Document Title:	Document Number:	ORAUT-TKBS-0054
Summary Site Profile for the S-50 Liquid Thermal Diffusion Project	Revision:	00
	Effective Date:	12/08/2006
	Type of Document:	TBD
	Supersedes:	None

Subject Experts: Elizabeth A. Langille, Paul A. Szalinski, and Bill R. Thomas

Approval:	Signature on File Paul A. Szalinski, Document Owner	Approval Date:	12/04/2006
Approval:	Signature on File John M. Byrne, Task 3 Manager	Approval Date:	12/04/2006
Concurrence:	Signature on File Edward F. Maher, Task 5 Manager	Concurrence Date:	12/05/2006
Concurrence:	Signature on File Kate Kimpan, Project Director	Concurrence Date:	12/06/2006
Approval:	Brant A. Ulsh Signature on File for James W. Neton, Associate Director for Science	Approval Date:	12/08/2006

☒ New ☐ Total Rewrite ☐ Revision ☐ Page Change

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

PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
12/08/2006	00	New document to describe the S-50 Liquid Thermal Diffusion Project to enable the preparation of dose reconstructions. First approved issue. Attributions and Annotations added to document. Incorporates formal internal and NIOSH review comments. There is no change to the assigned dose and no PER is required. Training required: As determined by the Task Manager. Initiated by Paul A. Szalinski.

TABLE OF CONTENTS

LIST OF TABLES

ACRONYMS AND ABBREVIATIONS

cGy	centigray
d	day
DOE	U.S. Department of Energy
DCF	dose conversion factor
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
ESE	entrance skin exposure
ft	foot
Gy	gray
HVL	half-value layer
ICRP	International Commission on Radiological Protection
in.	inch
IREP	Interactive RadioEpidemiological Program
kV	kilovolt
kVp	kilovolts peak, applied kilovoltage
LAT	lateral
lb	pound
mm	millimeter
NEPA	Nuclear Energy for the Propulsion of Aircraft (Project)
NIOSH	National Institute for Occupational Safety and Health
ORAU	Oak Ridge Associated Universities
PA	posterior-anterior
POC	probability of causation
psig	pounds per square inch gage
R	roentgen
S-50	S-50 Liquid Thermal Diffusion Project
SEC	Special Exposure Cohort
SRDB	Site Research Database
TBD	technical basis document
U.S.C.	United States Code
§	section or sections

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) define "performance of duty" for DOE employees with a covered cancer or restrict the "duty" to nuclear weapons work.

As noted above, the statute 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 contains an exclusion with respect to the Naval Nuclear Propulsion Program, 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 dosimetry monitoring results are considered valid for use in 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:

- Radiation from naturally occurring radon present in conventional structures
- Radiation from diagnostic X-rays received in the treatment of work-related injuries

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

1.1 PURPOSE

The purpose of this document is to provide guidance for dose reconstruction for EEOICPA-covered employees who participated in S-50 Liquid Thermal Diffusion Project (S-50) operations, specifically for non-SEC cancers and those presumptive cancer claims for workers who have fewer than 250 workdays under this employment or in combination with workdays within the parameters established for other classes of employees in the SEC.

An SEC class established for S-50 includes all employees of DOE predecessor agencies and their contractors and subcontractors who worked at S-50 from July 9, 1944, through December 31, 1951, who were monitored or should have been monitored for exposure to ionizing radiation (NIOSH 2006). This SEC applies to workers with covered cancers who were employed for a number of workdays, aggregating at least 250 workdays either solely under this employment or in combination with workdays within the parameters established for other classes of employees included in the SEC.

1.2 SCOPE

This site profile consists of seven sections: (1) Introduction, (2) Site Description, (3) Occupational Medical Dose, (4) Occupational Environmental Dose, (5) Occupational Internal Dose, (6) Occupational External Dosimetry, and (7) Attributions and Annotations.

2.0 SITE DESCRIPTION

2.1 S-50 LIQUID THERMAL DIFFUSION PLANT

The S-50 Liquid Thermal Diffusion Plant was a wartime uranium enrichment facility constructed in 1944 adjacent to the K-25 facility in Oak Ridge, Tennessee by H. K. Ferguson Company and operated by Fercleve Corporation, a wholly owned subsidiary of H. K. Ferguson Company that was organized for the sole purpose of operating the Plant. Groundbreaking for the facility was on July 9, 1944, and construction was complete on October 31, 1944. The main process building dimensions were 522 ft long by 62 ft wide by 75 ft high; the building had a concrete floor and foundation, and steel frames, sides, and roof (MED 1947). Uranium enrichment began on September 16, 1944, before construction was complete. Thermal diffusion operations shut down on September 9, 1945 (DOE 2005).

There was a tremendous amount of emphasis placed on high production output at this facility. Processed uranium from the Plant was used as feed material for the Y-12 facility, where it was further enriched; some of this material was used in the bomb dropped over Hiroshima (“Little Boy”). Operations at S-50 generally continued around the clock. The number of individuals employed by Fercleve Corporation reached a maximum of more than 1,500 in April 1945 (MED 1947).

Feed material came from Harshaw Chemical Company of Cleveland, Ohio, in nickel shipping containers as uranium hexafluoride (UF_6). The liquid thermal diffusion process at S-50 increased ^{235}U enrichment from natural (0.71%) to 0.85% (MED 1947).

The process to enrich uranium at S-50 consisted of multiple columns, each of which contained three concentric pipes. High-pressure (1,000-psig) steam passed through the innermost nickel pipe, which was inside a copper pipe. UF_6 was batch-charged into the gap between the nickel and copper pipes at about 1,500 psig. The nickel and copper pipes were inside the outermost steel pipe. Cold water passed between the steel pipe and the outer wall of the copper pipe. The enrichment process utilized convective flow, whereby the lighter ^{235}U molecules tended to move upward along the hot nickel pipe

wall while the heavier ^{238}U molecules moved downward along the cold copper wall (MED 1947). A graph of the production output from S-50 (Percentage of Original Theoretical Maximum Output) showed the racks operated at less than 5% until January 1945, at which time the production increased gradually to a maximum of approximately 90% in June 1945 (MED 1947).

Losses of UF_6 were common during S-50 operations, with UF_6 often escaping into the air or cooling water (MED 1947). The losses usually resulted from internal or external breaks in columns or other parts of the process, which were caused by failure of the materials under the high operating pressures. Other losses resulted from improper handling of open connections and from operational mistakes due, in part, to the number of new employees at the facility and the emphasis on high production rates. From March through July 1945, monthly losses of UF_6 ranged from 247 to 1,826 lb (DOE 2005). Accountability records showing losses for other months of operation are unavailable. The released UF_6 would rapidly oxidize and form uranyl fluoride (UO_2F_2) (DOE 2005), which would either exhaust through the building roof or settle to the process building floor. Operators were required to have a gas mask on their persons at all times for emergencies (MED 1947).

The S-50 Plant ceased enrichment operation in September 1945, shortly after the war ended (MED 1947). The uranium enrichment process used at S-50 was unique in that it was the only production-scale liquid thermal diffusion facility ever built. S-50 closed because it had become evident that the liquid thermal diffusion process would not be competitive with the gaseous diffusion process.

Disassembly of the S-50 process equipment was done in the late 1940s, at which time it was removed from the main process building and transported to the K-25 Powerhouse Area, where it was stored for some time before being either salvaged or buried (DOE 2005).

2.2 NUCLEAR ENERGY FOR THE PROPULSION OF AIRCRAFT PROJECT

From May 1, 1946, through December 31, 1951, the S-50 facilities were used to conduct feasibility studies for the Nuclear Energy for the Propulsion of Aircraft (NEPA) project. The NEPA operations were conducted by Fairchild Engine and Aircraft Corporation (NIOSH 2006). The NIOSH Site Research Database (SRDB) and Internet searches yielded no data that described specific NEPA-related activities or the radiological conditions of the buildings occupied during these post-1945 operations.

However, some information was obtained through the telephone interviews with S-50 claimants and one follow-up interview with an S-50 claimant (NIOSH 2006). It was learned from these interviews that S-50 employees fabricated blocks that contained enriched uranium and graphite as potential fuel for a nuclear-powered airplane. In addition, the employees recovered enriched uranium using nitric acid solutions. The recovered enriched uranium was used to fabricate the uranium and graphite blocks. One interviewee stated, “the place was highly radioactive given the enriched ^{235}U they were handling.” According to documented interviews with other claimants, activation analysis studies might have taken place at S-50 on items that had been irradiated at the X-10 Plant. In addition, employees during this period might have been exposed to contamination remaining from the earlier liquid thermal diffusion projects in this facility; NIOSH has no records that document decontamination of the facility at the conclusion of those operations (NIOSH 2006).

3.0 OCCUPATIONAL MEDICAL DOSE

NIOSH (2006) concluded that adequate reconstruction of medical dose for S-50 workers is possible by using assumptions that are favorable to claimants in the TBDs for other Oak Ridge facilities (ORAUT 2004, 2006a,b for K-25, X-10, and Y-12, respectively) and the use of applicable protocols

specified in the complex-wide Technical Information Bulletin for dose reconstruction from occupationally related X-ray procedures (ORAUT 2005).

It is assumed that the X-ray examination frequency and protocol was similar to that at K-25 because the S-50 facility was on the K-25 site (MED 1947). There are no specific data available on the S-50 occupational medical evaluation program. Assumptions about X-ray examinations at S-50 derive from K-25 knowledge. Table 3-1 lists the nominal frequency of examinations over the years at S-50, assuming the same protocol as that at K-25, during which work-related X-rays were required (ORAUT 2004). Some workers might have received occupational X-rays on a schedule different from that listed in the table. The reconstruction of occupational dose should include all occupational X-rays at the frequency listed in Table 3-1 unless the individual-specific frequency is known and is more frequent than that in the table.

Table 3-1. Frequency of occupational chest X-rays

Period	Frequency	Comment
1944–1945	Annual[a]	All employees
1946–1951	Annual[b]	All employees

a. Monthly for some workers with potential for exposure to uranium dust.
b. Turner, James E., ORAU Team Consultant to Integrated Environmental Management, Inc., 2006. Every few months for some workers with potential for exposure to uranium dust.

This document assumes that S-50 followed K-25 medical practices, which followed the standards of radiology practice during the 1930s and 1940s (ORAUT 2004). The amount of dose received depends on the type of equipment, the technique factors, and the number of examinations typical in the early years (Cardarelli et al. 2002). The earliest X-rays at K-25 used the photofluorographic technique. Photofluorography had widespread use throughout the United States for tuberculosis screening in the 1930s and was state-of-the-art medical technology when work began at the gaseous diffusion plant as part of the Manhattan Project.

Table 3-2 lists the X-ray equipment used at K-25 and the entrance skin exposure (ESE) produced by the machines (Cardarelli et al. 2002). The ESEs in Table 3-2 are from actual measurements made and documented in the literature.

Table 3-2. X-ray equipment (Cardarelli 2002).

Period	X-ray machine	kVp	Assumed HVL (mm Al eq)	Image size (in.)	Entrance skin exposure (cGy)
					PA
1944–1951	GE KX-10	80	2.5	4 × 5	2.488[a]

a. Quinn (1945); Cardarelli (2000).

Estimated organ doses for posterior-anterior (PA) chest X-rays were based on the dose conversion factors in International Commission on Radiological Protection (ICRP) Publication 34 (ICRP 1982). Lateral (LAT) chest x-rays were not performed. Organ doses from LAT chest radiography were greater than those from the corresponding PA doses based on the greater milliampere-second exposure per radiograph and the smaller source-to-skin distance.

ICRP (1982) contains tables of average absorbed dose (milligray) in selected organs for selected X-ray projections at a 1-Gy entrance kerma (i.e., air kerma without backscatter) for selected projections and beam qualities [i.e., various half-value layers (HVLs)]. These tables list the basic dose conversion factors for converting air kerma to organ dose. Air kerma was obtained from Table 3-2 for machine, projection, and period by assuming R = cGy (kerma). This assumption is

conservative [1]. The estimation is made by Equation 3-1, where *ESE* is the entrance skin exposure in roentgens (numerically equivalent to centigray or rem), *DCF* is the dose conversion factor (stated as milliroentgen per roentgen, milligray per gray, or millirem per rem), and *D* is the dose in millirem.

$$ESE \times DCF = D \qquad (3\text{-}1)$$

Table 3-3 lists the results of Equation 3-1 for the organs listed in ICRP (1982). The results of Table 3-3 assume poor collimation, which means that some organs are included in the primary beam that would not normally be had the beam been properly collimated.

Table 3-3. Organ dose[a] per X-ray procedure for X-ray examinations from 1944 to 1951.

Organ	View	**1944–1951** GE Model KX-10 Photofluorographic 4- × 5-in. 2.5-mm Al dose (rem)
Thyroid	PA	4.33E-01[b]
Eye/brain	PA	7.96E-02[c]
Ovaries	PA	2.07E-02[d]
Testes	PA	4.15E-03[d]
Lungs (male)	PA	1.04E+00
Lungs (female)	PA	1.12E+00
Breast	PA	1.22E-01
Uterus	PA	3.23E-03
Bone marrow (male)	PA	2.29E-01
Bone marrow (female)	PA	2.14E-01
Skin	PA	3.36E+00[e]

a. Dose conversion factors from ICRP (1982, Tables A.2 through A.9).
b. Dose conversion factor for anterior-posterior cervical spine multiplied by depth dose correction factor of 0.2.
c. Dose conversion factor for PA chest.
d. The ovaries and testes values were obtained as follows: There are no DCFs in ORAUT (2005) for these organs at the early time. What was done was to multiply the generic organ doses (ORAUT 2005, Table 6-5, p. 22) by the ratio of the K-25 ESE (2.488 cGy from ORAUT 2004, Table 3.2-1) [2] and the generic entrance kerma of 3.0 cGy (ORAUT 2005, p. 20). This gives for the ovaries and testes, respectively,
   2.5E-02 × (2.488 ÷ 3) = 2.07E-02 and
   5.0E-03 × (2.488 ÷ 3) = 4.15E-03.
e. Entrance kerma multiplied by a backscatter factor of 1.35.

The Interactive RadioEpidemiological Program (IREP) computer program specifies organs for which there are no ICRP (1982) dose conversion factors. Organs not listed in Table 3-3 can usually be assigned doses by analogy of anatomical location – thorax, abdomen, and head/neck. The ICRP (1982) reference organs in these locations are lung, ovaries, and thyroid, respectively, as listed in

Table 3-4. The dose for the analogous organ in Table 3-4 is assumed to be equal to that for the reference organ listed in Table 3-3 for the type of X-ray examination. Such a dose assignment will be conservative because the analogue organ is more distant or more shielded than the reference organ.

Table 3-4. Reference organs for IREP organs not included in ICRP Publication 34.

Anatomical location	ICRP 34 reference organ	IREP organ analogues
Thorax	Lung	Thymus, esophagus, stomach, bone surface, liver/gall bladder/spleen, remainder organs
Abdomen	Ovaries	Urinary/bladder, colon/rectum
Head and neck	Thyroid (unless otherwise specified)	Eye, brain

4.0 OCCUPATIONAL ENVIRONMENTAL DOSE

NIOSH has been unable to find any environmental monitoring data from S-50 operations. NIOSH determined in the *SEC Petition Evaluation Report* (NIOSH 2006) that it lacks sufficient personnel monitoring, air monitoring, or source term data to adequately reconstruct any internal or external occupational exposures at the S-50 Plant. As a consequence, NIOSH finds that it is not feasible to estimate with sufficient accuracy the radiation doses from internal or external ambient exposures at the S-50 Plant.

5.0 OCCUPATIONAL INTERNAL DOSE

Review of the available information concludes that bioassays were not obtained during the years of concern (1944 to 1951). This conclusion is based on the lack of information on bioassays and monitoring and the recommendations for treatment of exposures to workers and medical personnel when a worker “breathed process material” (MED 1947; Various ca. 1945).

NIOSH determined in the *SEC Petition Evaluation Report* (NIOSH 2006) that it lacks sufficient personnel monitoring, air monitoring, or source term data to adequately reconstruct the internal exposures at S-50. As a consequence, NIOSH finds that it is not feasible to estimate with sufficient accuracy the radiation doses from internal exposures during S-50 operations.

6.0 OCCUPATIONAL EXTERNAL DOSE

NIOSH considers the available external monitoring data and methods inadequate for performing external dose reconstruction at S-50. NIOSH determined in the *SEC Petition Evaluation Report* (NIOSH 2006) that it lacks sufficient personnel monitoring, area monitoring, or source term data to adequately reconstruct the external exposures at S-50. As a consequence, NIOSH finds that it is not feasible to estimate with sufficient accuracy the radiation doses from external exposures during S-50 operations.

7.0 ATTRIBUTIONS AND ANNOTATIONS

Where appropriate in this site profile, bracketed callouts have been inserted to indicate information, conclusions, and recommendations provided to assist in the process of worker dose reconstruction. These callouts are listed here in the Attributions and Annotations section with information provided to identify the source and justification for each associated item. Conventional references are provided in the References section that link data, quotations, and other information to documents available for review on the NIOSH Project computer network.

[1] Cember, Herman, 1996, *Introduction to Health Physics*, McGraw-Hill, New York, New York. This document describes the relationship of kerma to dose.

[2] Turner, James E., ORAU Team Consultant to Integrated Environmental Management, Inc., 2006.
The value 2.488 is called ESE in ORAUT (2004, Table 3-2-1), which one might assume to mean roentgens of exposure. But because the unit centigray is specified in the table, the given value was assumed to be the kerma. The distinction would introduce a factor of 0.876 rad for an exposure of 1 R.

REFERENCES

Cardarelli, J. J., II, 2000, *A Potential Consequence of Excluding Work-Related X-Ray Exposures when Computing Cumulative Occupational Radiation Dose at a Uranium Enrichment Plant*, Dissertation, University of Cincinnati, Cincinnati, Ohio. [SRDB Ref ID: 11105]

Cardarelli, J., H. Spitz, C. Rice, R. Buncher, H. Elson, and P. Succop, 2002, "Significance of Radiation Exposure From Work-Related Chest X-Rays for Epidemiological Studies of Radiation Workers," *American Journal of Industrial Medicine*, volume 42, pp. 490–501. [SRDB Ref ID: 4037, 11103, 11104]

ICRP (International Commission on Radiological Protection), 1982, *Protection of the Patient in Diagnostic Radiology*, Publication 34, Pergamon Press, Oxford, England.

MED (Manhattan Engineer District), 1947, *Manhattan District History Book VI, Liquid Thermal Diffusion (S-50) Project*, May 21. [SRDB Ref ID: 8623; contains Export Controlled Information]

NIOSH (National Institute for Occupational Safety and Health), 2006, *SEC Petition Evaluation Report, Petition SEC-00060*, Office of Compensation Analysis and Support, Cincinnati, Ohio, August 4.

ORAUT (Oak Ridge Associated Universities Team), 2004, *Technical Basis Document for the K-25 Site – Occupational Medical Dose*, ORAUT-TKBS-0009-3, Rev. 00, Oak Ridge, Tennessee, June 29.

ORAUT (Oak Ridge Associated Universities Team), 2005, *Dose Reconstruction from Occupationally Related Diagnostic X-Ray Procedures*, ORAUT-OTIB-0006, Rev. 03 PC-1, Oak Ridge, Tennessee, December 21.

ORAUT (Oak Ridge Associated Universities Team), 2006a, *Technical Basis Document for the Y-12 Site – Occupational Medical Dose*, ORAUT-TKBS-0014-3, Rev. 00 PC-3, Oak Ridge, Tennessee, April 18.

ORAUT (Oak Ridge Associated Universities Team), 2006b, *Technical Basis Document for the Oak Ridge National Laboratory – Occupational Medical Dose*, ORAUT-TKBS-0012-3, Rev. 01 PC-1, Oak Ridge, Tennessee, July 21.

Prince, R. P., 2005, *Compilation of Historical Document Reference Sources for Project S-50, Liquid Thermal Diffusion Plant*, ETTP-736, Bechtel Jacobs Company, East Tennessee Technology Park, Oak Ridge, Tennessee, May. [SRDB Ref ID: 17169]

Quinn, B., 1945, “Mass Miniature Radiography of the Chest using 4x5 [Inch] Film,” *Radiography*, volume 11, number 125, pp. 33–37.

Various authors, ca. 1945, collection of memoranda and surveys related to radiation hazards and medical treatment at S-50. [SRDB Ref ID: 16643]