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LICENSE NUMBER: 24-16273-01

LICENSEE: Sigma-Aldrich Company

SUBJECT: NRC SAFETY EVALUATION REPORT OF REVISED DECOMMISSIONING PLAN AND LICENSE TERMATION REQEUST FOR THE SIGMA-ALDRICH FORT MIMS SITE

1. BACKGROUND

The Sigma-Aldrich Company's (Sigma) Fort Mims Site is located at 11542 Fort Mims Drive, Maryland Heights, Missouri in a commercial/industrial park (Agencywide Document Access and Management System [ADAMS] Accession No. ML091330309). The site consists of a three-acre parcel of land previously used for the radiolabeling of chemicals with carbon-14 (C-14) and tritium (H-3). By letter dated May 12, 2009, the NRC approved Sigma's decommissioning plan by License Amendment (ADAMS Accession No. ML091330309). The decommissioning plan states that the licensee will rely on the screening values in Appendix H of NRC's "Consolidated Decommissioning Guidance: Characterization, Survey, and Determination of Radiological Criteria" (NUREG-1757), Vol. 2, Rev.1 to demonstrate that the Fort Mims Site meets the release criteria for unrestricted use specified in § 20.1402 of Title 10 of the *Code of Federal Regulations* (10 CFR). Commitments in the decommissioning plan included: (1) that all residual activity be remediated to levels below the approved screening values[1] and (2) that a groundwater monitoring plan would be submitted if soil contamination exceeds the screening values.

Soil sampling and analysis was conducted in five phases (ADAMS Accession No. ML20120A544) and demonstrated that residual activity at Fort Mims Facility exceeded the approved screening values. On October 21, 2010 (ADAMS Accession No. ML103010487), the NRC staff discussed with the licensee that the site was approved for screening values and that surface and subsurface contamination exceeded those values. Sigma discussed that they would amend their decommissioning plan to allow for site-specific Derived Concentration Guideline Levels (DCGLs).

During a public meeting on August 9, 2013 (ADAMS Accession No. ML13280A564), NRC staff discussed that groundwater monitoring and/or additional soil characterization was needed to demonstrate that the groundwater had not been impacted because of contamination that had been observed at all sampled depths.

By letters dated August 22, 2019, as supplemented on October 19, 2020 and April 27, 2020, an application was submitted to amend Sigma-Aldrich's decommissioning plan and terminate NRC Materials License No. 24-16273-01. In its revised decommissioning plan (ADAMS Accession No. ML19273A160), the licensee requested the option to perform direct dose assessment of residual radioactivity, in addition to using DCGLs, to demonstrate compliance with the requirements of the License Termination Rule (LTR), Subpart E of 10 CFR 20.1402 at the Fort Mims Site in Maryland Heights, Missouri.

[1] Table H.2 in NUREG-1757, Vol 2, Rev. 1 lists the screening values for H-3 and C-14 as 110 pCi/g and 12 pCi/g, respectively.

The requirements of 10 CFR 20.1402 state that a site will be considered acceptable for unrestricted use if the residual radioactivity that is distinguishable from background radiation results in a total effective dose equivalent (TEDE) to an average member of the critical group that does not exceed 25 mrem/yr[2], including that from groundwater sources of drinking water, and that the residual radioactivity has been reduced to levels that are As Low As Reasonably Achievable (ALARA).

Section 2.1 of NUREG-1757, Vol. 2, Rev. 1 states that the DCGL approach allows a licensee to calculate, a priori, a concentration limit (i.e., DCGL) for each radionuclide based on the dose criteria of the LTR and allows a licensee to then demonstrate that the residual radionuclide concentrations are below the DCGLs. Section 2.7 of NUREG-1757, Vol. 2, Rev. 1 provides a sum-of-fractions approach for sites with multiple radionuclides or sources, which is typically used to ensure that the dose from all radionuclides and all sources complies with the 10 CFR 20, Subpart E criteria.

In Sigma's technical basis document dated August 23, 2017 (ADAMS Accession No. ML17240A367), the licensee used RESRAD to calculate site-specific DCGLs for contaminated soils corresponding to the 25 mrem/yr criteria. NRC guidance in NUREG-1757, Vol. 2, Rev. 1 allows for the use of either the DCGL or dose assessment approach to demonstrate compliance with 10 CFR 20.1402.

2. SITE DESCRIPTION

The Fort Mims Site is located approximately 13 miles northwest of the city of St. Louis, Missouri. The 3-acre parcel of land is located within the Lakeside Crossing Industrial Park, which is zoned for industrial and commercial use (ADAMS Accession No. ML19273A160). The former building facility was constructed in the late 1960s and expanded in 1981. The effluent discharge points were an exhaust stack and a septic tank, which was located beneath the former facility. The use of the septic system ceased in 1981. The former building facility including the structures, foundation, and septic system were decontaminated, decommissioned, and removed from the site in 2010. In 2014, the asphalt parking lot was removed.

The soils at the Fort Mims Site range from approximately 10 to 15 m (33 to 50 ft) in thickness, are comprised of silty clay and clayey silt based on soil boring logs collected onsite and underlain by limestone bedrock. Surface runoff at the site flows predominantly to the south and is collected in municipal storm drains (ADAMS Accession No. ML091330309). Approximately 80 feet to the north of the site, an unnamed tributary flows into Fee Fee Creek. At a point approximately 5 miles from the Fort Mims Site, Fee Fee Creek flows into the Missouri River. The Fort Mims Site overlies the national Ozark Plateaus Aquifer system and the local St. Louis Limestone Aquifer. The groundwater elevation at the site ranges from 5 to 6 m (15 to 20 feet) below ground surface based on groundwater monitoring data. The Maryland Heights public water supply is drawn from the Missouri and Merrimac Rivers.

[2] 1 To convert from mrem/yr to mSieverts/yr, divide the mrem/yr dose by 100

3. SURVEYS

The former Sigma Fort Mims Facility operated as a chemical radiolabeling facility from November 11, 1974 until September 30, 2008 (ADAMS Accession No. ML091330309). During that period, Sigma produced approximately 2,000 C-14-containing compounds (ADAMS Accession No. ML13280A564). As discussed in the Phase 4 Sampling and Analysis Plan dated February 26, 2015 (ADAMS Accession No. ML15147A565), the site operational history indicated that there are different potential sources of soils contamination onsite:

- Soil deposition from exhaust stack emissions to the west of the former building
- Deposition from exhaust stack emissions on the roof in which rain runoff drained to the south and southwest corner of the Fort Mims Building
- Septic disposal. which was in use until 1981. of contaminants under the foundation of the former building, (ADAMS Accession No. ML091330309)

The residual contamination at the Fort Mims Site consists of C-14- and H3-contaminated soils located primarily to the south and west of the former building (ADAMS Accession No. ML17240A365). Soil sampling was conducted over five sampling phases. The licensee increased the number of sample locations because of the ineffectiveness of gamma scan surveys to detect elevated areas between samples for C-14 and H-3 (ADAMS Accession No. ML110950616). The estimated number of sample locations for the statistical evaluation of survey units Fort Mims Facility (FMF) -28 and FMF-29 were increased from the Wilcoxon Rank Sum test from 14 to 50 based on the Hahn-Meeker approach from Visual Sample Plan. Sigma increased the number of samples to ensure that hot spots were not missed. A summary of the soil sampling results is provided in Table 1 below. The distribution of the C-14 and H-3 contamination at the Fort Mims Site is shown in Figure 1 through Figure 4 below.

Table 1. Fort Mims Site - Soil Sampling Results

Sampling Phase	Reference	Number of Soil Samples	Fort Mims Site Survey Unit	Soil Depth (m)	Average Soil Activity (pCi/g)		Maximum Soil Activity (pCi/g)	
					C-14	H-3	C-14	H-3
Phase I	ML103490427	100	FMF-28	0-0.15	13.0	8.6	42.5	28.2
			FMF-29		83.4	9.0	305	42.5
Phase II	ML103490427	59	FMF-29	0-2	64.9	2.4	1290	11.6
Phase III	ML103490427	54	FMF-29	0.15-2	33.0	2.4	483	7.4
Phase IV	ML16070A174 ML16070A180 ML16070A185 ML16070A187	24	FMF-30	0.15-2	20.5	6.2	51.4	11.4
Phase V	ML21095A120	8	SAP[1]	0-0.15	21.4	10.3	41.4	10.3
Total		245			65.0	9.2	1290	42.5

[1] Southern Abutting Property (SAP)

As discussed by Sigma, the septic tank for the former Fort Mims Facility was discovered upon removal of the concrete pad (ADAMS Accession No. ML103490427). Liquid samples were collected from the septic tank with C-14 concentrations ranging from 7,870 pCi/L to 20,000 pCi/L and H-3 concentrations ranging from 11,500 pCi/L to 16,600 pCi/L. The abandoned septic system was removed from the site in 2010 (ADAMS Accession No. ML19273A160).

In the Groundwater Sampling Results report dated May 2, 2018 (ADAMS Accession No. ML18155A219), Sigma provided the groundwater monitoring results for C-14 and H-3. The groundwater was collected from a series of four onsite and four downgradient offsite wells, as shown in Figure 5 below. The data were collected over six quarters for the onsite wells and four quarters for the offsite wells. The maximum observed concentrations for C-14 and H-3 were 647 and 13,500 pCi/L, respectively.

4. DOSE ASSESSMENT

Sigma assumed an industrial worker scenario with a less likely, but plausible, scenario being a suburban resident. Tables 2-2 and 2-3 of Sigma's technical basis document show the exposure pathways that were considered in the analysis. The ingestion of water pathway was included in this analysis at 1.4 L/day (0.37 gal/day). Sigma used RESRAD Version 7.2 to calculate site-specific $DCGL_W$ values, which are applicable to the average concentration over a survey unit, for C-14 and H-3 that correspond to a dose of 25 mrem/yr for the likely future use of the site.

4.1. $DCGL_W$ Values

Table 2-4 of the Sigma's technical basis document lists the RESRAD parameters that were changed from the RESRAD default values and the bases for the changes. Sigma used the RESRAD default partition coefficient (K_d) for H-3. However, Sigma used a site-specific leachability study of soil samples to estimate the K_d for C-14 (ADAMS Accession No. ML17240A365; ML17240A366) because of the variety of compounds that were produced at the site.

To estimate the K_d for C-14, Sigma collected soil samples from four locations containing elevated C-14 concentrations in the upper 2 m (6.6 ft) of soil. From each of these locations, Sigma obtained samples approximately 0.6 m (2 ft) to the north, south, east, and west. Two composite samples were obtained across the interval depths of 0.5 m (1.6 ft) to 1 m (3.3 ft) and from 1.5 m (4.9 ft) to 2 m (6.6 ft) from each sample location. An aliquot from each soil sample was analyzed to determine the C-14 content in each soil sample. A separate aliquot of soil was used to measure the amount of water-soluble C-14. For each of the 32 samples, 100 mL of deionized water was added to a 30 g aliquot of soil. After sitting for a minimum of 12 hours, the water was decanted from the soil mixture and analyzed for C-14. The data were then interpreted to estimate the K_d of C-14 at the Fort Mims Site, which ranged from 0.7 to 74.1 mL/g with an average value of 29.9 mL/g. Sigma assumed a C-14 K_d value of 0.8 mL/g for their RESRAD analysis.

$DCGL_W$ values were calculated in RESRAD for dose to a potential receptor from 1 pCi/g in the contaminated zone for C-14 and H-3. Each value was then scaled to calculate the concentration in soils required to equal 25 mrem/yr. Site-specific $DCGL_W$ values were determined to be 401 pCi/g and 723 pCi/g for C-14 and H-3, respectively, for an industrial worker. For a suburban resident, the $DCGL_W$ values for C-14 and H-3 were 401 pCi/g and 722 pCi/g. Ingestion of contaminated groundwater was attributed to greater than 99% of the dose.

4.2. $DCGL_{EMC}$ Values

By letter dated January 23, 2019 (ADAMS Accession No. ML19017A049), NRC staff requested additional information for several areas at the Fort Mims Site that exceeded the $DCGL_W$ values proposed in Sigma's technical basis document dated August 16, 2017 (ADAMS Accession No. ML17240A365). By letter dated March 25, 2019 (ADAMS Accession No. ML19108A258), Sigma provided a dose assessment from four areas at the Fort Mims Site with concentrations exceeding the $DCGL_W$ values, as shown below in Figure 1, Figure 2, Figure 3, and Figure 4, for sample points 29-045, 29-047, 29-049, and 29-061. That assessment indicated that the projected dose to an industrial worker from the individual areas of elevated concentration would not exceed 25 mrem/yr. Sigma's projected dose was derived almost entirely from the drinking water pathway.

4.3. Groundwater

By letter dated May 2, 2018 (ADAMS Accession No. ML18155A219), Sigma provided updated groundwater monitoring results from eight monitoring wells at the Fort Mims Site, as shown in Figure 5 below. Both C-14 and H-3 were detected in the groundwater with maximum observed concentrations of 647 pCi/L for C-14 and 13,500 pCi/L for H-3. In the Groundwater Sampling Results report (ADAMS Accession No. ML18155A219), Sigma concluded that the dose contribution from both the C-14 and H-3 groundwater contamination would not exceed 4 mrem/yr.

4.4. ALARA

By letter dated April 27, 2020 (ADAMS Accession No. ML20120A544), Sigma stated that the site meets the ALARA criterion based on: (1) the low levels of contamination on site, (2) that every reasonable effort was made to maintain exposures to radiation as far below the dose limits as is practical, and (3) that the excavation and removal of the contaminated soils would present a higher potential risk to workers and the public rather than leaving the contamination in place.

5. NRC REVIEW

5.1. Site Description

As discussed in Section 2 of this report, Sigma provided site characterization information on the Fort Mims Site. NRC staff reviewed the site description information and determined that the data were adequate to evaluate the dose to potential receptors.

5.2. Surveys

Soil sampling was conducted in five phases at the Fort Mims Site with results shown above in Table 1 and groundwater monitoring was conducted over six quarters for onsite wells and four quarters for offsite wells. NRC staff determined that the combination of site operational history and soil and groundwater surveys are adequate to assess dose to potential future receptors and that risk-significant hot spots were not missed based on the following lines of reasoning:

- Sigma increased the number of soil sample points from 14 to 50 due to the difficulty in detecting C-14 and H-3.

- The observed hot spots are consistent with site operational history. Hot spots were identified beneath downspouts from the former Fort Mims Facility where contaminant deposition from exhaust stack emissions ran off the roof into the soils. Also, a hot spot was observed beneath the former septic tank.

- Additional soil samples were collected for the K_d study that were located 1 m (3.3 ft) to the north, south, east, and west of four hot spots. All of the C-14 concentrations from this study, which occurred seven years after the soil sampling phase that indicated the presence of hot spots, were less than the hot spot concentrations. Accordingly, the assumed C-14 concentrations for the areas of elevated concentration are likely reasonable, if not conservative.

- Groundwater monitoring in the shallow water table beneath the Fort Mims Facility provides further confidence that hot spots were accounted for adequately.

5.3. Scenarios and Exposure Pathways

The licensee assumed an industrial worker scenario with a less likely, but plausible, suburban resident scenario. In NRC staff's Safety Evaluation Report (SER) approving Sigma's decommissioning plan (ADAMS Accession No. ML091330309), NRC staff discussed that residential use of the Fort Mims Site in the near future is unlikely due to local zoning restrictions. However, as discussed in Appendix I (Section I.3.3.2) of NUREG-1757 Volume 2 Revision1,

> *"land uses that are plausible, generally because similar land historically was used for the purpose, but are counter to the current trends or regional experience could be characterized as less likely but plausible (e.g., rural use of property currently in an urban setting). Implausible land uses are those that because of physical limitations could not occur (e.g., residential land use for an underwater plot of land)."*

In RESRAD, the default exposure pathways for both an industrial worker and a suburban resident do not include ingestion of groundwater from an onsite well (see Table 2.2 in RESRAD 6 User's Manual). It is assumed that municipal water is used for drinking and irrigation purposes. However, the inclusion of ingestion of groundwater pathway from an onsite well provides risk information. Although the dose from the ingestion of groundwater from an onsite well at the Fort Mims Site does not form the basis for whether a site meets the criteria for unrestricted release, that information can be used to help inform decisions. Sigma did not include the plant food pathway in their analysis for a suburban resident. In Table 2.3 of the RESRAD User Manual, 10% of the plant food is assumed to be contaminated from an onsite garden. NRC staff included this pathway in their analysis below. NRC staff also evaluated a hypothetical resident farmer scenario to provide additional risk information.

5.4. Dose Assessment

Sigma relied on a DCGL approach using a site-specific dose model. In calculating the DCGLs, Sigma used a combination of default RESRAD parameters and site-specific parameters based on site data, licensed professionals, and laboratory analyses. Sigma calculated $DCGL_W$ and $DCGL_{EMC}$ values in addition to separately evaluating dose due to existing groundwater contamination for a hypothetical industrial worker and suburban resident. However, Sigma did

not evaluate the overall dose from the Fort Mims Site from these areas of soil and groundwater contamination. Sigma's dose modeling approach conservatively included the groundwater pathway from an onsite well for the industrial worker and suburban resident scenarios. The groundwater pathway results provide risk information but does not form the basis for determination with respect to 10 CFR 20.1402. Sigma also assumed a conservative K_d value for C-14.

One of the most risk significant and uncertain parameters in Sigma's DCGL calculations is the K_d value for C-14. The K_d value significantly affects C-14 transport and attenuation and, therefore, dose. During a public meeting held on August 9, 2013 (ADAMS Accession No. ML13280A564), NRC staff discussed that additional information is needed to support the C-14 K_d value due to the range of C-14-containing compounds produced at the site results. That range of compounds results in uncertainty in the K_d value. To reduce that uncertainty, Sigma collected soil samples from the Fort Mims Site and conducted a laboratory analysis to estimate a site-specific K_d value for C-14.

As discussed in documents dated August 16, 2017, Sigma collected soil samples from multiple areas and at multiple depths (ADAMS Accession No. ML17240A365; ML17240A366). NRC staff determined that this approach provides additional confidence that the range, and therefore sorption characteristics, of C-14 compounds at the site has been captured. Sigma then conducted a laboratory analysis of those samples to evaluate the range of sorption characteristics. The results of Sigma's laboratory analysis indicated that the K_d of C-14 at the Fort Mims Site ranged from 0.7 to 74.1 mL/g with an average value of 29.9 mL/g. Sigma selected an average C-14 K_d value of 0.8 mL/g for their RESRAD analyses. Sigma's assumption of a relatively low K_d for the Fort Mims Site is conservative, because lower K_d values result in an increase in contaminant transport and dose. However, NRC staff determined that there is uncertainty in Sigma's estimated K_d value, because the laboratory analysis did not appear to follow a standardized test methodology for sorption (e.g., it is not clear that the desorption experiments reached steady stated conditions, which could result in an overestimate of the K_d value). To address the uncertainty in the laboratory results, the NRC staff calculated a site-specific C-14 K_d based on soil characterization data and historical information from the Fort Mims Site.

To predict contaminant migration in the environment, K_d values are often used. However, for the case of the Fort Mims Site, site-specific information can be used to estimate a site-specific K_d value. NRC staff estimated K_d values based on the observed depth of C-14 contamination at several locations, average soil properties for bulk density and porosity, time since placement of the contamination, and an average rate of infiltration. From those data, NRC staff calculated a range of K_d values of 1.3 to 9.3 mL/g. Additionally, Yim and Caron (2006[3]) reviewed K_d values for C-14 used throughout the nuclear power industry. A review of 27 literature references showed that the first quartile K_d value for C-14 was 1 mL/g. Based on Sigma's laboratory analysis, NRC staff's independent analysis, and a literature review of the nuclear power industry, NRC staff determined that Sigma's assumed K_d of 0.8 mg/L in the unsaturated zone is slightly conservative.

Sigma also assumed a K_d value of 0 mL/g for C-14 in the saturated zone. NRC staff expect similar K_d values for C-14 in the saturated as in unsaturated zone based on the surficial soil ranging from approximately 10 to 15 m (33 to 50 ft) below ground surface.

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[3] Yim, M. and F. Caron. *Life Cycle and Management of Carbon-14 from Nuclear Power Generation*. Progress in Nuclear Energy, Vol 48, Issue 1, January 2006.

Sigma's analyses also included two significant, non-conservative assumptions. First, Sigma did not combine the doses from the areas characterized by average concentrations, areas of elevated concentration, and existing groundwater contamination. Second, Sigma did not include the plant food pathway in their analysis for a suburban resident, as discussed above. In Table 2.3 of the RESRAD User Manual, 10% of the plant food is assumed to be contaminated from an onsite garden. To address these uncertainties, NRC staff conducted independent analyses. The following DCGL and groundwater dose-assessment discussions include the combination of projected doses for the assumed scenarios. The industrial worker and suburban resident scenarios are evaluated with and without the groundwater pathway. The suburban resident analysis includes the plant food pathway. A hypothetical resident farmer scenario was also evaluated for risk information. This scenario includes the groundwater pathway by default.

5.4.1. $DCGL_W$ Values

Using RESRAD, Sigma calculated $DCGL_W$ values for an industrial worker and a suburban resident for C-14 and H-3 contamination based on a TEDE of 25 mrem/yr. Sigma calculated $DCGL_W$ values of 401 pCi/g and 723 pCi/g for C-14 and H-3, respectively, for an industrial worker. For a suburban resident, the $DCGL_W$ values for C-14 and H-3 were 401 pCi/g and 722 pCi/g. Because Sigma did not include the plant pathway in the suburban resident scenario and the assumed ingestion of drinking water from an onsite well is the same for these two scenarios (i.e., 1.4 L/day), the calculated $DCGL_W$ values are similar.

NRC staff reran the RESRAD model, but with several revisions, including: an arithmetic average concentration of C-14 and H-3, as shown in Table 1 above; a C-14 K_d value of 1.0 mg/L in both the unsaturated and saturated zones, inclusion of the plant pathway for a suburban resident, evaluation of the industrial worker and suburban resident scenarios with and without ingestion of groundwater from an onsite well, and evaluation of a resident farmer scenario.

As shown in Table 2, for the most likely scenario of an industrial worker, the dose from the average soil concentration with or without the groundwater pathway is projected to be less than 1 mrem/yr. The dose from the average soil concentration to a less likely, but plausible, scenario of a suburban resident would be 3.8 mrem/yr due primarily to consumption of contaminated plants. The dose to a resident farmer would be approximately 23 mrem/yr due to primarily plant and meat consumption.

Although the average concentrations of C-14 and H-3 for the site meet the release criteria, there were several areas that exceeded the $DCGL_W$ values (see $DCGL_{EMC}$ section below) in addition to existing groundwater contamination (see Groundwater section below).

5.4.2. $DCGL_{EMC}$ Values

For Sigma's $DCGL_W$ calculations using RESRAD, the conceptual model assumption is that the contamination is uniformly distributed over the contaminated volume of soil. In their analysis, Sigma assumed that the contamination was spread homogenously across an area of 4200 m^2 (45,000 ft^2). However, soil survey results indicated that there are several isolated areas of elevated concentration. As discussed in Appendix G.2.1 of NUREG-1757, Vol. 2, Rev. 1, generic guidance has not yet been developed to demonstrate regulatory compliance with elevated measurement comparisons (EMCs) for subsurface contamination (i.e. contamination

greater than 15 cm in depth). To address NRC staff concerns regarding areas of elevated concentrations, including subsurface contamination (ADAMS Accession No. ML19017A049), Sigma provided a dose assessment from four areas at the Fort Mims Site with concentrations exceeding the $DCGL_W$ values (ADAMS Accession No. ML19108A258). Sigma's assessment indicated that doses from the individual areas of elevated concentrations would not exceed 25 mrem/yr.

As NRC staff discussed in Section I.2.3.2 of NUREG-1757, Vol. 2, Rev. 1, a licensee can assess the dose attributable to each limited area of elevated concentration that can then be combined with the dose from the surrounding area. As documented by report dated March 25, 2019 (ADAMS Accession No. ML19108A258), Sigma's projected doses indicate that the dose from each area of elevated concentration is less than 25 mrem/yr, but collectively the dose from all of the areas of elevated concentrations would exceed 25 mrem/yr. In that section of the NUREG, NRC staff also stated:

> The licensee may also have to consider the impact of multiple areas of elevated concentration within a single larger area. In general, modeling two small areas independently and combining the results of the two dose assessments should result in a higher dose than if the two areas were combined and modeled as a single area. The higher dose is unrealistic in that it assumes that the receptor location relative to each contaminated area is such that the dose is maximized from each contaminated area independently. For a more reasonable estimate of potential dose, these smaller areas may be combined into a single larger area if the concentrations within the smaller areas are comparable. If this is not the case, then the licensee may model each smaller area individually and modify the scenario and critical group assumptions for each area (e.g., time spent on each area) and combine the results.

To make the dose assessment more realistic, NRC staff evaluated the dose for a combined area of elevated concentration and an individual area of maximum concentration to account for the size of a realistic garden for a suburban resident. The combined area of elevated concentrations is 430 m^2 (4600 ft^2) and the maximum observed soil concentration at the Fort Mims Site was 1290 pCi/g for C-14 and 42.5 pCi/g for H-3. This area of elevated concentration was used to assess the dose to an industrial worker and resident farmer. This area was also used for the suburban resident with the exception of the area for the suburban garden. Because it is unrealistic to assume a suburban resident would plant a garden in all of the separate areas of elevated concentration, NRC staff assumed an area of 100 m^2 (1100 ft^2). This accounts for the area with the highest C-14 contamination.

As shown in Table 2, for an industrial worker, the dose from the areas of elevated concentration is projected to be 0.02 mrem/yr without the groundwater pathway. With the groundwater pathway, the projected dose is 9.5 mrem/yr. The dose to a suburban resident without the groundwater pathway from the areas of elevated concentration is projected to be 1.5 mrem/yr from plant consumption and 9.5 mrem/yr with the groundwater pathway. The dose to a resident farmer from the areas of elevated concentration is projected to be approximately 59.8 mrem/yr due to primarily plant and meat consumption.

During a public meeting held on August 9, 2013 (ADAMS Accession No. ML13280A564), NRC staff discussed that additional site characterization, including groundwater monitoring, may be necessary. A limitation of Sigma's site characterization prior to 2013 was that fast-moving C-14-containing compounds could have migrated through the soil column to the groundwater. After additional soil sampling indicated contamination at depth in the soils, Sigma collected groundwater samples and assessed the potential dose from ingestion.

5.4.3. Groundwater

The groundwater at the Fort Mims Site is shallow (e.g., approximately 4.6-6.1 m [15-20 ft] below ground surface) and the permeability of the soils is low because of the fine-grained sediment (e.g., silty clay and clayey silt). In addition, contamination at the site decreases with depth as shown in Figure 1 through Figure 4. Accordingly, most of the contamination appears to be in the top 1 m (3.3 ft) of soil. However, contamination that may have migrated below the sampling depth would likely be observed in the groundwater monitoring wells shown in Figure 5. These wells are located beneath and down gradient from the Fort Mims Site.

By letter dated May 2, 2018 (ADAMS Accession No. ML18155A219), Sigma provided updated groundwater monitoring results from eight monitoring wells at the Fort Mims Site, as shown in Figure 5 below. Both C-14 and H-3 were detected in the groundwater with maximum observed concentrations of 647 pCi/L for C-14 and 13,500 pCi/L for H-3. Contaminant concentrations at these wells have remained relatively steady since the well monitoring began in May of 2016.

NRC staff, in coordination with the Oak Ridge Institute for Science and Education, conducted confirmatory groundwater sampling for C-14 and H-3 (ADAMS Accession No. ML16195A308, ML16195A309). Those sampling results were consistent with Sigma's results, which are documented in their revised decommissioning plan (ADAMS Accession No. ML19273A160). NRC staff also conducted an independent analysis of the dose due to ingestion of the groundwater. Based on the groundwater ingestion dose conversion factor in RESRAD, assumed ingestion of 1.4 L/day of water, and the maximum observed concentrations of C-14 and H-3 of 647 pCi/L and 15,003 pCi/L, respectively, the total potential dose from groundwater ingestion would be approximately 1.9 mrem/yr.

The licensee's collection of both soil and groundwater samples across the site provides confidence the contamination at the Fort Mims Site has been adequately captured and that higher concentrations of contaminants were unlikely to have been missed.

5.4.4. Fort Mims Site Projected Dose

The projected doses for an industrial worker, suburban resident, and residential farmer at the Fort Mims Site from the average site contamination, areas of elevated concentration, and groundwater contamination are provided in Table 2 below. These scenarios include doses for a hypothetical industrial worker and suburban resident with and without the ingestion of groundwater from an onsite well. The resident farmer scenario includes ingestion of groundwater from an onsite well by default.

Table 2. Projected Dose Results for Various Scenarios

Scenario	From Average Soil Concentration		From Combined Area of Elevated Concentration		From Groundwater Contamination		Fort Mims Site Peak Dose (mrem/yr)	Time of Peak Dose (year)
	Peak Dose (mrem/yr)	Time of Peak Dose (year)	Peak Dose (mrem/yr)	Time of Peak Dose (year)	Peak Dose (mrem/yr)	Time of Peak Dose (year)		
Industrial Worker	0.006	0	0.02	0	N/A	N/A	0.02	0
Industrial Worker With Onsite Groundwater Ingestion	0.9	18.7	9.5	18.7	1.9	0	9.5	18.7
Suburban Resident	3.8	0	1.5	0	N/A	N/A	3.8	0
Suburban Resident With Onsite Groundwater Ingestion	3.8	0	9.5	18.7	1.9	0	9.5	18.7
Resident Farmer	22.6	0	59.8	0	1.9	0	61.7	0

For an industrial worker without ingestion of groundwater from an onsite well, the projected dose from the Fort Mims Site is approximately 0.02 mrem/yr. NRC staff determined that this is the most likely scenario, based on the site currently being zoned for industrial and commercial use, current land use trends in the vicinity of the site, and the presence of a municipal water supply. If an industrial worker ingests groundwater from an on-site well, then the dose would still meet the release criteria with a dose of approximately 9.5 mrem/yr. Accordingly, NRC staff determined that site meets the criteria for unrestricted release in 10 CFR 20.1402.

Although an industrial worker scenario is the reasonably foreseeable scenario, additional scenarios may be less likely but still plausible. These scenarios provide risk information to inform decisions. Sigma also considered a suburban resident as a less likely but plausible scenario. For this scenario, the projected dose would be 3.8 mrem/yr. One of the differences between an industrial worker and a suburban resident would be the potential consumption of plants from an on-site garden. Typically, a municipal water supply is assumed for a suburban resident, which is consistent with the Fort Mims Site as a municipal water supply is available. However, if a suburban resident did ingest groundwater from an onsite well, then the projected dose would also be approximately 9.5 mrem/yr.

An additional scenario, which is very unlikely, is the resident farmer scenario. This scenario is often a bounding scenario and considers additional pathways (e.g., milk and meat, in addition to plants). The projected dose to a resident farmer would be approximately 62 mrem/yr. The projected peak dose occurs initially in the modeling period (i.e., in the very near term) while zoning restrictions are likely to be maintained. After 10 years, the dose to a resident farmer from plants, meat, and milk consumption is projected to be less than 1 mrem/yr, which provides additional confidence that projected doses to a resident farmer have a very low probability of occurrence.

Lastly, NRC staff compared C-14 soil concentrations collected at two different sample dates (i.e., November 4-5, 2009 [ADAMS Accession No. ML103490427] and October 25, 2016 [ADAMS Accession No. ML17240A366]) from similar locations. For the K_d study, the licensee collected soil samples that were 1 m (3 ft) to the north, south, east, and west of four hot spots at 1 m (3.3 ft) and 2 m (6.6 ft) depth. A comparison of the measured K_d values showed that after seven years, all of the C-14 concentrations were significantly lower. On average, there was a 50-fold reduction in concentration of C-14 with a range of a 3-fold to 150-fold reduction. As the plant pathway is the primary dose contributor for the resident farmer and near-surface C-14 contamination drives the plant dose, migration of the C-14 through the soil column reduces the peak dose. This is consistent with what is projected in RESRAD with the dose to a resident farmer decreasing rapidly. Accordingly, the projected peak dose for a resident farmer in Table 2 would likely be on the order of 1 mrem/yr based on the decreasing C-14 concentrations in the near surface.

5.5. ALARA

The unrestricted use criterion of 10 CFR 20.1402 also requires that residual radioactivity be reduced to levels that are ALARA. In Section 6.1 of NUREG-1757, Vol. 2, Rev. 1, NRC staff discussed that a licensee should submit a cost-benefit analysis (or qualitative arguments) to demonstrate compliance with the ALARA criteria. However, for sites with soil contamination, NRC staff further discussed in Section N.1.5 “When Mathematical Analyses Are Not Necessary”:

> 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 may have unrestricted release, generic analyses (see NUREG–1496, the examples in Sections 1.4, and other similar examples) show that shipping soil to a low-level waste disposal facility is unlikely to be cost effective for unrestricted release, largely because of the high costs of waste disposal. Therefore, shipping soil to a low-level waste disposal facility generally does not have to be evaluated for unrestricted release.

Although a detailed cost-benefit analysis is not necessary for the Fort Mims Site, a qualitative discussion provides additional insight. In Section N.1.1 of NUREG-1757, Vol. 2, Rev. 1, NRC staff provided guidance on evaluating compliance with the ALARA criteria. NRC staff discussed that for the ALARA analysis, the averted dose should be based on the same exposure scenario(s) used for the compliance demonstration (i.e., based on the reasonably foreseeable land use). For the Fort Mims Site, the reasonably foreseeable land use is an industrial worker at a facility with a municipal water supply. For that scenario, the projected dose is less than 1 mrem/yr. Accordingly, the benefit of removal of the residual soil contamination is minimal. In addition, the licensee noted in letter dated April 27, 2020 (ADAMS Accession No. ML20120A544) that excavation and removal of the contaminated soils would present a higher potential risk to workers and the public rather than leaving the contamination in place. The costs of those activities were not provided; however, NRC staff agrees that the costs would be significant. Based on the limited benefits of removal and the significant associated costs, both for disposal and risk to workers and the public, NRC staff concludes that the site meets ALARA in conformance with 10 CFR 20.1402.

6. CONCLUSIONS

As discussed in detail above, the NRC staff concludes that the site meets the criteria for unrestricted use in 10 CFR 20.1402 and that the residual radioactivity is ALARA. NRC staff has reasonable assurance that the potential dose to reasonably foreseeable activities (i.e., an industrial worker) from the residual soil contamination and the groundwater contamination does not exceed 25 mrem/yr. For the less likely, but plausible, scenario of suburban resident, NRC staff has reasonable assurance that the potential dose also does not exceed 25 mrem/yr. For the bounding scenario of a resident farmer, the potential dose could exceed 25 mrem/yr initially but that dose would quickly (i.e., less than 10 years) decrease to less than 25 mrem/yr. In addition, more recent soil sampling data indicates that the potential dose to a resident farmer would be significantly less due to migration of C-14 that has occurred since the initial soil sampling event. Accordingly, NRC staff concludes that this scenario and potential dose is very unlikely.

The NRC staff compared residual contamination levels at the Fort Mims Site with the trigger values in the "Memorandum of Understanding between the U.S. Environmental Protection Agency (EPA) and the NRC on Consultation and Finality on Decommissioning and Decontamination of Contaminated Sites." The staff concluded that the trigger levels were not exceeded and therefore, consultation with the EPA was not required.

The NRC staff concludes that the Fort Mims Site is consistent with applicable NRC criteria and guidance. The staff recommends that no further oversight be conducted by the NRC and that the site be designated for unrestricted use.

Figure 1. Carbon-14 soil concentrations from 0-15cm depth (adapted from ADAMS Accession No. ML17240A366)

Figure 2. Carbon-14 soil concentrations from 1m depth (adapted from ADAMS Accession No. ML17240A366)

Figure 3. Carbon-14 soil concentrations from 2m depth (adapted from ADAMS Accession No. ML17240A366)

Figure 4. Carbon-14 soil concentrations from 3m depth (adapted from ADAMS Accession No. ML17240A366)

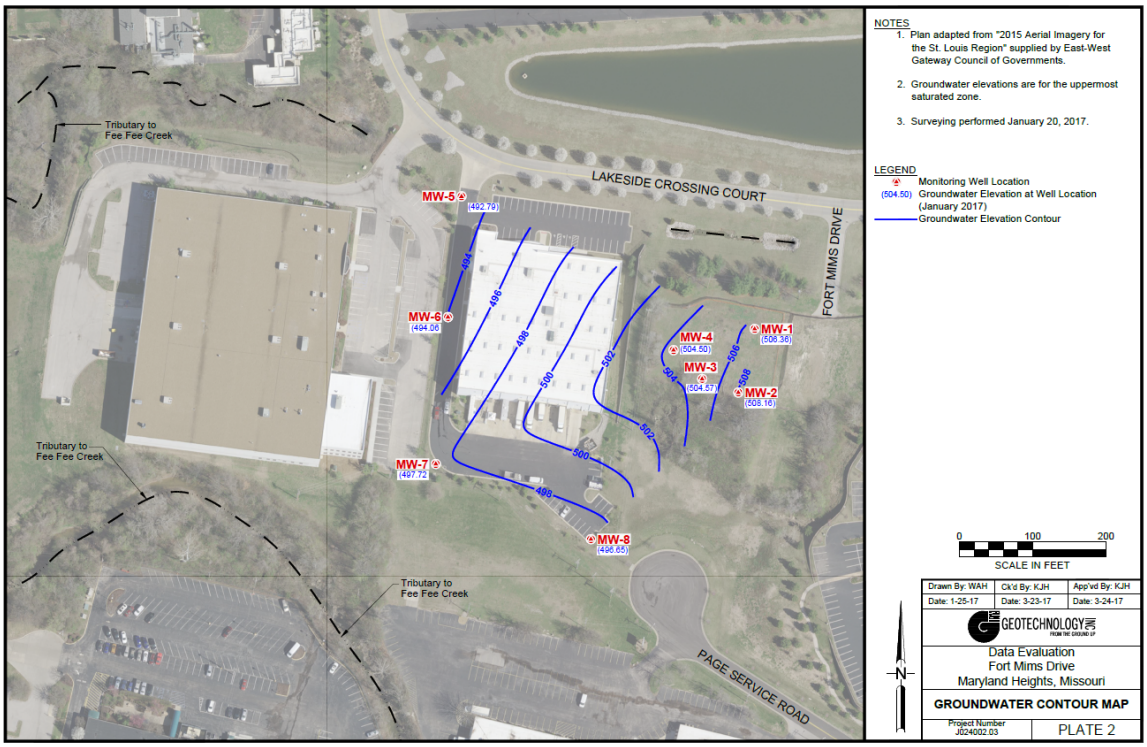

Figure 5. Groundwater Monitoring Well Locations and Water Table Elevation (adapted from ADAMS Accession No. ML17240A366)