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ACRONYMS AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
DOL	U.S. Department of Labor
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
HVL	half-value layer
IREP	Interactive RadioEpidemiological Program
IMBA	Integrated Modules for Bioassay Analysis (computer program)
NIOSH	National Institute for Occupational Safety and Health
ORAU	Oak Ridge Associated Universities
TBD	technical basis document
U.S.C.	United States Code
WSCP	Weldon Spring Chemical Plant
WSP	Weldon Spring Plant
WSQ	Weldon Spring Quarry
WSRP	Weldon Spring Raffinate Pits

1.1 INTRODUCTION

Oak Ridge Associated Universities (ORAU) leads the ORAU Team in support of the National Institute for Occupational Safety and Health (NIOSH) in conducting activities under the Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA). The purpose of this Site Profile is to support the ORAU Team with documentation of historical practices at the Weldon Spring Plant (WSP). This WSP Site Profile contains technical basis information the ORAU Team can use to evaluate the total occupational radiation dose for EEOICPA claimants. Dose reconstructors can use the information in this Site Profile to evaluate internal and external dosimetry data for unmonitored and monitored workers, and to serve as a supplement to, or substitute for, individual monitoring data.

Technical basis documents (TBDs) 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 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” or a “Department of Energy facility” as defined in the EEOICPA (42 U.S.C. § 7384l (5) and (12)).

The TBDs that comprise this Site Profile provide supporting technical data to evaluate, with claimant-favorable assumptions, the total WSP occupational radiation dose that can reasonably be associated with a worker’s radiation exposure. This dose results from exposure to external and internal radiation sources in WSP facilities, occupationally required diagnostic X-ray examinations, and onsite environmental releases. In addition, this Site Profile includes the dose that might have occurred while the worker was not monitored, or the dose that might have been missed. Over the years new and more reliable scientific methods and protection measures have been developed. This Site Profile identifies methods needed to account for these changes. The analyses for this Site Profile used the NIOSH Interactive RadioEpidemiological Program (IREP) and Integrated Modules for Bioassay Analysis (IMBA) computer codes to evaluate doses.

Information on measurement uncertainties is an integral component of the NIOSH approach. This Site Profile describes the evaluation of uncertainty for WSP exposure and dose records.

1.2 SITE PROFILE DESCRIPTION

The Site Profile consists of this introductory document and five major TBDs: Site Description, Occupational Medical Dose, Occupational Environmental Dose, Occupational Internal Dosimetry, and Occupational External Dosimetry. Some of these have attachments that provide critical data for dose reconstructors. In some cases, data and information specific to the WSP were unavailable. In such situations, the analysis examined TBDs that describe similar processes at other facilities to discern the situation at the WSP.

1.2.1 Site Description

The WSP Site Description TBD (ORAUT-TKBS-0028-2) discusses facilities and processes used in the processing of uranium concentrates and other uranium compounds from 1957 through 1966. WSP operations played an important role in the development of U.S. nuclear power and nuclear weapons. These operations focused on processing uranium and thorium from feed stocks to metal and

intermediate products for use at other facilities. This TBD contains documentation to assist in the evaluation of worker dose from WSP operations and processes.

Site History and Operations

In April 1941, the Department of the Army acquired 17,232 acres surrounding what is now the Weldon Spring Chemical Plant (WSCP) as the site for an explosives production facility known as the Weldon Spring Ordnance Works. By 1949, the ordnance works had been shut down and all but about 2,000 acres had been transferred to the State of Missouri and the University of Missouri.

In 1956, approximately 220 acres of the former Ordnance Works were transferred to the U.S. Atomic Energy Commission (AEC) for construction and operation of a Feed Materials Plant (the WSCP) to process uranium and thorium ore concentrates; this plant operated from 1957 through 1966. This Site Profile refers to the raffinate pits that were originally part of the WSCP as the Weldon Spring Raffinate Pits (WSRP) because they were managed separately in the postoperational period. In 1958, a 9-acre quarry site was transferred to the AEC; this is referred to as the Weldon Spring Quarry (WSQ).

In August 1967, the WSCP was returned to U.S. Army control for construction of an herbicide production facility (U.S. Army 1976). However, the AEC retained custody of the WSQ and the WSRP. In 1985, the U. S. Department of Energy (DOE; an AEC successor agency) regained responsibility for the WSCP and began site characterization and remediation. The quarry was placed on the National Priorities List in 1987; the listing was expanded to include the chemical plant area and associated waste storage areas in 1989.

Prior to remediation, there were four periods of the WSP site and WSCP history: Plant acquisition and development (1954-1957), operations (1957-1966), initial cleanup (1967-1969), and maintenance (1969—1985). The periods of concern for this Site Profile Document (SPD) are those during which the U.S. Department of Energy (DOE) or its predecessor agencies (the U.S. Atomic Energy Commission until 1975 and the Energy Research and Development Administration until 1977) had contractors on some or all of the WSP. These include the operational period (1957 through 1966) and the monitoring and remediation periods (1975 to present). The monitoring period, from 1975 through 1984, applies only to the raffinate pits and quarry areas because DOE did not assume control of the chemical plant until 1985. Part 2 of this Site Profile contains a more detailed description of these activities.

During its operation by the Uranium Division of Mallinckrodt Chemical Works from 1957 to 1966, the WSCP processed four types of nuclear material: natural uranium, depleted uranium, slightly enriched uranium, and natural thorium (DOE 1986).

- Natural uranium was received as ore concentrates that were refined to extract the uranium, after which the uranium was converted to various compounds and metal forms and shipped off the site. The processing of natural uranium was a continuous operation during the life of the Plant.

- Uranium depleted in the ^{235}U isotope below its natural isotopic abundance ratio was received and processed on an intermittent basis. This form of uranium was used primarily in product development activities and flow sheet improvements. Its use was confined primarily to pilot plant activities.

- Uranium enriched to 1% or less ^{235}U by weight was received and processed on an intermittent basis. This form of uranium was typically received in scrap metal or residues. The uranium contents were recovered, processed to various chemical forms, and shipped off the site.

- Natural thorium was typically received in either a nitrate or oxide form and processed on an intermittent batch basis in the refinery and oxide production/firing systems.

1.2.2 Occupational Medical Dose

The WSP Occupational Medical Dose TBD (ORAUT-TKBS-0028-3) provides information about doses received by individual workers from X-rays that were required as a condition of employment. Three reports for Mallinckrodt workers (1955 – 1957) and WSP workers in the period from 1958 through 1966 reference the frequencies and types of X-ray examinations; however, no protocol for frequency of a chest X-ray as a function of job category is available nor is there reference to any other type of X-ray examination. For the post-1985 remediation period, chest X-rays might have been performed on some workers, but might not have been mandatory on an annual basis. Respirator users or asbestos workers were probably required to have a chest X-ray during the first medical examination, after which X-ray examinations occurred every 2 or 5 years depending on the work performed (Lopez 2004).

Although the TBD analysis assumed that WSP radiological practices followed standards of medical practice to minimize dose to the patient, types of equipment, technique factors, and machine calibrations are not known. Some medical X-ray examinations were apparently administered on the site, with films read by an offsite radiologist (Thornton and Johnson 1965). Another report indicates that chest X-ray examinations occurred at Barnes Hospital Laboratories (Mason 1955; Quigley and Mason 1963).

Organ dose estimates for occupational X-ray examinations administered at the WSP are provided for the period from 1955 through 1966 using default dose estimates from the *Technical Information Bulletin: Dose Reconstruction from Occupationally Related Diagnostic X-Ray Procedures* (ORAU 2003) for chest X-rays. These default values apply to any year before 1970, and assume minimal beam collimation and a half-value layer (HVL) of 2.5 mm Al.

During the post-1985 period, X-ray examinations were performed but records are not available, so default estimates for lateral and posterior-anterior chest x-rays have been provided from the *Technical Information Bulletin: Dose Reconstruction from Occupationally Related Diagnostic X-Ray Procedures* (ORAU 2003). The post-1985 estimates assume beam collimation and an HVL of 4.0 mm Al.

Doses to other exposed organs from chest X-ray examinations have been calculated. The calculated dose takes into account the uncertainty associated with machine type, examination frequency, and job classification. This TBD presents doses received by organs in the body in tabular form for more convenient reference by dose reconstructors.

1.2.3 Occupational Environmental Dose

The WSP Occupational Environmental Dose TBD (ORAUT-TKBS-0028-4) considers doses that workers received when working outside buildings; from inhalation of or direct exposure to radioactive materials in the air; and from direct exposure to radionuclides in the soil. Exposure to these sources can result in an internal dose to the whole body or individual organs from inhaling radioactive materials, or could result in a whole- or partial-body external dose from deposited radionuclides or submersion in a cloud of radioactive material.

The WSCP processed uranium (^{235,238}U) and thorium (^{232}Th) ore concentrates and some scrap metal during its operational period. Waste materials associated with uranium and thorium processing at the chemical plant and other facilities were disposed of in the quarry. Radiological risks associated with the ^{235}U decay series were probably much lower than those of the ^{238}U series because the abundance

of ^{235}U in natural uranium ore concentrates represents less than 5% of the activity in natural uranium, and because the WSP processed only a small amount of slightly enriched uranium.

Radionuclide concentrations in WSP outdoor areas are based on limited environmental measurements at the site. The total amount of uranium emitted to the atmosphere has been estimated from monitoring data (Meshkov et al. 1986) and from a nuclear materials balance study (DOE 1986). Based on methods and data in these two reports, the estimated uranium activity emitted from the Plant ranged between 1 and 5 Ci/yr. An estimate of radon release, based on the amount of uranium processed during the operational period, ranges from 12 to 34 Ci/yr, assuming radium activity was 1% of uranium activity, radon was in equilibrium with radium, and all radon was released. Beginning in 1981, annual environmental monitoring reports provided estimates of air concentrations of particulate radionuclides and of radon at the WSCP and WSQ. These estimates reflect emissions during the later maintenance period, and throughout remediation activities. The TBD analysis used these data to derive annual estimates of intake for 1957 to 2004.

Measured air concentrations of radon during the operational period are not reported in the literature. Therefore, a simplistic screening-level model was used to estimate air concentrations at the WSCP.

Because no site-specific ambient gamma data were available for the WSCP during the operational period, this analysis evaluated ambient dose rates for the Feed Materials Plant in Fernald, Ohio, as reported in ORAU (2004). The reported net average dose rate for 1956 to 1970 was 0.18 mrem/hr, or 1,576 mrem/yr for continuous exposure. When this dose rate estimate is applied to the WSP operational period, the WSP site background rate of 99 mrem/yr (Bechtel 1986) is added to derive an ambient dose rate of 1,675 mrem/yr for continuous exposure. This corresponds to a 2,000-hr exposure of 382 mrem. Between 1982 and 2000, thermoluminescent dosimeters monitored ambient exposure at many perimeter locations around the WSCP, the WSRP, and the WSQ. These data are summarized in this TBD, which summarizes estimated ambient onsite dose for the WSRP, WSCP, and WSQ for periods between 1957 and 2004.

1.2.4 Occupational Internal Dosimetry

The WSP Occupational Internal Dosimetry TBD (ORAUT-TKBS-0028-5) discusses the internal dosimetry program and develops estimates of potential intakes. Radionuclides of concern at the site include naturally occurring isotopes of uranium (^{234}U, ^{235}U, and ^{238}U) and their decay products (primarily ^{230}Th and ^{226}Ra). Due to the amount of material processed, the primary radionuclides of concern for internal radiation dose are the uranium isotopes. Because WSP processed some natural thorium, dose reconstructors should consider ^{232}Th and its decay products, ^{228}Ra and ^{228}Th.

The primary modes of intake were chronic and acute inhalation. The internal dosimetry program required routine monitoring of environmental radon and thoron and their decay products when an individual was likely to receive an annual intake of 10% or more of the annual limit of intake. According to Revision 7 of the Internal Dosimetry Program Technical Basis Manual (DOE 2001), that threshold was never exceeded. Bioassay (urine) data estimate the activity of the radionuclide excreted in the urine following an inhalation. This TBD discusses these data, including history, sensitivity, and pertinent nuances of methods and data.

Urine bioassay data represent the primary information available to quantify uranium intake for the worker who is the subject of a claim. However, data are not always available for individual workers. These data can be supplemented by workgroup monitoring data, because essentially continuous bioassay monitoring of a worker was simulated by sampling at least one worker in the group each week, with Monday – Friday – Monday sampling for “exposed” workers.

Workgroup data have been reconstructed from urine data for all WSP workers by cost center. Solubility classes for ^{234}U, ^{235}U, ^{238}U, ^{228}Th, ^{230}Th, and ^{232}Th are summarized by location. Descriptive statistics of uranium concentration in urine are summarized by year and by cost center for available worker records. For 1958, available uranium in urine data is summarized. A more detailed analysis of "Monday" and "Friday" urine samples is summarized for each year from 1959 through 1966.

No quantitative *in vitro* or *in vivo* bioassay results have been found for thorium. Based on the assumption that thorium operations at Fernald were reasonably similar to those at WSP, this TBD suggests the use of the methods used in the Fernald TBD to assess natural thorium intakes. Under these assumptions, the claimant-favorable assumption results in an annual intake of approximately 60 nCi of ^{232}Th per year.

1.2.5 Occupational External Dosimetry

The WSP Occupational External Dosimetry TBD (ORAUT-TKBS-0028-6) describes methods and concepts for measuring occupational external dose to workers. It provides technical data dose reconstructors can use to evaluate, with claimant-favorable assumptions, external occupational doses that can reasonably be associated with worker radiation exposures.

During the operational period, external exposure at WSP was monitored using a two-element film badge that could distinguish between gamma and beta exposure. During the post-1985 remedial action period, WSP had a DOELAP accredited dosimetry program. During operations, badges were assigned to all workers who had a reasonable expectation of receiving a radiation dose or who worked in a "badged" area. During the remedial action period, all workers on the site probably wore dosimeters.

Energy distributions for uranium processes were evenly split between the 30- to 250-keV range and the greater-than-250-keV range. For thorium processes, three-fourths of the photons were likely to be above 250 keV, with the remainder between 30 and 250 keV. Electron energies are all considered to have been greater than 15 keV. Neutron energies, if present, were probably spread between 0.1 and 2 MeV.

This TBD discusses the process used to evaluate measured film densities and determine dose, as well as a bias correction to be applied to WSP recorded dose values. It also discusses historical administrative practices and explores common issues such as the handling of zero readings, missing entries, and changes in exposure geometry. It explores dosimetry of photons, neutrons, and electrons in some detail. It discusses treatment of data for unmonitored individuals. Other topics include limits of detection, dose-to-organ-dose conversion factors, and measurement uncertainty.

During the operational period of the Plant, maximum missed annual photon doses might have been as high as 600 mR if badges were exchanged on a biweekly basis. Monthly and quarterly exchanges are estimated to have maximum missed annual photon doses of 300 and 100 mR, respectively. During the remedial action period, missed annual photon doses were probably no higher than 60 mrem for monthly exchanges.

During the operational period, the estimated maximum missed electron dose for weekly badge exchanges was as high as 2,080 mrep annually. Semimonthly and monthly exchanges would result in missed annual electron doses as high as 960 and 480 mrep, respectively. Monthly badge exchanges during the remedial action period would have led to maximum missed annual doses of no more than 60 mrem.

In summary, all five technical TBDS for WSP provide, to the extent that information specific to the Plant was available, detailed information, data, explanations, and references for use during the reconstruction of worker doses (including WSQ, WSRP, and WSCP workers). In lieu of information specific to WSP, the analysis examined TBDs that describe similar processes at other facilities to estimate doses at the WSP. The Weldon Spring TBD User Guide (ORAUT-USGD-0028) combines key data from each TBD into a single document to enable more efficient use of the information by dose reconstructors.

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