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JUN 20 2008

OFFICE OF RADIATION PROTECTION

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June 14, 2008

Michael Elsen  
Washington Department of Health  
PO Box 47905  
Olympia, WA 98504-7905

RE DOE CONTRACT N16459

Dear Mr. Elsen:

Enclosed is a hard copy of the report entitled *Calibration of Tritium Release Rates to Vadose Zone and Ambient Air Measurements for the U.S. Ecology Low-Level Radioactive Waste Disposal Facility, Richland Washington*. This report contains an additional analysis of tritium released to the atmosphere compared to the draft report that was issued in March of this year, along with changes made in response to Kirsten Schwab's comments. I have provided a hard copy of my response to her very helpful comments. Enclosed is a CD containing all the computer files and codes that were used in the calculations and electronic copies of the report and supporting documentation.

I have enclosed my invoice for this work, along with a timesheet of the hours spent. Please feel free to contact me if you have any questions concerning this work or my billing.

Sincerely



Arthur S. Rood

**Response to Comments by Kristen Schwab on *Calibration of Tritium Release Rates to Vadose Zone and Ambient Air Measurements for the U.S. Ecology Low-Level Radioactive Waste Disposal Facility, Richland Washington***

**June 13, 2008**

**Table 1. What does "U" under Laboratory Qualifier stand for?**

**RESPONSE:** I have placed as an appendix a list of all laboratory qualifiers. U = the sample was analyzed for but the concentration was below the detection limit.

**Figure 2. Vadose Monitoring Well locations VZ A-D appear to angle bore-hole locations.**

**RESPONSE:** I separated the angle bore holes from the vadose zone monitoring wells on the map.

**Figure 2. Please add Solar Still locations (SS 100 -103) - I have the locations if you need them**

**RESPONSE:** Added Solar Stills to map

**Figure 3. Could you use different colors for the symbols? It is hard to distinguish the shades of red from each other**

**RESPONSE:** I changed the symbol size and the colors on Figures 3-4 and 6-7.

**Page 14. Typo. First sentence under Model Calibration "has" should be "as"**

**RESPONSE:** OK - changed

**Page 18 and 19. Do the "predicted" values refer to the calibrated values?**

**RESPONSE:** Made changes to the text that clarifies that the predicted concentration refers to the calibrated predicted concentration.

**Figure 6. Since the concentration of tritium increases as the depth approaches 20 m shouldn't the calibrated concentrations for 16-22 m be greater than that for 10-16 m?**

**RESPONSE:** Technically, yes, but the model does not have the spatial resolution to resolve the 3 m difference between the different measurement depths because the minimum layer thickness was about 6 m. Moreover, I have changed the comparison to observed values to reflect the spatial averaging that the model is based on (see next comment).

**Page 18 and 19. The calibrated concentration of 0-10m looks like it is about 7.5e4 pCi/l, not the predicted value of 5970 pCi/L as given in the discussion on page 18.**

**RESPONSE:** The calibrated value of 5970 pCi/L represent the average predicted concentration from January 1996 to December 2006. In response to your comment, I have made extensive changes to the figures and text. Because the model represents a spatial average across the site, I

performed some spatial averaging of the measured data. I also averaged temporally across each year for comparisons with the predicted data.

**General Comment: Are there conclusions for CASE 2?**

**RESPONSE:** I have included a graphs and a comparison of the original CASE1 and CASE2 drinking water dose and the drinking water dose with the calibrated tritium releases.

# FINAL REPORT

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## Calibration of Tritium Release Rates to Vadose Zone and Ambient Air Measurements for the U.S. Ecology Low-Level Radioactive Waste Disposal Facility, Richland Washington

Date June 13, 2008

*Submitted to Washington State Department of Health  
in partial fulfillment of contract No. N16459*

# FINAL REPORT

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## Calibration of Tritium Release Rates to Vadose Zone and Ambient Air Measurements for the U.S. Ecology Low-Level Radioactive Waste Disposal Facility, Richland Washington

Date June 13, 2008

Arthur S. Rood

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## EXECUTIVE SUMMARY

US Ecology Incorporated operates a low-level radioactive waste disposal facility on leased land from the U.S. Department of Energy's Hanford Reservation located near Richland Washington. The Washington State Department of Health (WDOH) developed an Environmental Impact Statement (EIS) for the site and published the final in 2004 (WDOH 2004). Groundwater transport calculations were documented in Rood (2004) and additional closure scenarios were documented in Rood (2007). Tritium ( $H^3$ ) was shown to be the dominant dose contributor for the 100 year period following closure and predicted concentrations exceeded the Maximum Contaminant Limit (MCL) for tritium of 20,000 pCi/L.

Observed concentrations of tritium in vadose zone pore water and aquifer were obtained from U.S. Ecology Site. Isoleth maps of tritium in the aquifer suggest that the tritium in the aquifer underlying US Ecology is from an upgradient source at the Hanford 200 Area West and not the US Ecology site.

In November 1991, three vadose zone vapor sampling wells were installed at the US Ecology site. In addition to the vadose zone monitoring wells, four Solar Stills were also installed in 1994. A solar-still is designed to measure water vapor that resides in soil pore air. Data from the vadose zone wells and Solar Stills from 1996 to 2006 were obtained. Both the vadose zone and the solar still measured concentrations are substantially lower than the corresponding model-predicted concentrations, typically by a order of magnitude or more.

A simple calibration method was used to reconcile the predicted and observed subsurface tritium concentrations in soil pore air. Two tritium-specific parameters were estimated; the waste-to-backfilled-soil partitioning coefficient and the removal rate constant from disposal trenches to the vadose zone. Initial estimates of these empirical parameters were made using measured and modeled data which were later refined so that the predicted to observed ratios approached a target value of 1.0.

Using the tritium calibration parameters described above, the predicted tritium aquifer concentration dropped below the tritium MCL and drinking water doses were less than 0.1 mrem/yr. The calibration is not unique and has many limitations including the assumption that the tritium inventory is correct.

Tritium was also measured in ambient air at monitoring stations located on the downwind perimeter of the US Ecology Site. A liquid-gas-phase transport model was developed to predict tritium in water vapor flux to the surface. This model, coupled with a Gaussian Plume atmospheric transport model and site specific meteorological data were used to estimate annual average tritium concentrations in ambient air and to compare these predictions with the corresponding observed values. Initial estimates indicated gross model underprediction. However, with the incorporation of a waste-to-soil partitioning coefficient, predicted values matched reasonably well the magnitude and temporal trend of the observed values.

Despite the limitations of the calibration, it is evident from the measurement data that the tritium transport model used for the US Ecology site overpredicts releases of tritium from the waste packaging to the backfilled soils. Tritium is not expected to be a major dose contributor in the future in contrast to earlier assessments (Rood 2004 and Rood 2007) given the fact that tritium has only a 12.5-year half-life. It is strongly recommended that vadose zone monitoring continue at the US Ecology site to verify future model predictions.

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## INTRODUCTION

US Ecology Incorporated operates a low-level radioactive waste disposal facility on leased land from the U.S. Department of Energy's Hanford Reservation located near Richland Washington. The Washington State Department of Health (WDOH) developed an Environmental Impact Statement (EIS) for the site and published the final in 2004 (WDOH 2004). Groundwater transport calculations were documented in Rood (2004). The groundwater analysis included evaluation of multiple cover designs and closure options for the site. In Rood (2007) groundwater concentrations and doses were recalculated for two additional closure scenarios:

- CASE 1: An enhanced cover is installed in 2012 instead of 2005 and waste disposal continues through 2056. Infiltration through the active trenches is restricted to no more than the design infiltration rate of the cover ( $0.05 \text{ cm yr}^{-1}$  for the enhanced cover).
- CASE 2: An enhanced cover is installed in 2012 instead of 2005 and waste disposal continues through 2056. Infiltration through the active trenches from 2012 to 2056 is set at the infiltration rate through an uncovered pit ( $7.5 \text{ cm yr}^{-1}$ ). The modeled infiltration through the entire disposal facility was calculated as the area-weighted infiltration through the portion of the disposal site that is covered with the enhanced cover and the infiltration rate through the active trenches.

Additionally, groundwater transport calculations in Rood (2007) were performed with the Mixing Cell Model (MCM) (Rood 2005) instead of the FOLAT (Rood 2003) model that was used in the original calculations. MCM is conceptually and mathematically identical to FOLAT and was shown to produce virtually identical results. However, quality assurance documentation and user options for MCM are more extensive than that of FOLAT, and for this reason, the MCM code was used for these calculations.

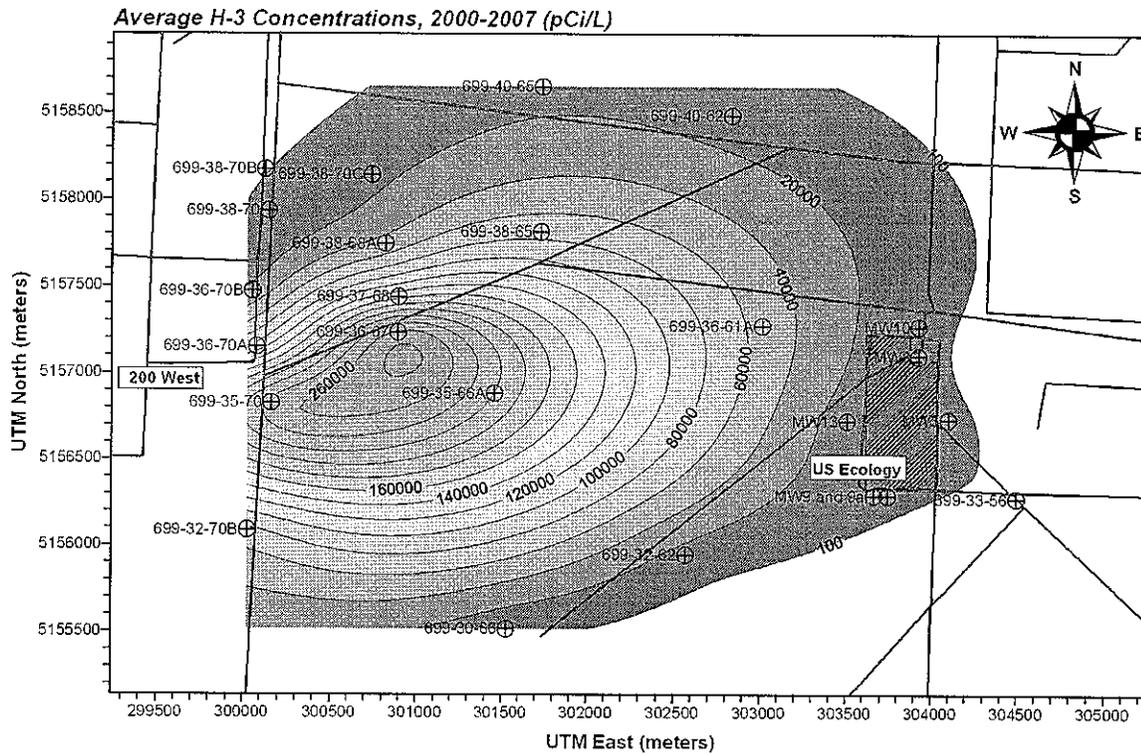
In Rood (2004) and Rood (2007), tritium ( $\text{H}^3$ ) was shown to be the dominant dose contributor for the 100 year period following closure. Maximum tritium dose was *about*  $5 \text{ mrem yr}^{-1}$  with a 95% confidence interval of *about*  $1 \text{ to } 20 \text{ mrem yr}^{-1}$  depending on the particular cover and closure scenario. Predicted maximum tritium concentrations in groundwater were about  $100,000 \text{ pCi L}^{-1}$  with an 95% confidence interval of about  $20,000 \text{ to } 270,000 \text{ pCi L}^{-1}$ . These concentrations are well above the Maximum Contaminant Limit (MCL) of  $20,000 \text{ pCi L}^{-1}$  set forth in 40 CFR 141.

This report presents tritium measurements in the aquifer, vadose zone, and ambient air, and compares them to predicted concentrations. A simple calibration procedure is then applied to the model to bring the predicted tritium concentrations in line with their corresponding measured values. Calibrated tritium concentrations in the aquifer and drinking water doses are presented and compared to the un-calibrated results.

## OBSERVED TRITIUM CONCENTRATIONS IN THE AQUIFER AND VADOSE ZONE

Concentrations of tritium in the vadose zone and aquifer were obtained from Robert Haight of the U.S. Ecology Site. Average concentrations of tritium in aquifer wells from year 2000 to 2007 are plotted Figure 1. The plot suggests that bulk of the tritium underneath the US Ecology site is from the 200 West area which is part of the U.S. Department of Energy Hanford

Reservation. Measured concentrations of tritium in aquifer wells are presented in Table 1. Time-averaged measured tritium concentrations in aquifer wells from ~1996 to 2006 are presented in Table 2. Based on the aquifer data, it appears likely that the tritium observed in MW3, MW8, and MW10 originated from the 200 West area and not the US Ecology site. Therefore, the vadose zone measurements provide a better indication of tritium migration from the waste disposed in the US Ecology facility.



**Figure 1.** Isopleth map of 2000 to 2007 average tritium concentration in wells near the US Ecology disposal site.

**Table 1. Measured tritium concentrations in aquifer wells near the US Ecology site.**

Well Name	UTM East (m)	UTM North (m)	H-3 (pCi/L)	Sample Date	Laboratory Qualifier <sup>b</sup>
699-30-66	301530	5155516	1.82E+02	10/20/05	U
699-30-66	301530	5155516	1.70E+02	06/01/07	U
699-30-66	301530	5155516	1.50E+02	12/01/06	U
699-30-66	301530	5155516	1.80E+04	09/09/04	
699-30-66	301530	5155516	3.50E+02	02/28/06	
699-30-66	301530	5155516	1.96E+02	05/23/05	U
699-30-66	301530	5155516	3.69E+01	02/14/05	U
699-30-66	301530	5155516	2.79E+02	11/30/04	U
699-30-66	301530	5155516	1.20E+02	10/05/04	U

**Table 1. Measured tritium concentrations in aquifer wells near the US Ecology site.**

Well Name	UTM East (m)	UTM North (m)	H-3 (pCi/L)	Sample Date	Laboratory Qualifier <sup>b</sup>
699-30-66	301530	5155516	3.60E+02	09/21/04	
699-30-66	301530	5155516	7.80E+02	09/21/04	
699-30-66	301530	5155516	1.63E+02	06/29/06	U
699-32-62	302569	5155947	8.59E+03	03/06/00	
699-32-62	302569	5155947	8.47E+03	01/23/03	
699-32-62	302569	5155947	9.12E+03	10/25/05	
699-32-70B	300025	5156086	6.07E+04	03/06/00	
699-33-56	304499	5156273	9.21E+01	03/24/03	U
699-35-66A	301458	5156881	2.44E+05	03/06/02	
699-35-66A	301458	5156881	2.46E+05	03/06/02	
699-35-66A	301458	5156881	1.85E+05	10/13/05	
699-35-66A	301458	5156881	1.60E+05	03/29/07	
699-35-66A	301458	5156881	2.59E+05	03/15/01	
699-35-70	300162	5156826	3.38E+05	10/06/00	
699-35-70	300162	5156826	2.77E+05	01/03/06	
699-35-70	300162	5156826	2.63E+05	01/23/03	
699-35-70	300162	5156826	2.78E+05	09/25/02	
699-35-70	300162	5156826	2.94E+05	03/22/02	
699-35-70	300162	5156826	3.06E+05	03/19/01	
699-35-70	300162	5156826	3.29E+05	03/22/00	
699-35-70	300162	5156826	3.01E+05	09/26/01	
699-36-61A	303014	5157270	5.29E+04	03/06/03	
699-36-61A	303014	5157270	5.10E+04	07/25/07	
699-36-61A	303014	5157270	5.33E+04	10/05/06	
699-36-61A	303014	5157270	4.94E+04	03/02/00	
699-36-61A	303014	5157270	5.72E+04	10/20/05	
699-36-61A	303014	5157270	5.83E+04	10/20/05	
699-36-67	300894	5157232	3.62E+05	03/20/01	
699-36-67	300894	5157232	3.26E+05	03/05/02	
699-36-70A	300077	5157152	6.79E+04	01/08/03	
699-36-70A	300077	5157152	7.83E+04	09/21/06	
699-36-70A	300077	5157152	5.50E+04	09/15/04	
699-36-70A	300077	5157152	6.48E+04	09/08/03	
699-36-70A	300077	5157152	7.40E+04	03/19/03	
699-36-70A	300077	5157152	5.99E+04	06/13/02	
699-36-70A	300077	5157152	6.16E+04	06/13/02	
699-36-70A	300077	5157152	5.37E+04	12/13/01	

**Table 1. Measured tritium concentrations in aquifer wells near the US Ecology site.**

Well Name	UTM East (m)	UTM North (m)	H-3 (pCi/L)	Sample Date	Laboratory Qualifier <sup>b</sup>
699-36-70A	300077	5157152	6.90E+04	06/04/01	
699-36-70A	300077	5157152	6.74E+04	12/20/00	
699-36-70A	300077	5157152	7.26E+04	09/29/00	
699-36-70A	300077	5157152	8.12E+04	06/08/00	
699-36-70A	300077	5157152	7.65E+04	01/19/00	
699-36-70A	300077	5157152	5.73E+04	03/06/02	
699-36-70A	300077	5157152	6.59E+04	06/11/03	
699-36-70B	300052	5157470	8.80E+03	08/18/04	
699-36-70B	300052	5157470	1.04E+04	08/30/05	
699-36-70B	300052	5157470	1.08E+04	05/16/05	
699-36-70B	300052	5157470	9.79E+03	02/14/05	
699-36-70B	300052	5157470	1.02E+04	11/30/04	
699-36-70B	300052	5157470	2.90E+02	09/23/04	
699-36-70B	300052	5157470	3.60E+02	09/23/04	
699-36-70B	300052	5157470	3.50E+03	09/14/04	
699-36-70B	300052	5157470	1.20E+03	08/31/04	
699-36-70B	300052	5157470	1.02E+04	09/05/06	
699-36-70B	300052	5157470	1.00E+03	09/09/04	
699-36-70B	300052	5157470	1.06E+04	04/19/06	
699-36-70B	300052	5157470	8.60E+03	01/26/07	
699-36-70B	300052	5157470	9.40E+03	04/18/07	
699-36-70B	300052	5157470	9.50E+03	06/01/07	
699-36-70B	300052	5157470	1.02E+04	05/26/06	
699-37-68	300897	5157436	1.21E+05	03/19/01	
699-37-68	300897	5157436	1.18E+05	03/08/02	
699-38-65	301731	5157810	2.14E+05	03/02/00	
699-38-65	301731	5157810	3.57E+04	11/02/06	
699-38-65	301731	5157810	3.48E+04	10/24/05	
699-38-65	301731	5157810	1.09E+04	08/11/04	
699-38-65	301731	5157810	4.05E+04	01/22/03	
699-38-65	301731	5157810	1.28E+05	03/21/01	
699-38-65	301731	5157810	3.20E+04	06/27/07	
699-38-65	301731	5157810	8.10E+04	03/21/02	
699-38-68A	300817	5157742	3.25E+04	01/23/03	
699-38-68A	300817	5157742	2.83E+04	08/30/05	
699-38-68A	300817	5157742	3.48E+04	03/21/02	
699-38-68A	300817	5157742	4.11E+04	02/23/00	

**Table 1. Measured tritium concentrations in aquifer wells near the US Ecology site.**

Well Name	UTM East (m)	UTM North (m)	H-3 (pCi/L)	Sample Date	Laboratory Qualifier <sup>b</sup>
699-38-68A	300817	5157742	4.02E+04	03/21/01	
699-38-70	300146	5157930	5.26E+03	03/23/00	
699-38-70	300146	5157930	6.90E+03	02/10/03	
699-38-70	300146	5157930	8.03E+03	08/11/04	
699-38-70	300146	5157930	8.17E+03	08/11/04	
699-38-70	300146	5157930	8.79E+03	10/20/05	
699-38-70	300146	5157930	7.41E+03	11/02/06	
699-38-70	300146	5157930	5.80E+03	07/02/07	
699-38-70B	300125	5158173	2.72E+02	02/23/05	U
699-38-70B	300125	5158173	1.40E+02	06/08/07	U
699-38-70B	300125	5158173	1.30E+03	12/27/06	
699-38-70B	300125	5158173	5.77E+01	08/11/04	U
699-38-70B	300125	5158173	7.10E+01	05/12/04	U
699-38-70B	300125	5158173	1.37E+02	11/01/04	U
699-38-70C	300739	5158140	9.22E+03	08/30/05	
699-38-70C	300739	5158140	9.00E+03	06/01/07	
699-38-70C	300739	5158140	1.10E+05	02/20/07	
699-38-70C	300739	5158140	8.30E+03	12/06/06	
699-38-70C	300739	5158140	9.17E+03	09/06/06	
699-38-70C	300739	5158140	8.77E+03	05/26/06	
699-38-70C	300739	5158140	7.70E+03	07/08/04	
699-38-70C	300739	5158140	1.00E+04	11/28/05	
699-38-70C	300739	5158140	8.16E+03	05/16/05	
699-38-70C	300739	5158140	7.10E+03	02/14/05	
699-38-70C	300739	5158140	7.11E+03	11/01/04	
699-38-70C	300739	5158140	7.87E+03	08/11/04	
699-38-70C	300739	5158140	9.68E+03	02/28/06	
699-40-62	302837	5158487	1.04E+04	02/04/00	
699-40-62	302837	5158487	9.00E+03	08/06/07	
699-40-62	302837	5158487	1.03E+04	11/18/05	
699-40-62	302837	5158487	7.97E+03	01/22/03	
699-40-65	301736	5158652	1.63E+04	08/30/05	
699-40-65	301736	5158652	1.50E+04	06/01/07	
699-40-65	301736	5158652	1.00E+04	02/07/07	
699-40-65	301736	5158652	1.63E+04	09/06/06	
699-40-65	301736	5158652	1.71E+04	02/28/06	
699-40-65	301736	5158652	1.48E+04	05/17/05	

**Table 1. Measured tritium concentrations in aquifer wells near the US Ecology site.**

Well Name	UTM East (m)	UTM North (m)	H-3 (pCi/L)	Sample Date	Laboratory Qualifier <sup>b</sup>
699-40-65	301736	5158652	1.25E+04	02/14/05	
699-40-65	301736	5158652	1.30E+04	11/01/04	
699-40-65	301736	5158652	1.48E+04	08/12/04	
699-40-65	301736	5158652	1.55E+04	07/08/04	
699-40-65	301736	5158652	1.52E+04	05/26/06	
MW3 <sup>a</sup>	304103	5156730	3.34E+03	02/16/06	
MW8 <sup>a</sup>	303932	5157097	2.34E+03	02/15/06	
MW8 <sup>a</sup>	303932	5157097	2.56E+03	02/28/07	
MW10 <sup>a</sup>	303932	5157268	3.66E+03	03/01/07	
MW9 <sup>a</sup>	303667	5156290	3.38E+03	03/17/05	
MW9a <sup>a</sup>	303746	5156290	3.17E+03	03/17/05	
MW9a <sup>a</sup>	303746	5156290	3.52E+03	03/17/06	
MW13 <sup>a</sup>	303509	5156724	6.38E+03	03/17/05	

a. Locations and UTM coordinates for these wells were estimated from Figure 2 in Rood (2004).  
b. Laboratory qualifier symbols are listed in Appendix A

**Table 2. Time-averaged tritium concentrations in aquifer wells near the US Ecology Disposal Site.**

Well Name	UTM East (m)	UTM North (m)	H-3 (pCi/L)
699-32-70B	300025	5156086	6.07E+04
699-36-70B	300052	5157470	7.18E+03
699-36-70A	300077	5157152	6.70E+04
699-38-70B	300125	5158173	3.30E+02
699-38-70	300146	5157930	7.19E+03
699-35-70	300162	5156826	2.98E+05
699-38-70C	300739	5158140	1.63E+04
699-38-68A	300817	5157742	3.54E+04
699-36-67	300894	5157232	3.44E+05
699-37-68	300897	5157436	1.20E+05
699-35-66A	301458	5156881	2.19E+05
699-30-66	301530	5155516	1.73E+03
699-38-65	301731	5157810	7.21E+04
699-40-65	301736	5158652	1.46E+04
699-32-62	302569	5155947	8.73E+03
699-40-62	302837	5158487	9.42E+03
699-36-61A	303014	5157270	5.37E+04
MW9	303667	5156290	3.83E+03
MW9a	303746	5156290	3.35E+03
MW13	303509	5156724	6.38E+03
MW8	303932	5157097	2.45E+03
MW10	303932	5157268	3.66E+03
MW3	304103	5156730	3.34E+03
699-33-56	304499	5156273	9.21E+01

The vadose zone measurements entailed sampling water vapor in the vadose zone pore air using a desiccant. The liquids collected are then analyzed for tritium. In November 1991, three vapor sampling wells were installed at the US Ecology site as a research project conducted at the request of the Washington Department of Health (Figure 2). Well VW-101 is between trenches 4 and 5 at a depth of 17 m (55 ft). Well VW-102 is located between trenches 10 and 11a at a depth of 20 m (67 ft). Well VW100 was located north of the facility at a depth of 25 m (82 ft) and was designated a background well.



**Table 3. Measured tritium concentrations in soil vapor in vadose zone wells and Solar Stills (designated as SS100, SS101, SS102, SS103) at the US Ecology site.**

Month	VW100 (pCi/L)	VW101 (pCi/L)	VW102 (pCi/L)	SS100 (pCi/L)	SS101 (pCi/L)	SS102 (pCi/L)	SS103 (pCi/L)
Jan-96	716+/-118	337000+/- 1000	451000+/- 2000	324+/-106	754+/-122	3264+/-187	
Feb				4094+/-202	5437+/-227	8569+/-276	
March				794+/-107	2144+/-145	5452+/-227	
April	85+/-85	323000+/- 2000	497000+/- 2000	19+/-77	1480+/-127	4531+/-193	
May				380+/-92	1945+/-139	5645+/-214	
June				106+/-83	1614+/-131	5667+/-213	
July	116+/-78	264000+/- 1000	421000+/- 2000	211+/-83	1980+/-137	7406+/-236	
Aug				155+/-90	2078+/-147	9408+/-274	
Sept				104+/-82	2232+/-148	10583+/-285	
Oct	1+/-79	256000+/- 1000	472000+/- 2000	130+/-82	2464+/-153	10658+/-287	
Nov				270+/-91	2475+/-156	10176+/-281	
Dec					2197+/-150	12006+/-307	
Jan-97	564+/-98	270000+/- 1000	446000+/- 2000		2103+/-148	10508+/-288	
Feb				144+/-83	1892+/-138	9394+/-266	
March					1999+/-139	9969+/-275	
April	66+/-84	189000+/- 1000	464000+/- 2000		1949+/-153	8755+/-273	
May					1567+/-140	8801+/-271	
June				194+/-90	1750+/-140	9042+/-271	
July	94+/-91	203000+/- 1000	488000+/- 2000	282+/-130		865+/-115	
Aug				423+/-116	1291+/-143	12801+/-329	135+/-93
Sept	94+/-94	207000+/- 1000	433000+/- 2000	175+/-86	609+/-113	10790+/-299	254+/-100
Oct	4+/-93	202000+/- 1000	459000+/- 2000	100+/-84	1117+/-120	11907+/-306	243+/-90
Nov	63+/-82	216000+/- 1000	436000+/- 2000	140+/-85	1293+/-133	12037+/-314	252+/-99
Dec	87+/-96	236000+/- 1000	435000+/- 2000	252+/-103	1323+/-127	12610+/-315	293+/-90
Jan-98	441+/-98	232000+/- 1000	449000+/- 2000	195+/-88	1086+/-120	22454+/-415	149+/-86
Feb	752+/-109	237000+/- 1000	483000+/- 2000	560+/-102	988+/-116	11622+/-303	267+/-91
March	1480+/-130	222000+/- 1000	484000+/- 2000	677+/-113	1180+/-122	12256+/-310	88+/-79
April	1570+/-130	230000+/- 1000	489000+/- 2000	130+/-88	1328+/-125	13305+/-322	117+/-83
May	952+/-116	240000+/- 10000	496000+/- 2000	234+/-208	502+/-208	17500+/-369	4920+/-207
June	1330+/-130	220000+/- 1000	520000+/- 2000	154+/-135	1076+/-127	14976+/-346	123+/-94
July	990+/-118	259000+/- 1000	469000+/- 2000	137+/-87	1144+/-123	16770+/-365	188+/-89
Aug	452+/-100	227000+/- 1000	536000+/- 2000	131+/-87	1172+/-179	16942+/-367	247+/-92
Sept	1270+/-130	245000+/- 1000	551000+/- 2000	643+/-181	1487+/-135	17090+/-370	599+/-110
Oct	1410+/-130	232000+/- 1000	540000+/- 2000	698+/-124	1297+/-127	16429+/-354	6932+/-239

**Table 3. Measured tritium concentrations in soil vapor in vadose zone wells and Solar Stills  
(designated as SS100, SS101, SS102, SS103) at the US Ecology site.**

Month	VW100 (pCi/L)	VW101 (pCi/L)	VW102 (pCi/L)	SS100 (pCi/L)	SS101 (pCi/L)	SS102 (pCi/L)	SS103 (pCi/L)
Nov	959+/-114	256000+/- 1000	149000+/- 1000	162+/-109	719+/-107	16417+/-355	179+/-86
Dec	1040+/-120	280000+/- 1000	580000+/- 2000	448+/-100	786+/-112	16300+/-351	167+/-89
Jan-99	1230+/-130	315000+/- 1000	558000+/- 2000	162+/-88	692+/-109	16325+/-359	203+/-92
Feb	1050+/-120	305000+/- 1000	564000+/- 2000	27419+/-505	20389+/-399	31191+/-490	14365+/-338
March	1150+/-160	270000+/- 1000	530000+/- 2000	164+/-183	611+/-153	15499+/-394	187+/-136
April	1170+/-120	244000+/- 1000	527000+/- 2000	359+/-93	1166+/-136	17575+/-372	426+/-95
May	863+/-120	235000+/- 1000	570000+/- 2000	354+/-123	982+/-118	17766+/-363	187+/-93
June	399+/-100	235000+/-100 232000+/- 1000	541000+/-200 573000+/- 2000	545+/-149	1408+/-165	19173+/-385	491+/-107
July	695+/-114	279000+/- 2000	612000+/- 2000	1894+/-250	1925+/-203	21358+/-406	597+/-111
Aug	54+/-101	292000+/- 1000	589000+/- 2000	516+/-175	1060+/-141	22603+/-438	115+/-100
Sept	1770+/-150	297000+/- 1000	594000+/- 2000	438+/-166	1153+/-149	22064+/-414	229+/-90
Oct	597+/-10	271000+/- 1000	579000+/- 2000	192+/-103	899+/-113	22239+/-415	221+/-99
Nov	495+/-10	264000+/- 1000	569000+/- 2000	5462+/-226	5805+/-232	24966+/-450	2043+/-156
Dec	162+/-10	300000+/- 2000	619000+/- 2000	306+/-103	736+/-118	22985+/-435	311+/-103
Jan-00	431+/-107	310000+/- 2000	599000+/- 2000	1157+/-128	1294+/-132	23956+/-438	417+/-106
Feb	655+/-96	313000+/- 2000	606000+/- 2000	275+/-104	699+/-119	21618+/-421	268+/-104
March	131+/-83	319000+/- 2000	604000+/- 2000	3097+/-177	1481+/-138	19902+/-398	660+/-114
April	973+/-123	347000+/- 2000	620000+/- 2000	6657+/-241	948+/-121	18668+/-387	233+/-94
May	1010+/-130	287000+/- 1000	628000+/- 2000	3079+/-211	2579+/-654	22921+/-430	185+/-97
June	923+/-120	282000+/- 1000	605000+/- 2000	8362+/-382	1220+/-130	26643+/-463	382+/-105
July	1890+/-150	270000+/- 1000	613000+/- 2000	10728+/-370	1117+/-158	28884+/-482	160+/-97
Aug	1230+/-130	303000+/- 4000	595000+/- 2000	1227+/-133	985+/-125	29907+/-492	213+/-97
Sept	1170+/-120	327000+/- 2000	588000+/- 2000	8270+/-299	895+/-113	28092+/-464	147+/-85
Oct	1070+/-130	326000+/- 2000	591000+/- 2000	3002+/-179	1009+/-127	28658+/-485	310+/-103
Nov	1090+/-120	338000+/- 2000	616000+/- 2000	634+/-130	1021+/-118	25549+/-447	593+/-104
Dec	1130+/-120	356000+/- 2000	597000+/- 2000	2940+/-231	956+/-117	26150+/-452	99+/-85
Jan-01	1270+/-90	352000+/- 2000	594000+/- 2000	542+/-72	927+/-122	25586+/-457	368+/-103
Feb	1910+/-150	308000+/- 2000	597000+/- 2000	507+/-138	829+/-122	26487+/-467	480+/-110
March	991+/-118	7+/-115	2167+/-151	22775+/-421	697+/-108		
April	1550+/-140	359000+/-	599000+/-	3150+/-251	854+/-123	25573+/-460	218+/-101

**Table 3. Measured tritium concentrations in soil vapor in vadose zone wells and Solar Stills (designated as SS100, SS101, SS102, SS103) at the US Ecology site.**

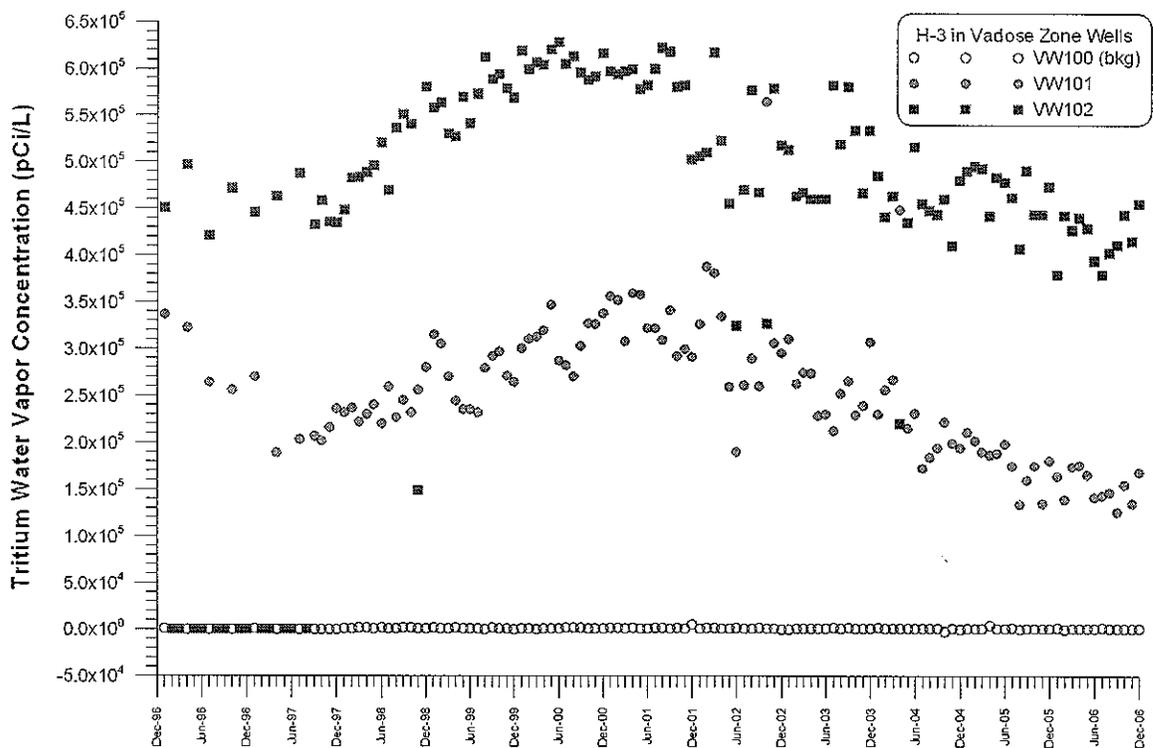
Month	VW100 (pCi/L)	VW101 (pCi/L)	VW102 (pCi/L)	SS100 (pCi/L)	SS101 (pCi/L)	SS102 (pCi/L)	SS103 (pCi/L)
		2000	2000				
May	1030+/-120	358000+/- 2000	578000+/- 2000	329+/-173	992+/-122	29523+/-472	216+/-90
June	899+/-110	322000+/- 2000	582000+/- 2000	211+/-151	1142+/-118	28170+/-455	349+/-91
July	1390+/-120	322000+/- 2000	600000+/- 2000	520+/-159	1157+/-166	30176+/-474	155+/-80
Aug	1170+/-120	309000+/- 1000	622000+/- 2000	1454+/-201	2079+/-146	32990+/-504	843+/-113
Sept	1050+/-130	341000+/- 2000	618000+/- 2000	153+/-152	1059+/-127	25886+/-456	198+/-97
Oct	1700+/-140	292000+/- 1000	580000+/- 2000	5375+/-282	2728+/-161	28224+/-462	670+/-104
Nov	867+/-110	299000+/- 2000	582000+/- 2000	1233+/-128	3335+/-177	21734+/-413	1551+/-136
Dec	5100+/-200	291000+/- 1000	503000+/- 2000	212+/-91	2520+/-146	17616+/-357	70+/-63
Jan-02	1000+/-110	326000+/- 2000	506000+/- 2000	2484+/-184	3022+/-216	14664+/-334	2028+/-141
Feb	1690+/-140	388000+/- 2000	510000+/- 2000	1478+/-137	1870+/-147	24152+/-430	1972+/-139
March	1250+/-120	381000+/- 2000	617000+/- 2000	6875+/-354	2243+/-157	22427+/-432	1104+/-116
April	854+/-107	334000+/- 2000	523000+/- 2000	1317+/-188	2596+/-172	22538+/-417	1597+/-129
May	829+/-110	259000+/- 1000	455000+/- 2000	791+/-162	1220+/-118	27831+/-475	1381+/-123
June	1210+/-110	190000+/- 1000	324000+/- 1000	310+/-136	1631+/-144	30175+/-475	208+/-80
July	922+/-108	261000+/- 1000	470000+/- 2000	791+/-219	1125+/-180	28111+/-464	67+/-73
Aug	398+/-88	289000+/- 1000	577000+/- 2000	4252+/-339	2555+/-209	33203+/-502	1417+/-126
Sept	1450+/-130	260000+/- 1000	468000+/- 2000	5947+/-322	3681+/-214	29609+/-487	1502+/-129
Oct	621+/-10	565000+/- 2000	327000+/- 2000	16942+/-596	11122+/-387	32816+/-523	4407+/-202
Nov	893+/-826	306000+/- 2000	579000+/- 2000	173+/-79	1080+/-121	30715+/-498	355+/-94
Dec	-43+/-66	295000+/- 1000	518000+/- 2000	251+/-111	655+/-118	19160+/-380	2413+/-149
Jan-03	286+/-99	310000+/- 2000	513000+/- 2000	916+/-115	1628+/-141	12727+/-318	751+/-115
Feb	831+/-10	263000+/- 1000	464000+/- 2000	1406+/-153	1122+/-111	14482+/-327	2174+/-142
March	918+/-103	274000+/- 1000	468000+/- 2000	1526+/-168	1945+/-135	17255+/-357	3561+/-172
April	376+/-8	273000+/- 1000	460000+/- 2000	421+/-86	1652+/-128	16180+/-345	221+/-91
May	529+/-100	228000+/- 1000	460000+/- 2000	862+/-181	1129+/-120	19895+/-394	268+/-89
June	422+/-10	230000+/- 1000	460000+/- 2000	936+/-221	951+/-116	22189+/-420	146+/-48
July	1240+/-12	213000+/-100	582000+/-200	1225+/-244	1137+/-154	30243+/-500	368+/-89
Aug	665+/-11	252000+/- 1000	519000+/- 2000	487+/-151	666+/-107	20181+/-410	324+/-97
Sept	1250+/-130	265000+/- 1000	580000+/- 2000	1783+/-230	462+/-107	20801+/-413	718+/-111

**Table 3. Measured tritium concentrations in soil vapor in vadose zone wells and Solar Stills  
(designated as SS100, SS101, SS102, SS103) at the US Ecology site.**

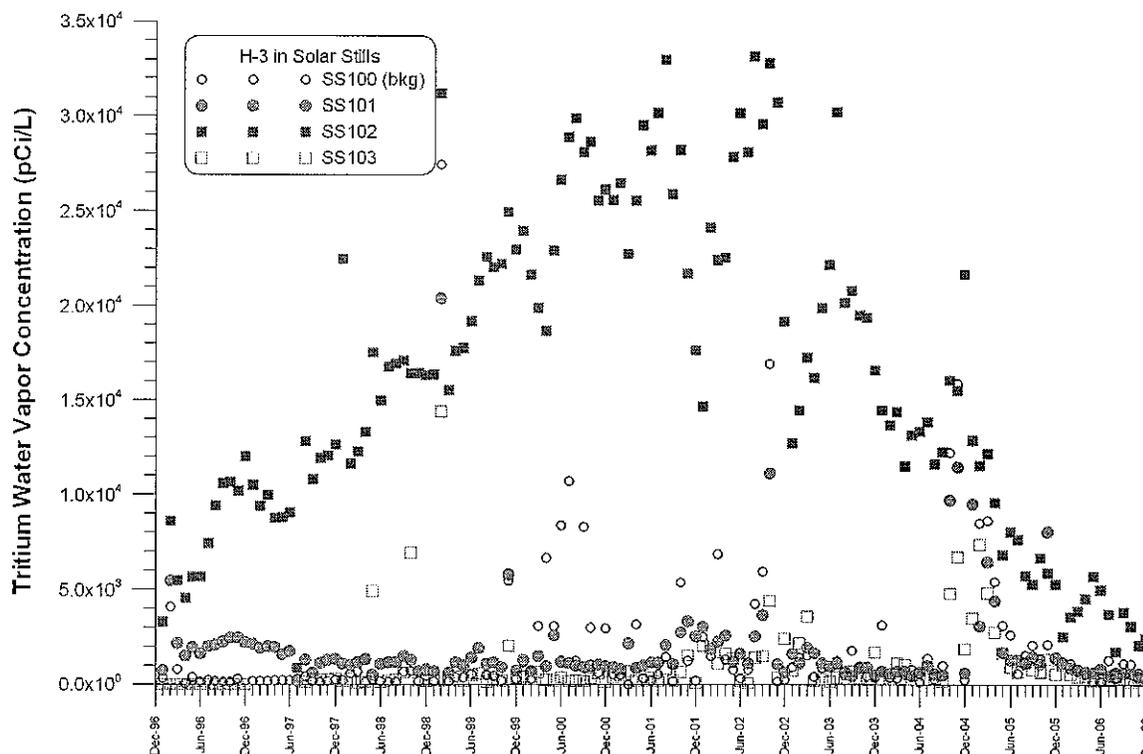
Month	VW100 (pCi/L)	VW101 (pCi/L)	VW102 (pCi/L)	SS100 (pCi/L)	SS101 (pCi/L)	SS102 (pCi/L)	SS103 (pCi/L)
Oct	371+/-9	229000+/- 1000	534000+/- 2000	946+/-166	860+/-143	19493+/-405	377+/-101
Nov	961+/-119	239000+/- 1000	467000+/- 2000	464+/-147	900+/-150	19397+/-404	469+/-102
Dec	398+/-94	307000+/- 2000	534000+/- 2000	361+/-107	493+/-98	16582+/-366	1721+/-138
Jan-04	1270+/-130	230000+/- 1000	485000+/- 2000	3112+/-191	697+/-106	14487+/-339	302+/-91
Feb	583+/-100	256000+/- 1000	441000+/- 2000	363+/-108	569+/-101	13672+/-328	285+/-90
March	843+/-10	267000+/- 1000	464000+/- 2000	331+/-149	681+/-110	14392+/-340	1115+/-124
April	1020+/-120	449000+/- 2000	220000+/- 1000	551+/-176	697+/-111	11512+/-307	1036+/-122
May	980+/-120	215000+/- 1000	435000+/- 2000	800+/-136	469+/-99	13116+/-324	292+/-92
June	625+/-10	231000+/- 1000	516000+/- 2000	121+/-85	678+/-107	13352+/-326	531+/-99
July	912+/-12	173000+/- 1000	455000+/- 2000	1373+/-230	980+/-117	13856+/-336	863+/-113
Aug	688+/-11	184000+/- 1000	448000+/- 2000	300+/-167	556+/-106	11633+/-311	324+/-97
Sept	1110+/-130	194000+/- 1000	444000+/- 2000	1006+/-175	477+/-98	12274+/-313	154+/-89
Oct	-3000+/-815	222000+/- 1000	460000+/- 2000	12194+/-365	9690+/-285	16060+/-361	4773+/-208
Nov	555+/-72	199000+/- 1000	410000+/- 2000	15882+/-373	11475+/-307	15518+/-379	6715+/-260
Dec	105+/-87	194000+/- 1000	480000+/- 2000	239+/-103	634+/-110	21697+/-411	1850+/-144
Jan-05	450+/-104	211000+/- 1000	490000+/- 2000	12819+/-335	9513+/-280	12891+/-327	3512+/-191
Feb	692+/-103	202000+/- 1000	495000+/- 2000	8488+/-277	3063+/-172	11545+/-294	7356+/-239
March	404+/-105	190000+/- 1000	493000+/- 2000	8609+/-363	6464+/-239	12159+/-302	4827+/-210
April	3610+/-180	187000+/- 1000	442000+/- 2000	5410+/-336	4433+/-207	9572+/-284	2760+/-175
May	813+/-114	188000+/- 1000	484000+/- 2000	3134+/-278	1686+/-150	6817+/-245	1680+/-151
June	658+/-126	198000+/- 1000	479000+/- 2000	2602+/-254	1272+/-133	8026+/-264	922+/-122
July	1210+/-130	175000+/- 1000	462000+/- 2000	563+/-252	1293+/-178	7617+/-267	642+/-126
Aug	73+/-31	134000+/- 1000	407000+/- 2000	1539+/-244	1115+/-137	5737+/-266	1178+/-123
Sept	1070+/-140	160000+/- 1000	491000+/- 2000	2095+/-204	1443+/-133	5277+/-227	796+/-113
Oct	527+/-104	175000+/- 1000	444000+/- 2000	1368+/-182	1067+/-140	6662+/-232	658+/-108
Nov	958+/-112	135000+/- 1000	444000+/- 2000	2131+/-183	8020+/-249	5859+/-216	1314+/-122
Dec	375+/-113	181000+/- 1000	474000+/- 2000	1318+/-205	1431+/-190	5285+/-222	549+/-118
Jan-06	1680+/-140	164000+/- 1000	379000+/- 2000	1211+/-138	1130+/-128	2537+/-167	1041+/-125
Feb	216+/-88	139000+/- 1000	443000+/- 2000	1136+/-168	870+/-137	3559+/-182	551+/-106

**Table 3. Measured tritium concentrations in soil vapor in vadose zone wells and Solar Stills (designated as SS100, SS101, SS102, SS103) at the US Ecology site.**

Month	VW100 (pCi/L)	VW101 (pCi/L)	VW102 (pCi/L)	SS100 (pCi/L)	SS101 (pCi/L)	SS102 (pCi/L)	SS103 (pCi/L)
March	732+/-101	174000+/-1000	427000+/-2000	714+/-89	790+/-103	3865+/-181	420+/-91
April	1100+/-130	176000+/-1000	440000+/-2000	524+/-140	656+/-111	4550+/-202	433+/-87
May	1070+/-110	166000+/-1000	429000+/-2000	169+/-98	631+/-95	5686+/-212	208+/-79
June	628+/-100	142000+/-1000	394000+/-2000	165+/-113	820+/-107	5005+/-89	335+/-79
July	1160+/-120	143000+/-1000	379000+/-2000	1288+/-241	467+/-91	3703+/-237	252+/-104
Aug	700+/-132	147000+/-1000	403000+/-2000	320+/-131	598+/-97	1756+/-185	437+/-104
Sept	890+/-114	126000+/-1000	411000+/-2000	1125+/-147	571+/-95	3824+/-213	317+/-87
Oct	432+/-97	155000+/-1000	444000+/-2000	1089+/-146	580+/-110	3063+/-173	173+/-86
Nov	469+/-91	135000+/-1000	415000+/-2000	602+/-135	402+/-93	2077+/-146	226+/-85
Dec	440+/-93	168000+/-1000	455000+/-2000	248+/-107	446+/-93	2433+/-155	285+/-89



**Figure 3.** Tritium concentration in condensed water vapor measured in the vadose zone wells from 1996 to 2006. The background concentrations measured in well VW100 are fairly stable.



**Figure 4.** Tritium concentration in condensed water vapor measured in the Solar Stills from 1996 to 2006.

The concentrations measured in Solar Stills SS100, SS101 and SS103 generally were constant, with sporadic local excursions above the mean value. Solar still SS102 shows significantly higher concentrations and a temporal trend that exhibited increasing concentrations from December 1996 to about June 2001 and then a gradual decrease to December 1996 levels by December 2006. Concentrations measured in the Solar Stills are about an order of magnitude lower and do not follow the same temporal trend as concentrations measured in the vadose zone wells.

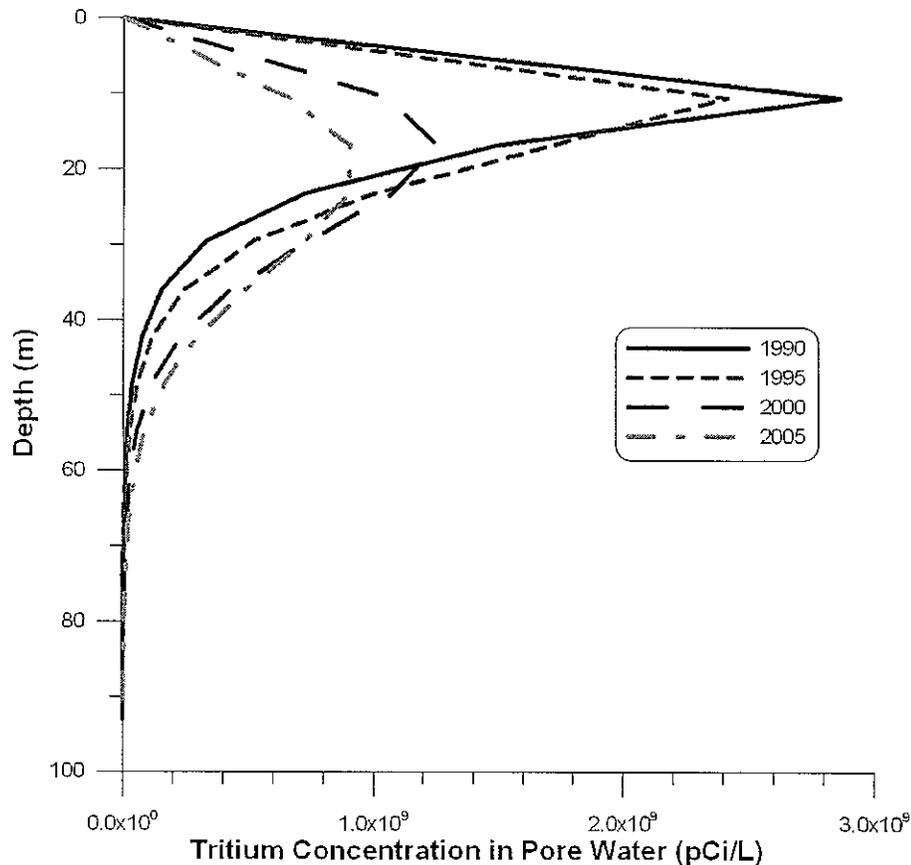
### MODEL CALIBRATION

Tritium typically exists as tritiated water (HTO) in the environment because tritium gas (HT) is rapidly oxidized to HTO in the soil. While the loss of HTO to the surface via diffusion can be measurable, it can be shown to be only several percent of the total tritium released from buried waste in an arid environment because the partitioning of HTO between the liquid and vapor phase is relatively small. If tritium exists as a gas (HT or T<sub>2</sub>), then gas diffusion is a much more important process. However, because of the rapid oxidation of HT to HTO, we have assumed most of the tritium exists as HTO in the subsurface environment.

Predicted tritium aquifer concentrations from 1996 to 2006 beneath the US Ecology site were around 10,000 pCi/L (based on CASE1 reported in Rood 2007) while measured concentrations were around 3800 pCi/L. If most of the tritium observed in the aquifer wells near

US Ecology is from the 200 West area, then the model-predicted aquifer concentrations are overestimates.

The model for tritium transport in the subsurface (Rood 2004) assumes liquid phase transport in the downward direction toward the aquifer. If we assume that the concentration of tritium in the water vapor phase (condensed to liquid) is the same as concentration in the liquid pore water, then tritium concentrations measured in the pore gas (as collected in condensed water vapor) are comparable with predicted tritium pore water concentrations. A depth profile of the predicted tritium pore water concentration (Figure 5) for 1990, 1995, 2000, and 2005 (from CASE1 in Rood 2004) shows the maximum concentrations near a depth of 20 m. Concentrations are substantially higher (about a factor of 5) than measurements in the vadose zone wells.



**Figure 5.** Predicted depth profile of tritium concentrations in pore water for 1990, 1995, 2000, and 2005.

The model calibration technique applied considered two processes; 1) the fraction of tritium in the waste that partitions to the soil pore water, and 2) rate constant that describes the release of tritium from the soil pore water to the underlying vadose zone. For these calculations, it is assumed that the inventory of H-3 is correct. The vadose zone well data was used to calculate an effective release rate constant of tritium from the waste trench to the vadose zone. The solar still data was used to estimate the partitioning of tritium between the waste and the backfilled soil in the trench. These two processes represent both temporal and spatial averages. The transport

model does not simulate individual trenches, and therefore, model-predicted concentrations represent spatial averages across the disposal area. Therefore, data from VW101 and VW102 were averaged for calibration purposes. Likewise, the solar still data from all the measurement points were averaged for calibration.

The effective release rate constant ( $K_{EP}$ ) from backfilled trench soil to the vadose zone was estimated as follows:

$$K_{EP} = \frac{\left( \frac{C_{OBS}}{C_{PRED}} \right)}{t} \quad (1)$$

where  $C_{OBS}$  = the observed average tritium concentration (pCi/L),  $C_{PRED}$  = the predicted average tritium concentration (pCi/L), and  $t$  = the averaging time (years). This rate constant describes the release of H-3 over time from the backfilled soil in the trench to the vadose zone. The average measured H-3 concentration from 1996 to 2006 in wells VW 101 and VW 102 was  $3.78 \times 10^5$  pCi/L. The average predicted tritium concentration in pore water at depths from 10-22 m was  $1.13 \times 10^9$  pCi/L, indicating substantial over prediction by the model. Substitution of the above values gives:

$$K_{EP} = \frac{\left( \frac{3.78 \times 10^5 \text{ pCi/L}}{1.13 \times 10^9 \text{ pCi/L}} \right)}{10 \text{ y}} = 3.36 \times 10^{-5} \text{ y}^{-1}$$

The fraction of H-3 inventory in the trench that partitions to the backfilled soil pore water and can subsequently be transport to the vadose zone was determined by computing a waste-to-backfilled soil partitioning coefficient. Mathematically, the waste-to backfilled soil partitioning coefficient ( $K_{dw}$ ) it is treated the same as a solid-to-liquid partitioning coefficient, but in this context, it means something else. That is, it describes the fraction of the H-3 waste inventory that is in soil pore water and that is available for liquid-phase transport to the vadose zone. The  $K_{dw}$  is calculated by

$$K_{dw} = \frac{I_{PRED} / ((L \times W \times T) \rho)}{C_{OBS}} \quad (2)$$

where  $I_{PRED}$  = the 1996-2006 average predicted H-3 inventory in the source compartment ( $1.15 \times 10^7$  pCi),  $L$ ,  $W$ , and  $T$  are the length, width, and thickness of the source compartment respectively (382 m, 518 m, 10.6 m respectively, Rood 2004),  $\rho$  = bulk density ( $1.97 \times 10^6$  g/m<sup>3</sup>, Rood 2004), and  $C_{MEAS}$  = the averaged measured pore water concentration from the Solar Stills (5690 pCi/L). The waste-to-pore-water partitioning coefficient ( $K_{dw}$ ) is then

$$K_{dw} = \frac{1.15 \times 10^{17} \text{ pCi}}{382 \text{ m} \times 518 \text{ m} \times 10.6 \text{ m} \times 1.97 \times 10^6 \text{ g/m}^3} \times 1000 \text{ mL/L} = 4890 \text{ mL/g}$$

Equations 1 and 2 provided initial estimates of  $K_{EP}$  and  $K_{dw}$ . Further adjustments were made to bring the 1996-2006 average predicted pore water concentration as close as possible to measured values. The final values arrived at were  $K_{EP} = 2.0 \times 10^{-5} \text{ yr}^{-1}$ , and  $K_{dw} = 1.4 \times 10^4 \text{ mL/g}$ .

## MODEL INPUT

With the exception of the  $K_{EP}$  and  $K_{dW}$  values, model input was identical to that used in Rood (2007). Model input is summarized in Table 4.

**Table 4. Radionuclide Independent Model Input Parameters**

Parameter <sup>a</sup>	Nominal value	Reference/Comments
Length of source parallel to groundwater flow (m)	382	Rood (2000)
Width of source perpendicular to groundwater flow (m)	518	Rood (2000)
Cover longevity (years)	500	Assumed
Source thickness (m)	10.6	Rood (2000)
Bulk density of source ( $\text{g cm}^{-3}$ )	1.97	Kincaid et al. (1998)
Saturated hydraulic conductivity for source ( $\text{m y}^{-1}$ )	555	Kincaid et al. (1998)
van Genuchten fitting parameter $\alpha$ for source ( $\text{m}^{-1}$ )	0.811	Kincaid et al. (1998)
van Genuchten fitting parameter $n$ for source	1.58	Kincaid et al. (1998)
Residual moisture content for source ( $\text{m}^3 \text{ m}^{-3}$ )	0.015	Kincaid et al. (1998)
Total porosity for source ( $\text{m}^3 \text{ m}^{-3}$ )	0.119	Kincaid et al. (1998)
Unsaturated thickness (m)	82.3	Rood (2000)
Number of unsaturated layers (compartments)	13	Rood (2004)
Thickness of each unsaturated layer (m)	6.331	Rood (2004)
Bulk density of unsaturated layer 1 ( $\text{g cm}^{-3}$ )	1.78	Kincaid et al. (1998)
Saturated hydraulic conductivity, unsaturated layer 1 ( $\text{m y}^{-1}$ )	3753	Kincaid et al. (1998)
van Genuchten fitting parameter $\alpha$ for unsaturated layer 1 ( $\text{m}^{-1}$ )	1.3	Kincaid et al. (1998)
van Genuchten fitting parameter $n$ for unsaturated layer 1	2.1	Kincaid et al. (1998)
Residual moisture content for unsaturated layer 1 ( $\text{m}^3 \text{ m}^{-3}$ )	0.026	Kincaid et al. (1998)
Total porosity for unsaturated layer 1 ( $\text{m}^3 \text{ m}^{-3}$ )	0.337	Kincaid et al. (1998)
Bulk density of unsaturated layers 2-13 ( $\text{g cm}^{-3}$ )	1.97	Kincaid et al. (1998)
Saturated hydraulic conductivity for unsaturated layer 2-13 ( $\text{m y}^{-1}$ )	555	Kincaid et al. (1998)
van Genuchten fitting parameter $\alpha$ for unsaturated layer 2-13 ( $\text{m}^{-1}$ )	0.811	Kincaid et al. (1998)
van Genuchten fitting parameter $n$ for unsaturated layer 2-13	1.58	Kincaid et al. (1998)
Residual moisture content for unsaturated layer 2-13 ( $\text{m}^3 \text{ m}^{-3}$ )	0.015	Kincaid et al. (1998)
Total porosity for unsaturated layer 2-13 ( $\text{m}^3 \text{ m}^{-3}$ )	0.119	Kincaid et al. (1998)
Longitudinal dispersivity in aquifer (m)	27.5	Rood (2000)
Transverse dispersivity in aquifer (m)	5	Rood (2000)
Well screen thickness (m)	15	Rood (2000)
Aquifer porosity ( $\text{m}^3 \text{ m}^{-3}$ )	0.1	Rood (2000)
Darcy velocity in aquifer ( $\text{m y}^{-1}$ )	32.9	Rood (2000)
Bulk density of aquifer ( $\text{g cm}^{-3}$ )	1.6	Rood (2000)

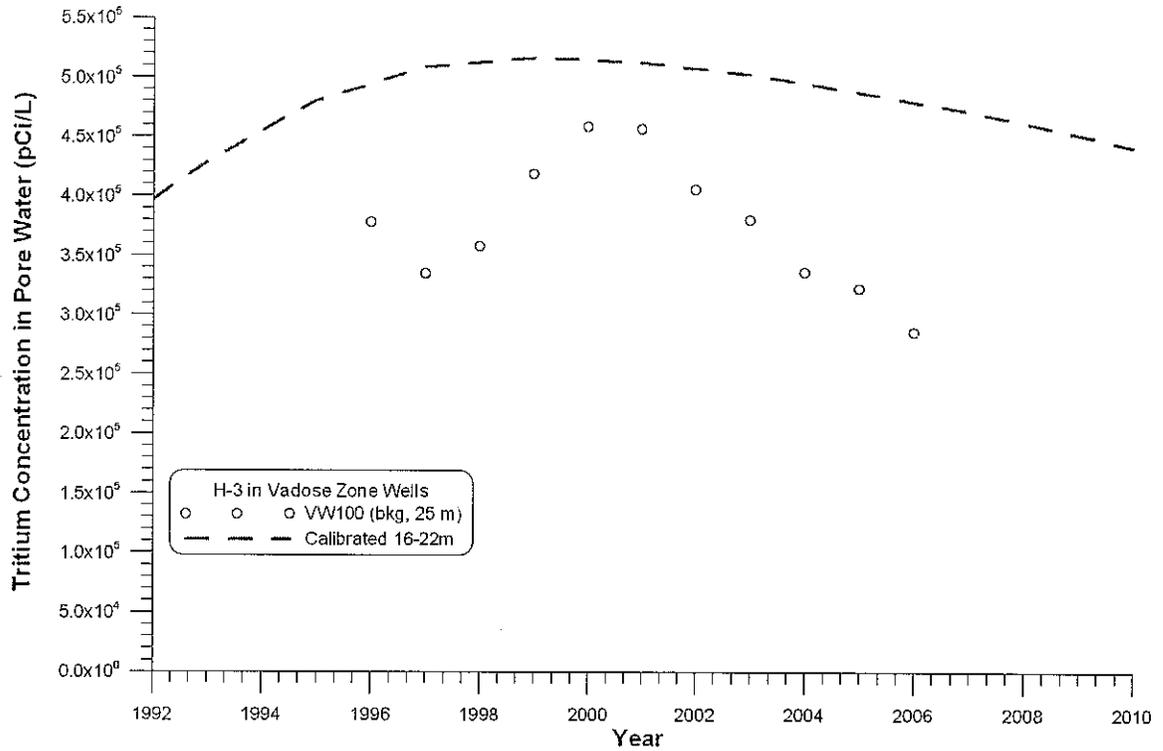
## RESULTS

Figure 6 and Figure 7 show the predicted and observed calibrated concentrations in the vadose zone and waste disposal pit respectively. The observed data for the vadose zone represent a spatial average of the data from 17 m and 20 m and both the vadose zone well and solar still monthly data were averaged across each year. The predicted calibrated values represent the average of the 10-16 m layer and the 16-22 m model layer.

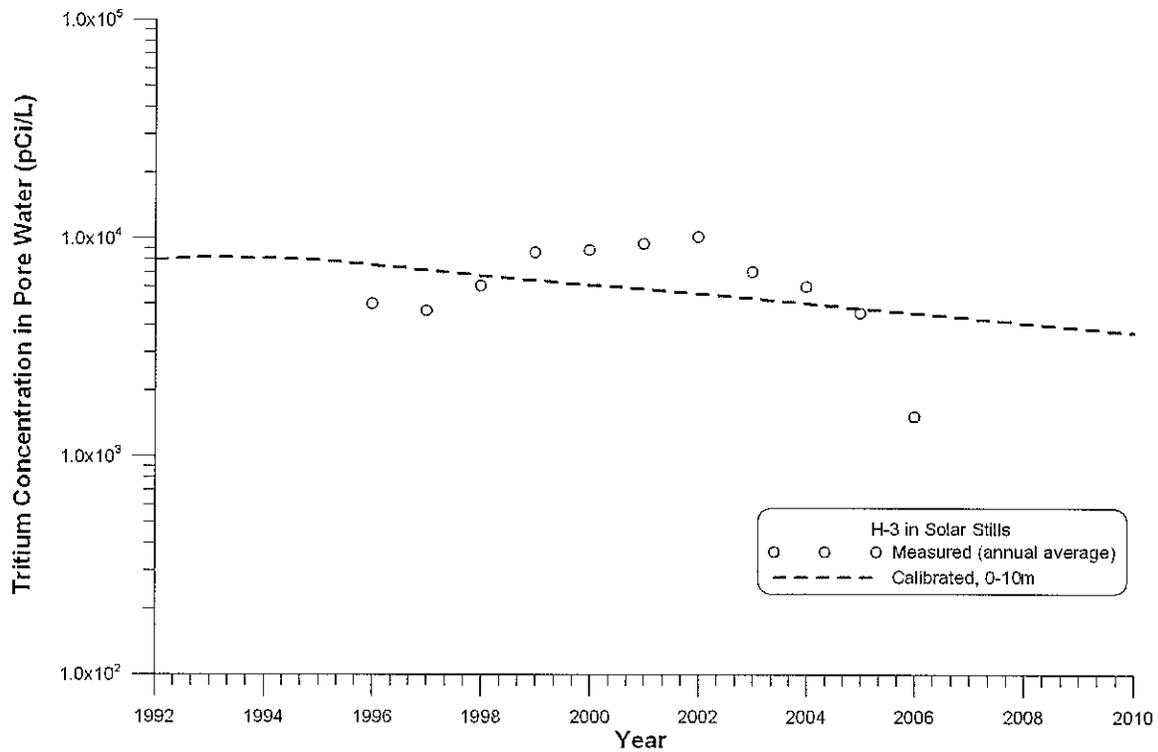
Predicted concentrations in the vadose zone wells exhibited a temporal trend similar to the observed values, although the observed values show a steeper slope before and after year 2000. Concentrations are consistently overpredicted by the model. The average predicted concentration over the measurement period (1996–2006) was  $5.0 \times 10^5$  pCi/L. The average observed concentration in wells VZ-101 and VZ-102 over the measurement period (1996–2006) was  $3.78 \times 10^5$  pCi/L. Vadose well VZ-100 was omitted from this average because it was purported to represent background. Therefore, the predicted-to-observed ratio was 1.31.

Predicted values in the surface soils down to 10 m exhibited a shallow decrease in concentration over time while the measured values appear to show a peak in the year 2002 and then decrease. The average predicted concentration over the measurement period (1996–2006) was 5960 pCi/L. The average observed concentration in Solar Stills SS-101, SS-102, and SS-103 over the measurement period (1996–2006) was 6840 pCi/L. Solar still SS-100 was omitted from this average because it was purported to represent background. Therefore, the predicted to observed ratio was 0.873.

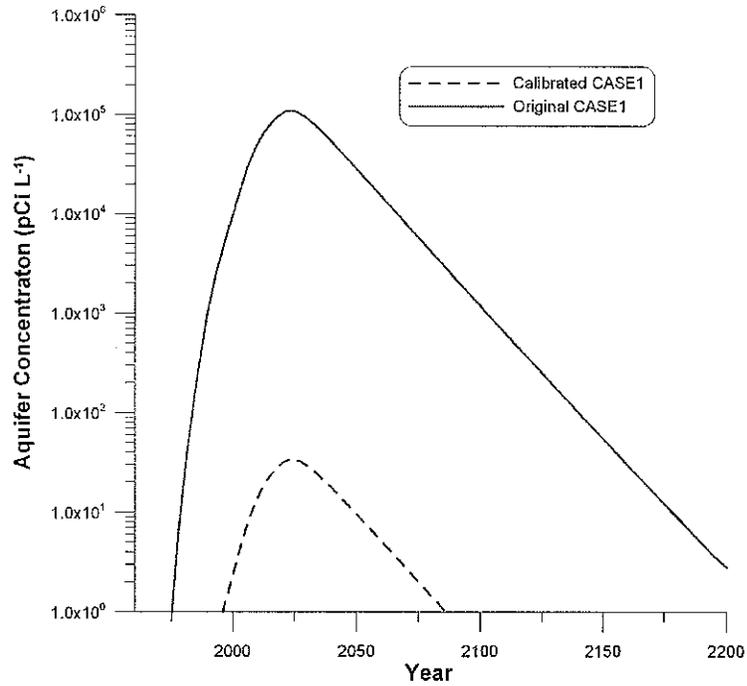
Predicted average tritium concentrations in the aquifer from 1996-2006 using the calibrated tritium release rates were around 3.5 pCi/L. This concentration is insignificant compared to the measured tritium in the aquifer from upgradient sources and substantially less than the predicted tritium concentration in Rood (2007). A comparison of the calibrated and un-calibrated predicted tritium concentration in the aquifer, and drinking water ingestion dose for CASE1 in Rood 2007 is shown in Figures 8 and 9 respectively.



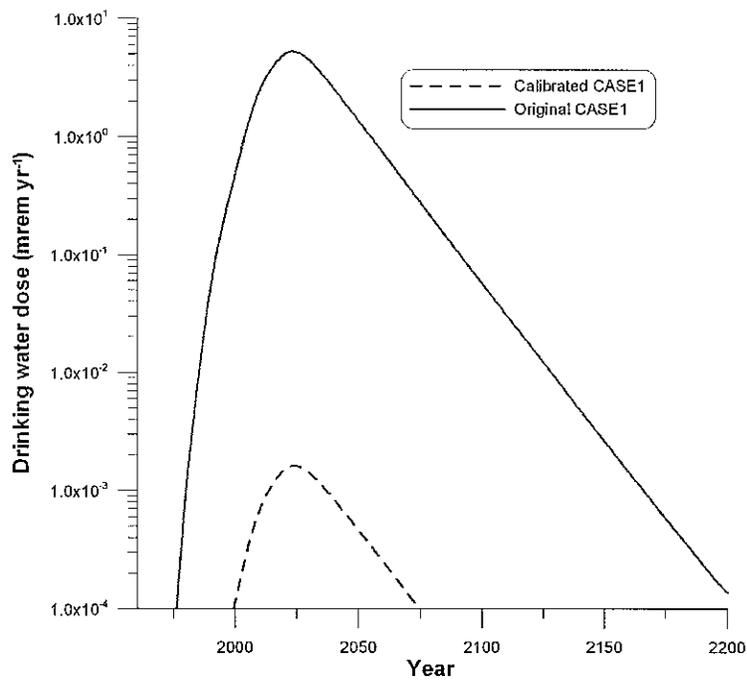
**Figure 6.** Predicted and observed tritium concentrations in vadose zone pore water. Measured concentrations are from the vadose zone monitoring wells.



**Figure 7.** Predicted and observed tritium concentrations in surface soil pore water. Measured concentrations are from the Solar Stills.



**Figure 8.** Predicted tritium concentrations in the aquifer for the calibrated and original (un-calibrated) simulations of the CASE1 closure scenario in Rood 2007.



**Figure 9.** Predicted tritium drinking water ingestion doses for the calibrated and original (un-calibrated) simulations of the CASE1 closure scenario in Rood 2007.

### **Total Doses for CASE1 and CASE2 using Calibrated Tritium Release Rates**

In Rood (2007), two alternate cases for site closure are presented. These cases are

- CASE 1: An enhanced cover is installed in 2012 instead of 2005 and waste disposal continues through 2056. Infiltration through the active trenches is restricted to no more than the design infiltration rate of the cover ( $0.05 \text{ cm yr}^{-1}$  for the enhanced cover).
- CASE 2: An enhanced cover is installed in 2012 instead of 2005 and waste disposal continues through 2056. Infiltration through the active trenches is set at the infiltration rate through an uncovered active pit ( $7.5 \text{ cm yr}^{-1}$ ). The total infiltration across the disposal facility is the area-weighted infiltration through the active and covered trenches.

The original closure case was presented in Rood (2004). In this section, the drinking water doses using the calibrated tritium releases rates for CASE1 and CASE2 are presented.

Maximum doses in the time period from the present out 250 years (Figure 10) for CASE1 decrease substantially because drinking water dose was dominated by tritium. The original CASE1 maximum dose presented in Rood (2007) was 5.8 mrem/yr. The maximum dose after tritium calibrations was 0.56 mrem. Drinking water doses are no longer driven by tritium but by the mobile fraction of the actinides.

Maximum doses in the time period from the present out 250 years (Figure 11) for CASE2 also decrease substantially because drinking water dose was dominated by tritium. The original CASE2 maximum dose presented in Rood (2007) was 5.9 mrem/yr. The maximum dose after tritium calibrations was 0.59 mrem. Drinking water doses are no longer driven by tritium but by the mobile fraction of the actinides.

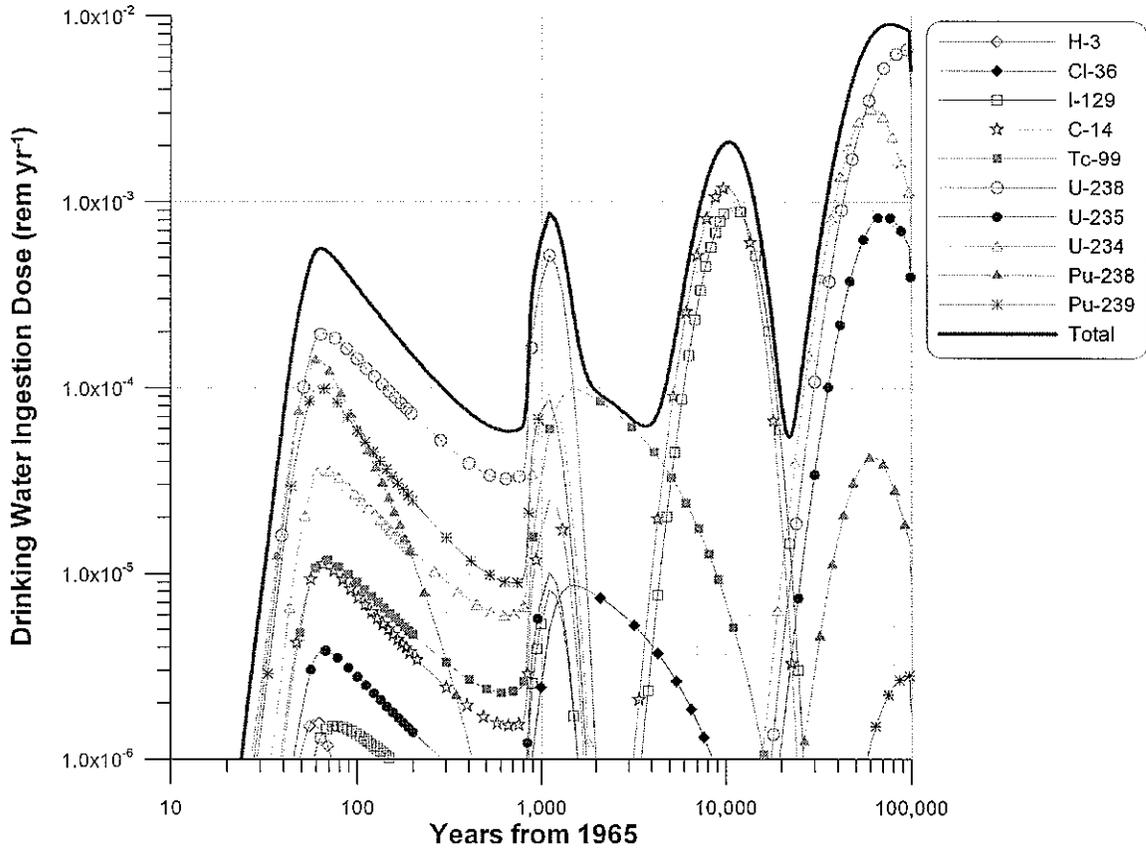


Figure 10. Drinking water dose as a function of time for CASE1 with the enhanced cover, closure in 2056, and calibrated tritium release rates.

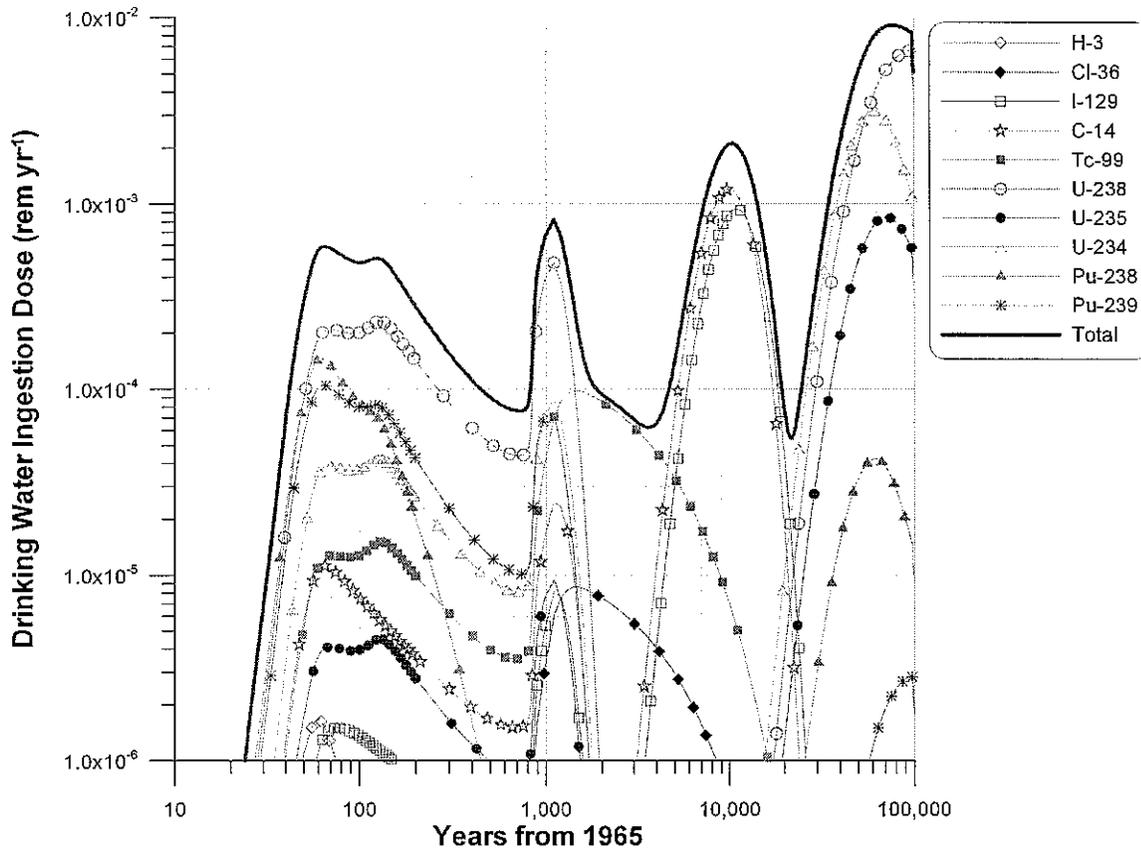


Figure 11. Drinking water dose as a function of time for CASE2 with the enhanced cover, closure in 2056, and calibrated tritium release rates.

### TRITIUM RELEASES TO THE GROUND SURFACE

Tritium can be released to the ground surface via vapor diffusion of either HT gas or HTO water vapor. Tritium oxidizes quickly in soil from HT to HTO therefore, these calculations assume tritium is in water vapor present in the soil pore air. Furthermore, the partitioning of pore water from the liquid to vapor phase is described by the Henry's Law constant and the concentration of tritium in the condensed pore vapor is the same as the concentration in the liquid phase.

The governing equation for multi-phase transport assuming gas-phase diffusion and liquid-phase advection is given by

$$\frac{\partial(\phi_a C_a + \phi_g C_g + \phi_s C_s)}{\partial t} = \nabla \cdot (D_e \phi_g \nabla C_g - v C_a) + S - \lambda(\phi_a C_a + \phi_g C_g + \phi_s C_s) \quad (3)$$

where

- $C_a$  = the concentration in aqueous phase ( $\text{Ci m}^{-3}$ )
- $C_g$  = the concentration in gas phase ( $\text{Ci m}^{-3}$ )
- $C_s$  = the concentration in solid phase ( $\text{Ci m}^{-3}$ )

$\phi_a$	=	aqueous filled porosity
$\phi_g$	=	gas filled porosity
$\phi_s$	=	Fraction of media that is solid matrix or $1 - \phi_T$ where $\phi_T$ = total porosity
$z$	=	the depth below the surface (m)
$v$	=	the unsaturated Darcy velocity (m yr <sup>-1</sup> )
$D_e$	=	the effective diffusion coefficient in the porous media (m <sup>2</sup> yr <sup>-1</sup> )
$S$	=	a source in the gas phase (Ci m <sup>-3</sup> yr <sup>-1</sup> )
$\lambda$	=	decay rate constant (yr <sup>-1</sup> )

The one-dimensional finite difference model, DUST (Sullivan 2000) was used to compute tritium fluxes to the surface from the US Ecology LLW facility. The governing equation in DUST is given by

$$\frac{\partial C}{\partial t} = \nabla \cdot \left( \frac{D}{R_d} \nabla C - \frac{v_d}{\phi_a R_d} C \right) + \frac{S}{\phi_a R_d} - \lambda C \quad (4)$$

where  $C$  is the aqueous-phase pore concentration (Ci m<sup>-3</sup>),  $D$  is the dispersion coefficient (m<sup>2</sup> yr<sup>-1</sup>),  $v_d$  is the Darcy velocity, and  $R_d$  is  $1 + K_d \rho_s / \phi_a$ . The aqueous phase concentration is related to the gas concentration by the dimensionless Henry's law constant,  $H$  and is given by  $C_a = C_g / H$ . The solid phase concentration is related to the aqueous phase concentration by the linear sorption coefficient or  $K_d$  and is given by  $C_s = K_d \rho_s C_a$ . Equilibrium between the gas and aqueous phase is assumed. Equation (3) can be rewritten in terms of the gas phase concentration only, substituting the previously stated relationship for  $C_a$  and  $C_s$ . After some rearrangement it is given by

$$\frac{\partial C_g}{\partial t} = \nabla \cdot \left( \frac{D_e}{R_d} \nabla C_g - \frac{v_e}{H \phi_g R_d} C_g \right) + \frac{S}{R_d} - \lambda C_g \quad (5)$$

where  $R_d$  is given by

$$R_d = \frac{\phi_a}{H \phi_g} + 1 + \frac{K_d \rho_b}{\phi_g H}, \quad \rho_b = \phi_s \rho_s \quad (6)$$

$D_e$  is given by

$$D_e = D \left( \frac{\phi_g^{7/3}}{\phi_T^2} \right) \quad (7)$$

and  $v_e$  is given by

$$v_e = \frac{v_d \phi_a}{H \phi_g} \quad (8)$$

where  $D$  is the diffusion coefficient of water vapor in air and  $\phi_T$  is the total porosity. The variables in Equation (4) can now be substituted with the equivalent variables in Equation (5). For

tritium, the soil-liquid partitioning coefficient ( $K_d$ ) is zero, and therefore the third term in Equation (6) is dropped. The retardation factor in DUST is calculated using the soil-liquid partitioning coefficient. Retardation however is calculated using Equation (6) and an equivalent  $K_{deff}$  is calculated for use in DUST as follows:

$$K_{deff} = (R_d - 1) \frac{\phi_a}{\rho} \quad (9)$$

The diffusion coefficient ( $D$  in  $\text{cm}^2 \text{s}^{-1}$ ) in air for water vapor was calculated using the WL (Wilke and Lee) method described in Lyman et al. 1990.

$$D = \frac{B'T^{3/2}\sqrt{M_r}}{P\sigma_{AB}^2\Omega} \quad (10)$$

where

$$B' = 0.00217 - 0.00050 \sqrt{\frac{1}{M_A} + \frac{1}{M_B}}$$

$$\Omega = \frac{a}{(T^*)^b} + \frac{c}{e^{T^*d}} + \frac{e}{e^{T^*f}} + \frac{g}{e^{T^*h}}$$

$$T^* = \frac{T}{\sqrt{(\varepsilon/k)_A(\varepsilon/k)_B}}, (\varepsilon/k)_A = 78.6\text{K}, (\varepsilon/k)_B = 1.15T_B$$

$$\sigma_{AB} = \frac{\sigma_A + \sigma_B}{2}, \sigma_A = 3.711\text{\AA}, \sigma_B = 1.18(V_B')^{1/3}$$

$$V_B' = \sum nL_{MV}$$

$$M_r = \frac{M_A + M_B}{M_A M_B}$$

$T$	=	temperature (assume 293 K)
$T_B$	=	boiling temperature of water (373 K)
$M_A$	=	molecular weight of air (28.97 g/mol)
$M_B$	=	molecular weight of water (18 g/mol)
$L_{MV}$	=	LeBas molar volume increments (3.7 for H, 7.4 for O, $\text{cm}^3/\text{mol}$ )
$n$	=	number of atoms in the molecule (2 for H, 1 for O)
a-h	=	constants, a = 1.06036, b = 0.15610, c = 0.19300, d = 0.47635, e = 1.03587, f = 1.52996, g = 1.76474, h = 3.89411
$P$	=	pressure (1 atm assumed)

Parameter values for the DUST simulation are given in Table 5

**Table 5. Parameter values for DUST simulation of Tritium Water Vapor Diffusion**

Parameter	Description	Value
$\phi_a$	aqueous-filled porosity	0.05
$\phi_g$	gas-filled porosity	0.222
$\phi_T$	total porosity	0.272
$H$	Henry law constant (dimensionless)	$1.73 \times 10^{-5}$
$\rho$	bulk density ( $\text{g cm}^{-3}$ )	1.6
$D$	diffusion coefficient in air, calculated ( $\text{cm}^2 \text{s}^{-1}$ )	0.24020
$D_e$	effective diffusion coefficient ( $\text{cm}^2 \text{s}^{-1}$ )	0.09758
$K_{d\text{eff}}$	Effective $K_d$ calculated with Equation 5 and 7 (mL/g)	406
$v_e$	Effective Darcy velocity from 0–40 years (cm/s)	$3.09 \times 10^{-3}$
$v_e$	Effective Darcy velocity from >40 years (cm/s)	$8.23 \times 10^{-4}$

For these calculations, the tritium inventory ( $8.6 \times 10^5$  Ci) for closure in 2056 was assumed as given in Table 2 of Rood (2004). Waste however was emplaced from 1965 to 2003. Furthermore, the tritium in waste was not partitioned between the waste and backfilled soil as described by the calibration. Instead, all the tritium was available for vapor-phase transport immediately after disposal.

Infiltration rates were assumed to be 7.5 cm/yr from 1965 to 2005 and reduced to 0.05 cm/yr after that in response to the emplacement of the cover. Zero concentration boundary conditions were applied to the top and bottom of the model domain.

### Measured and Modeled Concentrations of Tritium in the Atmosphere

Monthly-average concentrations of tritium in ambient air measured at sampling stations located around the perimeter of the US Ecology site were provided by Robert Haight of the U.S. Ecology Site (Table 6 and Figure 12). Monthly measurements were made from February 1993 to December 2006. Station 1 was identified as background station and had a mean concentration  $1.73 \text{ pCi/m}^3$ . Station 2 and 5, (see Figure 2), which are located on the north and south side of the eastern perimeter of the US Ecology site respectively, had mean concentrations of  $1.74 \text{ pCi/m}^3$ , and  $4.56 \text{ pCi/m}^3$  respectively. The mean concentration of all three stations was  $2.7 \text{ pCi/m}^3$  with a standard deviation of  $2.7 \text{ pCi/m}^3$ . A *t*-test indicated that the mean concentrations from Station 1 and 2 are not significantly different from one another but Station 5 is significantly different from Station 1 and 2. Assuming Station 1 and 2 represent background concentrations, the net average concentration from 1993-2006 at Station 5 is  $2.0 \text{ pCi/m}^3$ . This value was arrived at by subtracting the monthly average concentration at Station 1 from the monthly average concentration at Station 5 and then averaging across the each year and then averaging across the entire time measurement period. Net tritium concentrations in air at Station 5 show a general decrease over time.

**Table 6. Measured tritium concentrations in ambient air at the US Ecology site.**

Date	Station 1 ( $\mu\text{C/cm}^3$ )	Error ( $\mu\text{C/cm}^3$ )	Station 2 ( $\mu\text{C/cm}^3$ )	Error ( $\mu\text{C/cm}^3$ )	Station 5 ( $\mu\text{C/cm}^3$ )	Error ( $\mu\text{C/cm}^3$ )
Feb-93	2.82E-12	5.30E-13	4.35E-12	6.90E-13	4.48E-12	7.60E-13
Mar-93	1.71E-12	7.00E-13	1.05E-12	6.90E-13	1.39E-12	6.30E-13

**Table 6. Measured tritium concentrations in ambient air at the US Ecology site.**

Date	Station 1 ( $\mu\text{C}/\text{cm}^3$ )	Error ( $\mu\text{C}/\text{cm}^3$ )	Station 2 ( $\mu\text{C}/\text{cm}^3$ )	Error ( $\mu\text{C}/\text{cm}^3$ )	Station 5 ( $\mu\text{C}/\text{cm}^3$ )	Error ( $\mu\text{C}/\text{cm}^3$ )
Apr-93	2.43E-12	6.80E-13	6.29E-12	7.40E-13	4.38E-12	5.80E-13
May-93	3.30E-14	6.21E-13	8.20E-13	8.12E-13	1.65E-12	8.10E-13
Jun-93	6.80E-12	9.10E-13	1.02E-11	1.10E-12	8.16E-12	1.17E-12
Jul-93	1.00E-12	8.20E-13	1.95E-12	9.10E-13	7.69E-12	1.13E-12
Aug-93	3.15E-12	8.90E-13	2.22E-12	9.80E-13	1.19E-11	1.40E-12
Sep-93	6.25E-12	1.11E-12	8.70E-12	1.26E-12	1.98E-11	1.50E-12
Oct-93	3.11E-12	4.60E-13	3.63E-12	7.80E-13	6.09E-12	5.40E-13
Nov-93	2.05E-12	6.00E-13	3.67E-12	1.01E-12	2.63E-12	4.20E-13
Dec-93	8.08E-13	4.36E-13	9.83E-13	5.87E-13	8.30E-13	6.93E-13
Jan-94	1.76E-12	3.70E-13	2.12E-12	5.50E-13	2.22E-12	2.60E-13
Feb-94	3.32E-12	9.50E-13	2.22E-12	6.30E-13	4.42E-12	5.20E-13
Mar-94	2.07E-12	5.80E-13	1.66E-12	4.80E-13	2.20E-12	5.40E-13
Apr-94	9.90E-13	6.50E-13	1.21E-12	6.20E-13	3.89E-12	8.40E-13
May-94	2.05E-12	8.70E-13	4.68E-12	8.40E-13	5.98E-12	9.50E-13
Jun-94	2.80E-12	9.10E-13	2.30E-12	8.60E-13	4.35E-12	9.90E-13
Jul-94	1.62E-12	6.20E-13	1.37E-12	6.20E-13	5.17E-12	8.00E-13
Aug-94	3.20E-12	7.90E-13	4.61E-12	9.50E-13	8.55E-12	1.09E-12
Sep-94	1.59E-12	6.00E-13	1.38E-12	5.60E-13	4.89E-12	6.90E-13
Oct-94	1.03E-12	6.90E-13	5.32E-12	7.60E-13	9.98E-12	9.10E-13
Nov-94	2.05E-12	8.30E-13	1.83E-12	7.70E-13	4.72E-12	8.60E-13
Dec-94	1.42E-12	5.00E-13	2.07E-12	6.00E-13	3.61E-12	6.80E-13
Jan-95	2.39E-12	6.20E-13	2.63E-12	6.50E-13	2.67E-12	6.50E-13
Feb-95	1.61E-12	6.20E-13	3.69E-12	6.80E-13	7.11E-12	7.80E-13
Mar-95	3.66E-12	8.20E-13	3.15E-12	7.80E-13	1.87E-12	7.10E-13
Apr-95	1.26E-12	4.90E-13	1.03E-12	4.80E-13	2.94E-12	5.50E-13
May-95	1.44E-12	8.00E-13	3.39E-12	7.00E-13	5.99E-12	8.20E-13
Jun-95	8.90E-13	6.90E-13	1.00E-12	7.80E-13	5.22E-12	7.90E-13
Jul-95	2.01E-12	7.90E-13	2.11E-12	7.20E-13	1.08E-11	1.00E-12
Aug-95	1.01E-12	7.50E-13	3.67E-12	7.90E-13	1.44E-11	1.10E-12
Sep-95	2.53E-12	6.70E-13	2.44E-12	6.70E-13	1.22E-11	1.00E-12
Oct-95	2.68E-12	7.60E-13	2.14E-12	8.10E-13	1.35E-11	1.10E-12
Nov-95	9.50E-13	5.40E-13	1.43E-12	6.50E-13	5.34E-12	7.40E-13
Dec-95	1.68E-12	5.50E-13	1.59E-12	5.50E-13	4.93E-12	7.00E-13
Jan-96	7.00E-13	4.50E-13	9.00E-13	4.00E-13	6.45E-12	6.50E-13
Feb-96	9.90E-13	4.13E-13	1.24E-12	4.00E-13	1.79E-12	4.40E-13
Mar-96	1.99E-12	5.10E-13	1.27E-12	4.90E-13	6.54E-12	7.00E-13
Apr-96	1.03E-12	4.00E-13	1.12E-12	4.00E-13	3.20E-12	4.90E-13
May-96	1.12E-12	6.50E-13	8.18E-13	6.06E-13	1.91E-12	6.60E-13
Jun-96	1.69E-12	5.00E-13	6.01E-13	5.00E-13	5.16E-12	6.50E-13
Jul-96	8.83E-13	7.39E-13	4.00E-13	7.27E-13	1.75E-12	7.00E-13
Aug-96	2.17E-12	8.20E-13	2.65E-12	7.40E-13	6.12E-12	1.93E-12
Sep-96	1.07E-12	7.60E-13	2.17E-12	8.70E-13	1.10E-11	1.10E-12
Oct-96	7.20E-13	6.70E-13	2.60E-12	8.00E-13	1.10E-11	1.00E-12
Nov-96	9.58E-13	5.35E-13	2.21E-12	6.20E-13	7.22E-12	8.20E-13
Dec-96	1.24E-12	5.10E-13	1.10E-12	5.60E-13	3.11E-12	6.10E-13
Jan-97	3.30E-13	3.62E-13	7.02E-13	4.67E-13	2.48E-12	4.80E-13

**Table 6. Measured tritium concentrations in ambient air at the US Ecology site.**

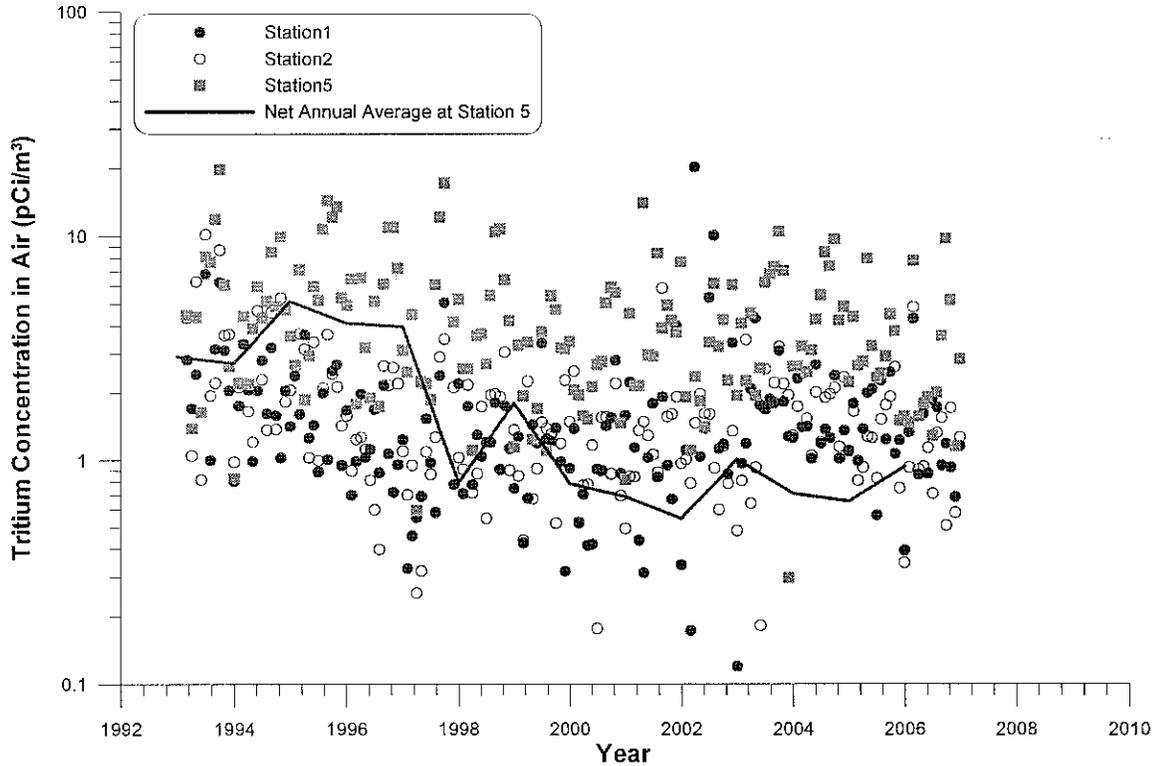
Date	Station 1 ( $\mu\text{C}/\text{cm}^3$ )	Error ( $\mu\text{C}/\text{cm}^3$ )	Station 2 ( $\mu\text{C}/\text{cm}^3$ )	Error ( $\mu\text{C}/\text{cm}^3$ )	Station 5 ( $\mu\text{C}/\text{cm}^3$ )	Error ( $\mu\text{C}/\text{cm}^3$ )
Feb-97	4.60E-13	4.10E-13	9.50E-13	4.60E-13	4.50E-12	6.00E-13
Mar-97	5.55E-13	4.59E-13	2.56E-13	4.21E-13	5.96E-13	4.24E-13
Apr-97	6.91E-13	5.22E-13	3.21E-13	5.27E-13	2.26E-12	5.70E-13
May-97	1.54E-12	5.80E-13	1.09E-12	5.80E-13	2.20E-12	6.60E-13
Jun-97	9.77E-13	5.74E-13	8.66E-13	6.16E-13	1.87E-12	7.20E-13
Jul-97	5.86E-13	6.54E-13	1.27E-12	6.70E-13	6.10E-12	8.30E-13
Aug-97	2.40E-12	1.09E-12	2.90E-12	1.05E-12	1.22E-11	1.30E-12
Sep-97	5.08E-12	9.20E-13	3.49E-12	8.90E-13	1.73E-11	1.40E-12
Nov-97	7.80E-13	6.80E-13	2.12E-12	8.20E-13	4.17E-12	9.00E-13
Dec-97	2.21E-12	6.70E-13	1.03E-12	7.80E-13	5.24E-12	6.50E-13
Jan-98	7.11E-13	4.49E-13	9.13E-13	3.48E-13	2.57E-12	5.90E-13
Feb-98	1.75E-12	6.60E-13	2.18E-12	7.40E-13	2.57E-12	7.80E-13
Mar-98	7.81E-13	5.62E-13	7.19E-13	4.97E-13	1.11E-12	3.50E-13
Apr-98	1.30E-12	5.40E-13	8.72E-13	2.84E-13	3.62E-12	5.20E-13
May-98	1.04E-12	6.70E-13	1.74E-12	6.90E-13	3.70E-12	7.80E-13
Jun-98	1.21E-12	7.10E-13	5.50E-13	6.10E-13	2.71E-12	7.50E-13
Jul-98	1.20E-12	8.80E-13	1.96E-12	9.40E-13	5.45E-12	1.11E-12
Aug-98	1.82E-12	8.00E-13	1.99E-12	9.10E-13	1.05E-11	1.20E-12
Sep-98	9.11E-13	9.22E-13	1.93E-12	9.70E-13	1.08E-11	1.20E-12
Oct-98	1.76E-12	6.90E-13	3.05E-12	6.90E-13	6.42E-12	1.04E-12
Nov-98	1.13E-12	5.40E-13	9.06E-13	5.90E-13	4.22E-12	6.90E-13
Dec-98	7.50E-13	6.22E-13	1.37E-12	5.70E-13	1.15E-12	5.50E-13
Jan-99	1.28E-12	5.10E-13	8.52E-13	4.55E-13	3.28E-12	5.90E-13
Feb-99	4.27E-13	4.65E-13	4.39E-13	6.91E-13	1.94E-12	4.80E-13
Mar-99	6.79E-13	7.71E-13	2.26E-12	5.40E-13	3.39E-12	6.50E-13
Apr-99	1.45E-12	7.50E-13	6.74E-13	5.00E-13	1.24E-12	4.20E-13
May-99	1.19E-12	5.50E-13	9.19E-13	5.95E-13	1.71E-12	9.60E-13
Jun-99	3.34E-12	1.14E-12	1.48E-12	1.08E-12	3.76E-12	1.09E-12
Jul-99	1.25E-12	6.20E-13	1.39E-12	6.20E-13	1.11E-12	6.10E-13
Aug-99	1.22E-12	1.12E-12	1.31E-12	1.31E-12	5.44E-12	1.10E-12
Sep-99	1.40E-12	7.90E-13	5.24E-13	7.58E-13	4.72E-12	6.80E-13
Oct-99	9.87E-13	5.58E-13	1.19E-12	6.00E-13	3.18E-12	7.50E-13
Nov-99	3.20E-13	1.05E-12	2.28E-12	1.21E-12	3.15E-12	1.26E-12
Dec-99	9.24E-13	5.27E-13	1.49E-12	5.80E-13	3.40E-12	6.30E-13
Jan-00	1.39E-12	4.50E-13	2.50E-12	6.20E-13	2.07E-12	8.40E-13
Feb-00	5.25E-13	5.65E-13	5.29E-13	5.63E-13	1.96E-12	6.20E-13
Mar-00	7.07E-13	4.85E-13	7.76E-13	4.76E-13	1.59E-12	4.80E-13
Apr-00	4.16E-13	4.92E-13	7.83E-13	4.59E-13	1.53E-12	9.20E-13
May-00	4.22E-13	8.82E-13	1.17E-12	4.80E-13	2.14E-12	7.00E-13
Jun-00	9.13E-13	7.30E-13	1.77E-13	7.70E-13	2.68E-12	8.10E-13
Jul-00	8.99E-13	6.69E-13	1.56E-12	6.40E-13	2.76E-12	7.30E-13
Aug-00	1.43E-12	7.10E-13	1.57E-12	8.90E-13	5.04E-12	8.40E-13
Sep-00	1.55E-12	8.60E-13	8.71E-13	8.12E-13	5.90E-12	9.60E-13
Oct-00	2.80E-12	7.50E-13	2.21E-12	7.60E-13	5.63E-12	1.14E-12
Nov-00	8.74E-13	7.40E-13	6.95E-13	6.96E-13	1.47E-12	8.10E-13
Dec-00	1.59E-12	7.40E-13	4.96E-13	6.04E-13	8.23E-13	6.10E-13

**Table 6. Measured tritium concentrations in ambient air at the US Ecology site.**

Date	Station 1 ( $\mu\text{C}/\text{cm}^3$ )	Error ( $\mu\text{C}/\text{cm}^3$ )	Station 2 ( $\mu\text{C}/\text{cm}^3$ )	Error ( $\mu\text{C}/\text{cm}^3$ )	Station 5 ( $\mu\text{C}/\text{cm}^3$ )	Error ( $\mu\text{C}/\text{cm}^3$ )
Jan-01	2.24E-12	5.20E-13	8.49E-13	3.35E-13	4.54E-12	6.00E-13
Feb-01	1.14E-12	5.00E-13	8.44E-13	5.33E-13	2.15E-12	4.80E-13
Mar-01	4.39E-13	5.85E-13	1.36E-12	7.10E-13	2.15E-12	4.80E-13
Apr-01	3.15E-13	5.91E-13	1.49E-12	5.80E-13	1.41E-11	1.00E-12
May-01	1.03E-12	5.00E-13	1.29E-12	5.20E-13	2.95E-12	5.60E-13
Jun-01	1.80E-12	7.50E-13	1.06E-12	8.10E-13	2.91E-12	8.40E-13
Jul-01	8.43E-13	6.14E-13	8.82E-13	6.30E-13	8.39E-12	9.50E-13
Aug-01	1.92E-12	6.40E-13	5.86E-12	7.70E-13	3.91E-12	3.40E-13
Sep-01	9.52E-13	5.71E-13	1.57E-12	6.00E-13	4.93E-12	7.50E-13
Oct-01	6.70E-13	5.40E-13	1.61E-12	6.10E-13	4.21E-12	7.50E-13
Nov-01	4.00E-12	7.90E-13	1.92E-12	5.40E-13	3.74E-12	7.10E-13
Dec-01	3.41E-13	7.80E-13	9.67E-13	7.78E-13	7.66E-12	8.00E-13
Jan-02	1.11E-12	4.30E-13	1.01E-12	4.30E-13	1.92E-12	4.80E-13
Feb-02	1.73E-13	3.61E-13	7.90E-13	3.90E-13	1.11E-12	4.20E-13
Mar-02	2.03E-11	1.00E-12	1.47E-12	4.40E-13	2.37E-12	5.10E-13
Apr-02	1.04E-12	4.20E-13	1.98E-12	4.60E-13	1.84E-12	4.90E-13
May-02	1.39E-12	4.30E-13	1.62E-12	4.80E-13	1.41E-12	2.50E-13
Jun-02	5.34E-12	7.60E-13	1.61E-12	6.00E-13	3.38E-12	6.90E-13
Jul-02	1.01E-11	1.00E-12	9.25E-13	5.47E-13	6.15E-12	7.40E-13
Aug-02	1.13E-12	5.80E-13	6.02E-13	4.89E-13	3.22E-12	6.60E-13
Sep-02	1.18E-12	5.50E-13	1.16E-12	4.70E-13	4.25E-12	6.10E-13
Oct-02	8.68E-13	4.69E-13	7.89E-13	4.59E-13	2.28E-12	5.10E-13
Nov-02	3.35E-12	6.20E-13	1.35E-12	5.00E-13	6.07E-12	7.10E-13
Dec-02	1.20E-13	2.08E-13	4.84E-13	4.20E-13	1.95E-12	5.10E-13
Jan-03	9.68E-13	4.74E-13	8.12E-13	4.82E-13	4.09E-12	4.86E-12
Feb-03	1.19E-12	3.70E-13	3.46E-12	4.60E-13	2.27E-12	4.30E-13
Mar-03	2.09E-12	4.00E-13	6.42E-13	4.48E-13	4.54E-12	6.00E-13
Apr-03	4.31E-12	8.80E-13	9.29E-13	4.05E-13	1.95E-12	4.40E-13
May-03	1.77E-12	5.50E-13	1.83E-13	5.70E-13	2.58E-12	5.90E-13
Jun-03	1.69E-12	6.00E-13	2.55E-12	6.10E-13	6.23E-12	8.00E-13
Jul-03	1.88E-12	6.00E-13	1.81E-12	5.10E-13	6.80E-12	7.40E-13
Aug-03	1.81E-12	6.80E-13	2.22E-12	7.30E-13	7.33E-12	9.10E-13
Sep-03	3.09E-12	7.00E-13	3.23E-12	7.20E-13	1.05E-11	1.00E-12
Oct-03	1.83E-12	5.00E-13	2.20E-12	5.90E-13	7.04E-12	7.70E-13
Nov-03	1.28E-12	4.20E-13	1.96E-12	4.30E-13	3.00E-13	4.79E-13
Dec-03	1.26E-12	5.10E-13	1.29E-12	3.80E-13	2.63E-12	5.00E-13
Jan-04	2.32E-12	4.10E-13	1.74E-12	4.00E-13	2.63E-12	4.20E-13
Feb-04	1.41E-12	5.20E-13	2.44E-12	5.30E-13	3.24E-12	6.70E-13
Mar-04	1.42E-12	4.70E-13	1.54E-12	4.30E-13	2.48E-12	5.00E-13
Apr-04	1.02E-12	4.90E-13	1.05E-12	4.80E-13	3.11E-12	5.50E-13
May-04	2.67E-12	6.50E-13	2.02E-12	6.40E-13	4.26E-12	7.40E-13
Jun-04	1.19E-12	5.40E-13	1.21E-12	6.20E-13	5.47E-12	7.80E-13
Jul-04	1.38E-12	4.60E-13	1.91E-12	5.20E-13	8.50E-12	7.80E-13
Aug-04	1.26E-12	7.50E-13	1.98E-12	7.20E-13	7.37E-12	9.60E-13
Sep-04	2.39E-12	6.90E-13	2.11E-12	6.80E-13	9.72E-12	9.60E-13
Oct-04	1.02E-12	6.10E-13	1.15E-12	6.50E-13	4.23E-12	9.60E-13

**Table 6. Measured tritium concentrations in ambient air at the US Ecology site.**

Date	Station 1 ( $\mu\text{C}/\text{cm}^3$ )	Error ( $\mu\text{C}/\text{cm}^3$ )	Station 2 ( $\mu\text{C}/\text{cm}^3$ )	Error ( $\mu\text{C}/\text{cm}^3$ )	Station 5 ( $\mu\text{C}/\text{cm}^3$ )	Error ( $\mu\text{C}/\text{cm}^3$ )
Nov-04	1.36E-12	5.40E-13	2.35E-12	5.70E-13	4.87E-12	7.10E-13
Dec-04	1.11E-12	3.80E-13	1.10E-12	4.40E-13	2.25E-12	5.10E-13
Jan-05	1.80E-12	4.20E-13	1.66E-12	4.10E-13	4.40E-12	5.30E-13
Feb-05	9.95E-13	3.60E-13	8.14E-13	3.56E-13	2.65E-12	5.00E-13
Mar-05	1.38E-12	5.40E-13	9.32E-13	4.14E-13	2.76E-12	5.30E-13
Apr-05	2.01E-12	4.90E-13	1.28E-12	5.50E-13	7.96E-12	7.60E-13
May-05	2.09E-12	7.60E-13	1.26E-12	7.20E-13	3.25E-12	7.70E-13
Jun-05	5.68E-13	4.78E-13	8.34E-13	5.50E-13	2.33E-12	6.30E-13
Jul-05	2.28E-12	7.00E-13	1.53E-12	5.90E-13	2.45E-12	7.00E-13
Aug-05	1.24E-12	4.90E-13	1.77E-12	5.40E-13	2.92E-12	6.90E-13
Sep-05	2.48E-12	6.60E-13	1.93E-12	7.40E-13	4.52E-12	8.70E-13
Oct-05	1.07E-12	7.90E-13	2.61E-12	8.40E-13	3.79E-12	9.30E-13
Nov-05	1.23E-12	6.60E-13	7.52E-13	4.81E-13	1.51E-12	5.00E-13
Dec-05	3.96E-13	4.55E-13	3.50E-13	4.02E-13	1.58E-12	4.90E-13
Jan-06	1.34E-12	4.00E-13	9.32E-13	5.69E-13	1.48E-12	5.30E-13
Feb-06	4.31E-12	3.38E-12	4.85E-12	3.20E-12	7.81E-12	3.26E-12
Mar-06	8.68E-13	2.86E-13	9.10E-13	3.68E-13	1.58E-12	3.90E-13
Apr-06	1.62E-12	4.30E-13	9.39E-13	3.10E-13	1.80E-12	5.40E-13
May-06	8.77E-13	3.89E-13	1.14E-12	4.50E-13	1.93E-12	5.00E-13
Jun-06	1.87E-12	5.40E-13	7.13E-13	6.82E-13	1.29E-12	7.90E-13
Jul-06	1.73E-12	5.40E-13	1.33E-12	5.30E-13	2.02E-12	5.60E-13
Aug-06	9.51E-13	7.15E-13	1.55E-12	5.20E-13	3.62E-12	6.70E-13
Sep-06	1.19E-12	6.10E-13	5.12E-13	4.92E-13	9.81E-12	2.26E-12
Oct-06	9.31E-13	6.06E-13	1.72E-12	6.90E-13	5.22E-12	8.50E-13
Nov-06	6.88E-13	3.71E-13	5.85E-13	3.72E-13	1.16E-12	4.10E-13
Dec-06	1.16E-12	3.80E-13	1.27E-12	3.90E-13	2.84E-12	4.60E-13



**Figure 12.** Measured tritium concentrations in air as measured at three monitoring stations near the perimeter of the US Ecology site. The net annual average from station 5 was obtained by subtracting the monthly average concentration measured at Station 1 from Station 5 and then averaging across year year.

Tritium fluxes to the ground surface were used in a Gaussian Plume model coded into a spreadsheet to calculate predicted annual average air concentrations. These predicted concentrations were then compared to the observed concentrations. The ground-level air concentration along the plume centerline (i.e.,  $y = 0$ ) for a ground-level point release is given by

$$C = \frac{Q}{\pi u \sigma_y \sigma_z} \quad (11)$$

where

$C$	=	air concentration ( $\text{pCi}/\text{m}^3$ )
$u$	=	mean wind speed (m/s)
$\sigma_y$	=	crosswind standard deviation of the plume (m)
$\sigma_z$	=	vertical standard deviation of the plume (m)
$Q$	=	emission rate ( $\text{pCi}/\text{s}$ )

The virtual source method was used to compute air concentration from a square area source as described in Turner (1994). The virtual source method computes an initial  $\sigma_y$  ( $\sigma_{y0}$ ) that is calculated by  $s/4.3$  where  $s$  is the length of one side of a square area source. The standard deviations ( $\sigma_y$ ,  $\sigma_z$ ) were obtained using the Pasquill-Gifford method as described in Turner

(1994). The area of the source was based on the footprint of the source that was used in the GWSCREEN groundwater calculations ( $382 \text{ m} \times 518 \text{ m} = 1.978 \times 10^5 \text{ m}^2$ ). The source area was assumed to be square and therefore, the length of one side of the source is  $(1.978 \times 10^5 \text{ m}^2)^{0.5} = 445 \text{ m}$ . For these calculations only Station 5 was considered and the distance downwind (which is used to determine  $\sigma_y$  and  $\sigma_z$ ) is only determined by the value of  $\sigma_{y0}$ .

Meteorological data was obtained from the Stage et al. 1993 (Table 7), which provided an 5-year summary from 1944–1949 at the Hanford meteorological station. Although these data are old and dated, the five-year annual average meteorological conditions do not vary substantially for different periods and are sufficient for this assessment.

**Table 7. Joint Frequency Distribution for Hanford Meteorological Tower, 1944–1949 (Stage et al., 1993)**

Mean wind speed (m/s)	Fraction from W to NW Sector	Atmospheric Stability		
		Stable	Neutral	Unstable
0.447	0.0974	0.0390	0.0026	0.0430
1.788	0.0974	0.1580	0.0228	0.1206
3.576	0.0974	0.0832	0.0890	0.0779
6.705	.284	0.0256	0.2493	0.0000
13.41	.284	0.0010	0.0875	0.0000

The annual average concentration is given by

$$\bar{C} = \sum_i C(u, \sigma_y, \sigma_z) f(u, \sigma_y, \sigma_z, WD) \quad (12)$$

where  $f$  is the frequency values given in Table 6 for stable, neutral, and unstable conditions for wind blowing from the W to NW sector ( $WD$ ), and  $\sigma_y$  and  $\sigma_z$  are the P-G sigma values for stability class F, D, and A. As stated earlier, the downwind distance  $x$  is determined by  $\sigma_{y0}$  for each stability class. The  $x$  distances that corresponds to a  $\sigma_{y0}$  of 445 m for stable, neutral, and unstable conditions are 3300 m, 1500m, and 400m respectively.

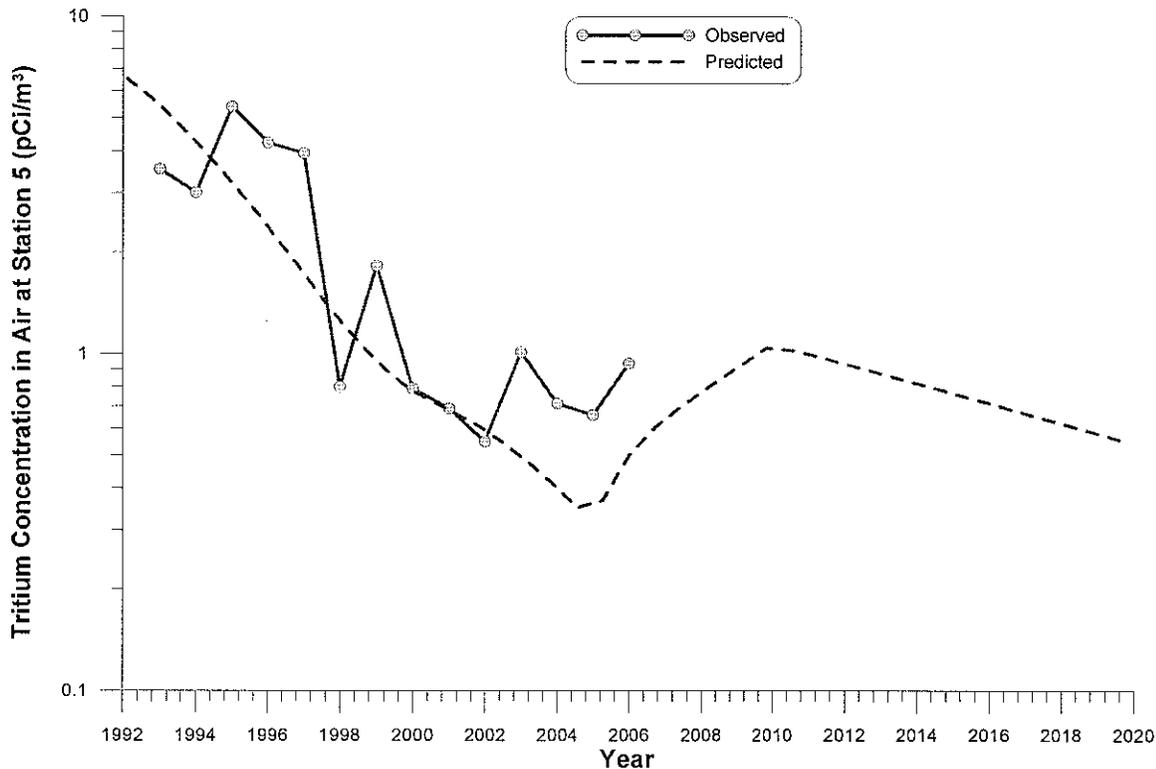
Using the parameter values in Table 5, predicted tritium fluxes to the surface were small resulting in air concentrations typically less than  $0.1 \text{ pCi/m}^3$ . Downward fluxes in the liquid phase overwhelmed diffusive fluxes upward, resulting in no net tritium diffusion to the surface. Several factors and limitations of the model contribute to this findings. First, as shown by the aqueous-phase calibration, tritium is not immediately available for release following disposal and was modeled by assigning a waste-to-soil partitioning coefficient. Second, if the form of tritium released is HT gas, then scoping calculations showed significantly higher fluxes to the surface because of higher Henry's law coefficient and diffusion coefficient for HT compared to HTO. Third, lack of knowledge about specific tritium waste forms, inventories, heterogeneities in the vadose zone, along with overall lack of understanding of the physical transport mechanisms and properties can certainly result in discrepancy between model predictions and measurements.

Adjustments to the model can be made to account for the apparent waste-to-soil partitioning by increasing the  $K_{def}$  value in the waste zone. Because  $K_{def}$  value represent the partitioning from waste to backfilled soil, and not the soil to water partitioning coefficient, the  $D_e$  value must be adjusted so that the value of  $D_e/R_d$  is the same as the original calculation.

Using a  $K_{def}$  of 4060 mL/g, calibrated tritium concentrations in air (Figure 13) are in the same magnitude and exhibit the same general temporal trend as the measured data. Based on

these results, tritium concentration in air are expected to rise to year 2010 and then decline. Furthermore, concentrations are shown to have already peaked. The second peak is due to recent disposals of tritium.

The model is not conclusive and the calibration is not unique. That is, the calibration results could also be obtained from adjusting the inventory or other model parameters. However, what is important is that assuming the reported inventory of tritium disposed in the US Ecology site is correct, it appears that the fraction of tritium released from the waste to the environment (backfilled soil) is smaller than what was originally thought. It does not appear that instantaneous availability of tritium for either liquid advection or gas-phase diffusion is a good assumption.



**Figure 13.** Predicted and observed annual average tritium concentrations (background removed) in ambient air from predicted surface fluxes of tritium at the US Ecology site.

## PARAMETER UNCERTAINTY ANALYSIS

This section presents the results of a parameter uncertainty analysis performed for the US Ecology Site using the calibrated release parameters for aqueous-phase transport of tritium to the aquifer. Details of the methodology are provided in Rood (2004). The parametric uncertainty analysis was performed for CASE 1 only described in Rood (2007). Parameter distributions used in the analysis are summarized in Table 8. The distribution for the tritium release rate constant and the waste-to-soil partitioning coefficient are discussed in the next section.

The output variables were the total drinking water dose and groundwater concentrations at specific times after 1965. Drinking water doses were calculated assuming 2 L/d ingestion rate for

365 days per year. Dose conversion factors were obtained from the International Commission on Radiation Protection (ICRP) database of dose coefficients (ICRP 1998) which is based on the methodology in ICRP-67 (ICRP 1993). Distributions of model output were developed from 500 model realizations. Only the radionuclides that contributed significantly to the total dose were included in the parametric uncertainty analysis.

**Table 8. Definition of Parameter Distributions used in the Uncertainty Analysis**

Parameter	Distribution	Comments/Reference
Background infiltration ( $\text{m yr}^{-1}$ )	Triangular: minimum 0.0025; mode 0.005, maximum 0.01	Rood (2000a)
Longevity of cover integrity (yr)	Triangular: minimum 250, mode 500, maximum 750	Assumed
Longitudinal dispersivity in aquifer (m)	Triangular: minimum 13.75, mode 27.5, maximum 41.25	Rood (2000a)
Transverse dispersivity in aquifer (m)	Triangular: minimum 2.5, mode 5.0, maximum 7.5	Rood (2000a)
Darcy velocity in aquifer ( $\text{m yr}^{-1}$ )	Truncated Lognormal: GM 32.9, GSD 2.33, minimum 3.0, maximum 250	Rood (2000a)
Bulk density, source unsaturated zone and aquifer ( $\text{g cm}^{-3}$ )	Triangular: minimum 1.58, mode 1.97, maximum 2.36	Nominal values based on Kincaid et al (1998). Distribution based on Rood (2000a)
Aquifer porosity ( $\text{m}^3 \text{ m}^{-3}$ )	Triangular: minimum 0.097, mode 0.10, maximum 0.103	Rood (2000a)
H-3 release rate constant ( $\text{yr}^{-1}$ )	Normal, mean = $2.0 \times 10^{-5} \text{ yr}^{-1}$ , standard deviation = $5.8 \times 10^{-6} \text{ yr}^{-1}$	Based on distribution of P/O ratios of H-3 concentrations in soil pore air
H-3 waste-to-soil partitioning coefficient	Normal, mean = $1.4 \times 10^4 \text{ mL/g}$ , standard deviation = $4.06 \times 10^3 \text{ mL/g}$	Based on distribution of P/O ratios of H-3 concentrations in soil pore air
Uranium $K_d$ ( $\text{mL g}^{-1}$ )	Log triangular: minimum 0.6, mode 3.0, maximum 79	Kincaid et al. (1998)
Thorium $K_d$ ( $\text{mL g}^{-1}$ )	Log triangular: minimum 40, mode 1000, maximum 2000	Kincaid et al. (1998)
Radium $K_d$ ( $\text{mL g}^{-1}$ )	Log triangular: minimum 8, mode 20, maximum 173	Kincaid et al. (1998)
Lead $K_d$ ( $\text{mL g}^{-1}$ )	Log triangular: minimum 2000, mode 6000, maximum 7900	Kincaid et al. (1998)
Carbon $K_d$ ( $\text{mL g}^{-1}$ )	Log triangular: minimum 0.25, mode 0.5, maximum 5.0	Kincaid et al. (1998)
Iodine $K_d$ layers 5-13 ( $\text{mL g}^{-1}$ )	Log triangular: minimum 0.3, mode 0.5, maximum 15	Kincaid et al. (1998)
Uranium solubility ( $\text{mg L}^{-1}$ )	Triangular: minimum 1.0, mode 25, maximum 50	Rood (2000a)

### Parameter Distribution for Waste-to-Soil Partitioning Coefficient and Release Rate Constant

The distribution of the parameters  $K_{dw}$  and  $K_{EP}$  was based on the distribution of predicted-to-observed ratios. Using the originally calculated values for  $K_{dw}$  and  $K_{EP}$ , the standard deviation of the P/O ratio was

$$\sigma_{PO} = \sqrt{\mu^2 \left( \frac{\sigma_o}{\mu_o} \right)^2} \quad (13)$$

where  $\sigma_{PO}$  = standard deviation of P/O ratios,  $\mu$  = the mean P/O ratio (1.31),  $\sigma_o$  = standard deviation of the observations ( $1.1 \times 10^5$  pCi/L),  $\mu_o$  = the mean of the observations ( $3.78 \times 10^5$  pCi/L). Equation 13 is derived from the propagation of error for a quotient and where the standard deviation of the modeled value is assumed to be zero. This distribution is imposed upon the final calibrated values of  $K_{dw}$  and  $K_{FP}$  by computing the coefficient of variation ( $CV = \sigma_{PO}/\mu = 0.29$ ) and multiplying the final calibrated values by the  $CV$ . A normal distribution is assumed so the standard deviation of  $K_{dw}$  is  $2.0 \times 10^{-5} \text{ yr}^{-1} \times 0.29 = 5.8 \times 10^{-6} \text{ yr}^{-1}$ . Likewise, the standard deviation of  $K_{FP}$  is  $1.4 \times 10^4 \text{ mL/g} \times 0.29 = 4060 \text{ mL/g}$ .

### Results of Uncertainty Analysis

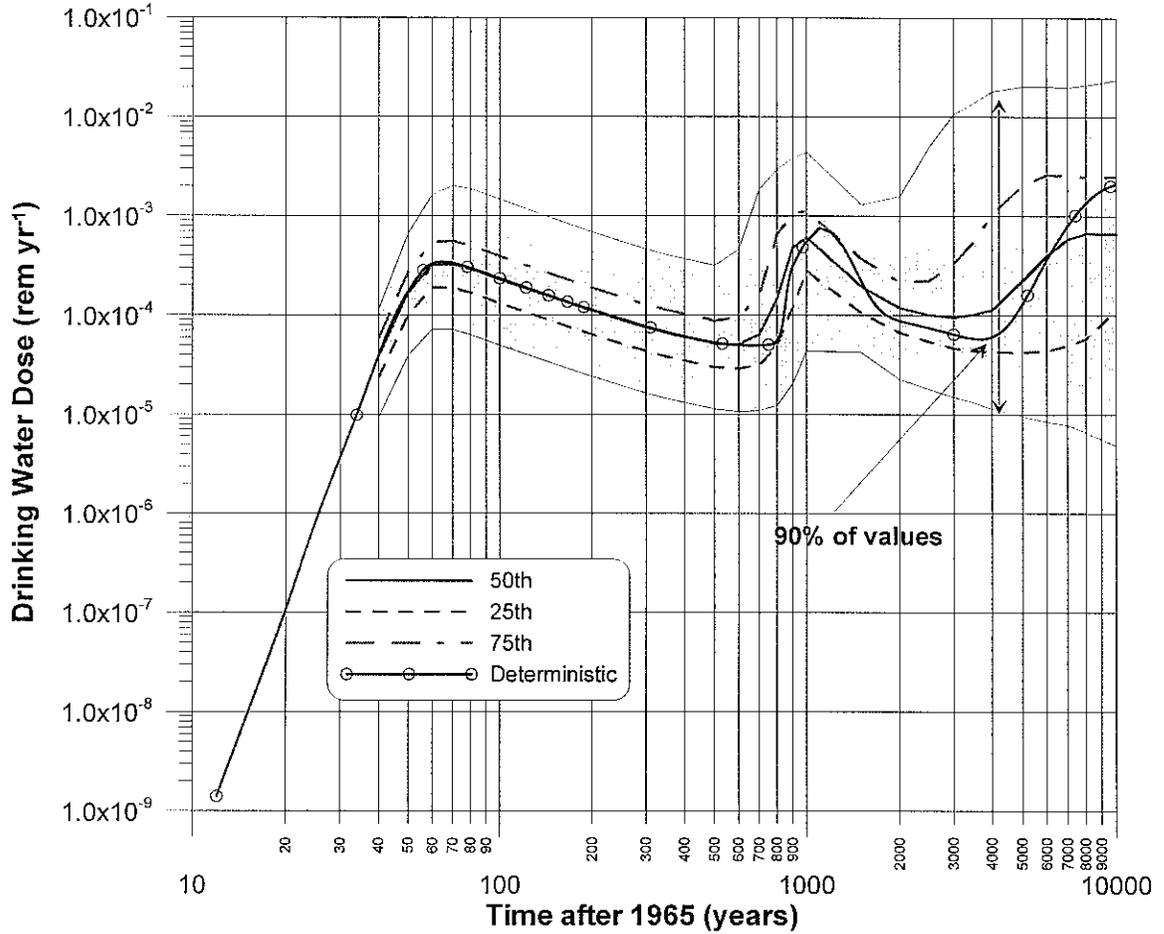
Distributions of drinking water ingestion doses are illustrated in Figure 14 and Table 9 and 10. Detailed output containing distributions of radionuclide concentrations in groundwater and drinking water doses for 28 separate output times are found in the ASCII files that accompany this report (see the D\*.dat and C\*.dat files).

Key dose contributors during the early times were the actinide mobile fractions (U-238, U-234, and Pu-239) that presumably travel as colloids. Tritium is no longer an important radionuclide in terms of drinking water dose because of its reduced release rate and output distributions of dose during the early time period are driven by mainly by the actinide mobile fractions. Distributions of doses for the longer time period (> 100 years) remain about the same as earlier analysis (Rood 2004; Rood 2007).

### Sensitivity Analysis

Rank correlation was used to compute the sensitivity of the output variable to the variability of each input parameter. As was shown in earlier analysis (Rood 2004; Rood 2007), the Darcy velocity was the most important parameter accounting for over 95% of the total variability in the drinking water dose up to about 500 years from the start of the simulation. At 10,000 years, the cover longevity (4.1%), background infiltration (11.25%), and the Darcy velocity (79.6%) accounted for most of the variability in the output variable.

A second sensitivity analysis was performed using the tritium concentration as the output variable at the 60-year output time. The Darcy velocity was the most sensitive (75.9%) followed by the waste-to-soil partitioning coefficient (19.9%).



**Figure 14.** Stochastic simulation of the enhanced cover for closure in 2056 CASE 1 with calibrated H-3 release rates showing the distribution of total drinking water dose as a function of time. The shaded area represents the area between the 5<sup>th</sup> and 95<sup>th</sup> percentiles of the distribution (with 95% confidence). Also shown are the 25<sup>th</sup>, 50<sup>th</sup> and 75<sup>th</sup> percentiles of the distribution, and the deterministic results.

**Table 9. Summary of Distribution of Predicted Total Drinking Water Dose at the Receptor Well for the CASE 1 Enhanced Cover for Closure in 2056 as Reported in Rood (2007) with Calibrated Tritium Release.**

Percentile	Year 2005 (40years) Dose (mrem)	Year 2015 (50years) Dose (mrem)	Year 2025 (60years) Dose (mrem)	Year 2035 (70years) Dose (mrem)	Year 2045 (80years) Dose (mrem)	Year 2065 (100years) Dose (mrem)
0.025	9.47E-03	3.91E-02	7.16E-02	7.11E-02	6.32E-02	4.99E-02
0.05	1.13E-02	4.67E-02	8.56E-02	8.51E-02	7.57E-02	5.97E-02
0.25	2.38E-02	1.01E-01	1.88E-01	1.89E-01	1.68E-01	1.32E-01
0.5	3.87E-02	1.68E-01	3.22E-01	3.25E-01	2.90E-01	2.29E-01
0.75	5.91E-02	2.73E-01	5.42E-01	5.59E-01	4.99E-01	3.93E-01
0.95	1.01E-01	5.39E-01	1.20E+00	1.35E+00	1.21E+00	9.54E-01
0.975	1.17E-01	6.69E-01	1.62E+00	2.01E+00	1.86E+00	1.47E+00

**Table 10. Summary of Distribution of Predicted Total Drinking Water Dose at the Receptor Well for the CASE 1 Enhanced Cover for Closure in 2056 as Reported in Rood (2007) with Calibrated Tritium Release.**

Percentile	Year 2115 (150 years) Dose (mrem)	Year 2165 (200years) Dose (mrem)	Year 2465 (500 years) Dose (mrem)	Year 2965 (1000 years) Dose (mrem)	Year 6965 (5000 years) Dose (mrem)	Year 11,965 (10,00 years) Dose (mrem)
0.025	3.24E-02	2.42E-02	1.14E-02	4.36E-02	9.58E-03	4.85E-03
0.05	3.88E-02	2.90E-02	1.36E-02	6.68E-02	1.18E-02	7.99E-03
0.25	8.57E-02	6.39E-02	3.01E-02	2.81E-01	4.23E-02	1.12E-01
0.5	1.48E-01	1.11E-01	5.19E-02	6.11E-01	2.24E-01	6.65E-01
0.75	2.54E-01	1.89E-01	8.88E-02	1.13E+00	2.04E+00	2.49E+00
0.95	6.13E-01	4.55E-01	2.12E-01	3.20E+00	1.28E+01	1.56E+01
0.975	9.34E-01	6.91E-01	3.19E-01	4.38E+00	2.03E+01	2.36E+01

## CONCLUSIONS

The calibrated tritium release rates and corresponding aquifer concentrations and doses provides an alternative analysis of facility performance for the US Ecology site. In this analysis, the tritium release rates were calibrated to measured tritium concentrations in the waste trench soil (as indicated by the solar still measurements) and vadose zone (as indicated by the vadose zone monitoring wells), and tritium fluxes to the surface were calibrated to measurements of tritium in the ambient air. The predicted aquifer concentration using the calibrated tritium release rates are less than the tritium MCL of 20,000 pCi/L. The calibration is based on a spatially and temporally limited data set, and therefore is not unique and is subject to change. For example, a

similar calibration could have been reached by reducing the total H-3 inventory disposed in the facility or decreasing the infiltration rate. Furthermore, the calibrated release rate constant and waste-to-soil partitioning coefficient are entirely empirical and do not represent a specific physical mechanism. Earlier calibration efforts of actinides and fission activation products detected below the trenches (Rood 2004) support the infiltration rates used in the model. Additionally, the vadose zone measurements indicate tritium is moving at about the rate predicted by the model but at much lower concentrations. Additional soil and vadose zone measurements, verification of the disposed tritium inventory, and knowledge of the tritium waste form, would help constrain and refine the calibration. The calibration attempted to reconcile the modeled data with the measurements using empirically-derived parameters, and project these calibrated results into the future. The calibration results in lower overall predicted tritium concentrations and doses.

Comparison of un-calibrated tritium concentrations in ambient air from predicted surface fluxes were grossly underpredicted with the gas-phase diffusion model. Incorporation of a waste-to-soil partitioning coefficient gave reasonable performance of the model both in magnitude and temporal history when compared to measured data.

Despite the limitations of both the vadose zone and ambient air calibration efforts, it is evident from the measurement data that the tritium transport model used for the US Ecology site overpredicts releases of tritium from the waste packaging to the backfilled soils, assuming the disposed inventory of tritium is correct. Tritium is not expected to be a major dose contributor in the future in contrast to earlier assessments (Rood 2004 and Rood 2007) given the fact that tritium has only a 12.5-year half-life. Maximum predicted tritium concentrations for CASE 1 Enhanced Cover Closure in 2012 decrease from  $1.09 \times 10^5$  pCi/L in 2023 to 34 pCi/L after calibration to vadose zone measurements.

It is strongly recommended that vadose zone monitoring continue at the US Ecology site, and not only for tritium, but also other mobile radionuclides like I-129 and Tc-99. Installation of lysimeters in the vadose zone is also suggested so that a comparison of tritium concentrations in the water vapor and liquid phase can be made. These measurements will provide the data needed to check and calibrate the performance assessment models, and evaluate the overall effectiveness of measures taken by US Ecology to limit radionuclide migration from the site.

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## APPENDIX A: DATA VALIDATION QUALIFIER SYMBOLS

Data Validation Qualifiers	Description
J	Estimated value (bias undetermined) – The analyte was positively identified; but the associated numerical value is the approximate concentration of the analyte in the sample.
JH	Estimated value (potential high bias) – The analyte was positively identified; but the associated numerical value is the approximate concentration, with a potential high bias of the analyte in the sample.
JL	Estimated value (potential low bias) – The analyte was positively identified; but the associated numerical value is the approximate concentration, with a potential low bias of the analyte in the sample.
UJ	Estimated non-detect - The analyte was not detected above the reported sample quantitation limit. However, the reported quantitation limit is approximate and may or may not represent the actual limit of quantitation necessary to accurately and precisely measure the analyte in the sample.
UJL	Estimated non-detect (potential low bias) – The analyte was not detected and the report sample quantitation limit is biased low.
UJH	Estimated non-detect (potential high bias) – The analyte was not detected and the reported sample quantitation limit is biased high.
M	The analytical result reported was obtained from a sediment sample found to contain between 50 and 90 percent moisture, and had no other data qualifiers added during the data validation process.
NJ	The organic analysis indicates the presence of an analyte that has been “tentatively identified”, and the associated numerical value represents its approximate concentration.
NJH	The organic analysis indicates the presence of an analyte that has been “tentatively identified”, and the associated numerical value represents its approximate concentration with a potential high bias of the analyte concentration.
EMPC	Estimated Maximum Possible Concentration.
Laboratory Qualifiers	Description
R	The sample results are rejected. Due to a significant QA/QC problem, the analysis is invalid and provides no information as to whether the analyte is present or not.
B	Inorganics – The reported value was obtained from an instrument reading that was less than the sample quantitation limit (SQL).
	Organics – The associated analyte was also detected in the method blank.
D	The organic analyte was quantitated from a diluted analysis.
E	Inorganics – The reported value is estimated because of the presence of an interference.
	Organics – The associated compound concentration exceeded the calibration range of the instrument.
G	Organic data indicated the presence of a compound that meets the identification criteria; the result is below the SQL but above the MDL.
N	The inorganic analysis is associated with a spike sample not within control limits.
P	The percent difference between the primary and confirmation column for pesticide/Aroclor analyses is greater than 25 percent.
U	The analyte was analyzed for, but was not detected above the reported sample quantitation limit.
*	The inorganic duplicate analysis was not within the established QC control limit. <sup>1</sup>
ND	The analyte was analyzed for, but was not detected.
R	The sample results are rejected. Due to a significant QA/QC problem, the analysis is invalid and provides no information as to whether the analyte is present or not.