RCRA FACILITY INVESTIGATION – REMEDIAL INVESTIGATION/ CORRECTIVE MEASURES STUDY – FEASIBILITY STUDY REPORT

SECTION 10.0: ATTACHMENT 1

CD ROM, Sitewide Radiation Dose Assessment White Paper

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1.0 INTRODUCTION

This white paper reports the calculated annual radiation dose due to residual radionuclide concentrations at the Rocky Flats Environmental Technology Site (RFETS or Site). A deterministic methodology and bounding analysis approach is used to allow a reasonably conservative screening of the calculated doses against radiation dose criteria specified in Colorado's radiation control regulations. The results will be evaluated as part of the RFETS Remedial Investigation/Feasibility Study (RI/FS) Report.[1]

The particular requirements considered in this white paper are from the Colorado Department of Public Health and Environment (CDPHE) Radiation Control Regulations, 6 Code of Colorado Regulations (CCR) 1007-1, Part 4. These regulations are considered to be applicable or relevant and appropriate requirements (ARARs) and are discussed in Section 10.0 of the RI/FS Report. The pertinent limits are summarized and discussed below.

- Section 4.61.1.2 – The maximum total effective dose equivalent (TEDE)[2] to the average member of the critical group[3] within the first 1,000 years after decommissioning must be calculated.

  This white paper provides the results of the required radiation dose rate calculations for the wildlife refuge worker (WRW) as the average member of the critical group based on the future RFETS land use, which is a wildlife refuge. While the Refuge is expected to have visitors, the results of the Comprehensive Risk Assessment (CRA) for RFETS for the WRW and the wildlife refuge visitor (WRV) demonstrate that the WRW is expected to receive more exposure to residual radioactivity. The CRA is Appendix A of the RI/FS Report. (See the results for the Wind Blown Exposure Unit [EU] [WBEU] in the RI/FS Report Appendix A, Volume 9.)

- Sections 4.61.3 and 4.61.3.2 – …a site may be released for restricted use so that the TEDE to the average member of the critical group will not exceed 25 millirems per year (mrem/yr). Provisions must be made for durable, legally enforceable institutional controls that provide reasonable assurance these levels will not be exceeded.

  The highest calculated dose rate for the WRW average member of the critical group is below 25 mrem/yr. The determination of the need for and extent of institutional controls to be implemented will be made in the final remedial decision.

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[1] Because remedial activities at RFETS are also being conducted under the Resource Conservation and Recovery Act (RCRA) and the Colorado Hazardous Waste Act (CHWA), the RI/FS Report will satisfy the RCRA/CHWA requirements for a RCRA Facility Investigation/Corrective Measures Study (RFI/CMS) Report. For simplicity, the Report is referred to as the RI/FS Report.

[2] "Total effective dose equivalent" (TEDE) means the sum of the deep dose equivalent for external exposures and the committed effective dose equivalent for internal exposures (6 CCR 1007-1, Part 1, sec. 1.2).

[3] "Critical group" means the group of individuals reasonably expected to receive the greatest exposure to residual radioactivity for any applicable set of circumstances (6 CCR 1007-1, Part 1, sec. 1.2).

- Section 4.61.3.3 – If institutional controls were no longer in effect, the TEDE above background is ALARA and would not exceed 100 mrem/yr.[4]

  Radiation dose rate calculations for a rural resident adult and child are presented because a rural residential land use scenario is considered reasonable if the Refuge use is not maintained in the future. The highest calculated dose rate for the rural resident scenario is below 100 mrem/yr.

The rural resident land use assumption is based on previous work to evaluate and develop RFETS radionuclide soil action levels (RSALs) undertaken by the U.S. Department of Energy (DOE), the U.S. Environmental Protection Agency (EPA), and CDPHE[5] as described in the RSAL Task 3 Report (EPA et al. 2002).[6] Other aspects of RSAL development are also applied in this white paper as discussed in Section 2.0, which presents the methodology and data used for the dose rate calculations.

Dose rates are calculated over a 1,000-year period based on radionuclide concentrations in surface and subsurface soil and sediment. Shallow groundwater is not a source of drinking water at RFETS and the RSAL evaluation concluded that shallow groundwater at RFETS will not support sustained use. However, several surface water drainage areas at RFETS have continuous flow. Thus, dose rates for surface water ingestion are calculated using post-1999 surface water sampling data. The results of the dose rate calculations are presented in Section 3.0.

An uncertainty discussion is presented in Section 4.0. The uncertainty evaluation considers the impact of the uranium-contaminated Solar Evaporation Ponds (SEP) groundwater plume on the surface water ingestion dose in one exposure area and also considers excavation for a residence basement. For simplicity, a background radiation dose rate subtraction was not performed. However, background and groundwater use uncertainties related to the dose assessment are also discussed in the uncertainties evaluation.

A discussion of the ALARA criteria in relation to development of final remediation goals is included in Section 5.0.

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[4] Alternate criteria above 100 mrem/yr TEDE may be approved. This is not evaluated in this paper because the stated criteria are met.

[5] The dose rate to a WRW as well as a rural resident was considered as a basis for RSAL modifications, which were used as a basis for evaluating the need for accelerated actions. For a discussion of action levels (ALs) and the Rocky Flats Cleanup Agreement (RFCA) accelerated action approach, see the Soil Action Levels Technical Memorandum (DOE 2003), developed under Task 2 of the Final Work Plan for the RI/FS Report (DOE 2002).

[6] Task 3 was one task in a reevaluation of the 1996 interim RSALs in RFCA Attachment 5, RFETS Action Levels and Standards Framework for Surface Water, Ground Water and Soils. A report for each task was prepared jointly by EPA, CDPHE, and DOE. Based on the outcome of the RSALs reevaluation, the RSALs were subsequently modified in 2003 by the RFCA Parties.

2.0 METHODOLOGY

The basic approach used for this evaluation is calculation of an upper-bound dose rate based on a reasonably conservative calculation method for comparison to the CDPHE dose-based limits. The RFETS sampling locations with the highest residual level of plutonium-239/240, americium-241, or uranium-233/234, uranium-235, or uranium-238 in the surface or the subsurface soil/sediment are identified from the data set used in preparing the RI/FS Report (the RI data set). An exposure point concentration (EPC) is then calculated for all samples collected within each specified exposure area.

For the WRW, the exposure areas coincide with the EUs used in the CRA. For the rural resident, 5-acre circular exposure areas representing small "ranchettes" are used, consistent with the RSAL development approach. The data set, identification of exposure areas, and the EPC calculation method are further discussed in this section.

The annual dose rate contribution for each of the radionuclide EPCs in the surface and subsurface is then calculated over a 1,000-year period using the Residual Radioactivity (RESRAD) computer model, version 6.3 (ANL 2005).[7] The RESRAD model calculates the TEDE based on the initial radionuclide EPC, the size of the exposure area, or contaminated zone, and the spatial distribution in the environmental media that result in external and internal exposure. The dose rate from external exposure is based on the type and energy of radiation emitted by the residual radionuclide concentration on or below the ground surface and the shielding effect of the soil. Internal exposure is based on the uptake of the radionuclide by the human receptor using inhalation and ingestion intake parameters for the receptor (for example, the breathing rate of contaminated air). Radionuclide-specific dose conversion factors are then applied to determine the internal radiation dose from the inhaled or ingested radionuclide. RESRAD also incorporates the environmental transport and radioactive decay characteristics of the radionuclide, which impacts the radionuclide concentrations and spatial distribution in the environmental media over time (for this assessment 1,000 years). The RESRAD model is further discussed in this section.

The annual dose rate from ingestion of surface water is calculated using post-1999 sampling data from the RI data set. Only post-1999 surface water sample results were used for the EPC calculation because these data are temporally representative of the ambient surface water quality.[8] The surface water ingestion pathway is assessed using standard EPA exposure parameters for drinking water for the rural resident exposure scenario. For the WRW the surface water ingestion pathway does not include drinking water use and is assessed using the incidental water ingestion exposure parameters from the CRA Methodology (DOE 2005) for the WRW exposure scenario.

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[7] The computer code is revised periodically to improve user features and maintain compatibility with computer hardware and software and to update imbedded parameters and functions based on newer authoritative scientific information used in the dose rate calculations. Version 6.3 is the most recent updated version. Configuration control is maintained by Argonne National Laboratory.

[8] A discussion of the temporal aspects of surface water sampling data is provided in the RI/FS Report Section 5, Nature and Extent of Surface Water and Sediment Contamination.

The total dose rate is the sum of the surface and subsurface soil and sediment internal and external dose rates and the surface water ingestion dose rates.

2.1 Data

The data set for plutonium-239/240 and americium-241 in soil and sediment is consistent with the soil and sediment RI data set used to prepare the RI/FS Report. However, the uranium sample depth interval is slightly different. Surface plutonium-239/240 and americium-241 concentration data are from 0 to 15 centimeters (cm) (0 to 6 inches) in depth. For uranium isotopes, surface concentration data are from 0 to 50 cm (0 to 29 inches) in depth to fully account for the external exposure contribution to the dose rate to the receptor on the surface. These surface data depths are consistent with the RSAL development methodology.

The RSAL development did not include a subsurface contamination evaluation. For this white paper the subsurface radionuclide concentration data are from the end of the surface depth, that is, 15 cm or 50 cm depth to 2.44 meters (m) (6 inches or 29 inches to 8 feet [ft]) in depth. The 2.44 m (8 ft) depth is consistent with the CRA Methodology. Thus, for americium-241 and plutonium-239/240, data for 0 to 15 cm below the surface were used, while for uranium isotopes data from 0 to 50 cm were used to find the maximum surface concentration location.

For the surface water stations assessed, the surface water data are consistent with the RI surface water data set.

2.2 Maximum Concentration Locations

The RFETS sampling locations with the maximum surface soil/sediment and subsurface soil/sediment concentrations of americium-241, plutonium-239/240, uranium-234, uranium-235, and uranium-238 were identified. The sampling locations are located within three CRA EUs for which the dose rate to the WRW is calculated: the WBEU, the Upper Woman Drainage EU (UWOEU), and the Industrial Area (IA) EU (IAEU). These EUs are fully described in the RI/FS Report, Appendix A, Volumes 9, 10, and 14, respectively.

For the purpose of evaluating rural residential dose, 5-acre circular areas containing these maximum residual surface and subsurface radionuclide concentrations were drawn to encompass as many higher concentration data points within the area as possible. Note that some 5-acre areas contain the maximum radionuclide concentration for more than one radionuclide. The location of the 5-acre areas containing the maximum concentrations within the three EUs are described below and shown on Figure A1.1 and Figure A1.2.

The maximum concentration locations are associated with the locations for historical Potential Areas of Concern (PACs), Individual Hazardous Substance Sites (IHSSs), or Under Building Contamination (UBC) Sites, as follows:

1. Former sites of Buildings 776/777, 778, and 707 (historical UBC Sites 776, 777, 778, and 707) (see Figure A1.3);

2. SEP (historical IHSS 101) (see Figure A1.3);

3. East Trenches area, Trenches T5 through T8 (historical IHSSs 111.2 through 111.5) (see Figure A1.4);

4. West Ash Pit areas (historical PAC SW-1702 and IHSSs 131.1, 131.3, and 131.5) (see Figure A1.5); and

5. East Ash Pit area (historical IHSS 131.2) (see Figure A1.5).

The description and history of historical PACs, IHSSs, and UBC Sites, which have been assigned unique identification numbers for reference, are contained in the RI/FS Report Appendix B, the RFETS Historical Release Report (HRR). Figure A1.2 shows the proximity of the historical PACs, IHSSs, and UBC Sites to the maximum concentration areas, and the closest surface water sampling stations for which RI surface water data were used to calculate the surface water consumption dose.

Figure A1.3 through Figure A1.5 show the maximum sample concentration locations and concentrations and all the RI data set points in and around the 5-acre circular areas. Figure A1.3 through Figure A1.5 also show the particular radionuclide surface or subsurface soil/sediment concentration and sampling location that resulted in the area being identified as containing the maximum concentration. In addition, whether the sample is for surface or subsurface soil/sediment and the range of concentrations is indicated by the shape and color coding of the data point locations.

2.3 Soil/Sediment Exposure Point Concentrations

The EPC represents the initial radionuclide concentration that the receptor will be exposed to in surface or subsurface soil/sediment. Surface and subsurface soil/sediment concentrations of americium-241, plutonium-239/240, uranium-234, uranium-235, and uranium-238 are aggregated separately in each EU and 5-acre area. The EPA ProUCL computer program, version 3.0, was used to calculate the EPCs in accordance with the CRA Methodology requirements.

Summary statistics and the calculated EPC for the EUs are listed in Table A1.1 and Table A1.2. Summary statistics and the calculated EPC for the 5-acre areas are listed in Table A1.3 and Table A1.4.

The following methodology was used to calculate the EPC. The 95% Upper Confidence Level (95UCL) of the mean concentration for each radionuclide in surface and subsurface soil/sediment using all radionuclide concentration data within the exposure areas was calculated for the EUs and 5-acre areas. The 95UCL is the EPC unless the 95UCL is greater than the maximum detected concentration (MDC). In this situation, the MDC is the EPC. For simplicity, the assessment conservatively assumes all dose is the result of anthropogenic radionuclides. Thus, the dose from background radionuclide concentrations is not calculated and a background subtraction is not performed for this assessment.

2.4 Residual Radioactivity Calculation Parameters

The RSAL Task 3 Report discusses the exposure scenarios used by DOE, EPA, and CDPHE for the calculation of the surface RSALs, as well as the methods of calculation, the associated input variables, and the results of the calculations and effects of uncertainties.

Both risk-based and dose-based RSALs were back-calculated based on a probabilistic distribution of exposure parameters for these receptor scenarios. The RSAL Task 3 Report also calculated deterministic point estimate (that is, single value rather than a distribution value) 25 mrem/yr dose-based RSALs for these radionuclides for comparison purposes.

The RSAL Task 3 probabilistic and point estimate RSAL calculations were performed using the RESRAD computer model, version 6.0 (ANL 2000). RSALs were not calculated for subsurface soil in the RSAL Task 3 Report. Surface water ingestion was determined to be a complete but insignificant pathway, while groundwater ingestion was determined to be an incomplete pathway in the RSAL Task 3 Report.

For the soil/sediment evaluation in this white paper, the deterministic method was used as a first screening step because the approach is simpler than the probabilistic method. For the probabilistic method, multiple calculation runs using input values selected from within the statistical range of the variable probabilistic inputs are required. Note that the deterministic method also yields somewhat more conservative results than the probabilistic approach because it uses only the upper percentile value of the distribution.

For the screening deterministic dose assessment in this white paper the dose rate is calculated using the point estimate exposure parameters. The dose rate was calculated at sufficient points in time during the 1,000-year calculation period to plot a dose rate over time curve so that the time at which the radionuclide contamination results in the maximum dose rate can be determined.

The RESRAD input parameters for this dose assessment are included in Table A1.5 through Table A1.7. They are mostly drawn from the RSAL Task 3 Report because most of the Task 3 values are pertinent to a forward-looking dose calculation. These tables list the parameters used in the RSAL Task 3 Report calculations, and the parameters used for the calculations in this white paper. An explanatory comment for any different parameters that were used for this dose assessment is provided in the tables.

Several of the key parameter differences are explained more fully below.

- The contaminated zone is assumed to be 5 acres in area for the rural resident scenario. The EU acreage is the contaminated zone size for the WRW exposure scenario. A 5-acre contaminated zone was used to calculate the uranium surface soil RSAL in the RSAL Task 3 Report. A 350-acre area was used to calculate the americium and plutonium surface soil RSAL. These sizes were considered appropriately conservative for surface soil RSAL development. The sensitivity of the contaminated zone parameter is discussed in the RSAL Task 3 Report. Based on that discussion, the sizes of the contaminated zones (rural resident "ranchette" and EU) are sufficiently large to minimize the sensitivity of this parameter in the calculated dose rates, except for the rural resident inhalation pathway. The 5-acre size will tend to underestimate the effects of airborne contamination that originates outside the 5-acre area, but exposes the resident rancher downwind on the 5-acre plot. This phenomenon is somewhat balanced by the assumption that airborne contamination originating on the 5-acre plot would migrate away in the prevailing wind and not be inhaled. However, extensive historical air monitoring on and around RFETS shows that airborne concentrations do not present a significant exposure hazard. Calculated dose rates based on this monitoring data, which were collected prior to and during accelerated actions, show that expected dose rates would be well below 1 mrem/yr. Refer to the RI/FS Report Section 6.0, Nature and Extent of Air Contamination, and Section 8.0, Contaminant Fate and Transport, for more detailed discussion on this topic.

- The groundwater fractional usage for irrigation water parameter was assumed to be 0 for the residential exposure scenario for all radionuclides because there is no sustainable source of groundwater for irrigation. This assumption may underestimate dose because irrigation water is assumed to come from a nonradionuclide-contaminated surface water source. This parameter was not defined in the RSAL Task 3 Report.

- The uranium distribution coefficient (Kd) value was set at 170 milliliters per gram (mL/g) based on site-specific studies (Honeyman and Santschi 1997) which cited a Kd range of 30 to 170 mL/g. The RSAL Task 3 Report used a Kd value for uranium isotopes of 50 mL/g. The use of 170 mL/g is a conservative assumption because high values of Kd will maximize radiation dose for contaminated soil exposure pathways given that radionuclides are leached out of the soil slower than for low Kd soils.

For subsurface soil, it was necessary to modify the following parameters for this assessment because the RSAL Task 3 Report did not assess a subsurface soil exposure scenario. The WRW exposure parameters were revised consistent with the CRA Methodology that was developed for the CRA for subsurface soil exposure.

- The inhalation rate is 11,388 cubic meters per year (m^3/yr) (1.3 cubic meters per hour [m3/hr] x 24 hours per day [hr/day] x 365 days per year [days/yr]).
- The indoor dust filtration factor is 1.0.
- The external gamma shielding factor is 1.0.
- The indoor time fraction is 0.
- The outdoor time fraction is 0.018. This is the fraction of the year that the WRW is exposed to the subsurface at the site ([20 days/yr x 8 hr/day] / [365 days/yr x 24 hr/day]).

The rural resident exposure parameters are based on the resident being on the property 24 hr/day, 350 days/yr (as in the RSAL Task 3 Report). However, it is assumed the rural resident indoor and outdoor time fraction for subsurface exposure is based on the 20 days/yr assumed for the WRW, involving property maintenance activities such as post hole digging for fencing. For the rural resident, such activities may include tilling a garden. A variation of this scenario to evaluate deeper excavation that might be associated with a building foundation is evaluated in the uncertainty section of this white paper.

No uncontaminated, unsaturated zone is defined for the residential and WRW exposure scenarios. This is a realistic assumption because the contaminated zone of subsurface soil is replacing the uncontaminated, unsaturated zone. A 3-m uncontaminated, unsaturated zone was used in the RSAL Task 3 Report.

2.5 Surface Water

The data used are for post-1999 sampling results, which is considered temporally representative of surface water quality, and are consistent with the surface water data used for the RI/FS Report nature and extent of surface water contamination.

For the purposes of WRW dose calculations, EU-wide surface water data are used for each of the EUs. For the purposes of rural resident dose calculation, the sampling data from surface water sampling stations identified in the 2005 Integrated Monitoring Plan (IMP) (K-H 2005) that are closest to the identified 5-acre areas were used to calculate the EPC for each radionuclide. Four separate surface water sampling locations were identified adjacent to the former Building 776 Area, the historical SEP area, the historical East Trenches area, and the historical East and West Ash Pits areas (see Figure A1.2). These surface water sampling locations were chosen based on their reasonable proximity to the elevated soil areas: SW018 is associated with the former Building 776 soil area; SW093 is associated with the historical SEP soil area; GS10 is associated with the historical East Trenches soil area; and GS59 is associated with the historical East and West Ash Pits soil areas.

Summary statistics for surface water for the EUs are listed in Table A1.8. Summary statistics for radionuclides in surface water for the SW018, SW093, GS10, and GS59 surface water sampling locations are listed in Table A1.9. Only total radionuclide concentrations in the surface water are assessed because the WRW is exposed through incidental ingestion of raw surface water and a resident may not filter the water before drinking. The dose calculations are performed based on an annual surface water ingestion rate for the WRW, the adult resident and child resident exposure scenarios. Annual water ingestion rates for the WRW are based on the CRA Methodology and are assumed to be 0.03 liter/day for 42 days/yr. Annual water ingestion rates for the Adult Resident are based on EPA guidance (EPA 1991) and are assumed to be 2 liters/day for 350 days/yr. Annual water ingestion rates for the child resident are based on EPA guidance (EPA 2002) and are assumed to be 0.9 liter/day (L/day) for 350 days/yr. The water ingestion dose conversion factors are from the RSAL Task 3 Report. ProUCL version 3.0 software was used to calculate the 95UCL surface water concentration. A background comparison for surface water is not performed for this assessment.

3.0 RESULTS

The RESRAD summary report printouts for the RESRAD calculations are provided as an appendix to this attachment. The summary reports list the input parameters for the calculation and the total dose rate for each time period calculated. A dose rate over time curve is also included for each summary report.

Table A1.10 through Table A1.12 present the highest dose rate for each radionuclide during the 1,000-year calculation period from the RESRAD summary reports for surface and subsurface exposure for the WRW, adult resident, and child resident, respectively. The highest dose rate over time is presented in the tables and the time when this occurs is also noted. Americium-241 decay over 1,000 years, based on its 421-year half-life, will reduce its inventory by more than 75 percent. The other radionuclides do not appreciably decay due to their very long half-lives. The dose rate over time curves primarily show the effects of the environmental transport mechanisms for the radionuclides. All doses are maximum at the beginning of these curves (that is, at time = 0 years).

Table A1.13 through Table A1.15 present the results of the surface water exposure calculations for the WRW, adult resident, and child resident, respectively. The surface water concentrations are assumed to be constant. This may overestimate or underestimate the potential exposure over time, but provides a perspective of the surface water exposure contribution to the total dose rate.

Table A1.16 and Table A1.17 summarize the dose rates in Table A1.10 through Table A1.15 to present the total dose rate for the WRW and the rural resident, respectively.

3.1 Soil/Sediment Dose Rate

The maximum RESRAD calculated dose rates for the WRW are below 1 mrem/yr in the three EUs in this assessment.

The maximum soil/sediment dose rates for four of the 5-acre areas using the point estimate deterministic approach are below approximately 5 mrem/yr for the rural resident adult and below approximately 7 mrem/yr for the rural resident child.

The exception is the historical West Ash Pits 5-acre area. For this exposure area the adult rural resident maximum dose rate for soil/sediment is approximately 50 mrem/yr, with uranium-238 in surface soil contributing approximately 36 mrem/yr. For the rural resident child in this area the maximum dose rate is approximately 64 mrem/yr, with uranium-238 in surface soil contributing approximately 46 mrem/yr.

The historical West Ash Pits deterministic calculation most likely overestimates the uranium-238 surface soil/sediment exposure pathway component. The uranium surface soil/sediment EPC for the 5-acre historical West Ash Pits area is the MDC

(209.28 picocuries per gram [pCi/g]), based on EPA guidance to default to the MDC when the UCL calculated using ProUCL is higher than the MDC. As can be seen from the summary statistics for this area in Table A1.3, seven of the eight sample results are much lower than the MDC and show a fairly consistent concentration. Figure A1.5 shows that these seven samples are also consistent with uranium concentrations surrounding the 5-acre area. The mean concentration for the eight samples (37.73 pCi/g), which is approximately 15 percent of the MDC value, is likely a more realistic estimate of the surface soil/sediment residual contamination contribution to these exposure pathways.

On the less conservative side, the rural resident garden is assumed irrigated with a noncontaminated surface water source for the 1,000-year assessment period. Because surface water may have elevated levels of radionuclides over time and could be used for irrigation, the radiation dose from plant ingestion may be underestimated. However, the major contributors to exposure are the uranium isotopes, and the uranium surface water EPC used in this evaluation is generally consistent with background levels. It would be appropriate to subtract the background contribution if contaminated irrigation water is assumed.

3.2 Surface Water Dose Rate

For the WRW scenario, surface water dose in all EUs is below 1 mrem/yr.

For the resident exposure scenarios, the radiation dose at surface water sampling locations SW018, SW093, GS10, and GS59 is below 1 mrem/yr. These results indicate that the surface water exposure pathway does not represent a significant dose rate contribution in relation to the dose rate limit or the dose rate from soil/sediment exposure. It should be noted that the naturally occurring uranium isotope surface water background concentrations have not been subtracted from the calculated EPCs.

4.0 UNCERTAINTIES

Uncertainties related to the exposure pathways, exposure parameters, and environmental transport parameters are discussed in detail in the RSAL Task 3 Report.

The surface water dose rate calculation in this white paper is based on the post-1999 surface water monitoring data; however, it is recognized that radionuclide contaminated groundwater could migrate to surface water in the future. In particular, the uranium plume associated with the historical SEP area is upgradient of surface water station SW093. Possible impacts to the rural resident dose assessment results from this source of uranium contamination are discussed more in Section 4.1.

The groundwater pathway is considered incomplete at RFETS. Uncertainties related to assuming no groundwater use are discussed in more detail in Section 4.2.

In addition, because the rural resident scenario assumes the same limited exposure to subsurface soil related to localized soil disturbances as for the WRW scenario, an evaluation of the surface dose to the rural resident assuming excavation into the subsurface to a depth of 3.66 m (12 ft) for a building basement is provided in Section 4.3.

4.1 Surface Water

The dose assessment for surface water is based on post-1999 surface water monitoring results. Section 8.0 of the RI/FS Report provides a contaminant fate and transport evaluation of the environmental pathways at RFETS. This includes consideration of impacts on surface water quality in the future. The primary pathway to surface water for americium and plutonium is surface soil erosion, while for uranium it is groundwater transport. The fate and transport evaluation includes an analysis of the projected surface water quality for these radionuclides based on these pathways. The evaluation concludes that future surface water loads of these contaminants will be greatly reduced, but are expected to remain at low levels. Because of diminished water volume in the RFETS final closure condition, the groundwater transport pathway for uranium could sometimes result in higher surface water concentrations in periods of low surface water base flow, when the groundwater contribution to base flow could make up a larger fraction of the total surface water volume. Thus, the dose assessment could underestimate the annual dose from uranium-contaminated groundwater in low-flow periods where surface water concentrations may be higher. Any tendency to store water obtained during high-flow periods would offset this trend however.

In addition, a Los Alamos National Laboratory (LANL) study, "Quantitative Evaluation of Mixture Components in RFETS Uranium Isotopic Analysis," LA-UR-05-7223, dated September 8, 2005, is included as an attachment in the RI/FS Report contaminant fate and transport evaluation. This study's surface water results show ranges in surface water of 0 to 66 percent depleted uranium (conversely, 34 to 100 percent natural uranium) and less than 1 percent enriched uranium. For simplicity, the calculated dose rates from surface water do not subtract the dominant natural background uranium concentrations and thus present a fairly conservative dose rate estimate for RFETS-related uranium in surface water.

The depleted uranium-contaminated groundwater plume at the historical SEP area (historical IHSS 101) is not expected to dissipate for many years. While there are wells in other areas with anthropogenic uranium concentrations, there are no other identified plumes. It is noted that anthropogenic uranium in groundwater not associated with the SEP plume may reach surface water, however, an evaluation of the SEP plume is a reasonable approach to estimate the impact of this issue from an uncertainty perspective.

To estimate the impact of the SEP plume concentrations on the surface water dose assessment for monitoring location SW093, an EPC was calculated using the uranium isotope concentrations in the wells associated with the SEP plume area. The SEP plume area is shown on Figure A1.6, along with the wells from which groundwater concentration data were used for the EPC calculation. The wells lay within an area circumscribed by line drawn from the upgradient (southern) boundary of the SEP outline, around the plume on the eastern and western boundaries and around the first wells downgradient (generally north) of the plume leading edge.

The EPC and summary statistics for the data from these wells are presented in Table A1.18, along with the calculated dose. Table A1.18 presents the summary statistics, EPC, and dose for groundwater data from post-1999 samples only. The post-1999 groundwater data set is the same time frame as the surface water data used in the surface water pathway dose assessment and provides a temporal comparison with that data.

The contaminant fate and transport evaluation in the RI/FS Report observes that the highest concentrations of uranium isotopes are decreasing in the groundwater beneath the historical SEP area. This attenuation is probably due to sorption to the porous media, dispersion, and dilution as the plume migrates. The contaminant source has been removed in the cleanup actions that addressed historical IHSS 101 and the plumes are expected to slowly attenuate through dispersion and dilution from groundwater recharge. In addition, the Solar Pounds Plume Treatment System (SPPTS) is designed to remove uranium from groundwater it captures.

Assuming a low precipitation year, this EPC was assumed to represent the surface water base flow condition (that is, groundwater flow to surface water makes up 100 percent of the surface water) to screen a “worst case” dose rate based on this concentration in surface water. It is unlikely that the SEP plume area concentration represented by the EPC used for this calculation would become 100 percent of the base flow. The drainage area for SW093 is much larger and most is unaffected by the SEP plume. It is also unlikely that surface water would consist of shallow groundwater base flow for an extended period. The effects of precipitation are likely to at least seasonally change the base flow contributions.

It should be noted that the EPC data include the natural background uranium concentrations and thus are conservative. Sampling location SW093 was not sampled for the LANL study; however, GS13, directly downstream in North Walnut Creek and influenced by the SEP groundwater plume, indicated 28 percent depleted uranium.

The resident adult and child surface water ingestion dose rates based on the predicted future EPC for the SEP plume area are approximately 32 and 38 mrem/yr, respectively, without considering the reduction for the uranium background contribution. Surface water for this area is associated with the SEP 5-acre area.

Thus, it appears unlikely that the SEP plume concentrations would be expected to impact surface water concentrations to an extent that would result in a total dose rate greater than 100 mrem/yr to the resident.

4.2 Groundwater

The RSAL Task 3 Report states in Section 3.2:

> *The only exposed individual who would potentially use shallow groundwater, as a drinking source would be the rural resident. This scenario does not assume a subsistence existence, but assumes instead a rural resident who lives on a five-acre plot and uses potable water derived either from a deep well or from a domestic water system.*

> *A recent white paper (RMRS, 2001) concluded that it might be possible for wells at Rocky Flats to provide sufficient quantities of water to serve as a primary source of drinking water. However, the study was limited to looking only at the potential yields of wells that were unaffected by any other withdrawal of water from that same shallow source, and included imported water now leaking into and potentially contributing to the shallow water table. The working group concluded that such wells could not provide enough water for domestic use on a sustained basis. The potentially contaminated shallow groundwater supply would not be sufficiently reliable to be used routinely nor would such use be legally acceptable practice. In none of the scenarios defined would the exposed individuals be expected to have access to or use groundwater.*

The study referenced in the Task 3 Report is included as Section 10.2 in the RFETS 2001 Annual Rocky Flats Cleanup Agreement (RFCA) Groundwater Monitoring Report (K-H 2002). In the study modeling to simulate well drawdown characteristics of 140 monitoring wells that had been tested for their hydraulic properties was conducted. The study concluded that 46 wells could theoretically sustain pumping to supply a family of four with water based on the modeling. The other 94 wells (66 percent) did not meet these criteria. The well locations are mapped in the study. Based on a review of this map, wells in or close by the 5-acre areas (including the uranium plume area associated with the SEP discussed above) used in this dose assessment for the resident scenario did not meet the study water use criteria. Thus, it appears that an exposure pathway from sustained use of contaminated groundwater is unlikely.

While the groundwater exposure pathway is considered unlikely, the evaluation of the SEP plume related to impacts to surface water, discussed above, can also be used to evaluate dose rates from theoretical direct consumption of contaminated groundwater related to this plume. (Note that there are no wells located in the SEP plume area that met the 2001 well study yield criteria.) The calculated dose rates to the rural resident adult and child are 32 and 38 mrem/yr, respectively, and subtracting the natural uranium background component reduces the dose attributable to RFETS contaminants. Thus, uncertainty related to groundwater use does not change the conclusion that the 100 mrem/yr dose limit is met.

4.3 Excavation

The excavation mixing calculation is based on excavation from the surface to a 3.66 m (12 ft) depth. This depth is generally accepted as within the range of building basement excavation depths (CDPHE 1994). Excavation would result in soil mixing from the process of excavation and the spreading of the excavated materials on the surface. Therefore, this essentially presents a new surface soil concentration, resulting in a different surface soil EPC and dose.

The data set used to calculate the EPC includes the 5-acre area surface and subsurface soil and sediment data from the 0 to 2.44 m depth (0 inches to 8 ft), which is presented in Table A1.3 and Table A1.4 along with data from below 2.44 m to 3.66 m (8 ft to 12 ft).

The resulting summary statistics and EPC for each of the 5-acre areas is presented in Table A1.19.

A deterministic screening resident dose calculation was performed and all areas resulted in less than a 100 mrem/yr maximum dose, except for the resident child calculation at the historical West Ash Pits area. The deterministic resident child dose is 120 mrem/yr. The results for the resident adult and resident child are presented in Table A1.20 and Table A1.21, respectively. The uranium-238 contribution is approximately 97 mrem/yr. The majority of this dose is attributable to the fruit and vegetable ingestion pathway.

The deterministic point estimate parameters are generally considered to range from conservative to realistic estimates, which are reasonably representative of the exposure pathway components. Certain input parameters were developed based on site-specific information or on expanded reviews of scientific studies as part of the RSAL Task 3 Report effort. The deterministic method was employed for this dose assessment as the simplest screening method for the dose evaluation.

For the probabilistic method the RSAL Task 3 Report recommended that values between the 10^{th} and 5^{th} percentiles of the probabilistic distributions (that is, the 90^{th} and 95^{th} percentile calculated doses) were representative of the reasonable maximum exposed individual.

Table A1.7 includes the parameters evaluated probabilistically for the resident child scenario in the RSAL Task 3 Report. A RESRAD probabilistic calculation for the resident child for the historical West Ash Pits area was performed using the probabilistic input parameters listed in Table A1.22, which were developed and selected as described in the RSAL Task 3 Report. The 90^{th} and 95^{th} percentile results for the uranium isotopes are approximately 45 and 56 mrem/yr, respectively, and for plutonium/americium less than 1 mrem/yr, making the total well below 100 mrem/yr. This probabilistic result illustrates the degree of conservatism in the deterministic screening method used for the calculations for this evaluation. Based on the probabilistic results, the hypothetical scenario of excavation for a building foundation is not expected to result in a maximum dose rate above 100 mrem/yr.

5.0 AS LOW AS REASONABLY ACHIEVABLE CONSIDERATION

The dose rate limit in the CDPHE regulations was promulgated based upon the U.S. Nuclear Regulatory Commission (NRC) regulations at 10 Code of Federal Regulations (CFR) 20, Subpart E, known as the “decommissioning rule.” The pertinent CDPHE regulatory text is the same as that in the NRC regulation. The NRC has issued the Nuclear Material Safety and Safeguards Decommissioning Standard Review Plan, NUREG -1727, dated September 2000 (NRC 2000) to, among other things, provide guidance on complying with the ALARA provisions of the decommissioning rule. CDPHE has not issued guidance on this topic.

NUREG -1727 Appendix D discusses the as low as reasonably achievable (ALARA) analysis required to demonstrate compliance with the rule. Section 1.0 presents a simplified method that considers whether a remediation action will be cost-effective using generalized estimates of the remedial action: "if the benefits are less than the costs, the levels of residual activity are already ALARA without taking remediation action."

Appendix D Section 1.5 also provides,

> *In certain circumstances, the results of an ALARA analysis are known on a generic basis and an analysis is not necessary. For residual radioactivity in soil at sites that will have unrestricted release, generic analysis …show that shipping soil to a low level waste disposal facility generally does not have to be evaluated for unrestricted release, largely because of the high costs of waste disposal.*

Because the dose rate limits are met, and soil removal is the only feasible alternative to reduce contamination levels further, no additional ALARA analysis is necessary.

6.0 CONCLUSION

The calculated dose rates show that the 25 mrem/yr limit is met for the WRW for the designated land use for RFETS, a wildlife refuge. In addition, if the Refuge land use is not maintained, the 100 mrem/yr limit is also met for the rural resident exposure scenario. Possible migration of contaminated groundwater to surface water, the assumption that sustained use of groundwater for drinking water is unlikely, and possible excavation for a residence basement were evaluated as uncertainties that could impact the dose rates. The uncertainty evaluation supports compliance with the dose rate limits.

7.0 REFERENCES

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Table A1.1
Summary Statistics for Surface Soil/Sediment - Exposure Units

Table A1.2
Summary Statistics for Subsurface Soil/Sediment - Exposure Units

Table A1.3
Summary Statistics for Surface Soil/Sediment - 5 Acre Areas

Table A1.4
Summary Statistics for Subsurface Soil/Sediment - 5 Acre Areas

Table A1.5
RESRAD Parameters - WRW Exposure Scenario

Table A1.6
RESRAD Parameters - Adult Resident Exposure Scenario

Table A1.7
RESRAD Parameters - Child Resident Exposure Scenario

Table A1.8
Summary Statistics for Surface Water - Exposure Units

Table A1.9
Summary Statistics for Surface Water - Vicinity of 5-Acre Areas

Table A1.10
RESRAD Radiation Dose - WRW

Table A1.11
RESRAD Radiation Dose - Adult Resident

Table A1.12
RESRAD Radiation Dose - Child Resident

Table A1.13
Surface Water Dose - WRW

Table A1.14
Surface Water Dose - Resident Adult

Table A1.15
Surface Water Dose - Resident Child

Table A1.16
Dose Assessment Summary - Total Radiation Dose for WRW

Table A1.17
Dose Assessment Summary - Total Radiation Dose for Resident Adult and Resident Child

Table A1.18
Uncertainty Evaluation - Summary Statistics and Resident Dose for Groundwater data Post-1999 - SEP Plume Area

Table A1.19
Uncertainty Evaluation - Summary Statistics for Soil/Sediment - Surface to 12 Ft Below Surface in 5-Acre Areas

Table A1.20
Uncertainty Evaluation - RESRAD Radiation Dose - Adult Resident Excavation for Soil/Sediment in 5-Acre Areas

Table A1.21
Uncertainty Evaluation - RESRAD Radiation Dose - Child Resident Excavation for Soil/Sediment in 5-Acre Areas

Table A1.22
Uncertainty Evaluation - RESRAD Probabilistic Parameters and West Ash Pits Area Dose Rate for Child Resident

Figure A1.1
Rocky Flats Environmental Technology Site Exposure Units

Figure A1.2
Five Acre Areas Selected For Soil/Sediment Analysis

Figure A1.3
Former Building 776 and Historical Solar Evaporation Ponds Five Acre Sites Selected For Soil/Sediment Analysis

Figure A1.4
Historical East Trenches Five Acre Site Selected For Soil/Sediment Analysis

Figure A1.5
Historical Ash Pits Five Acre Site Selected For Soil/Sediment Analysis

Figure A1.6
Historical Solar Evaporation Ponds Uranium Groundwater Plume Area of Interest