registered trademarks of Saint-Gobain Ceramics & Plastics in the United States and/or other countries.

Fiberfrax® is a registered trademark of Unifrax in the United States and/or other countries.

Globar® is a registered trademark of Sandvik Wire and Heating Technology Corporation in the United States and/or other countries.

All other trademarks are the property of their respective owners.

TABLE OF CONTENTS

| <u>SECTION</u> | <u>TITLE</u> | <u>PAGE</u> |
|----------------|---|-------------|
| | Acronyms and Abbreviations | 6 |
| 1.0 | Introduction | 8 |
| 1.1 | Purpose..... | 9 |
| 1.2 | Scope..... | 9 |
| 2.0 | Site Description..... | 10 |
| 2.1 | Plant and Process Descriptions | 10 |
| 2.1.1 | First Operational Period Process Descriptions, 1943..... | 13 |
| 2.1.2 | First Residual Period, 1943 to 1958 | 14 |
| 2.1.3 | Second Operational Period Process Descriptions, 1959 to 1967..... | 14 |
| 2.1.4 | Second Residual Period, 1968 to 1992..... | 19 |
| 2.2 | Radiological Exposure Sources from Operations | 20 |
| 2.2.1 | Internal Radiological Exposure Sources from Operations..... | 22 |
| 2.2.1.1 | First Operational Period, 1943 | 22 |
| 2.2.1.2 | First Residual Period, 1943 to 1958 | 22 |
| 2.2.1.3 | Second Operational Period, 1959 to 1967 | 22 |
| 2.2.1.4 | Second Residual Period, 1968 to 1992..... | 23 |
| 2.2.2 | External Radiological Exposure Sources from Operations..... | 23 |
| 2.2.2.1 | External Radiological Exposure Sources by Radiation Type | 23 |
| 2.2.2.1.1 | Photon..... | 23 |
| 2.2.2.1.2 | Beta..... | 24 |
| 2.2.2.1.3 | Neutron | 24 |
| 2.2.2.2 | External Radiological Exposure Sources by Period..... | 24 |
| 2.2.2.2.1 | First Operational Period, 1943 | 24 |
| 2.2.2.2.2 | First Residual Period, 1943 to 1958..... | 24 |
| 2.2.2.2.3 | Second Operational Period, 1959 to 1967 | 24 |
| 2.2.2.2.4 | Second Residual Period, 1968 to 1992..... | 26 |
| 3.0 | Occupational Medical Dose | 26 |
| 4.0 | Occupational Onsite Ambient and Environmental Dose | 27 |
| 5.0 | Occupational Internal Dose..... | 27 |
| 5.1 | Available Internal Monitoring Data | 27 |
| 5.2 | Methods for Bounding Unmonitored Internal Dose | 27 |
| 5.2.1 | First Operational Period, 1943..... | 28 |
| 5.2.2 | First Residual Dose Period, 1943 to 1958..... | 28 |
| 5.2.3 | Second Operational Period, 1959 to 1967 | 29 |
| 5.2.3.1 | Uranium..... | 30 |
| 5.2.3.2 | Plutonium | 31 |
| 5.2.3.3 | Summary of Second Operational Period Intake Rates..... | 31 |
| 5.2.4 | Second Residual Dose Period, 1968 to 1992 | 32 |
| 6.0 | Occupational External Dose | 33 |
| 6.1 | Available External Monitoring Data | 33 |
| 6.2 | Methods for Bounding Unmonitored External Dose..... | 33 |
| 6.2.1 | First Operational Period, 1943..... | 34 |

| | | |
|--------------|---|----|
| 6.2.2 | First Residual Period, 1944 to 1958 | 35 |
| 6.2.3 | Second Operational Period, 1959 to 1967 | 35 |
| 6.2.3.1 | Uranium | 36 |
| 6.2.3.2 | Plutonium | 37 |
| 6.2.3.2.1 | Geometry and Materials | 37 |
| 6.2.3.2.2 | Radiation Source Terms | 38 |
| 6.2.3.2.3 | Dose Equivalent Calculations | 39 |
| 6.2.3.2.4 | Simulation Results | 39 |
| 6.2.3.3 | X-Ray Diffraction | 40 |
| 6.2.4 | Second Residual Period, 1968 to 1992 | 42 |
| 7.0 | Attributions and Annotations | 42 |
| | References | 43 |
| | Glossary | 50 |
| ATTACHMENT A | RADIOLOGICAL CONTRACT WORK DURING THE SECOND OPERATIONAL PERIOD | 52 |

LIST OF TABLES

| <u>TABLE</u> | <u>TITLE</u> | <u>PAGE</u> |
|--------------|--|-------------|
| 2-1 | Radiological work during the first operational period | 14 |
| 2-2 | Isotopic analysis of plutonium mixture | 20 |
| 2-3 | Summary of Carborundum exposure sources over the contract timelines | 21 |
| 2-4 | Principal radiation emissions from natural uranium and short-lived decay products | 23 |
| 2-5 | Radioactive material inventory in 1962 | 25 |
| 5-1 | Inhalation intake rates for the first operational period | 28 |
| 5-2 | Ingestion intake rates for the first operational period | 28 |
| 5-3 | Uranium intake rates for the first residual period | 29 |
| 5-4 | Inhalation intake rates for the second operational period | 30 |
| 5-5 | Ingestion intake rates for the second operational period | 30 |
| 5-6 | RU mixture ratios | 30 |
| 5-7 | Isotopic analysis of plutonium mixture | 32 |
| 5-8 | Plutonium mixture isotopic to total alpha activity ratios | 32 |
| 5-9 | Total alpha intake rates for the plutonium mixture during the second residual period | 33 |
| 6-1 | Penetrating dose rates for the first operational period | 34 |
| 6-2 | Nonpenetrating dose rates for the first operational period | 34 |
| 6-3 | External dose rates for the first residual period | 36 |
| 6-4 | Penetrating dose rates for the second operational period | 37 |
| 6-5 | Nonpenetrating dose rates for the second operational period | 37 |
| 6-6 | Isotopic analysis of plutonium mixture | 38 |
| 6-7 | Isotopic analysis of uranium mixture | 38 |
| 6-8 | External dose from second operational period for plutonium | 40 |
| A-1 | Radiological contract work during the second operational period | 52 |

LIST OF FIGURES

| <u>FIGURE</u> | <u>TITLE</u> | <u>PAGE</u> |
|----------------------|--|--------------------|
| 2-1 | The Carborundum Company site on Buffalo Avenue in Niagara Falls, New York..... | 10 |
| 2-2 | Carborundum facility for investigating refractory materials | 12 |

ACRONYMS AND ABBREVIATIONS

| | |
|---------------|--|
| AEC | U.S. Atomic Energy Commission |
| ANSI | American National Standards Institute |
| AWE | atomic weapons employer |
| °C | degrees Celsius |
| cm | centimeter |
| d | day |
| DCF | dose conversion factor |
| DOE | U.S. Department of Energy |
| DOL | U.S. Department of Labor |
| dpm | disintegrations per minute |
| DU | depleted uranium |
| EEOICPA | Energy Employees Occupational Illness Compensation Program Act of 2000 |
| EU | enriched uranium |
| ft | foot |
| g | gram |
| GE | General Electric Company |
| GSD | geometric standard deviation |
| <i>H*(10)</i> | ambient dose equivalent at 10 millimeters depth in tissue |
| <i>Hp(10)</i> | personal dose equivalent at 10 millimeters depth in tissue |
| HHM | Herring-Hall-Marvin |
| hr | hour |
| <i>HT</i> | organ dose equivalent |
| ICRP | International Commission on Radiological Protection |
| in. | inch |
| keV | kiloelectron-volt, 1,000 electron-volts |
| kg | kilogram |
| lb | pound |
| m | meter |
| MeV | megaelectron-volt, 1 million electron-volts |
| mg | milligram |
| mL | milliliter |
| min | minute |
| NBS | National Bureau of Standards |
| NDA | Nuclear Development Corporation of America |
| NIOSH | National Institute for Occupational Safety and Health |
| NU | natural uranium |
| ORAU | Oak Ridge Associated Universities |
| ORNL | Oak Ridge National Laboratory |

| | |
|-------------|--|
| PHS | Public Health Service |
| ppm | parts per million |
| R | roentgen |
| R | exposure |
| RU | recycled uranium |
| SEC | Special Exposure Cohort |
| SRDB Ref ID | Site Research Database Reference Identification (number) |
| TBD | technical basis document |
| TCC | The Carborundum Company |
| UNC | United Nuclear Corporation |
| UPu | uranium-plutonium (alloy) |
| (UPu)C | uranium-plutonium (alloy) carbide |
| USC | <i>United States Code</i> |
| wt% | weight percent |
| XRD | X-ray diffraction analysis |
| yr | year |

1.0 INTRODUCTION

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

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

Under EEOICPA, a Part B cancer claim for benefits must be based on an energy employee’s eligible employment and occupational radiation exposure at a DOE or AWE facility during the facility’s designated time period and location (i.e., a “covered employee with cancer”). After DOL determines that a claim meets the eligibility requirements under Part B of EEOICPA, DOL transmits the claim to NIOSH for a dose reconstruction. EEOICPA provides, among other things, guidance on eligible employment and types of radiation exposure to be included in an individual dose reconstruction. Under EEOICPA, eligible employment at an AWE facility is categorized as employment either (1) during “a period when the [AWE] was processing or producing, for the use by the United States, material that emitted radiation and was used in the production of an atomic weapon, excluding uranium mining and milling,” (i.e., the operational period); or (2) during a period that NIOSH has determined that “there is a potential for significant residual contamination outside of the period in which weapons-related production occurred” (i.e., the residual contamination period) [42 USC 7384I(3)].

The EEOICPA definition for eligible AWE employment during the operational and the residual contamination periods creates two statutory frameworks directing types of radiation exposures to be included in individual dose reconstructions. For employment falling within an AWE facility’s operational period, NIOSH includes radiation exposures incurred in the performance of duty, such as medical X-rays received as a condition of employment for participating in DOE projects at an AWE facility in dose reconstructions. Additionally, the total measured, occupational radiation exposure during an operational period may include radiation exposure contributed by the Naval Nuclear Propulsion Program at the AWE facility and any radiation exposure received from the production of commercial radioactive products that were concurrently manufactured by the AWE facility during the operational period. In contrast, only two categories of radiation exposure are included in dose

reconstructions for claims involving employment during the residual contamination period [42 USC 7384n(c)(4)]. First, NIOSH must include exposures to radiological contaminants resulting from activities that had a nuclear-weapon nexus or conducted by or on behalf of the DOE (with an exclusion of activities related to, among other things, the Naval Nuclear Propulsion Program) that took place during the operational period [42 USC 7384n(c)(4)(A)]. Second, radiation doses from sources not included in the first category but cannot be distinguished through reliable documentation should also be included in dose reconstructions [42 USC 7384n(c)(4)(B)]. Furthermore, NIOSH does not include doses from medical X-rays performed during the residual contamination period in dose reconstructions because all DOE-related activities have ceased during the residual contamination period, and thus any medical X-ray performed during the residual contamination period is not a condition of employment for participating in DOE-related activities [NIOSH 2007].

Likewise, NIOSH does not consider the following types of exposure as those incurred in the performance of duty as a condition of employment for DOE-related activities at an AWE facility. Therefore, these exposures are not included in dose reconstructions for either the operational or residual contamination period [NIOSH 2010]:

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

1.1 PURPOSE

This site profile provides methods for dose reconstruction for The Carborundum Company in Niagara Falls, New York.

1.2 SCOPE

The covered operational periods for Carborundum are from June 1943 through September 1943 and from 1959 through 1967. The residual radiation periods are from October 1943 through 1958 and from 1968 through 1992.

In June of 1943, the Carborundum Company at its Gload Plant and Buffalo Avenue locations performed experimental grinding of uranium metal using a centerless grinder. The actual location of this work is unknown. Uranium slugs were received in June and shipped back in September 1943. From 1959 through 1967, the company used powder fabrication techniques to manufacture uranium, plutonium, and carbide pellets for a U.S. Atomic Energy Commission (AEC) research program. The Hanford facility supplied Carborundum with materials during that period.

Carborundum performed work during the 1950s that is not covered under EEOICPA, including fabricating nuclear fuel elements for commercial purposes and producing zirconium, hafnium, and titanium for AEC's special reactor materials program.

During the period of residual contamination, as designated by NIOSH and as noted in the dates above, employees of subsequent owners and operators of this facility are also covered under EEOICPA.

Section 2.0 describes facilities and operations at the site. Sections 3.0 through 6.0 discuss occupational medical, environmental, internal, and external dose, respectively. Attributions and annotations, indicated by bracketed callouts and used to identify the source, justification, or clarification of the associated information, are presented in Section 7.0.

2.0 SITE DESCRIPTION

2.1 PLANT AND PROCESS DESCRIPTIONS

The Carborundum Company was located at 1920 Buffalo Avenue (address on file from 1921 to 2001) in Niagara Falls, New York. The company was founded on September 21, 1891, after the discovery of crystal stones that chemical analysis revealed to be silicon carbide. Because the silicon carbide powder was considered an excellent abrasive material, the company became known as the electrochemical and electrometallurgical center of the world. The abrasive products appeared on grinding wheels, sharpening stones, and sandpaper. Carborundum developed newer and softer manmade abrasives, and before long it was a national and international enterprise [TCC 1991].

The Gload Plant is also listed in the covered facility definition for Carborundum. During the 1920s, the Wireless Resistor Company of America, based in Milwaukee, Wisconsin, pioneered the use of silicon carbide in an electric heating element called a "Gload." In 1927, Carborundum purchased that company, by then called the Gload Corporation, and moved its production to Niagara Falls. A new facility was constructed on Hyde Park Boulevard and the transfer was complete in August 1928 [Advameg 2015, p. 3; TCC 1991, p. 44; NYSDEC 2009].

No documentation has been found about the exact physical size of the facility or the exact number of buildings for any period at the site. Figure 2-1 shows a historical view of the facility's main offices and plant buildings. From interviews, it is estimated that 30 to 50 buildings were on site at Buffalo Avenue by the second operational period [ORAUT 2015a, 2015b]; one interviewee suggested that, at that time, the site encompassed about 200 acres [ORAUT 2015c]. In 1953, new modern quarters for the Research and Development Division were completed; these quarters occupied over 60,000 ft² in Building 1. This facility included complete laboratory and mechanical equipment; a battery of experimental, high-temperature electric furnaces; high-temperature and electronic microscopes; an analytical X-ray installation; sonic graders; a research machine shop; an extensive technical library; and one of the most comprehensive patent reference departments in the country [TCC 1991].

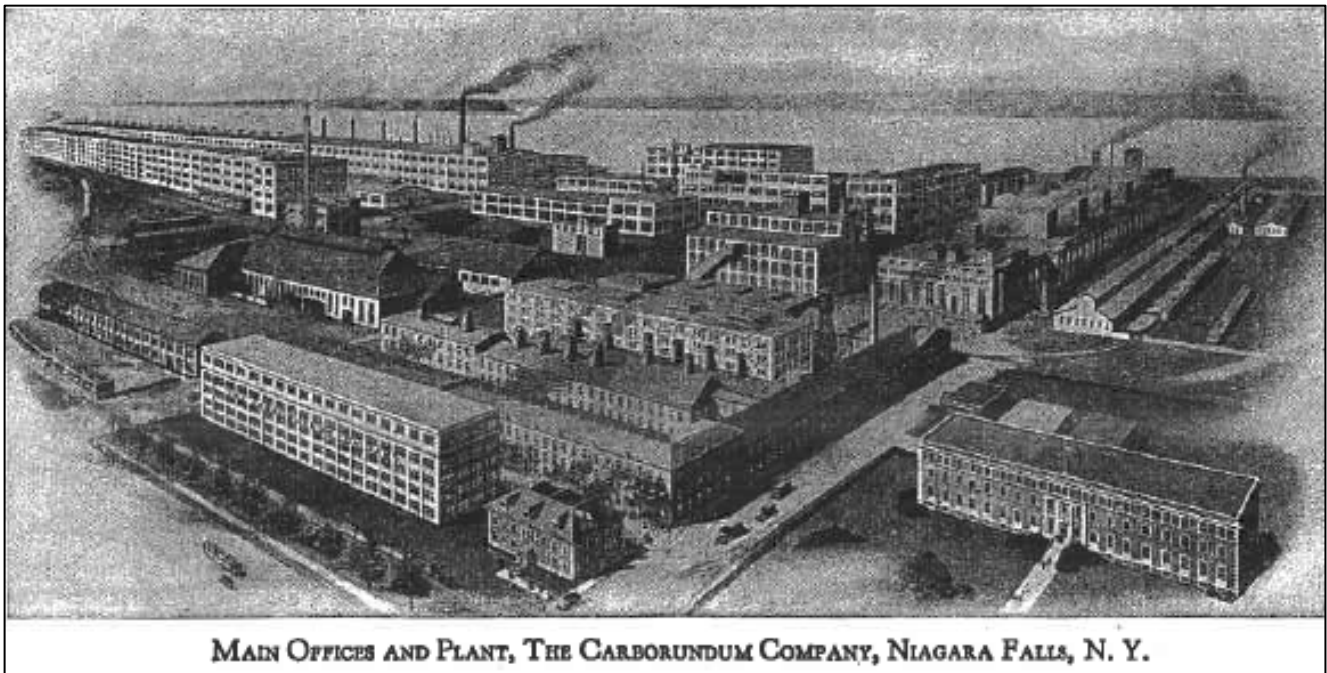


Figure 2-1. The Carborundum Company site on Buffalo Avenue in Niagara Falls, New York [TCC no date, p. 12].

Records show that Carborundum employed about 6,000 to 7,000 employees during the mid-to-late 1940s. Limited documentation has been found about the number of employees in later years up to the point in 1983 when the plant was closed and the remaining employees at the site lost their jobs [Kostoff 2008].

The Carborundum Niagara Falls location was involved with the Manhattan Engineer District (MED) programs in 1943 and did work for AEC from 1959 through 1967.

The 1943 work involved experimental centerless-grinding of uranium metal using different abrasives. It is assumed the 1943 work could have been performed at either the Buffalo Avenue location or the Global Plant location, although no information on the location of that work is currently available. Carborundum was also involved in nuclear fuel development work for the AEC from 1959 through 1967. The 1959 through 1967 work was performed in a building at the Buffalo Avenue location. The processes involved during these two separate AEC operational periods varied considerably. The following sections discuss the available information on Carborundum operations for the MED and AEC during these two periods.

DuPont, on behalf of the U.S. Government, subcontracted different companies to perform various types of work turning uranium billets into finished slugs for use in the Clinton and Hanford piles. In June 1943, DuPont had unfinished slugs delivered to Carborundum to determine the type of abrasive wheel and optimum speeds appropriate for production grinding; this experimental grinding was performed in June 1943.

Throughout the late 1940s and 1950s, between the first and second covered operational periods, Carborundum became a very successful company in the field of industrial technology and grew more sophisticated and complex, attracting many talented research scientists to Niagara Falls. In 1953, the company completed modern new quarters for its Research and Development Division, which developed new products such as Fiberfrax, a ceramic-fiber high-temperature insulation.

In 1959, under Contract No. AT (40-1)-2558, Carborundum did work for the U.S. Atomic Energy Commission (AEC) as part of the AEC Fuel Cycle Development Program. The objective of this work was to develop refractory uranium materials possessing sufficient advantage over uranium dioxide to warrant their use as reactor fuels. The initial contract covered the period from May 1959 through December 1960 [Taylor and McMurtry 1961a, p. 7]. The contract was modified and extended to continue this work. A letter from September 19, 1962, discusses inventory and instructions for disposal of the government-owned source and special nuclear materials in relation to the closeout of this contract [Rose 1962, p. 2].

Building 1 was the location of uranium and plutonium work from 1959 to 1967. Over the years, additions were added to Building 1. These additions were known as Buildings 4 and 16. However, all of the nuclear research work was done on fourth floor on the western side of Building 1 [ORAUT 2015b; ORAUT 2015e]. The X-ray laboratory was on the second floor, as was the spectrographic analysis [ORAUT 2015e].

In 1960, Carborundum completed a Central Laboratory facility upgrade for investigating the synthesis and fabrication of refractory materials containing plutonium in such forms as carbides, silicides, oxides, and nitrides, which was an addition to the uranium contract work. These materials are toxic and some are very sensitive to oxygen and moisture, especially in a finely divided form. To work with these materials, a leak-tight glovebox system was required. In addition, a decision to fabricate mainly by sintering at atmospheric pressure, rather than in a vacuum, required the glovebox to have a carefully controlled inert atmosphere. The facility was also protected by alarms and safety devices that were in continuous operation. The facility operated on a one-shift, five-day week basis [Saulino et al. 1962]. This facility was in the Central Laboratory; it was 15 ft wide, 48 ft long and 8.5 ft high with

enameled steel-paneled walls and ceiling and vinyl floor covering (see Figure 2-2). This area had a change room (11 by 15 ft) and a work space (15 by 37 ft). A helium purification and recirculation system serviced the building and occupied a 12-by 24-ft space in an adjacent room [Saulino et al. 1962, p. 3]. The Central Laboratory (also known as the Central Facility) refers to the fourth floor of Building 1.

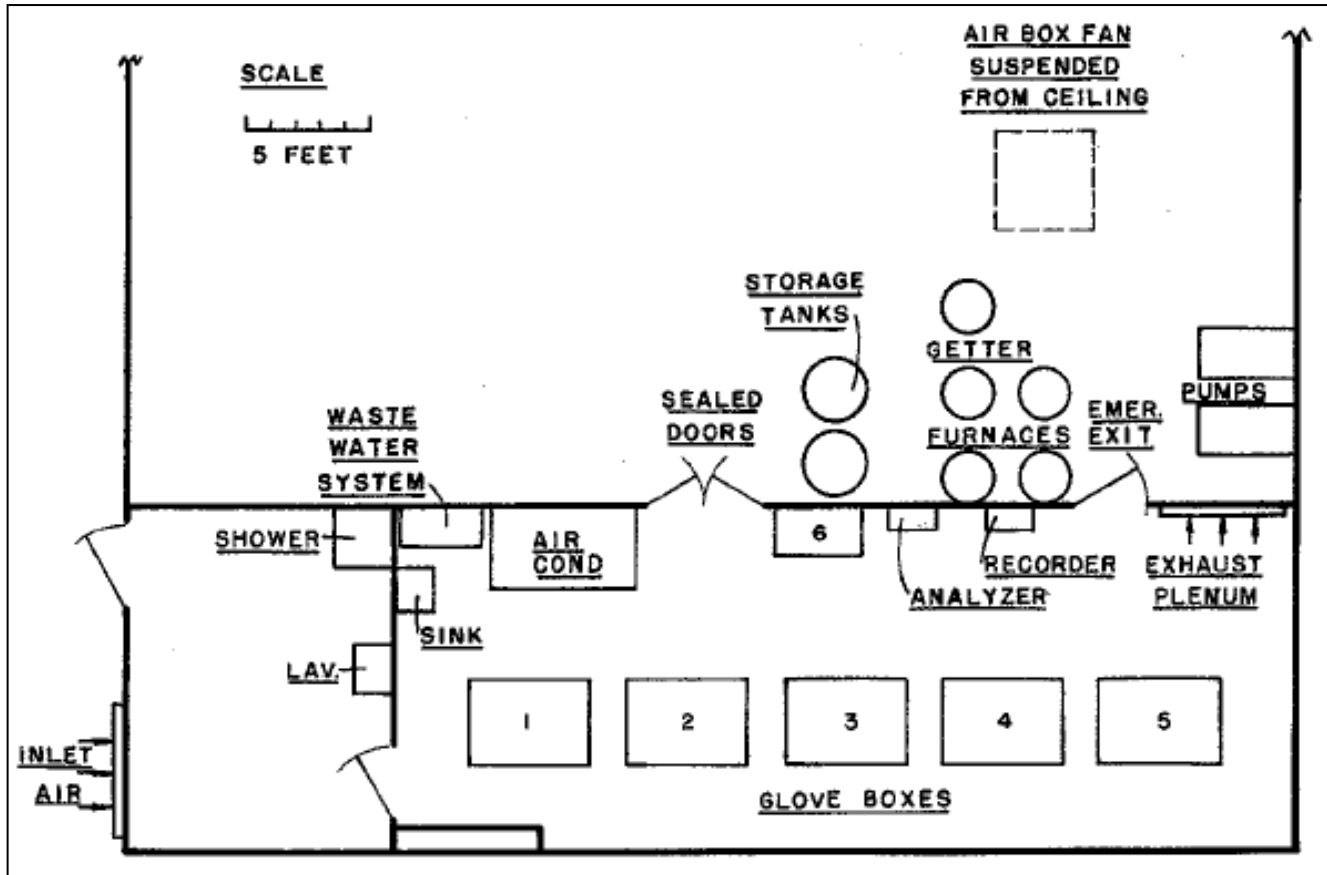


Figure 2-2. Carborundum facility for investigating refractory materials [Saulino et al. 1962, p. 3].

Of the gloveboxes indicated in Figure 2-2, numbers 1, 2, and 6 operated with an air atmosphere and numbers 3, 4, and 5 operated with a high-purity helium atmosphere. The gloveboxes averaged 3 ft high, 3.5 ft wide, and 5 ft long. They were constructed of welded aluminum plate with full side safety-plate glass windows. The air and helium glovebox systems were connected by a vacuum lock between numbers 2 and 3, while the remaining boxes (with the exception of number 6) were connected by two-layered flexible plastic tubing. Materials could be moved into or out of the box system by the pouching technique (which can also be referred to as bag outs), or directly through the O-ring-sealed sliding door of the number 1 box, which was maintained at a low level of contamination [Saulino et al. 1962].

Between 1959 and 1965, Carborundum was a subcontractor to United Nuclear Corporation (UNC), formerly known as Nuclear Development Corporation of America (NDA), under various contracts. UNC performed conceptual design, fuel evaluation, and fuel irradiation. Carborundum fabricated the fuel. Both companies operated plutonium-handling facilities [Strasser and Taylor 1963a].

From February 1, 1964, through October 30, 1965, Carborundum was subcontracted to UNC to study UPu monoxides. This work was sponsored jointly by AEC and the Joint U.S.-Euratom Research and Development Program [Forbes et al. 1966].

Carborundum performed work with the AEC under contract No. AT (30-1)-3713 from May 23, 1966, through February 28, 1967. The work studied the preparation of mixed-carbide fuel using coprecipitation and the synthesis of (UPu)C [McMurtry 1967].

During the mid-1960s and into the late 1970s, upon completion of AEC-related work, the company refocused on its core ceramic technology, moving beyond the capital goods market into the steel, paper, plastics, pollution control, and china industries. In the mid-1970s, Carborundum began the development of pressureless sintered alpha silicon carbide, which marked its entry into the world of structural ceramics. At the same time, Carborundum fought off a hostile takeover attempt by Eaton Corporation, only to be purchased by Kennecott Copper Corporation. Through the 1980s, Carborundum's name was changed twice before returning to the Carborundum name in 1988. During this time, the company was reorganized into three operating companies. Silicon carbide continued to be one of the company's core minerals with the development of Hexoloy alpha silicon carbide products. The company resumed its traditional investment focus in research, development, and capital expansion, and moved into development of materials for the growing semiconductor industry. A significant change occurred in 1983 when the Buffalo Avenue plant was closed and 650 people lost their jobs. In 1987, British Petroleum acquired Standard Oil and its Carborundum subsidiary. During this time, the company developed aluminum nitride substrates and ceramic packages for the semiconductor industry and continued developing new uses for its Fiberfrax technology while maintaining global leadership in sales of its Globar heating elements. By 1990, St. Gobain Ceramics & Plastics purchased the Carborundum abrasives unit [Advameg 2015; Niagara Gazette 2006].

A memorandum from Oak Ridge National Laboratory (ORNL) Region 1 dated June 23, 1993, provides followup information about potentially contaminated sites. The memorandum states that Carborundum Research Center on Buffalo Avenue was surveyed at the time of closure and that additional information was required to remove this site from the list [ORNL 1993]. Subsequent information for the nuclear material license number at Carborundum indicates the site was cleared from the ORNL list in 1993 [ORNL 1999].

2.1.1 First Operational Period Process Descriptions, 1943

The 1943 Carborundum experimental grinding operation for DuPont was for the purpose of determining the type of abrasive wheel to use and the optimum speeds to maintain during a production grinding job. The project report has a list of project correspondence that indicates there was a letter issued May 17, 1943, granting approval to send one uranium rod to Carborundum for centerless grinding experiments [DuPont 1945]. Details in the text of the report and shipping records do not indicate that a rod was sent, but indicate that 10 Clinton-sized unfinished slugs were shipped to Carborundum for experimental grinding to determine the type of abrasive wheel to use and the optimum speeds to maintain during a production grinding job. Shipping and receiving, and accountability records show Carborundum taking receipt of 30 lb of slugs from Herring-Hall-Marvin (HHM) Safe Company, one of the DuPont subcontractors, on June 1, 1943. Based on the most common size of Clinton slugs in the report (finish size: 1.1 in. diameter by 4 in. long), 30 lb of unfinished slugs would be nominally equivalent to 10 Clinton-sized unfinished slugs [Clinton 1943, p. 14; DuPont 1945, pp. 89, 103, 233, 273].

The shipping and receiving records indicate that Carborundum actually returned 33 lb of slugs to HHM Safe Company on September 27, 1943, which is 3 lb more than it received in June. The 3-lb discrepancy was noted in accountability records and presumably could be from differences in measured weights or possibly contaminated residues added to the return shipment (both the project report text and shipping records indicate that sweepings, machine turnings, and residues from various subcontractors had to be recovered and returned, but there is no such detailed information for the limited machining work done by Carborundum). Table 2-1 presents the information associated with the slug-grinding operation [TCC 1944; Clinton 1943; 1944; DuPont 1945, p. 273].

Table 2-1. Radiological work during the first operational period.^a

| Type of work | Radionuclides | Amounts | Report type | Project number |
|---|---------------|-------------------------------------|---|--|
| Grinding to determine the appropriate type of abrasive wheel and optimum speed for production grinding. | Uranium | Ten unfinished slugs totaling 30 lb | Metal Fabrication Program Dummy Slug Program and Unbounded Slug Program | Clinton Engineer Works Project 1553 |

a. Source: DuPont [1945, p. 103].

In a letter to DuPont on July 2, 1943, Carborundum reported on centerless grinding tests using a specific grinding wheel and various setups and abrasives. Although some chatter still existed after a particular test, various dressing speeds were tried. By using a 26-in./min traverse of the diamond, seven pieces were ground without chatter. Two other pieces were used at a slower traverse speed. The letter also states that there was one smaller piece. Carborundum returned 10 pieces according to DuPont instructions. This document only reported on the results obtained and did not include the actual setup, radiological exposure potential, or airborne potential [Currie 1943, p. 5].

2.1.2 First Residual Period, 1943 to 1958

After World War II, Carborundum embarked on an ambitious commercial expansion plan. Improvement of traditional product lines was part of this expansion. The company upgraded and expanded facilities to become more competitive in the postwar era. The Niagara Falls facilities were modernized and new facilities were built or purchased in other areas across the United States and Canada.

Carborundum was involved with many projects during the first residual period, many not specifically at the Buffalo Avenue plant. Carborundum began development of its Fiberfrax ceramic fiber and, in 1952, began to market its first commercial applications [Advameg 2015]. In October 1954, a new line of tool room wheels known as the V-40 line made a debut. The development of the V-40 wheels at the Bonded Abrasives Division was based on input and suggestions gathered in the field from grinding machine operators [TCC 1991, p. 73].

Beginning in 1955, Carborundum was involved with the production of silicon carbide for structural materials for the Aircraft Nuclear Propulsion Department of General Electric Company (GE). The GE contract went from September 28, 1955, to September 27, 1956. Carborundum proposed and was granted an extension to September 28, 1957 [TCC 1956]. A second extension was granted into 1958 [TCC 1957]. A second periodic report was issued in May 1958 [TCC 1958]. This contract was identified as commercial work and therefore is not included in the covered period evaluation.

Several former Carborundum employees who worked during the first residual period were interviewed. One former employee stated he worked in different departments in the Diamond Wheel Department and also worked on a lathe. He made diamond insets to cut different kinds of metals [ORAUT 2015d]. Another former employee stated he was involved with the synthesis of ceramic materials, borides, carbides, nitrides, and silicides. He handled enriched ¹⁰B and processed over 2,000 lb that was converted to boron carbide, which was not radioactive. He also stated he made thorium oxide and thorium carbide in the early stages of his work (ca. 1955) [ORAUT 2015e]. This thorium work is not considered covered AEC work; therefore, any exposures associated with thorium work is not covered under EEOICPA.

2.1.3 Second Operational Period Process Descriptions, 1959 to 1967

During the second operational period, Carborundum worked as a prime or subcontractor on many contracts for the AEC, including UNC. Table A-1 in Attachment A provides a list of the contracts within this operational period with brief descriptions of the work. Some of these contracts are discussed in

more detail in the subsequent text. There were seven contracts that covered the work during this second operational period (1959 to 1967).

Synthesis and Fabrication of Uranium Refractory Compounds

- Contract AT-(40-1)-2558 covered uranium work from May 1959 through December 1960. However, this contract was not officially closed until the end of 1962 [Cope 1962, pp. 3–4]. The purpose of this work was to develop methods to synthesize uranium mononitride (UN), uranium carbide (UC), and uranium disilicide (U_3Si_2). Many batches of UC were made with batch sizes ranging from about 30 g to 6 lb. This work was part of the AEC Fuel Development Program [Taylor and McMurtry 1961a, p. 13]. This was the beginning of the uranium contract work and covered AEC work for the second operational period.

This work is described in *Summary Report, Synthesis and Fabrication of Refractory Uranium Compounds* from February 1961 [Taylor and McMurtry 1961a]. The report covers the period from May 1959 through December 1960.

The object of the investigation was the development of refractory uranium materials possessing sufficient advantage over UO_2 to warrant their use as reactor fuels [Taylor and McMurtry 1961a]. To this end, the various properties of these materials had to be examined. The materials chosen for examination consisted of UC, UN, and the silicide U_3Si_2 , all of which have higher densities than UO_2 [Taylor and McMurtry 1961a]. The work program was divided into three phases [Taylor and McMurtry 1961a, p. 10]:

1. Development of methods for synthesis of the compounds.
2. Fabrication of the synthesized materials into bodies suitable for testing.
3. Determination of properties of the materials such as thermal conductivity, thermal expansion, and high-temperature strength.

The majority of the work was conducted on small samples of various solutions of the uranium. For example, the chemical analysis included a representative batch of 1,500 g of UC that was prepared from an unpelletized mix of uranium, combined carbon, uncombined carbon, nitrogen, iron, and oxygen. It appears that at various stages of the experimentation it was necessary to use different furnaces or enclosures. The types of furnaces and enclosures that were available included atmosphere induction furnaces, muffle furnaces, a vacuum induction furnace, nitriding furnaces, a quench furnace, a hot-pressing furnace, a thermal conductivity furnace, a high-temperature modulus-of-rupture apparatus, a high-temperature furnace, and gloveboxes [Taylor and McMurtry 1961a].

Another aspect of the work involved synthesis experiments with UC. Three approaches were considered for the preparation of UC:

1. Reduction of an oxide (UO_2 or U_3O_8) by carbon. For this experiment, carbon was heated with both UO_2 and U_3O_8 to produce UC. The reaction mixture was usually prepared for furnacing as follows: the oxide and carbon were mixed by dry ball-milling for 24 hours in a rubber-lined mill with stainless-steel balls and then pressed into pellets measuring 0.625 by 0.625 in. This was done at 15,000 to 20,000 lb/in.² using about 2% of water as a temporary binder [Taylor and McMurtry 1961a, p. 11]. It is unknown how many experiments were run or how much uranium was used for each experiment. However, many batches of UC were made by heating stoichiometric mixtures of UO_2 and carbon in the vacuum induction furnace at 1,750 °C to 1,800 °C. The size of the batches varied from about 30 g to 6 lb [Taylor and McMurtry 1961a, p. 13]. The resulting mixtures underwent an X-ray analysis to determine the characteristics of the resulting compounds.

2. Reaction of ammonium diuranate and carbon. This experiment was based on the assumption that ammonium diuranate would decompose to U_3O_8 under the reaction conditions and the carbon would then react with the U_3O_8 to form uranium carbide (uranium monocarbide). The pellets were heated in a ceramic tube furnace in an argon atmosphere. A temperature of about 700 °C was reached in approximately 20 minutes and the maximum temperature of 1,700 °C was reached in about 3 to 4 hours. The pellets were held at 1,700 °C for 1 hour and then allowed to cool in argon to room temperature [Taylor and McMurtry 1961a, p. 14].
3. Reaction of uranium and carbon. This method of preparation was used exclusively in connection with a simultaneous synthesis and fabrication process described above for fabrication of uranium carbide (uranium monocarbide) [Taylor and McMurtry 1961a, p. 14].

The exact quantities used in each experiment are not known. However, information from a September 19, 1962, contract closeout notification indicated that Carborundum notified the AEC of the radioactive material quantities on hand and requested disposal instruction before the closeout of contract AT(40-1)-2558 [Rose 1962].

Several former employees were interviewed to discuss the work that they performed at Buffalo Avenue [ORAUT 2015c; ORAUT 2015e]. They provided the following insight:

- All nuclear work in the facility was done on the fourth floor.
- Uranium ceramic compounds were fabricated with depleted and enriched uranium.
- At first, uranium was not carefully controlled because it was considered low-level work and therefore not a hazard; there were only minor restrictions. Workers were allowed to dress casually. Safety requirements were tightened once larger quantities of uranium were received.
- The work did involve the use of gloveboxes and furnaces. Gloveboxes were used for uranium work to control acid fumes, and eventually filters were installed. Uranium gloveboxes were in more than one room. However, small quantities of uranium were processed outside of a glovebox in a room under negative pressure.
- Plutonium work was performed only in a special room separate from the uranium work.
- One of the former workers recalled wearing radiation badges but could not recall an exact time frame. The worker also recalled that the site performed contamination surveys and collected uranium samples in the 1960s.

Synthesis and Study of Uranium-Plutonium Carbide Pellets

- Contract AT-(30-1)-2303 was part of the Carbide Fuel Development Program initiated in May 1959. Design and construction of a facility for carbide fabrication at Carborundum was completed in 1960. The equipment was tested by work with UC before the startup of operations with plutonium in March 1961 (the first shipment of Pu was received in June 1960). Seven batches of PuC were made by mixing PuO_2 and carbon and then furnacing at differing temperatures and hold times [Strasser and Taylor 1961, p. 14].
- Contract AT-(30-1)-2899 covered work from May 15, 1959, through October 15, 1965. As part of the Carbide Fuel Development Program, this work was concerned with the technology of UC-PuC fuels. The major goals were to produce (UPu)C and obtain data on its irradiation behavior for long burnups and at high-power generation rates [Strasser and Stahl 1965].

Synthesis and Study of Uranium/Plutonium Monoxides

- Contract AT-(30-1)-3305 covered work from February 1, 1964, through October 30, 1965. Carborundum was the subcontractor to UNC and conducted fabrication studies of uranium and plutonium monoxides in helium. Mixtures of UO_2 - PuO_2 were used to synthesize UPu compositions [Forbes et al. 1966, pp. 5–6].
- Contract AT(30-1)-3713 was associated with the AEC Fuel Cycle Development and studied the preparation of mixed carbide fuel using coprecipitation and the synthesis of (UPu)C. This contract covered the period May 23, 1966, through February 28, 1967 [McMurtry and Taylor 1966; McMurtry 1967].

Out-of-Pile Properties of Mixed Uranium Plutonium Carbides

- Contract AT-(30-1)-3118 covered the period from February 6, 1962, through December 6, 1963, and was closely coordinated with the AEC-sponsored Carbide Fuel Development Program. Carborundum was a subcontractor to UNC under which UNC performed the property determinations and Carborundum prepared the fuel samples. Four 100-g synthesis batches were prepared from UO_2 , PuO_2 , (UPu)C. UO_2 , PuO_2 , and carbon powder was synthesized in 70- to 100-g batches [Strasser et al. pp. 17, 22]
- Contract AT-(30-1)-3254 was closely coordinated with the Carbide Fuel Development Program. The goal under this contract was to determine the out-of-pile properties of (UPu)C that have the most significant effect on the operational characteristics of the fuel. The powder fabrication initiated under AT (30-1)-2889 continued with this contract [Stahl and Strasser et al. 1963, pp. 10, 14].

As noted by the contracts information, the first plutonium shipment was received in June 1960 and plutonium work began in March 1961. Carborundum was contracted to mix uranium and plutonium fuels as part of its work on the Carbide Fuel Development program in support of UNC. While different mixtures were possible, the most common carbide mixture included 95% uranium and 5% plutonium. All work with radioactive material was done in the Central Research Laboratory, which was specifically constructed to support this work. The classified work with plutonium was conducted on the fourth floor in a secure room that required an escort for entry [ORAUT 2015b].

Several former employees were interviewed to discuss the work that they performed at Buffalo Avenue. Some of the work consisted of mixing uranium and plutonium oxides together in relatively small amounts (milligrams to grams) to make pellets. The results of each experiment were recorded in logbooks, and the pellets were sent for spectroanalysis to determine the specific compounds that resulted. The employee also indicated that people wore lab coats (with the sleeves taped) and a half-face dust mask when working with radioactive material. The plutonium area was under negative pressure and was a clean room system; employees checked themselves out with a frisker, but sometimes a safety person helped [ORAUT 2015c].

Another interviewee described work on the fourth floor of the Central Research Laboratory in the special room built for plutonium work as including fabricating U-Pu pellets. Limits were in place that restricted the amount of material in process at any one time. The FBI brought the materials to the laboratory and took the pellets away when they were completed. The interviewee said he wore a radiation badge and participated in a medical monitoring program [ORAUT 2015b].

An abstract published in *Reactor Technology* on liquid metal fast breeder reactors discusses the Carbide Fuel Development Phase 1 Report for the period from May 15 to September 15, 1959 [AEC no date, p. 85]. The abstract references contract AT(30-1)-2303 between NDA and Carborundum. Subsequently, the Carbide Fuel Development project was the subject of a letter from March 30, 1960, to the New York Health and Safety Laboratory. This letter discusses the proposal for Carborundum to

manufacture ceramic pellets containing PuC mixed with UC (normal enrichment) at its Central Research Laboratories in Niagara Falls. Over a period of 3 years, a total of approximately 3 kg of plutonium were to be fabricated into pellets. The first shipment of plutonium from Hanford (the only shipment during 1960) was to consist of 500 g [Werner 1960].

The following processes were to be involved in the fabrication of PuC pellets (operational details unspecified):

1. Weighing the PuO₂ powder as received from the supplier,
2. Chemical analysis,
3. Addition of UO₂ and carbon,
4. Ball milling,
5. Heating to form the monocarbides,
6. Crushing,
7. Chemical and X-ray analysis,
8. Ball milling,
9. Cold pressing into pellets,
10. Sintering into dense form,
11. Grinding pellets, and
12. Inspection and shipment.

The results of the Carbide Fuel Development project are documented in many reports, as indicated in the listings in the Foreword section of each progress report [Strasser and Stahl 1965]. Handling standards for plutonium were established in a planning document, which consisted of the following requirements:

- All plutonium handling would be done in a glovebox.
- Any waste or scrap generated in the glovebox would be removed using the pouch method.
- The maximum amount of contained plutonium in storage could not exceed 600 g at any one time.
- No single container could contain more than 200 g of plutonium.
- No more than 200 g of plutonium or uranium-plutonium mix could be in process at any one time.
- No more than 100 g of plutonium could be used in any single batch in process, with a maximum of two simultaneous batches in operation at any given time.

Each phase of the operation of fuel fabrication and testing was performed in an inert helium atmosphere. The minimum critical mass for a water-reflected solution containing ²³⁹Pu was identified as 510 g, and the recommended safe mass was listed as 250 g. Considering this information, the Carborundum pellet process was recommended for approval because of the maximum of 200 g of plutonium that would be stored per container or be in process at any one time [Werner 1960].

These experiments and others were all part of the Carbide Fuel Development Program, which was concerned with the technology of the entire UC-PuC fuel cycle. The major goal of the program was to produce (UPu)C and to obtain data on its irradiation behavior for long burnups and at high-power generation rates. The program was initiated in May 1959 and, as originally outlined, covered a period of about 4.5 years [Strasser and Taylor 1963a, p. 18].

Many of the overall experiments consisted of synthesizing compounds and fabricating them into pellets, determining the coefficients of expansion, measuring melting points and vapor pressures, checking compatibility with other elements at various high temperatures, and performing irradiation tests (X-ray diffraction). These procedures involved handling of the radioactive material in one form or another to mix the chemicals and make transfers between the many enclosures for individual tests; this handling provided potential opportunities for exposure.

Various experiments were performed, and samples analyzed, to develop the optimal method to fabricate the mixed carbide fuel pellets. Table A-1 lists the contracts and information on the type of work. It has references for various reports that provide more details of the experiments.

X-Ray Diffraction

The ceramic pellets containing PuC-UC were manufactured by Carborundum as a subcontractor to UNC. The fuels were evaluated by various means, including X-ray diffraction analysis (XRD) [Werner 1960]. The X-ray powder diffraction method is used very extensively for compound or phase identification [Kehl 1971]. Carborundum used this method to analyze the fuel as part of the fuel fabrication process.

In XRD, a very small beam of low-energy monochromatic X-rays irradiates a sample of matter, mixed-oxide fuel (PuC-UC) in the case of Carborundum. The X-rays are scattered by the individual atoms in the sample. In crystalline samples, the atoms are arranged in a lattice pattern. The scattered X-rays from the sample interfere with each other and cause scattered X-rays to be emitted only in some directions and not others. This causes a diffraction pattern that can be recorded and analyzed and provides specific information about the atomic structure of the sample.

2.1.4 Second Residual Period, 1968 to 1992

All covered AEC work at Carborundum was completed in 1967, which marks the end of the second operational period and beginning of the second residual period. The residual radioactive materials that remained from covered operations occurring after the second (and first) operational period are all that must be accounted for in the second residual period. The operations that occurred between 1968 and 1992 at the Buffalo Avenue facility are of no radiological consequence; these interim operations are discussed in the following paragraphs.

There was some information on the nonradiological work that continued at Carborundum during the second residual period, which included the following:

- In 1968, Carborundum manufactured some boron carbide powder for GE Atomic Power. Some of this material was tested for composition and density by ORNL in 1969 [Ikeuye and Young 1970].
- In 1968, Carborundum did some studies for Westinghouse Astronuclear Laboratory on niobium carbide [Singleton 1969].
- In 1972, Carborundum produced some unirradiated cylindrical pellets of boron carbide for testing as part of the Experimental Breeder Reactor No. 2 program [Ruther and Greenburg 1972].

Several former Carborundum employees who worked during the second residual period were interviewed. One former employee stated that he worked in the mid-1970s and made bulletproof vests and armor for PT boats. The base product was carbon. The material was put into ovens to make the plating for the armor. Sometimes the plating would be cracked. If the plating could be fixed, it would need grinding and smoothing; this created a lot of dust. Masks were not used during this process and

there was no ventilation [ORAUT 2015d]. The plates for the armor vests were made for the Vietnam War and this work was done in Building 14. This building had a firing range to test the armor plating [ORAUT 2015a].

Although Carborundum is mentioned by name in numerous documents because of their grinding wheels, no additional information was identified on any other potentially covered radiological operations after 1967.

There are Carborundum annual reports available for 1971, 1972, and 1973 that discuss overall sales and expenditures; however, these reports do not discuss any further ongoing AEC-related processes [TCC 1972, 1973; 1974].

2.2 RADIOLOGICAL EXPOSURE SOURCES FROM OPERATIONS

The radionuclide-specific source terms that are applicable to operational and residual radioactivity periods at Carborundum are uranium and plutonium. The following subsections describe the radioactive materials applicable to the periods discussed in this section.

In February 1962, the Carborundum Company issued a progress report entitled, *Carbide Fuel Development*. This report described the work done in the uranium carbide-plutonium carbide fuel development program. Table 2-2 shows the isotopic analysis of the PuO₂ [Strasser and Taylor 1962b, p. 15].

Table 2-2. Isotopic analysis of plutonium mixture.

| Radionuclide | % mass |
|--------------|--------|
| Pu-238 | 0% |
| Pu-239 | 90.7% |
| Pu-240 | 7.9% |
| Pu-241 | 1.2% |
| Pu-242 | 0.1% |

As indicated in Strasser and Taylor [1962b, p. 15], Carborundum used plutonium provided by Hanford in the study of the preparation of (UPu)C powder.

In addition, the 1966 final summary report of the *Study of Uranium-Plutonium Monoxides Final Summary Report* [Forbes et al. 1966], indicated that the goal of the study was to find a uranium-plutonium monoxide fuel for water-cooled thermal reactors that would have a heat-generation capability better than, and water-corrosion resistance equivalent to, PuO₂ and (UPu)O₂.

Plutonium enrichment was employed in this study in anticipation of the day when sufficient plutonium would be available to reduce reliance on uranium isotope enrichment facilities. Although early core loadings would use ²³⁹Pu, subsequent ones could use increasing amounts of ²⁴⁰Pu to increase the reactivity burnup limit of the reactor. Total plutonium concentrations of up to 10% would be introduced into the uranium fuel [Forbes et al. 1966, p. 14]. In addition to ²³⁹Pu, ²⁴⁰Pu and ²⁴¹Pu could be sources of exposure.

Many of the contracts involving Carborundum overlapped for various periods and involved different process materials. Table 2-3 presents Carborundum contracts in parallel timelines; the corresponding process materials represent the respective source terms for the periods.

Table 2-3. Summary of Carborundum exposure sources over the contract timelines.^a

| Contract or type of work | 1943 | 1944 | 1945–1954 | 1955–1958 | 1959 | 1960 ^b | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 |
|--|------|------|-----------|-----------|---|---|--------------------------------------|--|---------|---|---|---------------|---------------|
| Clinton Engineer Works Project 1553: Experimental grinding of uranium [DuPont 1945]. | U | None | None | None | None | None | None | None | None | None | None | None | None |
| AT-(40-1)-2558: Synthesis and Fabrication of Refractory U Compounds [Taylor and McMurtry 1961a, 1961b] | None | None | None | None | UO ₂ , U ₃ O ₈ , UN powder, U ₃ Si ₂ | UO ₂ , U ₃ O ₈ , UN powder, U ₃ Si ₂ | Depleted UO ₂ ; | Depleted UO ₂ ; | None | None | None | None | None |
| AT(30-1)-2899: Carbide Fuel Development Program: Fuel Fabrication [Strasser and Stahl 1965] | None | None | None | None | UC | UC, Pu | UC, PuC powder containing NU, EU, Pu | UC, PuC pellets Powder containing NU, EU, Pu | UC, PuC | UC, PuC mixed carbides | UC, PuC mixed carbides | None | None |
| AT(30-1)-2303: Carbide Fuel Development [Strasser and Taylor 1961; Strasser and Stahl 1965] | None | None | None | None | None | UC, UO ₂ , Pu | None | None | None | None | None | None | None |
| AT[30-1)-3118; closely coordinated with AT(30-1)-2899 [Stahl et al. 1963] | None | None | None | None | None | None | UPu carbides | None | None | None | None | None | None |
| AT(30-1)-3254; closely related to AT(30-1)-1. Studies were a continuation of AT(30-1)-2889 [Strasser et al. 1963] | None | None | None | None | None | None | None | (UPu)C 80% UC-20% PuC | None | None | None | None | None |
| AT(30-1)-3305: Study of UPu Monoxides; UNC Project-2321 [Forbes et al. 1966] | None | None | None | None | None | None | None | None | None | U, Pu Depleted UO ₂ , PuO ₂ , UHx, UC, UN | U, Pu Depleted UO ₂ , PuO ₂ , UHx, UC, UN | None | None |
| AT (30-1)-3713; Associated with the AEC Fuel Cycle Development Program: Studies of the preparation of mixed carbide fuel utilizing co-precipitation; synthesis of (UPu)C. [McMurtry and Taylor 1966] | None | None | None | None | None | None | None | None | None | None | None | UN; Pu (UPu)C | UN; Pu (UPu)C |

a. None indicates there was no corresponding contract activity during this period.

b. The sources of Pu in 1960 were limited to a shipment received in late 1960; processing did not begin until March 1961.

2.2.1 Internal Radiological Exposure Sources from Operations

The primary potential source of internally deposited radioactivity from Carborundum operations was inhalation and ingestion of natural uranium (NU), depleted uranium (DU), and enriched uranium (EU) and plutonium. Uranium was present at the site as a powder. In addition, ^{239}Pu was present during the second operational period.

2.2.1.1 First Operational Period, 1943

As indicated previously, Carborundum was involved with centerless grinding testing using grinding wheels and different abrasives on uranium slugs. The quantity of material identified in the first operational period is approximately 30 lb of uranium (10 slugs) that were shipped between Carborundum and HHM Safe Company [Clinton 1943, pp. 9, 14]. It was also noted that one rod was authorized to be sent to Carborundum on May 17, 1943, for centerless grinding experiments [DuPont 1945, p. 273]. Based on the shipping records and description of work during the first operational period, a determination was made that Carborundum received a total of 10 slugs. The slugs were received on June 1, 1943; the grinding work was done that month and results were reported on July 2, 1943. Return shipment of the slugs was not made until September 27, 1943. DuPont reported that there was no required health supervision because of the limited amount of work [Daniels 1944, p. 13]. Although the work was limited, centerless grinding of uranium has been known to produce significant levels of airborne radioactivity and to create an inhalation and ingestion hazard.

2.2.1.2 First Residual Period, 1943 to 1958

Only the residual materials that were considered a primary source during the first operational period need to be considered during the first residual period. Therefore, only natural uranium is considered to be a source that must be accounted for during the residual period from 1943 to 1958.

2.2.1.3 Second Operational Period, 1959 to 1967

Work at Carborundum during the second operational period (1959 to 1967) consisted of research and development. During this period, Carborundum worked with uranium and plutonium powders and chemicals to synthesize fuel pellets and to develop refractory uranium materials possessing sufficient advantage over uranium dioxide to warrant their use as reactor fuels. Carborundum fabricated test samples of these materials and performed a variety of tests to verify their economic viability and their ability to replace uranium dioxide fuels. Although much of the experimentation and testing was conducted in enclosures, there was a potential for internal exposure (inhalation or ingestion) during the handling of uranium and plutonium powders and chemicals.

From May 1959 through 1962 [Cope 1962, pp. 3–4], Carborundum worked with uranium, under contract AT-(40-1)-2558, to develop methods to synthesize UN, UC, and U_3Si_2 [Taylor and McMurtry 1961a]. At its Central Research Laboratory in Niagara Falls, Carborundum manufactured ceramic pellets that contained PuC mixed with UC (normal enrichment). The first plutonium shipment came from Hanford in 1960 and was 500 g [Werner 1960]. However, the equipment was first tested with UC. The site then started up operations with plutonium in March 1961 [Strasser and Taylor 1961].

According to an interviewee, the [redacted] work he did was classified and he was the only one in the room making pellets with a mixture of uranium and plutonium [ORAUT 2015b].

At the time Carborundum closed out contract AT(40-1)-2558 for source and special nuclear material, it had in its possession various amounts of depleted and 10%-EU powder [Rose 1962]. These forms of uranium were used in the preparation of UC pellets, and various-sized pieces were used for testing

physical properties in connection with the Carbide Development Program [Strasser and Taylor 1962b, p. 15].

2.2.1.4 Second Residual Period, 1968 to 1992

As is the case with the first residual period, only the residual materials considered a primary source during the second operational period (and any carryover from the first operational period) need to be considered during the second residual period. Therefore, uranium and plutonium are considered to be sources that must be accounted for during the second residual period from 1968 to 1992.

2.2.2 External Radiological Exposure Sources from Operations

Based on the available information, the potential for external radiation doses from uranium, uranium decay products, and plutonium existed at Carborundum. The following sections discuss the external exposure sources for Carborundum workers evaluated in this report. The external sources result in the photon and beta radiations in Table 2-4, as well as some potential neutron exposures.

Table 2-4. Principal radiation emissions from natural uranium and short-lived decay products.^a

| Radionuclide | Half-life | Beta energy (max. MeV) | Photon (X or γ) energy (MeV) |
|--------------|-------------|------------------------|--------------------------------------|
| U-238 | 4.468E+9 yr | None | X: 0.013 (8.8%) |
| Th-234 | 24.1 d | 0.096 (25%) | X: 0.013 (9.6%) |
| Th-234 | 24.1 d | 0.189 (73%) | γ : 0.063 (3.8%) |
| Th-234 | 24.1 d | 0.189 (73%) | γ : 0.093 (5.4%) |
| Pa-234m | 1.17 min | 2.28 (98.6%) | γ : 0.765 (0.2%) |
| Pa-234m | 1.17 min | ~1.4 (1.4%) | γ : 01.001 (0.6%) |
| U-235 | 7.038E+8 yr | None | X: 0.013 (31%) |
| U-235 | 7.038E+8 yr | None | X: 0.090-0.105 (9.3%) |
| U-235 | 7.038E+8 yr | None | γ : 0.144 (10.5%) |
| U-235 | 7.038E+8 yr | None | γ : 0.163 (4.7%) |
| U-235 | 7.038E+8 yr | None | γ : 0.186 (54%) |
| U-235 | 7.038E+8 yr | None | γ : 0.205 (4.7%) |
| Th-231 | 25.5 hr | 0.206 (15%) | X: 0.013 (71%) |
| Th-231 | 25.5 hr | 0.288 (49%) | γ : 0.026 (14.7%) |
| Th-231 | 25.5 hr | 0.305 (35%) | γ : 0.084 (6.4%) |
| U-234 | 244,500 yr | None | X: 0.013 (10.5%) |
| U-234 | 244,500 yr | None | γ : 0.053 (0.2%) |

a. Source: NIOSH [2011]. The above table shows the principal radiation emissions from natural uranium and its short-lived decay products that are of concern for external radiation (not including bremsstrahlung).

2.2.2.1 External Radiological Exposure Sources by Radiation Type

2.2.2.1.1 Photon

Carborundum conducted work with NU, depleted uranium (DU), and EU as well as plutonium. External exposures to photon radiation would have resulted from the immediate progeny in the uranium decay chain. The progeny that result in the most significant photon exposures include ²³⁴Th and ^{234m}Pa [PHS 1970]. Note that these isotopes have relatively short half-lives and can be assumed to be in equilibrium with the parent ²³⁸U. Because of their short half-lives, the exposure potential from these isotopes is the same as that of the parent and will not be considered separately. Plutonium itself is not a major contributor to photon dose. However, ²³⁹Pu decays by alpha emission to ²³⁵U, whose short-lived progeny do contribute to total photon exposure. Table 2-4 shows the primary isotopes,

principal emissions, and photon energies associated with natural uranium and short-lived progeny. In addition, in a plutonium mixture, the decay of ^{241}Pu to ^{241}Am , which decays with the emission of a 60-keV photon, is the predominant source of photon exposure associated with plutonium mixtures.

2.2.2.1.2 Beta

Radiation fields from uranium are frequently dominated by contributions from its progeny. For example, nearly the entire beta radiation field from DU comes from the $^{234\text{m}}\text{Pa}$ and, to a lesser extent, from ^{234}Th .

Table 2-4 shows the principal beta emitters and their energies for uranium. Because ^{239}Pu decays directly to ^{235}U , the beta emitters present in this decay chain are already accounted for in Table 2-4. As indicated, there are a significant number of high-energy beta radiations that represent a shallow dose exposure concern for site workers. Workers who handled the uranium would have received shallow dose exposures. The primary exposure areas would have been the hands and forearms, the neck and face, and other areas of the body that might not have been covered.

2.2.2.1.3 Neutron

The source of neutrons would result from the work with uranium and plutonium in the gloveboxes during the second operational period. Neutron doses were calculated using the MCNP6.2 transport code. Dose rates were calculated at 1 ft and 1 m from the center of the fuel pellet. Based on the nature of the work and the forms of the materials, neutrons are only considered to be a potential external exposure source during the second operational period.

2.2.2.2 External Radiological Exposure Sources by Period

2.2.2.2.1 First Operational Period, 1943

As indicated previously, Carborundum was involved with testing centerless grinding with grinding wheels and different abrasives. This work was performed on 10 uranium slugs that were shipped between Carborundum and HHM Safe Company [Clinton 1943, pp. 9, 14].

2.2.2.2.2 First Residual Period, 1943 to 1958

Based on the removal of the exposure sources from the site during the first residual period, the external doses and potential for external exposures are considerably lower than that of the associated operational period.

2.2.2.2.3 Second Operational Period, 1959 to 1967

The second operational period included quantities of both uranium and plutonium that contributed to the onsite source term. Between 1959 and 1967, Carborundum had seven contracts for a variety of experimental procedures. The contracts included work with both uranium and plutonium.

The experimental procedures during the second operational period included different research and development methods, such as synthesis and fabrication of refractory uranium compounds, fabrication of plutonium pellets, fuel fabrication, and evaluation of mixed uranium-plutonium carbide fuels. Shipping and receipt records, contract descriptions, and licensing information provide an indication of the quantities of radioactive material that was on the Carborundum site. Quantities included 3 kg of plutonium over a 3-year period, 1,500 g of UN, 3 lb of UC, and various batches of different UPu alloy carbides. Table A-1 lists known quantities.

Although most of the experimental work was conducted in gloveboxes, there were potential sources of exposure for the workers. The work involved the investigation of methods for synthesizing the compounds, fabrication of the materials for testing, and determining the properties of these materials. Another major effort was the carbide fuel development program, which involved fabrication and testing uranium and plutonium fuel pellets and studying out-of-pile properties of mixed UPu carbides.

While many of these procedures do not provide the amounts of radioactive material, several other experiments do. Note that the dates in the parentheses in the bullets below are approximate based on progress and summary reports.

- During the synthesis of uranium monocarbide a representative batch of UC consisted of 1,500 g (1959 to 1960) [Taylor and McMurtry 1961a, p. 11].
- In another experiment designed to determine the effect of the thermal history of the UC powder (time and temperature used in the synthesis) on its subsequent sinterability, each experiment used 453.6 g of UO₂ [Taylor and McMurtry 1961b, p. 7]. The number of experiments conducted has not been stated (1961).
- During the synthesis of thermal conductivity specimens a total of 550 g of UO₂, PuO₂ and carbon powder was synthesized in 70- to 100-g batches (1961 to 1963) [Stahl et al. 1963a, p. 22].
- One of the steps in the evaluation of the out-of-pile properties of mixed uranium-plutonium carbides at the 5% PuC level was the preparation of the powder. In this procedure, about 400 g of (U_{0.95} Pu_{0.05})C_{0.98} powder was synthesized for the fabrication of test specimens (1959 to 1965) [Strasser and Stahl 1965, p. 77; Strasser and Taylor 1963a, p. 12].
- Other experiments during the fuel development program consisted of the fuel synthesis for the fabrication of UC-PuC irradiation testing. In one experiment, the natural uranium powder required for the specimens was synthesized. Reaction of the 760-g batch of PuO₂-UO₂-C yielded approximately 580 g of an essentially single-phase (U_{0.8}Pu_{0.2})C_{0.95} solid solution. In its synthesis, the reaction batch was divided into 16 lots of about 50 g each (1962 to 1963) [Strasser and Taylor 1962a, p. 11; 1963b, p. 19].

Other material that was available at Carborundum was documented in its letter to the AEC. On September 19, 1962, Carborundum notified the AEC of the closeout of contract AT(40-1)-2558 and requested instructions for the disposal of the radioactive material it possessed [Rose 1962]. Table 2-5 lists the radioactive material Carborundum had at that time.

Table 2-5. Radioactive material inventory in 1962.

| Contract: NU | |
|--|-------------------|
| Material category and uranium type | Amount (g) |
| As metallic uranium in powder form, as received | 9,260 U |
| As uranium monocarbide in powder form, as received | 44 UC |
| As uranium nitride in powder form, as received | 27 UN |
| As chemical residues | 14 U |

| Contract: DU | |
|--|-------------------|
| Material category and uranium type | Amount (g) |
| As uranium dioxide in powder form, as received | 13,379 U |
| As U ₃ O ₈ in powder form contains carbon as an impurity | 3,170 U |

Contract: 10% EU

| Material category and uranium type | Amount (g) |
|--|-------------------|
| As metallic uranium in powder form, as received | 54 U |
| As uranium dioxide in powder form, as received | 829 U |
| As U ₃ O ₈ in powder form contains carbon as an impurity | 609 U |
| As UC, on wipers, used containers and crucibles (questionable recovery) | 72 U |

License

| Material category and uranium type | Amount (g) |
|---|-------------------|
| Depleted uranium as metallic turnings | 340 U |
| Depleted uranium monocarbide as shot | 47 U |

X-Ray Diffraction Machines

An additional external exposure source that must be accounted for during the second operational period is the XRD machines for analyzing the UC-PuC materials. The greatest hazard from XRD machines is external exposure from the primary beam. This can occur most commonly during alignment procedures, when the target must be aligned with the output port, the sample with the primary beam, and the detector or film holder with the reflected beam [Lubenau 1969]. If the X-ray beam is inadvertently turned on during alignment, the operator's fingers or hands could be inadvertently exposed to the primary beam. Historically, these types of accidents are the primary hazard from XRD machines [Thomas 1971, p. 145]. No evidence of these types of radiation accidents has been found at Carborundum.

The scattered radiation is of low energy and occurs in small, directional beams. Radiation leakage through small cracks in the shielding or other components would also tend to be of low energy, and in small, directional beams. Operators are not usually monitored for radiation exposure because of the small likelihood of the very small beams interacting with the small dosimeter device [Blatz 1971, p. 76].

2.2.2.2.4 Second Residual Period, 1968 to 1992

As in the case of the first residual period, based on the removal of the exposure sources from the site during the second residual period, the external doses and potential for external exposures are considerably lower than that of the associated operational period.

3.0 OCCUPATIONAL MEDICAL DOSE

Medical X-rays are not required to be considered during residual radiation periods. Applicability of occupational medical dose during the operational periods is as follows:

- First Operational Period, 1943. According to ORAUT-OTIB-0006, *Dose Reconstruction from Occupational Medical X-Ray Procedures* [ORAUT 2019a], and ORAUT-OTIB-0079, *Guidance on Assigning Occupational X-ray Dose Under EEOICPA for X-Rays Administered Off Site* [ORAUT 2017], in the absence of information to the contrary, it is assumed that medical X-ray examinations were performed on site during the first operational period. Therefore, one posterior-anterior radiographic chest X-ray screening should be assumed to have been performed for workers during the first operational period. Doses should be assigned based on ORAUT-OTIB-0006.
- Second Operational Period, 1959 to 1967. No data relevant to medical X-rays at Carborundum for the second operational period was identified. According to ORAUT-OTIB-0006, *Dose Reconstruction from Occupational Medical X-Ray Procedures* [ORAUT 2019a], and ORAUT-

OTIB-0079, *Guidance on Assigning Occupational X-ray Dose Under EEOICPA for X-Rays Administered Off Site* [ORAUT 2017], in the absence of information to the contrary, it is assumed that medical X-ray examinations were performed on site during the second operational period. Therefore, preemployment, annual, and termination posterior-anterior radiographic chest X-ray screenings should be assumed to have been performed for workers during the second operational period. Doses should be assigned based on ORAUT-OTIB-0006.

4.0 OCCUPATIONAL ONSITE AMBIENT AND ENVIRONMENTAL DOSE

Sections 5.0 and 6.0 account for onsite ambient and environmental exposures in the assessment of unmonitored and residual internal and external worker intakes and doses.

5.0 OCCUPATIONAL INTERNAL DOSE

5.1 AVAILABLE INTERNAL MONITORING DATA

During a review of Carborundum's records no urinalysis, whole-body counts, or lung counts were found for either of the two operational periods or residual periods. However, interviews with former workers [ORAUT 2015b, 2015c, 2015e] indicated that the site did collect urine samples. If a claim file contains personal monitoring records, contact the Principal Scientist for Internal Dosimetry or Principal Scientist for AWEs on how to assess the data.

Uranium and plutonium air sample data have been found for the second operational period (1959 to 1967). These air sample results were used to provide a basis for estimates of internal doses that are favorable to the claimant in accordance with Battelle-TBD-6000, *Site Profiles for Atomic Weapons Employers that Worked Uranium Metals* [NIOSH 2011].

5.2 METHODS FOR BOUNDING UNMONITORED INTERNAL DOSE

Individual exposures are assigned based on the specific work performed using the categories described below [NIOSH 2011]:

- Operator. Individuals who operated the process equipment or routinely handled radiological materials. This is the default dose category for dose reconstructions when there is insufficient information to place a worker in a lower dose category.
- Laborer (and radiological work support personnel). Individuals who were in close contact with the radiological materials product for a portion of the working day. This category includes maintenance workers, laboratory workers, health physics monitors, and so forth, who might have occasionally been in contact with radioactive material in the performance of duties. If information in a claim is insufficient to determine whether or not a worker fits this description, the operator category should be used.
- Supervisor (and nonradiological work production personnel). Individuals who routinely worked in the production areas and might have been periodically in the vicinity of processing. This includes supervisory staff, engineers, and individuals who were not in contact with the radiological materials but who worked routinely in the production areas. If information in a claim is insufficient to determine that the worker did not handle radioactive material in the performance of their duties, a higher dose category should be used.
- Clerk (or other). Individuals who worked in the environment outside of the production areas where radiological work was being performed. This includes office workers and nonradiological

production workers who are clearly documented to be at a physically different location from the radiological work (e.g., a different building). If work location cannot be determined for a claim, one of the other categories of exposure should be used.

5.2.1 First Operational Period, 1943

For the first operational period, there are no bioassay data for Carborundum employees. Internal doses from uranium intakes during the first operational period are estimated using the data from the pre-1951 “Machining” operation in Battelle-TBD-6000 [NIOSH 2011]. The intake rates for inhalation and ingestion are provided in Table 5-1 and 5-2. Given the chemical and physical forms of uranium at the site, only type M or S solubility should be evaluated.

Table 5-1. Inhalation intake rates for the first operational period (dpm/calendar day).^a

| Period | Operator | Laborer | Supervisor and clerk ^b |
|-----------------------|----------|---------|-----------------------------------|
| 06/01/1943–09/27/1943 | 43,632 | 21,816 | 10,909 |

- Intakes are assigned as a lognormal distribution with a geometric standard deviation (GSD) of 5.
- Due to the limited information on the location of the uranium slug work, the Supervisor and Clerk job categories were combined.

Table 5-2. Ingestion intake rates for the first operational period (dpm/calendar day).^a

| Period | Operator | Laborer | Supervisor and Clerk ^b |
|-----------------------|----------|---------|-----------------------------------|
| 06/01/1943–09/27/1943 | 895 | 446 | 224 |

- Intakes are assigned as a lognormal distribution with a GSD of 5.
- Due to the limited information on the location of the uranium slug work, the Supervisor and Clerk job categories were combined.

The work at Carborundum was done for the purpose of experimentally determining the appropriate type of abrasive wheel and the optimum speeds to maintain. Carborundum was not the site where the actual final uranium production grinding operation was performed. The information from this operational period at Carborundum denotes that the scale of this uranium operation was very limited (30 lb of slugs) and occurred in June 1943. The 30 lb consisted of 10 slugs that were received from HHM Safe Company by Carborundum in June 1943 and returned in September 1943. Therefore, the Battelle-TBD-6000 method based on large-scale and large-quantity operations serves to support bounding internal exposures for Carborundum’s first operational period [NIOSH 2011].

Exposures associated with residual material after September 27, 1943, are covered in the section below describing the first residual period.

5.2.2 First Residual Dose Period, 1943 to 1958

Residual uranium inhalation intake rates are based on guidance in Battelle-TBD-6000 [NIOSH 2011]. A settling rate of 0.00075 m/s was assumed for 30 d resulting in a surface contamination level of 1.07×10^7 dpm/m². A resuspension factor of 1×10^{-5} /m was then used to estimate the initial contamination level in the air at the start of the residual period, 106.5 dpm/m³. The inhalation intake rate calculated based on that air concentration was then depleted over time based on the adjustments in ORAUT-OTIB-0070, *Dose Reconstruction During Residual Radioactivity Periods at Atomic Weapons Employer Facilities* [ORAUT 2012].

The intake rates for inhalation and ingestion are provided in Table 5-3. Given the chemical and physical forms of uranium at the site, only type M or S solubility should be evaluated.

Table 5-3. Uranium intake rates for the first residual period (dpm/calendar day).^{a,b}

| Period | Inhalation | Ingestion |
|----------------------|------------|-----------|
| 9/28/1943–12/31/1943 | 841 | 895 |
| 1944 | 841 | 895 |
| 1945 | 658 | 701 |
| 1946 | 515 | 549 |
| 1947 | 403 | 430 |
| 1948 | 316 | 337 |
| 1949 | 247 | 263 |
| 1950 | 194 | 207 |
| 1951 | 139 | 148 |
| 1952 | 109 | 116 |
| 1953 | 86 | 91 |
| 1954 | 67 | 71 |
| 1955 | 52 | 56 |
| 1956 | 37 | 40 |
| 1957 | 29 | 31 |
| 1958 | 23 | 24 |
| 1959 | 18 | 19 |
| 1960 | 14 | 15 |
| 1961 | 11 | 12 |
| 1962 | 8.6 | 9.1 |
| 1963 | 6.7 | 7.2 |
| 1964 | 5.3 | 5.6 |
| 1965 | 4.1 | 4.4 |
| 1966 | 3.2 | 3.4 |
| 1967 | 2.5 | 2.7 |
| 1968 | 2.0 | 2.1 |
| 1969 | 1.5 | 1.6 |
| 1970 | 1.2 | 1.3 |
| 1971 | 1.0 | 1.0 |
| 1972 | 0.74 | 0.79 |
| 1973–1992 | 0.58 | 0.62 |

- a. Intakes are assigned as a lognormal distribution with a GSD of 5.
b. Uranium intake rates should be assigned as 100% U-234.

Initial residual uranium ingestion intake rates were assumed to be equivalent to the ingestion rate for the Operator job category at the end of the first operational period. This ingestion intake rate was then depleted over time based on the adjustments in ORAUT-OTIB-0070 [ORAUT 2012].

Based on Battelle-TBD-6000 [NIOSH 2011], the number of hours worked were reduced from 48 per week in 1943, to 44 per week starting in 1951, then to 40 per week starting in 1956.

The intake rates in Table 5-3 apply to all Carborundum workers through 1958. If there is clear documentation that a worker was assigned to the Global Plant, then the worker should be assigned residual intakes from Table 5-3 in all applicable years.

5.2.3 Second Operational Period, 1959 to 1967

Air sample results for uranium and plutonium for the second operational period were used to provide an intake rate estimate that is favorable to the claimant. The operations during this period were of an experimental nature and the sample data are limited in scope. A statistical analysis was performed on both the uranium and plutonium sample results.

5.2.3.1 Uranium

Doses should be assigned based on airborne dust sampling data for November 1959 and April 1961 [AEC 1947–1961]. On November 9, 1959, a series of six general area airborne dust samples were taken. A second series of three samples, all with positive results, was collected on April 5, 1961. One other sample was taken; the sample date is unknown, but it was received on April 19; the record is not legible.

The geometric mean of this air sample data was 0.634 dpm/m³ with a geometric standard deviation (GSD) of 4.45. Based on this distribution, the 95th-percentile air concentration was determined to be 7.38 dpm/m³. This air concentration was assumed to represent the general area and was therefore used to calculate the intake rate for the Laborer exposure.

Based on Battelle-TBD-6000 [NIOSH 2011], the Operator intake rates were assumed to be twice the Laborer intake rates, the Supervisor intake rates were assumed to be half the Laborer intake rates, and the Clerk's intake rate was assumed to be 10% of the Supervisor intake rates.

Uranium intake rates for inhalation and ingestion are provided in Tables 5-4 and 5-5, respectively. Uranium doses are assigned as 100% ²³⁴U for individual uranium dose evaluation. Given the chemical and physical forms of uranium at the site, only type M or S solubility should be evaluated. Recycled uranium (RU) contaminants should be assigned based on Battelle-TBD-6000 [NIOSH 2011] (see Table 5-6).

Table 5-4. Inhalation intake rates for the second operational period (dpm/calendar day).^a

| Radionuclide | Operator | Laborer ^b | Supervisor | Clerk |
|---|----------|----------------------|------------|-------|
| Uranium (1959-1967) | 97.10 | 48.55 | 24.28 | 2.428 |
| Plutonium mixture-total alpha (1961–1967) | 7.650 | 3.825 | 1.913 | 0.191 |

- a. Intakes are assigned as a constant distribution.
- b. Based on the level of potential exposure, XRD operators should be assigned the more favorable Laborer exposure scenario.

Table 5-5. Ingestion intake rates for the second operational period (dpm/calendar day).^a

| Radionuclide | Operator | Laborer ^b | Supervisor | Clerk |
|---|----------|----------------------|------------|-------|
| Uranium (1959-1967) | 2.023 | 1.012 | 0.506 | 0.051 |
| Plutonium mixture-total alpha (1961–1967) | 0.159 | 0.080 | 0.040 | 0.004 |

- a. Intakes are assigned as a constant distribution.
- b. Based on the level of potential exposure, XRD operators should be assigned the more favorable Laborer exposure scenario.

Table 5-6. RU mixture ratios.^a

| Radionuclide | Ratio to U-Activity |
|--------------|---------------------|
| Pu-239 | 0.00246 |
| Np-237 | 0.00182 |
| Tc-99 | 0.379 |
| Th-232 | 2.73E-6 |
| Th-228 | 2.73E-6 |

- a. Source: NIOSH [2011].

Ingestion rates were based on OCAS-TIB-009, *Estimation of Ingestion Intakes* [NIOSH 2004].

5.2.3.2 Plutonium

Plutonium intake rates are based on airborne dust sampling data for April 1961 and June 1961 [AEC 1947–1961]. On April 5, 1961, a series of eight airborne dust samples was taken. Two were identified as general area samples and two as breathing-zone samples, and four were either without description or the description was illegible. All samples on this date had positive results. On June 7, 1961, a second series of eight samples was collected. Six of the samples were identified as breathing-zone samples, and two as general area samples. Four of the samples had positive results.

The geometric mean of this air sample data was 0.027 dpm/m³ with a GSD of 9.82. Based on this distribution, the 95th-percentile air concentration was determined to be 1.16 dpm/m³.

This air concentration was assumed to be representative of the work area and was therefore used to calculate the intake rate for the Operator exposure. Based on Battelle-TBD-6000 [NIOSH 2011], the Laborer intake rates were assumed to be half the Operator intake rates, the Supervisor intake rates was assumed to be half the Laborer intake rates, and the Clerk intake rates were assumed to 10% of the Supervisor intake rates.

Gross alpha plutonium mixture intake rates for inhalation and ingestion are provided in Tables 5-4 and 5-5, respectively. Given that these intake rates represent total alpha activity, the ratio for the plutonium mixture (see Table 5-8 next section) should be applied to determine the intake rate for each radionuclide in the mixture.

Ingestion rates were based on OCAS-TIB-009 [NIOSH 2004].

5.2.3.3 Summary of Second Operational Period Intake Rates

If there is clear documentation that a worker was assigned to the Global Plant, then the worker should be assigned residual intakes from Table 5-3 in all applicable years. Uranium-only work in the second operational period started in 1959, and the plutonium mixed carbide fuel pellets work started in 1961. The plutonium mixed carbide fuel pellets involved both uranium and plutonium. There was a separate uranium laboratory for experiments and fabrication of uranium (only) experimental pieces and fuel pellets. The estimated intake rates in the uranium laboratory are based on measured alpha air concentrations in the uranium laboratory. The plutonium laboratory was an isolated cell in the same building. The plutonium intake rates are based on measured gross alpha air concentrations in the plutonium laboratory. In the absence of definitive work locations for all workers, the assigned intake rates between 1961 and 1967 should be based on the work that results in the exposure most favorable to the claimant. Therefore, either the uranium laboratory or the plutonium laboratory should be assigned, but not both. This is based on the assumption that a worker was not simultaneously exposed in two different areas of the Carborundum facility.

Though the plutonium laboratory used both uranium and plutonium in the fabrication of fuel pellets, the intake rates for the plutonium laboratory are based on gross alpha air concentration estimates. Because workers could have been exposed to either uranium or plutonium, or a mixture, it is more favorable to assume all of gross alpha intake for the plutonium laboratory was 100% plutonium. This is because the estimated uranium gross alpha intake rates for the uranium laboratory are greater than those for the plutonium laboratory.

In addition, it is assumed that a worker could have been exposed in both laboratories at different times for portions of their work. Therefore, the application of the more favorable internal and external dose scenario is treated separately to ensure total doses are not underestimated. This means that it is acceptable to assign internal exposures based on the more favorable uranium laboratory intake rates

and still assign external exposures based on the more favorable plutonium laboratory dose rates, and vice versa.

The plutonium was assumed to be weapons grade having the weight fractions shown in Table 5-7 [Strasser and Taylor 1962b, p. 15].

Table 5-7. Isotopic analysis of plutonium mixture.

| Radionuclide | % mass |
|--------------|--------|
| Pu-238 | 0% |
| Pu-239 | 90.7% |
| Pu-240 | 7.9% |
| Pu-241 | 1.2% |
| Pu-242 | 0.1% |

The activities of the radionuclides at 5 years after separation were calculated using the Radiological Toolbox 3.0.0. This resulted in the following ratios of isotope to total alpha activity (Table 5-8).

Table 5-8. Plutonium mixture isotopic to total alpha^a activity ratios.

| Radionuclide ^b | Ratio |
|---------------------------|--------|
| Pu-239 | 0.678 |
| Pu-240 | 0.216 |
| Pu-241 | 11.740 |
| Am-241 | 0.106 |

- Sum of Pu-239, Pu-240, and Am-241.
- Pu-242 is considered an insignificant contributor to dose and therefore not assessed.

5.2.4 Second Residual Dose Period, 1968 to 1992

Residual inhalation intake rates were based on Battelle-TBD-6000 [NIOSH 2011]. The initial airborne contamination level was determined by setting the operational air concentration at a rate of 0.00075 m/s for 30 days and then resuspended at a rate of 1×10^{-5} /m. The inhalation intake rates calculated based on those air concentrations were then depleted over time based on the adjustments found in ORAUT-OTIB-0070 [ORAUT 2012].

The initial uranium intake rate at the start of the residual period was determined to be 0.94 dpm/calendar day inhalation and 2.023 dpm/calendar day ingestion. This is less than the intake rate from the first residual period in 1968 (see Table 5-3). Given that the work location for the second operational period was in the research and development building that did not exist in 1943, the first residual period uranium intakes are considered more favorable for all years during the second residual period. Given the chemical and physical forms of uranium at the site, only type M or S solubility should be evaluated.

Gross alpha plutonium mixture intake rates for inhalation and ingestion are provided in Table 5-9. Given that these intake rates represent total alpha activity, the ratio for the plutonium mixture (Table 5-8), should be applied to determine the intake rate for each radionuclide in the mixture.

Plutonium ingestion intake rates at the beginning of the residual period were assumed to be equivalent to the Operator ingestion intakes from the second operational period. Exposures for this second residual period were adjusted based on guidance in ORAUT-OTIB-0070 [ORAUT 2012].

Table 5-9. Total alpha intake rates for the plutonium mixture during the second residual period (dpm/calendar day).^a

| Period | Inhalation | Ingestion |
|--------|------------|-----------|
| 1968 | 0.15 | 0.159 |
| 1969 | 0.12 | 0.125 |
| 1970 | 0.091 | 0.098 |
| 1971 | 0.071 | 0.077 |
| 1972 | 0.056 | 0.060 |
| 1973 | 0.044 | 0.047 |
| 1974 | 0.034 | 0.037 |
| 1975 | 0.027 | 0.029 |
| 1976 | 0.021 | 0.022 |
| 1977 | 0.017 | 0.018 |
| 1978 | 0.013 | 0.014 |
| 1979 | 0.0101 | 0.011 |
| 1980 | 0.0079 | 0.0085 |
| 1981 | 0.0062 | 0.0066 |
| 1982 | 0.0048 | 0.0052 |
| 1983 | 0.0038 | 0.0041 |
| 1984 | 0.0030 | 0.0032 |
| 1985 | 0.0023 | 0.0025 |
| 1986 | 0.0018 | 0.0020 |
| 1987 | 0.0014 | 0.0015 |
| 1988 | 0.0011 | 0.0012 |
| 1989 | 0.00088 | 0.00094 |
| 1990 | 0.00069 | 0.00073 |
| 1991 | 0.00054 | 0.00058 |
| 1992 | 0.00042 | 0.00045 |

a. Intakes are assigned as a constant distribution.

Summary of Second Residual Period Intake Rates

If there is clear documentation that a worker was assigned to the Global Plant, then the worker should be assigned residual intakes from Table 5-3 in all applicable years.

The uranium intake rates in Table 5-3, or the plutonium mixture intake rates in Table 5-9, whichever results in the higher dose, apply to all Carborundum workers. The choice of which scenario, uranium or plutonium, is more favorable is independent of the selection of exposure scenario that is more favorable for external exposures.

6.0 OCCUPATIONAL EXTERNAL DOSE

6.1 AVAILABLE EXTERNAL MONITORING DATA

No Carborundum or DOE documentation was identified that would show that the operational areas or the workers were personally monitored for external radiation during the two operational or two residual radiation periods. However, interviews with former workers [ORAUT 2015b, 2015c, 2015e, 2016] indicated that the site did provide monitoring badges. If a claim file contains personal monitoring records, contact the Principal Scientist for External Dosimetry or Principal Scientist for AWEs on how to assess the data.

6.2 METHODS FOR BOUNDING UNMONITORED EXTERNAL DOSE

Individual exposures are assigned based on the specific work performed, using the same categories for internal dose: Operator, Laborer, Supervisor, and Clerk (Section 5.2).

6.2.1 First Operational Period, 1943

As indicated above, the operations for this period at Carborundum were very limited (30 lb of slugs) and occurred in June 1943. The 30 lb consisted of 10 slugs that were received from HHM Safe Company by Carborundum in June 1943 and returned in September 1943. Therefore, exposures associated with residual material after September 27, 1943, are covered in the section below describing the first residual period.

Given that the guidance in Battelle-TBD-6000 [NIOSH 2011] is based on large-scale and large-quantity operations, the exposure rates for the machining (grinding) work in Carborundum slug grinding experiments was considered bounding for Carborundum exposures.

Individual external doses should be assigned based on the specific work as shown below. Daily dose rates are provided in Tables 6-1 and 6-2.

- Operator's basis. 0.000524 rem/hr @ 1 ft rate based on an array of 10 slugs [NIOSH 2011; Table 6.1]. This results in an annualized penetrating dose rate of 0.6288 rem/yr or 0.00172 rem/calendar-day assuming 50% of a 2,400-hr work year [NIOSH 2011].
- Laborer basis. 0.0000519 rem/hr @ 1 m rate based on an array of 10 slugs [NIOSH 2011, Table 6.1]. This results in an annualized penetrating dose rate of 0.06228 rem/yr or 0.000171 rem/calendar-day assuming 50% of a 2,400-hr work year [NIOSH 2011].

Table 6-1. Penetrating dose rates for the first operational period (rem/calendar day).^a

| Period | Operator | Laborer | Supervisor and Clerk ^b |
|-----------------------|----------|----------|-----------------------------------|
| 06/01/1943–09/27/1943 | 1.72E-03 | 1.71E-04 | 8.53E-05 |

- a. Doses are assigned as a lognormal distribution with a GSD of 5.
b. Assumed to be 50% of the Laborer's dose rate [NIOSH 2011].

Based on Battelle-TBD-6000 [NIOSH 2011], the nonpenetrating (beta) dose rate for the operator is assumed to be 10 times the penetrating dose rate.

Table 6-2. Nonpenetrating dose rates for the first operational period (rem/calendar day).^a

| Period | Operator | Laborer ^b | Supervisor and Clerk ^c |
|-----------------------|----------|----------------------|-----------------------------------|
| 06/01/1943–09/27/1943 | 1.72E-02 | 8.61E-03 | 8.61E-04 |

- a. Doses are assigned as a lognormal distribution with a GSD of 5.
b. Assumed to be 50% of the Operator's dose rate [NIOSH 2011].
c. Assumed to be 10% of the Laborer's dose rate [NIOSH 2011].

Penetrating doses should be applied as 100% 30- to 250-keV photons assuming acute exposure and deep dose equivalent ($H_p(10)$) to organ dose equivalent (HT) dose conversion factor (DCF) values in accordance with OCAS-IG-001 [NIOSH 2007]. Nonpenetrating doses should be applied as >15-keV electrons using an acute exposure rate and a DCF in accordance with ORAUT-OTIB-0017, *Interpretation of Dosimetry Data for Assignment of Shallow Dose* [ORAUT 2005].

Surface contamination and air submersion DCFs for uranium are based on Battelle-TBD-6000 [NIOSH 2011]. Battelle-TBD-6000 [NIOSH 2011] Tables 3.9 and 3.10 were used to estimate the exposure rates from residual contamination.

Surface Contamination

- Deep: 3.94×10^{-13} R/hr/dpm/m²
- Shallow: 3.82×10^{-11} rad/hr/dpm/m²

Air Submersion

- Deep: 2.46×10^{-12} R/hr/dpm/m³

The surface and airborne contamination levels for the operational period were determined to be 1.07×10^7 dpm/m² and 5,480 dpm/m³, respectively. This results in an operational exposure rate for June 1, 1943, to September 27, 1943, of 2.77×10^{-5} R/calendar day penetrating and 2.68×10^{-3} R/calendar day nonpenetrating. These doses are assigned to all workers as a lognormal distribution with a GSD of 5.

Penetrating doses associated with operations should be applied as 100% 30- to 250-keV photons using the acute exposure rate and exposure (*R*)-to-organ (*HT*) DCF values in accordance with OCAS-IG-001 [NIOSH 2007]. Penetrating doses associated with surface contamination and submersion should be applied as 71.8% <30 keV; 17.8% 30- to 250-keV, and 10.4% >250-keV photons [NIOSH 2011], given that the penetrating doses are mainly attributed to the contaminated surface, using acute exposure rate and exposure (*R*)-to-organ (*HT*) DCF values in accordance with OCAS-IG-001 [NIOSH 2007]. Nonpenetrating doses should be applied as >15-keV electrons using an acute exposure rate and a DCF in accordance with ORAUT-OTIB-0017 [ORAUT 2005].

6.2.2 First Residual Period, 1944 to 1958

Residual surface contamination and air submersion DCFs from uranium are based on Battelle-TBD-6000 [NIOSH 2011]. The Battelle-TBD-6000 [NIOSH 2011] surface contamination and air submersion DCFs in Section 5.2.2 were used to calculate the first residual period external dose exposure rates.

The initial surface and airborne contamination levels for the start of the first residual period were determined to be 1.07×10^7 dpm/m² and 1.065×10^2 dpm/m³, respectively. This results in an initial exposure rate of 1.01×10^{-2} R/yr penetrating and 9.77×10^{-1} rad/yr nonpenetrating. These exposure rates were then depleted over time based on the adjustments in ORAUT-OTIB-0070 [ORAUT 2012]. The penetrating and nonpenetrating exposure rates are provided in Table 6-3.

Based on Battelle-TBD-6000 [NIOSH 2011], the number of hours worked were reduced from 48 per week in 1943, to 44 per week starting in 1951, then to 40 per week starting in 1956.

These exposure rates apply to all Carborundum workers.

Penetrating doses associated with surface contamination and submersion should be applied as 71.8% <30 keV; 17.8% 30- to 250-keV, and 10.4% >250-keV photons [NIOSH 2011], given that the penetrating doses are mainly attributed to the contaminated surface, using acute exposure rate and exposure (*R*)-to-organ (*HT*) DCF values in accordance with OCAS-IG-001 [NIOSH 2007]. Nonpenetrating doses should be applied as >15-keV electrons using an acute exposure rate and a DCF in accordance with ORAUT-OTIB-0017 [ORAUT 2005].

6.2.3 Second Operational Period, 1959 to 1967

The more favorable exposure scenario between uranium, plutonium, or X-ray diffraction should be assigned. All three scenarios occurred in different work locations. However, the assumption made on the more favorable internal exposure scenario does not dictate the assumed scenario for external exposure. That is, the choice of the more favorable internal and external scenarios is independent to ensure total doses are not underestimated. This means that it is acceptable to assign internal exposures based on the more favorable uranium laboratory intake rates and still assign external exposures based on the more favorable plutonium laboratory or X-ray diffraction, or vice versa.

Table 6-3. External dose rates for the first residual period.^a

| Period | Penetrating (R/yr) | Nonpenetrating (rad/yr) |
|-----------------------|--------------------|-------------------------|
| 09/28/1943–12/31/1943 | 2.62E-03 | 2.54E-01 |
| 1944 | 1.01E-02 | 9.77E-01 |
| 1945 | 7.89E-03 | 7.65E-01 |
| 1946 | 6.18E-03 | 5.99E-01 |
| 1947 | 4.84E-03 | 4.69E-01 |
| 1948 | 3.79E-03 | 3.67E-01 |
| 1949 | 2.96E-03 | 2.87E-01 |
| 1950 | 2.33E-03 | 2.26E-01 |
| 1951 | 1.67E-03 | 1.62E-01 |
| 1952 | 1.30E-03 | 1.26E-01 |
| 1953 | 1.03E-03 | 9.94E-02 |
| 1954 | 8.01E-04 | 7.76E-02 |
| 1955 | 6.27E-04 | 6.08E-02 |
| 1956 | 4.47E-04 | 4.33E-02 |
| 1957 | 3.49E-04 | 3.39E-02 |
| 1958 | 2.74E-04 | 2.65E-02 |
| 1959 | 2.14E-04 | 2.08E-02 |
| 1960 | 1.68E-04 | 1.63E-02 |
| 1961 | 1.31E-04 | 1.27E-02 |
| 1962 | 1.03E-04 | 9.97E-03 |
| 1963 | 8.06E-05 | 7.81E-03 |
| 1964 | 6.31E-05 | 6.12E-03 |
| 1965 | 4.94E-05 | 4.79E-03 |
| 1966 | 3.87E-05 | 3.75E-03 |
| 1967 | 3.03E-05 | 2.94E-03 |
| 1968 | 2.37E-05 | 2.30E-03 |
| 1969 | 1.86E-05 | 1.80E-03 |
| 1970 | 1.45E-05 | 1.41E-03 |
| 1971 | 1.14E-05 | 1.10E-03 |
| 1972 | 8.92E-06 | 8.65E-04 |
| 1973–1992 | 6.98E-06 | 6.77E-04 |

a. Doses are assigned as a lognormal distribution with a GSD of 5.

6.2.3.1 Uranium

Given that the guidance found in Battelle-TBD-6000 [NIOSH 2011] is based on large-scale and large-quantity operations, the exposure rates for the machining (grinding) work for slug production was considered bounding for Carborundum exposures.

Individual external doses should be assigned based on the specific work using the categories described below. Daily dose rates are provided in Tables 6-4 and 6-5.

- Operator basis. 0.000231 rem/hr at 1-ft rate based on a flat plate [NIOSH 2011, Table 6.1]. This results in an annualized penetrating dose rate of 0.231 rem/yr or 0.000633 rem/calendar-day assuming 50% of a 2,000-hr work year [NIOSH 2011].
- Laborer basis. 0.0000278 rem/hr at 1-m rate based on a flat plate [NIOSH 2011, Table 6.1]. This results in an annualized penetrating dose rate of 0.0278 rem/yr or 0.000076 rem/calendar-day assuming 50% of a 2,000-hr work year [NIOSH 2011].

Table 6-4. Penetrating dose rates for the second operational period (rem/calendar day).^a

| Period | Operator | Laborer | Supervisor ^b | Clerk ^c |
|-----------|----------|----------|-------------------------|--------------------|
| 1959–1967 | 6.33E-04 | 7.62E-05 | 3.81E-05 | 3.81E-06 |

- Doses are assigned as a lognormal distribution with a GSD of 5.
- Assumed to be 50% of the Laborer's dose rate [NIOSH 2011].
- Assumed to be 10% of the Supervisor's dose rate [NIOSH 2011].

Table 6-5. Nonpenetrating dose rates for the second operational period (rem/calendar day).^a

| Period | Operator ^b | Laborer ^c | Supervisor ^d | Clerk ^e |
|-----------|-----------------------|----------------------|-------------------------|--------------------|
| 1959–1967 | 1.11E-02 | 5.55E-03 | 5.55E-04 | n/a |

- Doses are assigned as a lognormal distribution with a GSD of 5.
- Based on MCNP analysis of uranium metal plate [ORAUT 2018a].
- Assumed to be 50% of the Operator's dose rate [NIOSH 2011].
- Assumed to be 10% of the Laborer's dose rate [NIOSH 2011].
- No exposure assumed [NIOSH 2011].

Penetrating doses associated with operations should be applied as 100% 30- to 250-keV photons using acute exposure rate and deep dose equivalent ($H_p(10)$) to organ dose equivalent (HT) DCF values in accordance with OCAS-IG-001 [NIOSH 2007]. Nonpenetrating doses should be applied as >15-keV electrons using an acute exposure rate and a DCF in accordance with ORAUT-OTIB-0017 [ORAUT 2005].

Surface contamination and air submersion dose correction factors for uranium are based on Battelle-TBD-6000 [NIOSH 2011].

The surface and airborne contamination levels for the second operational period were determined to be 2.87×10^4 dpm/m² and 14.77 dpm/m³, respectively. This results in an operational exposure rate for 1959 to 1967 of 6.22×10^{-8} R/calendar day penetrating and 6.01×10^{-6} rad/calendar day nonpenetrating. These doses should be assigned to all workers.

Penetrating doses associated with surface contamination and submersion should be applied as 71.8% <30 keV; 17.8% 30- to 250-keV, and 10.4% >250-keV photons [NIOSH 2011], given that the penetrating doses are mainly attributed to the contaminated surface, using acute exposure rate and exposure (R)-to-organ (HT) DCF values in accordance with OCAS-IG-001 [NIOSH 2007]. Nonpenetrating doses should be applied as >15-keV electrons using an acute exposure rate and a DCF in accordance with ORAUT-OTIB-0017 [ORAUT 2005].

6.2.3.2 Plutonium

From 1961 through 1967, as described in Section 2.1.3, Carborundum operated a facility for the study and fabrication of plutonium refractory materials for an AEC fuel development program.

6.2.3.2.1 Geometry and Materials

Pellet Geometry

The radiation source for these dose calculations is a small pellet of UPu carbide having a density of 12.8 g/cm³ [Strasser and Stahl 1965]. The carbide fuel pellets had a range of densities. This density (12.8 g/cm³) was mentioned in the text of the final report as starting material for experiments related to out-of-pile properties of mixed UPu carbides [Stahl et al. 1963, p. 14]. The chosen density was identified as the density of fuel that had been sintered without sintering aids. This density was chosen to maximize the amount of fuel in a single fuel pellet. Fuel that had been sintered with a sintering aid (0.1 without Ni) had a higher density of 13.1 g/cm³ [Stahl et al. 1963, p. 14]. Dose estimates were made for a single pellet that is a cylinder 0.2 in. in diameter and 0.2 in. tall [Strasser and Stahl 1965]. The pellets were assumed to be unclad.

Glovebox Geometry

The pellets were assumed to be housed in a glovebox 3 ft high, 5 ft long, and 3.5 ft deep [Saulino et al. 1962]. The side walls, roof, and floor of the glovebox were 0.25-in. welded aluminum plate. The front and back walls were 0.25-in. safety glass. The safety glass consisted of two 0.125-in. layers of plate glass and a 15-mil inner layer of polyvinyl butyral that inhibited shattering of the glass.

In addition to the glovebox, the model contained a concrete back wall, a ceiling, and a floor to generate albedo. Steel panels 0.0625 in. thick were installed on the ceiling and walls of the room.

6.2.3.2.2 Radiation Source Terms

Isotopic Compositions of Uranium and Plutonium

The plutonium was assumed to be weapons grade having the weight fractions shown in Table 6-6 [Strasser and Taylor 1962b]. The uranium was enriched as shown in Table 6-7. Three isotopic compositions for plutonium were used during the course of the experiments at Carborundum. The composition for dose reconstruction purposes was chosen based on the material that had the highest weight fraction of ²⁴¹Pu. Plutonium-241 decays to ²⁴¹Am, which drives the photon dose because it emits a 60-keV photon that penetrates shielding more readily than the lower energy photons from plutonium isotopes.

Table 6-6. Isotopic analysis of plutonium mixture.

| Radionuclide | % mass |
|---------------------|---------------|
| Pu-238 | 0% |
| Pu-239 | 90.7% |
| Pu-240 | 7.9% |
| Pu-241 | 1.2% |
| Pu-242 | 0.1% |

Table 6-7. Isotopic analysis of uranium mixture.

| Radionuclide | % mass |
|---------------------|---------------|
| U-234 | 0.132% |
| U-235 | 24% |
| U-238 | 75.868% |

The isotopic composition of the uranium for the carbide fuel pellets was not explicitly stated in the reports. An enrichment of 24% was chosen to be consistent with material known to have been used at Carborundum [Strasser and Taylor 1962b]. The calculated dose rate from the fuel pellets is not strongly influenced by the isotopic composition of the uranium for the fuel pellets.

Photon Source Calculations

The photon component of the dose rates from (U_{0.8}Pu_{0.2})C is due mainly to the radioactive progeny of the nuclides in Tables 6-6 and 6-7. The activities of the progeny radionuclides at 5 years after separation were calculated using the Radiological Toolbox 3.0.0. The photon intensities and energies emitted by the radionuclides were obtained from Bé et al. [2004, Volume 2 - A] and International Commission on Radiological Protection (ICRP) Publication 107 [ICRP 2008]. Bé et al. [2004, Volume 2 - A] is noted in the source definition section of the MCNP6.2 input files as "CEA".

Neutron Source Calculations

The neutron source term was calculated using the SOURCES 4C computer code. The volumetric source considered for these calculations included neutrons emitted from within the volume of the source region by spontaneous fission and by (alpha,n) interactions.

Input to SOURCES 4C included the desired energy structure of the neutron spectrum, the number density of the actinide isotopes, and the fraction of the (alpha,n) target nuclides to the total number density. Neutron spectra were calculated in 760 groups with a minimum energy of 0 MeV and a maximum energy of 4.49 MeV. SOURCES 4C reports that ^{240}Pu produces about 73% of all spontaneous fission and (alpha,n) neutrons that form the source term.

Carbon-13 was the only target isotope considered for calculations of (alpha,n) neutrons because the atom fraction of ^{13}C exceeded the atom fractions of other impurity isotopes by about a factor of 100.

6.2.3.2.3 Dose Equivalent Calculations

Fluence to Dose Conversion Coefficients

MCNP6.2 was used to calculate the fluence rates of neutrons and photons that entered volume elements that represented dosimeters [ORAUT 2019b]. Two dosimeters were implemented in the MCNP6.2 input file, one at 30.48 cm from the center of the fuel pellet and one at 100 cm. The pellet and the dosimeter were assumed to be positioned 24 cm above the floor of the glovebox.

Conversion coefficients were used to translate the fluence rates to dose equivalent rates. The conversion coefficients were included in the MCNP6.2 input file and the conversion from fluence to dose equivalent was performed by MCNP6.2.

The selected neutron conversion coefficients are from Table A.42 of ICRP Publication 74 [ICRP 1996]. The photon data were derived using conversion coefficients in Tables A.1, A.21, and A.24 of ICRP [1996].

Tallies

Photon exposures were divided into three energy bins (< 30 keV, 30- to 250-keV, and >250 keV). Neutrons were divided into five energy bins (<0.01 MeV, 0.01 to 0.1 MeV, 0.1 to 2 MeV, 2 to 20 MeV, and >20 MeV). For both neutrons and photons, the upper energy bins were divided in two to help elucidate the energy spectra of the radiations especially to determine if the tally energies exceeded the energy of the DCFs.

The tallies were accumulated into two air volumes that represented dosimeters. The air volumes were 5.08 cm x 5.08 cm x 0.2 cm, and the centers were located 30.48 cm (1 ft) and 100 cm from the center of the fuel pellet.

6.2.3.2.4 Simulation Results

Dose rates were calculated at 1 ft (30.48 cm) and 1 m from the center of a single pellet [ORAUT 2018b]. The dose rates from a single pellet were then scaled upward to account for the maximum amount of plutonium allowed to be processed in any batch.

The potential dose for each job category is based on the following assumption, consistent with the Battelle-TBD-6000 [NIOSH 2011]. Table 6-8 lists external doses.

- Operator basis. 50% of the workday was spent at 1 ft (30.48 cm) from the fuel object containing 525 g of pellets (i.e., 100 g of plutonium).
- Laborer basis. 50% of the workday was spent at 1 m from the fuel object containing 525 g of pellets (i.e., 100 g of plutonium).
- Supervisor basis. 50% of the Laborer exposure rate [NIOSH 2011].

- Clerk basis. 10% of the Supervisor exposure rate [NIOSH 2011].

Table 6-8. External dose from second operational period for plutonium (rem/yr).

| Category | Penetrating | Neutron |
|-----------------|-------------|---------|
| Operator | 6.303 | 0.154 |
| General laborer | 0.590 | 0.017 |
| Supervisor | 0.295 | 0.008 |
| Clerk | 0.029 | 0.001 |

For the Operator, the penetrating dose should be applied as 0.16% <30-keV, 91.35% 30- to 250-keV, and 8.49% >250-keV photons. For the Laborer, Supervisor, and Clerk, the penetrating dose should be applied as 0.05% <30 keV, 91.68% 30- to 250-keV, and 8.27% >250-keV photons.

For the Operator, the neutron dose should be applied as 0.02% <0.01-MeV, 0.21% 0.01- to 0.1-MeV, 43.59% 0.1- to 2 MeV, and 56.17% >2-MeV neutrons. For the Laborer, Supervisor, and Clerk, the penetrating dose should be applied as 0.13% <0.01-MeV, 0.44% 0.01- to 0.1-MeV, 47.09% 0.1- to 2-MeV, and 52.33% >2-MeV neutrons.

Photon and neutron doses are treated as constant distributions. All doses should be assessed using ambient dose equivalent ($H^*(10)$) to organ dose equivalent (HT) values in accordance with OCAS-IG-001 [NIOSH 2007]. All photon doses should be assigned as acute exposures, and all neutron doses should be assigned as chronic exposures. ICRP Publication 60 corrections factors [ICRP 1991] should be applied to the neutron doses in accordance with ORAUT-OTIB-0055, *Technical Basis for Conversion from NCRP Report 38 Neutron Quality Factors to ICRP Publication 60 Radiation Weighting Factors for Respective IREP Input Neutron Energy Ranges* [ORAUT 2006].

6.2.3.3 X-Ray Diffraction

Carborundum XRD Machines

XRD machines can have a range of sizes and configurations from bench-top units to standalone devices in a laboratory. The operator's position during operation is variable depending on the configuration of the XRD machine.

A former Carborundum worker who [redacted] the XRD machine [ORAUT 2016] was asked about the configuration of the XRD machine. The worker stated it sat on the floor and was not moved because water was plumbed to it. People could walk through the room but generally, only the people who worked with one of the three analytical devices in the room occupied it. According to the worker, these people "knew not to stand around" [ORAUT 2016, p. 2]. This worker further stated that the XRD machine operated for about 40 minutes per sample and there were about 10 sample runs per day.

The interviewed worker also described some technical details of the XRD machine. It had a hood and a shield, and workers prepared the sample, placed it in the XRD machine (with the shutter closed), closed the shield over the assembly, and opened the shutter to irradiate the sample. Once the assembly was in place, the worker walked away for the duration (about 40 minutes) of the sample operation [ORAUT 2016, p. 2].

Hazard Associated with an XRD Machine

The greatest hazard from XRD machines is from external exposure to the primary beam. This can occur most commonly during alignment procedures in which the target must be aligned with the output port, the sample with the primary beam, and the detector or film holder with the reflected beam [Lubenau 1969]. The primary beam of $K\alpha$ characteristic X-rays has a very small area, on the order of 0.01 cm² at the exit port [Rudman 1971, p. 82]. This primary beam is very intense with an exposure

rate in the hundreds of thousands of R/s [Thomas 1971, p. 145]. If the X-ray tube is energized during alignment, the operator's fingers or hands can be exposed to the primary beam. Historically, these types of accidents are the major hazard from XRD machines [Thomas 1971, p. 145]. No evidence of these types of radiation accidents has been found for Carborundum operations.

Other than exposure to the primary beam, an operator would be exposed to leakage, diffracted radiation, and scatter radiation from the sample and other components. Each of these has slightly different properties, as discussed below.

Leakage from the tube housing is assumed to be minimal [de Castro 1986, p. 10].

The source of the low-energy X-rays striking the sample is the $K\alpha$ characteristic X-rays from the tube target materials, commonly copper or iron. There is evidence that Carborundum used an XRD unit with a copper target [Strasser 1963, p. 30; TCC 1966, p. 101]. The former XRD [redacted] at Carborundum stated that the XRD machine had a copper target [ORAUT 2016, p. 3]. The energy of the $K\alpha_1$ characteristic X-ray of copper is 8.1 keV [Lubenau 1969].

The diffracted radiation would be emitted from the sample with an energy of 8.1 keV in small directional beams. Given that the interviewed worker stated that the XRD machine had a shield over the entire assembly [ORAUT 2016, p. 2], it is assumed that most of the diffracted radiation would have been absorbed in the shield material.

Electrons accelerated through a potential difference of about 35 to 50 kV (typical of a copper target tube) produce a bremsstrahlung X-ray spectrum in addition to the characteristic X-rays of copper. The average energy of the bremsstrahlung photons is about 20 keV [ANSI 1971, p. 20]. The scatter radiation emitted isotropically with an average energy of about 20 keV is assumed to be the major exposure source to workers in the XRD laboratory. Air attenuation can be quite large at low energies [Granlund 1971, p. 181], but is ignored in this work.

Dose from Scattered X-Ray Beam

Lubenau [1969] provides measurements of scatter from a 1966 survey of XRD units in Pennsylvania. Scatter measurements for three XRD units with copper targets ranged from 0.0005 to 0.002 R/hr at the table edge. These measurements are reported as maximum scatter values from the respective machines during operation. The highest scatter measurement of 0.002 R/hr was used as the starting point for dose assessment for Carborundum. Lubenau does not specify the measurement distance, so a 30-cm distance was assumed as a practical distance from an enclosure or barrier for making a measurement [NBS 1964 p. 9].

Measurement of low-energy X-rays (8- to 20-keV) can require correction because most ion chamber survey instruments are calibrated at the much higher photon energy from ^{137}Cs (662 keV). Lubenau [1969] used a Victoreen 440RF ion chamber when measuring scatter from XRD machines in Pennsylvania. Els [1971] provides an instrument correction factor of about 2.48 for a Victoreen 440 RF ion chamber measuring 8-keV photons diffracted from a copper target.

According to the XRD [redacted] [ORAUT 2016, p. 3], the run-time of the XRD machine was 40 minutes per sample and there were about 10 samples per day. In addition, the worker estimated a total of 4 to 5 minutes of exposure to each sample in the vicinity of the machine. Therefore, over the course of 50 weeks, the total exposure time would be 208.3 hr/yr (5 min/sample \times 10 samples/d \times 250 workdays/yr = 12,500 min/yr). This results in an annual exposure of 2.83×10^{-3} R/calendar day (208.3 hr/yr \times 0.002 R/hr \times 2.48 low-energy correction factor = 1.033 R/yr).

Penetrating doses should be applied as a constant distribution, assuming 100% <30-keV photons using acute exposure rate, and exposure (*R*)-to-organ (*HT*) DCF values in accordance with OCAS-IG-001 [NIOSH 2007].

Based on the level of potential exposure, XRD operators should be compared to the Battelle-TBD-6000 Laborer exposure scenario [NIOSH 2011].

6.2.4 Second Residual Period, 1968 to 1992

Residual surface contamination and air submersion DCFs from uranium are based on Battelle-TBD-6000 [NIOSH 2011]. The Battelle-TBD-6000 [NIOSH 2011] surface contamination and air submersion DCFs in Section 5.2.4 were used to calculate the initial residual external dose exposure rates.

The initial surface and airborne contamination levels for the start of the first residual period were determined to be 2.87×10^4 dpm/m² and 2.87×10^{-1} dpm/m³, respectively. This results in an initial exposure rate of 2.26×10^{-5} R/yr penetrating and 2.19×10^{-3} R/yr nonpenetrating. These doses will not be used because the 1968 dose rates for exposure in the centerless grinding work area in Table 6-3 are higher, therefore would always be more favorable.

7.0 ATTRIBUTIONS AND ANNOTATIONS

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

REFERENCES

- Advameg [2015]. Carborundum Company – company profile, information, business description, history, background information on Carborundum company. In: referenceforbusiness.com. Advameg. [SRDB Ref ID: 140566]
- AEC [1947–1961]. Data analysis results 1947 through 1961. Washington, DC: U.S. Atomic Energy Commission, Health and Safety Laboratory. [SRDB Ref ID: 11452]
- AEC [no date]. Liquid metal fast breeder reactors 1948–1961. TID-3333 Part I. Washington, DC: U.S. Atomic Energy Commission, Technical Information Center. [SRDB Ref ID: 142107]
- ANSI [1971]. ANSI N43.2-1971 American national standard – radiation safety for x-ray diffraction and fluorescence analysis equipment. New York, NY: American National Standards Institute. October 6. [SRDB Ref ID: 20839]
- Bé MM, Christé V, Dulieu C, Browne E, Chechev V, Kusmenko N, Helmer R, Nichols A, Schonfeld E, Dersch R [2004]. Table of radionuclides 2 vols. and comments. BIPM-5. Paris, France: Bureau International des Poids et Mesures. [SRDB Ref ID: 168372]
- Blatz H [1971]. Public health experience in x-ray diffraction. In: Moore TM, Gundaker WE, Thomas JW, eds. Radiation safety in x-ray diffraction and spectroscopy, proceedings of a conference held on January 6-7, 1970 at the University of Pennsylvania, Philadelphia, Pennsylvania. DHEW Publication No. (FDA) 72-8009. Rockville, MD: U.S. Department of Health, Education, and Welfare, Public Health Service, Food and Drug Administration, Bureau of Radiological Health. September. pp. 60–67. [SRDB Ref ID: 178442]
- Clinton [1943]. Clinton Engineer Works monthly accountability reports for 1943. Clinton Engineer Works, Oak Ridge, TN: Clinton Laboratories. [SRDB Ref ID: 120588]
- Clinton [1944]. Clinton Engineer Works monthly accountability reports for 1944. Clinton Engineering Works, Oak Ridge, TN: Clinton Laboratories. [SRDB Ref ID: 120591]
- Cope [1962]. Contract AT (40-1)-2558 – Close-out. The Carborundum Company. December 10. [SRDB Ref ID: 147239]
- Currie DH [1943]. Subject - Centerless Grinding. Letter to Lange CF (E. I. du Pont de Nemours and Company). Niagara Falls, NY: The Carborundum Company. July 2. [SRDB Ref ID: 126763]
- Daniels CE [1944]. T-metal fabrication. Memorandum to Gehrman GH. Wilmington, DE: E. I. du Pont de Nemours and Company. October 11. [SRDB Ref ID: 178454]
- de Castro TM [1986]. Dosimetry of x-ray beams: the measure of the problem. LBL-22169. Lawrence Berkeley Laboratory, Berkeley, CA: University of California. August. [SRDB Ref ID: 21582]
- DuPont [1945]. The metal fabrication program for the Clinton Engineer Works and the Hanford Engineer Works including the dummy slug program and the unbonded slug program - Project 1553. Wilmington, DE: E. I. du Pont de Nemours and Company. August. [SRDB Ref ID: 33190]

Els RA [1971]. The response of various survey instruments to low energy x-rays. In: Moore TM, Gundaker WE, Thomas JW, eds. Radiation safety in x-ray diffraction and spectroscopy, proceedings of a conference held on January 6-7, 1970 at the University of Pennsylvania, Philadelphia. Philadelphia, Pennsylvania. DHEW Publication No. (FDA) 72-8009. Rockville, MD: U.S. Department of Health, Education, and Welfare, Public Health Service, Food and Drug Administration, Bureau of Radiological Health. September. pp. 141–166. [SRDB Ref ID: 178443]

Forbes RL, Fuhrman N, Anderson J, Taylor K [1965]. Study of uranium-plutonium monoxides quarterly progress report period of July 1, 1965 through September 30, 1965. UNC-5138. White Plains, NY: United Nuclear Corporation. October 30. [SRDB Ref ID: 65010]

Forbes RL, Fuhrman N, Andersen J, Taylor K [1966]. Study of uranium-plutonium monoxides final summary report. UNC-5144. Elmsford NY: United Nuclear Corporation. Niagara Falls, NY: The Carborundum Company. January 31. [SRDB Ref ID: 65007]

Granlund R [1971]. Routine radiation monitoring. In: Moore TM, Gundaker WE, Thomas JW, eds. Radiation safety in x-ray diffraction and spectroscopy, proceedings of a conference held on January 6-7, 1970 at the University of Pennsylvania, Philadelphia. Philadelphia, Pennsylvania. DHEW Publication No. (FDA) 72-8009. Rockville, MD: U.S. Department of Health, Education, and Welfare, Public Health Service, Food and Drug Administration, Bureau of Radiological Health. September. pp. 167–177. [SRDB Ref ID: 178444]

ICRP [1991]. 1990 recommendations of the International Commission on Radiological Protection. ICRP Publication 60. Ann ICRP 21(1/3). [SRDB Ref ID: 11517]

ICRP [1996]. Conversion coefficients for use in radiological protection against external radiation. ICRP Publication 74. Ann ICRP 26(3/4). [SRDB Ref ID: 7979]

ICRP [2008]. Nuclear decay data for dosimetric calculations. ICRP Publication 107. Ann ICRP 38(3). [SRDB Ref ID: 136400]

Ikeye DT, Young FE [1970]. Fabrication of non-fuel core components for SEFOR. GEAP-13595. Sunnyvale, CA: General Electric Company. February. [SRDB Ref ID: 142149]

Kehl WL [1971]. Uses and users of analytical x-ray equipment. In: Moore TM, Gundaker WE, Thomas JW, eds. Radiation safety in x-ray diffraction and spectroscopy, proceedings of a conference held on January 6-7, 1970 at the University of Pennsylvania, Philadelphia. Philadelphia, Pennsylvania. DHEW Publication No. (FDA) 72-8009. Rockville, MD: U.S. Department of Health, Education, and Welfare, Public Health Service, Food and Drug Administration, Bureau of Radiological Health. September. pp. 7–30. [SRDB Ref ID: 178445]

Kostoff B [2008]. Web exclusive! Local history: Franchot Tone's industrialist father widely admired. Niagara Falls, NY: Niagara Falls Reporter. February 26. [SRDB Ref ID: 141626]

Lubenau J [1969]. Analytical x-ray hazards: a continuing problem. Health Phys 16:739–746. [SRDB Ref ID: 142196]

McMurtry CH [1967]. Studies of the preparation of mixed carbide fuel utilizing coprecipitation, final report to the USAEC for the period May 23, 1966 through February 28, 1967. NYO-3713-3. Niagara Falls, NY: The Carborundum Company. April 15. [SRDB Ref ID: 143094]

McMurtry CH, Taylor KM [1966]. Studies of the preparation of mixed carbide fuel utilizing coprecipitation. Quarterly progress report no. 2 September 1, 1966 through November 30, 1966. NYO-3713-2. Niagara Falls, NY: The Carborundum Company. [SRDB Ref ID: 53582]

NBS [1964]. Safety standard for non-medical x-ray and sealed gamma-ray sources. Handbook 93. Washington, DC: U.S. Department of Commerce, National Bureau of Standards. January 3. [SRDB Ref ID: 11306]

Niagara Gazette [2006]. Headline no. 3: Carborundum timeline. Niagara Falls, NY. July 24. [SRDB Ref ID: 140563]

NIOSH [2004]. Estimation of ingestion intakes. OCAS-TIB-009 Rev. 00. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. April 13. [SRDB Ref ID: 22397]

NIOSH [2007]. External dose reconstruction implementation guideline. OCAS-IG-001 Rev. 3. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. November 21. [SRDB Ref ID: 38864]

NIOSH [2010]. Radiation exposures covered for dose reconstructions under Part B of the Energy Employees Occupational Illness Compensation Program Act. DCAS-IG-003 Rev. 1. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. October 5. [SRDB Ref ID: 88929]

NIOSH [2011]. Site profiles for atomic weapons employers that worked uranium metals. Battelle-TBD-6000 Rev. 1. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. June 17. [SRDB Ref ID: 101251]

NYSDEC [2009]. Environmental investigation activities continue at the Gobar facility in the Town of Niagara. Site # 932036. Buffalo, NY: New York State Department of Environmental Conservation. September. [SRDB Ref ID: 178457]

ORAUT [2005]. Interpretation of dosimetry data for assignment of shallow dose. ORAUT-OTIB-0017 Rev. 01. Oak Ridge, TN: Oak Ridge Associated Universities Team. October 11. [SRDB Ref ID: 19434]

ORAUT [2006]. Technical basis for conversion from NCRP Report 38 neutron quality factors to ICRP Publication 60 radiation weighting factors for respective IREP input neutron energy ranges. ORAUT-OTIB-0055 Rev. 00. Oak Ridge, TN: Oak Ridge Associated Universities Team. June 5. [SRDB Ref ID: 29980]

ORAUT [2012]. Dose reconstruction during residual radioactivity periods at atomic weapons employer facilities. ORAUT-OTIB-0070 Rev. 01. Oak Ridge, TN: Oak Ridge Associated Universities Team. March 5. [SRDB Ref ID: 108851]

ORAUT [2015a]. Documented communication SEC-00223 with [redacted] on all pertinent information on Carborundum Company. Documented communication with former Carborundum employee. Oak Ridge, TN: Oak Ridge Associated Universities Team. February 23. [SRDB Ref ID: 142194]

ORAUT [2015b]. Documented communication SEC-00223 with [redacted] on Carborundum. Documented communication with former Carborundum employee. Oak Ridge, TN: Oak Ridge Associated Universities Team. February 16. [SRDB Ref ID: 142172]

ORAUT [2015c]. Documented communication SEC-00223 with [redacted] on Carborundum. Documented communication with former Carborundum employee. Oak Ridge, TN: Oak Ridge Associated Universities Team. February 13. [SRDB Ref ID: 142192]

ORAUT [2015d]. Documented communication SEC-00223 with [redacted] on all pertinent information on Carborundum Company. Documented communication with former Carborundum employee. Oak Ridge, TN: Oak Ridge Associated Universities Team. February 13. [SRDB Ref ID: 142173]

ORAUT [2015e]. Documented communication SEC-00223 with [redacted] on all pertinent information on Carborundum Company. Documented communication with former Carborundum employee. Oak Ridge, TN: Oak Ridge Associated Universities Team. February 16. [SRDB Ref ID: 142193]

ORAUT [2016]. Documented communication SEC-00223 with [redacted] on Carborundum Company. Documented communication with former Carborundum employee. Oak Ridge, TN: Oak Ridge Associated Universities Team. May 12. [SRDB Ref ID: 156789]

ORAUT [2017]. Guidance on assigning occupational x-ray dose under EEOICPA for x-rays administered off site. ORAUT-OTIB-0079 Rev. 02. Oak Ridge, TN: Oak Ridge Associated Universities Team. June 15. [SRDB Ref ID: 166967]

ORAUT [2018a]. Supporting documentation for ORAUT-TKBS-0061. March 23. [SRDB Ref ID: 179230]

ORAUT [2018b]. Carborundum report, Rev. 0-B support files.zip spreadsheets. Oak Ridge, TN: Oak Ridge Associated Universities Team. August 1. [SRDB Ref ID: 172546]

ORAUT [2019a]. Dose reconstruction from occupational medical x-ray procedures. ORAUT-OTIB-0006 Rev. 06. Oak Ridge, TN: Oak Ridge Associated Universities Team. September 27. [SRDB Ref ID: 178310]

ORAUT [2019b]. ORAUT-TKBS-0061 Rev. 00 site profile for the Carborundum Company with MCNP Input/Output files zip file. Oak Ridge, TN: Oak Ridge Associated Universities Team. September 24. [SRDB Ref ID: 178255]

ORNL [1993]. Potentially contaminated sites from ORNL Region I. Oak Ridge, TN: Oak Ridge National Laboratory. [SRDB Ref ID: 42260]

ORNL [1999]. Potentially contaminated sites from ORNL Region I. Oak Ridge, TN: Oak Ridge National Laboratory. August 10. [SRDB Ref ID: 40810]

PHS [1970]. Radiological health handbook. Rev. ed. Rockville, MD: U.S. Department of Health, Education, and Welfare, Public Health Service. January. [SRDB Ref ID: 75017]

Rose CG [1962]. Closeout of contract AT(40-1)-2558 source and special nuclear materials. Letter to Cope DF (U.S. Atomic Energy Commission). Niagara Falls, NY: The Carborundum Company. September 19. [SRDB Ref ID: 46754]

Rudman R [1971]. Survey of x-ray diffraction and x-ray spectroscopy equipment. In: Moore TM, Gundaker WE, Thomas JW, eds. Radiation safety in x-ray diffraction and spectroscopy, proceedings of a conference held on January 6-7, 1970 at the University of Pennsylvania, Philadelphia. Philadelphia, Pennsylvania. DHEW Publication No. (FDA) 72-8009. Rockville, MD: U.S. Department of Health, Education, and Welfare, Public Health Service, Food and Drug Administration, Bureau of Radiological Health. September. pp. 71–75. [SRDB Ref ID: 178455]

Ruther WE, Greenberg S [1972]. Investigations of materials compatibility relevant to the EBR-II system. ANL-7918. Argonne National Laboratory, Argonne, IL: University of Chicago. July. [SRDB Ref ID: 142151]

Saulino FA, Andersen JC, Taylor KM [1962]. Research facility for the synthesis and fabrication of refractory plutonium materials. In: 10th hot lab proceedings. La Grange Park, IL: American Nuclear Society. pp. 277–286. [SRDB Ref ID: 56948]

Singleton RH [1969]. Effects of composition and processing on the properties of niobium carbide - graphite composite material. WANL-TME-1950. Westinghouse Astronuclear Laboratory. November. [SRDB Ref ID: 142150]

Stahl D, Strasser A, Taylor K, Anderson J [1963]. Out-of-pile properties of mixed uranium-plutonium carbides final report. UNC-5074. Elmsford, NY: United Nuclear Corporation. Niagara Falls, NY: The Carborundum Company. December 6. [SRDB Ref ID: 65005]

Strasser A, Stahl D, Taylor K [1963]. Out-of-pile properties of mixed uranium-plutonium carbides progress report, period of February 6, 1962 to October 31, 1962. White Plains, NY: United Nuclear Corporation. Niagara Falls, NY: The Carborundum Company. September 18. [SRDB Ref ID: 64284]

Strasser A, Stahl D [1965]. Carbide fuel development final report, period of May 15, 1959 to October 15, 1965. UNC-5134 Vol. 1. Elmsford, NY: United Nuclear Corporation. Niagara Falls, NY: The Carborundum Company. October 15. [SRDB Ref ID: 53617]

Strasser A, Taylor K [1961]. Carbide fuel development progress report period of February 1, 1961 to April 30, 1961. NDA 2162-3. White Plains, NY: Nuclear Development Corporation of America. Niagara Falls NY: The Carborundum Company. June 1. [SRDB Ref ID: 61981]

Strasser A, Taylor K [1962a]. Carbide fuel development progress report period of January 1, 1962 to March 31, 1962. UNC-5013. White Plains, NY: United Nuclear Corporation. Niagara Falls, NY: The Carborundum Company. May 28. [SRDB Ref ID: 61995]

Strasser A, Taylor K [1962b]. Carbide fuel development progress report period of September 1, 1961 to December 31, 1961. UNC-5003. White Plains, NY: United Nuclear Corporation. Niagara Falls, NY: The Carborundum Company. February 9. [SRDB Ref ID: 61996]

Strasser A, Taylor K [1962c]. Carbide fuel development progress report period of April 1, 1962 to June 30, 1962. UNC-5030. White Plains, NY: United Nuclear Corporation. Niagara Falls, NY: The Carborundum Company. August 10. [SRDB Ref ID: 61990]

Strasser A, Taylor K [1963a]. Carbide fuel development progress report period of October 1, 1962 to March 31, 1963. UNC-5056. White Plains, NY: United Nuclear Corporation. Niagara Falls, NY: The Carborundum Company. May 1. [SRDB Ref ID: 65092]

Strasser A, Taylor K [1963b]. Carbide fuel development Phase IV report period of September 15, 1961 to September 30, 1962. UNC-5055. White Plains, NY: United Nuclear Corporation. Niagara Falls, NY: The Carborundum Company. March 31. [SRDB Ref ID: 65097]

Taylor KM [1960]. Contract No. AT(40-1)-2558. Letter to Cope DF (U.S. Atomic Energy Commission, Oak Ridge Operations Office). Niagara Falls, NY: The Carborundum Company. January 12. [SRDB Ref ID: 46756]

Taylor KM, McMurtry CH [1960a]. Synthesis and fabrication of refractory uranium compounds, fifth quarterly report, August 1 through October 31, 1960. Niagara Falls, NY: The Carborundum Company. November 15. [SRDB Ref ID: 140518]

Taylor KM, McMurtry CH [1960b]. Synthesis and fabrication of refractory uranium compounds, monthly progress Report 10, September 1 through September 30, 1960. Niagara Falls, NY: The Carborundum Company. October 13. [SRDB Ref ID: 140496]

Taylor KM, McMurtry CH [1960c]. Synthesis and fabrication of refractory uranium compounds, monthly progress Report 11, November 1 through November 30, 1960. Niagara Falls, NY: The Carborundum Company. November 15. [SRDB Ref ID: 140498]

Taylor KM, McMurtry CH [1961a]. Summary report, synthesis and fabrication of refractory uranium compounds. ORO-400. Niagara Falls, NY: Carborundum Company. February. [SRDB Ref ID: 140519]

Taylor KM, McMurtry CH [1961b]. First quarterly report, synthesis and fabrication of refractory uranium compounds. Niagara Falls, NY: The Carborundum Company. June 29. [SRDB Ref ID: 45329]

Taylor KM, Lenie CA, Doherty PE, Hailey LN, Keaty TJ [1960a]. Synthesis and fabrication of refractory uranium compounds monthly progress report 6 January 1 through January 31, 1960. Niagara Falls, NY: The Carborundum Company. February 8. [SRDB Ref ID: 140489]

Taylor KM, Lenie CA, Doherty PE, Hailey LN, Keaty TJ [1960c]. Synthesis and fabrication of refractory uranium compounds monthly progress report 6 April 1 through April 31, 1960. Niagara Falls, NY: The Carborundum Company. May 10. [SRDB Ref ID: 140492]

Taylor KM, Lenie CA, Doherty PE, McMurtry CH [1960b]. Synthesis and fabrication of refractory uranium compounds, fourth quarterly report, March 1 through July 31, 1960. Niagara Falls, NY: The Carborundum Company. August 10. [SRDB Ref ID: 140516]

Thomas JW [1971]. Radiation safety: objectives and considerations. In: Moore TM, Gundaker WE, Thomas JW, eds. Radiation safety in x-ray diffraction and spectroscopy, proceedings of a conference held on January 6-7, 1970 at the University of Pennsylvania, Philadelphia. Philadelphia, Pennsylvania. DHEW Publication No. (FDA) 72-8009. Rockville, MD: U.S. Department of Health, Education, and Welfare, Public Health Service, Food and Drug Administration, Bureau of Radiological Health. September. pp. 133–140. [SRDB Ref ID: 178456]

TCC [1944]. Monthly accountability report. Niagara Falls, NY: The Carborundum Company. [SRDB Ref ID: 121034]

TCC [1956]. Extension and expansion of research on dense silicon carbide materials. Proposal to General Electric Company. Niagara Falls, NY: The Carborundum Company. August 2. [SRDB Ref ID: 93471]

TCC [1957]. Proposal on extension of research on dense silicon carbide. Proposal to General Electric Company. Niagara Falls, NY: The Carborundum Company. August 28. [SRDB Ref ID: 93472]

TCC [1958]. Dense silicon carbide for use as a structural and a fuel element material in air-cooled reactors, second periodic report January 1, 1958 to April 30, 1958. Niagara Falls, NY: The Carborundum Company. May 23. [SRDB Ref ID: 93474]

TCC [1966]. 1965 Annual report. Niagara Falls, NY: The Carborundum Company. [SRDB Ref ID: 141412]

TCC [1972]. 1971 annual report. Niagara Falls, NY: The Carborundum Company. [SRDB Ref ID: 141425]

TCC [1973]. 1972 annual report. Niagara Falls, NY: The Carborundum Company. [SRDB Ref ID: 141426]

TCC [1974]. 1973 annual report. Niagara Falls, NY: The Carborundum Company. [SRDB Ref ID: 141427]

TCC [1991]. The Carborundum Company the first 100 years 1891-1991. Niagara Falls, NY: The Carborundum Company. [SRDB Ref ID: 73136]

TCC [no date]. The romance of Carborundum. Niagara Falls, NY: The Carborundum Company. [SRDB Ref ID: 141423]

Werner HV [1960]. Carborundum Company feasibility report for fabrication of plutonium carbide pellets. Memorandum to Katine E. New York, NY: U.S. Atomic Energy Commission. June 6. [SRDB Ref ID: 19739]

GLOSSARY

alpha radiation

Positively charged particle emitted from the nuclei of some radioactive elements. An alpha particle consists of two neutrons and two protons (a helium nucleus) and has an electrostatic charge of +2.

beta radiation

Charged particle emitted from some radioactive elements with a mass equal to 1/1,837 that of a proton. A negatively charged beta particle is identical to an electron. A positively charged beta particle is a positron.

depleted uranium

Uranium with a percentage of ^{235}U lower than the 0.7% found in natural uranium.

dose

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

dose conversion factor (DCF)

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

dose reconstruction

Process of analyzing the available information including evaluation of historical methods and data to estimate the dose a person could have received from one or more radiation exposures.

enrichment

Isotopic separation process that increases the percentage of a radionuclide in a given amount of material above natural levels. For uranium, enrichment increases the amount of ^{235}U in relation to ^{238}U . Along with the enriched uranium, this process results in uranium depleted in ^{235}U .

external dose

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

exposure

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

glovebox

Enclosure with special rubber gloves through which an operator can handle radioactive or toxic material without risk of injury or contamination, normally operated at a slightly reduced pressure so that air leakage, if any, is inward.

half-life

Time in which half of a given quantity of a particular radionuclide disintegrates (decays) into another nuclear form. During one half-life, the number of atoms of a particular radionuclide

decreases by one half. Each radionuclide has a unique half-life ranging from millionths of a second to billions of years.

internal dose

Dose received from radioactive material in the body (e.g., plutonium or uranium) that was inhaled, ingested, absorbed, or injected through a wound.

natural uranium

Uranium as found in nature, approximately 99.27% ^{238}U , 0.72% ^{235}U , and 0.0054% ^{234}U by mass. The specific activity of this mixture is 2.6×10^7 becquerel per kilogram (0.7 microcuries per gram). See *uranium*.

neutron (n)

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

neutron radiation

Radiation that consists of free neutrons unattached to other subatomic particles emitted from a decaying radionuclide. Neutron radiation can cause further fission in fissionable material such as the chain reactions in nuclear reactors, and nonradioactive nuclides can become radioactive by absorbing free neutrons. See *neutron*.

nuclide

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

photon radiation

Electromagnetic radiation that consists of quanta of energy (photons) from radiofrequency waves to gamma rays.

radiation

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

**ATTACHMENT A
RADIOLOGICAL CONTRACT WORK DURING THE SECOND OPERATIONAL PERIOD**

Table A-1. Radiological contract work during the second operational period.

| Contract | Years reported | Type of work | Radionuclides | Amounts | Comments | Sources |
|-----------------|-----------------------|---|--|---|---|---|
| AT-(40-1)-2558 | 05/1959-12/1960 | Synthesis and fabrication of refractory U compounds: Three phases: (1) development of methods for synthesis of compounds; (2) fabrication of synthesized materials; and (3) determination of properties such as thermal conductivity, thermal expansion, high-temperature strength. Purpose: to develop methods to synthesize the materials UN, UC, and U ₃ Si ₂ and methods of fabrication and to study various properties of the compounds for use as reactor fuel | UO ₂ , U ₃ O ₈ , UN (powder), U ₃ Si ₂ Request for 10 pounds of U shot [Taylor 1960] Make batches of UC ranging from about 30 g to 6 lb [Taylor and McMurtry 1961a] | 1,500-g batch of UN 1,200 g of UN was made [Taylor et al. 1960a] 3-lb lot of UC prepared by the carbon reduction of UO ₂ 100 g of U metal shot acid treated [Taylor et al. 1960b] | Part of the AEC Fuel Development Program The goal was to develop refractory uranium materials possessing a sufficient advantage over UO ₂ . Initial contract period was 05/13/59 through 11/01/60. No work done during May/June for facility improvements. Carborundum had to replace a glovebox that was being used for some of the uranium work on this contract [Taylor et al. 1960b]. | Summary Report [Taylor and McMurtry 1961a] Fourth Quarterly Report [Taylor et al. 1960c] Fifth quarterly report [Taylor and McMurtry 1961b] Monthly report [Taylor et al. 1960a] Report 8 [Taylor et al. 1960b] Report 10 [Taylor and McMurtry 1960a] Report 11 [Taylor and McMurtry 1960c] |
| AT-(40-1)-2558 | 03/01/1961–05/31/1961 | Synthesis and fabrication of refractory U compounds Sintering of U monocarbide | Depleted UO ₂ ; Thermax Theratomic Carbon | 453.6 g of UO ₂ ; 60.5 g of carbon for each synthesis experiment | Purpose of work: develop refractory U materials possessing sufficient advantages over UO ₂ to warrant their use as reactor fuels. The UC was a powder. Depleted UO ₂ from ORNL; Thermax Theratomic Carbon from R.T. Vanderbilt Co. Two modifications were made to this contract to go beyond 12/60. | First Quarterly Report [Taylor and McMurtry 1961b] |

ATTACHMENT A
RADIOLOGICAL CONTRACT WORK DURING THE SECOND OPERATIONAL PERIOD (continued)

| Contract | Years reported | Type of work | Radionuclides | Amounts | Comments | Sources |
|-----------------|---------------------------|--|---|---|--|--|
| AT(30-1)-2303 | 06/06/1960 | Fabrication of plutonium carbide pellets using some of the following methods: ball milling, chemical analyses, crushing, cold pressing, sintering, grinding pellets | PuO ₂ , UO ₂ | 3 kg of Pu over 3 yr; the first and only shipment in 1960 of 500 g of Pu from Hanford | Carbide Fuel Development. Report states that if there is any external radiation exposure it will be to the hands. All Pu compounds will be handled on a containment basis. Maximum amount of contained Pu will not exceed 600 g. No more than 200 g of Pu shall be in process. | Feasibility Report [Werner 1960] |
| AT(30-1)-2303 | 02/01/1961– 04/30/1961 | Fuel fabrication and evaluation: explore various methods of fuel preparation and fabrication into cylindrical pellets, beginning with powders and evaluate pellet density measurements | Pu, Pu+U-235, PuC-UC, UO ₂ | Synthesis of PuC from PuO ₂ . Seven batches of PuC made by mixing PuO ₂ and carbon then furnacing at differing temperatures and hold times | The Pu facility started operations in March 1961. Prior to 1961, the equipment was tested by work with UC. Six reports are listed in covering 10/15/59 to 2/28/61 [Strasser and Taylor 1961]; these reports are currently unavailable. | Progress Report [Strasser and Taylor 1961] |
| AT(30-1)-3118 | 02/06/1961– 12/06/1963 | Determine out-of-pile properties of mixed UPu carbides to determine the properties of (UPu)C | Pu, U Materials produced. 80% UC-20% PuC solid solutions | Four 100-g synthesis batches prepared from UO ₂ , PuO ₂ , (UPu)C 550-g total of UO ₂ , PuO ₂ and carbon powder synthesized in 70- to 100-g batches | Prepared fuel samples. This program was closely coordinated with the Carbide Fuel Development program (AT30-1)-2899. | Final Report [Stahl et al. 1963] |

ATTACHMENT A
RADIOLOGICAL CONTRACT WORK DURING THE SECOND OPERATIONAL PERIOD (continued)

| Contract | Years reported | Type of work | Radionuclides | Amounts | Comments | Sources |
|---------------|---------------------------|--|--|--|--|---|
| AT(30-1)-2899 | 05/1959- 10/15/1965 | UNC: conceptual design, fuel evaluation, and fuel irradiation Carborundum: fuel fabrication | UC, PuC Investigate mixed carbides at 20 wt% PuC, except property measurements which were made at 5 w/o PuC fuel. | 400 g of (U _{0.95} Pu _{0.05})C _{0.98} powder synthesized for fabrication (70 pellets fabricated) | The Carbide Fuel Development Program was concerned with the technology of the entire UC-PuC fuel cycle. The major goals were to produce (UPu)C and obtain data on its irradiation behavior for long burnups and at high-power generation rates. Other areas of the fuel cycle were explored to discover possible problems. Program initiated in May 1959; continued for 4.5 yr. | Final Report [Strasser and Stahl 1965] Six reports were published under this contract, Phases I-VI |
| AT(30-1)-2899 | 09/15/1961– 12/31/1961 | Explore methods for preparation of fuel from powders and its fabrication into cylindrical pellets, evaluate pellets by density measurement, chemical analysis, X-ray diffraction, hardness | UC-PuC Synthesize powder from oxides and carbons | Produce (U _{0.8} Pu _{0.2})C _{0.95} | NOTE: Comment in report says Pu facilities continued satisfactory operation at zero contamination levels. NOTE: Pu is lost during synthesis or sintering and a small amount of Pu being lost during annealing. | [Strasser and Taylor 1962b] |
| AT(30-1)-2899 | 01/01/1962– 03/31/1962 | Fuel fabrication for AEC Fuel Cycle Development Program concerned with entire UC-PuC fuel cycle | Pu, U UC-PuC pellets | Sintering experiments with (U _{0.8} Pu _{0.2})C _{0.95} | Carbide Fuel Development, part of AEC Fuel Cycle Development Program. Fuel made of UC and PuC had a potential of reducing fuel-cycle cost of existing fast-breeder reactors. | Progress Report [Strasser and Taylor 1962b] |

ATTACHMENT A
RADIOLOGICAL CONTRACT WORK DURING THE SECOND OPERATIONAL PERIOD (continued)

| Contract | Years reported | Type of work | Radionuclides | Amounts | Comments | Sources |
|-----------------|---------------------------|---|------------------------------|---|--|---|
| AT(30-1)-2899 | 04/01/1962– 06/30/1962 | Fabrication of the UC-PuC irradiation tests | UC, PuC, UC-PuC pellets | Synthesize powder required for the NU Reaction to 760-g batch of PuO ₂ -UO ₂ -C yielded ~580 g of single phase (U _{0.2} Pu _{0.2})C _{0.95} solid solution | There are 10 previous reports listed in this progress report. | Progress Report [Strasser and Taylor 1962c] |
| AT(30-1)-2899 | 09/15/1961– 09/30/1962 | Conceptual design, fuel evaluation, and fuel irradiation | Powder containing NU, EU, Pu | 760-g batch of PuO ₂ -UO ₂ -C yielded ~580 g of (U _{0.8} Pu _{0.2})C _{0.95} 200 g of (U _{0.8} Pu _{0.2})C _{0.95} powder produced in 40-g lots Each specimen contained 16 fuel pellets | Carbide Fuel Development, this project is sponsored by the AEC Division of Reactor Development Goal was to produce UC-PuC to obtain data on irradiation behavior for long burnups and at high-power generation rates. Goal was to develop method for preparation of high density pellets for irradiation studies Experiments were run with both NU and EU. 11 previous reports listed. | Phase IV Report [Strasser and Taylor 1963b] |
| AT(30-1)-2899 | 10/01/1962– 03/31/1963 | Production of (UPu)C and collection of data on its irradiation behavior for long burnups and at high-power generation rates | (UPu)C | Synthesis of about 400 g of (U _{0.95} Pu _{0.05})C _{0.98} | 50-g reaction mixes of PuO ₂ , UO ₂ were blended and cold pressed. There were 8 synthesis experiments. | Progress Report [Strasser and Taylor 1963a] 12 NDA and UNC progress reports listed before this report from 10/15/1959-03/31/1963 |

ATTACHMENT A
RADIOLOGICAL CONTRACT WORK DURING THE SECOND OPERATIONAL PERIOD (continued)

| Contract | Years reported | Type of work | Radionuclides | Amounts | Comments | Sources |
|-----------------|-----------------------|---|--|---|---|---|
| AT(30-1)-3254 | 02/06/1962-10/31/1962 | Determine out-of-pile properties of mixed UPu carbides Carborundum: prepare the fuel samples Powder fabrication initiated under AT(30-1)-2889 continues | (UPu)C 80% UC-20% PuC | Sintering experiments with (U _{0.8} Pu _{0.2})C _{0.95} | This program was closely coordinated with the Carbide Fuel Development program. The studies were a continuation of work performed under AT(30-1)-2899. 8 previous reports listed | Progress Report [Strasser et al. 1963] |
| AT(30-1)-3305 | 02/01/1964-10/30/1965 | Study of UPu monoxides. UPu monoxide compositions synthesized by carbon and U reduction methods | U, Pu Depleted UO ₂ , PuO ₂ , UHx, UC, UN | Started with UO ₂ -PuO ₂ mixtures to synthesize UPu monoxide type materials | Two synthesis routes: (1) reduction of mixed PuO ₂ and UO ₂ with carbon; (2) reduction of mixed dioxides with U metal: carried out in helium and vacuum at temps from 1450-1900 °C. Previous progress in reports: UNC: 5096, 5102, 5117, 5132, 5138, covering 02/01/1964-09/30/1965. | Final Summary Report [Forbes et al. 1966] |
| AT(30-1)-3305 | 07/01/1965-09/30/1965 | Study of UPu monoxides | Materials containing as high as 85 w/o of a (UPu)(OC) composition | Synthesis of (U _{0.8} Pu _{0.2})C | Related reports: AT(30-1)3254, 02/06/1962-10/31/1962 (see above). | Quarterly Progress Report [Forbes et al.1965] |
| AT(30-1)-3713 | 09/01/1966-11/30/1966 | Part of the AEC Fuel Cycle Development Program Studies of the preparation of mixed carbide fuel using coprecipitation and synthesis of (UPu)C X-ray analysis | U as UO ₂ ; Pu Concentration of the U or UPu in the nitrate solutions was ~0.15 g/mL | (U _{0.8} Pu _{0.2})C | Object is to extend the technology to the preparation of (UPu)C fuels. Uranyl nitrate and Pu nitrate solutions were mixed to yield 4/1 ratio of U to Pu. | Quarterly Progress Report No. 2 [McMurtry and Taylor 1966] |
| AT(30-1)-3713 | 11/23/1966-02/28/1967 | Part of the AEC Fuel Cycle Development Program Study of synthesis (UPu)C compounds using coprecipitation of carbon and metal-bearing materials from a common solvent | (UPu)C | Started with (U _{0.8} Pu _{0.2})C | Object is to extend the technology to the preparation of (UPu)C fuels. | Final Report May 23, 1966-February 28, 1967 [McMurtry 1967] |