Determination of Site-Specific Derived Concentration Guideline Levels

Fort Mims Site
Maryland Heights, Missouri

U.S. Nuclear Regulatory Commission
Radioactive Materials License No. 20-16276-01

Prepared for:

Sigma-Aldrich Manufacturing, LLC
PO Box 14508
St. Louis, MO 63178

Prepared by:

DDES, LLC
345 North Ave, 2nd Floor

Wakefield, MA 01880

August 16, 2017

Table of Contents

1.0 INTRODUCTION

The Fort Mims Site (FMS) is an open land site in Maryland Heights, Missouri. This three (3) acre parcel of land was once used by Sigma-Aldrich for the manufacture of radiolabeled chemical compounds. All structures and utilities were removed from the site in 2010. Sigma-Aldrich Manufacturing, LLC currently holds Nuclear Regulatory (NRC) License No. 24-16273-01 which allows for the possession, transfer and disposal of source material from decommissioning operations.

This is a technical basis document for determining site-specific Derived Concentration Guideline Levels (DCGLs) to comply with the requirements of the License Termination Rule (LTR), Subpart E of Title 10 of the Code of Federal Regulations (CFR) Part 20.1402 "Radiological Criteria for Unrestricted Use."

Radioactive materials historically used at the Fort Mims facility consisted primarily of tritium (^{3}H) and carbon (^{14}C). RESRAD Version 7.2 site specific dose modeling was used to calculate the DCGLs for ^{3}H and ^{14}C in soils. These methods ensure technically defensible data is generated to aid in determining whether the FMS meets the release criteria for unrestricted use specified in 10 CFR 20 Subpart E based on a 25 mrem per year limit for Total Effective Dose Equivalent (TEDE) for potential receptors.

RESRAD was used to calculate the potential TEDE for the likely future use of the property. Two potential use scenarios were considered for the FMS. The most likely occupancy scenario is the property continues to be used as an industrial site since the property is located in a well-developed industrial park. A less likely use scenario is that condominium units could be built sometime in the next 1,000 years which would be occupied by a suburban resident. Both use scenarios were assessed in this technical basis document and the more conservative was selected to calculate the site-specific DCGLs. The site-specific DCGLs were determined to be 401 pCi/g and 773 pCi/g for ^{14}C and ^{3}H respectively for the suburban resident scenario.

2.0 FMS SITE-SPECIFIC RESRAD MODEL

RESRAD Version 7.2 was used to predict the average annual dose to site occupants from residual radioactivity from present time to 1,000 years into the future. This section discusses the site location and physical dimensions, surrounding area, surface and subsurface soil characteristics, hydrology, climate, and zoning. Site-specific parameters were used where indicated to make the dose modeling for potential receptors as accurate as possible.

2.1 Site and Surrounding Area

The total area of the site is 12,000 m^2 and located at 11542 Fort Mims Drive, Maryland Heights, Missouri. The immediate surrounding area is zoned industrial and commercial. The nearest residential area is approximately 800 meters due south. A storm water drainage pond lies north of the site across Lakeside Crossing Court.

2.2 Soil Contamination

The areas to the south and west of the former building footprint have been identified as having the highest concentrations of contamination present. A total of three hundred thirty-four (334) discrete soil samples have been obtained from the four (4) meters of soils with the majority of samples coming from the first six (6) inches (0.15m) of soil. Contamination in these areas range from non-detectable to 978 pCi/g for ^{14}C and from 0.42 to 136 pCi/g for ^{3}H.

The old septic system was removed after the building was demolished but the exact location of the leachate field could not be determined. It was not found on any site drawing or plans that were available during the preparation of this document. However, prior to connecting to the municipal sewer system in 1981, the septic system served all sinks onsite including laboratories.

Since the facility operated as a custom compound synthesis laboratory, any number of compounds could have been labeled with ^{14}C and ^{3}H. The molecular composition of the labeled compound would then drive solubility and mobility of the radioactive material in environmental media.

A 4,200 m^2 area from the surface to 3 meters deep have been designated as the Contaminated Zone for dose modeling purposes. It is important to note that the majority of soils contamination at the FMS is in the upper 6 inches of soil. Of the 4,200 m^2 of contaminated soils only an area of 800 m^2 has contamination below 6 inches in depth. We have added a substantial level of conservancy by designating this entire depth interval as the Contamination Zone in the RESRAD dose model.

2.3 Soil Characteristics

The Web Soil Survey for the subject property, prepared by the United States Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS) was reviewed to further assess soils in the area. The site has been mapped with two primary soil types: Urban Land-Harvester Complex, and Urban Land Upland. The soil parent material is a

loess. The soil profile is generally comprised of silt loam, underlain by silty clay loam and clay loam. Natural drainage class was defined as: Moderately well drained.

2.4 Geology

According to the Geologic Map of Missouri, the site is underlain by stratified sequences of shale and limestone of the DesMoinesian Series of the Pennsylvanian System in the Paleozoic Era.

The Missouri Department of Natural Resources geologic map for the area indicates that the site is located near the boundary between the Pennsylvanian age Cherokee Group, which is comprised mainly of shale, siltstone, coal, and sandstone and the Mississippian age St. Genevieve limestone. A historic water well log reported near the site indicates limestone bedrock is present. Based on site boring logs, surficial soils on top of bedrock are mostly silty clay (CL) and clayey silt (ML) with soil thickness ranging from approximately 33 feet to 50 feet.

Available documentation indicates an aquifer suitable for drinking and irrigation is at least 47 meters below the ground surface. The saturated zone is 7 meters below ground surface. This perched water zone has a slow recharge rate and flows from northeast to the southwest. The upper 3 meters of soils have been designated as the Contaminated Zone.

2.5 Hydrology

According to the United Stated Geological Survey (USGS) topographic map and site observations, surface water generally flows toward the west and an unnamed tributary to Fee Fee Creek. Fee Fee Creek flows into the Missouri River approximately four miles to the northwest of the site.

Groundwater elevation data collected from shallow monitoring wells installed at the site indicates that the shallow groundwater flow direction is mainly towards the west. Saturation in soil on the site property occurs at depths generally ranging from 15-20 feet below ground surface. The depth to groundwater is less than ten feet below ground surface at off-site properties to the west of the site.

Water wells in this area are required by Missouri state regulations to include approximately 80 feet of surface casing. Groundwater shallower than approximately 80 feet cannot be used for domestic purposes.

Sigma retained Philotechnics Ltd. of Oak Ridge, Tennessee to assess site specific soil conditions to support the selection of site specific RESRAD parameters in 2012. The parameters detailed in Section 2.4 of the “Final RESRAD Modeling In Support of Release for Unrestricted Use” Revision 1 dated April 2012 (ML12095A221) were used as follows in Table 2-1:

Table 2-1
Site Specific Parameters

Soil Type	Density	Total Porosity (Pt)	Effective Porosity	Field Capacity	Hydraulic Conductivity (ksat)	b Parameter
Contaminated Zone	1.75	0.55	0.18	0.4	3.1	10.4
Unsaturated Zone	1.75	0.55	0.18	0.4	3.1	10.4
Saturated Zone	3.7	0.5	0.36	0.2	315	10.4

2.6 Climate

The average annual temperature and rainfall in the area are 57.0 degrees Fahrenheit and 40.92 inches, respectively. The prevailing winds are generally from the south and southeast in the spring, south or northwest in the summer, the south or northwest in the fall, and the northwest in the winter.[1]

Average wind speed is 4.8 $m\text{-}s^{-1}$ (National Oceanic and Atmospheric Administration (http://www.ncdc.noaa.gov/oa/climate/online/ccd/avgwind.html) Average annual precipitation is 1 m (National Oceanic and Atmospheric Administration (http://www.crh.noaa.gov/lsx/climate/COU/annualrainfall.php).

2.7 Occupancy Scenario and Exposure Pathways

RESRAD provides the user with a number of editable occupancy scenarios. For the FMS, the Industrial Worker and Suburban Resident scenarios were selected for evaluation. While the Industrial Worker is the most plausible future use scenario, the Suburban Resident could be possible in the total period of 1,000 years evaluated. All exposure pathways associated with working on the property, including commercial business, are considered. Pathways to be Considered for Suburban Resident and Industrial Worker are detailed in Table 2-2 below.

Table 2-2

Exposure Pathways

Pathway	Suburban Resident	Industrial Worker
External gamma exposure	Yes	Yes
Inhalation of dust	Yes	Yes
Radon Inhalation	No	No
Ingestion of plant foods	Yes	No
Ingestion of meat	No	No
Ingestion of milk	No	No
Ingestion of fish	No	No

[1] http://www.windfinder.com/windstats/windstatistic_st_louis_lambert_airport.htm (July 2009 - July 2013).

Ingestion of soil	Yes	Yes
Ingestion of water	Yes	Yes*

*While the RESRAD default is OFF, this pathway is turned ON for this scenario, assuming water is consumed from an onsite well.

Table 2-3 presents a comparison of Key Default Parameters Used in the Suburban Resident and Industrial Worker scenarios.

Table 2-3

Key Default RESRAD Parameters

RESRAD Parameter		Industrial Worker	Suburban Resident	Unit
Exposure duration		25	30	yr
Inhalation rate		11,400	8400	m^3/yr
Fraction of time indoors		0.17	0.50	-
Fraction of time outdoors		0.06	0.25	-
Contaminated Fractions of	Plant food	-	-	-
	Milk	-	-	-
	Meat	-	-	-
Aquatic food		-	-	-
Soil ingestion		36.5	36.5	g/yr
Drinking water intake		510*	510*	L/yr

*EPA guidelines assume drinking water intake of 1.4 L/day

2.8 Site-Specific Parameters

The Table 2-4 presents the parameters that were changed from the RESRAD default values and the basis for the change.

Table 2-4
Site-Specific RESRAD Parameters

RESRAD Parameter	Default Value	Suburban Resident Value	Industrial Worker Value	Reason
Area of Contaminated Zone, (m^2)	10,000	4,200	4,200	Size based on soil sampling data
Thickness of Contaminated Zone, (m)	2	3	3	Depth based on soil sampling data
Length Parallel to the Aquifer Flow, (m)	60	100	100	Site geometry and groundwater elevation
Contaminated Zone Total Porosity	0.4	0.42	0.42	Licensed geologist*
Contaminated zone hydraulic conductivity, (m/yr)	10	5.0	5.0	Licensed geologist*
Contaminated Zone b Parameter	5.3	10.4	10.4	RESRAD User's Manual based on soil type

Average annual wind speed, (m/s)	2.0	4.3	4.3	NOAA published data
Density of Saturated Zone, (g/cm^3)	1.5	3.7	3.7	Licensed geologist*
Unsaturated zone thickness, m	4.2	4.0	4.0	Actual site data
Saturated zone total porosity	0.4	0.5	0.5	Licensed geologist*
Saturated zone effective porosity	0.2	0.36	0.36	Licensed geologist*
RESRAD Parameter	**Default Value**	**Suburban Resident Value**	**Industrial Worker Value**	**Reason**
Saturated zone hydraulic Conductivity, (m/yr)	100	315	315	Licensed geologist*
Unsaturated Zone Thickness, (m)	4	9	9	From onsite monitoring well completion logs
Unsaturated Zone Soil Density, (g/cm^3)	1.5	1.75	1.75	Licensed geologist*
Distribution Coefficient for ^{14}C	0	0.8	0.8	Site specific leachate sampling study
Inhalation Rate (m^3/yr)	8,400	8,400	11,400	RESRAD User's Manual
Exposure Duration, (yr)	30	30	25	RESRAD User's Manual
Fraction of Time Spent Indoors (onsite)	0.50	0.50	0.17	RESRAD User's Manual
Fraction of time spent outdoors (onsite)	0.25	0.25	0.06	RESRAD User's Manual

*Parameters obtained from "Final RESRAD Modeling In Support of Release for Unrestricted Use" Revision 1 dated April 2012 (ML12095A221).

2.9 Partition Coefficient Determination

The partition coefficient (Kd) has a significant effect on the estimated dose to a potential receptor population. We believe applying the default value for ^{3}H for the site is appropriate. Selecting the Partition coefficient value for ^{14}C is more problematic due to the variety of compounds that were labeled at the site. The molecular structure and properties of these compounds can affect the solubility of ^{14}C in soils. This could make ^{14}C contaminants more mobile when in contact with groundwater. We also recognize that the solubility of these contaminants reduces over time as groundwater infiltrates through the soils. Given these variables, DDES assembled a site-specific leachability study to assess the solubility of ^{14}C to more accurately estimate the Partition coefficient for the site.

We selected four (4) locations where the highest ^{14}C concentrations in the upper two (2) meters of soil were found during previous soils sampling phases. Samples were obtained from two (2) feet North, South, East, and West of each location. Two (2) interval composite samples were obtained from 0.5 to 1 meter and from 1.5 to 2 meters from each sample location. The soil samples were sent to Test America Laboratory in Earth City,

Missouri for ^{14}C analysis.

An aliquot from each sample was analyzed to determine the ^{14}C content in soil. A separate sample aliquot was analyzed to determine the amount of ^{14}C in soil that was soluble in water. Geotechnology Inc. in St. Louis Missouri was tasked with interpretation of the data and estimating the Partition coefficient for the Fort Mims Site. Their technical memorandum "Carbon 14 Partition Coefficient, Fort Mims Drive, Maryland Heights, MO" dated February 21, 2017 is presented as Appendix A.

Analysis of this data indicated that leachable ^{14}C was detectable in a number of soil samples. Further, the site data indicates that reasonable site specific partition coefficient values could range from approximately 10 to >100 in soils at the Fort Mims Site. Based on this data we propose to select a conservative default Partition coefficient value of 0.8. This value is more than an order of magnitude below the lowest estimated partition coefficient of 10 based on the sampling results. We believe this Partition coefficient value aligns with the As-Low-As-Reasonably-Achievable (ALARA) principle and is protective of potential future receptors. We propose to adopt the value of 0.8 for use in site-specific RESRAD modeling to more accurately calculate site-specific DCGLs for ^{14}C at the Fort Mims Site.

2.10 DCGL Dose Calculations

The RESRAD computer code has been used to perform pathway analyses for land areas at the FMS that have been impacted by the former custom labeling operations. RESRAD is a computer code developed by ANL, and recognized by the NRC, to calculate site-specific residual radioactive material guideline values as well as radiation dose and excess lifetime cancer risk to a theoretical, critically exposed on-site occupant. This section serves as the technical basis for determination of the Site's residual radioactive material guideline levels.

Dose limits are typically stated as TEDE, while risk is usually stated in terms of morbidity (probability of cancer incidence) or mortality (probability of cancer death). Whether stated in terms of dose or risk, such release limits generally cannot be measured directly. As a consequence, pathway analyses were performed to translate dose and/or risk into equivalent environmental concentrations. These environmental concentrations are called DCGLs. The DCGLs have been analytically determined by evaluating Site industrial/commercial and suburban resident future use scenarios wherein the exposure pathways are direct radiation exposure and ingestion/inhalation of radioactive materials.

The DCGL values are radionuclide specific; the numerical value of each area-specific radionuclide concentration is defined in units known as picocuries/gram (pCi/g) homogeneously distributed in the contaminated zone, and is equivalent to a TEDE of 25 mrem/year for the above-referenced exposure pathways calculations. Multiple radionuclide guideline values are desirable when mixtures of radioactive material contribute to changes in the relative levels of principal radionuclides, i.e., when the ratios of the ^{14}C and ^{3}H isotopes are variable, as is the case at this Site.

Sample results collected on Site and analyzed for the isotopes ^{14}C and ^{3}H were compared to the DCGL release criteria using the Sum Fraction Unity Rule explained further below. The Unity Rule is satisfied (is less than the release criterion TEDE) when radionuclide mixtures yield a combined fractional concentration limit that is less than or equal to one.

The following isotope specific DCGL values for ^{14}C and ^{3}H have been determined as the Site soil guideline values based on RESRAD composite site exposure pathway calculations and presented in table 2-5: NUREG 1757, "Consolidated NMSS Decommissioning Guidance," contains default Screening Values, based on 25 mrem/year. Site-specific DCGLs were calculated using the above stated parameters. The DCGLs were calculated for dose in mrem/yr to a potential receptor from 1 pCi/g in the Contaminated Layer of soil for each isotope. Each value was then scaled to calculate the concentration in soils required to equal 25 mrem/yr. Table 2-5 presents the site-specific DCGLs for each exposure scenario at the FMS. The supporting RESRAD data sheets have been provided in Appendix B.

Table 2-5
Site-Specific DCGLs
Based on 25 mrem/year

Isotope	Suburban Resident	Industrial Worker
^{14}C	401 pCi/g	401 pCi/g
^{3}H	722 pCi/g	723 pCi/g

The values for both suburban resident and industrial worker are almost identical even though the fraction of time spent onsite is substantially different. At the request of the NRC, the drinking water pathways for both exposure scenarios have been made active. Over 99% of the calculated potential dose to receptors is due to the ingestion of contaminated groundwater under this RESRAD modeling. It is highly unlikely that drinking water would be used due to poor water qualify and low production rates from this upper aquifer. The FMS will use the most conservative DCGLs from the suburban resident scenario for decommissioning the FMS.

2.10.1 Sample Calculation for DCGL Sum Fraction Unity Rule

As discussed above, each of the individual DCGL soil criteria equate to 25 mrem/year and are evaluated by the sum-fraction unity rule. For this RESRAD model, the initial soil concentrations were established at 1/2 of the DCGL:

$$\frac{200.5\ \mathrm{pCi/g_{14C}}}{401\ \mathrm{pCi/g_{14C}}} + \frac{361\ \mathrm{pCi/g_{3H}}}{722\ \mathrm{pCi/g_{3H}}} = 1.0\ (25\ \mathrm{mrem/year})$$

This design model implies that the entire contaminated zone (0-3 m) is uniformly contaminated at the above soil concentrations. This is a highly conservative assumption

for the current Site condition; actual averaged soil concentrations in the (0-3 m) contaminated layer are lower than the design model by an average factor of 10.

Soil sample radioactivity concentrations will be evaluated against the respective DCGL values as follows:

Consider soil sample with concentration ^{14}C = 100 pCi/g and ^{3}H = 50 pCi/g, then,

$$\frac{100\ \mathrm{pCi/g}_{14C}}{401\mathrm{pCi/g}_{14\mathrm{C}}} + \frac{50\ \mathrm{pCi/g}_{3\mathrm{H}}}{722\ \mathrm{pCi/g}_{3\mathrm{H}}} = 0.32$$

0.32 is less than 1.00 thus soil is acceptable and remediation is not required. This is known as the Sum Fraction Unity Rule.

2.10.2 Summary of Dose and Excess Cancer Risk for Design Model

Historically, radiation exposure and cleanup levels have been expressed in units unique to radiation, e.g., milli-rem (mrem) or pCi/g. NRC's 25 mrem/year standard establishes that cleanup of radioactivity is governed by a risk range that represents an excess upper bound lifetime cancer risk to an individual of between 10^{-4} to 10^{-6}. The upper boundary of the risk range is not a discrete line at 2.5 x 10^{-4} and a specific site risk estimate around 10^{-4} can be acceptable if based on reasonable risk management decisions. The dose criteria for this risk design model of 25 mrem/year, consistent with the NRC regulatory standard, equates to approximately 5 x 10^{-4} excess lifetime cancer risk.

3.0 SENSITIVITY AND UNCERTAINITY ANALYSES

The RESRAD model depends on the setting of parameters that could significantly alter the projected dose to a future or current occupant of the site. The site contaminants are both low energy beta emitters, so external radiation exposure is negligible. Because no food is grown on site, internal dose for contaminated foodstuffs were not considered. The largest variation in individual dose prediction is dependent on whether or not contaminated water is ingested from an onsite well.

Sensitivity analyses for the site were run previously in the "Final RESRAD Modeling In Support of Release for Unrestricted Use" Revision 1 dated April 2012 (ML12095A221). Sensitivity analyses indicated the parameters having the most influence on potential dose to future occupants of the property are the Distribution Coefficient for ^{14}C in the Contaminated Zone, and Thickness of the Contaminated Zone.

Appendix A - Carbon 14 Partition Coefficient, Fort Mims Drive, Maryland Heights, MO

Appendix B – Site Specific RESRAD DCGLs Modeling