Oak Ridge Associated Universities l Dade Moeller & Associates l MJW Corporation

Document Title:		Document Number:	ORAUT-OTIB-0066
		Revision:	00
Calculation of Dose from Intakes of Special Tritium Compounds		Effective Date:	04/26/2007
		Type of Document:	OTIB
		Supersedes:	None
Subject Expert(s):	Thomas R. LaBone		
Site Expert(s):	N/A		

Approval:	Signature on File	Approval Date:	04/19/2007
	James P. Griffin, Document Owner		
Concurrence:	Signature on File	Concurrence Date:	04/23/2007
	Edward F. Maher, Task 5 Manager		
Concurrence:	Signature on File	Concurrence Date:	04/19/2007
	Kate Kimpan, Project Director		
Approval:	Brant A. Ulsh Signature on File for	Approval Date:	04/26/2007
	James W. Neton, Associate Director for Science		

☒ 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
04/26/2007	00	Approved new document to provide guidance for the calculation of best estimates of the annual organ doses for intakes of tritium bound to organic compounds (organically bound tritium; OBT) and tritium in a metal matrix (stable metal tritide; SMT). 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 Thomas R. LaBone.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS AND ABBREVIATIONS

AMAD   activity median aerodynamic diameter

d   day
DOE   U.S. Department of Energy

GI   gastrointestinal

HTO   tritiated water

ICRP   International Commission on Radiological Protection
IMBA   Interactive Modules for Bioassay Analysis

L   liter

mCi   millicurie

NIOSH   National Institute for Occupational Safety and Health

OBT   organically bound tritium

pCi   picocurie

SAF   self-absorption factor
SMT   stable metal tritide

TIB   technical information bulletin

U.S.C.   United States Code

µCi   microcurie
µm   micrometer

§   section or sections

1.0   INTRODUCTION

Technical information bulletins (TIBs) 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. TIBs may be used to assist NIOSH staff in the completion of individual dose reconstructions.

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 of 2000 [42 U.S.C. § 7384l(5) and (12)].

2.0   PURPOSE

The purpose of this TIB is to provide guidance on how to use urine bioassay data to calculate the best estimates of the annual organ doses for intakes of tritium bound to organic compounds (organically bound tritium; OBT) and tritium in a metal matrix (stable metal tritide; SMT).

3.0   BIOKINETIC MODELS FOR TRITIUM COMPOUNDS

Figure 3-1 shows the biokinetic model for tritiated water (HTO) as implemented in the Interactive Modules for Bioassay Analysis (IMBA) software. The only difference between this model and the International Commission on Radiological Protection (ICRP) HTO model in Publication 67 (ICRP 1994a) is that the IMBA model specifically includes the urinary bladder whereas the ICRP model does not. The *water* compartment has a biological half-life of 10 d, and it is assumed that 1.4/3 = 0.47 of the HTO in this compartment goes to urine.
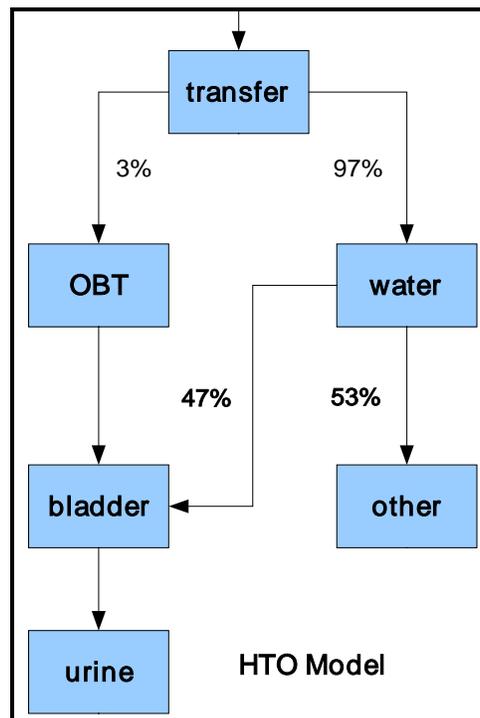
Figure 3-1. Biokinetic model for HTO.

The *OBT* compartment represents tritium that is incorporated into carbon compounds and is retained with a half-life of 40 d as described in the ICRP carbon biokinetic model (ICRP 1994a). All of the tritium in this compartment is assumed to be excreted in urine. By default, IMBA does not have a urinary excretion function for HTO, which prevents modeling of the urinary excretion of HTO. Instructions on how to enable IMBA to evaluate HTO urinary excretion data are given elsewhere (DOE 2006).

SMTs are metals such as titanium that absorb and store tritium (i.e., H-3) atoms in the crystalline structure of the metal. When an SMT is inhaled, the lungs retain the material, which slowly releases tritium. This release of tritium occurs as the particle of the SMT dissolves and the tritium diffuses out of the particle. Tritium released from the SMT particle is assumed to be converted to HTO that subsequently behaves according to the HTO biokinetic model. The SMT biokinetic model shown in Figure 3-2 is therefore the HTO biokinetic model with an ICRP Publication 66 Human Respiratory Track Model feed compartment (ICRP 1994b).
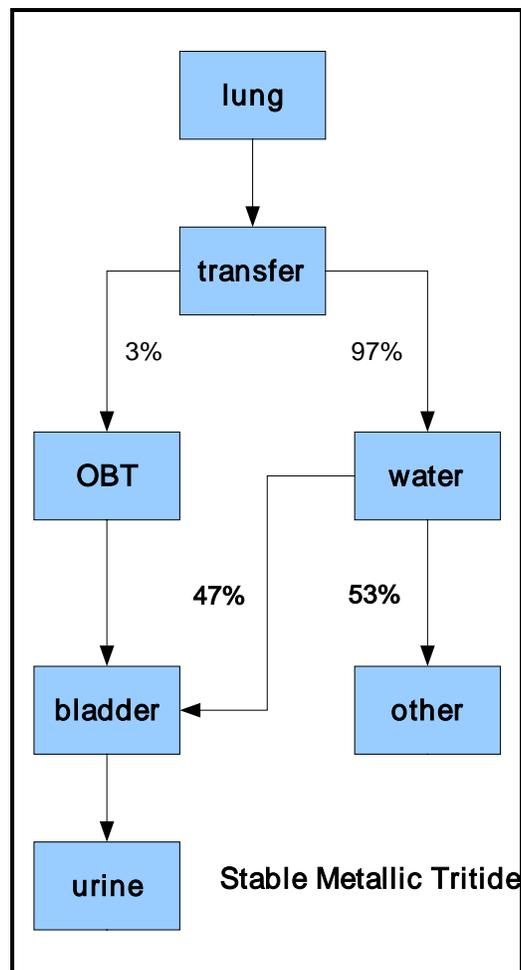
Figure 3-2. Biokinetic model for SMTs.

The solubility of tritides in the lung is a function of the metal substrate (e.g., titanium versus hafnium) and the size and shape of the particles. Of the SMTs discussed in the literature, titanium and zirconium appear to be best described as type M, whereas hafnium is best described as type S (Mound 2004). Other tritides that consist of more reactive metals such as lithium and uranium are

expected to be best described as type F. [Note that lung dose from the uranium in a uranium tritide will be much larger than the lung dose from tritium in the uranium tritide.]

Tritium can be taken into the body already bound to carbon compounds. Such materials are referred to OBT <u>compounds</u> as opposed to the OBT <u>compartment</u> in the biokinetic model. The ICRP model assumes that 50% of the OBT compounds taken into the body are immediately converted to HTO and the other 50% remain OBT.

Figure 3-3 shows the biokinetic model for OBT compounds as implemented in IMBA. The only difference between this model and the HTO model is the 50/50 split between HTO and OBT versus the 97/3 split for water.
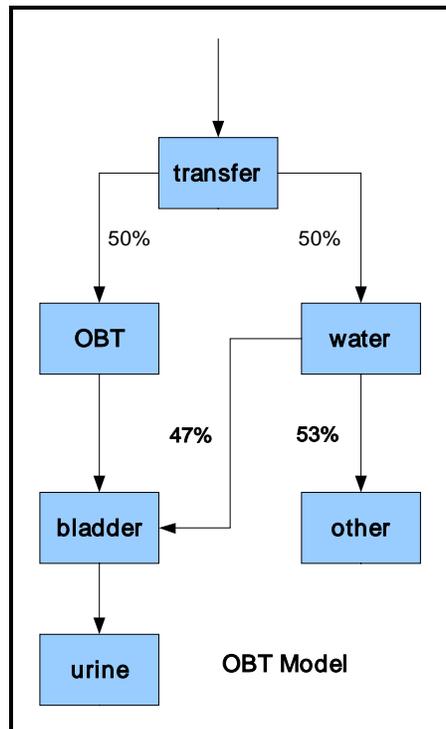
Figure 3-3. Biokinetic model for OBT.

Figure 3-4 shows the predicted urinary excretion curves after acute 1-pCi intakes of various tritium compounds, and Figure 3-5 shows these excretion curves normalized to the same peak excretion rate.
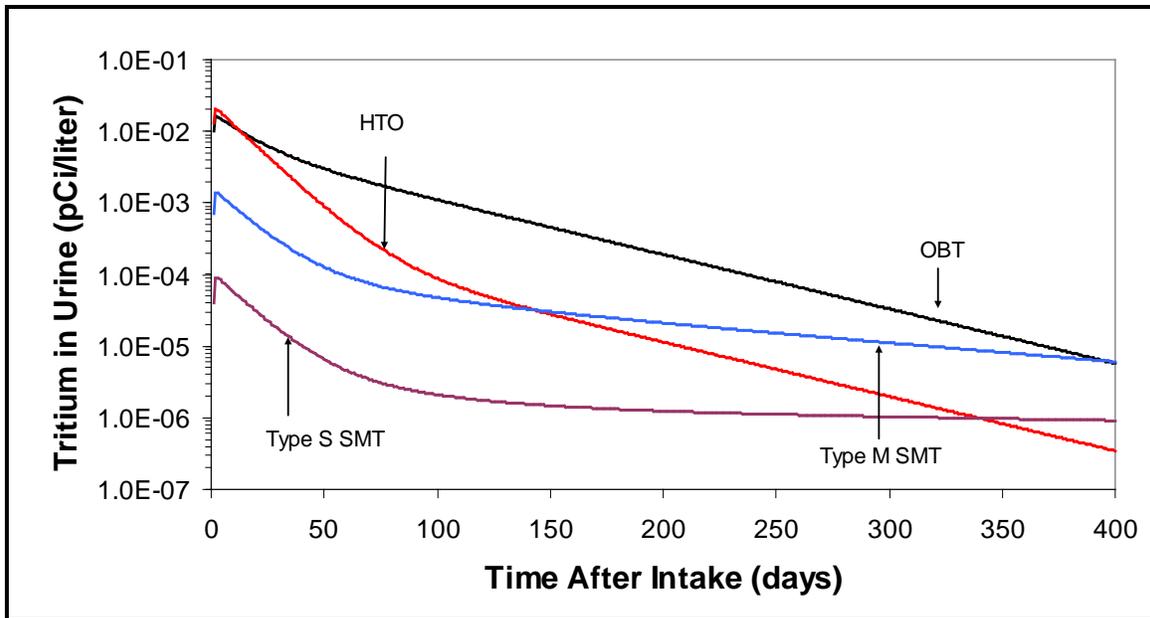
Figure 3-4. Concentration of tritium in the urine after 1-pCi intakes of various tritium compounds.
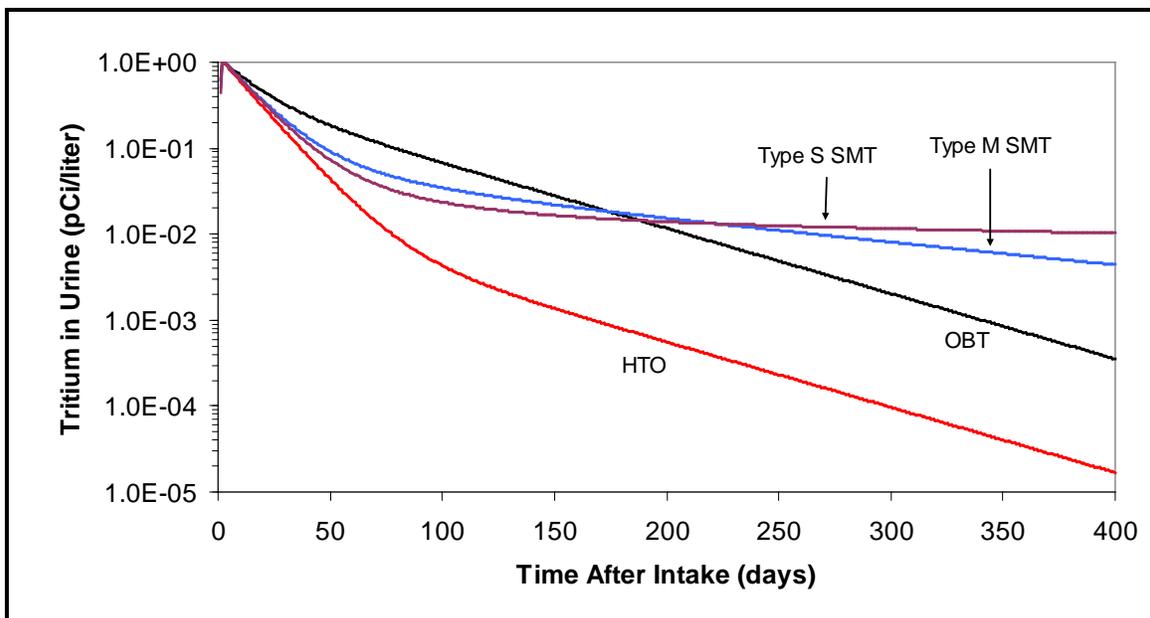
Figure 3-5. Concentration of tritium in the urine from Figure 3-4 normalized to the same peak concentration.

4.0   DOSE CALCULATIONS

Intakes of HTO are usually evaluated using an isotopic dilution technique (HPS 1994), which is based on the following assumptions:

1. HTO is metabolized like H_2O.

2. The metabolic space of H_2O is the 42 L of body water.

3. The concentration of HTO in the urine is the same as the concentration of HTO in the body water.

These assumptions are embodied in the ICRP Publication 30 HTO biokinetic model (ICRP 1979). Given that these assumptions are valid, the quantity of HTO in the body at any given time is simply the concentration of HTO in the urine times the volume of body water, and the dose to the soft tissues of the body is proportional to the area under the excretion curve.

The standard method for calculating the dose from intakes of tritiated water given in ORAUT-OTIB-0011, *Tritium Calculated and Missed Dose Estimates* (ORAUT 2004), uses three different techniques to calculate the area under the excretion curve. As shown in Figure 4-1, a Type 1 tritium dose calculation is a linear interpolation that is performed when two urinary excretion measurements are less than 40 d apart. This is the classical connect-the-dots area calculation. A Type 2 tritium dose calculation is an exponential extrapolation from the first point to another that is performed when the two measurements are more than 40 d apart. A Type 2 calculation, which gives an area that is smaller than a Type 1 calculation, is used because it is assumed that the person did not work with tritium if there was no sampling for more than 40 d. Finally, a Type 3 tritium dose calculation is an exponential extrapolation to t = infinity that is performed to account for the "tail" after the last measurement.
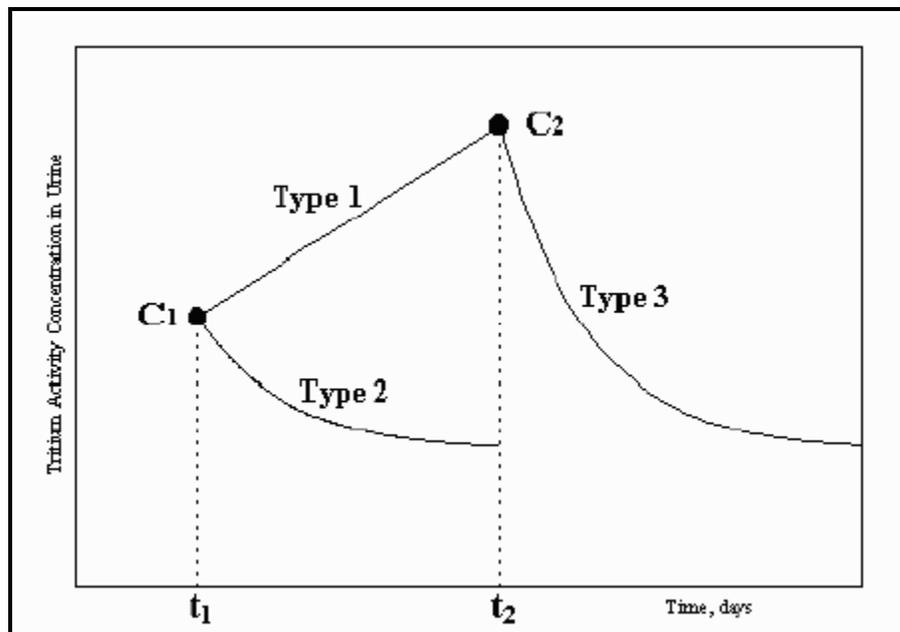
Figure 4-1. Diagram from ORAUT-OTIB-0011 that shows the types of methods used to determine the area under an excretion curve.

The introduction of the OBT compartment into the ICRP HTO biokinetic model technically invalidates this approach because the tritium in the OBT compartment is not uniformly distributed in the body-water space. However, the introduced error in dose is slight (about 10% is often mentioned in the literature) because only 3% of the HTO goes to the OBT compartment. The methodology in ORAUT-OTIB-0011 compensates for this slight underestimate by adjusting the dose conversion factor upward, which makes the dose to systemic organs from a Type 1 calculation slightly conservative (about 5% high) for intakes of HTO (ORAUT 2004). Because SMTs in the lung are essentially a longer term feed compartment for HTO going to the systemic organs, a Type 1 calculation is also slightly conservative for systemic organ dose for these materials. On the other hand, a Type 1 calculation underestimates

systemic dose by approximately 30% for intakes of OBT because half of the intake is not uniformly distributed in the body-water space. In practice, the error is smaller because occupational sources of OBT (e.g., pump oil) tend to have a significant HTO component.

Type 2 and 3 calculations make an exponential extrapolation of the urine concentration with the assumption of a 10-d half-life. As shown in Figure 3-5, portions of the urinary excretion curves have half-lives that are significantly longer than 10 d. Given a urine concentration, the dose to systemic organs (the area under the urinary excretion curve) from OBT and the SMTs will be underestimated by Type 2 and 3 calculations because they assume a 10-d half-life when the actual half-life is significantly longer than 10 d. As an example of a worst-case scenario, if a single urine result is evaluated using a Type 3 calculation (i.e., assuming it is HTO) and it is in fact from an intake of Type S tritide, the systemic dose for the tail (not the total dose) will be underestimated by a factor of about 6.

The degree to which the total systemic dose is underestimated for OBT and SMT depends on the fraction of the systemic dose from Type 2 and 3 calculations. For example, if the entire systemic dose up to the time of diagnosis is determined with Type 1 calculations, the systemic dose can be taken to be accurate regardless of the material. On the other hand, if most of the systemic dose is determined with Type 2 and 3 calculations and the material is type S SMT, the systemic dose could be significantly underestimated.

The dose to the lung from intakes of SMT can be underestimated by orders of magnitude if ORAUT-OTIB-0011 calculations are used to calculate the lung dose from urinary excretion measurements (ORAUT 2004). For example, consider the doses in Table 4-1 that result from a 1-pCi acute intake of the material:

Table 4-1. Comparison of calculated doses for a 1-pCi acute intakes of tritium compounds (mrem).

	ORAUT-OTIB-11 soft tissue dose	IMBA soft tissue dose	IMBA lung dose
Type S SMT	6.58E-10	6.30E-10	3.86E-06
Type M SMT	7.28E-09	6.93E-09	5.52E-07
HTO	7.11E-08	6.76E-08	6.76E-08
OBT	1.08E-07	1.52E-07	1.52E-07

5.0   **RECOMMENDATIONS**

1. In the vast majority of occupational exposures to tritium it is not possible to identify the tritium compound taken into the body based on the observed urinary excretion. Therefore, the selection of the appropriate tritium compound in an intake evaluation must usually be based on process knowledge of the source terms in the workplace.

2. The methodology in ORAUT-OTIB-0011 (ORAUT 2004) can be used without modification to calculate doses from intakes of HTO and OBT to all organs and tissues.

3. If the observed urinary excretion of tritium is deemed to be the result of intakes of SMT, ORAUT-OTIB-0011 (ORAUT 2004) can be used to calculate systemic dose if the majority of the dose is calculated with the Type 1 method. This will typically be the case if there are a relatively large number of urine samples over a relatively long period. On the other hand, if the

majority of the systemic dose is calculated with Type 2 or 3 methods, IMBA should be used to calculate the dose rather than ORAUT-OTIB-0011 (see next recommendation).

4. If the observed urinary excretion of tritium is deemed to be the result of intakes of SMT and the dose to the lung or gastrointestinal (GI) tract is needed, the urinary excretion data must be evaluated with IMBA in the same fashion as any other radionuclide [see Attachment A]. Note that the urinary excretion that results from a small intake of HTO (which gives a small lung dose) translates into a large SMT intake (which gives a large lung dose) if the observed urinary excretion is assumed to be the result of an SMT intake. This is important because the SMT would be expected to be associated with varying amounts of HTO in an occupational setting.

5. If the metal substrate of the SMT is not known, type S solubility should be assumed. However, fairly modest tritium urine concentrations can imply extremely large type S SMT exposures that might be quite implausible. For example, 1 µCi/L of tritium in the urine that is assumed to be the result of an intake of Type S SMT 30 d earlier implies an unencapsulated source term in excess of 300 mCi. This assumes that the fraction of an accidental release inhaled is 1×10^{-6}.

REFERENCES

DOE (U.S. Department of Energy), 2004, *DOE Handbook on Radiological Control Programs for Special Tritium Compounds*, DOE-HDBK-1184-2004, Washington, D.C., September.

DOE (U.S. Department of Energy), 2006, *Guidance on Use of IMBA Software for DOE Safety Applications*, DOE-HS-0002, Washington, D.C., December.

HPS (Health Physic Society), 1994, *Internal Dosimetry Programs for Tritium Exposure*, ANSI N13.14-1994, American National Standards Institute, New York, New York.

ICRP (International Commission on Radiological Protection), 1979, *Limits for the Intake of Radionuclides by Workers, Part 1*, Publication 30, Part 1, Pergamon Press, Oxford, England.

ICRP (International Commission on Radiological Protection), 1994a, *Age-Dependent Doses to Members of the Public from Intake of Radionuclides: Part 2 Ingestion Dose Coefficients*, Publication 67, Oxford, England.

ICRP (International Commission on Radiological Projection), 1994b, *Human Respiratory Tract Model for Radiological Protection*, Publication 66, Oxford, England.

ICRP (International Commission on Radiological Protection), 1996, *Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 4 Inhalation Dose Coefficients*, Publication 71, Pergamon Press, Oxford, England.

Mound, 2004, *Mound Technical Basis Document for Stable Tritiated Particulate and Organically Bound Compounds*, MD-10516, January 24.

ORAUT (Oak Ridge Associated Universities Team), 2004, *Technical Information Bulletin: Tritium Calculated and Missed Dose Estimates*, ORAUT-OTIB-0011, Rev. 00, Oak Ridge, Tennessee, June 29.

ATTACHMENT A
USING IMBA TO EVALUATE INTAKES OF HTO
Page 1 of 2

Arguably, the most common form of tritium to which workers are exposed is tritiated water, which is called inorganic tritium in IMBA. IMBA is not typically used to evaluate tritium urine bioassay data resulting from intakes of tritiated water because there are simple approaches that allow complex intake patterns to be readily evaluated, i.e., the method described in ORAUT-OTIB-0011 (ORAUT 2004). However, the ORAUT-OTIB-0011 approach is frequently not applicable to urine bioassay data resulting from intakes of SMT. In these cases the urine data must be evaluated with IMBA in the same fashion as urine bioassay data from other radionuclides. The problem is that while IMBA has a default urine bioassay model for organic tritium, it does not offer a default urine bioassay function for inorganic tritium. This shortcoming can be easily rectified with the following procedure:

- Select the inorganic tritium model.
- Go to the Bioassay Model panel (shown in Figure A-1).
- Select the *Urine* as the bioassay function.
- Select *User Defined* as the mode.
- Enter the coefficients and rate constants from the following table:

A(i) Coefficient	Lam(i) Rate Constant
9.639E-03	1.200E+01
3.237E-02	6.931E-02
5.239E-04	1.733E-02
-4.253E-02	2.773E+00

- Enter 10^{-7} for the blood half-time.

Urine bioassay data in units of activity per day can now be used to directly evaluate intakes of inorganic tritium (SMT).

The intake retention function calculated from this user defined urine bioassay function is the 24-hour incremental urinary excretion with units of activity per day rather than per liter. This means that tritium urine bioassay results, which are typically in units like µCi/L, must be multiplied by 1.4 L/day to obtain µCi/day before being entered into IMBA.

IMBA files for the inhalation of Type M and Type S SMT aerosols are provided at http://imbadownloads.oraucoc.org/.

These templates have the urine bioassay function preloaded along with the parameters for SMT aerosols from ICRP Publication 71 (ICRP 1996). It is recommended that these templates be used as the starting point for all evaluations of SMT intakes. Note that reloading the default parameters in these files (i.e., hitting the "ICRP DEFS LOAD" button on the IMBA main screen) will delete the HTO urinary excretion model.

ATTACHMENT A
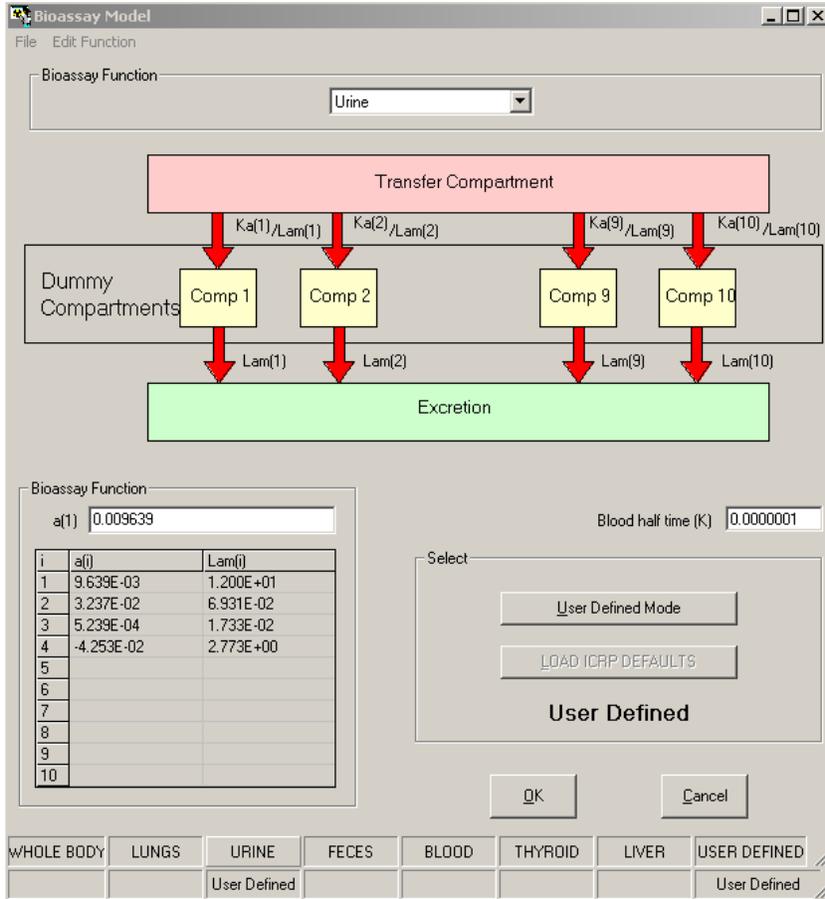**USING IMBA TO EVALUATE INTAKES OF HTO**
Page 2 of 2

Figure A-1. IMBA urine bioassay model for inorganic tritium.