

# Critical Evaluation of $^{239}\text{PuO}_2$ Wound and Lymph Node Retention Predicted by NCRP 156's Recommended Biokinetic Transfer Rates

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## Abstract:

A Powerbasic (PBCC 4.03) code has been developed to implement explicitly the general structure of the NCRP Publication 156 recycling biokinetic wound model, which partitions accidentally injected material into four characteristic initial states: (1) soluble, (2) colloid & intermediate state, (3) particles, aggregates & bound state, and (4) fragment. This was bench-marked (quality assured) against compartmental retention values calculated separately for each of the four possible material states for  $^{239}\text{Pu}$  (as a function of time after intake) by several European institutions. The new code also implements simultaneously the ICRP Publication 67 systemic biokinetic model for plutonium, to calculate the daily excretion of plutonium in urine and liver as a function of time resulting from the combined blood uptake kinetics (from the wound) and that of plutonium subsequently transferred to body organs. The utility of the NCRP wound model structure (and recommended inter-compartmental transfer rates) for predicting the wound and axillary lymph node retention measured for USTUR Case 0262 was examined. This worker died 33 y after receiving an accidental finger-puncture wound contaminated with  $^{239}\text{PuO}_2$  particles and other plutonium material. A previously published empirical analysis of the data available in this case yielded four distinguishable phases of wound clearance, varying in characteristic rate over 5 orders of magnitude. The 'mechanistic' analysis carried out here examines the hypothetical fractionation between material states represented in the NCRP 156 wound model that is needed to 'fit' the USTUR Case 0262 data and the goodness-of-fit so obtained.

## Introduction:

Radionuclide-contaminated wounds are a concern. By definition, a contaminated wound breaches the skin and the contaminating radionuclide has direct access to both blood and body fluids and ultimately to internal tissues and organs. Frequently, radioactive material remains in the wound site for a substantial amount of time and as a consequence, it may deliver a significant radiation dose to the tissue.

At the end of 2007 National Council of Radiation Protection published a document (NCRP 156) entitled "Development of a Biokinetic Model for Radionuclide-Contaminated Wounds and Procedures for their Assessment, Dosimetry and Treatment". This new wound biokinetic model was designed and parameterized using experimental animal data because of a lack of data from humans who have had radionuclide-contaminated wounds that were not surgically removed or chemically decontaminated. Long term it is very important to test this model using the available human data and examine their predicative capability for humans.

The NCRP 156 wound biokinetic model consists of five compartments that comprise the wound site (Figure 1A). These compartments are: 1. Soluble, 2. Colloid and Intermediate State (CIS), 3. Particles, Aggregates and Bound State (PABS), 4. Fragment, and 5. Trapped Particles and Aggregates (TPA). Additionally, there are two compartments: blood and lymph nodes, which can receive the materials leaving the wound site and therefore, act as a clearance pathways of the radionuclides.

The compartmental design of the NCRP model is based on the physical and chemical form of the deposited radioactive material which include: soluble, mixtures of soluble and colloidal material, particulate or fragment. These categories encompass the majority of material forms experienced in the workplace and thus are suitable to describe the initial conditions for modeling purposes. Soluble material by itself is divided into four categories, which are weak, moderate, strong and avid. Therefore, there are seven total default wound retention categories. Transfer of material between compartments is characterized by first-order rate constants, which appears to be adequate for describing the data sets investigated to date.

The NCRP 156 model attempts to address both phenomenologic and mechanistic perspectives while providing flexibility. Depending on the data available, NCRP allows wound-site compartments to be evaluated independently. This implies that for a given form of the contaminating radionuclide only a portion of the wound model needs to be used, so typically efforts to model wounds involve only three compartments. Figure 1B illustrates the simplified wound model for soluble, colloid, particle and fragments forms respectively. If the contaminating material consists of a mixture of forms, then all the applicable compartments of the model may be employed.

In this study we present forward calculations based on NCRP and ICRP biokinetic models and an assumed unit intake, using IMBA Professional Plus Academic Edition and Power Basic for Windows (PB/CC 4.03). Default transfer rates published in NCRP 156 for the various categories of radionuclides in wounds were used to carry out the calculations.

## Materials and Methods

A Powerbasic (PBCC 4.03) code has been developed to explicitly implement the general structure of the NCRP Publication 156 recycling biokinetic wound model, which partitions accidentally injected material into four characteristic initial states: (1) soluble, (2) particles, aggregates & bound state, (3) colloid & intermediate state, and (4) fragment. This was bench-marked against lymph node and wound retention values calculated separately for each of the four possible material states for  $^{239}\text{Pu}$  (as a function of time after intake) by several European institutions. In addition, IMBA Professional Plus was used to calculate the same retention values for  $^{239}\text{Pu}$  and was compared with the sum of the retention values for the wound and LN, because IMBA doesn't separate retention functions for wound and lymph node individually.

Another set of codes were developed for 7 different material categories that implement simultaneously the ICRP Publication 67 systemic biokinetic model for plutonium, to calculate the daily excretion of plutonium in urine and a concentration of Pu in liver as a function of time resulting from the combined blood uptake kinetics (from the wound) and that of plutonium subsequently transferred to body organs.

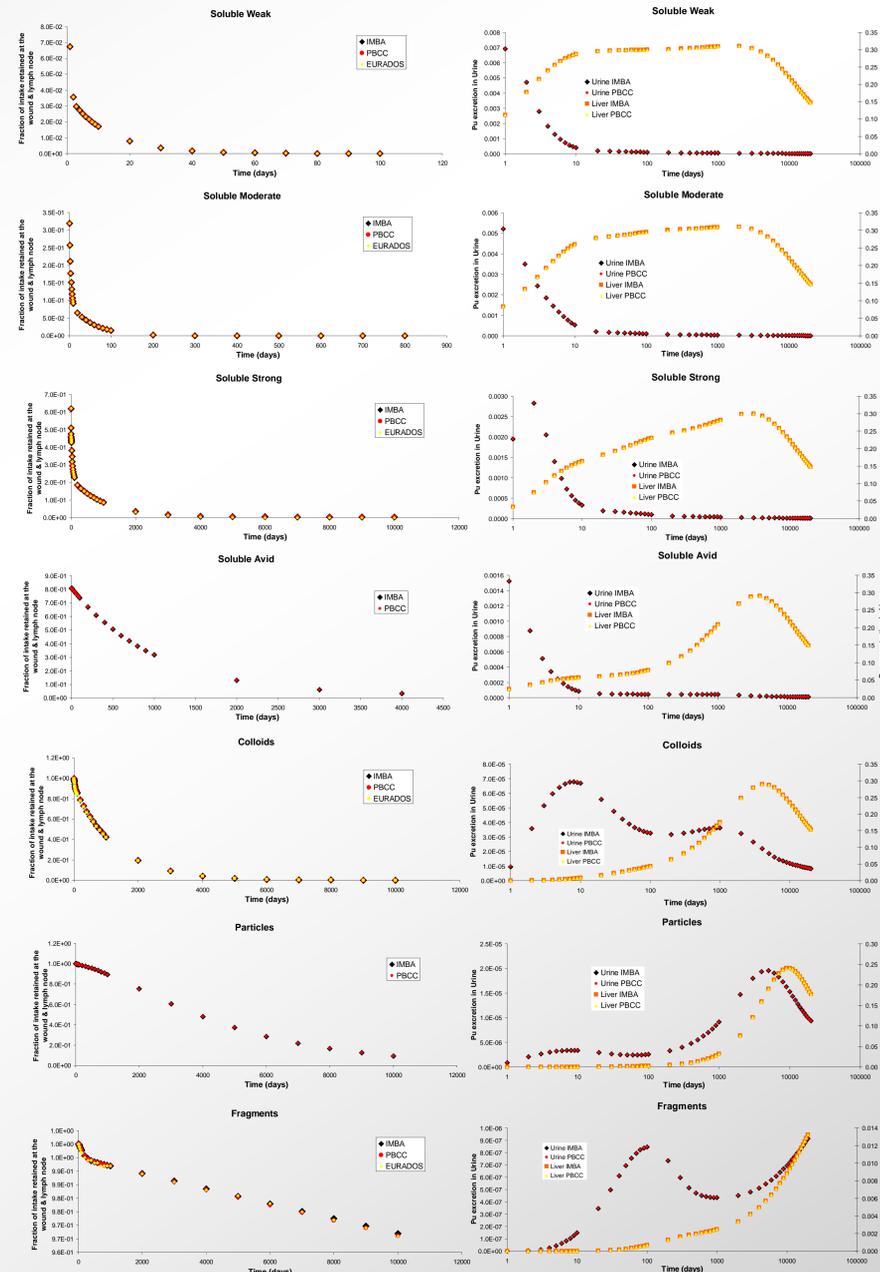
The utility of the NCRP wound model structure (and recommended inter-compartmental transfer rates) for predicting the wound and axillary lymph node retention measured for USTUR Case 0262 was examined. This worker died 33y after receiving an accidental finger-puncture wound contaminated with  $^{239}\text{PuO}_2$  particles and other plutonium material. A previously published empirical analysis of the data available in this case yielded four distinguishable phases of wound clearance, varying in characteristic rate over 5 orders of magnitude. The analysis carried out here examines the hypothetical fractionation between material states represented in the NCRP 156 wound model that is needed to 'fit' the USTUR Case 0262 data and the goodness-of-fit so obtained.

## Results and Discussions

In the first set of codes, fractions of intake retained at the wound site and lymph node were calculated individually for the seven default categories of the NCRP wound model. In addition, wound retention coefficients were taken from IMBA Professional Plus for all the default categories and a retention equation  $R(t) = \sum A_i e^{-\lambda_i t}$  was used to calculate retention values over time for each ( $R(t)$  is the percent of injected radioactive material retained at the wound site and  $t$  is the time in days after injection). The percent difference between the data sets calculated with two different methods didn't exceed 0.5%. These were also compared to the data obtained by several European institutions. The results are presented on graphs on Figure 2.

In the second part of this study PBCC was used to develop set of codes that implement simultaneously the ICRP Publication 67 systemic biokinetic model for plutonium, to calculate the daily excretion of plutonium in urine and Pu concentration in liver as a function of time. For the comparison, IMBA PP was also used to calculate daily excretion values for the same default categories for urine. Intercomparison graphs are presented on Figure 3. The percent difference between the data sets obtained with two different methods was less than 0.5%.

In the third part of this study USTUR case 262 was examined. Urine bioassay data were applied in IMBA. Hypothetical fractionation between material states represented in the NCRP 156 wound model was considered and best fit was obtained. Total chi-square sum comparison is reported in Table 1.



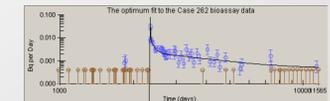
**Figure 2:** Fractions of intake retained at the wound site and lymph node calculated individually for seven default categories of the NCRP wound model with IMBA and PBCC. These values are compared to each other and also to the retention values calculated by European institutions

**Figure 3:** Pu excretion in Urine and Pu concentration in Liver for seven default categories, calculated by two different methods, using IMBA and PBCC.

Series 1 included all seven default categories of material states. Since weak and particle categories played insignificant amount towards the total intake, they were neglected from series 2 calculations. After eliminating avid and colloid categories as well, moderate category played no role to the total intake (Series 3). The final series 4 calculations were only comprised by the strong and fragment categories. Series 3 had the minimal total chi-square sums, as well as little higher urine chi-square and autocorrelation statistical probability, therefore it is considered to be the optimum fit series. A graphical representation of this optimum fit to the Case 262 bioassay data is shown on Figure 4.

Radionuclide Category	Intake Activity Distribution (Bq)			
	Series 1	Series 2	Series 3	Series 4
Weak	0.0029006			
Moderate	24.352	8.5895	0	
Strong	6.4094	26.515	37.835	37.165
Avid	5.4223	1.2242		
Colloid	1.45	1.1268		
Particle	0.00006382			
Fragment	120.3	120.39	120.13	120.57
$\Sigma\chi^2$ (probability)	<b>58.6 (0.0691)</b>	<b>55.1 (0.121)</b>	<b>53.2 (0.16)</b>	<b>53.8 (0.148)</b>
Autocorrelation probability	0.172	0.225	0.295	0.261

**Table 1:** Case 262 results by IMBA Professional Plus Analysis



**Figure 4:** The optimum fit to the Case 262 bioassay data obtained by IMBA

## Conclusions

A set of Power Basic codes were developed to calculate retention values separately for each of the possible  $^{239}\text{Pu}$  material states (as a function of time after intake). The same calculations were done using IMBA PP. These were bench-marked (quality assured) against compartmental retention values calculated by several European institutions. All data sets were within 0.5%.

The second set of the codes implemented the ICRP Publication 67 systemic biokinetic model for plutonium, to calculate the daily excretion of plutonium in urine as a function of time resulting from the combined blood uptake kinetics (from the wound) and that of plutonium subsequently transferred to body organs. The data sets obtained from the codes were compared to the data sets obtained by IMBA. All data sets were within 0.5%.

The third part of the study examined an USTUR case 262. The analysis that was carried out examined the hypothetical fractionation between material states represented in the NCRP 156 wound model and optimum fit of data was obtained.

## References:

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**Figure 1:** A. Schematic compartmental representation of the NCRP wound biokinetic model. B. Sections of the wound model according to the injection material type