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PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
08/13/2004	00-A	New document to establish the technical basis for the development of a radiation exposure matrix for Bridgeport Brass Company: Havens Laboratory and Adrian Plant. Initiated by Cindy W. Bloom.
12/31/2004	00-B	Modified based on ORAUT comments and new information. Housatonic processed U and Th. Adrian residual radioactivity updated. Initiated by Cindy W. Bloom.
05/06/2005	00-C	Modified based on OCAS comments and to correct errors. Modified and corrected thorium numbers, analyzed coworker bioassay data, and analyzed coworker film badge data. Initiated by Robert Vogel and Cindy W. Bloom.
05/09/2005	00-D	Modified coworker intake approach to be more consistent with the bioassay data and fairer in assigning intakes for certain periods, updated internal and external dose-related tables, edited language/format, added graphs of bioassay data showing fitting of intakes. Initiated by Cindy W. Bloom.
07/08/2005	00-E	Adjusted intake numbers to 95th percentiles as requested by OCAS (Table 3-9 is modified) and added constant dose distribution assumption. Corrected wording in first column of Table 3-9. Provided additional analyses of film badge data, annual doses and residual nonpenetrating doses are adjusted. Initiated by Cindy W. Bloom.
09/06/2005	00-F	Modified external coworker doses to 95th percentile doses using Crystal Ball. Added clarifying words to the internal section at the request of Bernie Olsen. Revised Section 1.0 was added. Initiated by Cindy W. Bloom.
09/07/2005	00-G	Table numbering was modified, and the List of Tables was updated. Some of references to tables in the text were corrected. The use of air sample results was clarified to indicate that this only was used for the earliest period at Havens. Initiated by Cindy W. Bloom.
09/15/2005	00	First approved issue. Training required: As determined by the Task Manager. Initiated by Cindy W. Bloom.

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Acronyms and Abbreviations

AEC U.S. Atomic Energy Commission

BZ breathing zone

cm centimeter

d day
DOE U.S. Department of Energy
dpm disintegrations per minute

ft foot

GA general area
GM geometric mean
GSD geometric standard deviation

HASL Health and Safety Laboratory
hr hour

in. inch

keV kilovolt-electron, 1,000 electron volts
kg kilogram

L liter
LOD limit of detection

m meter
MAC maximum allowable concentration
MDA minimum detectable activity
mg milligram
mm millimeter
mR milliroentgen
mrad millirad
mrem millirem

NIOSH National Institute for Occupational Safety and Health

pCi picocurie
psi pounds per square inch

s second

U.S.C. United States Code

yr year

α alpha particle
γ gamma
µCi microcurie
µg microgram

1.0 INTRODUCTION

Technical Basis Documents and Site Profile Documents are general working documents that provide guidance concerning 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 the National Institute for Occupational Safety and Health (NIOSH) 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" (AWE facility) or a "Department of Energy facility" as defined in the Energy Employees Occupational Illness Compensation Program Act of 2000 [EEOICPA; 42 U.S.C. Sections 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 contamination period.

Employment at an AWE facility is categorized as either (1) during the 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 outside of the period in which weapons-related production occurred). For contract period employment, all radiation exposures must be included in dose reconstructions. For residual contamination period employment, only the radiation exposures defined in 42 U.S.C. § 7384n(c)(4) (*i.e.,* radiation doses received from DOE/AEC-related work) must be included in dose reconstructions. This TBD covers only exposures resulting from nuclear weapons-related work. Exposures resulting from non-weapons related work, if applicable, will be covered elsewhere.

2.0 SITE DESCRIPTION AND OPERATIONAL HISTORY

This document provides an exposure matrix for two Bridgeport Brass Company sites: Havens Laboratory (including the Housatonic Pilot Plant) and the Adrian Plant. The sites are geographically separate facilities but the operations were similar. Havens Laboratory in Bridgeport, Connecticut was primarily involved 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 also was involved in uranium extrusion research and development but had a higher production capacity. Both sites also processed thorium.

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 26, 1952, which was the period between experimental activities and the effective date of the U.S. Atomic Energy Commission (AEC) contract. Following decontamination in August 1962, the Havens Laboratory was sold and converted to a school. No residual radioactive contamination period is assumed for Havens Lab.

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.

Bridgeport Brass 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 according to current maps. An inspection report states that the Pilot Plant was also located at 30 Grand Street (Cavanaugh c. 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 maintained at the Havens Laboratory and at the Housatonic Building (Dowling 1955b). Current maps indicate Housatonic Avenue intersects with Grand Street, but is physically separated from the Havens Laboratory by a body of water. Grant Avenue was not located 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 rods processed 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 acceptable concentration (MAC) value (Klevin 1951). A MAC was defined as 70 α-dpm/m^3. The sample was reported as "128 γ/m^3," [the symbol, γ, was shorthand used by the AEC for μg]. General 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. 12). There are no other references to work involving uranium or other radioactive materials until the beginning of the AEC-Bridgeport Brass contract 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, 1950, 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* (AEC 1952)*.*

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's 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." The Havens Laboratory performed metallography and X-ray crystallography examinations on uranium and thorium samples from the pilot plant (Dowling 1955b).

An inspection report (Cavanaugh c. 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-ton 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 taken on February 20, 1962, 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.

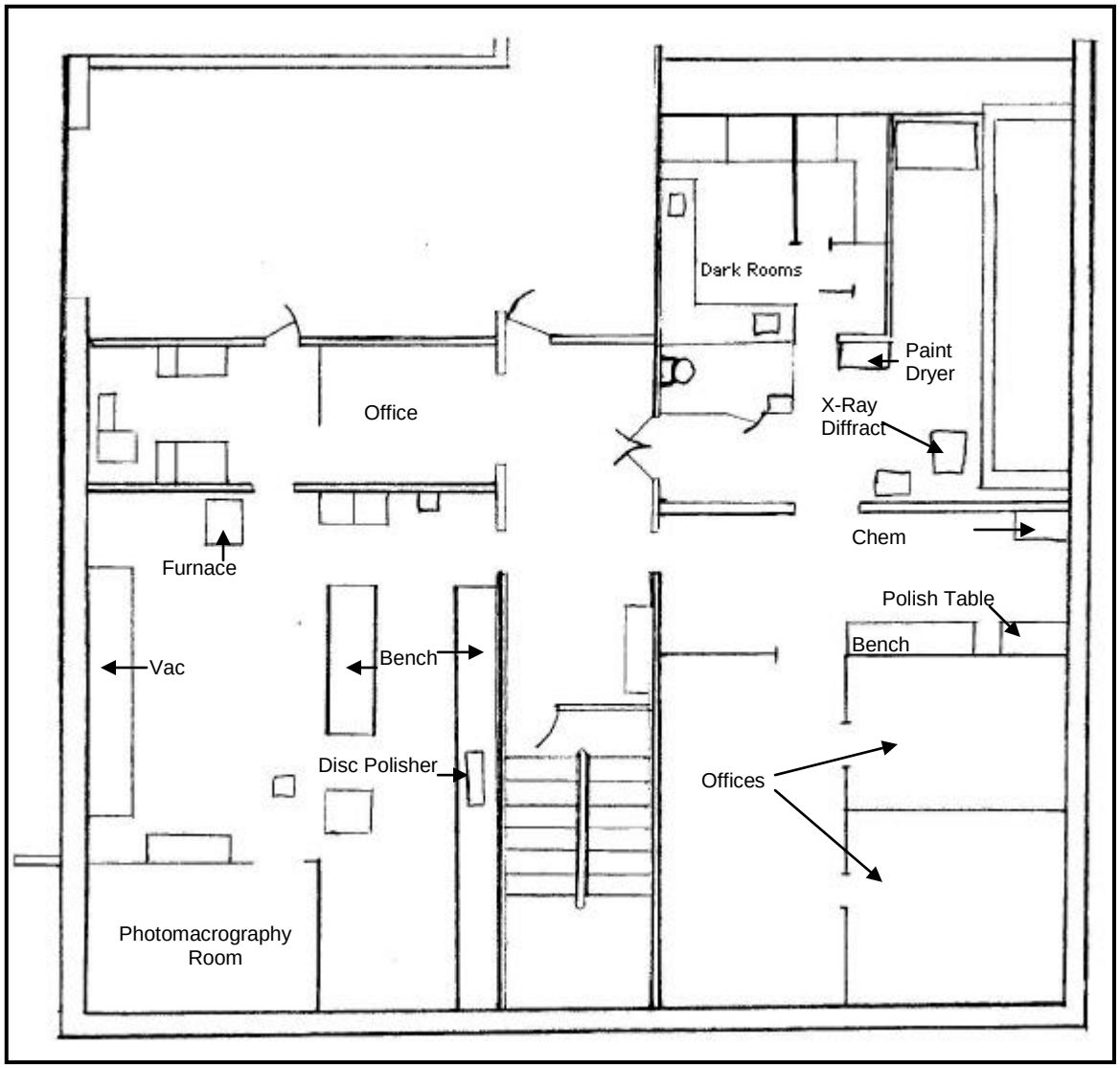

Figure 2-1. Laboratory area at Havens Laboratory.

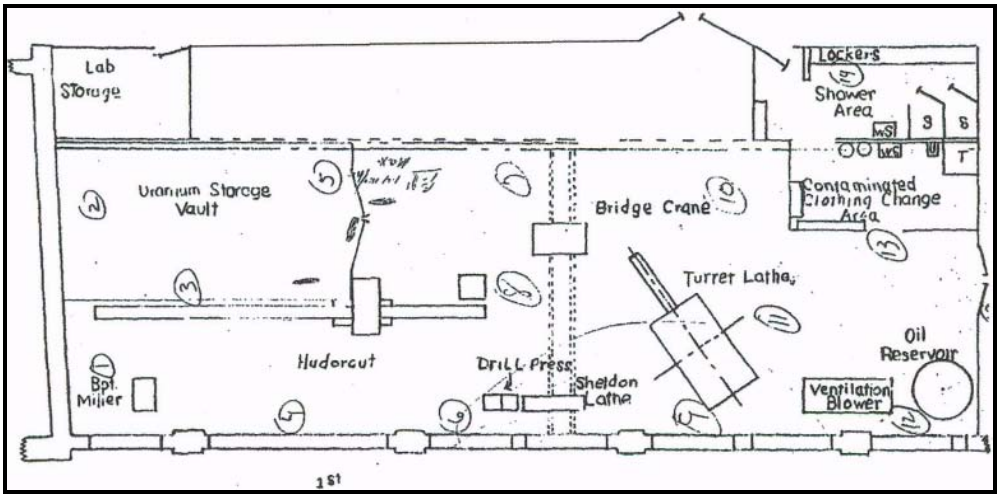

Figure 2-2. First floor, main building, Havens Laboratory.

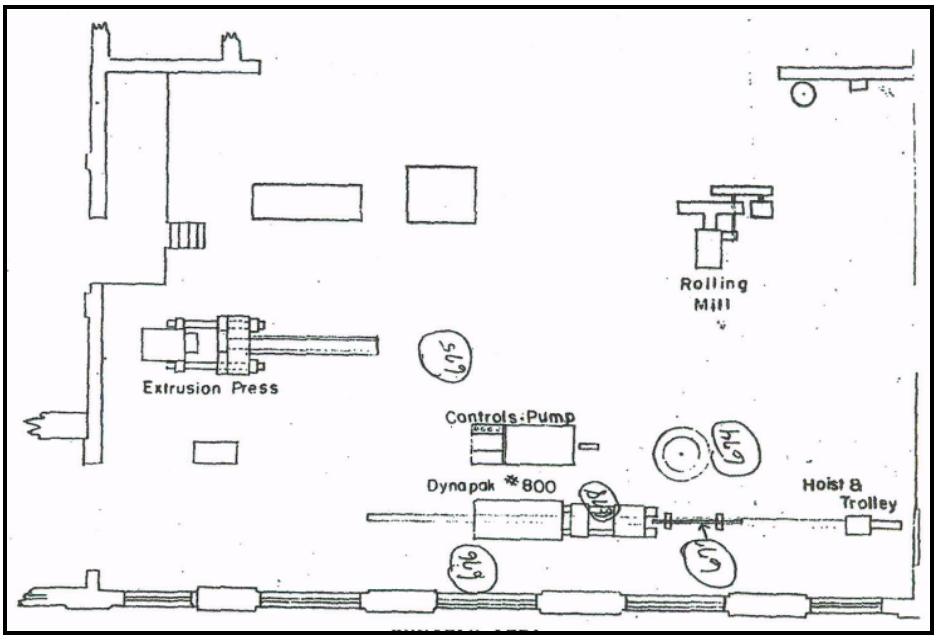

Figure 2-3. Dynapak Area, Havens Laboratory.

A Bridgeport Brass monthly report from February or March of 1954 provides details of some of the work at Havens Laboratory (Bridgeport Brass 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 both 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. Following 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.

Bridgeport Brass (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 (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 Lab. A designation of Station MBB also referred to Bridgeport Brass (Dowling 1955b).

Source and Special Nuclear Materials Accountability Statements (Dowling 1955b) 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 respectively received 190 and 1,570 kg of thorium, which is less than 5% of the uranium source term by

mass. To simplify calculations for both Havens Lab and Adrian Plant and to account for uncertainty in the relative masses of handled uranium and thorium, this analysis assumed that the mass of thorium processed was 10% of the mass of uranium processed.

There is mention of X-ray crystallography work in the AEC contract to inspect metal samples, but no information about the X-ray machine design or safety precautions 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.)

RMI (Bean 1967), 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, CT.

In 1962, the Havens Laboratory AEC operation was moved to Seymour Specialty Wire, another Bridgeport site in Seymour, Connecticut (DOE 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. Radiation exposure from residual radioactivity at Adrian Plant is assumed to have occurred beginning January 1, 1963.

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.

Before May 25, 1954, when Bridgeport Brass took over the facility at Adrian, there had been limited AEC work done there by previous contractors (the facility was also known as Air Force Plant No. 60 and the Air Force Experimental Methods Plant). Subcontract No. 31-109-38-313 between Gerity-Michigan Manufacturing Corporation and Argonne National Laboratory was signed on December 8, 1950, but was effective before then on July 25, 1950 (Wallo 1985). This was reportedly a services contract and was for extrusion work on an as-required basis. One memorandum suggests the contract may have been for extruding aluminum alloys. The contract terminated on March 15, 1951 (Wallo 1985). Negotiations with a new contractor (Reynolds Company) began, but no contractual agreement was reached. Mack Industries operated the plant under a maintenance agreement for the U.S. Air Force before Bridgeport Brass leased the facility. The DOE Office of Worker Advocacy website listed Gerity as a "Beryllium Vendor" and notes that Gerity began work in 1949 for the AEC (Vogel 2004). In addition, Reynolds Metals Company and Mack Industries were not listed as covered facilities. Therefore, it is assumed that no AEC radiological work occurred at the site before the AEC-Bridgeport Brass contract modification noted in the following paragraph.

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 at Havens Laboratory (AEC 1955a).

The contract also called for Adrian Plant to be able to produce extruded rods or tubes at a semi-production 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 the 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 Feed Materials Division [AEC], 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 1955a). 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 Operations 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 being 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 appeared to indicate that the primary focus of the AEC Health and Safety Laboratory (HASL) was uranium. A limited review of other DOE and Atomic Weapons Employer 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. 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 2004a). 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).

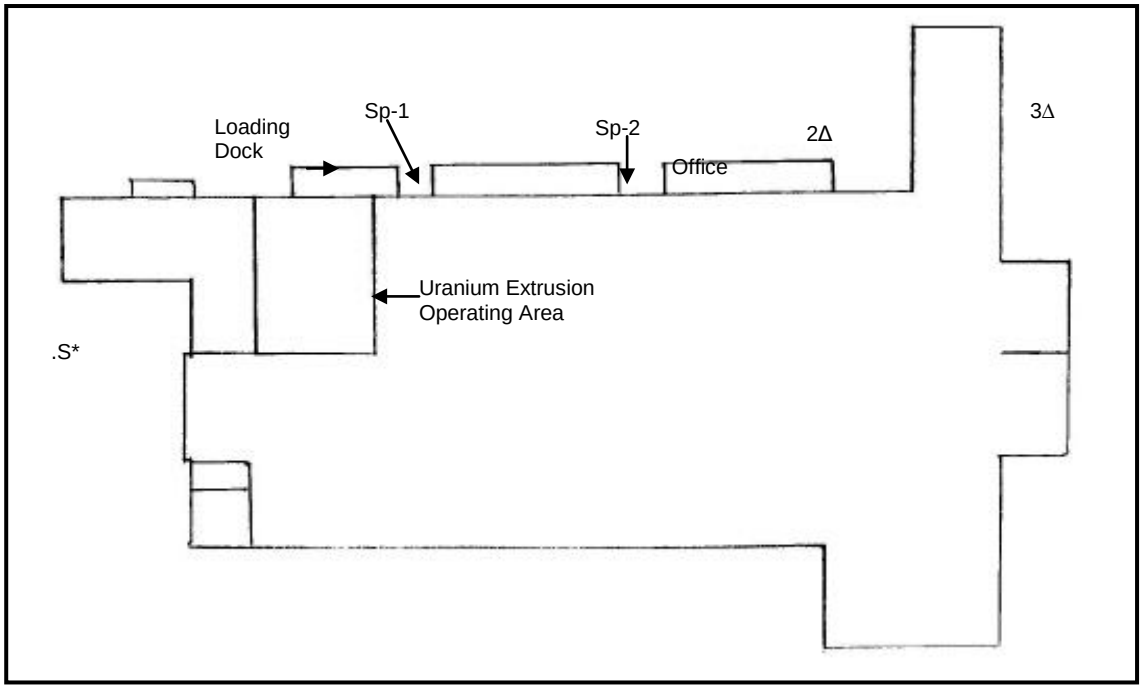

Figure 2-4. Locations of AEC activity at Adrian Plant.

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.

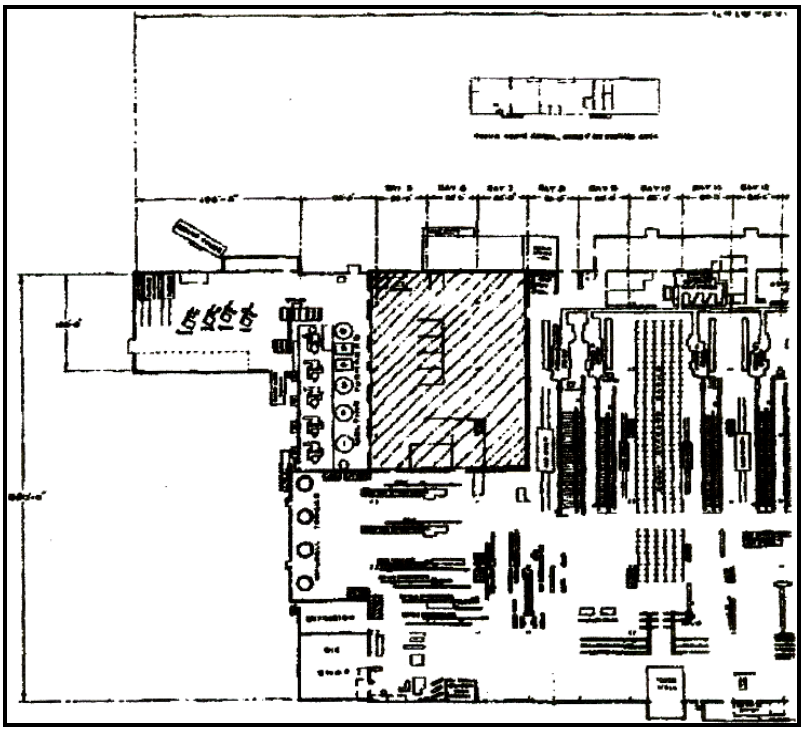

Figure 2-5. Area of Adrian Plant involved with AEC activity (area marked with diagonal lines).

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 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 two 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 one year of data available, enrichment is assumed to be the largest of the reported values, which was 2%.

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

RMI (Bean 1967) noted that before approximately June 1955, the operations were sporadic and no regular hourly press crew was assigned to the AEC work. 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.), another Bridgeport Brass Company relation in Ashtabula, Ohio. Decontamination and closeout 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 the November 29, 1961, for the period July 1, 1961 to June 30, 1962. In 1961, Bridgeport Brass' Ashtabula facility (also know as 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, date unknown). 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 at the Adrian Plant, and that exposure was due to residual radioactivity after that. Decontamination and survey activities were reported in 1976, 1985 and 1995.

3.0 ESTIMATION OF INTERNAL EXPOSURE

The primary source of internal exposure at Havens Laboratory and Adrian Plant was radioactive dust produced 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:

Main factors contributing to airborne radioactivity exposure:

- *fumes and smoke from extrusion press discharge*
- *oxidation of extruded rod surface to oxide which subsequently flaked off upon rod movement and became airborne*

- *transfer of rod from run-off table to cart due to dustiness created when loose oxide from rod surface is 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 open area near tool heating furnace*
- *cutting off of butt end of extruded rod and from deburring of the die block*
- *high general air (GA) concentration in vicinity of straighteners due to flaking off of loose oxide scale on surface of extruded rod upon stretching*
- *high plant general air (GA) due to high concentration at 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), indicating absorption type S (0.1% and 99.9% with clearance half-times on the order of 10 minutes and 7000 days, respectively). Other *in vitro* dissolution studies of compounds found at uranium facilities have shown that oxides of uranium exhibit moderate solubility (Eidson 1994; Heffernan et al. 2001) suggesting 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 produced 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 produced at Havens Lab 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 claimant-favorable to assume that uranium results reported in mass are 2% enriched. After 1952, recycled uranium may have been handled.

3.1.1 Uranium Bioassay

Individual uranium urinalysis results are available for some Havens Lab 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 performed by the University of Rochester and the AEC NYOO were similar to those performed 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 1958). 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 coworkers' uranium intakes.

The first available bioassay samples for Havens Lab were dated September 10,1952: urinalyses approached an annual frequency prior to 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 was 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, one day before the first rushed air sample on a Saturday, and continued through April 21, 1961, the day after the first bioassay. Additionally 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 was 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 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, and e raised to the line's y-intercept value was assumed to be the geometric mean and e raised to the slope value was assumed to be the geometric standard deviation (GSD) of the data. Results reported as zero were ranked, but used only indirectly in the fitting of the line. The 84^{th} percentile was estimated as the geometric mean multiplied by the GSD. The number of results for a given date ranged from 1 to 13 at Havens Lab and from 1 to 38 at Adrian Plant. The statistical fit parameter (R^2) results averaged ranged from 0.53 (three results) to 0.97 at Havens, and 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 mg/L by reference man's daily urine output (1.4 L/day) (ICRP 1975). Because Adrian used slightly enriched uranium, their results were multiplied by 1616 pCi/mg to obtain the a daily uranium concentration in pCi/day. The Havens uranium was assumed to be unenriched and a factor of 683 pCi/mg was used to convert to activity per day. Appendix A shows the bioassay results used in the intake analyses. Table 3-1 shows a summary of the estimated geometric median GM, 84^{th} percentile, and maximum uranium urinalyses used to derive intakes from the chronic inhalation intake regimes. Graphs showing the fits of these intake regimes are provided in Appendix 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 is usually assumed to be inhalation, unless there is information that indicates that other modes of intake are 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.

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

Havens Lab coworker uranium urinalysis results						Adrian Plant coworker uranium urinalysis results					
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**	
9/10/1952	2.07	4.83	0.002	0.005	<LOD	**12/14/1954**	<22.62	<22.62	<0.01	<0.01	<LOD
9/11/1952	3.82	3.82	0.004	0.004	<LOD	**1/12/1955**	<22.62	<22.62	<0.01	<0.01	<LOD
9/1/1953	1.10	1.38	0.001	0.001	<LOD	**4/6/1955**	<22.62	<22.62	<0.01	<0.01	<LOD
10/1/1953	0.96	0.96	0.001	0.001	<LOD	**8/3/1956**	<22.62	<22.62	<0.01	<0.01	<LOD
2/4/1954	3.13	8.55	0.003	0.009	<LOD	**8/22/1958**	10.00	21.28	0.004	0.009	
6/1/1954	1.94	3.35	0.002	0.004	<LOD	**10/10/1958**	<22.62	<22.62	<0.01	<0.01	<LOD
2/27/1956	2.81	6.59	0.003	0.007		**10/16/1959**	3.43	18.53	0.002	0.008	
10/7/1957	8.49	19.85	0.009	0.021		**11/13/1959**	<22.62	<22.62	<0.01	<0.01	<LOD
1/27/1958	3.60	8.77	0.004	0.009		**7/14/1960**	14.50	30.74	0.006	0.014	
7/3/1958	2.34	3.16	0.002	0.003	<LOD	**8/23/1960**	14.69	42.40	0.006	0.019	
9/15/1958	1.93	3.49	0.002	0.004	<LOD	**9/6/1960**	14.99	45.00	0.007	0.020	
1/19/1959	2.45	7.27	0.003	0.008		**9/12/1960**	24.11	91.22	0.011	0.040	
2/25/1959	1.84	6.42	0.002	0.007	<LOD	**9/19/1960**	12.13	31.67	0.005	0.014	
3/16/1959	2.41	10.10	0.003	0.011		**9/22/1960**	6.21	18.13	0.003	0.008	
8/28/1959	0.00	0.00	0.000	0.000	<LOD	**10/14/1960**	10.59	19.91	0.005	0.009	
10/19/1959	0.61	1.59	0.001	0.002		**11/18/1960**	12.84	25.38	0.006	0.011	
2/5/1960	0.00	0.00	0.000	0.000	<LOD	**12/19/1960**	7.45	22.56	0.003	0.010	
5/26/1960	3.14	4.99	0.003	0.005	<LOD	**1/13/1961**	8.63	21.21	0.004	0.009	
10/26/1960	17.26	51.38	0.018	0.054		**1/23/1961**	6.33	15.62	0.003	0.007	
1/9/1961	2.23	4.51	0.002	0.005	<LOD	**1/30/1961**	13.29	27.41	0.006	0.012	
4/1/1961	5.59	7.13	0.006	0.007	<LOD	**2/10/1961**	51.24	126.30	0.023	0.056	
4/20/1961	61.23	228.78	0.064	0.239		**2/28/1961**	42.27	63.51	0.019	0.028	
4/21/1961	12.59	44.29	0.013	0.046		**3/13/1961**	43.18	61.34	0.019	0.027	
4/24/1961	9.40	18.03	0.010	0.019		**3/27/1961**	38.45	56.46	0.017	0.025	
5/22/1961	16.29	35.44	0.017	0.037		**4/10/1961**	26.55	105.79	0.012	0.047	
5/26/1961	13.39	13.39	0.014	0.014		**4/24/1961**	6.02	13.96	0.003	0.006	
9/25/1961	0.72	2.68	0.001	0.003	<LOD	**5/8/1961**	11.61	21.31	0.005	0.009	
9/26/1961	1.10	3.55	0.001	0.004	<LOD	**5/22/1961**	5.96	14.43	0.003	0.006	
3/3/1962	2.32	5.20	0.002	0.005		**6/5/1961**	6.63	16.26	0.003	0.007	
3/9/1962	2.07	4.37	0.002	0.005	<LOD	**6/26/1961**	26.63	54.00	0.012	0.024	
3/12/1962	1.30	2.05	0.001	0.002	<LOD	**7/25/1961**	16.49	30.74	0.007	0.014	
						7/28/1961	21.87	68.56	0.010	0.030	
						7/31/1961	4.96	18.22	0.002	0.008	
						10/2/1961	4.72	16.09	0.002	0.007	
						10/6/1961	7.43	33.95	0.003	0.015	
						10/9/1961	4.24	11.41	0.002	0.005	

a. Multiply results in mg/L by 1.4 L/day to obtain results in mg/day. Havens results are multiplied by 683 pCi/mg to get pCi/day, and Adrian results are multiplied by 1616 to get pCi/day.

The intakes were determined with IMBA Expert™ OCAS-Edition, Version 3.2.20, 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 not used directly in the

fitting. The geometric standard deviations (GSDs) for the intakes were calculated by dividing the intake from the 84th percentile regime by the intake from geometric mean intake regime. Table 3-2 shows the inhalation intake distributions from the analyses of the Havens Lab 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.

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

Havens Coworker Intake Scenario Choices						
Scenario	**Start**	**End**	**Type M**		**Type S**	
			pCi/d	**GSD**	**pCi/d**	**GSD**
Chronic **or**	6/26/1952	8/27/1962	1.03E+02	2.29	1.43E+03	2.28
Chronic plus incident	6/26/1952	8/27/1962	9.59E+01	2.14	1.32E+03	2.16
	4/15/1961	4/21/1961	1.13E+03		3.62E+04	
Adrian Coworker Intake Scenario Choices						
Scenario	**Start**	**End**	**Type M**		**Type S**	
			pCi/d	**GSD**	**pCi/d**	**GSD**
One chronic **or**	5/24/1954	12/31/1962	1.69E+02	2.76	2.31E+03	2.76
Two Chronics	5/24/1954	12/31/1962	1.32E+02	2.96	1.62E+03	2.87
	10/1/1960	4/11/1961	3.03E+02		9.79E+03	

To estimate intakes for the purpose of dose reconstruction, the following approach has been prescribed: the geometric mean of the intake is adjusted to the 95th percentile using the larger of a GSD of 3 or the GSD pf the distribution itself, and this 95th percentile is assigned as a constant distribution in IREP. This document adjusts the intakes in Table 3-2 to 95th percentile intakes by multiplying the geometric means by a GSD of 3 raised to the 1.645 power. The resulting intakes are summarized in Table 3-9.

For Havens Lab 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 will 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 it was noted that the average of the ten 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 two-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 about 200 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 issued 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. This study was 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:

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

The air samples included radioactive particulate concentration measurements of breathing zones (BZs), general areas (GAs), 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 1955). 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. These recommendations were restated in the April 1956 report:

1. *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.*
2. *Provide dust catch pans underneath all roller conveyers to reduce the spread of contamination and maintenance time.*
3. *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."* (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:

> *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,* (AEC 1956)

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.* (AEC 1956)

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 exposures at both Adrian Plant and Havens Laboratory employees.

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 taken after salt was no longer used indicated that 8 of the 17 employees studied 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 geometric mean of the Table 3-4 daily weighted averages is 115 dpm/m^3, and the geometric standard deviation (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 geometric mean 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 average daily weighted concentration (there are nine concentrations) is 2.2.

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**	

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

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 are based on an upper estimate of air exposure (constant distribution), the metabolic models are 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, and the resulting values are summarized in Table 3-9.

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	11/8/1950	12/31/1950	Inhalation	U-natural	M, S	2.07E+02
	11/8/1950	12/31/1950	Ingestion	U-natural	(a)	4.32E+00
	6/26/1952	8/27/1962	Inhalation	U-natural	M,S	7.40E+02
	6/26/1952	8/27/1962	Ingestion	U-natural	(a)	1.54E+01
Adrian Plant	5/25/1954	12/31/1962	Inhalation	U-234	M, S	7.40E+02
	5/25/1954	12/31/1962	Ingestion	U-234	(a)	1.54E+01

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' workers' 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 a review of recycled uranium contaminants at Hanford and Fernald, is shown below 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 depleted uranium source term (pCi contaminant per pCi uranium).

Uranium	Pu-239	Np-237
1	0.00246	0.00182

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 located after this date. AEC records indicate that there was continuing interest in thorium after 1955. It is claimant favorable 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 located.

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 claimant favorable to assume natural uranium when determining the relative activity of thorium. To determine the relative activities of uranium to thorium, the specific activity Th-232 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.

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 SUMMARY AND ASSUMPTIONS

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, neptunium, plutonium and thorium are assumed to be independent.

At **Havens Laboratory**, intakes are assumed to be from naturally enriched 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
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 April 15 to 21, 1961. The second scenario accounts for the higher exposures during the period 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 October 14, 1960 to April 11, 1961. The second scenarios accounts for the higher exposures during the period October 14, 1960 to April 11, 1961, and should be used for unmonitored exposures that overlapped this period.

Table 3-8 can be used for both Havens Lab 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.

Table 3-8. Assumed activity fractions of other radionuclides relative to uranium (pCi other radionuclide per pCi uranium).

Uranium	Th-228	Th-232	Pu-239	Np-237
1	0.0161	0.0161	0.00246	0.00182

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

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

Havens Lab	Start	End	Intake mode	Intake type	Radio-nuclide	Type	Uranium type M pCi/d	Uranium type S pCi/d
Choose one of the two bordered scenarios. Choose the second scenario if work overlapped the period April 15-22, 1961. Choose intakes based on either type M or S uranium, not both.	11/8/1950	12/31/1950	Inhalation	Chronic	U-234	(a)	1.26E+03	1.26E+03
	11/8/1950	12/31/1950	Ingestion	Chronic	U-234	(b)	2.63E+01	2.63E+01
	6/26/1952	8/27/1962	Inhalation	Chronic	U-234	(a)	6.29E+02	8.71E+03
	6/26/1952	8/27/1962	Inhalation	Chronic	Th-228	S	1.01E+01	1.40E+02
	6/26/1952	8/27/1962	Inhalation	Chronic	Th-232	S	1.01E+01	1.40E+02
	6/26/1952	8/27/1962	Inhalation	Chronic	Pu-239	M, S	1.55E+00	2.14E+01
	6/26/1952	8/27/1962	Inhalation	Chronic	Np-237	M	1.15E+00	1.59E+01
	11/8/1950	12/31/1950	Inhalation	Chronic	U-234	(a)	1.26E+03	1.26E+03
	11/8/1950	12/31/1950	Ingestion	Chronic	U-234	(b)	2.63E+01	2.63E+01
	6/26/1952	8/27/1962	Inhalation	Chronic	U-234	(a)	5.84E+02	8.02E+03
	4/15/1961	4/21/1961	Inhalation	Chronic	U-234	(a)	6.91E+03	2.20E+05
	6/26/1952	8/27/1962	Inhalation	Chronic	Th-228	S	9.41E+00	1.29E+02
	4/15/1961	4/21/1961	Inhalation	Chronic	Th-228	S	1.11E+02	3.55E+03
	6/26/1952	8/27/1962	Inhalation	Chronic	Th-232	S	9.41E+00	1.29E+02
	4/15/1961	4/21/1961	Inhalation	Chronic	Th-232	S	1.11E+02	3.55E+03
	1/1/1953	8/27/1962	Inhalation	Chronic	Pu-239	M, S	1.44E+00	1.97E+01
	4/15/1961	4/21/1961	Inhalation	Chronic	Pu-239	M, S	1.70E+01	5.42E+02
	1/1/1953	8/27/1962	Inhalation	Chronic	Np-237	M	1.06E+00	1.46E+01
	4/15/1961	4/21/1961	Inhalation	Chronic	Np-237	M	1.26E+01	4.01E+02
Adrian Plant	**Start**	**End**	**Intake mode**	**Intake type**	**Radio-nuclide**	**Type**	**Uranium type M pCi/d**	**Uranium type S pCi/d**
Choose one of the two bordered scenarios. Choose the second scenario if work overlapped the period Oct. 1, 1960 to April 11, 1961. Choose intakes based on either type M or S uranium, not both.	5/25/1954	12/31/1962	Inhalation	Chronic	U-234	(a)	1.03E+03	1.41E+04
	5/25/1954	12/31/1962	Inhalation	Chronic	Th-228	S	1.66E+01	2.26E+02
	5/25/1954	12/31/1962	Inhalation	Chronic	Th-232	S	1.66E+01	2.26E+02
	5/25/1954	12/31/1962	Inhalation	Chronic	Pu-239	M, S	2.53E+00	3.46E+01
	5/25/1954	12/31/1962	Inhalation	Chronic	Np-237	M	1.87E+00	2.56E+01
	5/25/1954	12/31/1962	Inhalation	Chronic	U-234	(a)	8.03E+02	9.85E+03
	10/1/1960	4/11/1961	Inhalation	Chronic	U-234	(a)	1.85E+03	5.97E+04
	5/25/1954	12/31/1962	Inhalation	Chronic	Th-228	S	1.29E+01	1.59E+02
	10/1/1960	4/11/1961	Inhalation	Chronic	Th-228	S	2.98E+01	9.61E+02
	5/25/1954	12/31/1962	Inhalation	Chronic	Th-232	S	1.29E+01	1.59E+02
	10/1/1960	4/11/1961	Inhalation	Chronic	Th-232	S	2.98E+01	9.61E+02
	5/25/1954	12/31/1962	Inhalation	Chronic	Pu-239	M, S	1.97E+00	2.42E+01
	10/1/1960	4/11/1961	Inhalation	Chronic	Pu-239	M, S	4.55E+00	1.47E+02
	5/25/1954	12/31/1962	Inhalation	Chronic	Np-237	M	1.46E+00	1.79E+01
	10/1/1960	4/11/1961	Inhalation	Chronic	Np-237	M	3.36E+00	1.09E+02

a. 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.

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

4.0 ESTIMATION OF EXTERNAL EXPOSURE

Individual film badge results for Havens Laboratory and Adrian Plant are reported from late1958 through early 1961.

Because film badge data are available for about a two-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. This technical basis document also provides an estimate of external dose based on analysis of coworkers film badge dosimetry records for unmonitored workers or unmonitored periods.

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 emitted 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 will have a hardened photon spectrum, exposure to a thin layer of uranium on a surface will result 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 claimant favorable. 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 associated with photons of energies 30 keV or greater, and
- nonpenetrating assumed to be associated with photons of energies less than 30 keV or with electrons.

Adrian Plant initially put film badges (detecting beta, X-ray, and gamma radiations) on some "AEC" workers during a trial 26-week period that ran from about November 3, 1958 through May 3, 1959. It was noted, "A second 26-week period which includes all AEC personnel will follow." A review of the available bioassay records indicates that some workers included in the bioassay program were not included in this second period of film badge use. The badge wear-periods were nominally two 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 prior to 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 located for badges dated between about May 4, 1959 and August 23, 1959. No record indicated that monitoring occurred during the week between September 17 and 25, 1961. No results were found for the badges reportedly assigned September 25, 1961 through October 23, 1961. Results for badges reportedly worn from October 1 through October 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 Inc*. located in Cambridge, Massachusetts. No details on the dosimeter design or the film type are available currently. It is possible that two types of badges or badge holders were used based on a note regarding the January 8, 1961 badges indicating that 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, 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, sometimes they were reported to be the same.

Neutron doses were reported for periods ending May 1, 1960 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 14E6 neutrons/cm^2. In the early periods, results were reported as less than 0.8E6 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 0.3E6 neutrons/cm^2), and the maximum result was 1E6 neutrons/cm^2, which would equal about 100 mrem. Neutron dosimeters were calibrated with a polonium beryllium (PoBe) 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 indicates that although detection limits are reported as 10 mR or 10 mrad, other documents indicates a limit of detection (LOD) of 40 mrem for penetrating and shallow doses measured with film badge dosimeters in this era (ORAUT 2004b). To estimate doses for periods when dosimetry data are unavailable, the following approach was taken. Results for badges that were reported as assigned to an individual, or that were greater than or equal to the reporting limit of 10 mrem and were not reported as assigned to an area were used in the analysis. This accounts for the possibility that positive results on a badge might have been associated with a worker, even though the actual association between a specific worker and a badge is unknown. Badges reported as <10 mrem, and noted as "one week" (versus the normal two-week period) or lost on the assignment sheet, were excluded from the analysis. Contaminated badges for which there were reported results were used in the analysis. Badges with illegible results were not considered in the analysis. These criteria resulted in 12 to 37 results per monitoring period.

Because of the small number of results for some monitoring periods, the trial nature of the monitoring and periods with no results; the data were pooled and analyzed as a single set of penetrating and a single set of nonpenetrating radiation measurements.

The geometric means of the sets 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, and e raised to the line's y-intercept value was assumed to be the geometric mean and e raised to the slope value was assumed to be the geometric standard deviation (GSD) of the data. Results reported as zero or were ranked, but used only indirectly in the fitting of the line. The analysis used the value itself when a less-than-number was greater than 10. For each monitoring period that was fit, the 84th percentile was estimated as the geometric mean multiplied by the GSD. Because it was not clear if all workers who handled or worked near uranium were monitored during these trial periods, the 95th percentile doses are used to estimate coworker exposures. For the beta measurements at Adrian, the statistical fit parameter (R^2) was 0.94. The geometric mean beta dose per monitoring period was 31.2 mrad and the GSD was 3.83. .

The Adrian coworker photon dose was estimated in a similar manner. The R^2 fit parameter was 0.97. The geometric mean photon dose per monitoring period was 4.27 mrem and the GSD was 3.70.

The geometric means and GSDs were used to estimate the 50th and 95th percentiles for an annual penetrating and nonpenetrating dose distributions by combining the distributions for the 26 (2-week) dose periods using Crystal Ball and assuming correlated doses. For the first year, 16 2-week periods were combined. The GSDs for these annual distributions were less than two. The calculated 95th percentile annual doses are shown in Table 4-1. These doses are applied to unmonitored workers including the period of earlier years of operations, which are likely to have had similar exposure potentials.

For Havens Laboratory, about 26 months of film badge results from *controls for radiation Inc*. are available. These data extend from late 1958 through early 1961. A few gaps in monitoring periods were found. The report formats are the same as described for Adrian. No record of neutron badge use was found for Havens Lab, and neutron exposures are deemed insignificant for this site, also. At Havens Laboratory, some badges were used to measure ambient doses rather than personnel doses, and so were not used In the coworker dose analysis. Badges were used to measure the hospital x-ray room operator's dose; these results were included in the coworker dose analysis.

For the beta measurements at Havens, the statistical fit parameter (R^2) was 0.97. The geometric mean beta dose per monitoring period was 6.99 mrad and the GSD was 5.46.

For the Havens coworker photon dose, the R^2 fit parameter was 0.94. The geometric mean photon dose per monitoring period was 3.31 mrem and the GSD was 3.57. Again the geometric means and GSDs were used to estimate the 50th and 95th percentiles for an annual penetrating and nonpenetrating dose distributions by combining the distributions for the 26 (2-week) dose periods using Crystal Ball and assuming correlated doses. Dose periods consisting of 17, 14 and 4 weeks were combined for those less-than-one-year periods. The GSDs for these annual distributions were less than three, and all but one was less than two. The calculated 95th percentile annual doses are shown in Table 4-1. These doses are applied to unmonitored workers including the period of earlier years of operations, which are likely to have had similar exposure potentials.

4.1 OCCUPATIONALLY REQUIRED MEDICAL X-RAY

Information regarding whether or not occupationally required medical X-ray examinations were performed at Havens Laboratory and Adrian Plant is unavailable. AEC usually, but not always, required "preemployment" and periodic (annual) medical examinations of workers involved in the larger uranium processing programs. The term "preemployment" as used here, means prior to performing AEC-contracted radiological work. The typical AEC medical program included a preliminary chest x-ray examination with annual examinations thereafter. The type and frequency of x-ray examination should be based on current ORAU Team guidance. Organ doses can be obtained from the current revision of ORAUT-OTIB-0006, *Technical Information Bulletin: Dose Reconstruction from Occupationally Related Diagnostic X-Ray Procedures* (ORAUT 2003).

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 cobalt-60 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 non penetrating radiation. Table 4-1 summarizes annual external doses. The annual exposures can be used to estimate doses for unmonitored workers or unmonitored periods.

Table 4-1. External exposure summary.

Site	Exposure Category	Exposure type	Basis	Year	Annual exposure	IREP distribution
Haven Laboratory		Penetrating	Analysis of Havens film badge results	1950 1952 1953 1954 1955 1956 1957 1958 1959 1960 1961 1962	0.079 0.200 0.335 0.335 0.335 0.335 0.335 0.335 0.335 0.335 0.335 0.233	Constant
		Non-penetrating	Analysis of Havens film badge results	1950 1952 1953 1954 1955 1956 1957 1958 1959 1960 1961 1962	0.372 1.035 1.666 1.666 1.666 1.666 1.666 1.666 1.666 1.666 1.666 1.175	Constant
	Medical X-ray				See ORAUT-OTIB-0006, (ORAUT 2003)	
Adrian Plant		Penetrating	Analysis of Adrian film badge results	1954 1955 1956 1957 1958 1959 1960 1961 1962	0.306 0.452 0.452 0.452 0.452 0.452 0.452 0.452 0.452	Constant
		Non-penetrating	Analysis of Adrian film badge results	1954 1955 1956 1957 1958 1959 1960 1961 1962	2.369 3.558 3.558 3.558 3.558 3.558 3.558 3.558 3.558	Constant
	Medical X-ray				See ORAUT-OTIB-0006, (ORAUT 2003)	

5.0 ESTIMATION OF DOSE FROM RESIDUAL RADIOACTIVITY

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, and the figures show the locations of sampling for each area (Ruch 1962). The conclusion of the post-decontamination 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 (ORNL 1985). 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 1987). A letter (Fiore 1987) to the Superintendent of Schools for Bridgeport restated this conclusion.

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 Lab are not included.

Adrian Plant
In 1961, work was transferred from Adrian Plant to Reactive Metals, Inc. (also know as Extrusion Plant) in Ashtabula, Ohio. At this 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 closeout in 1962. In November 1961, Bridgeport Brass (Jefferson 1961) reported results of a contamination survey in the Adrian press area. The largest alpha contamination result in dpm/100 cm^2 was 23,460 on equipment, 13,260 dpm/100 cm^2 on the floor, 6,100 in the pits, and 4,080 on the walls. There was one beta/gamma measurement of 31 mR/h at 1 cm from some equipment and a spot 1 cm from the floor that was about 20 mR/h, but most beta/gamma measurements were well under 1 mR/h.

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 a subsequent decontamination effort in 1976, 866 kg of dust containing 3.9 kg of uranium were removed from roof supports.

In 1976, following an Energy Research and Development Agency news release, General Motors initiated a radiation survey of the plant which consisted of 1) air filter samples, 2) surface wipe tests, 3) alpha and beta-gamma monitoring, and 4) radioassay of dust and dirt samples. The methods of sampling are described in the radiation survey report (Hill 1977):

> *Surface Wipes: Whatman No. 1 filter papers (42-mm diameter) were used to wipe 100 cm^2 test areas of the plant for removable radioactivity. The wipe samples were evaluated for radioactivity by alpha counting in a gas flow proportional chamber.*
>
> *Alpha and Beta-Gamma Surveys: The plant floor was surveyed for total radioactivity by alpha and beta-gamma counting with portable instruments. The instruments (Eberline PRM5-3 AC-3-7 for alpha surveys, and Nuclear Chicago*

2650 for beta-gamma surveys) were calibrated with uranium and plutonium standards.

Dust Samples: Samples of dust and/or dirt were selected at random from various regions of the plant and evaluated for uranium content by gamma counting in a NaI (T1) scintillation well detector. Using uranium nitrate counting standards, the weight of uranium per gram of sample was determined.

Results and Discussions

Surface Wipes: The surface wipe samples obtained from various sections of the plant floor indicated that some radioactive material did exist in the portion of the plant where uranium was handled. The removable radioactivity on the wipe samples varied from 1 to 1300 dpm/100cm^2, the highest being 30 percent about the maximum permissible level for removable radioactive material.

Alpha and Beta-Gamma Surveys: Portable instruments were used to survey various locations within the plant for total radioactivity. Several of the surveys along the equipment foundations and in the transformer crib revealed radiation fields as high as 10 mR/hr at 1 cm.

Dust Samples: To evaluate specific areas more completely, dust and/or dirt samples were obtained and radioassayed for uranium content. The uranium concentration ranged from 2 to 241 milligrams of uranium per gram of sample (mg/g) obtained along the equipment foundations. Dust samples taken from the steel roof supports above the transformer crib contained a maximum of 33 mg/g. (Hill 1977)

Following the survey, 1,241 kg of dust and solid debris, and six stack duct packages weighing 938 kg were shipped to National Lead of Ohio in October of 1976 for disposal. There were approximately 8 kg of uranium in the shipped material.

Documentation reviewed indicates that there was residual contamination outside the listed operational period of 1954 to 1961 (specifically 1962 to 1976). The report on residual radioactivity states in Appendix A-2 that the period of potential residual contamination extends from 1954 to 1995 (NIOSH 2004b). This is partially due to the contamination in service pits beneath the extrusion units found in the 1976 survey (Hill 1977). As these service pits were inaccessible, the contamination there posed no risk unless the material in the pits was removed. In 1985, the site was designated for remediation under the Formerly Utilized Site Remediation Action Program and at least one drain line was removed. The maximum air concentration measured during two-week removal period in December 1985, was 2.9E-12 uCi/cm^3 (Hill and Schneider, 1986) Remediation of the service pits and removal of some drainage pipes took place in 1995, the maximum air concentration measured was 1.7E-12 uCi/cm^3 (TMA/Eberline 1995). Most measured air concentrations were much less than these were (1E-13 uCi/ml or less).

To estimate internal exposure from residual activity this analysis assumed that the median uranium exposure was associated with uniform contamination of the Adrian Plant to a level of 23,460 dpm/100 cm^2. This was the maximum alpha contamination level (fixed and total) measured in the 1961 survey of the Adrian Plant. Using a resuspension factor of 1E-6/m (NRC 2002b), results in an air concentration of 1E-12 uCi/ml, which is consistent with the higher 1976 air concentration measurement (33.2% of a maximum permissible concentration of 3E-12

uCi/ml) prior to decontamination (Hill and Glaza 1976). Although this underestimates some of the largest short term air concentrations, it is unlikely to underestimate total exposure. Multiplying the estimate air concentration by an air intake rate of 2,400 m^3 per work year results in a calculated uranium annual inhalation intake of 2540 pCi. Using the method described in Section 3.0, the calculated annual ingestion intake was 52.8 pCi. These intake values were used to estimate the daily Adrian residual contamination intake rates shown in Table 5-1. GSDs of 3 are assigned to account for uncertainty in the metabolic models.

To estimate external exposure to residual radioactivity after the end of AEC operations, this analysis assumed that workers were exposed to the maximum measured exposure at one meter, 0.036 mR/h penetrating radiation (ORNL 1982). The non-penetrating exposure rate was determined by assuming that 7.7, the ratio of non-penetrating to penetrating exposure rates for external exposures at Adrian during the operational exposure period, provided a reasonable estimate of the ratio of non-penetrating to penetrating exposure rate during the residual exposure period. The resulting non-penetrating exposure rate estimate was 0.278 mrad/h. The GSDs for external dose were assumed to be 3, based on the calculated GSDs for the operational period.

The estimated annual penetrating and non-penetrating external exposures to residual radioactivity from AEC operations at the site, listed in Table 5-1, were calculated by assuming that workers were exposed for 2,000 hours per year.

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 regarding residual exposures should be consistent with assumptions from the operational period.

Table 5-1. Annual internal and external exposure to residual radioactivity.

Internal	**Start**	**End**[b]	**Exposure**	**Absorption type**	**Intake (pCi/d)**	**IREP distribution**
U-234	1/1/1963	10/5/1976	Inhalation	M, S	6.66E-02	Lognormal GSD 3
	1/1/1963	10/5/1976	Ingestion	(a)	1.39E-03	Lognormal GSD 3
External	**Start**	**End**[b]	**Exposure**	**Basis**	**Exposure/y**	
	1/1/1963	10/5/1976	Penetrating	Survey Instrument	0.072 R	Lognormal GSD 3
	1/1/1963	10/5/1976	Non-Penetrating	Penetrating dose and ratio of operational estimated doses	0.556 rad	Lognormal GSD 3

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

b. No end date is set, because there is no evidence that the site is restricted or has been remediated.

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Appendix A

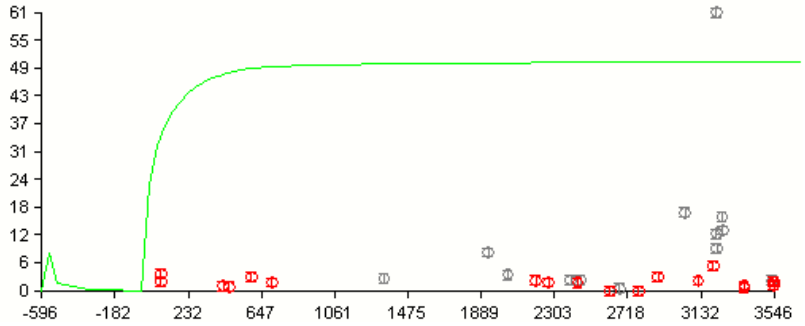
Graphs showing predicted bioassay from air, and fits of coworker bioassay.

Graphs showing the geometric means (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 pCi/day of uranium excreted in urine. For the Havens Laboratory graphs day zero is June 26, 1952 and day 3714 is August 27, 1962. For the Adrian Plant graphs, day zero is May 24, 1954 and day 3142 is December 31, 1962. Some graphs end on the last day of bioassay results rather than the last day of the intake period.

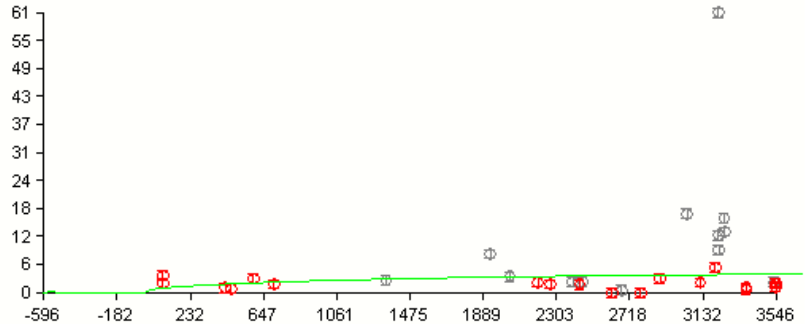
The following set of graphs showing predicted bioassay results from the estimated air intakes, superimposed on the geometric mean (GM), and 84th percentile bioassay results.

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.

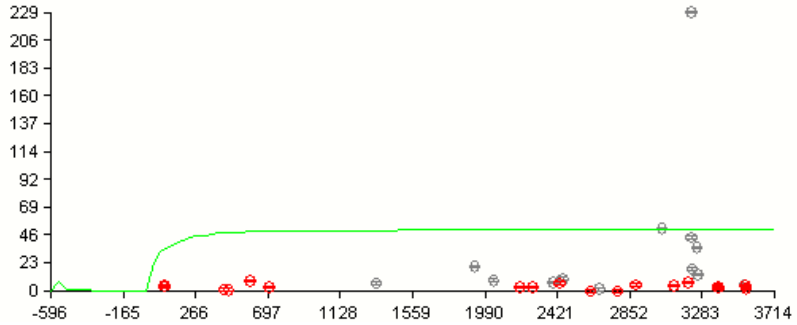
Havens Laboratory, type M, GM.



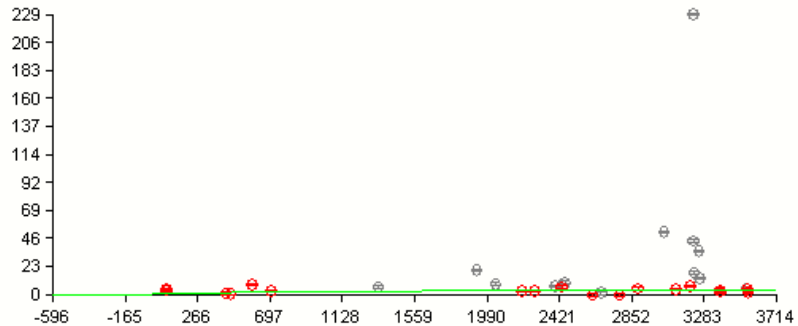
Havens Laboratory, type S, GM.



Havens Laboratory, type M, 84th.

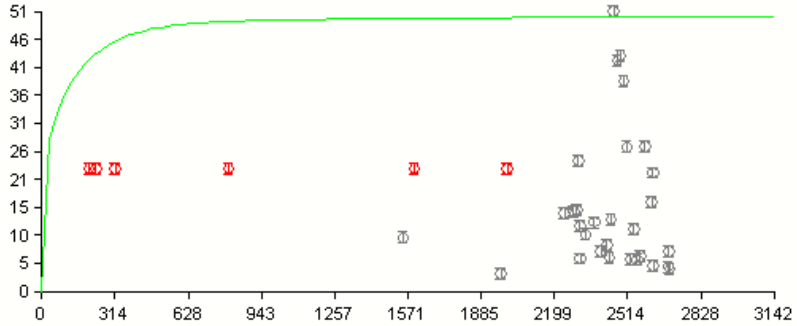


Havens Laboratory, type S, 84th.

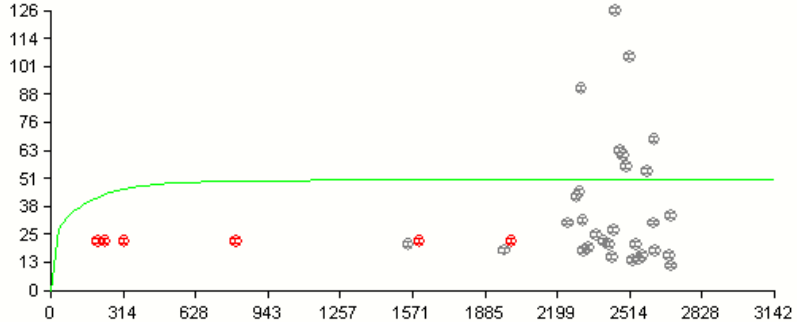


At Adrian Plant, the intake rates of 740 pCi/d inhalation and 15.4 pCi/d ingestions estimated from air samples and a type M assumption overestimate most of the GM data, and overestimate the early 84th percentile data. For a type S, assumption the air concentration determined intake rate is a low for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

Adrian Plant, type M, GM.



Adrian Plant, type M, 84th.



Adrian Plant, type S, GM.

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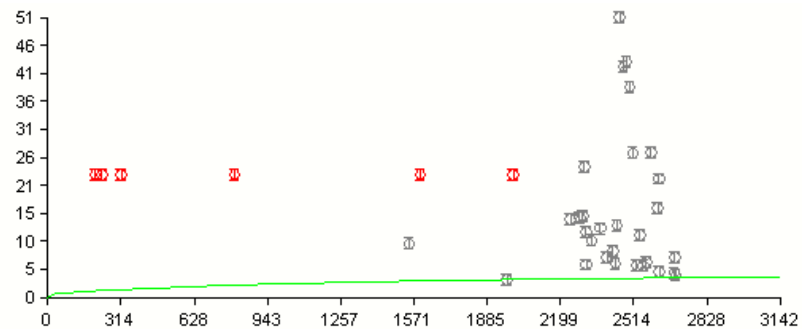
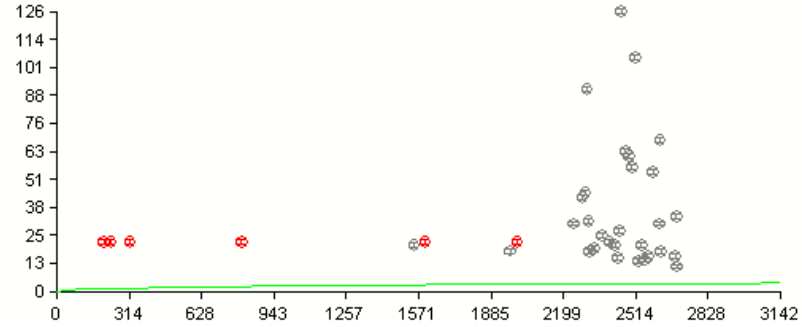


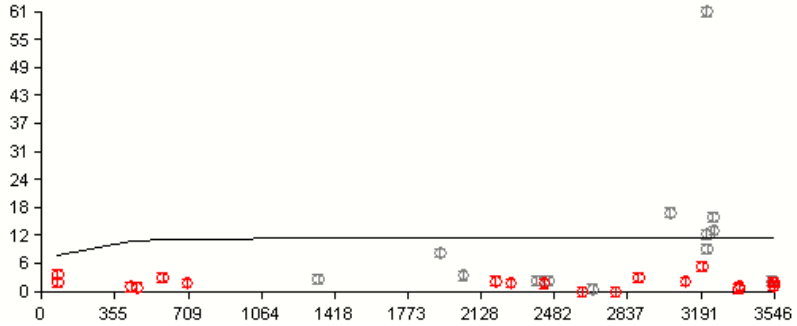
Adrian Plant, Type S, 84th.



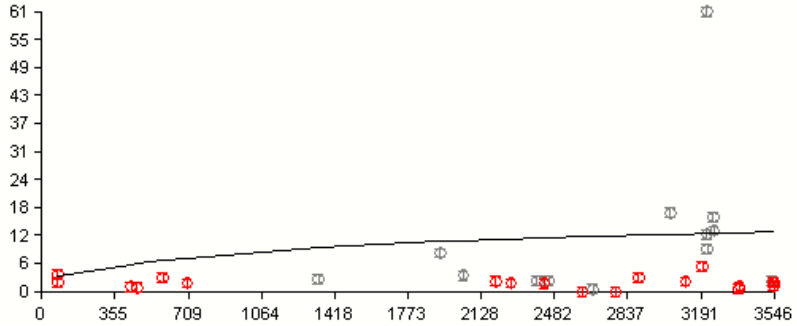
This set of graphs shows fitting of coworker bioassay data to **one chronic** inhalation intake. These data fits were not used to assign intakes.

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

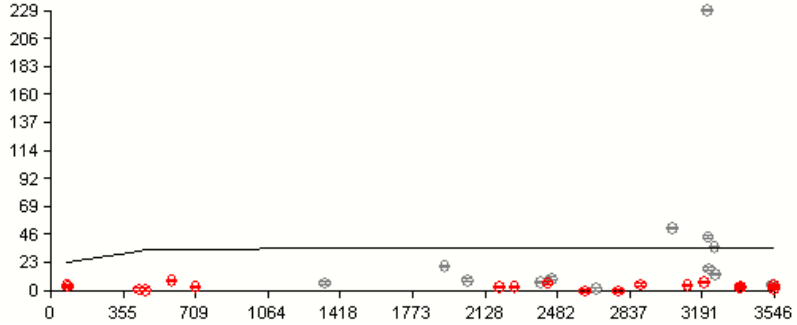
Havens Laboratory, type M, GM. Intake rate 174.3 pCi/d.



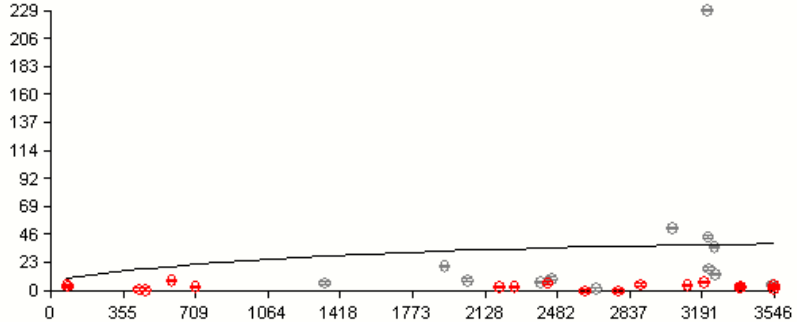
Havens Laboratory, type S, GM. Intake rate 2390 pCi/d.



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

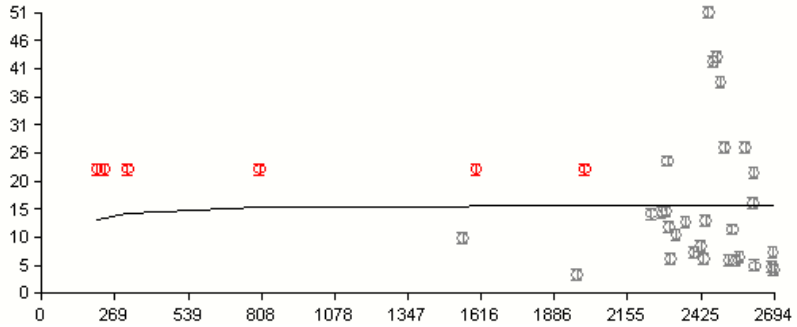


Havens Laboratory, type S, 84th. Intake rate 7063 pCi/d.

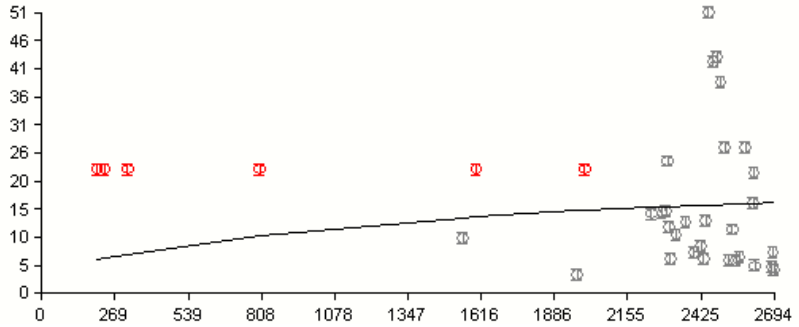


For Adrian Plant, it can be seen that the elevated results in later years cause a slight over-prediction in the majority of uranium urinalysis results.

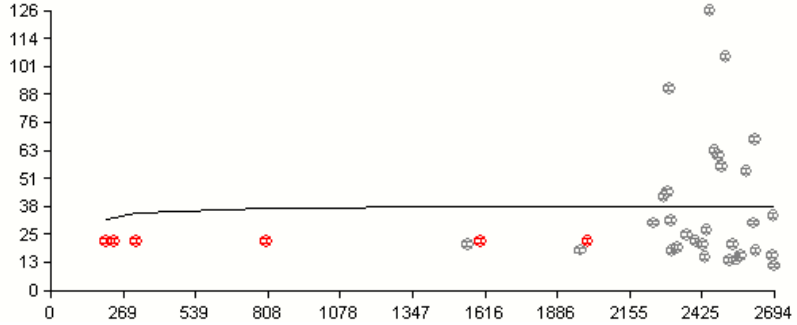
Adrian Plant, type M, GM. Intake rate 235.9 pCi/d.



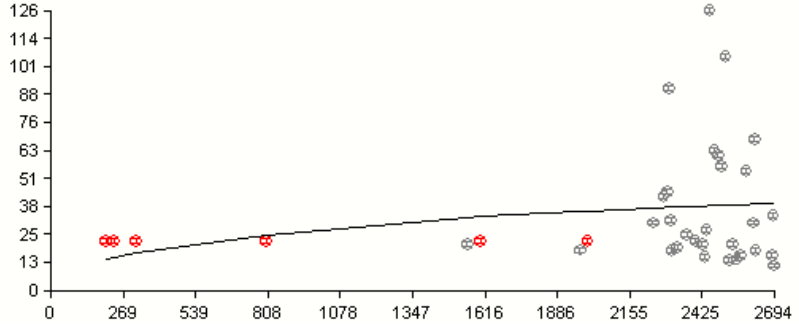
Adrian Plant, type S, GM. Intake rate 3223 pCi/d.



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

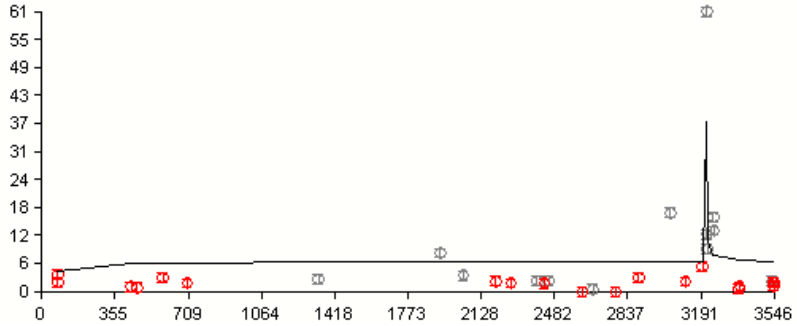


Adrian Plant, type S, 84th. Intake rate 7718 pCi/d.

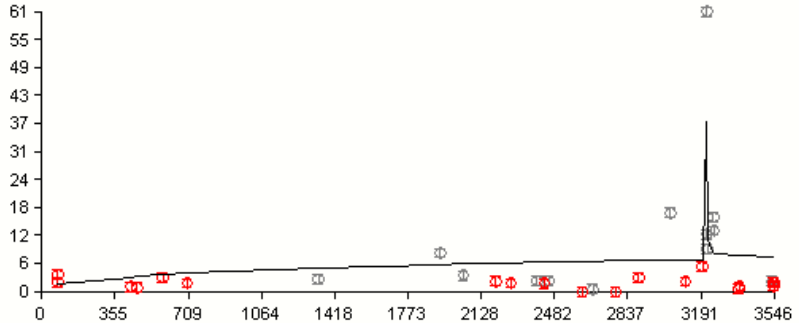


Graphs showing fitting of coworker bioassay data with two inhalation intakes. The first listed intake rate is for the period June 26, 1952 to August 27, 1962. The second listed intake rate is for the period April 15, 1961 to April 21, 1961

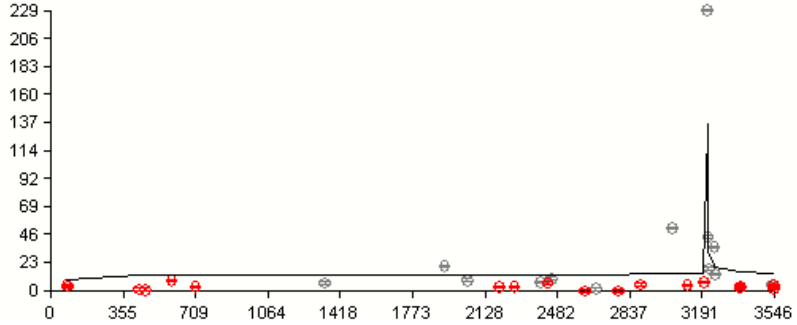
Havens Lab, type M, GM. Intake rates 95.88 and 1134 pCi/d.



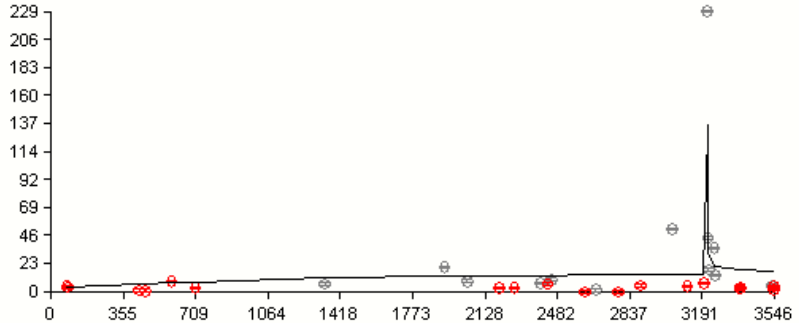
Havens Lab, type S, GM. Intake rates 1316 and 36,170 pCi/d.



Havens Lab, type M, 84th. Intake rates 201.5 and 4519 pCi/d.

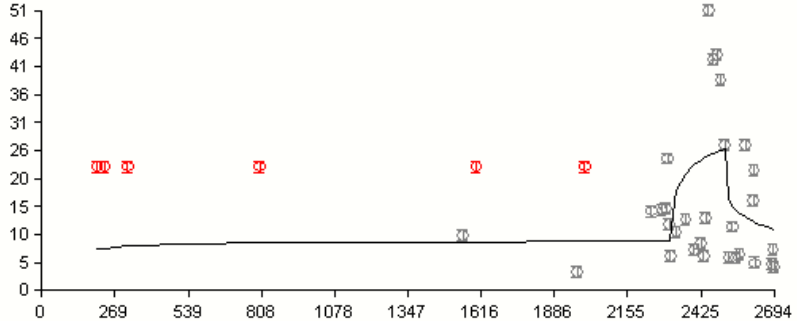


Havens Lab, type S, 84th. Intake rates 2729 and 146,000 pCi/d.

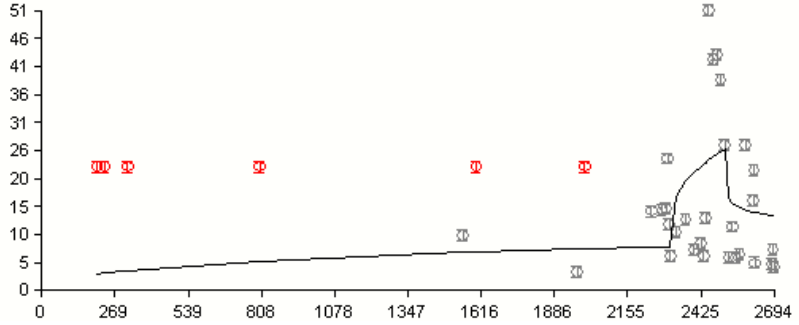


Graphs showing fitting of coworker bioassay data with two inhalation intakes. The first listed intake rate is for the period May 24, 1954 to December 31, 1962. The second listed intake rate is for the period October 1, 1961 to April 11, 1961.

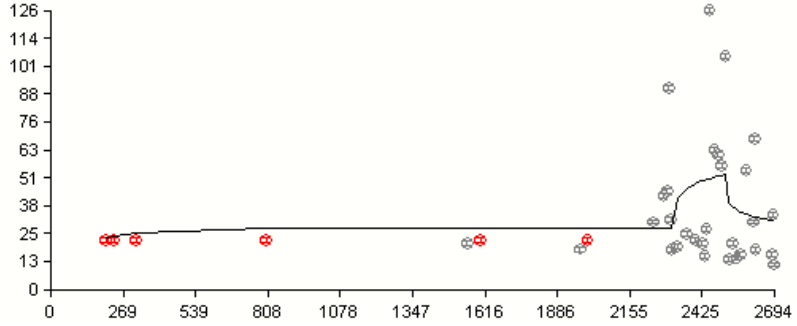
Adrian Plant, type M, GM. Intake rate 131.7 and 303.4 pCi/d.



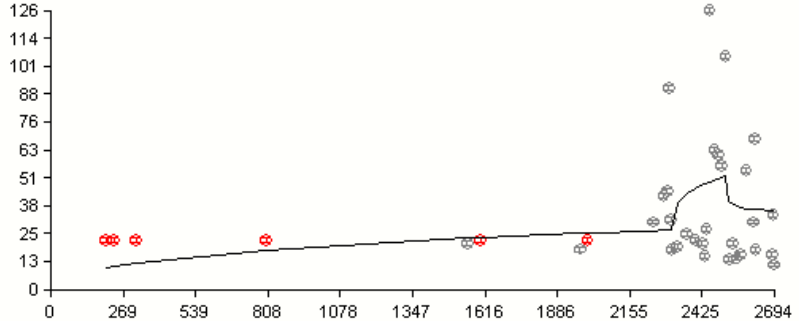
Adrian Plant, type S, GM. Intake rate 1617 and 9791 pCi/d.



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



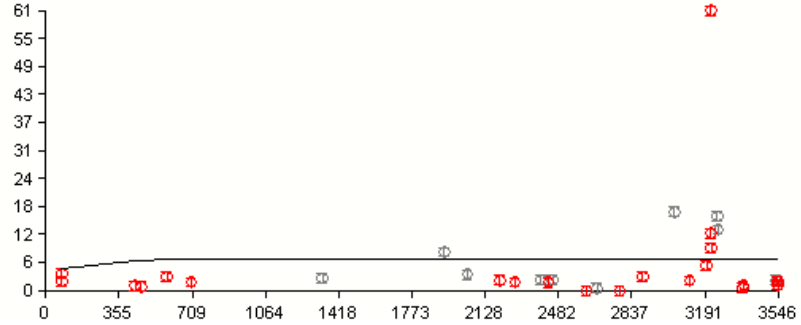
Adrian Plant, type S, 84th. Intake rate 5540 and 13,260 pCi/d.



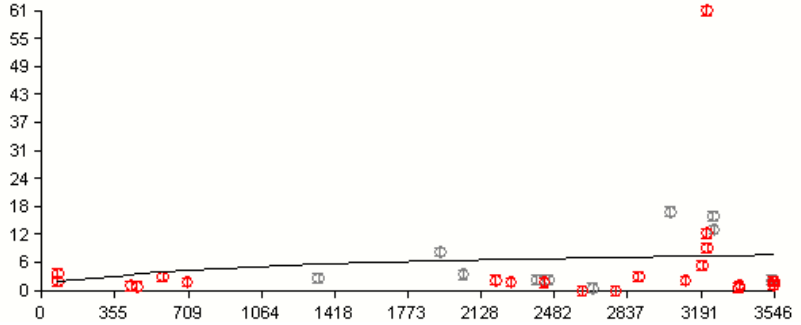
The following graphs show the fitting of the bioassay data when data that seems to be associated with an incident are excluded from the analyses.

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

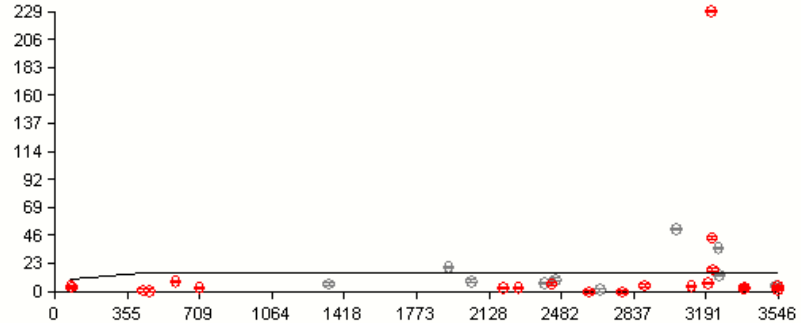
Havens Laboratory, type M, GM. Intake rate 103.3 pCi/d.



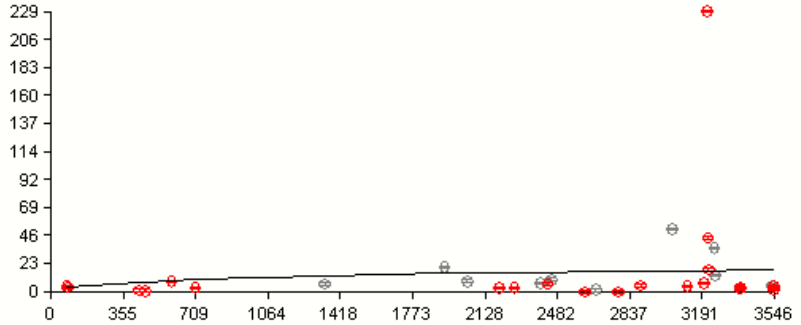
Havens Laboratory, type S, GM. Intake rate 1430 pCi/d.



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

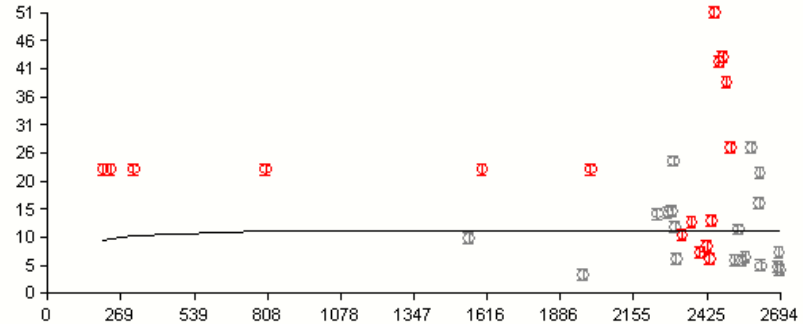


Havens Laboratory, type S, 84th. Intake rate 3259 pCi/d.

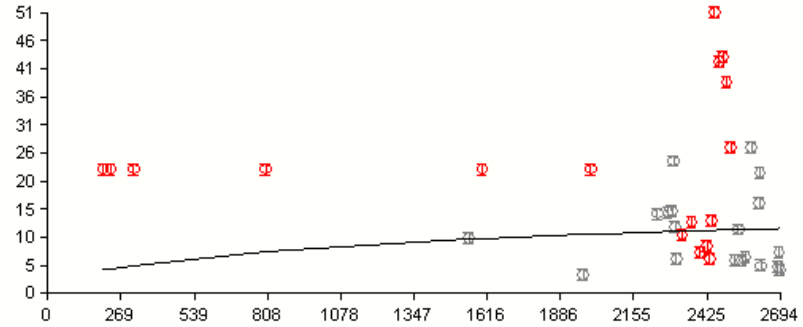


For Adrian Plant additional data from October l4, 1960 through April 10, 1961 were excluded from the analysis.

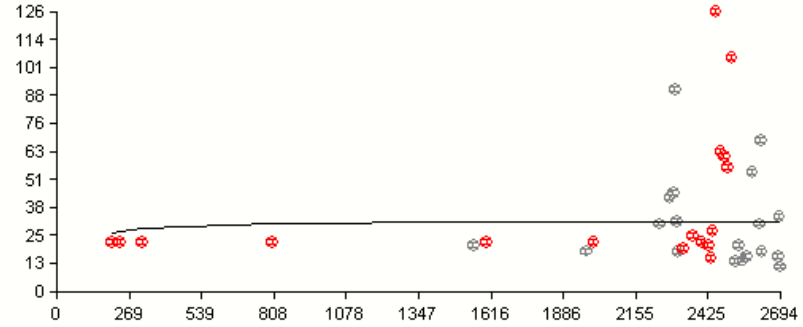
Adrian Plant, type M, GM. Intake rate 169.0 pCi/d.



Adrian Plant, type S, GM. Intake rate 2307 pCi/d.



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



Adrian Plant, type S, 84th. Intake rate 6367 pCi/d.