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ADVISORY BOARD ON
RADIATION AND WORKER HEALTH

National Institute for Occupational Safety and Health

SC&A'S EVALUATION OF ORAUT-OTIB-0006, REVISION 05, "DOSE RECONSTRUCTION FROM OCCUPATIONAL MEDICAL X-RAY PROCEDURES"

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ABBREVIATIONS AND ACRONYMS

ABRWH	Advisory Board on Radiation and Worker Health
AP	anterior-posterior
cGy	centigray
DCF	dose conversion factor
DOE	U.S. Department of Energy
ENSD	entrance skin dose
EXSD	exit skin dose
Gy	gray
ICD-9	International Classification of Diseases, Ninth Edition
ICRP	International Commission on Radiological Protection
kerma	kinetic energy released per unit mass
LAT	lateral
Lum. Vert.	lumbar vertical
mGy	milligray
NIOSH	National Institute for Occupational Safety and Health
ORAUT	Oak Ridge Associated Universities Team
OTIB	ORAUT technical information bulletin
PA	posterior-anterior
PFG	photofluorography
RSD	remote skin dose
SID	source-to-image distance
SRDB	Site Research Database

1.0 INTRODUCTION AND BACKGROUND

As a result of tasking on December 3, 2018, after the Subcommittee for Procedure Reviews meeting of October 31, 2018, SC&A has performed a technical review of ORAUT-OTIB-0006, Revision 05, *Dose Reconstruction from Occupational Medical X-Ray Procedures* (NIOSH 2018, referred to as "OTIB-0006").

This report presents SC&A's evaluation of the technical approach and documentation in OTIB-0006.

2.0 OVERVIEW OF ORAUT-OTIB-0006

The following is a brief outline of OTIB-0006.

- **Purpose** – According to page 9 of OTIB-0006, the purpose of the document "*is to describe medical X-ray dose reconstruction in general, and to provide organ dose equivalents that can be used complex-wide when site-specific information is specious or not available*."

- **Technical Factors that Affect Medical X-Ray Dose** – Section 3.0 provides a brief discussion of the technical factors that affect medical x-ray dose, which are:

  - Kilovoltage, filtration, and type of high-voltage generator
  - Current and exposure time
  - Distance
  - Collimation
  - Screens, grids, and other factors

- **Determining Incident Air Kerma** – Section 4.0 provides a brief discussion of the methods used to determine incident air kinetic energy released per unit mass (kerma), which are:

  - Using beam measurements
  - Using technical factors
  - Using published values from medical literature

  Table 4-1 provides a lists of incident air kerma used in OTIB-0006.

- **Determining Dose Equivalent to Organs Other than Skin** – Section 5.0 discusses the basic concept of deriving the main objective of OTIB-0006 for organ dose reconstruction: the organ dose equivalent, which is the incident air kerma multiplied by the organ dose conversion factor (DCF), as shown in Equation 5-1 on page 18 of OTIB-0006.

  Section 5.0 also addresses poorly collimated beam issues (through 1970) and summarizes the recommended organ DCFs as a function of the x-ray procedure performed using poorly collimated x-ray beams. Attachment B of OTIB-0006 provides a more detailed

and complete listing of recommended organ DCFs as a function of the x-ray procedure performed.

- **Determining Dose Equivalent to Skin –** Section 6.0 discusses the concept of deriving the main objective of OTIB-0006 for skin dose reconstruction: the entrance skin dose (ENSD). The equation for deriving ENSD is provided in Equation 6-1 on page 23 of OTIB-0006.

  Section 6.0 also addresses the exit skin dose (EXSD), the dose to the skin outside, but near, the primary beam, and the remote skin dose (RSD).

- **Types and Frequency of X-Ray Screening –** Section 7.0 summarizes the most commonly used occupational medical procedures, which are:

  - Radiographic chest
  - Chest photofluorographic
  - Chest fluoroscopy
  - Lumbar spine
  - Pelvis
  - Thoracic and cervical spine

- **Uncertainty Analysis –** Section 8.0 discusses the derivation of an overall uncertainty of ±30% in occupational medical x-ray dose assignment.

- **Attachment A –** This attachment lists the name of the organ to use for a given International Classification of Diseases, Ninth Edition (ICD-9), code as a function of the type of x-ray procedure performed, which includes:

  - Chest: Tables A-1 and A-2
  - Lumbar spine: Table A-3
  - Thoracic spine: Table A-4
  - Cervical spine: Table A-5

- **Attachment B –** This attachment lists the DCFs, skin dose guidance, and organ or skin dose numerical values as a function of the type of x-ray procedure performed. The attachment includes:

  1. **DCFs:**
     - Thoracic and cervical spine: Table B-1
     - Chest: Tables B-2 and B-3
  2. **Skin dose guidance:**
     - Chest through 1970: Table B-4
     - Lumbar spine and pelvis: Table B-5
     - Thoracic spine: Table B-6
     - Cervical spine: Table B-7

- Chest after 1970: Table B-8
- Lumbar spine: Table B-9

3. **Organ dose (in units of rem):**

- Chest view: Table B-10
- Lumbar spine and pelvis view: Table B-13
- Thoracic and cervical spine view: Table B-15

4. **Skin dose (in rem):**

- Chest view: Tables B-11 and B-12
- Lumbar spine and pelvis view: Table B-14
- Thoracic and cervical spine view: Table B-16

3.0 SC&A'S EVALUATION OF ORAUT-OTIB-0006

The following sections summarize SC&A's evaluation of the technical approach and documentation used in OTIB-0006.

3.1 EVALUATION OF THE TECHNICAL APPROACH USED IN ORAUT-OTIB-0006

SC&A evaluated the technical approach the National Institute for Occupational Safety and Health (NIOSH) used in OTIB-0006 to derive dose reconstruction parameters for assigning dose from occupational medical x-ray. The following major areas that could affect dose reconstruction were evaluated.

3.1.1 Equations and Units

SC&A analyzed the equations and units used in OTIB-0006 and found them to be generally applicable and correct, with one observation.

Observation 1: Need Clarification for DCF Units in Attachment B – Tables B-1, B-2, and B-3 (captions on pages 87, 88, and 89, respectively) list DCFs for various x-ray projections in units of "*(mGy/Gy × 10^{-3} rem-Gy/cGy-mGy)*" where Gy = gray, cGy = centigray, and mGy = milligray.

It is not obvious what unit the multiplication factor of 10^{-3} applies to and why it is there, because 1.0 rem is equal to 1.0 cGy for photon dose, and there are units of mGy/mGy and Gy/Gy that cancel each other out.

3.1.2 Terminology

SC&A found the terminology used in OTIB-0006 to be consistent with other documents used in assigning occupational medical x-ray dose, such as ORAUT-PROC-0061, Revision 04, *Occupational Medical X-Ray Reconstruction* (NIOSH 2017), and ORAUT-OTIB-0005, Revision 05, *Internal Dosimetry Organ, External Dosimetry Organ, and IREP Model Selection by ICD-9 Code* (NIOSH 2012).

3.1.3 Technical Information

SC&A analyzed the technical information presented in OTIB-0006 and found it to be applicable and mostly correct. However, several areas appeared to need clarification or more complete information. These are discussed in the following observations.

Observation 2: Need Clarification for Changing Chest Thickness – OTIB-0006 Table 3-1 lists the body part thickness for various x-ray procedures. Table 3-1 lists 24 centimeters (cm) for the thickness of the chest and abdomen; Footnote a of Table 3-1 states this value without citing a reference in the footnote. The description of revisions on page 3 of OTIB-0006 states:

> *Changed part thickness in Table 3-1 for anterior-posterior and posterior-anterior projections to 24 cm, except the cervical spine.*

Other sources list the chest thickness as ranging from 20 cm to 25 cm (Cahoon 1961, PDF page 33), and 20 cm to 26 cm (Kereiakes and Rosenstein, 1980, PDF pages 34–35). While a selection of 24 cm for the standard chest thickness is reasonable, it would be helpful to clarify the reasoning for changing the value from 23 cm in the previous ORAUT-OTIB-0006, Revision 04 (NIOSH 2011), to 24 cm in OTIB-0006, Revision 05.

Observation 3: Difference in Source-to-Image Distance – OTIB-0006 Table 3-1 lists the source-to-image distance (SID) for various x-ray procedures. For a cervical spine lateral procedure, Table 3-1 lists the SID as 72 inches/183 cm, with Footnote d stating:

> *The 72-in.* [183 cm] *SID is used for the LAT cervical spine to reduce magnification.*

However, International Commission on Radiological Protection (ICRP) Publication 34 (ICRP 1982), Table A9, PDF page 36, lists a SID of 102 cm for a cervical spine view. The use of a SID of 183 cm in OTIB-0006 instead of 102 cm needs further clarification.

Observation 4: Need References and Derivation of Kerma Values in Table 4-1 – OTIB-0006 Table 4-1 lists incident air kerma values for various x-ray procedures. However, while some of the footnotes provide site research database (SRDB) references, most do not provide PDF page numbers. These are generally large documents and PDF page numbers would be very helpful. Additionally, it would be helpful to indicate the numerical value of the original data used, such as the number of milliroetgen, etc., used to derive the resulting kerma values listed in Table 4-1. As it presently stands, it is very difficult to use the references listed to verify the values recommended in Table 4-1.

Observation 5: Thoracic and Cervical Spine Dose Assignments after 1970 Need Clarification – Table B-1 lists DCF values for determining dose equivalents from thoracic and cervical spine procedures through 1970. OTIB-0006 provides DCF values *after* 1970 for other x-ray procedures, such as for the chest. It needs to be clarified if dose from thoracic and cervical spine procedures are to be assigned after 1970, since DCFs are not provided post-1970 for thoracic and cervical spine procedures.

Observation 6: Breast Dose Reference Needs Clarification – OTIB-0006 Table B-3, Footnote e on page 89, and Table B-13, Footnote f on page 108, both list a reference to Huda and Bissessur (1990) for deriving dose to the breast. However, Huda and Bissessur (1990) only mention the breast in Table II, PDF page 5, and lists dose fraction values for the breast as a function of x-ray procedure. Dose fraction values for the breast listed in Huda and Bissessur relevant to Tables B-3 and B-13 of OTIB-0006 are 0.10 for the lumbar-spine anterior-posterior procedure, and 0.00 for lumbar-spine lateral and pelvis anterior-posterior procedures. It is not obvious how the dose values for the breast in Table B-13, page 107, were derived using the dose fractions from the Huda and Bissessur (1990) reference.

Observation 7: Need to Retain Important Information from Attachment C of ORAUT-PROC-0061 – There are three situations regarding the amount of information provided for occupational medical dose reconstruction in a site's profile document:

1. **Site profile provides complete skin dose information for the various skin locations –** In this situation, the skin doses in OTIB-0006 and information in Attachment C of ORAUT-PROC-0061, Revision 03, *Occupational Medical X-ray Dose Reconstruction for DOE Sites* (NIOSH 2010), are not needed.

2. **Site profile does not provide any occupational medical dose data –** In this situation, the skin doses in OTIB-0006 can be used.

3. **Site profile provides some skin dose information** – Some site profiles provide basic information on skin dose, such as ENSD, but do not provide detailed dose values as is contained in Tables B-10 through B-16 of OTIB-0006 for various skin cancer locations. Since the ENSD for that site may be different than that recommended in OTIB-0006, Tables B-10 through B-16 of OTIB-0006 would not be applicable. It then becomes necessary to manually calculate the EXSD, RSD, and the ENSD near but outside the primary beam, using equations provided on page 20 of ORAUT-PROC-0061, Revision 03 (NIOSH 2010), in conjunction with data in Tables C-3 and C-4 of ORAUT-PROC-0061, Revision 03. However, it appears that this necessary information in Attachment C of ORAUT-PROC-0061, Revision 03, is being phased out without being retained in either ORAUT-PROC-0061, Revision 04 (NIOSH 2017), or OTIB-0006. The description of changes on page 2 of ORAUT-PROC-0061, Revision 04 (NIOSH 2017), states:

> *Revision initiated to ensure consistency with ORAUT-OTIB-0006. Appendix C on the calculation of skin dose* ***deleted*** *as duplicate of ORAUT-OTIB-0006 content.* [Emphasis added.]

SC&A recommends that the essential information for skin dose that is contained in Attachment C, pages 20-22 of ORAUT-PROC-0061, Revision 03 (NIOSH 2010), be retained and carried forward for further use in dose reconstructions for sites without detailed skin dose data.

3.2 Evaluation of Documentation Used in ORAUT-OTIB-0006

SC&A evaluated the documentation used in OTIB-0006 for assigning occupational medical x-ray dose and found the document is well written and informative. It is a relatively complex and large document, and, as such, SC&A found several items of documentation that need to be corrected or clarified.

- Page 3: The description in this paragraph of the revisions that took place in OTIB-0006, Revision 05, is difficult to follow because many of the tables are labeled incorrectly (it applies the old table numbers from Attachment A of Revision 04 [NIOSH 2011] to the new tables in Attachment B in Revision 05). The following are some examples:

  - "*Added dose for bone surface anterior-posterior lordotic in Table B-7 for 1971 to 1985*" – It appears that this should read Table B-2, not Table B-7.

  - "*Corrected Table B-10 entrance skin dose through 1970 for anterior-posterior and lateral lumbar spine to account for proper backscatter factor.*" – It appears that this should read Table B-13, not Table B-10.

  - "*Corrected Table B-11 lateral lumbar spine through 1970 for back torso: buttocks (iliac crest and below) to include E-02.*" – It appears that this should read Table B-14, not Table B-11.

  - "*Corrected Table B-13 fourth column title to left posterior oblique thoracic spine.*" – It appears that this should read Table B-16, not Table B-13, and the fifth column, not the fourth column (counting all columns from left to right).

  - "*Corrected Table B-1 to B-3 anterior-posterior lordotic chest dose conversion factors and added footnote.*" – It appears that this should read Table B-2, not Table B-1 to B-3, because the term "AP [anterior-posterior] lordotic" only appears in Table B-2.

- Page14: The last paragraph on this page states:

  > *An assumption of poor collimation of radiographs through 1970 might necessitate the use of DCFs from ICRP Publication 34 (ICRP 1982)* ***other than those for the intended examination****, because ICRP Publication 34 DCFs are based on properly collimated beams.* [Emphasis added.]

  Additionally, the captions of Tables A-2, A-3, A-4, and A-5 use the terminology:

  > *Selection of organs for* [various procedures] *X-ray dose reconstruction based on ICD-9 code when different organ selection required based on view*

  SC&A assumes that this means that the dose reconstructor may need to use a different organ than would normally be used because of the x-ray procedure (i.e., view) used in the exam. However, this is not very obvious from the wording and it would be helpful to

have this concept more clearly stated. It would also be beneficial to provide an example or more details regarding appropriate organ selection.

- Page 26: The second paragraph on this page states:

  > *The incident air kerma for a LAT chest X-ray is assumed to be 2.5 times that of a PA chest, a conservative value based on measurements from Hanford (Kirklin et al. ca. 1969) where a factor of 1.94 was observed…*

  Because of the many pages in the referenced document, it would have been helpful for the page number to have been included. It appears that the factor of 1.94 was derived from dividing the LAT chest dose of 0.153 roentgen by the PA chest dose of 0.079 roentgen, as provided on PDF pages 161 and 162, respectively, of the reference.

- Page 27: The last paragraph on this page states:

  > *The resolution of PFG systems was not as good as conventional film screen systems; only 6 line/pairs per mm rather than about **9 or** per mm…* [Emphasis added.]

  SC&A found that, according to Goodwin, Quimby, and Morgan (1970), p. 108 (PDF page 63), this should read:

  > *The resolution of PFG systems was not as good as conventional film screen systems; only 6 line/pairs per mm rather than about **9 or 10 line/pairs** per mm…* [Emphasis added.]

- Page 37: The last paragraph on this page states:

  > *Using the inverse square law, the entrance skin dose is calculated based **on the part** thickness for PA Chest and LAT…* [Emphasis added.]

  SC&A found that this apparently should read:

  > *Using the inverse square law, the entrance skin dose is calculated based **in part on the** thickness for PA Chest and LAT…* [Emphasis added.]

- Page 38: The second column, second row, of Table 8.1 reads:

  > *Lumb. Vert 37-32*

  SC&A found that for the lumbar vertical (Lum. Vert.) view, the thickness value (according to Cahoon 1961, PDF page 33) should read:

  > *Lumb. Vert 27-32*

This error did not affect the derivation of the 7.5 cm chest thickness value quoted at the top of page 38, which was derived from averaging the maximum and minimum values already correctly listed in Table 8.1 (i.e., (34.4 cm – 27 cm) = 7.4 cm, rounded to 7.5 cm.

- Page 52: The fourth column (for the lumbar spine view) in the table on this page for ICD-9 code 170.4 should instruct the dose reconstructor to "See Table A-3," not Table A-5.

- Page 52: The fourth column (for the lumbar spine view) in the table on this page for ICD-9 code 170.5 should instruct the dose reconstructor to "See Table A-3," not Table A-5.

- Page 60: The fourth column (for the lumbar spine view) in the table on this page for ICD-9 code 195.4 should instruct the dose reconstructor to "See Table A-3," not Table A-5.

- Page 113: Footnote a for Table B-15 provides the following references:

  > *Dose equivalents through 1970 are based on measured values (Lincoln and Gupton 1958) for skin, testes, and ovaries for the thoracic spine, and measured values (Braestrup and Wycoff 1958) for testes, ovaries, and uterus for the cervical spine.*

  Lincoln and Gupton 1958 (Table IX, PDF page 8) does provide the dose values as listed in Table B-15 of OTIB-0006 for the thoracic spine view for the skin, testes, and ovaries. However, Braestrup and Wycoff 1958 is a textbook and does not provide the doses for the testes, ovaries, and uterus for the cervical spine view. This may be an incorrect reference.

4.0 SUMMARY AND CONCLUSIONS

Equations and Units – SC&A analyzed the equations and units used in OTIB-0006 and found them to be generally applicable and correct, with one observation, which is discussed in Section 3.1.1 of this report:

- **Observation 1: Need Clarification for DCF Units in Attachment B**

Terminology – SC&A found the terminology used in OTIB-0006 to be consistent with other documents used by NIOSH for assigning occupational medical x-ray dose.

Technical Information – SC&A analyzed the technical information presented in OTIB-0006 and found it to be applicable and mostly correct. However, there were several areas that appear to need clarification or more complete information. SC&A had the following observations, which were discussed in Section 3.1.3 of this report:

- **Observation 2: Need Clarification for Changing Chest Thickness**
- **Observation 3: Difference in Source-to-Image Distance**

- **Observation 4: Need References and Derivation of Kerma Values in Table 4-1**
- **Observation 5: Thoracic and Cervical Spine Dose Assignments after 1970 Need Clarification**
- **Observation 6: Breast Dose Reference Needs Clarification**
- **Observation 7: Need to Retain Important Information from Attachment C of ORAUT-PROC-0061**

Documentation – SC&A evaluated the documentation used in OTIB-0006 for assigning occupational medical x-ray dose and found the document was well written and informative. It is a relatively complex and large document, and, as such, SC&A found several items that need to be corrected or clarified. These items are discussed in Section 3.2 of this report.

5.0 REFERENCES

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