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ACRONYMS AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
AWE	atomic weapons employer
BZ	breathing zone
CFR	Code of Federal Regulations
cm	centimeter
d	day
DOE	U.S. Department of Energy
DOL	U.S. Department of Labor
dpm	disintegrations per minute
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
ft	foot
g	gram
GA	general area
GM	geometric mean
GSD	geometric standard deviation
HASL	Health and Safety Laboratory
hr	hour
IMBA	Integrated Modules for Bioassay Analysis
in.	inch
IREP	Interactive RadioEpidemiological Program
keV	kiloelectron-volt, 1,000 electron-volts
kg	kilogram
L	liter
LOD	limit of detection
m	meter
MAC	maximum allowable concentration
mg	milligram
mm	millimeter
mR	milliroentgen
mrad	millirad
mrem	millirem
NIOSH	National Institute for Occupational Safety and Health
ORAU	Oak Ridge Associated Universities
pCi	picocurie
POC	probability of causation
psi	pounds per square inch
R	roentgen

RMI	Reactive Metals, Inc.
SRDB Ref ID	Site Research Database Reference Identification (number)
t	ton
U.S.C.	United States Code
yr	year
α	alpha particle
γ	gamma
µCi	microcurie
µg	microgram
§	section or sections

1.0 INTRODUCTION

Official NIOSH Language for the DOE Adrian Facility

Technical basis documents and site profile documents are not official determinations made by the National Institute for Occupational Safety and Health (NIOSH) but are rather general working documents that provide historical background information and guidance to assist in the preparation of dose reconstructions at particular sites or categories of sites. They will be revised in the event additional relevant information is obtained about the affected site(s). These documents may be used to assist NIOSH staff in the completion of the individual work required for each dose reconstruction.

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

For employees of DOE or its contractors with cancer, the DOE facility definition only determines eligibility for a dose reconstruction, which is a prerequisite to a compensation decision (except for members of the Special Exposure Cohort). The compensation decision for cancer claimants is based on a section of the statute entitled "Exposure in the Performance of Duty." That provision [42 U.S.C. § 7384n(b)] says that an individual with cancer "shall be determined to have sustained that cancer in the performance of duty for purposes of the compensation program if, and only if, the cancer … was at least as likely as not related to employment at the facility [where the employee worked], as determined in accordance with the POC [probability of causation[1]] guidelines established under subsection (c) …" [42 U.S.C. § 7384n(b)]. Neither the statute nor the probability of causation guidelines (nor the dose reconstruction regulation, 42 C.F.R. Pt. 82) restrict the "performance of duty" referred to in 42 U S. C. § 7384n(b) to nuclear weapons work (NIOSH 2010a).

The statute also includes a definition of a DOE facility that excludes "buildings, structures, premises, grounds, or operations covered by Executive Order No. 12344, dated February 1, 1982 (42 U.S.C. 7158 note), pertaining to the Naval Nuclear Propulsion Program" [42 U.S.C. § 7384l(12)]. While this definition excludes Naval Nuclear Propulsion Facilities from being covered under the Act, the section of EEOICPA that deals with the compensation decision for covered employees with cancer [i.e., 42 U.S.C. § 7384n(b), entitled "Exposure in the Performance of Duty"] does not contain such an exclusion. Therefore, the statute requires NIOSH to include all occupationally-derived radiation exposures at covered facilities in its dose reconstructions for employees at DOE facilities, including radiation exposures related to the Naval Nuclear Propulsion Program. As a result, all internal and external occupational radiation exposures are considered valid for inclusion in a dose reconstruction. No efforts are made to determine the eligibility of any fraction of total measured exposure for inclusion in dose reconstruction. NIOSH, however, does not consider the following exposures to be occupationally derived (NIOSH 2010a):

- Background radiation, including radiation from naturally occurring radon present in conventional structures

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

- Radiation from X-rays received in the diagnosis of injuries or illnesses or for therapeutic reasons

Official NIOSH Language for the AWE Bridgeport Brass Co., Havens Laboratory Facility

Technical basis documents and site profile documents are not official determinations made by the National Institute for Occupational Safety and Health (NIOSH) but are rather general working documents that provide historical background information and guidance to assist in the preparation of dose reconstructions at particular sites or categories of sites. They will be revised in the event additional relevant information is obtained about the affected site(s). These documents may be used to assist NIOSH staff in the completion of the individual work required for each dose reconstruction.

In this document the word "facility" is used as a general term for an area, building, or group of buildings that served a specific purpose at a site. It does not necessarily connote an "atomic weapons employer [AWE] facility" or a "Department of Energy [DOE] facility" as defined in the Energy Employees Occupational Illness Compensation Program Act of 2000 [EEOICPA; 42 U.S.C. § 7384l(5) and (12)]. EEOICPA, as amended, provides for employees who worked at an AWE facility during the contract period and/or during the residual period.

Under EEOICPA, employment at an AWE facility is categorized as either (1) during the DOE contract period (i.e., when the AWE was processing or producing material that emitted radiation and was used in the production of an atomic weapon), or (2) during the residual contamination period (i.e., periods that NIOSH has determined there is the potential for significant residual contamination after the period in which weapons-related production occurred). For contract period employment, all occupationally derived radiation exposures at covered facilities must be included in dose reconstructions. This includes radiation exposure related to the Naval Nuclear Propulsion Program and any radiation exposure received from the production of commercial radioactive products that were concurrently manufactured by the AWE facility during the covered period. NIOSH does not consider the following exposures to be occupationally derived (NIOSH 2010a):

- Background radiation, including radiation from naturally occurring radon present in conventional structures

- Radiation from X-rays received in the diagnosis of injuries or illnesses or for therapeutic reasons

For employment during the residual contamination period, only the radiation exposures defined in 42 U.S.C. § 7384n(c)(4) [i.e., radiation doses received from DOE-related work] must be included in dose reconstructions. Doses from medical X-rays are not reconstructed during the residual contamination period (NIOSH 2010a). It should be noted that under subparagraph A of 42 U.S.C. § 7384n(c)(4), radiation associated with the Naval Nuclear Propulsion Program is specifically excluded from the employee's radiation dose. This exclusion only applies to those AWE employees who worked during the residual contamination period. Also, under subparagraph B of 42 U.S.C. § 7384n(c)(4), radiation from a source not covered by subparagraph A that is not distinguishable through reliable documentation from radiation that is covered by subparagraph A is considered part of the employee's radiation dose. This site profile covers only exposures resulting from nuclear weapons-related work. Exposures resulting from non-weapons-related work, if applicable, will be covered elsewhere.

1.1 PURPOSE

This document provides an exposure matrix for two sites: Havens Laboratory (including the Housatonic Pilot Plant) and the Adrian Plant.

1.2 SCOPE

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

2.0 SITE DESCRIPTION AND OPERATIONAL HISTORY

The Havens Laboratory and the Adrian Plant were geographically separate facilities, but the operations were similar. Havens Laboratory in Bridgeport, Connecticut, was involved primarily with uranium extrusion research and development. The other site, referred to in this document as the Adrian Plant, was in Adrian, Michigan. The Adrian Plant was also involved in uranium extrusion research and development but had a higher production capacity. Both sites processed thorium in addition to uranium.

2.1 HAVENS LABORATORY

The information that follows supports an assumed covered period of operations at Havens Laboratory and Housatonic Pilot Plant from November 8, 1950, through December 31, 1950, involving experimental uranium work, and from June 26, 1952, to August 27, 1962, involving uranium contract work. No exposure is assumed for the period from January 1, 1951, to June 25, 1952, which was the period between experimental activities and the effective date of the U.S. Atomic Energy Commission (AEC) contract. After decontamination in August 1962, the Havens Laboratory was sold and converted to a school. No residual radioactive contamination period is assumed for Havens Laboratory.

The Havens Laboratory radiological source term consisted primarily of natural uranium metal (a single data sheet mentioned depleted uranium), uranium oxides, and natural uranium's short-lived progeny. Long-lived progeny prevent significant ingrowth past ^{234}U in the ^{238}U decay series and beyond ^{231}Th in the ^{235}U decay series. The source term also included smaller amounts of thorium.

Havens Laboratory was at Kossuth and Pulaski Streets in Bridgeport, Connecticut. The DOE site elimination report states, "the area under consideration consists of one building containing a laboratory and associated work areas" (Jones 1987). The Bridgeport Brass Company office was several blocks away at 30 Grand Street. An inspection report states that the Pilot Plant was also located at 30 Grand Street (Cavanaugh ca. 1954). Some claimants have noted other Bridgeport Brass locations as Housatonic Avenue or Grant Avenue. On September 15, 1952, Bethlehem Steel was requested to ship six rods to Bridgeport Brass Company, Housatonic Avenue (Belmore 1952). In June 1955, AEC surveyed the source and special nuclear controls at the Havens Laboratory and at the Housatonic Building (Dowling 1955a). Current maps indicate Housatonic Avenue intersects with Grand Street, but is physically separated from the Havens Laboratory by a body of water. Grant Avenue does not appear on current maps of Bridgeport, Connecticut.

Before the AEC contracted work at Havens Laboratory in 1952, AEC experimental work was reported on November 8 and December 11, 1950 (Klevin 1950; Stroke 1950). The November 8, 1950, experiment with uranium rod coating was deemed successful, and it was noted that no air samples were collected and, "no health and safety problems appear to exist for this type of operation" (Klevin 1951). The December 11, 1950, experiment involved the cold drawing of hot rolled rods of uranium, pickling to remove the oxide coating, and the drawing of a few unpickled rods. For this December 11 experimental work, the total number of processed rods was 12, involving up to three passes in the drawing process for each rod. Ten air samples were collected, but only the sample taken at the time of the pickled rod jam, which resulted in rapid oxidation despite a heavily coated lubricant, exceeded the maximum allowable concentration (MAC) value (Klevin 1951). The MAC was defined as 70 α-dpm/m^3. The sample was reported as "128 γ/m^3" [the Greek letter γ was shorthand used by the

AEC for milligrams]. General area (GA) air samples taken before and after the drawing operations were reported as zero.

Some exposure could have occurred during the drawing operations. The amount of work and the limited time involved would clearly limit this exposure. An AEC monthly report states, "the drawing of uranium rods was observed and dust samples were collected during the drawing. Of ten dust samples, only one showed any uranium material. It is believed that this sample is not representative of the operation [because it was collected during the rod jam]. No contamination of the plant was found" (AEC 1951, p. 13). There are no other references to work involving uranium or other radioactive materials until the beginning of the contract between AEC and Bridgeport Brass in 1952. It is not clear what happened during the time between the two uranium rod experiments in 1950. In addition, it is not clear when the rods left the site, but a date of December 31, 1950, is assumed. The daily inhalation intake from November 8 through December 31, 1950, was unlikely to exceed the MAC. This site profile assumes that area contamination after this brief operation was limited and so only accounts for exposure during the assumed experimental period.

Havens Laboratory conducted laboratory-scale work under AEC contract AT(30-1)-1405, effective beginning June 26, 1952, for "research on drawing uranium and related operations" (AEC 1952). The contract specifically called for the contractor to:

> *…perform research work calculated to develop suitable and economic procedures for the following:*
>
> a. *Alpha extrusion* [alpha extrusion has to do with the temperature of the metal] *of uranium*
>
> b. *Extrusion of zirconium or zirconium alloy tubing*
>
> c. *Mechanical cladding of uranium with aluminum, zirconium or zirconium alloy and the development of slug and closures*
>
> d. *Investigation of other commercial procedures such as drawing, rolling, rocking, annealing, etc. at various temperatures pertinent to the above*
>
> e. *The execution of such metallographic, thermocycling and X-ray crystallography in connection with the above work necessary to evaluate and control the products in regard to their suitability for pile operation and such additional work as the Commission may require.*

The work included cold forming (extrusion) of natural uranium metal and associated cutting, storage, and laboratory support. From the beginning of the contract in June 1952, it is assumed that AEC work was full-time, although not all work involved radioactive material. This is apparent from the AEC portion of Havens Laboratory costs set from 1% to 5% with most AEC costs being allocated at 2% or less in the contract. The Plant Laboratory (Department 385-B), Technical Director's Office (Department 385 A), Safety Services (Department 307-D), and Guard Service (Department 314) exceeded 2%.

The Housatonic Pilot Plant operation involved "the annealing, cold drawing and swaging of uranium and thorium rolled and extruded rods" (Dowling 1955a). The Havens Laboratory performed metallography and X-ray crystallography examinations on uranium and thorium samples from the pilot plant (Dowling 1955a).

An inspection report (Cavanaugh ca. 1954) describes the laboratory as, “on the front portion of an old Trade School Building.” In addition, there was work with uranium on the first floor of the main building. In 1960, a fully equipped machine shop was installed, including a 500-t extrusion press. The areas involved in uranium activities are shown in Figures 2-1, 2-2, and 2-3. Because the work areas were physically separate, it was necessary to move the uranium from area to area, which affected internal and external exposure. For example, an air dust sample from February 20, 1962,

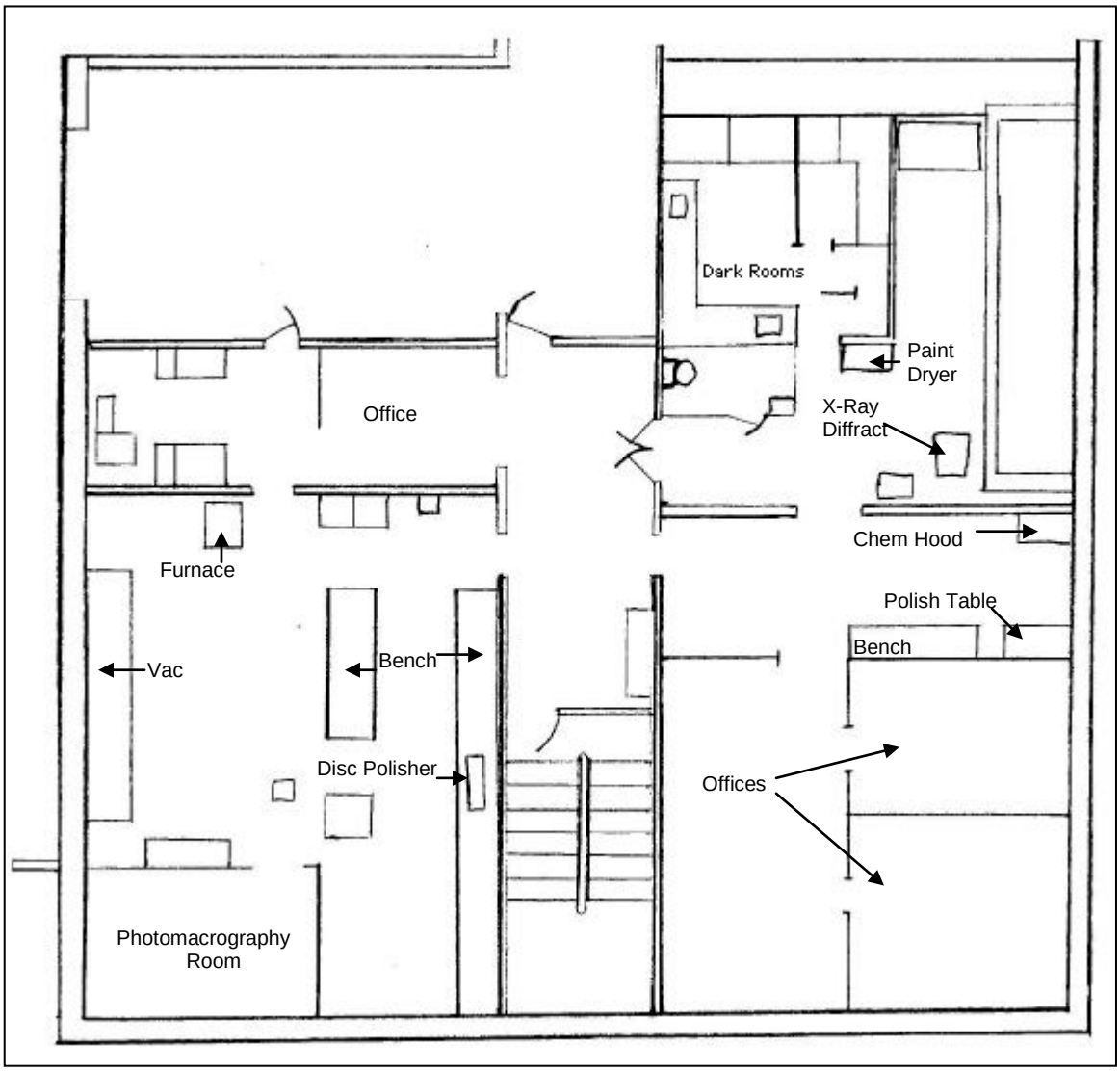

Figure 2-1. Laboratory area at Havens Laboratory (JG 1962a).

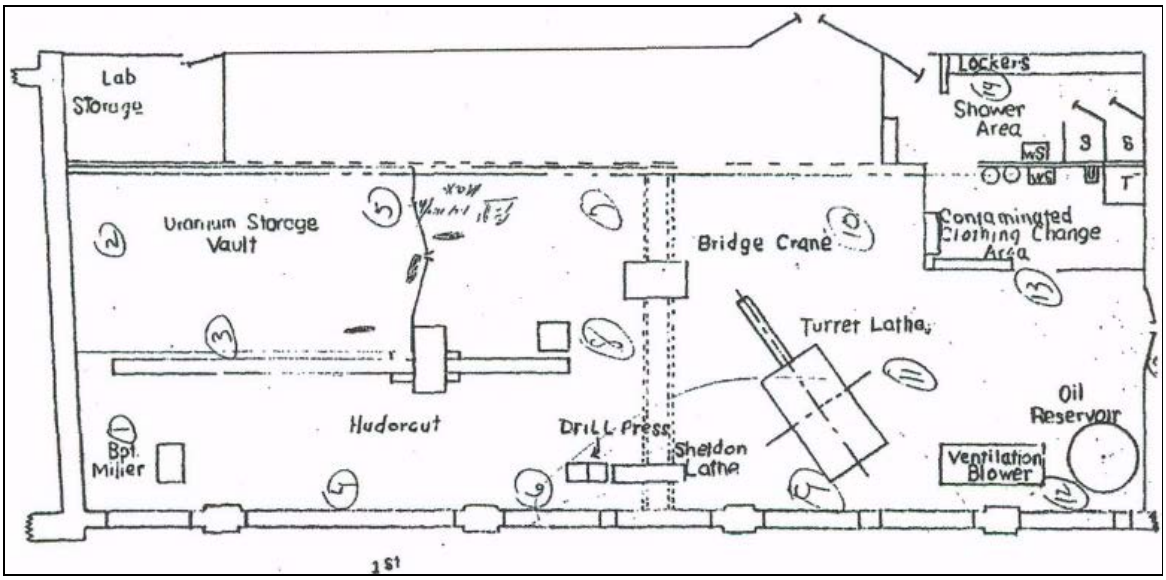

Figure 2-2. First floor, main building, Havens Laboratory (JG 1962b).

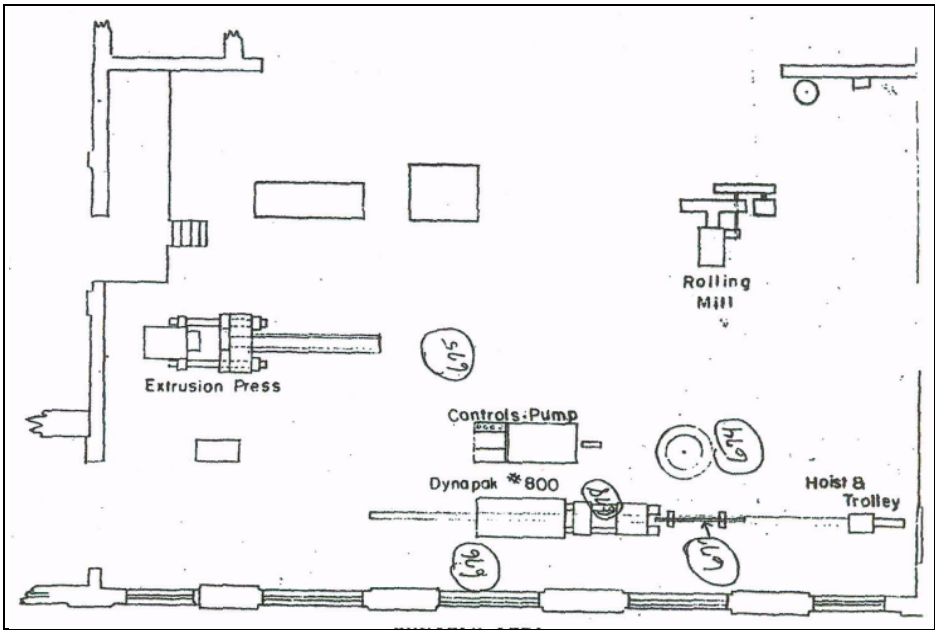

Figure 2-3. Dynapak Area, Havens Laboratory (JG 1962b).

and labeled "general BZ Billet transfer team" was 1,300 dpm/m^3. The relative physical size of the three areas is indicated by the figures, and the ventilated areas of the laboratory are shown.

A Bridgeport Brass monthly report from February or March of 1954 provides details of some of the work at Havens Laboratory (Treco 1954): Ten uranium rods of 1.405-in. average diameter and 20 ft. in length were received from Fernald. They were degreased with hydrex and pickled with a solution of 50% water and 50% concentrated nitric acid. The rods were then cut into lengths of 77 in. (6 ft., 5 in.) each. The pickling, which removed the coating that reduced oxidation, and the cutting of the rods each contributed to increased air dust concentrations. These rods were then machine-pointed in a lathe to a diameter of 1.270 in. with a point length of 6 in. After this, the rods were drawn with a standard 1.375-in. standard brass rod-drawing die with a calculated area reduction of 4.2%. However, subsequent measurements indicated that springback had lowered this reduction to 3.5%. The pointing of the rods in the lathe was a source of airborne uranium, and the close work involved in

measuring the rods provided potential exposure from the surface of the metal. Zirconium tube fabrication, extrusion of zirconium and its alloys, cans for cladding, and laboratory technical service sections of the report indicate that the uranium work was only part of the AEC activities.

Treco (1954) described the installation of a monorail system for handling heavy billets, which may have reduced doses by decreasing manual handling of the billets. In addition, ventilation for newly installed pickle and waste tanks was added. White duck (a cotton or linen fabric a bit lighter than canvas) coats and coveralls were procured for visitors and workers in the pilot plant. Rubber shoe covers were available for visitors.

AEC and U.S. Department of Energy (DOE) inventory reports use a designation of BBA to identify Bridgeport Brass facilities. This designation could include Bridgeport Brass facilities other than Havens Laboratory. A designation of Station MBB also referred to Bridgeport Brass (Dowling 1955a).

Source and Special Nuclear Materials Accountability Statements (Dowling 1955a) indicate that Havens Lab received about 11,000 kg of uranium between July 1, 1953, and June 30, 1954, and received another 50,000 kg by May 31, 1955. During these same periods, Havens received 190 and 1,570 kg of thorium, respectively, which is less than 5% of the uranium source term by mass. To simplify calculations for both Havens Laboratory and Adrian Plant and to account for uncertainty in the relative masses of handled uranium and thorium, this analysis assumed that the mass of processed thorium was 10% of the mass of processed uranium.

There is mention of X-ray crystallography work in the AEC contract to inspect metal samples, but no information about the design or safety precautions of this analytical equipment was found. Late 1958 to 1960 biweekly film badge results for areas specified as “X-ray” were usually reported as <10 mrem. In addition, film badge records show monitoring of the hospital’s X-ray technologist. (One former employee reported that Bridgeport Brass had a small hospital on site.)

Reactive Metals, Inc. (RMI), formerly Bridgeport Brass, noted that it was not possible to obtain the names of hourly employees who participated in very early (1953 to 1954) uranium forming experiments in Bridgeport, Connecticut (Bean 1967).

In 1962, the Havens Laboratory AEC operation was moved to Seymour Specialty Wire, another Bridgeport site in Seymour, Connecticut (DOE ca. 1987). (Seymour Specialty Wire is a covered facility.) On August 27, 1962, Bridgeport reported that the cleanup of Havens Laboratory was complete and that decontamination was accomplished (Jefferson 1962). The Havens Laboratory was transferred to the local Catholic diocese for use as a school. It is not clear whether the Grand Avenue/Housatonic Street site was also transferred.

2.2 ADRIAN PLANT

The information that follows supports an assumed covered period of operations at Adrian Plant from May 25, 1954, to December 31, 1962.

Like the Havens Laboratory, the Adrian Plant radiological source term also consisted primarily of uranium metal, uranium oxides, and their short-lived progeny. Adrian also processed thorium.

On May 25, 1954, the Adrian Plant was added to AEC contract AT(30-1)-1405 via Modification 7 to work with uranium and thorium (Wallo 1985). This was followed by Modification 9 on February 18, 1955, which specified research and development work to be done in extrusion development and drawing research at Adrian Plant and Havens Laboratory (AEC 1955a). The contract also called for Adrian Plant to be able to produce extruded rods or tubes at a semiproduction scale. Modification 9

required the production of approximately 1,600 extruded rods between October 26, 1954, and April 1, 1955.

Modification 9 noted that the "Extrusion Development work for Thorium … shall be effective as of October 1, 1954" (AEC 1955a). A July 6, 1955, Bridgeport Brass memorandum indicates that because of a curtailment in both the uranium and thorium programs, Bridgeport needed to rethink the request for a replacement for the salt bath furnace pot to replace the existing uranium-contaminated pot to allow this salt bath to be used for "thorium extrusion as well as other items" (Stearns 1955). On July 22, 1955, curtailment of only the thorium program is mentioned in a letter from Bridgeport Brass Company to AEC (Treco 1955). On September 8, 1955, Bridgeport Brass stated, "there was no production of thorium to report for the month of August at Bridgeport Brass Company – MBA" (Schaeffer 1955a). (MBA is the AEC/DOE inventory report designation for the Adrian Plant.)

On September 15, 1955, a letter from the AEC Feed Materials Division, reported that "approximately sixty-five billets of thorium have been delivered to the Adrian, Michigan Plant by National Lead Co. [Fernald] and that the extrusion of this metal has been scheduled for September 19 and 20, 1955" (Dowling 1955b). The same letter indicates that this work was a special order and was assigned as "Production Order No. 3." In August 1955, thorium production was reported as "none" (Schaeffer 1955a). In September 1955, 5 tons of thorium ingots were received, and 4 tons of thorium rods and 1 ton of thorium scrap were produced (Schaeffer 1955b). A November 28, 1955, teletype between AEC offices notes that the "Thorium Operating Schedule" effectively meant that the Commission would not have facilities for converting thorium nitrate to thorium metal (Karl 1955).

While it is clear that thorium was processed at Adrian Plant, research found no thorium bioassay or contamination measurement data. In addition, the Adrian Plant thorium source term and production period information is limited. The records appear to indicate that the primary focus of the AEC Health and Safety Laboratory (HASL) was uranium. A limited review of other DOE and AWE sites seems to indicate that thorium was only a minor portion of the source term for most facilities. At Fernald, it was noted that thorium represented less than about 5% of the uranium-plus-thorium emissions (by mass) from plant processes. Also at Fernald, thorium emissions were reported in 1954 and 1955 but were not listed again until 1966. For 1954, the thorium emission percentage at Fernald was about 7% by mass. Fernald uranium and thorium workplace air sample results were similar in magnitude (ORAUT 2004). No available information indicated that Adrian Plant thorium to uranium ratios would have been much different from the ratios at Fernald. Based on the reviewed thorium information, as well as the relative abundance of uranium information for Adrian Plant, it is assumed that thorium exposure could have occurred at Adrian Plant from May 25, 1954, to December 31, 1955, and that the thorium source term was not likely to be more than 10% of the uranium source term by mass.

Adrian Plant was located at 1450 East Beecher Street; it occupied several structures on approximately 73 acres of land. Only a small fraction of the overall facility was involved in AEC work. This consisted of approximately 44,500 ft^2 in the main plant and about 2,000 ft^2 of office space in the main plant. There were a loading dock area and a storage area outside of the main plant (Figure 2-4).

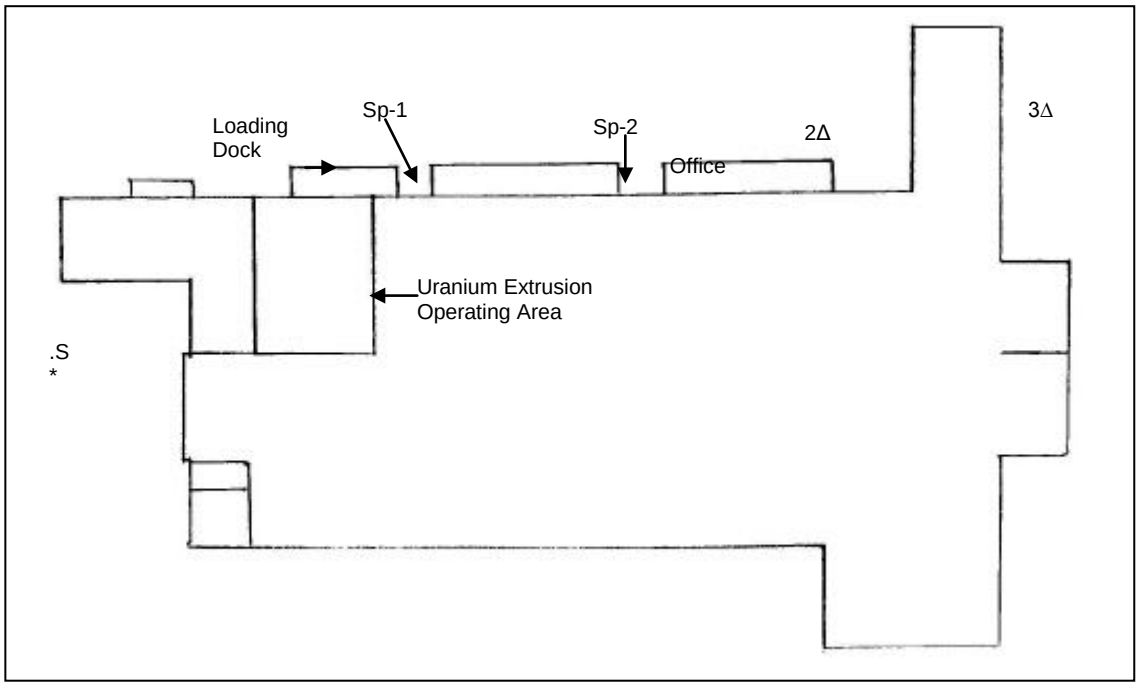

Figure 2-4. Locations of AEC activity at Adrian Plant (Haywood et al. ca. 1993, p. 6).

The metal extrusion, cutting, and other support activities were carried out in three bays of the main plant (Figure 2-5). The ceiling height varied from 45 to 55 ft. Crane rails, roof drain lines, electrical wires and conduits, water pipes, space heaters, and off-gas ducts were supported from a steel framework. Blowers were located on the roof for numerous off-gas ducts in the exhaust system.

Summary statements of activities at Adrian Plant indicate that depleted, normal, and low-enriched uranium were processed. Before 1960, there is no indication that enriched material was processed at

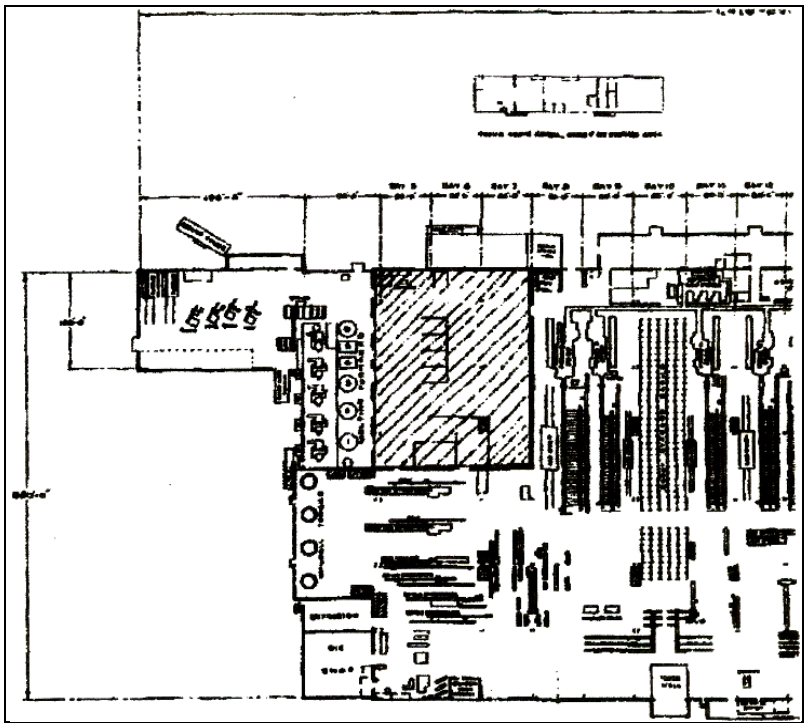

Figure 2-5. Area of Adrian Plant involved with AEC activity (area marked with diagonal lines) (Hill 1976).

Adrian Plant. On May 12, 1960, the AEC HASL noted, "The company is planning to extrude, in the near future, uranium of 2% enrichment" (AEC 1960). A ventilation system was partially installed in Press #7 by the time of the dust survey on December 14, 1960. On December 14, 1960, what appear to be the first low-enrichment (0.947%) billets at Adrian Plant were extruded (AEC 1961). A summary of the flow of recycled uranium indicates that Adrian Plant shipped and received depleted, normal, and low-enriched (0.947%) uranium to and from Fernald from October 1, 1961, to September 30, 1962, and the low-enriched uranium mass was more than a 2 times larger than either the normal or the depleted mass (DOE 2000) during that period. Because Adrian Plant could have received uranium from other facilities and because there is just 1 year of data available, enrichment is assumed to be the largest of the reported values, which was 2%.

A wipe test analyzed for ^{60}Co indicates that there was a sealed source in use at Adrian. The source was used to check the criticality alarm monitor.

RMI noted that before approximately June 1955 the operations were sporadic and no regular hourly press crew was assigned to the AEC work (Bean 1967). Crews were commonly assembled from available staff, resulting in many employees being involved in the AEC work.

AEC operations were coming to an end at Adrian Plant in 1961. The operations were relocated to Extrusion Plant (Reactive Metals, Inc.) in Ashtabula, Ohio. Decontamination and close-out work were completed in 1962. The Adrian Plant was still named in Contract No. AT-(30-1)-1405, Modification No. 37, which was entered into on November 29, 1961, for the period from July 1, 1961, to June 30, 1962. In 1961, the Bridgeport Brass Ashtabula facility (also known as the Extrusion Plant or Reactive Metals, Inc.) began operations. Employee claim information indicates that a number of Adrian Plant employees transferred to Ashtabula and bioassay records confirm this beginning in early 1962. A copy of a folder or a divider includes Bridgeport Brass Company and the Adrian address and states, "No samples received after 10/5/1961" (Author unknown, undated). The Adrian Plant AEC contract work was officially terminated on August 30, 1963, by Modification No. 42 or 47 [both numbers are cited] (Wallo 1985). This site profile assumes that operations might have continued through December 31, 1962. Decontamination and survey activities were reported in 1995.

3.0 ESTIMATION OF INTERNAL EXPOSURE

The primary source of internal exposure at Havens Laboratory and Adrian Plant was radioactive dust from the handling and oxidation of uranium and smaller amounts of thorium during the various processes at the facilities. The specific sources of uranium dust were described in what appears to be the second of a series of evaluations of occupational exposure at Adrian Plant (AEC 1955b). This report outlines the main factors contributing to exposure to dust:

- Fumes and smoke from extrusion press discharge,
- Oxidation of extruded rod surface to oxide that subsequently flaked off on rod movement and became airborne,
- Transfer of rod from run-off table to cart due to dust created when loose oxide from rod surface was rendered airborne,
- High concentrations at run-off table area due to presence of loose oxide scale on surface of rod and rollers,
- Storage of hot crops in an open area near a tool heating furnace,
- Cutting off the butt ends of extruded rods and from deburring of the die block,

- High GA air concentrations in the vicinity of straighteners due to flaking of loose oxide scale on surface of extruded rod on stretching, and

- High GA air concentrations at the extrusion exhaust, operators area, run-off table area, and crop cooling areas (AEC 1955b).

Individual uranium urinalysis data are available from both Havens Laboratory and Adrian Plant. For unmonitored workers or unmonitored periods, an analysis of air monitoring data is provided for use in reconstructing internal dose. This document estimates thorium intakes based on uranium intakes.

3.1 URANIUM

Human and animal studies have indicated that oxides of uranium can be very insoluble in the lung (ICRP 1995), which indicates absorption type S (0.1% and 99.9% with clearance half-times on the order of 10 minutes and 7,000 days, respectively). Other *in vitro* dissolution studies of compounds at uranium facilities have shown that oxides of uranium exhibit moderate solubility (Eidson 1994; Heffernan et al. 2001), which suggests absorption type M (10% and 90% with clearance half-times on the order of 10 minutes and 140 days, respectively). *In vitro* dissolution tests on oxides from uranium metal during depleted uranium armor penetrator tests have indicated multicomponent dissolution rates, with 25% of uranium dissolving with a half-time of less than or equal to 0.14 days and 75% dissolving with a half-time of 180 days. Because there was no specific information on the solubility of aerosols at Havens Laboratory and Adrian Plant, this analysis assumed that both types M and S were available. The selection of absorption type should depend on the organ of interest. Dose reconstructions should assume International Commission on Radiological Protection (ICRP) Publication 66 default parameters for particle deposition (ICRP 1994).

Havens Laboratory handled uranium of natural enrichment. At Adrian Plant, there is no indication that uranium enrichment ever exceeded about 2%, and the records seem to indicate that natural uranium was typical. It is favorable to claimants to assume that uranium results reported in mass were 2% enriched. After 1952, recycled uranium might have been handled.

3.1.1 Uranium Bioassay

Individual uranium urinalysis results are available for some Havens Laboratory and Adrian Plant workers during some periods. Urine samples were not collected from all Bridgeport Brass uranium workers, so the lack of bioassay for an individual should not result in a conclusion of no internal exposure.

The uranium fusion photofluorimetry urinalyses by the University of Rochester and the AEC New York Operations Office were similar to those at other AEC facilities. The default detection threshold for uranium urinalysis is assumed to be 10 µg/L based on a reported sensitivity of 5 to 10 µg/L for uranium fluorimetry urinalysis in the early years (Wilson 1959). Because bioassays were analyzed by photofluorimetry, which is a uranium mass detection method, results at Adrian should be modified to account for an enriched source term.

For unmonitored workers or unmonitored periods, this site profile analyzes the bioassay results to provide estimates of uranium intakes based on coworker data.

The first available bioassay samples for Havens Laboratory were dated September 10, 1952: urinalyses approached an annual frequency before 1958, when the frequency was increased, although no one frequency could be determined from the data. The last available set of sample results was reported for March 12, 1962. Samples were collected sometimes in the mornings and sometimes in the afternoons, and this is noted on some records. For some sampling periods, the

analytical laboratory noted that hydrochloric acid was added to some of the containers, but it is not clear what the purpose for this was. An incident appears to have occurred in April 1961, based on rushed air sample requests and bioassays repeated within a day. For the purpose of coworker intake determinations, it was assumed that the elevated intakes from the incident began on April 15, 1961, 1 day before the first rushed air sample on a Saturday, and continued through April 21, 1961, the day after the first bioassay. In addition, a chronic intake was assumed from June 26, 1952, through August 27, 1962.

The first available bioassay samples for Adrian Plant were dated December 14, 1954, and were listed as "before operating" results. A few workers had multiple samples in 1955; a few samples were collected in 1956. No results were found for 1957, and sampling appeared to be annual in 1958 and 1959. Beginning in July 1960, sampling appears to have approached a monthly frequency. The last available set of sample results was reported for October 9, 1961. Samples were collected sometimes in the mornings and sometimes in the afternoons, and this is noted on some records. For some sampling periods, the analytical laboratory noted that hydrochloric acid was added to some of the containers, but it is not clear what the purpose for this was. Uranium urinalyses appeared to be elevated beginning in late 1960 and early 1961 and started to fall again after April 1961. This analysis assumes a chronic intake at Adrian Plant from May 24, 1954, through December 31, 1962. An additional intake from October 1, 1960, through April 11, 1961 to account for the later elevated urinalysis data was assumed.

For each bioassay date, geometric means (GMs) were estimated by ranking the data, determining the *z*-scores, and plotting the respective *z*-score versus the natural log of the data. A line was fit to the data; *e* raised to the line's *y*-intercept value was assumed to be the GM, and *e* raised to the slope value was assumed to be the geometric standard deviation (GSD) of the data. Results that were reported as zero were ranked but used only indirectly in the fitting of the line. The 84th percentile was estimated as the GM multiplied by the GSD. The number of results for a given date ranged from 1 to 13 at Havens Laboratory and from 1 to 38 at Adrian Plant. The statistical fit parameter (R^2) results ranged from 0.53 (three results) to 0.97 at Havens, from 0.63 to 0.98 at Adrian, and were considered adequate for this set of data.

The daily uranium excretion in urine was calculated by multiplying the results in milligrams per liter by reference man's daily urine output (1.4 L/d) (ICRP 1975). Because Adrian used slightly enriched uranium, those results were multiplied by 1,616 pCi/mg to obtain a daily uranium concentration in picocuries per day. The Havens uranium was assumed to be unenriched, and a factor of 683 pCi/mg was used to convert to activity per day. Attachment A shows the bioassay results that were used in the intake analyses. Table 3-1 shows a summary of the estimated GM, 84th-percentile, and maximum uranium urinalyses that were used to derive intakes from the chronic inhalation intake regimes. Graphs showing the fits of these intake regimes are provided in Attachment A. Additional intakes and alternate periods were tried, but fits were not more satisfactory than those chosen. When intakes are estimated from bioassay data, the mode of intake should usually be assumed to be inhalation, unless there is information that indicates that other modes of intake were more likely. When using bioassay data, the inhalation intake model assumes that some of the intake behaves as ingested material. In general, intakes from bioassay will be larger when an inhalation rather than an ingestion intake is assumed.

The intakes were determined with the Integrated Modules for Bioassay Analysis (IMBA) assuming an absolute uniform error of 1 and normal error distributions for each bioassay result. Data noted as less than the limit of detection (<LOD) is shown on the graph but was not used directly in the fitting. The GSDs for the intakes were calculated by dividing the intake from the 84th-percentile regime by the intake from GM intake regime. Table 3-2 shows the inhalation intake distributions from the analyses of the Havens Laboratory and Adrian Plant uranium urinalysis data, assuming that either a type M or a type S (but not both) intake occurred. Two intake scenarios are shown for each site. One scenario

excludes some of the elevated data and assumes that workers were exposed chronically throughout their employment: this scenario should be used only for workers whose employment period does not overlap the period of assumed elevated exposure. For workers whose employment coincided with the period of elevated exposure, the appropriate site two-intake scenario should be assumed if there are no available bioassay data.

To estimate intakes for the purpose of dose reconstruction, the following approach has been prescribed: the GM of the intake is adjusted to the 95th percentile using the larger of a GSD of 3 or the GSD of the distribution itself, and this 95th percentile is assigned as a constant distribution in the Interactive RadioEpidemiological Program (IREP). This document adjusts the intakes in Table 3-2 to 95th-percentile intakes by multiplying the GMs by a GSD of 3 raised to the 1.645 power. The resulting intakes are summarized in Table 3-8 later in the document.

For Havens Laboratory an additional intake is estimated for 1950 based on air sampling data.

3.1.2 Uranium Air Sampling

Air samples were collected at both Havens Laboratory and Adrian Plant. Because samples were measured by alpha activity detection systems, enrichment did not affect the results.

For the assumed experimental uranium work period at Havens Laboratory from November 8, 1950, through December 31, 1950, the daily intake was derived by assuming that the median air concentration was equal to the MAC of 70 dpm/m^3. This is likely to overestimate actual exposures, but is believed to account adequately for any uranium exposure that might have occurred during this 2-month period based on the air sample results noted in Section 2.1. The MAC was chosen to estimate this intake based on the fact that 10 air samples were collected on one uranium workday and

Table 3-1. Uranium urinalysis results from coworker data.[a]

Havens Laboratory							Adrian Plant						
Date	#	GM (pCi/d)	84th (pCi/d)	GM (mg/L)	84th (mg/L)		Date	#	GM (pCi/d)	84th (pCi/d)	GM (mg/L)	84th (mg/L)	
09/10/1952	5	2.07	4.83	0.002	0.005	<LOD	12/14/1954	7	<22.62	<22.62	<0.01	<0.01	<LOD
09/11/1952	1	3.82	3.82	0.004	0.004	<LOD	01/12/1955	6	<22.62	<22.62	<0.01	<0.01	<LOD
09/01/1953	5	1.1	1.38	0.001	0.001	<LOD	04/06/1955	5	<22.62	<22.62	<0.01	<0.01	<LOD
10/01/1953	2	0.96	0.96	0.001	0.001	<LOD	08/03/1956	4	<22.62	<22.62	<0.01	<0.01	<LOD
02/04/1954	3	3.13	8.55	0.003	0.009	<LOD	08/22/1958	10	10	21.28	0.004	0.009	
06/01/1954	8	1.94	3.35	0.002	0.004	<LOD	10/10/1958	1	<22.62	<22.62	<0.01	<0.01	<LOD
02/27/1956	6	2.81	6.59	0.003	0.007		10/16/1959	18	3.43	18.53	0.002	0.008	
10/07/1957	7	8.49	19.85	0.009	0.021		11/13/1959	15	<22.62	<22.62	<0.01	<0.01	<LOD
01/27/1958	8	3.6	8.77	0.004	0.009		07/14/1960	16	14.5	30.74	0.006	0.014	
07/03/1958	2	2.34	3.16	0.002	0.003	<LOD	08/23/1960	11	14.69	42.4	0.006	0.019	
09/15/1958	8	1.93	3.49	0.002	0.004	<LOD	09/06/1960	10	14.99	45	0.007	0.02	
01/19/1959	5	2.45	7.27	0.003	0.008		09/12/1960	10	24.11	91.22	0.011	0.04	
02/25/1959	4	1.84	6.42	0.002	0.007	<LOD	09/19/1960	11	12.13	31.67	0.005	0.014	
03/16/1959	3	2.41	10.1	0.003	0.011		09/22/1960	18	6.21	18.13	0.003	0.008	
08/28/1959	0	0	0	0	0	<LOD	10/14/1960	9	10.59	19.91	0.005	0.009	
10/19/1959	4	0.61	1.59	0.001	0.002		11/18/1960	8	12.84	25.38	0.006	0.011	
02/05/1960	0	0	0	0	0	<LOD	12/19/1960	12	7.45	22.56	0.003	0.01	
05/26/1960	5	3.14	4.99	0.003	0.005	<LOD	01/13/1961	19	8.63	21.21	0.004	0.009	
10/26/1960	7	17.26	51.38	0.018	0.054		01/23/1961	15	6.33	15.62	0.003	0.007	
01/09/1961	8	2.23	4.51	0.002	0.005	<LOD	01/30/1961	16	13.29	27.41	0.006	0.012	
04/01/1961	3	5.59	7.13	0.006	0.007	<LOD	02/10/1961	15	51.24	126.3	0.023	0.056	
04/20/1961	10	61.23	228.78	0.064	0.239		02/28/1961	14	42.27	63.51	0.019	0.028	
04/21/1961	9	12.59	44.29	0.013	0.046		03/13/1961	19	43.18	61.34	0.019	0.027	
04/24/1961	8	9.4	18.03	0.01	0.019		03/27/1961	28	38.45	56.46	0.017	0.025	
05/22/1961	7	16.29	35.44	0.017	0.037		04/10/1961	32	26.55	105.79	0.012	0.047	
05/26/1961	1	13.39	13.39	0.014	0.014		04/24/1961	35	6.02	13.96	0.003	0.006	
09/25/1961	6	0.72	2.68	0.001	0.003	<LOD	05/08/1961	37	11.61	21.31	0.005	0.009	
09/26/1961	7	1.1	3.55	0.001	0.004	<LOD	05/22/1961	38	5.96	14.43	0.003	0.006	
03/03/1962	13	2.32	5.2	0.002	0.005		06/05/1961	37	6.63	16.26	0.003	0.007	
03/09/1962	13	2.07	4.37	0.002	0.005	<LOD	06/26/1961	19	26.63	54	0.012	0.024	
03/12/1962	11	1.3	2.05	0.001	0.002	<LOD	07/25/1961	24	16.49	30.74	0.007	0.014	
							07/28/1961	30	21.87	68.56	0.01	0.03	
							07/31/1961	16	4.96	18.22	0.002	0.008	
							10/02/1961	35	4.72	16.09	0.002	0.007	
							10/06/1961	32	7.43	33.95	0.003	0.015	
							10/09/1961	35	4.24	11.41	0.002	0.005	

a. Assumes 1.4 L/d and 683 pCi/mg for Havens and 1,616 pCi/mg for Adrian.

Table 3-2. Inhalation intakes based on coworker data.

Havens coworker intake scenario choices						
			Type M		Type S	
Scenario	Start	End	GM (pCi/d)	GSD	GM (pCi/d)	GSD
Chronic or	06/26/1952	08/27/1962	1.03E+02	2.29	1.43E+03	2.28
Chronic plus incident	06/26/1952	08/27/1962	9.59E+01	2.14	1.32E+03	2.16
	04/15/1961	04/21/1961	1.13E+03		3.62E+04	
Adrian coworker intake scenario choices						
			Type M		Type S	
Scenario	Start	End	GM (pCi/d)	GSD	GM (pCi/d)	GSD
One chronic or	05/24/1954	12/31/1962	1.69E+02	2.76	2.31E+03	2.76
Two chronics	05/24/1954	12/31/1962	1.32E+02	2.96	1.62E+03	2.87
	10/01/1960	04/11/1961	3.03E+02		9.79E+03	

it was noted that the average of the 10 samples was essentially zero (Klevin 1951). One sample was about 2.5 times the MAC. Because the uranium operations were believed to be very limited and intermittent during this period both in terms of time and source material, one MAC is used to provide an upper estimate of a chronic intake for this 2-month period. The daily inhalation intake rate can be determined by multiplying the air concentration by the breathing rate per work year (2,400 m^3/yr), adjusting from disintegrations per minute to picocuries, and dividing by the number of calendar days in a year. The result is 207 pCi/d.

Adrian Plant work was evaluated for air dust levels near the very beginning of operations. Data from these evaluations were documented in a series of HASL documents beginning with HASL-B-BRA-2 in March 1955 (AEC 1955b), the first available document in the series. This 1955 report consisted of three dust studies performed October 26 to 27, 1954; December 14 to 16, 1954; and January 11 to 13, 1955. Those studies were followed by air sample studies on February 16 and 24, 1956 (AEC 1956); January 27 to 29, 1960 (AEC 1960); and December 14, 1960 (AEC 1961). The purposes of these studies were:

- To evaluate and document occupational exposure to alpha-emitting dust,
- To identify sources of uranium air contamination and recommend corrective actions where necessary, and
- To appraise the effectiveness of the ventilation system and existing control measures.

The air samples included radioactive particulate concentration measurements of breathing zones (BZs), GA, processes, and effluents. The air sample results were matched with information about worker categories, locations, tasks, and the time at each location or task. Daily weighted-average exposures were then determined for job categories.

The April 1956 report (AEC 1956) noted progress in exposure control since the March 1955 report (AEC 1955b). Progress included installation of ventilation equipment at the extrusion press discharge and crop waste discharge areas, which effectively reduced airborne uranium concentrations in these areas. "For example, process air concentrations of 343 dpm/m^3, 1200 dpm/m^3, and 128 dpm/m^3 obtained during the survey of January, 1955, at the extrusion press discharge, die head operator position and 6 feet south of the extrusion press, respectively, were reduced to 80 dpm/m^3, 107 dpm/m^3, and 18 dpm/m^3 during the present survey" (AEC 1956).

Average BZ concentrations of 7,600 dpm/m^3 obtained during diehead operations of January 1955 were reduced to 95 dpm/m^3. These improvements were the result of mechanical changes in the

process as well as such changes in the process components as the use of salt as a dust suppressant. In addition, quench water was used at varying flow rates to reduce dust with results somewhat dependent on the type of extrusion.

These safety gains were offset by unimplemented recommendations and facility modifications from the March 1955 report (AEC 1955b):

> 2. *Use better housekeeping techniques to prevent the accumulation of loose oxide on the run-off conveyers, table and general operating area. These areas should be thoroughly vacuumed at the end of each 12-ingot heat if possible. Eliminate broom sweeping.*
>
> 3. *Provide dust catch pans underneath all roller conveyers to reduce the spread of contamination and maintenance time.*
>
> 4. *Unless the floors can be kept clean, provide steel matting on the operating floor areas to reduce the spread of both airborne and direct surface contamination.*

These recommendations were reiterated by reference in the April 1956 report (AEC 1956).

The significance of broom sweeping is that it was an unauthorized activity noted as contributing to elevated dust concentrations. However, elevated levels from sweeping were unlikely to have been directly included in the HASL surveys of airborne radioactivity.

The effect of not implementing recommendations 2 and 3 was noted (AEC 1956):

> *Visible loose oxide concentration found was on the discharge conveyor after the passage of each extruded rod. Average air concentrations obtained in the conveyor area during extrusion 25 ft and 50 ft south of the extrusion press discharge were 368 dpm/m^3 and 463 dpm/m^3 respectively. Alpha radiation measurements made in this area with a Juno Survey Meter (SIC 17C) showed surface contamination of 15,000-40,000 α-dpm/100 cm^2 …*

and

> *All the uncontrolled sources of dust which have been pointed out contributed to raising the general air concentration throughout the plant including such areas as the operating and tool heating sites. Excessive air concentrations found in these areas were primarily responsible for the undesirable exposures reported for the Extrusion Press Operator, Die Head Man, Foreman and Project Engineer.*

The 1960 HASL report (AEC 1960) again restated the need to implement Recommendations 2 and 3 from the March 1955 report, so it appears that these recommendations had not been implemented after 5 years.

There are some air sampling data for Havens Laboratory, and the results seem generally consistent with the Adrian Plant results. However, the data are not organized into weighted daily averages by job category. Because the Havens Laboratory and Adrian Plant activities were very similar, it seemed reasonable to apply the Adrian uranium air sampling data to estimations of employee exposures at both Adrian Plant and Havens Laboratory.

Air dust measurements are very affected by location, ongoing processes and their variations (salt, no salt, quench rate, as well as type of extrusion), and ventilation. Table 3-3 shows the process-effect of applying salt coatings and quenching uranium.

Table 3-3. Comparison of daily weighted-average air dust measurements at Adrian Plant (dpm/m^3) for various quenching and salting strategies.[a]

Individual	2-psi quench tube extrusion	Salting plate extrusion, no quench-	17.5-psi quench tube extrusion
Die head man	2,000	1.6	131

a. Source: AEC (1956).

A report from Adrian Plant (AEC 1960) states that before November 1957 the use of salt to coat hot uranium before and after extrusion was effective in suppressing air dust concentrations. When salt coatings were used, no average time-weighted dust concentrations in excess of the MAC were reported. Sometime after November 1957, it was determined that the use of salt coatings induced undesirable properties in the finished product. Therefore, this method of dust suppression was abandoned. Measurement of air dust concentrations after salt was no longer used indicated that 8 of the 17 studied employees were exposed to average time-weighted dust concentrations in excess of the MAC. It was clear that the use of salt to coat hot uranium reduced air dust concentrations. The role of salt in the extrusion process at Havens Laboratory is unclear. Use of salt coatings and quench water in the extrusion process could explain the measurement fluctuations of air dust concentrations.

An example of air concentrations is shown in Table 3-4 where air dust levels had previously been reduced through facility and process modification. The data are daily weighted averages (incorporating time spent in each activity as well as time spent away from the workplace, such as at lunch or in the washroom) rather than raw air dust values.

Table 3-4. Adrian Plant daily weighted-average air dust concentrations by operator position measured January 11 to 13, 1955.

Job category	Concentration (dpm/m^3)
Salt bath operator	54
Salt bath helper	51
Extrusion press operator	97
Die head operator	2,000
Run out and winch operator	28
Weigh man	120
Lube man and winch operator	280
Foreman	83
Project engineer	87

The GM of the Table 3-4 daily weighted averages is 115 dpm/m^3, and the GSD is 3.5. The daily weighted average from 1955 can be compared to similarly measured daily weighted-average exposures from HASL-85 (AEC 1960) in Table 3-5.

The GM of the Table 3-5 individual daily weighted-average air concentration is 250 dpm/m^3, and the GSD of the exposures is 1.9 (there are 17 concentrations associated with the workers). However, the GSD of the daily weighted-average concentration (there are nine concentrations) is 2.2.

Table 3-5 has the largest GM of the reported daily weighted-average uranium air concentrations at Adrian, and its GM was used to calculate intakes for unmonitored Havens Laboratory and Adrian Plant employees beginning in 1952.

Table 3-5. Adrian Plant daily weighted-average air dust concentrations from January 27 to 29, 1960.

Operator	Number of workers	Average daily weighted exposures (dpm/m^3)
Heater	2	200
1st general helper	2	200
2nd general helper	2	200
Press operator	2	420
Die head man	2	470
Finished saw man	2	330
Inspector	2	310
Foreman	2	270
Machinist	1	32
Total	**17**	

In the case where inhalation intakes are calculated from air concentrations, ingestion intakes are also to be considered. NIOSH (2004a) states that the daily ingestion rate in picocuries can be estimated by multiplying the daily air concentration in picocuries per cubic meter by a factor of 0.2, so the daily uranium ingestion rate based on an air concentration of 250 dpm/m^3 would be 23 pCi/workday. The ingestion rate associated with an air concentration of 70 dpm/m^3 would be 6.3 pCi/workday.

A summary of estimated uranium intake rates based on air concentrations is shown in Table 3-6. Although these intakes were based on an upper estimate of air exposure (constant distribution), the metabolic models were assumed to have an uncertainty associated with a lognormal distribution and a GSD of 3. The Table 3-6 intakes for the period November 8, 1950, to December 31, 1950, are adjusted to 95th-percentile intakes for the purpose of dose reconstruction by multiplying by a factor of 3 raised to the 1.645 power. The resulting values are summarized in Table 3-8 later in this section.

Table 3-6. Estimated uranium intake rates based on time-weighted air concentrations.

	Start	End	Intake mode	Radionuclide	Absorption type	Exposure rate (pCi/d)
Havens Laboratory	11/08/1950	12/31/1950	Inhalation	U-natural	M, S	2.07E+02
	11/08/1950	12/31/1950	Ingestion	U-natural	(a)	4.32E+00
	06/26/1952	08/27/1962	Inhalation	U-natural	M, S	7.40E+02
	06/26/1952	08/27/1962	Ingestion	U-natural	(a)	1.54E+01
Adrian Plant	05/25/1954	12/31/1962	Inhalation	U-234	M, S	7.40E+02
	05/25/1954	12/31/1962	Ingestion	U-234	(a)	1.54E+01

a. Choose same f_1-value as used for inhalation per NIOSH (2004a).

3.1.3 Comparison of Uranium Bioassay and Air Concentration Estimates

Except for 1950, summary estimates of uranium intakes shown in Section 3.4 are based on Bridgeport Brass bioassay data.

Estimates of total intakes derived from urinalysis data and air concentrations appear to be similar. Differences in the values of intake estimates from air and bioassay data are likely due to a multitude of factors, but one of the more significant factors is the choice of uranium absorption type. For interpretation of both the air and bioassay data, intake pattern assumptions were simplified based on the limited information. If the time patterns of intake are assumed reasonable, it appears reasonable to conclude that workers were not exposed to a source term that was clearly pure type M or pure type S.

3.1.4 Recycled Uranium

Recycled uranium might have been processed at Havens Laboratory and Adrian Plant after 1952. An estimate of contaminants that might contribute the most to internal doses, based on *Site Profiles for Atomic Weapons Employers that Worked Uranium Metals* (NIOSH 2011), is shown in Table 3-7. It is unlikely that recycled uranium would constitute the entire source term. In addition, the activity fractions assume that the uranium specific activity is based on depleted uranium, which increases the proportion of the contaminants by activity. The contaminant levels for depleted uranium overestimate the contaminants in uranium of normal enrichment by about 40%. The contaminants are assumed to be oxides. Plutonium oxides are assumed to be type M or S. All chemical forms of neptunium are assumed to be type M.

Table 3-7. Estimate of contaminant activity fractions in a recycled uranium source term (pCi contaminant per pCi uranium).

Uranium	Pu-239	Np-237	Tc-99	Th-232	Th-228
1	0.00246	0.00182	0.379	2.73E-06	2.73E-06

3.2 THORIUM

It is not clear when thorium work started at Havens Laboratory. The Adrian Plant records indicate that extrusion of thorium most likely started on May 25, 1954. Records indicate that thorium work might have slowed down or ceased after 1955, but no inventory records were found after this date. AEC records indicate that there was continuing interest in thorium after 1955. It is favorable to claimants to assume that thorium processing continued throughout the AEC work periods. To date, no records of thorium air monitoring or bioassay for either site have been found.

To account for unmonitored thorium exposures at Havens Laboratory and Adrian Plant, it is assumed that the thorium intake is equal to 10% of the uranium intake by mass for the same period. Natural uranium has a lower specific activity than enriched uranium, so it is favorable to claimants to assume natural uranium when determining the relative activity of thorium. To determine the relative activities of uranium to thorium, the specific activity of ^{232}Th is divided by the specific activity of natural uranium and multiplied by 10%. This results in a relative ^{232}Th -to-uranium intake fraction by activity of 0.0161. Further, it is assumed that ^{232}Th is in equilibrium with ^{228}Th, so the ^{228}Th to uranium activity fraction is also 0.0161. Exposure from ^{228}Ra (half-life of 5.75 years) is assumed to be insignificant because the thorium was likely to have been recently produced and because the dose conversion factor is small compared to thorium. Thorium intakes are summarized in Table 3-8.

Table 3-8. Estimated thorium intake rates based on uranium intakes.

	Start	End	Intake mode	Radionuclide	Absorption type	Exposure rate (pCi/d)
Havens Laboratory	11/08/1950	12/31/1950	Inhalation	Th-232 & Th-228	M, S	3.33E+00
	11/08/1950	12/31/1950	Ingestion	Th-232 & Th-228	(a)	6.96E–02
	06/26/1952	08/27/1962	Inhalation	Th-232 & Th-228	M, S	1.19E–01
	06/26/1952	08/27/1962	Ingestion	Th-232 & Th-228	(a)	2.48E–01
Adrian Plant	05/25/1954	12/31/1962	Inhalation	Th-232 & Th-228	M, S	1.19E+01
	05/25/1954	12/31/1962	Ingestion	Th-232 & Th-228	(a)	2.48E–01

a. Choose same f_1-value as used for inhalation per NIOSH (2004a).

3.3 MISCELLANEOUS INFORMATION RELATED TO INTERNAL DOSE

This section includes internal dose information that could be of value for specific dose reconstructions. This analysis did consider the information generically, but it should also be considered in dose reconstructions based on individual dosimetry analysis.

Air samples labeled “rush” were dated April 16 and 17, 1961, for Havens Laboratory. These combined with the collection of multiple urine bioassay samples from workers on April 20 and 21, 1961, are indicative of an incident that may have resulted in internal exposures.

3.4 OCCUPATIONAL INTERNAL DOSE RECONSTRUCTION ASSUMPTIONS AND SUMMARY

The assumed uranium photofluorimetry detection threshold is 10 µg/L. Intakes of neptunium, plutonium, and thorium are derived from intakes of uranium. The solubility types for uranium and its contaminants should be determined in accordance with ORAUT-OTIB-0010, *Internal Dose Reconstruction* (ORAUT 2007).

At Havens Laboratory, intakes are assumed to be from natural uranium (0.683 pCi/µg). Thorium intakes should be assumed beginning June 26, 1952. Recycled uranium contaminants are included after 1952. There are two periods of operational exposure:

- November 8, 1950, to December 31, 1950; and
- June 26, 1952, to August 27, 1962.

The 1950 intake is assigned to all Havens Laboratory workers, whose covered work period overlapped the 1950 intake period. For unmonitored work periods or workers, two exposure scenarios for Havens are shown in Table 3-9. The first can be used for unmonitored internal exposures that did not include work during the period from April 15 to 21, 1961. The second scenario accounts for the higher exposures during the period from April 15 to 21, 1961, and should be used for unmonitored exposures that overlapped this period.

At Adrian Plant, intakes are likely to be from natural (0.683 pCi/µg) or low-enriched (0.973 or 1.616 pCi/µg) uranium and thorium. Only natural uranium enrichment is likely before 1960. The default enrichment assumption for 1960 through 1962 is 2% (1.616 pCi/µg).

There is one period of operational exposure: May 25, 1954, to December 31, 1962.

At Adrian Plant, thorium and recycled uranium contaminant intakes should be assumed for the entire operational exposure period.

For unmonitored work periods or workers, two exposure scenarios for Havens are shown in Table 3-9. The first can be used for unmonitored internal exposures that did not include work during the period from October 14, 1960, to April 11, 1961. The second scenario accounts for the higher exposures during the period from October 14, 1960, to April 11, 1961, and should be used for unmonitored exposures that overlapped this period.

Table 3-7 can be used for both Havens Laboratory and Adrian Plant to estimate intakes of the other radionuclides from intakes of uranium, such as when intakes are derived from uranium bioassay or from uranium air concentrations after 1952.

For unmonitored workers or unmonitored periods, Table 3-9 lists uranium intake rate assumptions. The intakes are assumed to be chronic. The dose distributions are assumed to be constant.

4.0 ESTIMATION OF EXTERNAL EXPOSURE

Individual film badge results for Havens Laboratory and Adrian Plant are reported from late 1958 through early 1961.

Table 3-9. Chronic uranium intake assumptions for unmonitored workers.

Assumptions for unmonitored workers	Scenarios	Start	End	Intake mode	Intake type	Radionuclide	Type	Uranium type M[a] (pCi/d)	Uranium type S[a] (pCi/d)
Havens Laboratory									
Choose one of the two bordered scenarios. Choose the second scenario if work overlapped the period from April 15 to 22, 1961. Choose intakes based on either type M or S uranium, not both.	1	11/08/1950	12/31/1950	Inhalation	Chronic	U-234	(b)	1.26E+03	1.26E+03
		11/08/1950	12/31/1950	Ingestion	Chronic	U-234	(c)	2.63E+01	2.63E+01
		06/26/1952	08/27/1962	Inhalation	Chronic	U-234[d]	(b)	6.29E+02	8.71E+03
	2	11/08/1950	12/31/1950	Inhalation	Chronic	U-234	(b)	1.26E+03	1.26E+03
		11/08/1950	12/31/1950	Ingestion	Chronic	U-234	(c)	2.63E+01	2.63E+01
		06/26/1952	08/27/1962	Inhalation	Chronic	U-234[d]	(b)	5.84E+02	8.02E+03
		04/15/1961	04/21/1961	Inhalation	Chronic	U-234[d]	(b)	6.91E+03	2.20E+05
Adrian Plant									
Choose one of the two bordered scenarios. Choose the second scenario if work overlapped the period from October 1, 1960, to April 11, 1961. Choose intakes based on either type M or S uranium, not both.	1	05/25/1954	12/31/1962	Inhalation	Chronic	U-234[d]	(b)	1.03E+03	1.41E+04
	2	05/25/1954	12/31/1962	Inhalation	Chronic	U-234[d]	(b)	8.03E+02	9.85E+03
		10/01/1960	04/11/1961	Inhalation	Chronic	U-234[d]	(b)	1.85E+03	5.97E+04

a. Calculated at the 95th percentile using a GSD of 3 and assigned as a constant.
b. Choose intake rates from the appropriate column based on the assumption of either a type M or a type S (not both) uranium intake. For each dose reconstruction, intake rates should be chosen from only one column, not from multiple columns.
c. Choose same f_1-value as used for inhalation per NIOSH (2004a).
d. Assign recycled uranium contaminants per Table 3-7 and using ORAUT (2007) guidance on solubility.

Because film badge data are available for about a 2-year period for at least some workers, this document does not attempt to address worker external exposures based on workplace data. When film badge results are available for a worker, the individual's dosimeter results can be used to estimate dose. For unmonitored workers or unmonitored periods, this site profile provides an estimate of external dose based on analysis of coworker film badge dosimetry records.

The majority of photons from natural uranium metals are in the 30- to 250-keV energy range. Solid uranium objects provide considerable shielding of the lower energy photons and harden the spectrum, causing the majority of photons from a solid uranium object, such as a billet or a rod, to have energies greater than 250 keV. While it is recognized that solid uranium sources have a hardened photon spectrum, exposure to a thin layer of uranium on a surface results in a larger fraction of exposure to lower energy photons. This analysis assumed workers were exposed to photon energies in the 30- to 250-keV range, which is favorable to claimants. Nonpenetrating dose from natural uranium consists primarily of electrons with energies above 15 keV. For consistent presentation, exposure or dose is reported as:

- Penetrating, assumed to be from photons of energies 30 keV or greater, and
- Nonpenetrating, assumed to be from photons of energies less than 30 keV or from electrons.

Adrian Plant initially used film badges (detecting beta, X-ray, and gamma radiations) for some workers on the AEC contract during a trial 26-week period from about November 3, 1958, through May 3, 1959. The badge wear periods were nominally 2 weeks. The film badge data were tabulated using the end date on the badge report, but this sometimes differs by several days from the badge assignment records.

Contamination of the badges was a problem especially before 1959. During the period ending about February 22, 1959, the badge assignment sheet indicates that several of the badges were used to monitor the hacksaw, abrasive saw, induction heater, billet storage area, and salt bath for 24 hours, and then used by the workers. In later periods, some badges were assigned to work areas rather than people. Some badges might not have been used when there were no records of assignment, but elevated doses on some unassigned badges indicate that the badges were in areas of elevated radiation. No assignment has been found for badges dated between about May 4 and August 23, 1959. No record indicated that monitoring occurred between September 17 and 25, 1961. No results were found for the badges reportedly assigned from September 25 through October 23, 1961. Results for badges reportedly worn from October 1 through 31, 1961, only included names for individuals who did not return the badges. It is possible that the names for the October 23, 1961, period should be associated with the overlapping October 31 period. It appears this last set of badges might have been worn for more than 2 weeks, but the doses are consistent with a 2-week period.

Film badges were supplied to Adrian Plant by Controls for Radiation in Cambridge, Massachusetts. No details on the dosimeter design or the film type are currently available. It is possible that two types of badges or badge holders were used based on a note about the January 8, 1961, badges that indicated the films were inserted improperly in the badge holders and were not read. A similar note was included with the February 5, 1961, badges, but results were reported for this period. The reporting format also changed about the same time in 1961. Instead of reporting X-ray or gamma and beta results as <10 mR or mrad, the results were reported as 0 mrem with a footnote that 0 "indicates less than minimum detectable dose – 5 mrem for X and γ <175 keV; 10 mrem for hard X, γ and β, 60 mrem for neutrons." Eighteen of the 35 photon results for the period ending August 6, 1961, and one less-than result for the period ending October 18, 1959, were illegible.

Control badge doses were reported for most periods. These were generally reported as <10 mrem, but ranged up to 167 mrem for both photon and beta doses. For some periods, the photon and beta control badge doses differed from each other, but sometimes they were reported to be the same.

Neutron doses were reported for periods ending May 1 through September 4, 1960 and from December 25, 1960, through September 17, 1961 (except the week ending March 5, 1961). It was noted that calculated neutron doses were based on the assumption of a fast neutron source term, and that 1 rem equaled 14×10^6 neutrons/cm^2. In the early periods, results were reported as less than 0.8×10^6 neutrons/cm^2 which, using the conversion above, is consistent with the 60-mrem reporting threshold. Neutron dosimeters had an unshielded portion and a cadmium-shielded portion. All 938 reported results for the shielded portion of the dosimeter were less than 60 mrem. Five of the 938 results for the unshielded portion of the dosimeter equaled or exceeded the detection threshold (one other result reported neither as nonzero or "less than" was 0.3×10^6 neutrons/cm^2), and the maximum result was 1×10^6 neutrons/cm^2, which would equal about 100 mrem. Neutron dosimeters were calibrated with a polonium-beryllium source. This analysis concludes that the reported neutron dose results are consistent with the assumption of no significant neutron exposures, and the 0.5% rate of positive results is not necessarily indicative of workplace neutron exposures.

Badges were assigned to 14 to 37 workers per monitoring period. Historical review of film badge detection limits for this era indicated that although detection limits were reported as 10 mR or 10 mrad, other documents indicates an LOD of 40 mrem for penetrating and shallow doses that were measured with film badge dosimeters in this era (ORAUT 2006). The exposure (R) organ dose conversion factors should be used to assess dose during this period.

To estimate doses for periods when dosimetry data are unavailable, the approach described in ORAUT-OTIB-0020, *Use of Coworker Dosimetry Data for External Dose Assignment* (ORAUT 2011a) was used. The cycle data was converted to annual for all workers. For totals based on less than 1 year of cycle data, the partial year doses were prorated to an annual dose. Cycled data below the LOD/2 were treated as missed dose. The 50th and 95th percentiles are in Table 4-1.

Table 4-1. External dose (rem) for unmonitored workers.

	Havens		Adrian	
Percentile	**Gamma**	**Beta**	**Gamma**	**Beta**
50th	0.520	0.798	0.596	1.495
95th	1.225	2.932	1.221	5.832

If applicable, adjustments to the whole-body dose should be made for the extremities (e.g., hand and forearms) to account for geometry issues using the guidance in DCAS-TIB-0013, *Selected Geometric Exposure Scenario Considerations for External Dose Reconstruction at Uranium Facilities* (NIOSH 2010b).

4.1 OCCUPATIONALLY REQUIRED MEDICAL X-RAYS

Information about occupationally required medical X-ray examinations at Havens Laboratory and Adrian Plant is unavailable. AEC usually, but not always, required preemployment and periodic (annual) medical examinations of workers who were involved in the larger uranium processing programs. The term preemployment as used here means before performing AEC-contracted radiological work. The typical AEC medical program included a preemployment chest X-ray examination with annual examinations thereafter. The type and frequency of X-ray examination should be based on current Oak Ridge Associated Universities (ORAU) Team guidance. Organ doses can be obtained from the current revision of ORAUT-OTIB-0006, *Dose Reconstruction from Occupational Medical X-Ray Procedures* (ORAUT 2011b).

4.2 MISCELLANEOUS INFORMATION RELATED TO EXTERNAL DOSE

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

Havens Laboratory performed X-ray crystallography and had medical X-ray equipment.

Adrian used a ^{60}Co source to check criticality monitors.

4.3 OCCUPATIONAL EXTERNAL DOSE RECONSTRUCTION ASSUMPTIONS AND SUMMARY

Limited individual film badge results are available to determine doses. The detection limit is assumed to be 40 mR for penetrating radiation and 40 mrad for nonpenetrating radiation. Tables 4-2 and 4-3 summarize annual external doses for Havens Laboratory and the Adrian Plant, respectively. The annual exposures can be used to estimate doses for unmonitored workers or unmonitored periods.

Table 4-2. External exposure summary for Havens Laboratory.

Site	Exposure category	Exposure type	Basis	Year	50th-percentile annual exposure	95th-percentile annual exposure	IREP distribution
Havens Laboratory		Penetrating[a]	Analysis of Havens film badge results	1950[b]	0.076	0.178	Constant
				1952[b]	0.268	0.631	
				1953	0.520	1.225	
				1954	0.520	1.225	
				1955	0.520	1.225	
				1956	0.520	1.225	
				1957	0.520	1.225	
				1958	0.520	1.225	
				1959	0.520	1.225	
				1960	0.520	1.225	
				1961	0.520	1.225	
				1962	0.520	1.225	
		Nonpenetrating	Analysis of Havens film badge results	1950[b]	0.116	0.427	Constant
				1952[b]	0.411	1.510	
				1953	0.798	2.932	
				1954	0.798	2.932	
				1955	0.798	2.932	
				1956	0.798	2.932	
				1957	0.798	2.932	
				1958	0.798	2.932	
				1959	0.798	2.932	
				1960	0.798	2.932	
				1961	0.798	2.932	
				1962	0.798	2.932	
	Medical X-ray	See ORAUT-OTIB-0006 (ORAUT 2011b)					

a. The exposure (R) organ dose conversion factors should be used to assess dose during this period.
b. Annual dose is prorated due to dose potential only occurring for part of the calendar year.

Table 4-3. External exposure summary for Adrian Plant.

Site	Exposure category	Exposure type	Basis	Year	50th-percentile annual exposure	95th-percentile annual exposure	IREP distribution
Adrian Plant		Penetrating[a]	Analysis of Adrian film badge results	1954[b]	0.360	0.738	Constant
				1955	0.596	1.221	
				1956	0.596	1.221	
				1957	0.596	1.221	
				1958	0.596	1.221	
				1959	0.596	1.221	
				1960	0.596	1.221	
				1961	0.596	1.221	
				1962	0.596	1.221	
		Nonpenetrating	Analysis of Adrian film badge results	1954[b]	0.904	3.525	Constant
				1955	1.495	5.832	
				1956	1.495	5.832	
				1957	1.495	5.832	
				1958	1.495	5.832	
				1959	1.495	5.832	
				1960	1.495	5.832	
				1961	1.495	5.832	
				1962	1.495	5.832	
	Medical X-ray	See ORAUT-OTIB-0006 (ORAUT 2011b)					

a. The exposure (R) organ dose conversion factors should be used to assess dose during this period.
b. Annual dose is prorated due to dose potential only occurring for part of the calendar year.

5.0 ESTIMATION OF DOSE FROM REMEDIATION ACTIVITIES

Havens Laboratory

The areas shown in Figures 2-1 to 2-3 were the areas being used for uranium activities when operations ceased at Havens Laboratory, and the figures show the locations of sampling for each area (JG 1962a, 1962b). The conclusion of the postdecontamination survey was that decontamination was successful.

Havens Laboratory was sold to the local Catholic diocese for use as a school. It was subsequently resold to the City of Bridgeport Board of Education for use as a high school and later as an educational center. A report describes the results of an Oak Ridge National Laboratory radiological survey of the site (MMES 1985, p. 48). An Office of Remedial Action and Waste Technology report stated that the site required no remedial action and would not be included in the Formerly Utilized Sites Remedial Action Program (DOE ca. 1987). A letter to the Superintendent of Schools for Bridgeport restated this conclusion (Fiore 1987).

According to the NIOSH Residual Radioactivity survey (NIOSH 2004b), there is little potential for significant residual contamination outside the period of weapons-related work at the site. Therefore, for the purpose of dose reconstruction, potential doses from residual radioactivity at Havens Laboratory are not included.

Adrian Plant

In 1961, work was transferred from Adrian Plant to RMI at the Extrusion Plant in Ashtabula, Ohio. At that time, one large extrusion press was shipped to Ashtabula and put in operation there. Other equipment formerly used at Adrian Plant was dismantled and scrapped. The whereabouts of this material is unknown. Bridgeport Brass completed decontamination and close out in 1962.

The Adrian Plant was sold to Martin Marietta in the early 1960s. It was used by that company until 1974 when it was sold to General Motors Chevrolet Manufacturing Division. In 1995, remediation of the service pits and removal of some drainage pipes took place from April to July. The maximum measured air concentration was 1.7×10^{-12} µCi/cm^3 (TMA/Eberline 1995). Multiplying this air concentration by an air intake rate of 1.2 m^3/hr and an exposure period of 704 hours (for the entire months of April through July) resulted in a calculated uranium annual inhalation intake of 1,436 pCi. Using the method in Section 3.0, the calculated ingestion intake was 28.7 pCi. Table 5-1 lists annual internal and external exposure during remediation activities at the Adrian Plant.

The postremediation survey report concluded that both indoor and outdoor average gamma radiation levels cannot be distinguished from background at this site (Wallo 1985). Therefore no further dose should be assessed.

Table 5-1. Annual internal and external exposure during remediation activities at the Adrian Plant.

Internal	Start	End	Exposure	Absorption type	Intake (pCi/d)	IREP distribution
U-234	04/01/1995	07/31/1995	Inhalation	M, S	1.18E+01	Constant
	04/01/1995	07/31/1995	Ingestion	(a)	2.35E–01	Constant

a. Choose same f_1 value as used for inhalation per NIOSH (2004a).

Recycled uranium contaminants and thorium were not included in the assumed intakes for the residual period because the overestimate of uranium intake should be large enough to account for dose from all intakes. Other assumptions about residual exposures should be consistent with assumptions from the operational period.

6.0 ATTRIBUTIONS AND ANNOTATIONS

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

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ATTACHMENT A
GRAPHS SHOWING PREDICTED BIOASSAY FROM AIR AND FITS OF COWORKER BIOASSAY

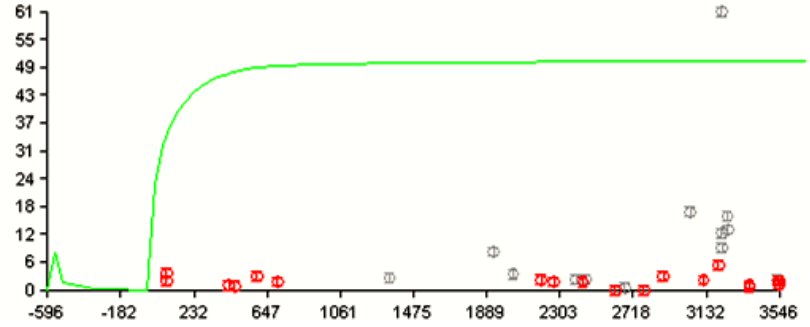
Graphs showing the GMs (or detection thresholds in some cases) of the coworker uranium urinalysis data are shown on the following pages. Data in black were considered for fitting intakes, data in red were excluded from the fitting. The *x*-axis is in units of days, and the *y*-axis is in units of picocuries per day of uranium excreted in urine. For the Havens Laboratory graphs, day 0 is June 26, 1952, and day 3,714 is August 27, 1962. For the Adrian Plant graphs, day 0 is May 24, 1954, and day 3,142 is December 31, 1962. Some graphs end on the last day of bioassay results rather than the last day of the intake period.

ATTACHMENT A
GRAPHS SHOWING PREDICTED BIOASSAY FROM AIR AND FITS OF COWORKER BIOASSAY

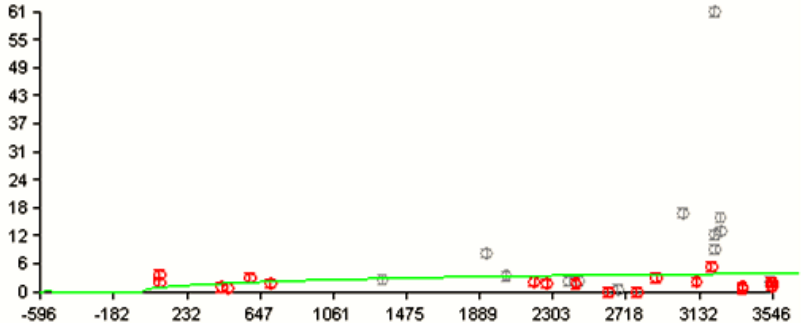
The following set of graphs showing predicted bioassay results from the estimated air intakes, superimposed on the GM and 84th-percentile bioassay results.

At Havens Laboratory the assumed early excretion (estimated from air samples) from intake rates of 740 pCi/d inhalation and 15.4 pCi/day for a type M assumption overestimate most of the GM and 84th-percentile data are shown starting on day –596 (November 8, 1950). For a type S assumption, the prediction is a little low for the GM data and underestimates most of the 84th-percentile data.

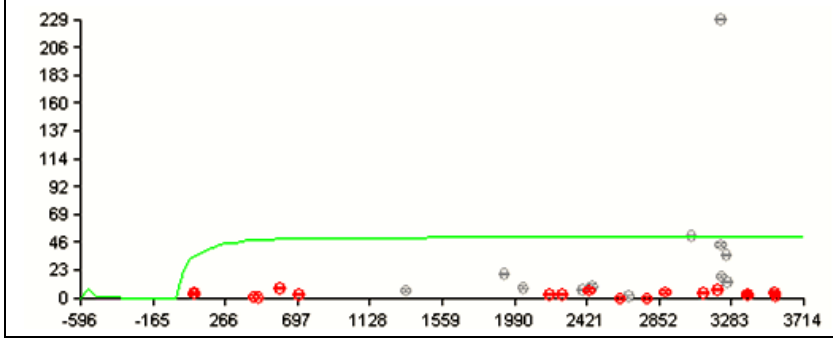
Havens Laboratory, type M, GM.



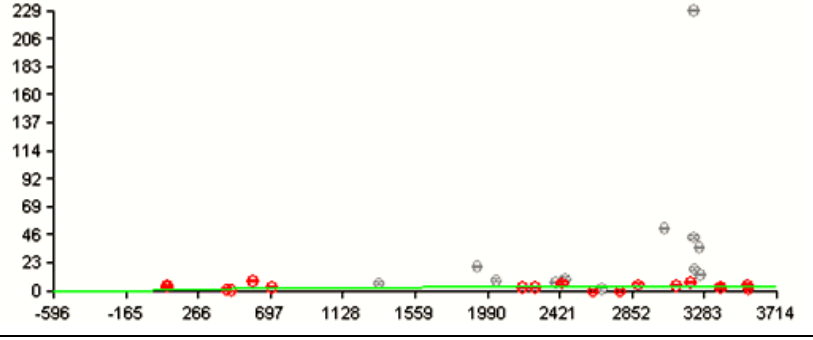
Havens Laboratory, type S, GM.



Havens Laboratory, type M, 84th.



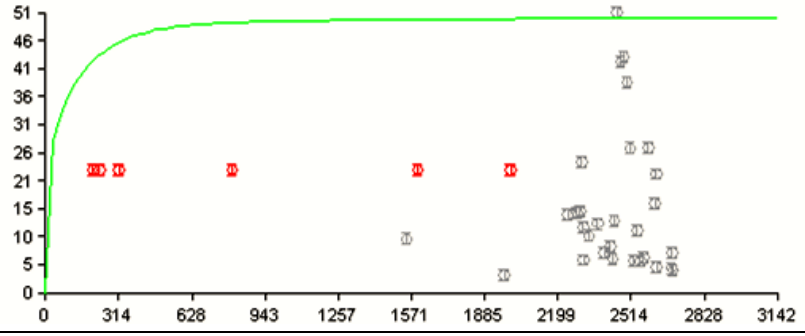
Havens Laboratory, type S, 84th.



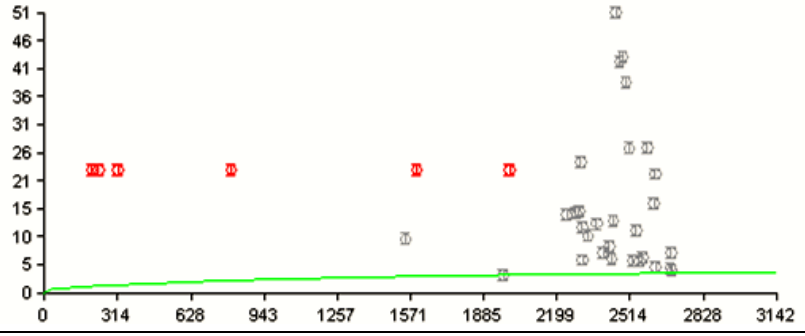
ATTACHMENT A
GRAPHS SHOWING PREDICTED BIOASSAY FROM AIR AND FITS OF COWORKER BIOASSAY

At Adrian Plant, the intake rates of 740 pCi/d inhalation and 15.4 pCi/d ingestions estimated from air samples and a type M assumption overestimate most of the GM data and the early 84th-percentile data. For a type S assumption, the air concentration that was determined from the intake rate is a low for the GM data and underestimates all of the 84th-percentile data.

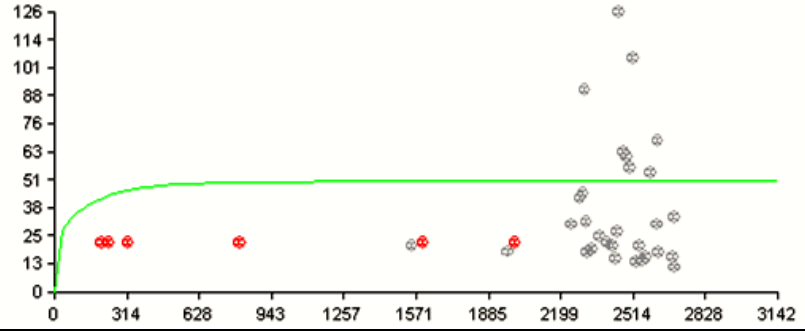
Adrian Plant, type M, GM.



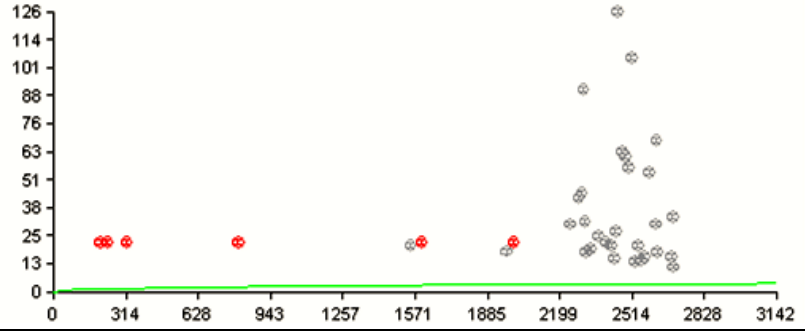
Adrian Plant, type S, GM.



Adrian Plant, type M, 84th.



Adrian Plant, Type S, 84th.

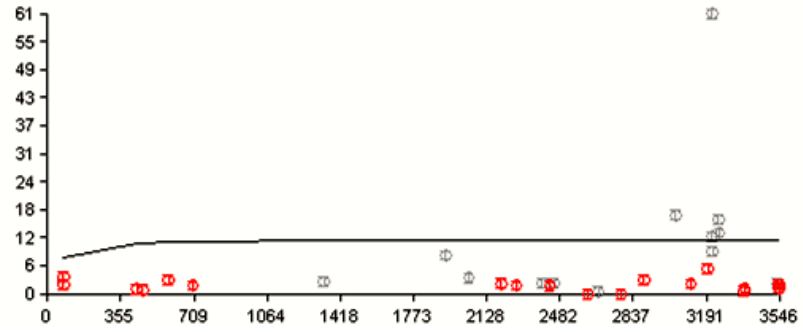


ATTACHMENT A
GRAPHS SHOWING PREDICTED BIOASSAY FROM AIR AND FITS OF COWORKER BIOASSAY

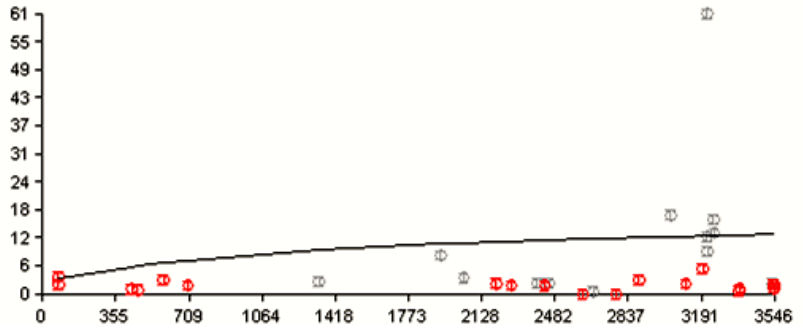
This set of graphs shows fitting of coworker bioassay data to one chronic inhalation intake. These data fits were not used to assign intakes.

For Havens Laboratory it can be seen that the incident data cause the overprediction of the uranium urinalysis results for the early years.

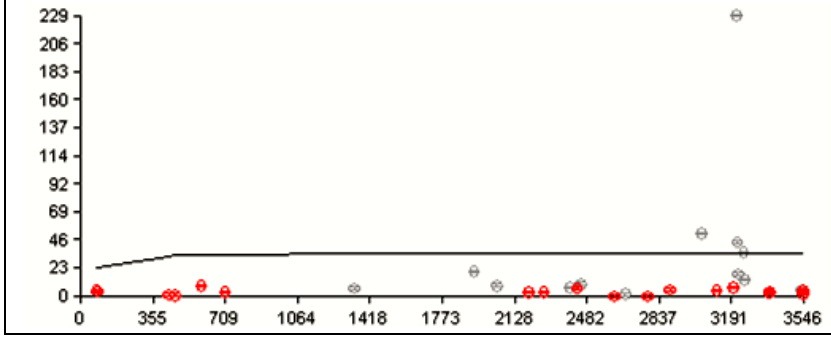
Havens Laboratory, type M, GM. Intake rate 174.3 pCi/d.



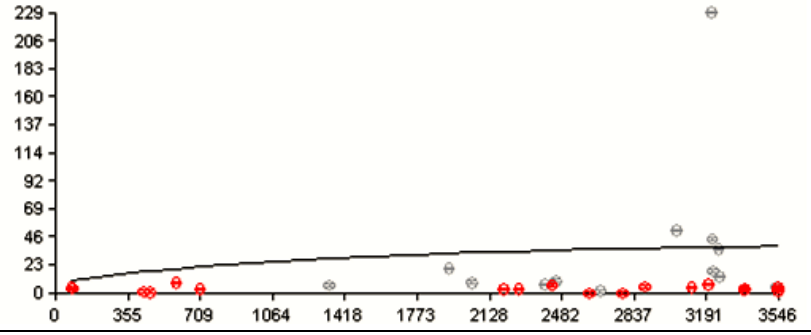
Havens Laboratory, type S, GM. Intake rate 2,390 pCi/d.



Havens Laboratory, type M, 84th. Intake rate 514.0 pCi/d.

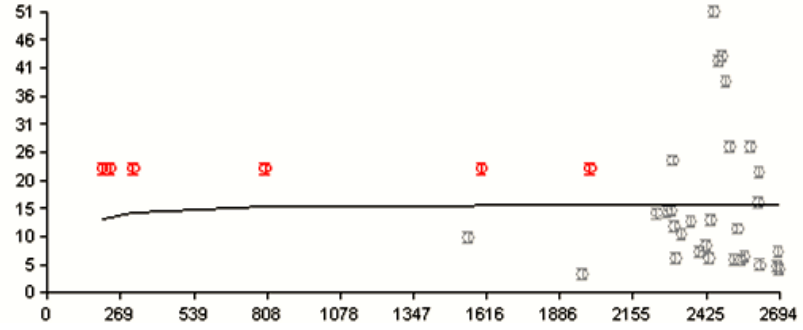


Havens Laboratory, type S, 84th. Intake rate 7,063 pCi/d.

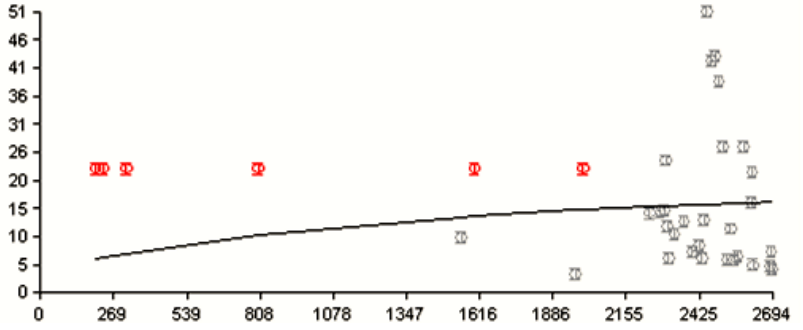


For Adrian Plant, it can be seen that the elevated results in later years cause a slight overprediction in the majority of uranium urinalysis results.

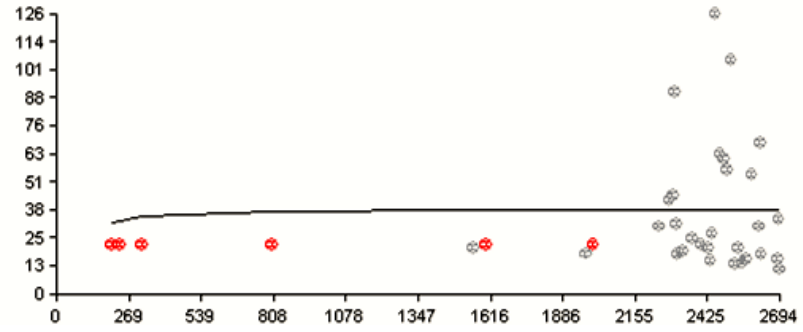
Adrian Plant, type M, GM. Intake rate 235.9 pCi/d.



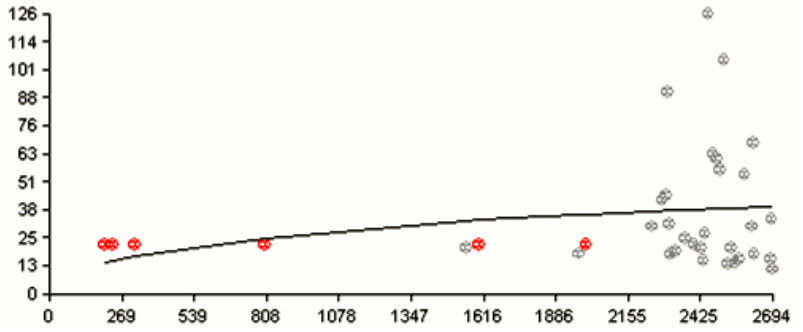
Adrian Plant, type S, GM. Intake rate 3,223 pCi/d.



Adrian Plant, type M, 84th. Intake rate 564.8 pCi/d.



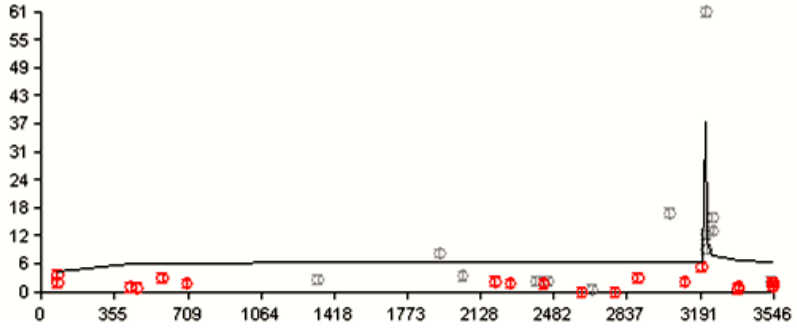
Adrian Plant, type S, 84th. Intake rate 7,718 pCi/d.



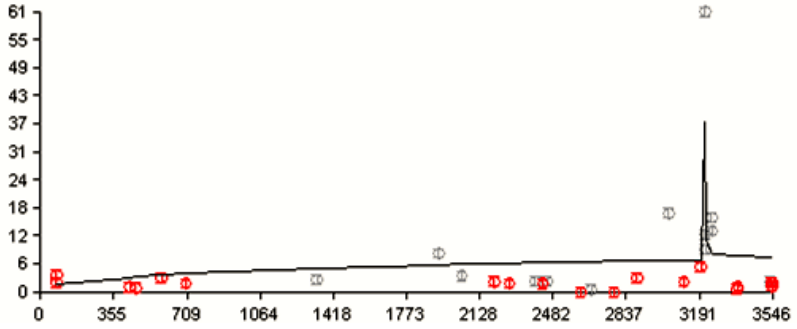
ATTACHMENT A
GRAPHS SHOWING PREDICTED BIOASSAY FROM AIR AND FITS OF COWORKER BIOASSAY

Graphs showing fitting of coworker bioassay data with two inhalation intakes. The first listed intake rate is for the period June 26, 1952, to August 27, 1962. The second listed intake rate is for the period April 15 to 21, 1961.

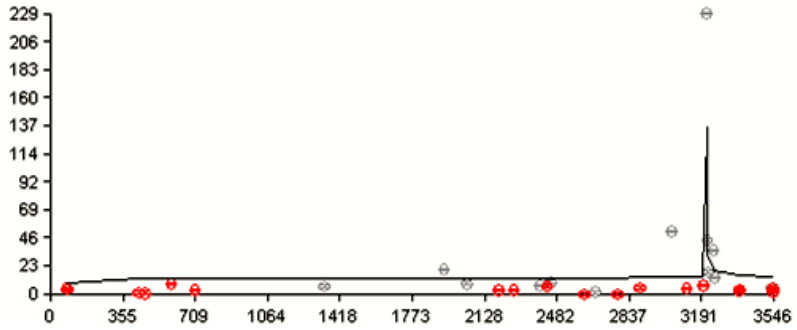
Havens Lab, type M, GM. Intake rates 95.88 and 1,134 pCi/d.



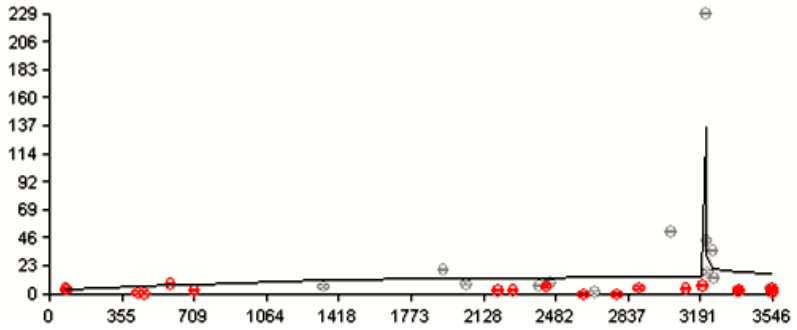
Havens Lab, type S, GM. Intake rates 1,316 and 36,170 pCi/d.



Havens Lab, type M, 84th. Intake rates 201.5 and 4,519 pCi/d.



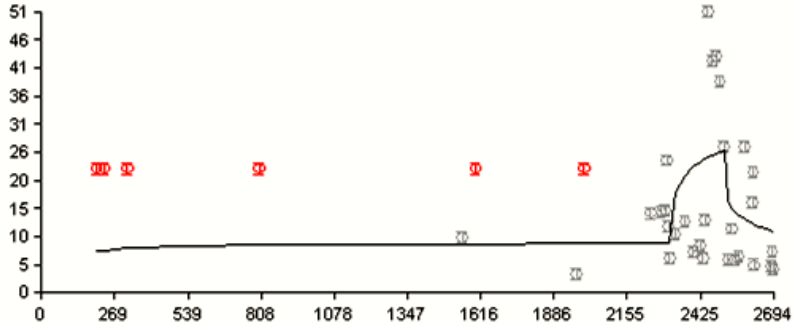
Havens Lab, type S, 84th. Intake rates 2,729 and 146,000 pCi/d.



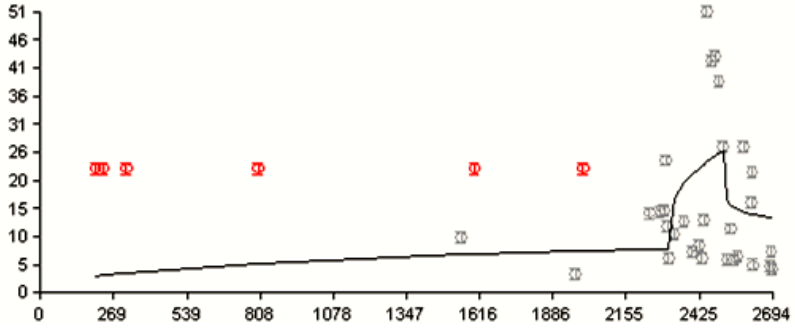
ATTACHMENT A
GRAPHS SHOWING PREDICTED BIOASSAY FROM AIR AND FITS OF COWORKER BIOASSAY

Graphs showing fitting of coworker bioassay data with two inhalation intakes. The first listed intake rate is for the period May 24, 1954, to December 31, 1962. The second listed intake rate is for the period October 1 to April 11, 1961.

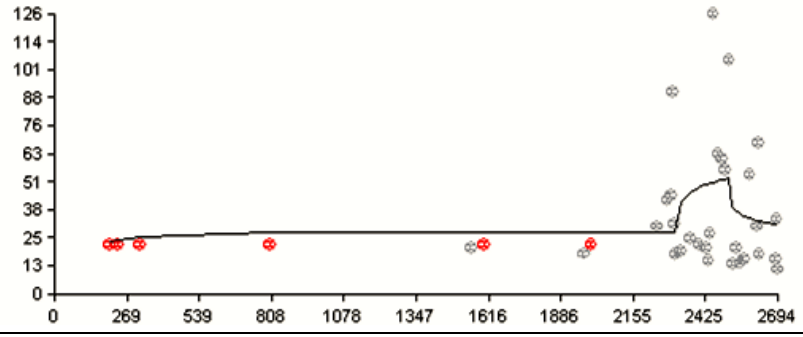
Adrian Plant, type M, GM. Intake rates 131.7 and 303.4 pCi/d.



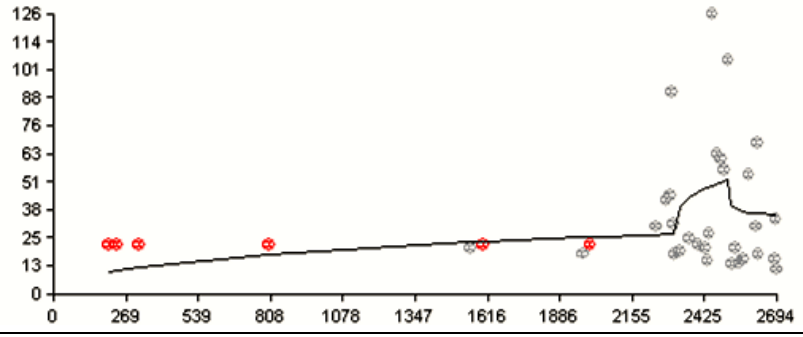
Adrian Plant, type S, GM. Intake rates 1,617 and 9,791 pCi/d.



Adrian Plant, type M, 84th. Intake rates 418.0 and 427.7 pCi/d.



Adrian Plant, type S, 84th. Intake rates 5,540 and 13,260 pCi/d.

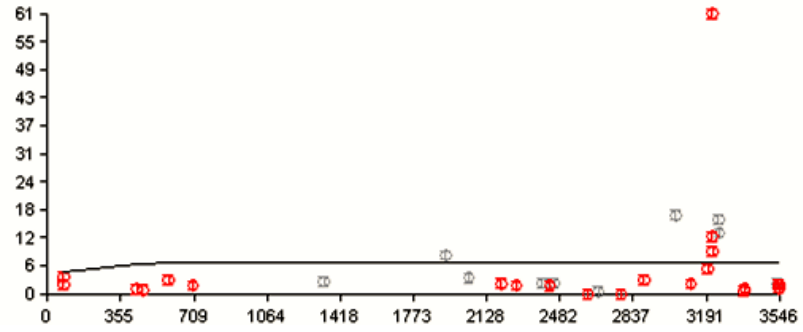


ATTACHMENT A
GRAPHS SHOWING PREDICTED BIOASSAY FROM AIR AND FITS OF COWORKER BIOASSAY

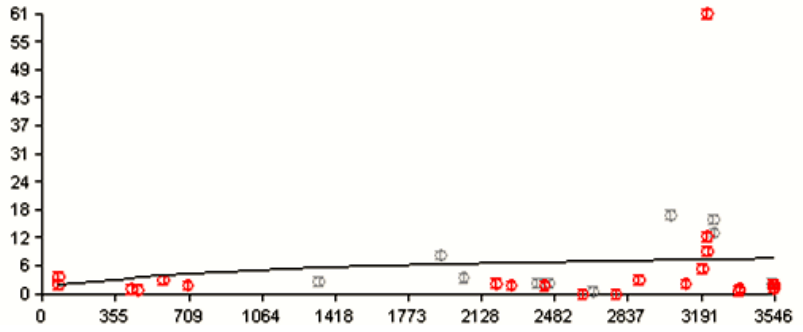
The following graphs show the fitting of the bioassay data when data that seems to be associated with an incident are excluded from the analyses.

For Havens Laboratory additional data from April 22 to 24, 1961 were excluded from the analysis.

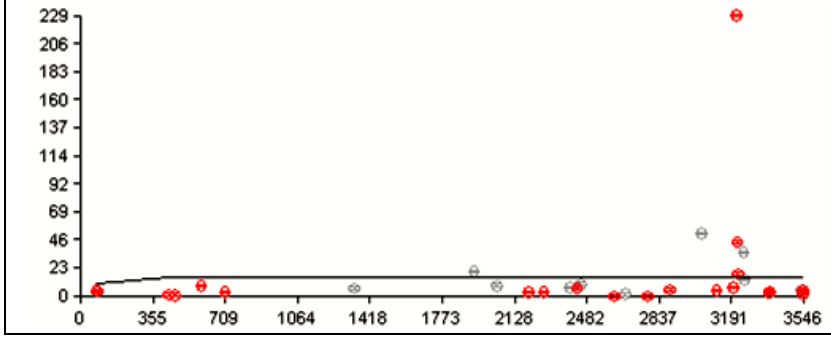
Havens Laboratory, type M, GM. Intake rate 103.3 pCi/d.



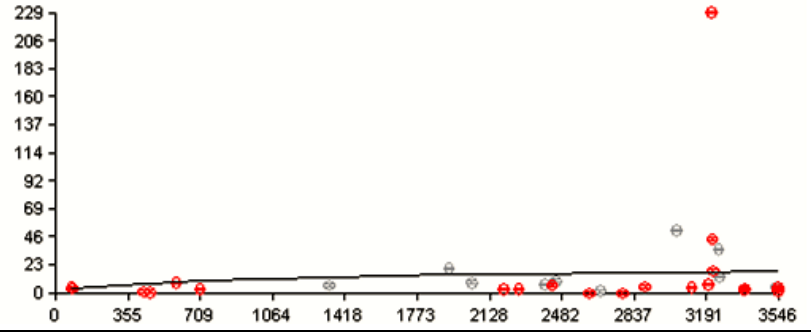
Havens Laboratory, type S, GM. Intake rate 1,430 pCi/d.



Havens Laboratory, type M, 84th. Intake rate 236.6 pCi/d.

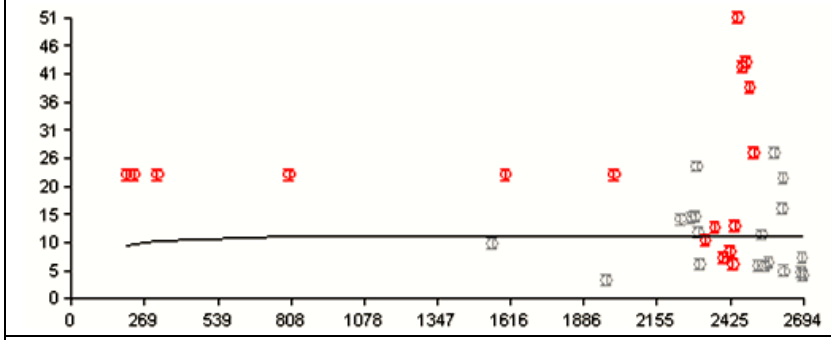


Havens Laboratory, type S, 84th. Intake rate 3,259 pCi/d.

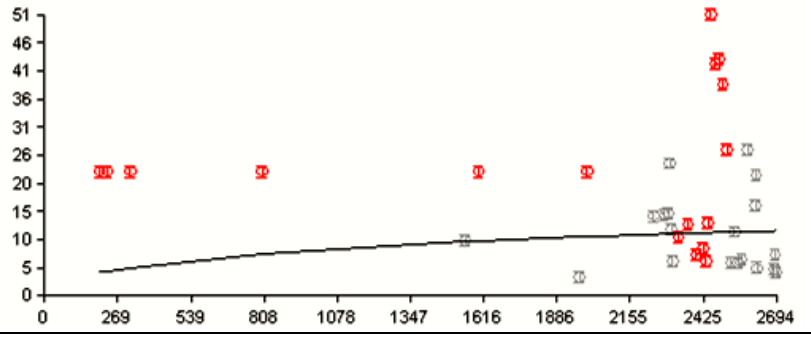


For Adrian Plant, additional data from October 14, 1960, through April 10, 1961, were excluded from the analysis.

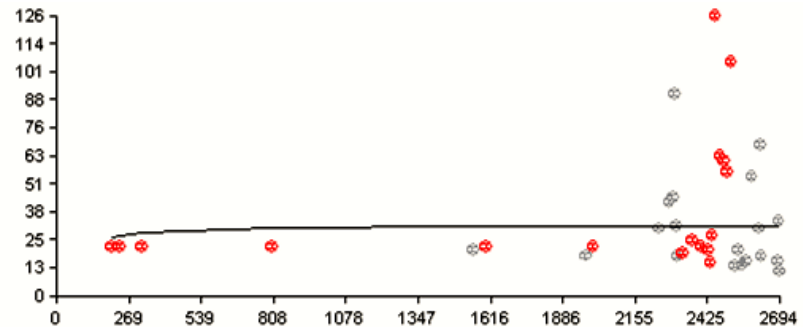
Adrian Plant, type M, GM. Intake rate 169.0 pCi/d.



Adrian Plant, type S, GM. Intake rate 2,307 pCi/d.



Adrian Plant, type M, 84th. Intake rate 466.3 pCi/d.



Adrian Plant, type S, 84th. Intake rate 6,367 pCi/d.