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SC&A REVIEW OF PART II, ROCKY FLATS TRITIUM DOSE ASSIGNMENT FOR 1973, ATTACHMENT A

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ABBREVIATIONS AND ACRONYMS

AGIR	Advisory Group on Ionising Radiation
Bq	Becquerel
d	day
GI	gastrointestinal
h	hour
HPA	Health Protection Agency
HTO	tritiated water
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
L	liter
LLNL	Lawrence Livermore National Laboratory
µCi	microcurie
mrem	millirem
NCRP	National Council on Radiation Protection & Measurements
NIOSH	National Institute for Occupational Safety and Health
OBT	organically bound tritium
pCi	picocurie
Pdf	portable document format
RFP	Rocky Flats Plant
SC&A	S. Cohen and Associates (SC&A, Inc.)
SCR	Sample Channel Ratio
SEC	Special Exposure Cohort
SRDB	Site Research Database
UK	United Kingdom
y	year

EXECUTIVE SUMMARY

The following is a follow-up review of questions and issues SC&A first raised during a September 12, 2013, meeting of the Rocky Flats Special Exposure Cohort (SEC) Work Group. These questions focused in part on analyses and proposed dose estimation approaches contained in a paper presented by the National Institute for Occupational Safety and Health (NIOSH) titled, *White Paper: Follow-up Efforts on SEC-00192 RFP Tritium Issues*, by J.S. Bogart, E.M. Brackett, and Dan Stempfley (Bogart et al. 2013), specifically Table A-6 of Part II, "Rocky Flats Tritium Dose Assignment for 1973," and later Attachment A, "Rocky Flats 1973 H-3 Dose Assignment." In accordance with a request made by the Work Group during the meeting, SC&A performed a review of the tritium intakes and doses to Workers A, B, C, D, and H associated with the April 1973 tritium incident at Rocky Flats.

Assuming the possible tritium intake dates would correspond to April 9–25, 1973, the dates for processing of plutonium contaminated with tritium in Building 779A, at least 150 days elapsed between possible workers' contamination in the April 1973 incident and the H-3 bioassay sampling. When sampling began, most of the HTO had already been excreted from the body. The current International Commission on Radiological Protection (ICRP) 78/88 (ICRP 1997, ICRP 2001) model does not describe well the excretion rates of HTO at long times after intake. The lack of an official ICRP model for HTO that can be used for samples taken at 150 to 180 days after the April 1973 accident is a problem and adds to the uncertainty on intakes and dose calculations.

In addition, when a worker is exposed to HTO in several incidents, the HTO excretion rate will be dominated by his/her most recent exposure. Thus, sampling just after the last incident will reflect the most recent exposure, hiding the ones that occurred months before the sampling. For example, this could have happened with the exposure from Worker A, for which three different scenarios were assumed: (1) exposure in September, (2) mixed exposure in April and September, and (3) exposure in the April incident. All three scenarios fit the excretion results reasonably well, but the differences in doses between the worst case scenario and lower dose scenario were above 3 orders of magnitude.

All five cases analysed had initial samples that were not distilled, with one to five later distilled samples. In general, the two sets of results were not consistent, with the distilled samples yielding lower values. The pre-distilled sample results were used in the development of the white paper. The efficiency of the non-distilled samples was low and results were not consistent with the ones from the distilled samples. The uncertainty on these urine results is high and a perfect fit should not be expected for all possible exposure scenarios.

SC&A recommends that bounding intakes of 9E4 µCi and doses of 6E3 mrem should be assigned, based on the assumption that Worker A was exposed in April 1973. However, uncertainties surround use of these bounding intakes and doses:

- The model used to derive this intake was the draft ICRP model, posted on the ICRP web site, but this model is not officially endorsed by the ICRP.

- When a worker is exposed to HTO in several incidents, the HTO excretion rate will be dominated by his/her most recent exposure. Many different scenarios may fit the excretion rate results. Doses may vary by more than 3 orders of magnitude, depending on the exposure scenario that is chosen.

- Results from non-distilled samples were used to derive intakes.

However, on balance, SC&A believes use of these bounding intakes offers a more conservative and claimant-favorable approach for estimating tritium doses in 1973.

1.0   INTRODUCTION: ICRP TRITIUM (HTO) BIOKINETIC MODELS AND INTERPRETATION OF URINARY EXCRETION RATES

The current ICRP models for HTO and OBT were defined in ICRP Publication 56 (ICRP 1989b). They were used to derive activity concentration rates in ICRP Publication 78 (ICRP 1997). A clarification of the model was published in ICRP Publication 88 (ICRP 2001).

Ingested or inhaled HTO is assumed to be translocated directly and instantaneously from the site of intake to blood without consideration of nuclear transformations in either the respiratory or gastrointestinal (GI) tracts. From the blood, activity is taken to be transferred with a biological half-time of 0.25 days to two whole-body compartments (Compartment Total Body A and Compartment Total Body B). It is assumed that 97% of activity equilibrates with body water and is retained with a biological half-life 10 days (Compartment Total Body A). The remaining 3% is assumed to be incorporated into organic molecules and retained with a biological half-life of 40 days (Compartment Total Body B).

For most nuclides in ICRP Publication 78 (ICRP 1997), biokinetic models are used to calculate the predicted values of the radionuclide (Bq per Bq intake) in daily urinary excretion. Urine samples are aggregated over a whole day. HTO is a special case. For bioassay purposes, the activity concentration in urine is calculated by dividing the whole-body activity (the activity in blood and both whole-body compartments) by the volume of body water, 42 L (total volume of body water value from ICRP Publication 23 (ICRP 1975). For dosimetric purposes, however, the activity is taken to be distributed throughout the whole body (excluding the lumen of the GI tract).

Bioassay results for tritiated water are given in terms of activity concentration in urine (Bq/L). Figure A1.1 from ICRP 78 (ICRP 1997) shows the predicted values of activity concentration in urine (Bq/L per Bq intake) following acute intake by inhalation, ingestion or injection. This figure is reproduced below.
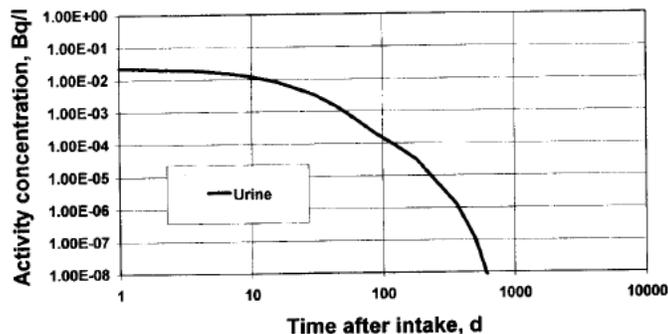
Fig. A.1.1. ³H (tritiated water) inhalation, ingestion or injection: predicted values (Bq per Bq intake) following acute intake.

Figure 1. Predicted Values of Activity Concentration in Urine in Bq/L as a Function of Time after Intake

The following table shows the values of activity concentration in urine per unit activity intake that reproduces the values in the figure above. Those values are the same as the ones published in the International Atomic Energy Agency (IAEA) Safety Guide, *Assessment of Occupational Exposures Due to Intakes of Radionuclides* (IAEA 1999). Only the first 100 days were published in the IAEA document. In addition, the values in Table 1 reproduce the ones published by Potter (2004), *Application of the ICRP Clarification of the Tritium Metabolic Model*.

Table 1. Predicted Values (Bq/L per Bq Intake) for Ingestion, Injection and Inhalation of Tritiated Water

Time after Intake days	Activity Concentration in Urine (Bq/L)
1	2.3E-02
2	2.1E-02
3	2.0E-02
4	1.9E-02
5	1.7E-02
6	1.6E-02
7	1.5E-02
8	1.4E-02
9	1.3E-02
10	1.2E-02
20	6.4E-03
30	3.4E-03
40	1.8E-03
50	1.0E-03
60	6.2E-04
70	3.9E-04
80	2.7E-04
90	1.9E-04
100	1.5E-04
110	1.2E-04
120	9.4E-05
130	7.7E-05
140	6.4E-05
150	5.3E-05
160	4.4E-05
170	3.7E-05
180	3.1E-05
190	2.6E-05
200	2.2E-05

For time periods long after the intake of HTO, most of H-3 is organic, and the method described in ICRP Publications 78 (1997) and 88 (2001) is not adequate. The assumption that activity concentration in urine is similar to the activity in the whole-body activity divided by the volume of body water is not valid for such protracted time periods. In addition, 24-hour urine samples should be measured instead of the activity concentration in spot urine samples when evaluating tritium excretion rates long after the intake of tritium has occurred.

A table of reference values for retention and excretion of H-3 as a function of time after acute ingestion or inhalation of HTO is given in the National Council on Radiation Protection & Measurements (NCRP) Publication 161 (NCRP 2008) and is reproduced below:

Table 2. Reference Values for Retention and Excretion of H-3 and Corresponding Activity in Urine per L

Day After Intake	% of intake 24-h Urinary Excretion	% of intake 24-h Fecal Excretion	% of intake Retained in Body	Urine Activity/L 1.4L/d	Urine Activity/L 1.6L/d
1	3.6E+00	2.5E-01	9.4E+01	2.6E-02	2.3E-02
2	3.4E+00	2.3E-01	8.7E+01	2.4E-02	2.1E-02
3	3.1E+00	2.2E-01	8.2E+01	2.2E-02	1.9E-02
5	2.7E+00	1.9E-01	7.1E+01	1.9E-02	1.7E-02
7	2.4E+00	1.7E-01	6.2E+01	1.7E-02	1.5E-02
10	1.9E+00	1.3E-01	5.1E+01	1.4E-02	1.2E-02
15	1.4E+00	9.5E-02	3.7E+01	1.0E-02	8.8E-03
20	9.8E-01	6.8E-02	2.6E+01	7.0E-03	6.1E-03
30	5.0E-01	3.4E-02	1.4E+01	3.6E-03	3.1E-03
40	2.5E-01	1.8E-02	7.6E+00	1.8E-03	1.6E-03
50	1.3E-01	9.0E-03	4.3E+00	9.3E-04	8.1E-04
60	7.0E-02	5.0E-03	2.6E+00	5.0E-04	4.4E-04
70	3.8E-02	3.0E-03	1.7E+00	2.7E-04	2.4E-04
80	2.2E-02	2.0E-03	1.1E+00	1.6E-04	1.4E-04
90	1.4E-02	1.0E-03	8.2E-01	1.0E-04	8.8E-05
100	9.0E-03	1.0E-03	6.3E-01	6.4E-05	5.6E-05

Source: NCRP 2008

The values in Table 2 are slightly different than the values in Table 1, especially at longer times after intake. The values of urine activity per liter were obtained using both the reference excretion rate of 1.4L/d from ICRP 23 (ICRP 1975) and the reference excretion rate of 1.6L/d for males from ICRP 89 (ICRP 2002).

The UK Health Protection Agency in its publication, *Review of Risks from Tritium* (HPA 2007), discusses the ICRP model for tritium. It proposes a three-component exponential model to describe the retention of tritium following intakes of HTO. The third component accounts for 0.02% of the tritium transferred from blood to the body, and has a biological half-life of 350 days. The dose coefficients based on the HPA proposed model are only slightly lower than those currently published by the ICRP. The main difference is in the interpretation of tritium in urine made more than about 100 days after intake.

The ICRP has posted on its web site (www.icrp.org) a draft of its new intended publication, *Occupational Intakes of Radionuclides, Part 2*, for public consultation. This report is one of a series of publications intended to replace the publication 30 series, Publication 68 (ICPR 1994) Publication 54 (ICRP 1989a) and ICRP 78 (1997). Although this draft consultation document is not aproved for publication by the ICRP, and ICRP explicity warns against citing it and using it before final aproval, it is worthwhile to compare the current HTO model with the most recent HTO draft model, which is based on selected models appearing in the open literature in recent years.

The draft HTO model is a recycling model with four compartments, representing (1) Blood, (2) extravascular body water (Extravascular HTO) that exchanges rapidly with Blood, (3) organically bound tritium (OBT1) with intermediate turnover rate (a biological half-life of 40 days) and (4) organically bound tritium (OBT2) with slow turnover rate (a biological half-life of 1 year). The transfer coefficient from Blood to Excreta is set to yield an initial removal half-life from the body of 10 d. It is assumed that urine accounts for 55% of the excreta.

The following figure shows the draft model predictions of urinary excretions after an acute intake of HTO, normalized to a urine concentration of 1.0 on day 1, and data from published cases of HTO intakes.
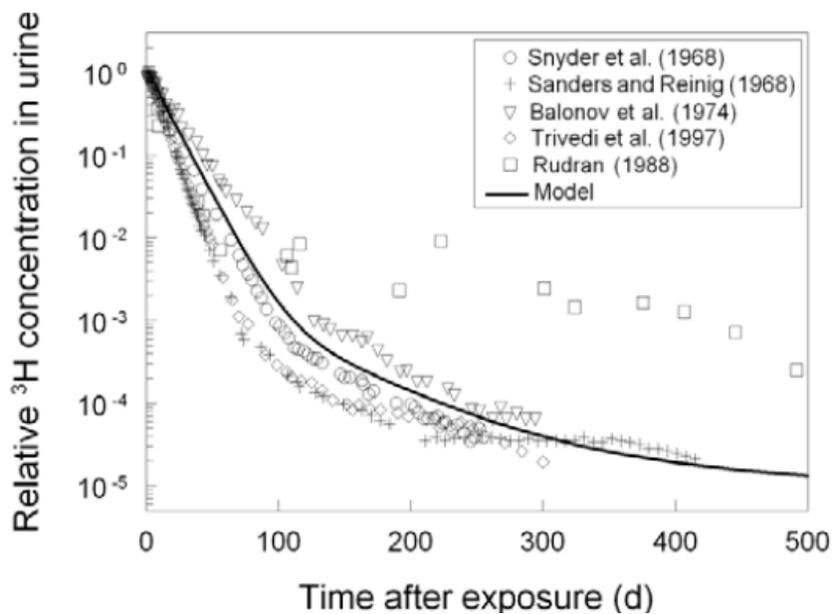
Figure 2. Observations and Model Predictions of Urinary Excretion of H-3 as Function of Time after Acute Intake of HTO, Normalized to Day 1

Table 3 shows predicted urine excretion rates following an acute intake of HTO. The urinary excretion rates were obtained by SC&A using a model with half-lives and compartment transfer fractions that are compatible with the transfer coefficients in the systemic model for HTO given in the draft ICRP document. SC&A's compartment fractions are rounded numbers. The values in Table 3 are not ICRP values. They should be used with caution, and are only going to be used by SC&A to discuss the validity of using the current ICRP 78 (1997) model for HTO at long time periods after the intake. The excretion rates were normalized to day 1, to compare with the draft model predictions of urinary excretions shown in Figure 2. The values in Table 3 are close to the ones in the figure.

Table 3. Urine Excretion Rates Derived by SC&A using Half-Lives and Compartment Transfer Fractions that were Obtained from the Transfer Coefficients given in the Draft ICRP Model

Time	Draft Model 24-h Urine Activity/ Activity Intake	Draft Model Urine Activity Normalized to Day 1
1	3.8E-02	1.0E+00
2	3.4E-02	9.1E-01
3	3.2E-02	8.5E-01
4	3.0E-02	7.9E-01
5	2.8E-02	7.4E-01
6	2.6E-02	6.9E-01
7	2.4E-02	6.4E-01
8	2.2E-02	5.9E-01
9	2.1E-02	5.5E-01
10	1.9E-02	5.1E-01
20	9.5E-03	2.5E-01
30	4.6E-03	1.2E-01
40	2.3E-03	6.1E-02
50	1.1E-03	3.0E-02
60	5.8E-04	1.5E-02
70	3.0E-04	7.9E-03
80	1.6E-04	4.2E-03
90	8.8E-05	2.3E-03
100	5.2E-05	1.4E-03
150	1.0E-05	2.8E-04
180	6.1E-06	1.6E-04
200	4.4E-06	1.2E-04
300	1.2E-06	3.3E-05
400	6.0E-07	1.6E-05

Table 4 compares the predicted excretion rates using the draft ICRP model, the current HTO ICRP 78 (1997) model, and NCRP 161 (2008) published values.

Table 4. Activity Concentration of H-3 in Urine Following an Acute Intake of HTO

Time	Draft Model Activity in 24-h Urine/L*	Current ICRP Model Urine Activity/L	NCRP 161 Activity in 24-h Urine/L
	(1.6L/day)		(1.6L/d)
1	2.3E-02	2.3E-02	2.3E-02
2	2.1E-02	2.1E-02	2.1E-02
3	2.0E-02	2.0E-02	1.9E-02
4	1.9E-02	1.9E-02	
5	1.7E-02	1.7E-02	1.7E-02
6	1.6E-02	1.6E-02	
7	1.5E-02	1.5E-02	1.5E-02
8	1.4E-02	1.4E-02	
9	1.3E-02	1.3E-02	
10	1.2E-02	1.2E-02	1.2E-02

Table 4. Activity Concentration of H-3 in Urine Following an Acute Intake of HTO

Time	Draft Model Activity in 24-h Urine/L* (1.6L/day)	Current ICRP Model Urine Activity/L	NCRP 161 Activity in 24-h Urine/L (1.6L/d)
20	5.9E-03	6.4E-03	6.1E-03
30	2.9E-03	3.4E-03	3.1E-03
40	1.4E-03	1.8E-03	1.6E-03
50	7.1E-04	1.0E-03	8.1E-04
60	3.6E-04	6.2E-04	4.4E-04
70	1.9E-04	4.0E-04	2.4E-04
80	9.8E-05	2.7E-04	1.4E-04
90	5.5E-05	1.9E-04	8.8E-05
100	3.3E-05	1.5E-04	5.6E-05
150	6.5E-06	5.3E-05	
180	3.8E-06	3.1E-05	
200	2.8E-06	2.2E-05	
300	7.8E-07	3.8E-06	
400	3.7E-07	6.6E-07	

Values derived by SC&A, based on the draft ICRP model for HTO. Those values are not ICRP values. The model used to derive those values is not yet approved by the Commission, although it was posted on the ICRP website for public consultation.

As seen in Table 4, at 50 days after intake, the values start to divert. At 100 days after exposure, the value predicted by the new draft model is of the same order of magnitude as the NCRP 161 (2008) value, but much lower than the one predicted by the current ICRP 78 (1997) model. At 150 days, 180 days, and 200 days after exposure, the draft ICRP model predicts the urinary excretion rate is one order of magnitude lower than the one predicted by the current ICRP 78 (1997) model.

The excretion rates from 100 days to 200 days are part of a grey area in terms of interpretation of urine excretion results. ICRP has not officially changed its model for HTO. On the other hand, there is a hint on how the model is going to be changed, as it was posted on the ICRP website for public consultation. The HPA in the UK is considering similar changes.

2.0 REVIEW OF NIOSH'S INTERPRETATION OF THE H-3 URINARY RESULTS FOR THE FIVE WORKERS IDENTIFIED AS HAVING THE LARGEST H-3 URINALYSIS RESULTS

As stated in NIOSH's white paper:

> *...the report, Investigation of the Tritium Release Occurrence at the Rocky Flats Plant (SRDB 24165, pdf p. 16), describes a 1973 incident that prompted the site to sample a number of workers for tritium exposure. A shipment of scrap plutonium from LLNL was discovered to have been contaminated with tritium. This material was processed at the Rocky Flats Plant from April 9 to 25, 1973 in Building 779A. Because it was not immediately identified as being contaminated, monitoring of potentially-exposed individuals did not begin until late September 1973.*
> [Emphasis added.]

For the workers that potentially worked on the processing of plutonium contaminated with tritium on April 9–25, 1973, more than 150 days had elapsed between possible exposure and urine sample collection. After 150 days from the intake of HTO, the current ICRP 78/88 (ICRP 1997, ICRP 2001) may not describe correctly the activity concentration of H-3 in urine. For this reason, SC&A is applying the HTO model described in the draft ICRP report that was posted on the ICRP website, although the ICRP warns not to use it until final approval by the Commission.

Case A:

1. SC&A tested two hypotheses, using the urinary excretion rates predictions from the draft ICRP model for HTO:
    a. The worker was exposed on the 21st of April
    b. The worker was exposed on September 19th
        Both hypotheses gave acceptable correlations between predicted excretion rates and results.
        Hypothesis (a) is compatible with an acute intake of 9.2E4 µCi, while Hypothesis (b) is compatible with an intake of 40 µCi.

2. The predicted activity concentration of H-3 in urine on September 25th due to an acute intake on 21st of April is 9.1E-6 of the intake. Most of the H-3 has already left the body. The uncertainty is very high.

3. If the worker had an intake around the 19th of September, this intake will dominate the excretion rate, and would totally hide other excretion rates that could have occurred 1, 2, or 3 months before. A simple look at Table 3 will confirm this statement. A combination of exposure dates is possible, as well as a combination of intake rates. For example, an acute intake of 1E4 µCi on the 21st of April followed by an additional intake of 35 µCi on September 19th will cause equivalent excretion rates as a single intake of 40 µCi on September 19th. Figure 3 illustrates that the predicted excretion rates from these imaginary intakes match well the real urinary excretion results. Other variations and

combinations of intakes, on various dates, can produce good fits to the urinary excretion results, in addition to the chosen example.
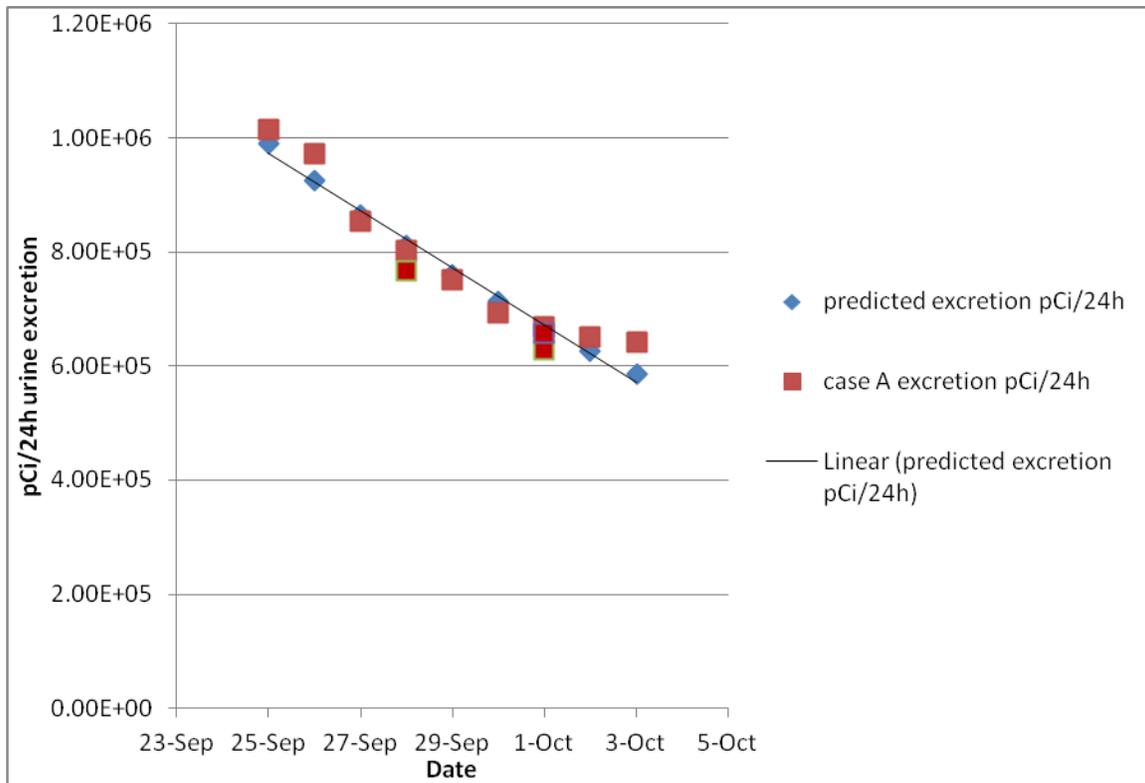
Figure 3. Predicted Excretion Rates (due to imaginary acute intakes of 1E4 µCi on the 21st of April and 35 µCi on September 19th) versus Actual Excretion Rates

Figure 4 illustrates how the worker's excretion rates (non-distilled) compare with the predicted urinary excretion rates from three different exposures scenarios:

a. Combined acute intakes of 1E4 µCi on the 21st of April and 35 µCi on September 19th
b. Acute intake of 40 µCi on September 19th
c. Acute intake of 9.2E4 µCi on April 21st
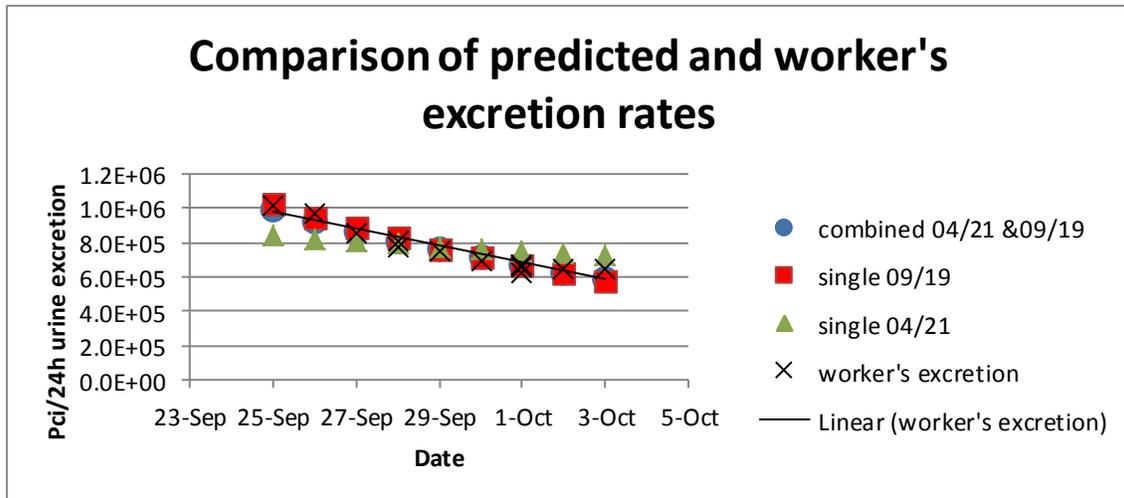
**Figure 4. Comparison of Predicted and Worker's Excretion Rates
for Three Different Scenarios**

4. In conclusion, it is not possible with the dataset of bioassay results available for Worker A to infer either a single date or a single exposure intake for this worker. A plausible bounding intake, though, would be the worst-case scenario, in which an acute intake of 9.2E4 µCi on April 21st is assigned to the worker. Although this is not the scenario that gives the best fit for the data, it is the bounding scenario, with an acceptable fit.

5. The dose corresponding to the combined scenario (1E4 µCi on the 21st of April and 35 µCi on September 19th) is 666 mrem.

6. The dose corresponding to the scenario of an acute intake of 40 µCi on September 19th is 2.7 mrem.

7. The dose corresponding to the bounding scenario of an acute intake of 9.2E4 µCi on April 21st is 6,120 mrem.

8. This example illustrates the huge uncertainty on the possible intakes and doses that may be assigned to the worker for different scenarios that fit the real results reasonably well.

Case B:

As stated by NIOSH in the white paper, the earliest date that Worker B could have been contaminated was July 1st, 1973. Worker B was probably not involved in the contamination accident that took place in April 1973. The worst-case scenario would be a delay of 86 days between the first date of intake and the first bioassay sample collection. Worker A worst-case scenario assumes 157 days delay between the possible day of intake and urine sample collection, a much longer delay than experienced by Worker B. In addition, the highest excretion activity for Worker B is lower than the majority of the excretion activities for case A.

The worst case scenario for Worker B assumes a single intake occurring on the 1st of July. The intake, calculated using the draft model from the ICRP, is calculated as 1.6E9 pCi, and the corresponding dose is 106 mrem.

NIOSH assumes two other scenarios:

- – Continuous intake from July 1 to September 25th
- – Acute intake on September 19th

Both scenarios give the same results using the new draft model and the current ICRP 78/88 (ICRP 1997, ICRP 2001) HTO model. This is because both models predict the same excretion rates for the first weeks after the intake. In the case of the continuous intake, the excretion rates are dominated by the intakes that occur close to September 25th. Thus, both models predict the same daily intakes and the same doses. Therefore, Case B results do not provide a bounding intake for 1973.

Case C:

NIOSH in its white paper stated that Worker C could not have been exposed to tritium before August 27th, 1973. Worker C was probably not involved in the contamination accident that occurred in April 1973.

NIOSH assumes two possible scenarios for this worker;

- – Acute intake on the first day of work, the 27th of August. In this case, 29 days elapsed between the intake and the first sample. The new draft model and the current ICRP (ICRP 1997, ICRP 2001) model predict the similar excretion rates for 30–40 days after the intake. SC&A agrees with the intake and dose assigned to Worker C.
- – Continuous intake from August 27th until September 25th: The new draft model and the current ICRP (ICRP 1997, ICRP 2001) model predict the similar excretion rates for 30–40 days after the intake. SC&A agrees with the daily intake of 0.24 µCi assigned to Worker C. In this case, the corresponding dose is 0.48 mSv (48 mrem).

The worst-case scenario is a delay of 29 days between the first date of intake and the first bioassay. This delay is shorter than the Case A worst-case scenario (157 days delay between the possible day of intake and urine sample collection). In addition, the highest excretion activity for Worker C is lower than the majority of the excretion activities for Case A.

Case C results do not provide a bounding intake for 1973.

Case D:

SC&A agrees with the NIOSH statement that Worker D bioassays consist of few samples and results follow no specific pattern. The worst-case scenario is a delay of 159 days between the first date of intake and the first bioassay. This delay is about the same delay as the worst-case scenario for Worker A (157 days delay). The highest H-3 activity excreted in urine by Worker D is more than an order of magnitude lower than most non-distilled results for Worker A.

If one assumes an acute intake on April 10th, using the new draft model for HTO, the calculated intake of the worker would be about 5,400 µCi, with a corresponding dose of 360 mrem.

NIOSH assumes two scenarios:

- Chronic intake from April 10th to April 25th: Using the new ICRP draft model, this scenario yields daily intakes of 293 µCi from April 10th to April 25th. The intake rates calculated using the new draft model are about four times higher than the daily intakes calculated by NIOSH using the current ICRP 78/88 (ICRP 1997, ICRP 2001) model. The corresponding dose is 313 mrem, approximately four times the dose calculated using the current ICRP 78/88 (ICRP 1997, ICRP 2001) model.

- Chronic intakes from April 10th to June 15th: Using the new ICRP draft model, this scenario yields daily intakes of about 35 µCi from April 10th to June 15th. The intake rates calculated using the new draft model are about four times higher than the daily intakes calculated by NIOSH using the current ICRP 78/88 (ICRP 1997, ICRP 2001) model. The corresponding dose is 156 mrem, approximately four times the dose calculated using the current ICRP 78/88 (ICRP 1997, ICRP 2001) model.

Case D results do not provide a bounding intake for 1973.

Case H:

SC&A agrees with NIOSH that the only available information indicates that an acute intake occurred on April 6th. There are only two non-distilled urine results, on September 30th and October 1st, 1973, which make it impossible to use a curve fitting. The average intake calculated using the two non-distilled urine results and the draft ICRP model is 5,420 µCi. This intake is about four times the intake calculated by NIOSH. The corresponding dose is 360 mrem, about four times higher than the dose calculated by NIOSH.

3.0   CONCLUSIONS

- In its white paper, NIOSH proposes to use bioassay results from urine samples taken at the end of September and beginning of October of 1973 to assign bounding doses to workers in 1973. The white paper cites a 1973 incident that prompted the site to sample a large number of workers for tritium exposure. Scrap plutonium contaminated with tritium was processed at Rocky Flats from April 9–25, 1973. Monitoring of potentially exposed workers did not begin until late September 1973.

- At least 150 days elapsed between possible workers' contamination in the April 1973 incident and the H-3 bioassay sampling. When sampling began, most of the HTO had already been excreted from the body. The current ICRP 78/88 (ICRP 1997, ICRP 2001) model does not describe well the excretion rates of HTO at long times after intake. The predicted excretion rates of HTO, given in ICRP 78 (ICRP 1997), were derived with the purpose of guiding individual monitoring programs for workers. For HTO exposures, it only gives activity concentrations in urine for special monitoring up to 10 days after exposure and for routine monitoring up to 30 days after exposure. The current ICRP 78/88 guidance for deriving activity concentrations in urine by dividing the whole-body activity by the volume of body water (42 L) should not be used to calculate intakes from urine bioassay results if samples were collected more than 100 days after exposure. The lack of an official ICRP model for HTO that can be used for samples taken at 150 to 180 days after the April 1973 accident is a problem and adds to the uncertainty on intakes and dose calculations in this particular case. SC&A used the new draft model posted by the ICRP in its website for public consultation, even without official endorsement by the ICRP.

- The NIOSH white paper estimates intakes and doses of five workers identified as having the largest H-3 urinalysis results in the September-October sampling. In this analysis, other contamination dates besides the April incident were considered as possible contamination dates for the worker. One example is the worker's contamination when taking samples from a tritium-contaminated water bubbler during September 19–25, 1973.

- When a worker is exposed to HTO in several incidents, the HTO excretion rate will be dominated by the most recent exposure. Thus, sampling just after the last incident will reflect mostly the most recent exposure, hiding the ones that occurred months before the sampling. This could have happened, for example, with the exposure from Worker A. As shown by SC&A, the urine excretion rate from Worker A fit an exposure scenario of contamination in the September bubbler accident equally well as a scenario of high intake in the April 1973 accident, followed by additional contamination in the September incident. Other scenarios could fit the urinary excretion rates results equally well.

- As stated by NIOSH, all five cases analyzed had initial samples that were not distilled, with one to five later distilled samples. In general, the two sets of results were not consistent, with the distilled samples yielding lower values. The pre-distilled sample results were used in the development of the white paper.

- The efficiency of the non-distilled samples was low and results were not consistent with the ones from the distilled samples. The uncertainty of these urine results is high and a perfect fit should not be expected for all possible exposure scenarios. The results from Worker D illustrate this uncertainty well. Results from October 2nd were 18,500 pCi/L (2 Sigma error of 4,700) for non-distilled analysis and 20,800 pCi/L (2 Sigma error of 1,100) for distilled analysis. Results for October 3rd were 28,100 pCi/L (2 Sigma error of 2,000) and 15,000 pCi/L (2 Sigma error of 2,000) with SCR (Sample Channel Ratio). Thus, decisions on the best fit scenario based on the reproduction of non-distilled sample results could lead to mistakes, as the uncertainty on the individual urine results is very high.

- Bounding intakes and doses might be assigned based on Worker A's maximum possible intake. Using the new draft ICRP model posted on the ICRP web site, this intake is about 9E4 µCi. The order of magnitude of this intake is correct, although small differences might be expected when the ICRP publishes its Occupational Exposures Series Reports. Other scenarios are possible, all predicting well the excretion rates of the worker. SC&A provided three possible scenarios. The differences in the assigned doses to the worker are huge: 2.7 mrem, 670 mrem, and 6,000 mrem. The uncertainties are too high. The reason for this large uncertainty is the large delay between sample collection and the possible involvement of the worker in the April accident.

- The following table illustrates SC&A-calculated bounding intakes and doses (worst-case scenario that produces a reasonable fit to the urinary excretion results) for the five cases, compared to NIOSH results.

Table 5. Summary of Intake and Dose Assessments for Five Workers that had the Highest H-3 Bioassay Results among the Samples Collected in September and October 1973

(Highest possible intakes are displayed)

Case	NIOSH Intake Date	NIOSH Intake (µCi)	NIOSH Dose (mrem)	SC&A Intake Date	SC&A Intake (rounded) (µCi)	SC&A Dose (rounded) (mrem)
A	9/19/73	38.7	2.6	04/21/73	9.0E4	6000
B	7/1/73 thru 9/25/73	28.1	1.9	7/1/73	1.6E3	100
C	8/27/73	21.3	1.4	8/27/73	21	1.4
D	4/10/73–4/25/73	1070	72	4/10/73–4/25/73	5.0E3	300
H	4/6/73	1240	84	4/6/73	5.4E3	360

The differences between NIOSH and SC&A assessments of intake and doses are caused by:

- For Cases A and B: Different dates were assigned for the intake and New Model for HTO was used by SC&A.

- For cases D and H, the same dates were assigned but new model for HTO was used.

For case C, the same dates and same intakes and doses were assigned, because the current ICRP 78 (ICRP 1997) model for HTO gives similar predictions for the H-3 excretion rates as the new one, for about 30 days after exposure.

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