ENERGYSOLUTIONS

CS-RS-RP-009-03

Phase II Final Status Survey Report Mallinckrodt Columbium-Tantalum Plant

St. Louis, Missouri

Chapter 3

Project No. 137131 **Revision 0**

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[X] Non-Proprietary	[X] New
[ ] Proprietary	[ ] Title Change
[ ] Restricted Information	[ ] Revision
[ ] Safeguards Information	[ ] Rewrite
[ ] Sensitive Security Information	[ ] Cancellation

Effective Date 8/28/2013

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ABBREVIATIONS AND ACRONYMS

β	beta
Ac	actinium
ALARA	as low as reasonably achievable
AF	area factor
Bi	bismuth
C-T	columbium-tantalum
CFR	Code of Federal Regulations
DCGL	derived concentration guideline level
DP	decommissioning plan
dpm/100 cm^2	disintegrations per minute per 100 square centimeters
EMC	elevated measurement comparison
m^2	square meters
mrem/yr	millirem per year
NRC	U.S. Nuclear Regulatory Commission
Pb	lead
pCi/g	picoCuries per gram
Ra	radium
ROC	radionuclides of concern
SOF	sum of fractions
Th	thorium
TEDE	Total Effective Dose Equivalent
U	uranium
WRS	Wilcoxon Rank Sum

3.0 SITE RELEASE CRITERIA

U.S. Nuclear Regulatory Commission (NRC) guidance provided in NUREG-1757, Vol. 2, Section 2.5, notes that there is "flexibility in the general approach to demonstrating compliance with Title 10, Code of Federal Regulations (CFR), Part 20, Subpart E." Two major approaches described in the NRC guidance include 1) development of derived concentration guideline levels (DCGLs) and performance of final status surveys and 2) dose modeling following characterization and remediation as necessary. The first approach, DCGLs and final status surveys, is described in Chapters 5 and 14 of the NRC-approved Columbium-Tantalum (C-T) Phase II Decommissioning Plan (DP). The NRC guidance adds that the two approaches are not mutually exclusive and that both are acceptable to show that the dose is acceptable.

The 25 millirem per year (mrem/yr) dose-based unrestricted release criterion of 10 CFR 20, Subpart E, is satisfied provided the following conditions established in C-T Phase II DP Section 5.11 are met:

- $DCGL_W$ and $DCGL_{EMC}$ values are not exceeded in soil, and separately that
- $DCGL_W$ and $DCGL_{EMC}$ values are not exceeded on pavement.

The unrestricted release provisions of 10 CFR Subpart E also require that residual radioactivity be reduced to levels that are as low as reasonably achievable (ALARA). An ALARA evaluation was performed and is documented in C-T Phase II DP Chapter 7. The evaluation concludes that residual radioactivity reduced to $DCGL_W$ levels is also ALARA and that no further remediation is needed.

For most survey units, Mallinckrodt was able to demonstrate compliance with the NRC-approved approach as described in Chapters 5 and 14 of the C-T Phase II DP; however, for a limited number of survey units, compliance could not be demonstrated through the application of the DCGLs alone and a dose assessment was performed. Performance of direct dose assessment for compliance demonstration following the guidance of NUREG-1757 is not included in the C-T Phase II DP and the use of this means of compliance demonstration represents an adjustment, or change, to the approved DP. Section 9.5 of the C-T Phase II DP describes adjustments to the decommissioning process and provides a list of conditions that must be satisfied for a justified change related to the decommissioning process to be acceptable to the NRC without filing an application for amendment. All conditions of Section 9.5 of the C-T Phase II DP (a through m) are either not applicable to this change or are satisfied and approved by Mallinckrodt's and Energy*Solutions*' Project Managers and Radiation Safety Officers.

The application of the dose assessment was limited to situations where inaccessible but characterized residual contamination exceeded the DCGLs. The characterized residual contamination was inaccessible and could not be remediated because the remediation activities would negatively impact active plant buildings or systems (e.g., residual contamination under the vertical pipe stands in Plant 5).

3.1 RADIONUCLIDES OF CONCERN

The radionuclides of concern (ROCs) were identified in the review of C-T process history and in the evaluation of radiological characterization of the site, described in C-T Phase II DP Chapter 4. They are summarized in C-T Phase II DP Section 14.1 and are provided below.

- Uranium-238 (^{238}U), uranium-235 (^{235}U), and uranium-234 (^{234}U), all from naturally occurring uranium and their progeny [thorium-230 (^{230}Th), radium-226 (^{226}Ra), bismuth-214 (^{214}Bi), and other short-lived isotopes]; and
- Thorium-232 (^{232}Th) from naturally occurring thorium, and its progeny [radium-228 (^{228}Ra), thorium-228 (^{228}Th), lead-210 (^{210}Pb), actinium-228 (^{228}Ac), and other short-lived isotopes].

3.2 DERIVED CONCENTRATION GUIDELINE LEVELS

Dose modeling was performed to develop DCGL values for subsurface materials and surface activity. C-T Phase II DP Chapter 5 provides the details of the DCGL development, with summaries presented below.

3.2.1 Subsurface Materials

DCGLs in terms of bulk concentration (activity per unit mass) were developed for subsurface materials to be applied to land areas (i.e., bare soil) affected by C-T process operation. They are given in Table 3-1. Their derivation is described in C-T Phase II DP Section 5.8. Table 3-1 below summarizes these values and also provides the measurement surrogate radionuclide that is used to demonstrate compliance with the $DCGL_W$ values, e.g. ^{228}Ac activity concentrations are compared to the $DCGL_W$ value of 23.9 picoCuries per gram (pCi/g).

Table 3-1 DCGLs for Subsurface Materials

Radionuclide Grouping	Reference Nuclide	$DCGL_W$[a]	Measurement Surrogate
Th series[b]	^{232}Th	23.9 pCi/g	^{228}Ac
6 ^{230}Th + ^{226}Ra + ^{210}Pb[c]	^{226}Ra	29.4 pCi/g	^{214}Bi[e]
Natural Uranium[d]	^{238}U	721 pCi/g	^{234}Th

[a] C-T Phase II DP Table 5-3

[b] Thorium series radionuclides assumed to be in radioactive equilibrium.

[c] ^{226}Ra and its progeny, including ^{210}Pb, are assumed to be in radioactive equilibrium and are referenced to the measured ^{226}Ra concentration; ^{230}Th is associated with ^{226}Ra and ^{210}Pb because ^{226}Ra, to which it decays, presents the dominant dose factor. Section 5.8.4 of the C-T Phase II DP discusses that the factor of 6 with respect to ^{230}Th would be expected to encompass the dose from 99% of soil samples.

[d] ^{238}U through ^{234}U assumed to be in radioactive equilibrium; actinium (^{235}U) series assumed to exist in its naturally-occurring proportion to the uranium series.

[e] Measurement of ^{214}Bi as a surrogate only when in radioactive equilibrium with ^{226}Ra.

3.2.2 Surface Activity

Exposure to bare soil and to pavement cannot occur simultaneously. The scenario assuming bare soil necessarily excludes pavement and any exposure to it. Thus, derivation of DCGLs for work on soil is independent of exposure to pavement. On the other hand, pavement would exist atop soil. With the aid of dose modeling of outdoor exposure to gamma radiation penetrating nominal 4-inch-thick pavement, a meter of soil containing a spectrum of radionuclides observed in soil (C-T Phase II DP, Appendix C) at the concentration corresponding to $DCGL_W$ in soil would be estimated to contribute 5.0 mrem/yr through the pavement. Subtracting that from 25 mrem/yr allotted to DCGL would imply reduction of allowable contribution from residue on pavement itself to 20 mrem/yr, or 0.80 of the $DCGL_W$ derived and proposed for pavement.

C-T Phase II DP Table 5-4 provides the areal activity concentrations that produce 20 mrem/yr for the individual radionuclides and summaries for the three series listed in Table 3-1. Because radioactive contamination on surfaces is often surveyed by gross activity detection, the contamination limits were presented in units consistent with the measurement, which are disintegrations per minute per 100 square centimeters (dpm/100 cm^2). A composite (alpha and beta) limit of $6.2x10^4$ dpm/100 cm^2 was developed based on relative concentration relationships between the contaminants (C-T Phase II DP Table 5-5) in the 24 samples of scabbled pavement surfaces in Plant 5. To enable practical survey of the radionuclide spectrum observed on pavement by measuring gross beta (β) radiation, the $DCGL_W$ was established to be 1.8 $x10^5$ β dpm/100 cm^2.

3.3 UNITY RULE

The unity rule, or sum of fractions (SOF), was used to demonstrate compliance to the DCGLs for mixtures of radionuclides. Application of the unity rule is discussed below for subsurface materials and surface activity.

3.3.1 Subsurface Materials

C-T Phase II DP Chapter 5, Equation 7 provides the SOF calculation for subsurface material samples.

$$SOF = \frac{C_{232Th}}{DCGL_{W\ Th\ Series}} + \frac{C_{226Ra}}{DCGL_{W\ 226Ra}} + \frac{C_{238U}}{DCGL_{W\ U}}$$

where: SOF = sum-of-fractions of $DCGL_W$ (unitless)

C_{232Th} = concentration of ^{232}Th (pCi/g)

C_{226Ra} = concentration of ^{226}Ra (pCi/g)

C_{238U} = concentration of ^{238}U (pCi/g)

$DCGL_{W\ U}$ = $DCGL_W$ of ^{238}U + ^{234}U + actinium (^{235}U) series in its naturally-occurring ratio to the uranium series (pCi/g)

$DCGL_{W\ 226Ra}$ = $DCGL_W$ of 6 ^{230}Th + ^{226}Ra and its progeny, including ^{210}Pb, in radioactive equilibrium (pCi/g)

$DCGL_{W\ Th\ series}$ = $DCGL_W$ of ^{232}Th and its progeny, including ^{228}Ra and ^{228}Th, in radioactive equilibrium (pCi/g)

3.3.2 Surface Activity

The derivation of the surface activity $DCGL_W$ of $1.8\text{x}10^5$ β dpm/100 cm^2 embedded the use of the unity rule. Therefore collected beta surface activity measurements are compared directly to the surface activity $DCGL_W$.

3.4 AREA FACTORS

The magnitude by which the concentration within a small area of elevated radioactivity may exceed the $DCGL_W$ while maintaining compliance with the release criterion is defined as an area factor (AF). AFs for subsurface materials and surface activity are discussed below.

3.4.1 Subsurface Materials

C-T Phase II DP Chapter 5, Equation 8 provides the AF calculation for subsurface material samples as follows:

$$Area\ Factor = \frac{composite\ dose\ factor\ for\ survey\ unit\ area}{composite\ dose\ factor\ for\ local\ area\ of\ contamination}$$

Figure 3-1 (C-T Phase II DP Figure 5-3) provides the calculated AFs as a function of a localized area of radioactive contamination for the radionuclide groupings listed in Table 3-1. The maximum AF considered corresponds to 10 square meters (m^2) of elevated contamination.

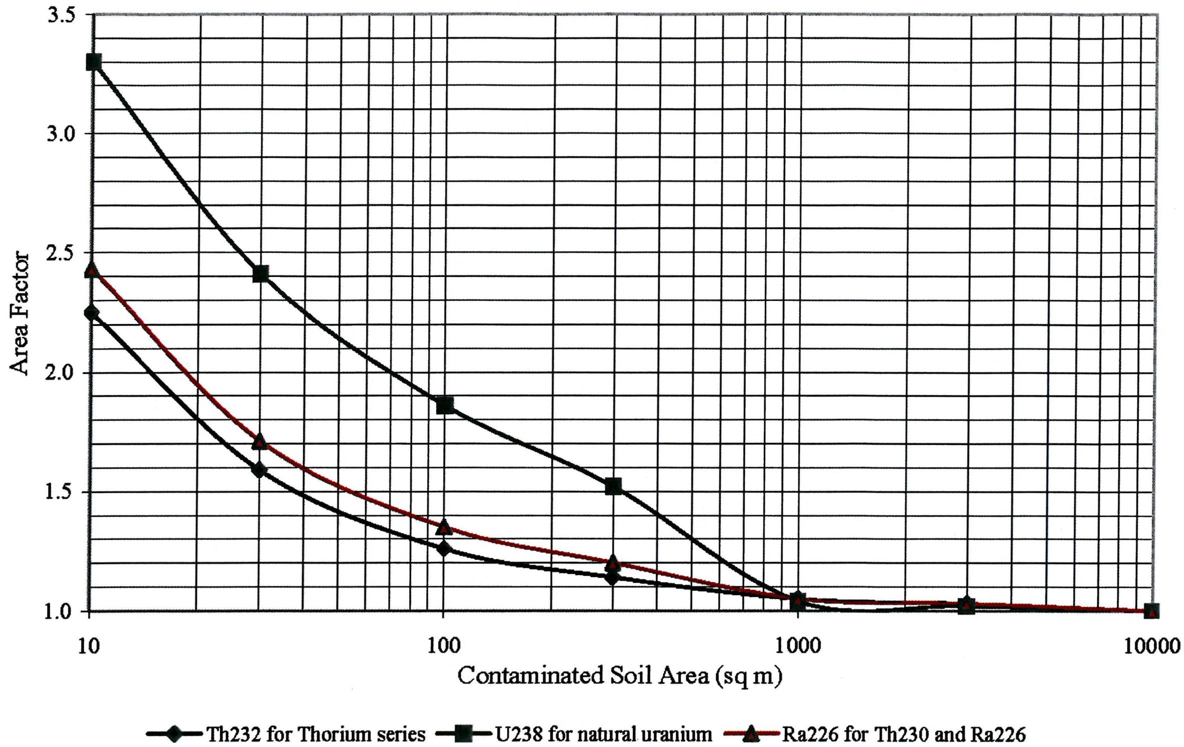

Figure 3-1 Area Factors for Subsurface Materials

3.4.2 Surface Activity

C-T Phase II DP Chapter 5, Equation 13 provides the AF calculation for surface activity as follows:

$$Area\ Factor = \frac{composite\ areal\ DCGL\ for\ survey\ unit\ area}{composite\ areal\ DCGL\ for\ local\ area\ of\ contamination}$$

Figure 3-2 (C-T Phase II DP Figure 5-4) provides the calculated AFs as a function of a localized area of radioactive contamination separately for the uranium series (including actinium series present in natural uranium), thorium series, and the ratios of principal radionuclide in pavement scabble samples as a function of a localized area of radioactive contamination on pavement (labeled as "Cinder Fill Nuclide Spectrum" on the figure). The maximum AF considered corresponds to 10 m^2 of elevated contamination.

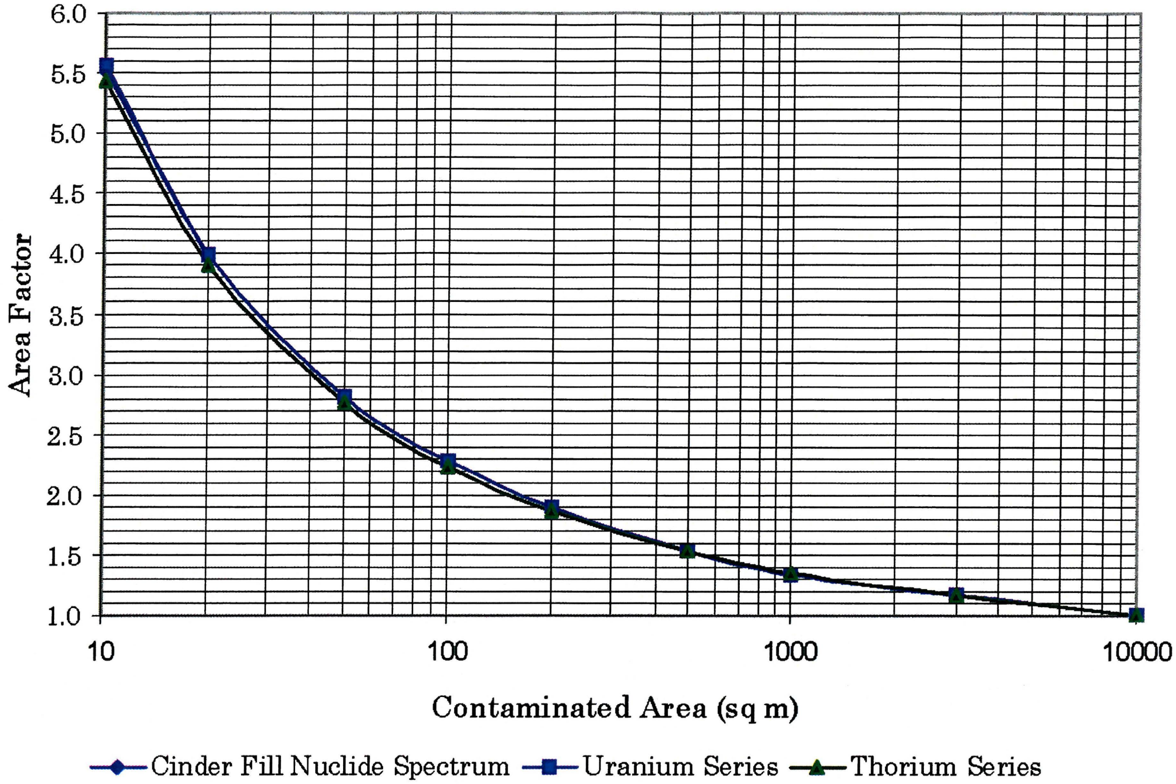

Figure 3-2 Area Factors for Surface Activity

3.5 Elevated Measurement Comparison

In the event that a survey unit has elevated areas exceeding the $DCGL_W$, the survey unit may still meet the release criterion. This is demonstrated by ensuring that each individual elevated area is shown to have an SOF less than unity using an elevated measurement comparison (EMC) DCGL. The $DCGL_{EMC}$ is calculated based upon the size of the elevated area and the appropriate AF, as shown below.

$$DCGL_{EMC} = AF \times DCGL_W$$

The application of the unity rule to the EMC is discussed below for subsurface materials and surface activity.

3.5.1 Subsurface Materials

C-T Phase II DP Chapter 5, Equation 9 provides the calculation of a unity rule index that represents radioactivity in a small area. The $DCGL_{EMC}$ occurs when Index = 1 and is exceeded when Index > 1.

$$Index = \frac{C_{Th232}}{(AF \times DCGL_W)_{Th\ series}} + \frac{C_{Ra226}}{(AF \times DCGL_W)_{Ra226}} + \frac{C_{U238}}{(AF \times DCGL_W)_U}$$

Page 14-26 of the C-T Phase II DP notes that the EMC is not applicable for subsurface survey units; however, the C-T Phase II DP specifies that investigation levels for surface activity (pavement) include the evaluation of the EMC and these investigation levels are applicable to exposed soil. Therefore, when soil was exposed, the C-T Phase II DP was interpreted to allow the use of the EMC.

3.5.2 Surface Activity

C-T Phase II DP Chapter 5, Equation 14 provides the calculation for the $DCGL_{EMC}$, which is the maximum tolerable areal density of residual radioactive contamination, above background, within a small area of elevated radioactivity. Since the area factors curves in Figure 3-2 are nearly coincident, it is reasonable to adopt the area factor curve representing the composite of the radionuclide distribution observed in scabble samples of pavement.

$$DCGL_{EMC} = Area\ Factor\ \times DCGL_W$$

3.6 REFERENCES

Mallinckrodt, *Mallinckrodt Columbium-Tantalum Phase II Decommissioning Plan*, Revision 2, August 2008.

U.S. Nuclear Regulatory Commission, *Consolidated Decommissioning Guidance: Characterization, Survey, and Determination of Radiological Criteria*, NUREG-1757, Vol. 2, Rev. 1, September 2006.