| **Office of Compensation Analysis and Support**<br><br>Technical Basis Document for the Huntington Pilot Plant, Huntington, West Virginia | Document Number: OCAS-TKBS-0004<br>Effective Date: 8/13/2008<br>Revision No.: 00<br><br>Page 1 of 30 |
|---|---|
| Subject Experts: Tom Tomes, Sam Glover, Christine Corwin<br><br>Approval: Signature on file Date: 8/12/2008<br>James W. Neton, Associate Director for Science | Supersedes:<br><br>ORAUT-TKBS-0004 |

TABLE OF CONTENTS


| Section | | Page |
|---|---|---|
| 1.0 | Introduction | 4 |
| 2.0 | Site Description and Operational History | 5 |
| 3.0 | Process Description | 8 |
| 4.0 | Uranium Concentration and Enrichment | 9 |
| 5.0 | Internal Dose during Operations | 10 |
| 5.1 | Uranium Intakes | 10 |
| 5.2 | Recycled Uranium | 13 |
| 6.0 | External Dose during Operations | 14 |
| 6.1 | Deep Dose | 14 |
| 6.2 | Shallow Dose | 15 |
| 7.0 | Dose during Remediation | 15 |
| 8.0 | Internal and External Dose Summary | 16 |
| 9.0 | Occupational Medical Exposures | 17 |
| 10.0 | References | 18 |
| Attachment A | | 22 |

## LIST OF TABLES

| Table | | Page |
|---|---|---|
| 1 | Specifications for Starting Material | 9 |
| 2 | Estimates of Historical Nickel Exposures | 10 |
| 3 | Annual Intakes of Uranium | 13 |
| 4 | Annual Intakes of Recycled Uranium Contaminants | 14 |
| 5 | Summary of Inhalation and Ingestion Intakes | 16 |
| 6 | Summary of External Doses | 17 |
| A1 | Radionuclides in Drums of Residue | 24 |
| A2 | Gamma Ray Spectra Used for Analysis of Dose Rate | 25 |
| A3 | Beta Particle Emission Rates | 26 |
| A4 | Dose Rate from Gamma Sources | 27 |

## LIST OF FIGURES

| Figure | | Page |
|---|---|---|
| A1 | Energy Distribution for Photon Emissions | 27 |
| A2 | Distribution of Dose from Bremsstrahlung | 28 |
| A3 | Photon Dose at 77.9 cm above Array of Drums | 29 |
| A4 | Bremsstrahlung Dose at 77.9 cm above Array of Drums | 30 |

RECORD OF ISSUE/REVISIONS

| ISSUE AUTHORIZATION DATE | EFFECTIVE DATE | REV. NO. | DESCRIPTION |
|---|---|---|---|
| Draft | 7/18/2008 | 00-A | Draft document for review to replace ORAUT-TKBS-004 as the technical basis for reconstructing radiation doses for former workers from the Huntington Reduction Pilot Plant. Newly available references have been incorporated with additional internal and external dose evaluations. |
| Draft | 7/30/2008 | 00-B | Incorporated formal review comments. |
| 8/12/2008 | 8/13/2008 | 00 | Approved for use. |

## 1.0 Introduction

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

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

For employees of DOE or its contractors with cancer, the DOE facility definition only determines eligibility for a dose reconstruction, which is a prerequisite to a compensation decision (except for members of the Special Exposure Cohort). The compensation decision for cancer claimants is based on a section of the statute entitled "Exposure in the Performance of Duty." That provision [42 U.S.C. § 7384n(b)] says that an individual with cancer "shall be determined to have sustained that cancer in the performance of duty for purposes of the compensation program if, and only if, the cancer … was at least as likely as not related to employment at the facility [where the employee worked], as determined in accordance with the POC [probability of causation[1]] guidelines established under subsection (c) …" [42 U.S.C. § 7384n(b)]. Neither the statute nor the probability of causation guidelines (nor the dose reconstruction regulation, 42 C.F.R. Pt. 82) define "performance of duty" for DOE employees with a covered cancer or restrict the "duty" to nuclear weapons work (NIOSH 2007).

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

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

exposures are considered valid for inclusion in a dose reconstruction. No efforts are made to determine the eligibility of any fraction of total measured exposure for inclusion in dose reconstruction. NIOSH, however, does not consider the following exposures to be occupationally derived (NIOSH 2007):

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

The following information from the Department of Energy's Office of Health, Safety and Security EEOICPA Find Facilities webpage defines the EEOICPA covered periods for the Huntington Pilot Plant.

| | |
|---|---|
| Site: | Huntington Pilot Plant |
| Alternate Names: | Reduction Pilot Plant |
| Location: | Huntington, West Virginia |
| Covered Period: | 1951 – 1963; 1978 – 1979 |
| Facility Type: | Department of Energy |

This document contains a summary of the description of the site as well as the Atomic Energy Commission activities performed there, and provides the technical bases to be used to evaluate the occupational radiation doses for EEOICPA claims.

## 2.0 Site Description and Operational History

The Huntington Pilot Plant (also known as the Reduction Pilot Plant) was built by the Atomic Energy Commission (AEC) in 1951 to supply nickel powder used to make gaseous diffusion barriers for the gaseous diffusion plants in Paducah, Kentucky, and Portsmouth, Ohio (Clark and Cottrell 1980, Berger 1981, US DOE 2007). A 1957 letter supplement also indicates that the AEC's operating contractor receiving the nickel powder was Union Carbide Nuclear Company (AEC 1957a). A facility data report (AEC 1955) and an International Nickel Company (INCO) memorandum both suggest that the powder was shipped to K-25 for barrier production (AEC 1957d). INCO was the operating contractor of the plant.

A memorandum survey report (AEC 1950) indicates that in January 1950 the AEC was considering awarding a contract to the International Nickel Company to produce nickel powder by melting K-25 scrap at their plant in Huntington, West Virginia. The proposal was to utilize Huntington Works Furnace No. 5 in the Refinery Building. According to the survey report, a railroad siding adjoined the Refinery Building, which would make it possible to unload and weigh the scrap at the siding, place it in buckets while it was still in the sealed cartons, and charge the furnace with the sealed cartons. The memorandum also suggested that the intended schedule was to use furnace No. 5 for melting K-25 scrap for two weeks each month and that the melt period took eight hours. At the time of the memorandum survey report, it was estimated that about one million pounds of nickel scrap was waiting to be melted (White 1950). There are

no records indicating the proposed plan to process scrap nickel in the existing Huntington Works Refinery Building was pursued.

A January 1951 AEC memo detailed a meeting between the AEC and INCO regarding the construction of a new facility to produce nickel powder for the AEC from nickel oxide. INCO was to purchase property adjoining their existing Huntington Works site. The AEC would then purchase the property from INCO and construct the new building. INCO would then lease the building from the AEC and perform the AEC nickel operations (AEC 1951).

The AEC Site consisted of 3.2 acres located east of International Nickel Company's "Huntington Works" plant. The property was bounded on the north by the Chesapeake and Ohio Railroad, on the east by Cole Street, on the south by Altizer Avenue, and on the west by the "Huntington Works" site (Smith 1957). "Huntington Works" referred to the INCO site that was owned by INCO and not involved with AEC work. The AEC site, which was totally enclosed by a chain link fence, was referred to as the Huntington Pilot Plant, or the Reduction Pilot Plant. Both names are used interchangeably in site documents and in this document.

The AEC contracted with Rust Engineering to construct the new AEC building, which was called the Reduction Pilot Plant (RPP). Construction included necessary support buildings, the installation of the equipment and utilities, the construction of a railroad spur, access road and security fence. The scheduled completion date for the construction of the Reduction Pilot Plant was December 31, 1951. Due to the inability of a vendor to furnish a satisfactory gas separation plant, the completion date was pushed back to January 31, 1952 (AEC 1952).

As discussed above, large quantities of nickel scrap were owned by the AEC. Records indicate that the scrap nickel was contaminated with uranium, and trace amounts of transuranic elements that are associated with recycled uranium from having been used as barrier in the gaseous diffusion cascades (AEC 1958c, INCO 1958). There are several documents that indicate INCO received relatively small quantities of nickel scrap from the AEC starting in February 1956. The scrap was to be processed in the RPP with the AEC receiving a credit against current invoices for nickel powder purchases. The purpose of this work was to determine the feasibility of converting larger quantities of such scrap material to reduced metal. In February 1956 the AEC approved INCO processing "10,000 pounds of government owned nickel scrap material for the purpose of determining the feasibility of converting larger quantities of such scrap material to reduced metal" (AEC 1956a). Another letter on April 6, 1956, indicates that the AEC authorized processing an additional 20,000 pounds of nickel scrap (AEC 1956b). Then on April 27, 1956, the AEC authorized processing of 22,000 pounds of scrap and approximately 3,000 pounds per day for 60 days (AEC 1956c). In November 1956 the AEC authorized an additional 12,000 pounds of scrap to be processed (AEC 1956c). All of the authorizations for scrap processing required INCO to keep material segregated to the extent practical and required them to deliver both the reduced metal and scrap residues to the AEC in labeled drums.

In June 1956 the AEC authorized expenditures for installation of some new equipment to process scrap, but did not fully fund modifications of the RPP for processing scrap until fiscal year 1957 (AEC 1956d). The AEC issued a Directive on February 14, 1957, for INCO to modify the Reduction Pilot Plant to permit the processing of scrap barrier into nickel powder. A progress

report dated December 9, 1957, indicated the plant should be ready to use the new material by January 31, 1958 (AEC 1957b, AEC 1957e).

In a January 1957 letter from the AEC to INCO, the AEC discussed the maximum uranium contamination that was expected for the scrap material. The letter states that INCO had visited Oak Ridge in September of 1956 to observe and learn of the health and safety problems that may result from the processing of the contaminated scrap material. The AEC expected levels of 300 ppm at an average assay of 1-2% U-235. The AEC suggested monitoring the process through the various stages with a suitable radiation detection instrument. Union Carbide (the AEC's operating contractor for the K-25 Gaseous Diffusion Plant) had provided INCO the radiation detection instrumentation (AEC 1957c).

Two December 1957 documents discussed the "new starting material" and the associated radiation hazards of the material (INCO 1957a) (INCO 1957b). The documents also state that operations with the new starting material will begin shortly.

In February of 1958 the AEC and Union Carbide began regular shipments of scrap to INCO for processing. An AEC letter documented that "clean" scrap barrier was to be shipped to INCO the weeks of February 2 and 9 for processing (150,000 lbs. total), and that "contaminated" scrap was to be shipped the weeks of February 23, March 2 and March 9 for processing (240,000 lbs. total). Details of shipping arrangements were made for the material moving between Huntington and Oak Ridge (AEC 1958b). A 1960 AEC document stated that nine million pounds of scrap barrier material had been processed by INCO (AEC 1960a).

An additional document (AEC 1961) gave details of starting material transactions of the Oak Ridge Gaseous Diffusion Plant (ORGDP) for fiscal years 1959 through 1961. According to this document, during this time period ORGDP shipped between 1,980,000 and 2,587,000 pounds of starting material to INCO per year. A narrative attached to the document indicates that these quantities were the required amounts that satisfied ORGDP's portion of the total quantity of starting material that was to be shipped to INCO by the three gaseous diffusion plants. The amounts required by INCO were based on the assumption of receipts of powder from INCO at the rate of 390,000 pounds per month.

A memorandum route slip indicates that the Huntington Pilot Plant was shut down on Tuesday, December 11, 1962, (AEC 1962a) and maintained in stand-by condition by Huntington Alloys, Inc., a subsidiary of INCO. This was accomplished by discontinuing shipments of starting material to the plant and processing the inventory reserves. All classified material was removed from the facility. Production systems were then purged, drained and lubricated. Equipment instrumentation was removed and put in storage. Routine facility and equipment maintenance as well as security inspections would be performed while the facility was in stand-by condition (INCO 1962a).

The Department of Energy (DOE) performed a preliminary radiological survey of the site and recommended that the site be decontaminated. The decontamination and demolition of classified and contaminated equipment at the facility took place between November 27, 1978, and May 18, 1979 (Clark and Cottrell 1980). According to reports, the classified and contaminated scrap was

transported to the Portsmouth Plant in Ohio in 59 truckloads and 4 railcar loads. There were 138 truckloads of clean scrap that were removed by the Cleveland Wrecking Company (Clark and Cottrell 1980). The only original building remaining on the AEC site was the Compressor Building.

## 3.0 Process Description

There were two sources of feed material used for the nickel powder production for the AEC. One source was nickel oxide, and the other source was barrier scrap supplied by the AEC.

According to process descriptions documented by the AEC, nickel oxide was processed using carbonyl to produce high-purity nickel powder. This process was conducted in the Reduction Pilot Plant. The process involved reducing the NiO to nickel with hydrogen in a reduction vessel. The following process description was provided in an AEC memorandum: "The nickel is then volatized by combining it with carbon monoxide in a pressure vessel at approximately 300 lbs. PSI, thus forming a gaseous nickel carbonyl. This gaseous carbonyl is passed through a condenser to change it to a liquid status. The liquid carbonyl is then purified by selective distillation, removing the iron oxide and other impurities. The purified carbonyl then passes through the decomposer (a vertical vessel approximately 5' in diameter x 13' high) and, by controlled temperature, the pure carbonyl is broken down, dropping out of the bottom of the vessel as metal powder. The metal powder then passes over screens to remove lumps, etc. After screening operations are completed, the metal powder is packed and ready for shipment" (AEC 1951).

The contaminated scrap nickel barrier material that was processed in the Reduction Pilot Plant on a pilot scale starring in 1956 was expanded into a routine operation in 1958. A modification was made to the nickel carbonyl process in order to process the scrap barrier. The process modification was described by McAlduff (AEC 1958a). The scrap nickel furnished by the AEC contained only small quantities of NiO; therefore, the reduction step previously utilized for the NiO starting material was eliminated. The scrap nickel was activated with hydrogen in 4000 lb. batches in two kilns. The material was then dumped through an air tight seal into two storage vessels, which were previously used as the reduction and activation reactors for NiO. The process from this step forward was the same as the process described above for NiO starting material.

The solid contaminants that resulted from the purification and distillation of the nickel starting material were removed from the system as a residue. As part of a radiological safety evaluation in 1957, INCO described how the residues were handled and stored. The residues contained the majority of the radiological contaminants and were concentrated in a much smaller mass than were present in the received scrap. The residues were placed into 20 gallon drums and then stored on the ground floor of the plant spaced over a 40 ft. by 105 ft. area until shipped back to the AEC (INCO 1957b). All of the residues from a single 4,000 lb. batch of scrap were stored in a single 20 gal. drum (UCNC 1958c).

## 4.0 Uranium Concentration and Enrichment

The nickel scrap sent to the RPP from the AEC included scrap barrier material that was contaminated with uranium from having been used in the uranium enrichment process. Records also indicate that some of the scrap was not contaminated (AEC 1958b). The contaminated scrap was decontaminated at the gaseous diffusion plants prior to shipment to the RPP (AEC 1960a). However, the scrap still contained small quantities of uranium and associated radionuclides.

The AEC provided specifications for the material shipped to the RPP (AEC 1958d). The specifications are shown in Table 1. The values were noted to be guaranteed minimum nickel and maximum contaminate levels. All other documentation and actual data indicates lower levels of uranium.

Table 1. Specifications for Starting Material

| Constituent | Maximum | Minimum |
|---|---|---|
| Nickel | | 98.0% |
| Water | 0.50% | -- |
| Iron | 0.40% | -- |
| Uranium-235 | 0.0875 grams per pound of starting material average in any one drum | -- |
| Total Uranium | 500 ppm | -- |

1. Reproduced from AEC 1958d.

Reports also stated that nickel scrap from the K-25 plant was contaminated with uranium with a maximum enrichment of 4% (by weight) (Clark and Cottrell 1980, Berger 1981). In late 1956 the AEC and Union Carbide evaluated criticality concerns prior to the approval of modifications of the RPP to allow processing scrap barrier. The evaluation concluded that the AEC would be sending barrier scrap containing a maximum of 300 ppm with an average enrichment of 1-2% U-235, noting that some degree of uncertainty can be expected (AEC 1957c). However, the AEC agreed to make reasonable efforts to deliver the starting material at the lowest practicable enrichment.

In January of 1958 Union Carbide sent a letter to INCO stating that INCO will be receiving two samples of starting material that differ in uranium content and U-235 assay, indicating that the uranium content of these samples was higher than normal and it was agreed that special written notice would be given in such instances. The letter stated that the samples will contain 0.78% uranium and 3.5% U-235 assay. The scrap with the 3.5% enrichment uranium contained only 24 ppm total uranium compared to the 165 ppm total uranium concentration of the 0.78% material (AEC 1958c).

Another reference provides average uranium concentration and enrichment. A 1960 AEC document stated that over 9,000,000 pounds of AEC scrap barrier had been processed at the RPP. It was reported that composite samples indicated the residues resulting from the nickel recovery at the RPP had “a total uranium content of less than one percent with a U-235 content of about 0.90 %.”

## 5.0 Internal Dose during Operations

### 5.1 Uranium Intakes

There are no records available of airborne radioactivity monitoring during the period that contaminated scrap nickel was processed at the Reduction Pilot Plant, although there are several available documents of radiation safety evaluations before the routine scrap operations began in 1958. Records indicate that the changes made to the RPP for scrap processing included engineered controls for transferring contaminated residues to drums and a vacuum system for handling contaminated residues (AEC 1957e).

In May 1958 the AEC asked Union Carbide to perform uranium bioassay services for two rounds of uranium urinalyses. The request by the AEC to Union Carbide was prompted by an INCO request to the AEC. INCO did not expect an exposure problem but wanted the analyses to evaluate the effectiveness of their controls (AEC 1958e). However, no other documentation on the bioassay request or bioassay records has been located.

Airborne uranium concentrations have been estimated from an evaluation of personnel exposure to airborne nickel at the Huntington Works. The results of that evaluation are provided in Table 2 below.

Table 2. Estimates of Historical Nickel Exposures
(reproduced from Enterline and Marsh 1982)

| Department | Exposure (mg Ni/$m^3$) |
|---|---|
| Acid reclaim | 0.02 |
| Blacksmith shop | 0.02 |
| Carpenter shop[b] | 0.02 |
| Chipping and hammer | 0.75[c] |
| Cold drawing (acid reclaim 1970 on) | 0.10[c] |
| Combustion[b] | 0.05 |
| Electrical[b] | 0.10 |
| Extrusion | 0.20[c] |
| General offices[b] | 0.01 |
| Heat treatment | 0.02 |
| Machine shop | 0.03[c] |
| Mechanical[b] | 0.01 |
| Melting and casting | 0.25[c] |
| Merchant mill | 0.30[c] |
| Night superintendent[b] | 0.01 |
| Pipe shop[b] | 0.08 |
| Polishing | 0.10[c] |
| Primary mill | 0.06 |
| Reduction pilot plant | 0.02 |
| Refinery | 5.00[c] |

| | |
|---|---|
| Research and development[b] | 0.05 |
| Roll grinding | 0.03 |
| Roll turning | 0.03 |
| Sheet mill (acid reclaim to 1970) | 0.20[c] |
| Shipping | 0.01 |
| Standards or industrial engineering[b] | 0.01 |
| Steel shop[b] | 0.12 |
| Stocks | 0.01 |
| Stores | 0.01 |
| Strip mill | 0.20[c] |
| Transportation[b] | 0.01 |
| Vacuum melting | 0.15 |
| Welding products | 0.02 |
| Yard[b] | 0.10 |
| Warehouse | 0.01 |
| Watchman[b] | 0.01 |
| Inspection (unassigned) [b] | 0.05 |

[a]Based on current measurements except as noted.
[b]Plant-wide work assignment.
[c]Based on historic midget impinger counts.

These exposure estimates, made by INCO for each of the various departments, were intended to represent average airborne concentrations of nickel in all forms over an 8-hour period. Generally, modern exposure data were used to estimate historic exposures and, whenever possible, were adjusted on the basis of process changes and environmental controls that were implemented over the years. For some departments, historical sample data were available that were obtained by the midget impinger particle counting technique. These data were then converted to the modern gravimetric expression (Enterline and Marsh 1982).

The data in Table 2 includes a result for average worker exposure in the Reduction Pilot Plant. However, the single value has no reported uncertainty. To determine a bounding airborne nickel exposure at the Reduction Pilot Plant, the Huntington Works department exposure values in Table 2 have been ranked and fit to a lognormal distribution, which results in a median value of 0.046 mg Ni/$m^3$ with a geometric standard deviation of 3.9. The 95th percentile value of the distribution is 0.44 mg Ni/$m^3$. The 95th percentile value will be used as the upper bound concentration of airborne nickel in the RPP. Intakes of uranium and associated radionuclides are then derived from the nickel concentration.

The residues resulting from processing contaminated scrap nickel contained the most concentrated source of uranium in the RPP. As discussed above, the enrichment was expected to be between 1% and 2% U-235 with some variations expected (AEC 1957c). The AEC reported in 1960 that the uranium concentration in the residues were less than 1% total uranium from processing over 9,000,000 pounds of scrap with a U-235 enrichment of about 0.90% (AEC 1960a). Thus 2% U-235 enrichment is assumed for the residues to allow for variation and to bound uranium radioactivity based on mass to radioactivity conversion.

Residues were not the only potential source of uranium exposure in the RPP, but are assumed to have the highest dose potential based on source term and process information. Residues had significantly higher uranium concentration than both the incoming contaminated nickel and the RPP nickel produced from contaminated scrap (AEC 1960a). A 1959 letter indicates that the AEC had requested INCO to consider blending residues with future scrap nickel. This was apparently an inquiry to determine if the unreacted nickel reporting to the residues from the nickel carbonyl process at the RPP could be recovered. INCO rejected the proposal because they feared that such a new operation could result in dust problems. INCO also performed laboratory scale tests of reprocessing residues, the results of which indicated that it was feasible. INCO proposed a few trial runs to determine the feasibility of using the residues as starting material (INCO 1959). The 1960 report (AEC 1960a) on processed material does not indicate residues as a source. Also, the AEC was considering shutting down the RPP in 1960 and performed cost studies on nickel processing. That December 1960 report indicated the AEC had only two agreements with INCO: lease of the facility, and the contract for nickel production from recovery of nickel from scrap. The cost of contract obligations was a consideration in keeping the plant open past 1960 (AEC 1960b). Also, there was no indication that the AEC had re-evaluated the basis for criticality that would likely be required to reprocess residues. There is no documentation indicating the residues were ever used as a source of starting material other than the small scale tests mentioned above. Worker exposures from the tests are considered insignificant in comparison to exposure from processing large quantities of contaminated scrap.

The 95th percentile airborne nickel concentration of 0.44 mg Ni/$m^3$ is considered to be a bounding estimate for concentration in the RPP. The AEC reported that the residues were less than 1% uranium. The residues were known to contain nickel as well as other contaminants that may have concentrated in the residues during nickel refining. The ratio of nickel to uranium in the residue is estimated by using the upper bound 1% uranium concentration (AEC 1960a) and assuming that 1% of the nickel in the starting material reported to the residues. Starting material was at least 98% nickel (AEC 1958d), thus each 4,000 pound batch of processed starting material would have resulted in at least 39.2 pounds of nickel in the drum of residue, assuming 1% loss. The mass of residue in each batch was estimated to be 50 pounds (UCNC 1958c). For a uranium concentration of less than 1%, the mass of uranium in each drum of residue would be less than 0.5 pounds. Thus, the uranium to nickel ratio in the residue is 0.013 lb U per pound Ni (0.5 lb/39.2 lb). This estimate accounts for 40 of the 50 pounds of residue per drum. Other contaminates, including iron, are assumed to account for the remainder.

Airborne uranium concentration based on the 95th percentile nickel airborne concentration is estimated to be:

$$\frac{0.44\ mg\ Ni}{m^3} * \frac{0.013\ mg\ U}{mg\ Ni} = \frac{0.00572\ mg\ U}{m^3}$$

Mass of 2% enriched uranium is estimated to be 1200 pCi/mg (DOE 2004). Uranium isotopic radioactivity concentrations are estimated to be 68% U-234, 28% U-238, and 4% U-235. Maximally exposed workers are assumed to have been exposed to the bounding concentration for 2,000 hours per work year at the breathing rate of 1.2 $m^3$/hr resulting in the following annual inhalation intake of total uranium:

$$\frac{0.00572\ mg\ U}{m^3} * \frac{1.2E3\ pCi\ U}{mg\ U} * \frac{2400\ m^3}{yr} = \frac{1.6E4\ pCi\ U}{yr}$$

Daily ingestion of uranium is estimated to be 0.2 times the airborne activity per cubic meter (OCAS 2004). Therefore, exposure to the bounding airborne concentration for 250 work days per year also results in an annual ingestion intake of 340 pCi total uranium per year.

Production workers are assumed to be maximally exposed. Workers in the Production category include production operators, laborers, supervisors and maintenance personnel. Intakes for those workers are based on the 95th percentile values discussed above. Other workers in the RPP are assumed to have been exposed at the median value, which results in an annual intake equal to 10.5% of the maximally exposed worker. Workers in the Administrative category include managers, secretaries and other administrative personnel.

Annual intakes are summarized in Table 3 below.

Table 3. Annual Intakes of Uranium

| Worker Category | Radionuclide | Airborne Concentration, $pCi/m^3$ | Inhalation, pCi/yr | Ingestion, pCi/yr |
|---|---|---|---|---|
| Production | Total U | 6.87 | 1.6E+4 | 340 |
| Administrative | Total U | 0.72 | 1.7E+3 | 36 |

## 5.2 Recycled Uranium

Recycled uranium may have been present with the contaminated scrap material that was processed beginning in 1956 (AEC 1958c). Recycled uranium is uranium that has been irradiated in a reactor and from which the uranium has been extracted from the plutonium, fission products and other elements. However, small quantities of some radioactive elements are still present in the material and may have been present on the contaminated scrap barrier shipped to the RPP. Pu-239 and Np-237 are the contaminants that are likely to have contributed to significant dose at the RPP.

Plutonium and neptunium were present in the recycled uranium that was fed into the gaseous diffusion plants. The recycled uranium comprised a significant portion of the feed to the gaseous diffusion plants starting in 1952. The AEC had accumulated large quantities of scrap nickel prior to the introduction of recycled uranium into the AEC complex. Additionally, the scrap nickel sent to INCO consisted of both contaminated scrap (from used barrier material) and uncontaminated nickel (nickel not used in the enrichment cascades) (AEC 1961). Assuming all scrap was contaminated with both uranium and recycled uranium contaminants would result in an overestimate of worker exposure.

The operational barrier material used in the gaseous diffusion plant equipment was located in the converters. Much of the plutonium and neptunium was removed by other processes at the

gaseous diffusion plants prior to introduction of $UF_6$ into the converters. However, some plating of the contaminants likely occurred due to the presence of trace quantities in the gas. The default isotopic ratios of Pu-239 and Np-237 from the Technical Basis Document *K-25 Gaseous Diffusion Plant - Occupational Internal Dose* (ORAUT 2006) are applied to the uranium intakes estimated for the RPP. Table 4 below contains the relative activities and annual intakes for inhalation and ingestion based on the values for uranium in Table 3 above.

Table 4. Annual Intakes of Recycled Uranium Contaminants

| Worker Category | Contaminant | Contaminant Activity[1] | Inhalation, pCi/yr | Ingestion, pCi/yr |
|---|---|---|---|---|
| Production | Pu-239 | 0.063 | 1.0E+3 | 2.1E+1 |
| | Np-237 | 0.0050 | 8.0E+1 | 1.7 |
| Administrative | Pu-239 | 0.063 | 1.1E+2 | 2.2 |
| | Np-237 | 0.0050 | 8.4 | 0.18 |

1. Relative to total uranium activity.

## 6.0 External Dose during Operations

### 6.1 Deep Dose

Penetrating photon dose at the RPP has been modeled based on continuous exposure to the residues, which contained the highest concentration of radioactive constituents in the plant (AEC 1960a). The process residue from each 4,000 lb. batch of scrap was discharged from the nickel carbonyl reaction chamber into a 20 gallon drum. The drums of residue were stored on the ground floor and spaced over a 40' by 105' area. Residue from as much as 150,000 lbs. of starting material (contaminated scrap) would be stored in this area at a given time (INCO 1957b, UCNC 1958c).

External whole body dose rates at 30 cm and at 100 cm have been estimated from source term information using MCNP. A summary of the evaluation is in Attachment A. Doses were modeled assuming a worker was standing in front of a row of drums that were stored with no space between them. The total whole body deep dose rates are estimated to be 3.24E-5 rad/hr and 1.70E-5 rad/hr at distances of 30 cm and 100 cm, respectively.

The maximally exposed worker dose was estimated by assuming that the worker was located 30 centimeters from the center of a row of drums for 2000 hours per year. This results in an annual exposure of 0.065 rad per year. This value applies to those Production personnel who may have been continually working with the drums of material, such as operators, laborers, supervisors and clerks. Other workers at the RPP are assumed to have been exposed at one half the value of the maximally exposed worker, or 0.033 rad per year. This value applies to Administrative personnel such as managers, secretaries, and other office workers.

The annual whole body doses are to be converted to organ doses by multiplying the estimated air kerma doses discussed above by the "Kerma ($K_a$) to Organ Dose ($H_T$)" photon dose conversion factors found in Appendix B of the NIOSH External Dose Reconstruction Implementation Guideline (US DHHS 2007). The exposure geometry was assumed to be anterior-posterior (AP)

and the whole body dose rate is to be divided equally between photons with E=30-250 keV and photons with E>250 keV and applied as a constant distribution.

### 6.2 Shallow Dose

Shallow dose from nonpenetrating radiation is assumed to have occurred from exposure to uncontained residues. Sealed drums of residue effectively shield emitted beta particles. For dose reconstruction purposes the shallow dose from uranium is considered to be from electrons greater than 15 keV.

The AEC evaluated beta dose rates at the RPP. They estimated an upper bound dose rate from the residues at 0.024 mrep/hour on contact (UCNC 1958c). Workers would not normally handle uncontained residues. However, some direct contact would be possible due to maintenance activities or incidental contact by those who directly handled the material and equipment. It is assumed that some workers could have had direct contact with the residues for fifty hours per year resulting in a shallow dose to the hands and forearms of 1.2 rem per year. This dose would only be applied to the equipment operators and maintenance workers with potential for direct contact with the residues.

Shallow dose to other tissues are determined by estimating the dose rate at 30 cm from the surface of the residues. The beta dose rate from aged yellowcake drops by a factor of approximately 75 from contact to 30 cm (NRC 2002). The bounding contact dose rate estimated for the residues is thus divided by 75 to determine beta dose rates at 30 cm from the surface of the residues, resulting in a beta dose rate of 0.00027 mrem per hour. Production Operators are assumed to have been exposed at that rate for 2,000 hours per year resulting in a maximum shallow dose of 0.54 rem per year. Workers who only had intermittent exposure to uncontained material are assumed to have been exposed at the 30 cm rate for 1,000 hours resulting in a beta dose rate of 0.27 rem per year, which is applied to Production Workers other than Operators, which would include laborers and supervisors. Administrative personnel who did not work with equipment or open containers are assumed to have had no significant beta exposure.

## 7.0 Dose during Remediation

The RPP ceased production in 1962 and was placed in a standby status in 1963. Procedures were developed in 1962 to remove material and chemicals, and to purge all systems and place the plant in an acceptable standby condition. The residue areas were also required to be completely cleaned. The plant was never restarted. It was demolished from 1978 through 1979. There are no available records of radiation monitoring during the demolition period. Survey results are available for the area after the plant was demolished. The only remaining structure was a Compressor Building that was located adjacent to the plant (INCO 1962, Berger et al., AEC 1962b).

Internal and external doses during the remediation period in 1978 through 1979 are to be assigned at the same level as estimated for the operational period in Sections 5 and 6.

## 8.0 Internal and External Dose Summary

Table 5 summarizes the intake data contained in Section 5.0 for the purposes of reconstructing internal doses at the Huntington Reduction Pilot Plant. The values have been normalized to intake per calendar day. These values should be applied as a continuous chronic intake. Intakes should be considered constants for dose reconstruction purposes because the methods used to derive intakes were based on bounding assumptions.

Table 5. Summary of Inhalation and Ingestion Intakes

| Production Workers[c] | | | | | |
|---|---|---|---|---|---|
| Start[b] | End[b] | Radionuclide | Intake Mode | Absorption Type | Intake Rate pCi/day |
| 01/01/1956<br>01/01/1978 | 12/31/1963<br>12/31/1979 | Total U | Inhalation | M or S | 44 |
| | | | Ingestion | (a) | 0.93 |
| 01/01/1956<br>01/01/1978 | 12/31/1963<br>12/31/1979 | Pu-239 | Inhalation | M or S | 2.7 |
| | | | Ingestion | (a) | 5.8E-2 |
| | | Np-237 | Inhalation | M | 2.2E-1 |
| | | | Ingestion | (a) | 4.7E-3 |
| Administrative Workers[c] | | | | | |
| Start | End | Radionuclide | Intake Mode | Absorption Type | Intake Rate pCi/day |
| 01/01/1956<br>01/01/1978 | 12/31/1963<br>12/31/1979 | Total U | Inhalation | M or S | 4.7 |
| | | | Ingestion | (a) | 0.099 |
| 01/01/1956<br>01/01/1978 | 12/31/1963<br>12/31/1979 | Pu-239 | Inhalation | M or S | 0.30 |
| | | | Ingestion | (a) | 6.0E-3 |
| | | Np-237 | Inhalation | M | 2.3E-2 |
| | | | Ingestion | (a) | 4.9E-4 |

(a) The f1 absorption value for ingestion should be chosen to be consistent with the inhalation material type.
(b) Intakes are normalized to calendar days and are to be assigned based on actual start and stop dates during the listed covered period.
(c) See Section 5 for determination of Production or Administrative Workers.

Table 6 summarizes the external doses contained in Section 6 for the purposes of reconstructing external doses at the Huntington Reduction Pilot Plant. The dose values are normalized per calendar year. These values should be applied as a chronic exposure. The external doses should be considered constants for dose reconstruction purposes because the methods used to derive intakes were based on bounding assumptions.

Table 6. Summary of External Doses

| Production Workers[c] | | | | |
|---|---|---|---|---|
| Start[a] | End[a] | Dose Type | Annual dose, rad[b] | Radiation and energy |
| 01/01/1956<br>01/01/1978 | 12/31/1963<br>12/31/1979 | Deep Dose | 0.065 | photons<br>30 - 250 keV 50%<br>> 250 keV 50% |
| 01/01/1956<br>01/01/1978 | 12/31/1963<br>12/31/1979 | Shallow Dose | 0.540 (Operators)<br><br>0.270 (other Production Workers) | electrons<br>> 15 keV |
| | | Shallow Dose (hands and forearms) | 1.000 (Operators and Maintenance only) | electrons<br>> 15 keV |
| Administrative Workers[c] | | | | |
| Start | End | Dose Type | Annual dose, rad[b] | Radiation and energy |
| 01/01/1956<br>01/01/1978 | 12/31/1963<br>12/31/1979 | Deep Dose | 0.033 | photons<br>30 - 250 keV 50%<br>> 250 keV 50% |
| 01/01/1956<br>01/01/1978 | 12/31/1963<br>12/31/1979 | Shallow Dose | none | |

(a) Doses are normalized to calendar days and are to be assigned based on actual start and stop dates of covered employment during the listed covered period.
(b) Whole body photon doses are to be converted to organ doses using the Kerma to Organ Dose conversion factors (US DHHS 2007).
(c) See Section 6 for determination of Production or Administrative Workers.

## 9.0 Occupational Medical Exposures

No information regarding occupational medical dose specific to Huntington Pilot Plant was found. Information to be used in dose reconstructions for which no specific information is available is provided in ORAUT-OTIB-0006, the technical information bulletin covering diagnostic X-ray procedures. The assumption is made that workers received an annual occupationally related diagnostic X-ray beginning with the start of the AEC contract in 1951 and continuing through 1963 when AEC operations ended. X-rays are also assumed for 1978 and 1979 during the remediation period. Annual PA chest X-rays should be applied in accordance with the current revision of ORAUT-OTIB-0006, Technical Information Bulletin: Dose Reconstruction from Occupationally Related Diagnostic X-Ray Procedures (ORAUT 2003). Annual organ doses are entered into the NIOSH-IREP program as the annual dose due to an acute exposure to photons (E=30-250 keV). The distribution is assumed to be normal with a standard deviation of 30%.

## 10.0 References

AEC 1950, Memo Survey Report on International Nickel Company, Inc. from C.V. White, AEC, January 24, 1950 [SRDB Ref ID 22128].

AEC 1951, Memo from F. C. Hungerford, AEC, to N. Williams, Acting Director of Production and Engineering, AEC, January 31, 1951 [SRDB Ref ID 19713].

AEC 1952, Memo from F. R. Dowling, Acting Director of Production and Engineering, to S. R. Sapirie, Manager, January 4, 1952 [SRDB Ref ID 19717].

AEC 1955, Facility Data Report on International Nickel Company, Inc., February 17, 1955 [SRDB Ref ID 22126].

AEC 1956a, Letter from John R. Moore, Contracting Officer AEC, to the International Nickel Company, Inc., February 10, 1956 [SRDB Ref ID 21998].

AEC 1956b, Letter from R. G. Humphries, Contracting Officer AEC, to the International Nickel Company, Inc., April 6, 1956 [SRDB Ref ID 21999 pp. 2-3].

AEC 1956c, Letter from John R. Moore, Contracting Officer AEC, to the International Nickel Company, Inc., April 27, 1956 [SRDB Ref ID 21999, pp. 4-5].

AEC 1956d, Letter from S. R. Sapirie, Manager, Oak Ridge Operations, to the International Nickel Company, Inc., June 29, 1956 [SRDB Ref ID 21999, p. 6].

AEC 1956e, Letter from John R. Moore, Contracting Officer, to the International Nickel Company, Inc., November 23, 1956 [SRDB Ref ID 21999, pp. 7-8].

AEC 1957a, Letter Supplement from R.G. Humphries, Contracting Officer AEC, to the International Nickel Company, Inc., June 13, 1957 [SRDB Ref ID 22106].

AEC 1957b, Memo from W. J. Hayes, Director Construction Division AEC, to N.A. Shearon, Director, Budget and Reports Division AEC, December 9, 1957 [SRDB Ref ID 19710].

AEC 1957c, Letter from R. C. Armstrong, Director, Production Division, Oak Ridge Operations, to G. K. Crosby, The International Nickel Company, Inc., January 15, 1957 [SRDB Ref ID 19726].

AEC 1957d, Memo from C.A. Keller, Director Production Division, to F.F. Gallagher, Security Division, September 11, 1957 [SRDB Ref ID 22125].

AEC 1957e, Memo from E. A. Wende, Deputy Manager Oak Ridge Operations, to Director, Production Division, Oak Ridge Operations, February 14, 1957 [SRDB Ref ID 22000].

AEC 1958a, Memo from H. J. McAlduff, Deputy Director Inspection Division AEC, to C.A. Keller, Director Production Division AEC, March 5, 1958 [SRDB Ref ID 18870].

AEC 1958b, Memo from R. S. Kendall, Assistant Chief, Physical Security Branch AEC, to F.P. Callaghan, Director, Security Division AEC, February 3, 1958 [SRDB Ref ID 18866].

AEC 1958c, Letter from S. R. Sapirie, Manager, Oak Ridge Operations, to the International Nickel Company, Inc., February 28, 1958 [SRDB Ref ID 18869].

AEC 1958d, *Appendix "C" – Specifications for Starting Material*, undated c. 1958 [SRDB Ref ID 22105].

AEC 1958e, Letter from C. A. Keller, Director of Production Division, AEC, to A. P. Huber, Plant Superintendent, ORGDP, Union Carbide Nuclear Company, May 26 [SRDB Ref ID 18811].

AEC 1960a, Memo from G. F. Quinn, Director, Division of Production, to S. R. Sapirie, Manager, Oak Ridge Operations, August 29 [SRDB Ref ID 19657].

AEC 1960b, Memo from R. G. Armstrong, Assistant Manager for Operations, to Charles A. Keller, Director, Production Division, December 7 [SRDB Ref ID 19655].

AEC 1961, *Supplemental Information Required for Fiscal Year 1961 Budget* [SRDB Ref ID 22104].

AEC 1962a, Memo from John R. Moore, Assistant Manager for Administration, Oak Ridge Operations, AEC, to Leo W. Meyer, Division of Contracts, Washington D. C., AEC, et al., December 14, 1962 [SRDB Ref ID 21999, p. 24].

AEC 1962b, Memo to file by C. F. Fullam, Assistant Chief, Audit Branch, Shutdown of INCO Plant, August 17 [SRDB Ref ID 21999, p. 23].

Andersson, K.G., et al, *Radiation Dose Implications of Airborne Contaminant Depositions to Humans*, Health Physics, 82(2), pp. 226-232, 2002.

Battelle 2006, *Site Profiles for Atomic Weapons Employers that Worked Uranium and Thorium Metals*, Battelle-TBD_6000, Rev F0, PNWD-3738 Rev 0, December 13.

Berger, J.D., et al, Oak Ridge Associated Universities, *Radiological Assessment of the Former Reduction Pilot Plant Huntington Alloys, Inc., Huntington, West Virginia*, July 2, 1981 [SRDB Ref ID 9018].

BJC (Bechtel Jacobs Company) 2000, *Recycled Uranium Mass Balance Project, Oak Ridge Gaseous Diffusion Plant Site Report*, BJC/OR-584, June [SRDB Ref ID 16497].

Browne 1986, *Table of Radioactive Isotopes*, E. Browne and R. Firestone, John Wiley and Sons, New York.

Clark, C., and Cottrell, D., *Preliminary Radiological Survey of the Former Reduction Pilot, Huntington*, West Virginia 1980 [SRDB Ref ID 9018].

CRC, Handbook of Chemistry and Physics, 67th Edition, R.C. Weast, Ph.D., Editor-in-Chief, CRC Press, Inc., Boca Raton, FL, 1986.

DOE 2004, *DOE Standard, Guide of Good Practices for Occupational Radiological Protection in Uranium Facilities*, DOE-STD-1136-2004, Washington, D.C., December.

Enterline P.E, Marsh, G.M., *Mortality Among Workers in a Nickel Refinery and Alloy Manufacturing Plant in West Virginia*, JNCI 1982; 6:925-933

Fogh, C.L., et al, *Quantitative Measurement of Aerosol Deposition on Skin, Hair and Clothing for Dosimetric Assessment – Final Report, Roskilde, Denmark: Riso National Laboratory*, Riso-R-1075(EN), 1999.

INCO 1957a, Letter from C.B. Goodrich, Section Head, Special Projects INCO, to N. Williams, Deputy Assistant Manager for Operations AEC, December 11, 1957 [SRDB Ref ID 19709].

INCO 1957b, Letter from C.B. Goodrich, Section Head, Special Projects INCO, to H.H. Stoner, Union Carbide, December 11, 1957 [SRDB Ref ID 18862].

INCO 1958, Letter from R.R. Clappier to S. R. Sapirie, Manager, Oak Ridge Operations, May 15, 1958 [SRDB Ref ID 18874].

INCO 1959, Letter from C. B. Goodrich, Section Head – Technical Services, INCO, to C. A. Keller, Director, Production Division, AEC, July 6 [SRDB Ref ID 23564].

INCO 1962a, Letter from R. R. Clappier, INCO, to N. Williams, Deputy Assistant Manager for Operations, AEC, May 3 [SRDB Ref ID 21999, pp. 13-22].

Kocher, D.C., and Eckerman, K.F., *Electron Dose-Rate Conversion Factors for External Exposures of the Skin from Uniformly Deposited Activity on the Body Surface*, Health Physics, 53(2), pp. 135-141, 1987.

NIOSH (National Institute for Occupational Safety and Health) 2007, *Radiation Exposures Covered for Dose Reconstructions Under Part B of the Energy Employees Occupational Illness Compensation Program Act*, OCAS-IG-003, Rev. 0, Office of Compensation Analysis and Support, Cincinnati, Ohio, November [SRDB Ref ID 35987].

NiPera (Nickel Producers Environmental Research Association), *Safe Use of Nickel in the Workplace*, 1997, http://www.nipera.org/index.cfm/ci_id/13034/la_id/1.htm#APPENDIX%20A

NRC 2002, *U. S. Nuclear Regulatory Commission Regulatory Guide 8.30, Health Physics Surveys in Uranium Recovery Facilities*, Rev 1, Figure 2, Beta Dose Rate from Yellowcake Separated from Ore for More Than 100 Days, May 2002.

OCAS (NIOSH Office of Compensation Analysis and Support) 2004, *Estimation of Ingestion Intakes*, OCAS-TIB-009, Rev 0, Cincinnati, OH, April 13.

ORAUT 2006, *K-25 Gaseous Diffusion Plant - Occupational Internal Dose*, ORAUT-TKBS-0009-5, Rev 01 PC-1, October 4.

Smith, R.M., Final Report of Annual Fire Survey of Reduction Pilot Plant, Huntington, West Virginia, July 2-3, 1957 [SRDB Ref ID 18812].

UCNC (Union Carbide Nuclear Company) 1958a, Letter from W.E. Tewes, Technical Division Union Carbide, to C.B. Goodrich, INCO, January 31, 1958 [SRDB Ref ID 18865].

UCNC 1958b, Memo from H.F. Henry, Safety, Fire and Radiation Control to E.C. Bollinger, January 22, 1958 [SRDB Ref ID 18063].

UCNC 1958c, H. F. Henry, to E. C. Bollinger, Oak Ridge Gaseous Diffusion Plant, *Study of INCO Radiation Problem*, January 22, SRDB Ref ID 18863.

U.S. DOE (United States Department of Energy) Worker Advocacy Web Site Facility List, November 2007, http://tis.eh.doe.gov/advocacy/faclist/findfacility.cfm.

U.S. DHHS (United States Department of Health and Human Services), *External Dose Reconstruction Implementation Guideline*, Rev. 3, Appendix B, National Institute of Occupational Safety and Health, 2007.

# Attachment A

# Determination of Dose from Nickel Scrap at the Huntington Pilot Plant

Background:

Huntington Pilot Plant (or Reduction Pilot Plant) produced nickel barrier material for the Atomic Energy Commission (AEC). One of the raw materials was contaminated nickel scrap that was contaminated with low levels of low enriched uranium (AEC 1957c). The feed was called starting material (SM). The contaminated SM was processed in no more than 4,000 pound batches, and all residues from a batch were stored in a 20 gallon drum (INCO 1957b). Information from a variety of sources was used to develop source term information for the residues for the purpose of modeling the external dose to workers from these drums.

Geometry:

The uranium-bearing residues were stored in "20-gallon drums spaced over a 40 ft. by 105 ft. area" (INCO 1957b) which implies a spaced configuration of the drums. For external dose modeling purposes it was assumed that the drums of residues are stored in a row without spacing, and that workers were exposed to the center of a row of drums containing the uranium bearing residues.

Uranium Source term:

The material being considered was nickel scrap from the gaseous diffusion plants. Reference indicates that controls were in place to process no more than 4,000 pounds of material at one time. That was based on an assumption of an always safe U-235 mass of 350 grams (UCNC 1958c). Specifications included a maximum U-235 concentration in the feed of 0.0875 gram per pound of SM (AEC 1958d). The UCNC (1958c) reference indicates that all the residues from a 4,000 pound batch would be placed in a 20 gallon drum, and that the maximum U-235 content in the drum was less than 350 grams, the always safe concentration. That reference also assumed the maximum total uranium concentration in the starting material was 200 ppm.

Another reference provided guaranteed specifications (see Section 4.0) that the total uranium would always be less than 500 ppm. This would result in a limiting amount of 2 pounds of uranium per 4,000 pound batch of starting material feed. If all the contained uranium in a 4,000 pound batch was collected as residue in a 20 gallon drum, the 2 pounds of total uranium per batch can be used to bound the uranium concentration of the residue. The maximum enrichment of received starting material is assumed to be 4% U-235. However, as discussed in Section 4.0, the average uranium concentration and enrichment were lower than these bounding assumptions used to model dose. Based on these values the maximum uranium content of each 20 gallon drum was 908 grams of 4% enriched U per an evaluation done by Oak Ridge in 1958 (UCNC 1958c).

Drum contents:

The source term (908 grams of total uranium in 50 pounds of residue) was modeled for the determination of external dose using a fixed source term. The mass of residue was a variable for which we have no specific data. The Oak Ridge evaluation report (on radiation exposure from the drums) stated their evaluation was done with conservative assumptions.

For the purposes of this evaluation, it was determined that a 50 pound source term and a container ¾ full would be modeled. Since distance was a factor in estimating the dose, the drums were assumed to be 3/4 full (and hence contained 15 gallons of residue). Test runs of the process had been completed, hence a 20 gallon drum provided likely excess capacity per batch. For 50 pounds this results in a density of 0.4 g/cc. But, for example, if we assume a 2 g/cc density, the mass of the 15 gallons of residue would be 250 pounds, which is more than indicated by the references. Use of the lower density for a fixed source term was determined to be claimant favorable because of the reduced shielding implied.

For a constant radiological source term, an increase in density will result in a lower dose rate. So, we can bound dose rates by assuming 50 lb. of residue at a 0.4 g/cc density, which results in a height of approximately 14 inches (from assumed drum dimensions of 18.25 inches in diameter by 19.25 inches high). The contaminated nickel scrap had a specified 98% minimum nickel concentration (see Section 4.0).

The residues contained nickel that was not fully recovered in the process (at one point the AEC was considering blending the residues with other Ni feed to recover more of the Ni at RPP) (INCO 1959). This external dose analysis is based on the 98 % minimum nickel concentration in the feed and the assumption the nickel carbonyl process achieved 99% efficiency for nickel recovery, which would result in 40 pounds of nickel lost to the drummed residue. Based on the limit for iron in the specifications, iron may have been present in trace quantities. For dose modeling purposes the residues are assumed to contain nickel and uranium. Other radiological impurities are assumed to be present based on a function of the uranium content.

Radioactivity in a 20-gallon drum: Table A1 below contains radionuclides of concern including recycled U contaminates.

**Table A1. Radionuclides in Drums of Residue[a,b]**

| | Mass fraction | Specific Act., µCi/g | µCi/(g total U) | Total in drum, µCi |
|---|---|---|---|---|
| U-234 | negligible | - | 1.56 | 1420 |
| U-235 | 0.04 | 2.16 | 0.0864 | 78 |
| U-238 | 0.96 | 0.338 | 0.324 | 295 |
| Th-234 | | | | 295 |
| Pa-234m | | | | 295 |
| Pa-234 | | | | 0.471 |
| Th-231 | | | | 78 |
| Pu-239 | | | | 0.00486 |
| Np-237 | | | | 0.00359 |
| Tc-99 | | | | 0.748 |

a. Specific concentration of 4% enriched uranium=1.97 µCi/g of uranium
b. Total mass of uranium in drum=908 g

## Dose Calculations

### Content of drums

Assume the material is 908 g of uranium, and the rest of the 50 pounds (22,680 grams) per drum was nickel (22,680-908 = 21,773 g of nickel). The material used for this analysis consisted of:

| | mass % | Total Mass (g) | Isotopic mass (g) | Mass % of Mixture |
|---|---|---|---|---|
| U-235 | 4.00% | 907 | 36.28 | 0.16% |
| U-238 | 96.00% | 907 | 870.72 | 3.84% |
| natural nickel | 100.00% | 21773 | 21773 | 96.00% |
| total | | | 22680 | |

### Gamma dose rate

Results were determined using MCNPX 2.6f. 77.9 cm was chosen as the height of the testes and as an overestimate for many organs. 8 drums were modeled in a close packed geometry and the dose rate determined from the center of the drums.

### Photons per decay of $^{238}$U

The number and energy of photons per unit decay of $^{238}$U was compiled from ENSDF files from NUDAT (11/28/1005) located at http://www.nndc.bnl.gov/nudat2/indx_dec.jsp. These emissions were binned by emission probability as summarized in the following table (normalized per decay of $^{238}$U). The resulting total photon emission probability per decay of $^{238}$U was 0.7728 for the energy range of 0.001 to 2.2 MeV.

**Table A2: Gamma Ray Spectra Used for Analysis of Dose Rate (normalized per $^{238}$U decay)**

| Lower, MeV | Upper, MeV | Photons per decay $^{238}$U | Photons per second per Ci $^{238}$ | Relative flux |
|---|---|---|---|---|
| 0.001 | 0.01 | 0.000087252 | 1.162E+10 | 0.01% |
| 0.01 | 0.015 | 0.307244729 | 4.092E+13 | 39.76% |
| 0.015 | 0.02 | 0.001287628 | 1.715E+11 | 0.17% |
| 0.02 | 0.03 | 0.0373962 | 4.981E+12 | 4.84% |
| 0.03 | 0.04 | 0.000142811 | 1.902E+10 | 0.02% |
| 0.04 | 0.05 | 0.001174059 | 1.564E+11 | 0.15% |
| 0.05 | 0.06 | 0.007275764 | 9.691E+11 | 0.94% |
| 0.06 | 0.08 | 0.049808992 | 6.635E+12 | 6.45% |
| 0.08 | 0.1 | 0.109028516 | 1.452E+13 | 14.11% |
| 0.1 | 0.15 | 0.048335431 | 6.438E+12 | 6.25% |
| 0.15 | 0.2 | 0.168322232 | 2.242E+13 | 21.78% |
| 0.2 | 0.3 | 0.019368187 | 2.580E+12 | 2.51% |
| 0.3 | 0.4 | 0.000392679 | 5.230E+10 | 0.05% |
| 0.4 | 0.5 | 0.000169829 | 2.262E+10 | 0.02% |
| 0.5 | 0.6 | 0.000370926 | 4.941E+10 | 0.05% |
| 0.6 | 0.8 | 0.005213862 | 6.945E+11 | 0.67% |
| 0.8 | 1 | 0.006946372 | 9.253E+11 | 0.90% |
| 1 | 1.2 | 0.008687465 | 1.157E+12 | 1.12% |
| 1.2 | 1.4 | 0.000162724 | 2.167E+10 | 0.02% |
| 1.4 | 1.6 | 0.000488166 | 6.502E+10 | 0.06% |
| 1.6 | 1.8 | 0.000369724 | 4.925E+10 | 0.05% |
| 1.8 | 2 | 0.000539191 | 7.182E+10 | 0.07% |
| 2 | 2.2 | 6.56E-08 | 8.738E+06 | 0.00% |

**Beta particle emission per decay of $^{238}$U**

The number and energy of beta particle emissions per unit decay of $^{238}$U in aged uranium was compiled from the RADAR (Health Physics 83(4):471-475, 2002) and supplemented as necessary using data from the Table of Radioactive Isotopes (Browne 1986). These emissions were binned by emission probability as summarized in the following table (normalized per decay of $^{238}$U). The resulting total beta emission probability per decay of $^{238}$U was 2.20.

**Table A3: Beta Particle Emission Rates**

| Lower, MeV | Upper, MeV | Betas per decay $^{238}U$ | Betas per second per Ci of $^{238}U$ | Relative flux |
|---|---|---|---|---|
| 0.001 | 0.01 | 0.183809669 | 2.448E+13 | 8.35% |
| 0.01 | 0.015 | 0.010281587 | 1.370E+12 | 0.47% |
| 0.015 | 0.02 | 0.150193582 | 2.001E+13 | 6.82% |
| 0.02 | 0.03 | 0.142229865 | 1.895E+13 | 6.46% |
| 0.03 | 0.04 | 0.118989077 | 1.585E+13 | 5.41% |
| 0.04 | 0.05 | 0.100401518 | 1.337E+13 | 4.56% |
| 0.05 | 0.06 | 0.084726918 | 1.129E+13 | 3.85% |
| 0.06 | 0.08 | 0.137967375 | 1.838E+13 | 6.27% |
| 0.08 | 0.1 | 0.089276301 | 1.189E+13 | 4.06% |
| 0.1 | 0.15 | 0.191455688 | 2.550E+13 | 8.70% |
| 0.15 | 0.2 | 0.03381993 | 4.505E+12 | 1.54% |
| 0.2 | 0.3 | 0.078860315 | 1.050E+13 | 3.58% |
| 0.3 | 0.4 | 0.072597099 | 9.670E+12 | 3.30% |
| 0.4 | 0.5 | 0.077502183 | 1.032E+13 | 3.52% |
| 0.5 | 0.6 | 0.08059423 | 1.074E+13 | 3.66% |
| 0.6 | 0.7 | 0.081581916 | 1.087E+13 | 3.71% |
| 0.7 | 0.8 | 0.080614842 | 1.074E+13 | 3.66% |
| 0.8 | 0.9 | 2.37416E-05 | 3.162E+09 | 0.00% |
| 0.9 | 1 | 0.077835735 | 1.037E+13 | 3.54% |
| 1 | 1.1 | 0.073435665 | 9.782E+12 | 3.34% |
| 1.1 | 1.2 | 0.067673436 | 9.014E+12 | 3.07% |
| 1.2 | 1.3 | 0.060809325 | 8.100E+12 | 2.76% |
| 1.3 | 1.4 | 0.053143 | 7.079E+12 | 2.41% |
| 1.4 | 1.5 | 0.0449251 | 5.984E+12 | 2.04% |
| 1.5 | 1.65 | 0.03647 | 4.858E+12 | 1.66% |
| 1.65 | 1.8 | 0.0281167 | 3.745E+12 | 1.28% |
| 1.8 | 1.95 | 0.0331863 | 4.420E+12 | 1.51% |
| 1.95 | 2.1 | 0.0071157 | 9.478E+11 | 0.32% |
| 2.1 | 2.3 | 0.003223461 | 4.294E+11 | 0.15% |

The dose rate fields in the plane of the 77.9 cm height (Figure A3 and A4) shows the dose rates to be uniform in the center of the array. The following tallies were obtained:

- Tally 5: dose rate in rad/hr 30 cm from front edge of center barrel array, 77.9 cm above ground.
- Tally 15: dose rate in rad/hr 100 cm from front edge of center barrel array, 77.9 cm above ground.
- Tally 25: photon flux in photons/cm$^2$/hr 30 cm from front edge of center barrel, 73 cm above ground.

**Table A4. Dose Rate from Gamma Sources**

| Distance from center drum | Tally | Gamma Dose rate (rad/hr) | Brem. Dose Rate (rad/hr) | Total Dose Rate (rad/hr) |
|---|---|---|---|---|
| 30 cm | 5 | 2.56E-05 | 6.76E-6 | 3.24E-5 |
| 100 cm | 15 | 1.34E-05 | 3.55E-6 | 1.70E-5 |

Approximately a 50/50 split for 0-250 keV/>250 keV for dose is supported by evaluating the cumulative dose graph for the dose from photon emissions and bremsstrahlung (Figures A1 and A2). Figures A3 and A4 show the dose rate distribution for photon dose and bremsstrahlung dose, respectively, in the horizontal plane (77.9 cm in height) which lies above the drums. The dose rate (rad/hr) levels are shown above the 8 drums configuration (at 77.9 cm above ground) from photon emissions. This corresponds to the dose rate in the plane (similar to a table top 77.9 cm off the ground) above this array of drums. These figures provide further evidence in the claimant favorable nature of the location used for the dose evaluation.

**Figure A1: Energy Distribution for Photon Emissions**

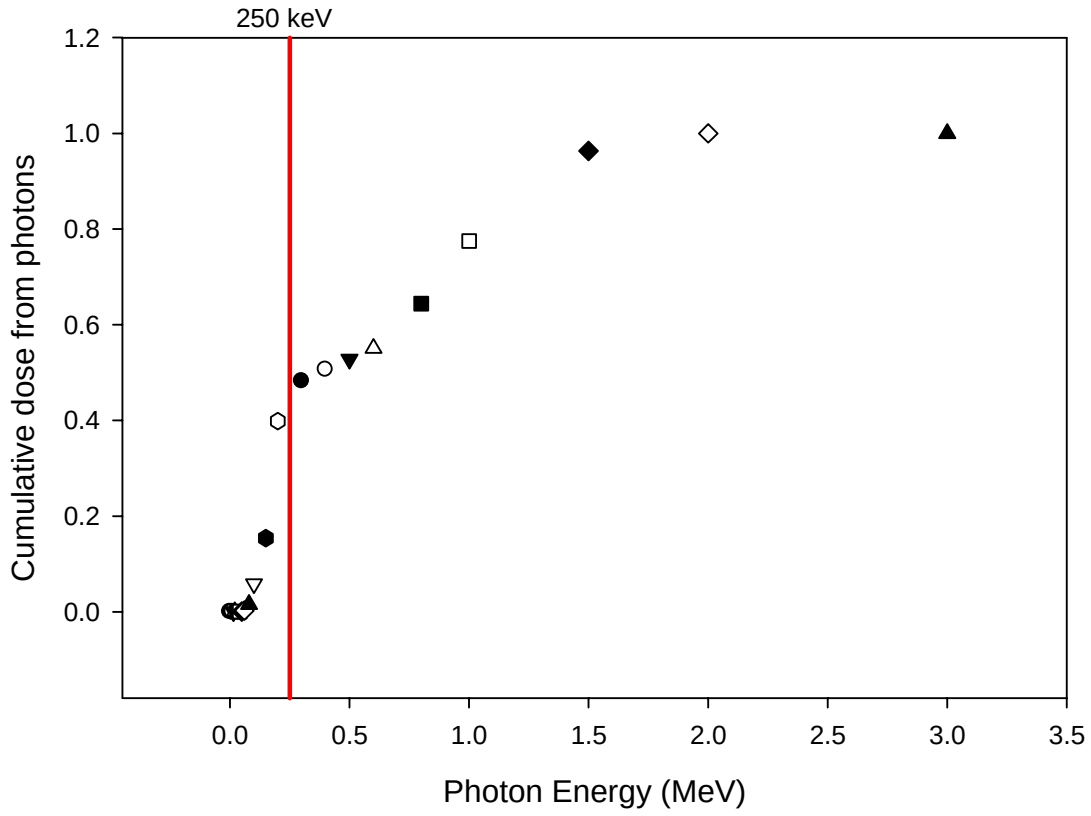

**Figure A2: Distribution of Dose from Bremsstrahlung**

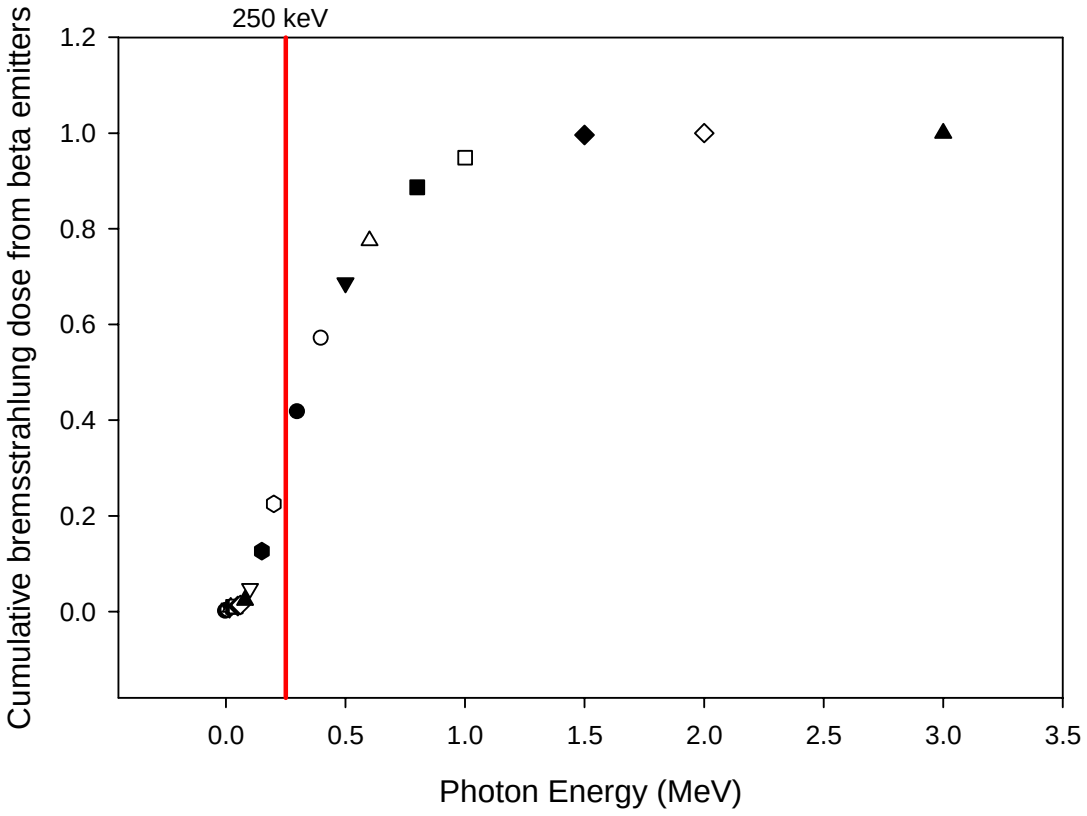

**Figure A3: Photon Dose at 77.9 cm above Array of Drums (rad/hr)**

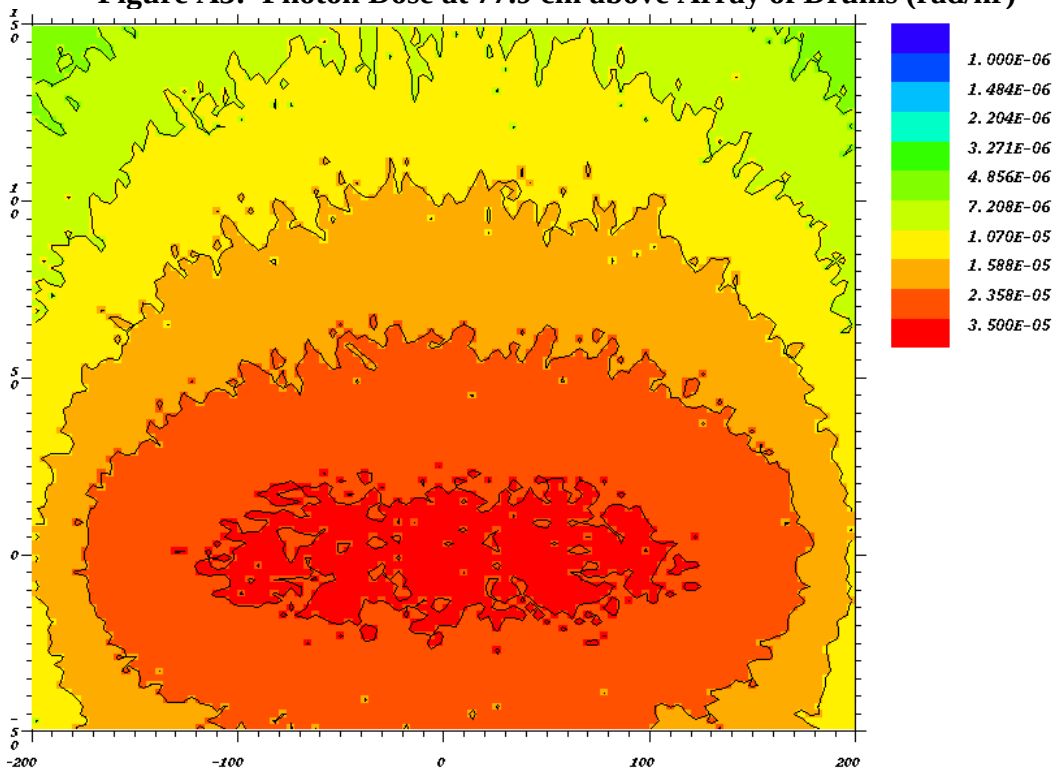

**Figure A4: Bremsstrahlung Dose at 77.9 cm above Array of Drums (rad/hr)**