July 6, 2009

MEMORANDUM TO: John Buckley, Sr. Project Manager
Reactor Decommissioning Branch
Decommissioning and Uranium Recovery
Licensing Directorate
Division of Waste Management
and Environmental Protection
Office of Federal and State Materials
and Environmental Management Programs

THRU: Christepher McKenney, Chief **/RA/**
Performance Assessment Branch
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Division of Waste Management
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FROM: Karen Pinkston, Systems Performance Analyst **/RA/**
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Division of Waste Management
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SUBJECT: REVIEW OF DOSE MODELING FOR THE MALLINCKRODT PHASE II DECOMMISSIONING PLAN

The Performance Assessment Branch has completed its review of the dose modeling and DCGL values generated by Mallinckrodt as part of their Phase II Decommissioning Plan (ML083150652) and has provided a Technical Evaluation Report (enclosed). Based upon our review, staff finds that the licensee-derived DCGLs meet the U.S. Nuclear Regulatory Commission dose criteria for license termination.

CONTACT: Karen Pinkston, DWMEP/PAB
301-415-3650

Docket No.: 40-6563
License No.: STB-401

Enclosure: Dose Modeling Evaluations
for Mallinckrodt Phase II
Decommissioning Plan

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Technical Evaluation Report

Dose Modeling Evaluations for Mallinckrodt Phase II Decommissioning Plan

Karen Pinkston

June 30, 2009
Docket No.: 40-6563 License No.: STB-401

1.1 Introduction

The Mallinckrodt Site is located in St. Louis, Missouri in an urban, industrial area. Mallinckrodt has operated under a Nuclear Regulatory Commission (NRC) license for the extraction of columbium and tantalum (C-T process) since 1961. This license was originally issued by the Atomic Energy Commission (AEC). Prior to this, activities related to the production of uranium compounds and metals in support of the early atomic weapons program of the Manhattan Engineering District (MED) and the AEC were also conducted at the Mallinckrodt site. The residual radiation from these activities is being cleaned up by the U.S. Army Corps of Engineers (USACE) under the Formerly Utilized Sites Remedial Action Program (FUSRAP). The licensed C-T process activities were primarily located in the Plant 5 portion of the site, while the MED/AEC activities were primarily located on other parts of the site.

Mallinckrodt intends to release the site for unrestricted use in compliance with the requirements of 10 CFR 20.1402. These requirements state that residual radioactivity levels that are distinguishable from background remaining at the site at the time of license termination cannot result in a total effective dose equivalent (TEDE) to an average member of the critical group that exceeds 0.25 mSv/yr (25 mrem/yr), and that residual radioactivity must be reduced to levels that are as low as reasonably achievable (ALARA). Mallinckrodt performed dose assessments to establish radionuclide specific derived concentration guideline levels (DCGLs) for contaminated soil and pavement corresponding to the 0.25 mSv/yr (25 mrem/yr) criteria.

1.2 Source Term

The residual radiation in Plant 5 at the Mallinckrodt site includes the thorium series (Th-232 and progeny), the uranium series (U-238 and progeny), and the actinium series (U-235 and progeny). The Mallinckrodt site contains both contaminated soil and contaminated pavement. In some locations, the contaminated pavement is located over contaminated soil.

1.3 Scenarios and Exposure Pathways Evaluated

The analysis used by the licensee to generate DCGL values assumed an industrial land use scenario. This scenario was selected because the site is located in an urban industrial area in St Louis. Mallinckrodt has operated chemical manufacturing facilities on the site since 1867.

Enclosure

Mallinckrodt intends to continue industrial use of the site, and the foreseeable future use of the site is continued industrial or commercial use. The NRC staff finds that the industrial land use scenario is an acceptable scenario. In addition, NRC staff concludes that the industrial worker is the receptor that is reasonably expected to receive the greatest exposure to residual radioactivity at the Mallinckrodt site.

Under the industrial land use scenario, the critical group is the industrial workers. The pathways of exposure included for the industrial worker are:

- direct gamma irradiation of the worker while outside;
- inhalation of contaminated dust while outside;
- inadvertent ingestion of contaminated dust;
- direct gamma radiation of the worker while the worker is indoors; and
- inhalation of contaminated dust while inside.

The groundwater pathway is not present because the groundwater beneath the site is saline, of poor quality, and is not used as a source of drinking water. The Mallinckrodt site is also located near the Mississippi River, which provides a large volume of high-quality water, so it is not expected that the groundwater beneath the site would be used as a drinking water source in the future. In addition, there are no surface streams or lakes on-site, so the surface water pathway is also not present.

The NRC staff finds that the exposure pathways selected by Mallinckrodt for their dose assessment are appropriate.

1.4 Input Parameters and RESRAD calculations

The RESRAD code (version 6.4) was used by Mallinckrodt to calculate DCGL values that correspond to a dose of 0.25 mSv/yr (25 mrem/yr). DCGL values were generated for both contaminated soil and contaminated pavement. The NRC staff finds the use of the RESRAD code is appropriate for this site and that the conceptual model assumed in RESRAD is consistent with the conceptual model assumed for the site.

1.4.1 Calculation of Soil $DCGL_W$ Values

The radionuclides present in the soil at the site were divided into three groupings when calculating the DCGL values. These groups included: the thorium series (Th-232 and its progeny), natural uranium (U-238 through U-234 and U-235 and its progeny), and a group that includes Th-230, Ra-226, and Pb-210. A DCGL value was calculated for each of these groups. The calculated DCGL value was referenced to one of the radionuclides in the group (Th-232 for the Th-232 series, U-238 for the natural uranium group, and Ra-226 for the group containing Th-230 and the remaining progeny of the uranium series). This approach was used to allow for the use of surrogates when performing analytical measurements of the radionuclides.

The thorium series was entered into RESRAD as consisting of Th-232, Ra-228, and Th-228 present in equal concentrations since the measurements of these radionuclides in soil on the site indicated that this series was in equilibrium. Similarly, the radionuclides in the natural uranium group (U-238, U-234, U-235, Pa-231, and Ac-227) were also assumed to be present in their naturally occurring ratios. These ratios are presented in Table 1.1.

Table 1.1 Relative ratios of radionuclides in the natural uranium series

Radionuclide	Relative Ratio
U-238	1
U-234	1
U-235	0.0455
Pa-231	0.0455
Ac-227	0.0455

The group that consists of Th-230, Ra-226, and Pb-210 was assumed to have equal amounts of Ra-226 and Pb-210, and Th-230 was assumed to be present at a level six times as much as Ra-226. The staff finds that this ratio reasonably bounds the range of ratios expected on in the soil on the site because only 3 samples of the more than 500 samples had a Th-232 to Ra-226 ratio that exceeded 6. In addition, Mallinckrodt performed a sensitivity analysis to determine how sensitive the calculated dose is to this assumption. It was found that increasing this ratio resulted in a small amount of increased dose.

The contaminated zone was modeled in RESRAD assuming the RESRAD default area of 10,000 m^2. The thickness of the contaminated zone was modeled probabilistically with a uniform distribution of 0 to 1 m. This distribution was based on an analysis performed by Mallinckrodt on the effect of the thickness of the contaminated zone on the dose. The results of this analysis indicated that the dose reached an asymptote at a thickness of 30 cm and that the use of larger values for the contaminated zone did not increase the calculated dose. The default value of 0.15 m was used for the soil mixing layer thickness, and a cover depth of 0 m was assumed. A wind speed of 4 m/s was used based on a reported average wind speed value of 4.3 m/s (9.5 mi/hr) for St. Louis.

The receptor was assumed to be an industrial worker who spent 2000 hours per year on site (40 hours per week for 50 weeks). The worker was assumed to spend 80% of their work day indoors and 20% of their time outdoors. These assumptions correspond to parameter values of 0.1825 for the indoor time fraction and 0.04566 for the outdoor time fraction. A parameter value of 1.4 m^3/hr or 12,270 m^3/yr was used for the inhalation rate. The external gamma shielding factor was modeled with a probabilistic distribution that is described in Table 5-2 of the C-T Phase II Decommissioning Plan. This distribution was derived by calculating the fraction of the gamma dose that penetrates the floor as a function of floor thickness. A probabilistic distribution was also used for the mass loading for inhalation parameter. This distribution was developed based on NUREG/CR-6697, Table 4.6-1. This distribution is described in Table 5-1 of the Decommissioning Plan. A value of 0.6 was used for the indoor dust filtration factor. The RESRAD default value of 36.5 g/yr was used for the soil ingestion rate. The NRC staff finds that the use of these parameter values is appropriate for modeling the dose from soil at the Mallinckrodt site.

The parameter values described above were used in RESRAD to calculate the dose from each radionuclide group. A composite dose factor was determined by dividing the sum of the dose from each radionuclide in the group (present in the ratios described above) by the concentration of the referenced radionuclide used in the RESRAD calculations. $DCGL_W$ values corresponding to a dose of 0.25 mSv/yr (25 mrem/yr) were calculated for each group by dividing 0.25 mSv/yr (25 mrem/yr) by the composite dose factor. A sum of fractions approach will be used for the three groups to demonstrate that the total dose from all three groups of radionuclides will be less than the 0.25 mSv/yr (25 mrem/yr) limit.

Table 1.2 Soil $DCGL_W$ values

Radionuclide Group	Composite Dose Factor (mrem/yr)/(pCi/g)*	$DCGL_W$ (pCi/g)	Referenced Radionuclide
Th-232	1.05	23.9	Th-232
Natural Uranium	0.0347	721	U-238
6 Th-230 + Ra-226 + Pb-210	0.852	29.4	Ra-226

* multiply this dose factor by 0.27 to obtain this dose factor in (mSv/yr)/(Bq/g)

1.4.3 Calculation of Pavement DCGL values

The pavement $DCGL_W$ values were calculated using the RESRAD code in a similar manner as was used for the soil $DCGL_W$ values. However, one difference in these analyses is that while it is not possible for a receptor to be exposed to both a dose from bare soil and from pavement, it is possible for a receptor to be exposed to both the dose from contaminated pavement and the external dose from contaminated soil located beneath that pavement. Because of this, the calculation of the $DCGL_W$ values for pavement account for the dose that the receptor might also be receiving from contaminated soil. To do this, Mallinckrodt calculated the external gamma dose from contaminated soil through the pavement using soil concentrations of radionuclides that would result in a dose of 0.25 mSv/yr (25 mrem/yr) to a receptor located on bare soil (i.e., the maximum concentration of radionuclides expected in the soil following the completion of decommissioning activities). A pavement thickness of 4 in (10 cm) and a contaminated soil thickness of 1 m were assumed in this analysis. The peak dose calculated in this analysis was 0.0495 mSv/yr (4.95 mrem/yr). Therefore, the $DCGL_W$ values for pavement were based on a maximum dose of 0.20 mSv/yr (20 mrem/yr) instead of 0.25 mSv/yr (25 mrem/yr) to account for the dose that a receptor might also receive from the contaminated soil.

The parameter values used in RESRAD for the derivation of pavement $DCGL_W$ values were the same as those used in calculating the soil $DCGL_W$ values, with the exception of the contaminated zone parameters. The contaminated zone for pavement was modeled as having the RESRAD default area of 10,000 m^2 and a thickness of 0.3 cm. This thickness was based on an analysis that showed that the maximum pavement dose occurred at this value. A cover depth of zero was assumed, and the erosion rate was also assumed to be zero. The NRC staff finds these parameters values to be appropriate.

The dose from contamination present on pavement determined using RESRAD for unit concentrations of each of the radionuclides is shown in Table 1.3. The radionuclides were grouped into the same three groups as in the soil DCGL calculations (i.e., the thorium series, a natural uranium group, and a group consisting of Th-230, Ra-226, and Pb-210). The dose from all of the radionuclides in each group was summed to generate composite dose factors. The areal densities corresponding to 0.2 mSv/yr (20 mrem/yr) were then calculated for the reference radionuclide in each group based on these dose factors.

Table 1.3 Pavement DCGL values

Radionuclide Group	Composite Dose Factor (mrem/yr)/(pCi/g)*	Areal density equal to 0.2 mSv/yr (i.e., 20 mrem/yr) (dpm/100 cm^2)	Referenced Radionuclide
Th-232 series	6.42e-2	3.11e4	Th-232
Natural Uranium	1.91e-3	1.05e6	U-238
Th-230 + Ra-226 + Pb-210	4.67e-2	4.28e4	Ra-226

* multiply this dose factor by 0.27 to obtain this dose factor in (mSv/yr)/(Bq/g)

These areal densities were combined into a composite $DCGL_W$ of 6.16×10^4 dis/(min·100 cm^2) based on the sum of fractions approach assuming that the radionuclide groups were present in the relative ratios described in Table 1.4. These relative ratios were derived based on the natural log mean of ratios measured in scabble samples of pavement. The value of the composite $DCGL_W$ value is not very sensitive to the relative ratios of radionuclides present. The composite $DCGL_W$ was converted to a value of 1.80×10^5 β/(min·100 cm^2) to allow for the use of gross beta radiation measurements.

Table 1.4 Relative ratios of radionuclide groups assumed for the pavement

Radionuclide Group	Relative Ratio
Th-232 series	1
Natural Uranium	3
Th-230 + Ra-226 + Pb-210	4.2

1.4.3 Calculation of $DCGL_{EMC}$ values

Area factors were calculated for soil for each of the radionuclide groups in order to assess whether small areas of elevated radioactivity in the soil comply with the 0.25 mSv/yr (25 mrem/yr) dose criteria. A sum of fractions approach was used to account for the dose from all three radionuclide groups. The area factors for soil are provided in Figure 5-3 of the Decommissioning Plan. Area factors were also calculated for pavement in order to generate $DCGL_{EMC}$ values for small areas of elevated radioactivity on pavement. These area factors are presented in Figure 5-4 of the Decommissioning Plan.

1.5 Conclusions

The NRC staff has reviewed the dose modeling analyses provided as part of the review of Mallinckrodt's Phase II Decommissioning Plan, and the staff concludes that the dose modeling completed is reasonable and is appropriate. NRC staff evaluated the proposed critical group, land use scenario, and set of pathways used in the assessment and finds them acceptable. NRC staff also found that an appropriate conceptual model and input parameters were used in the development of the DCGL values for soil and pavement. NRC staff performed independent calculations of the DCGL values for both soil and pavement and found that Mallinckrodt's calculations were performed accurately. However, it is important to note that Mallinckrodt plans to use surrogate radionuclides in measuring the residual radioactivity and demonstrating compliance with the DCGL values. Because the development of the DCGL values for surrogate radionuclides is dependent on the ratio of radionuclides present, it is important for the actual ratios of radionuclides to be consistent with those that were assumed.

NRC staff concludes that the DCGL values developed for pavement and soil at the Mallinckrodt site are consistent with the 0.25 mSv/yr (25 mrem/yr) annual dose criterion for unrestricted release in 10 CFR 20.1402 and that there is reasonable assurance that the dose to the average member of the critical group is not likely to this dose criterion.