FINAL

SITE-SPECIFIC
DERIVED CONCENTRATION GUIDELINE LEVEL

ADDENDUM

NAVAL STATION GREAT LAKES
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ALARA	as low as reasonably achievable
cc	cubic centimeter
CFR	Code of Federal Regulations
cm	centimeter
cm^3	cubic centimeters
DCGL	derived concentration guideline level
DSR	dose-to-source ratio
EPA	U. S. Environmental Protection Agency
EMC	elevated measurement comparison
g	gram
K_d	element partition coefficient
m	meter
m^2	square meter
NRC	U.S. Nuclear Regulatory Commission
pCi/g	picocurie per gram
RCOC	radionuclide contaminant of concern
TEDE	total effective dose equivalent
yr	year
^{228}Ra	radium-228
^{228}Th	thorium-228
^{232}Th	thorium-232

1.0 INTRODUCTION

This report is an addendum to the site-specific derived concentration guideline level (DCGL) for the radionuclide contaminants of concern (RCOC) in soil at the Naval Station Great Lakes (hereafter referred to as the Site) resulting from storage of monazite sand in 1974. The original site-specific DCGL was based on an "industrial use" scenario. However, after further consideration, it has been determined that a more conservative approach to achieve unrestricted use of the Site is appropriate. Therefore, a "resident gardener" is proposed in lieu of an "industrial use" scenario.

1.1 Purpose

The purpose of the analyses presented in this report is to provide a site-specific DCGL in support of decisions regarding the need for additional remediation at the Site and/or demonstrating that the Site can be release for unrestricted use. Specifically, when the DCGL is applied to the final status survey and the survey data demonstrates that the DCGL has been satisfied, the following requirements of Title 10, Code of Federal Regulations (CFR), Part 20 (10 CFR 20), Paragraph 1402 (10 CFR 20.1402) are achieved:

> *A site will be considered acceptable for unrestricted use if the residual radioactivity that is distinguishable from background radiation results in a TEDE to an average member of the critical group that does not exceed 25 mrem per year, 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). Determination of the levels which are ALARA must take into account the consideration of any detriments, such as deaths from transportation accidents, expected to potentially result from decontamination and waste disposal.*

In addition to 10 CFR 20, several Nuclear Regulatory Commission (NRC) and Environmental Protection Agency (EPA) reference documents were used in the derivation of the site-specific DCGL presented in this report.

2.0 DETERMINATION OF DERIVED CONCENTRATION GUIDELINE LEVEL

Methods for determining the DCGL involved a three step process, presented in order in this section:

1. Identifying the regulatory limit for the total effective dose equivalent (TEDE) per year, to which an acceptable level of residual contamination corresponds;
2. Developing a site environmental model (conceptual site model) that accounts for the physical characteristics of the site, identifies exposure pathways from the residual radioactivity, and computes the annual TEDE per unit concentration of natural thorium and natural uranium;
3. Using RESRAD Version 6.3 (Yu 2005) to calculate the TEDE per year per unit concentration or area, respectively, of natural thorium. Computation models must output the TEDE as a function of time, out to 1000 years, to determine allowable soil concentrations to meet the requirements of 10 CFR 20.1402. Microsoft Excel was utilized to generate additional output results based on the dose assessment model results.

2.1 Annual Public Dose Limit

The NRC annual dose limit for a member of the public is 100 mrem TEDE associated with licensed activities and exclusive of background (and other) sources, as specified in 10 CFR 20.1301. As described in Section 1.1 of this report, 10 CFR 20.1402, *Radiological Criteria for Unrestricted Use*, specifies that an average member of the critical population group may not receive a TEDE in excess of 25 mrem, including groundwater sources of drinking water. The RESRAD model utilized this required input parameter (25 mrem) for the applicable dose limit to establish the resulting DCGL for the Site

2.2 Conceptual Site Model

The conceptual site model has been developed on the basis of Site review, how the Site is currently used and the most probable use of the Site once released, and a complete understanding of the most relevant exposure pathways to occupants/residents on the Site.

Figure 2-1, from the *Users Manual for RESRAD Version 6* (Yu 2001), presents all potential exposure pathways, using a worst case, resident farmer exposure scenario.

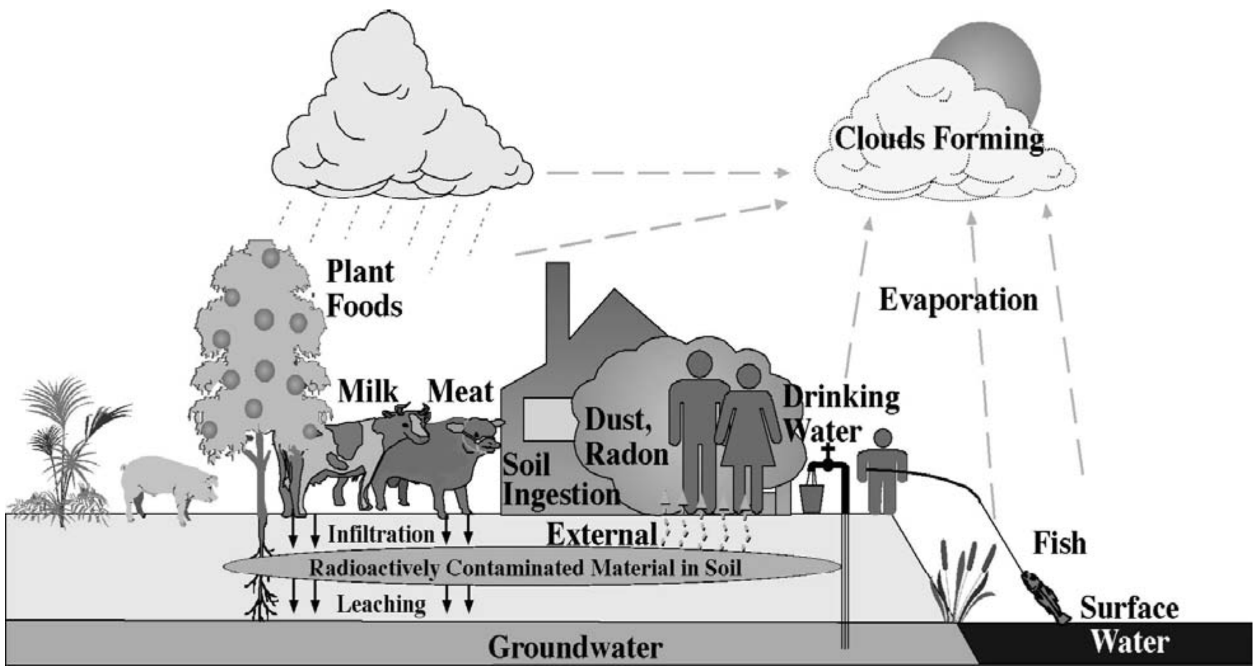

Figure 2-1: Exposure Pathways Considered in RESRAD

This is also presented schematically in Figure 2-2.

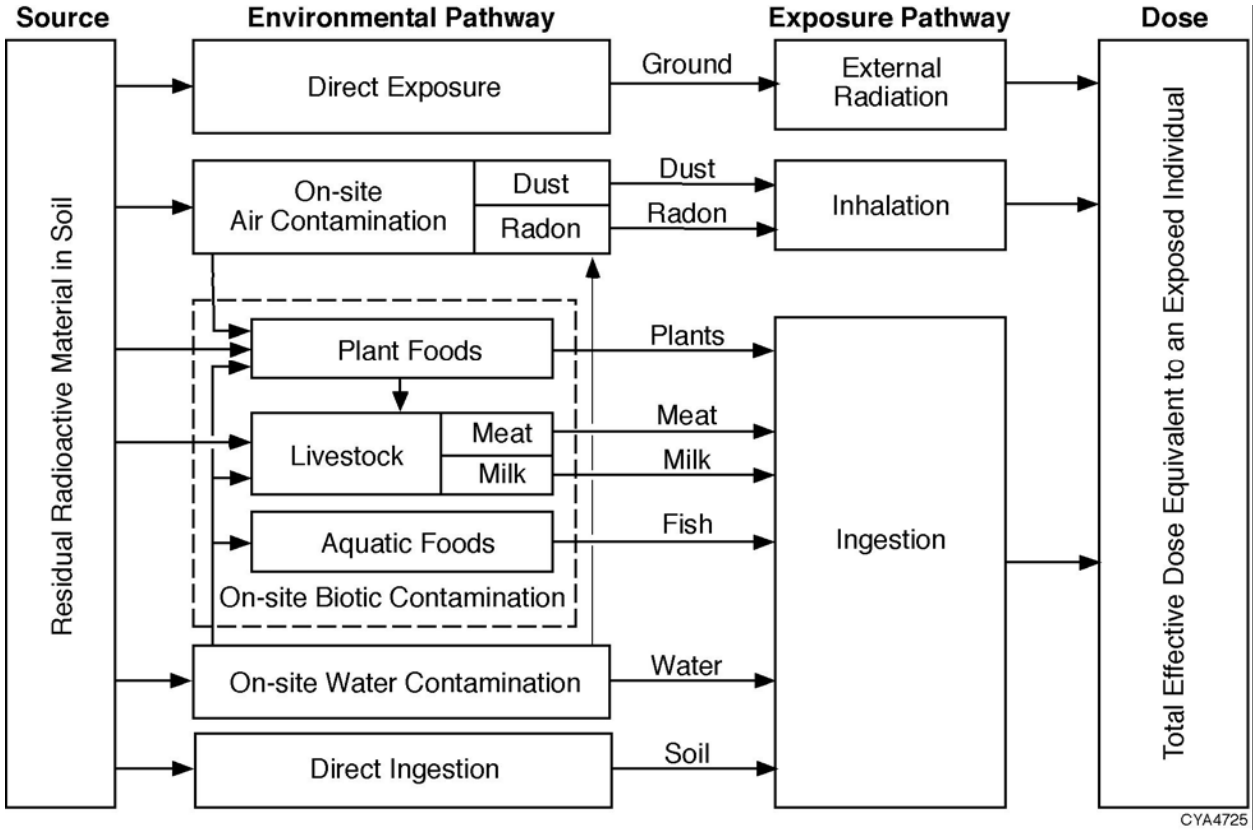

Figure 2-2: Schematic Representation of RESRAD Pathways

As mentioned previously, Figures 2-1 and 2-2 present all potential exposure pathways for a worst case resident farmer scenario. This assumes the area of a site that may be occupied by a future resident is large enough to support raising livestock for meat and milk, and growing crops, fruit, etc. to support a large portion of the resident farmer's dietary intake needs, as well as provide feed for livestock. The Site, however, is not in a rural location conducive to farming activities at present nor will this be the most plausible future land use. Therefore, a site-specific exposure scenario is proposed based on the following justifications:

- The Site is located in an urbanized area of Lake County, used predominantly for single and multi-family residences, as well as industrial use.
- The Site is currently bounded on all sides by residential areas and industrial properties.
- The Site is approximately 36 miles from Chicago, Illinois, which is a rapidly expanding urban area.
- Portions of the Site are already designated for residential use and privatization efforts are underway to further utilize this area for residential purposes.

- The size of residential properties at the Site is typical of residential lots, averaging approximately 0.25 acres but not exceeding 0.5 acres. This property size is not sufficient to support a farm with livestock as a source of food and milk or raising crops for food. Additionally, typical urban area zoning ordnances prohibit raising livestock.
- The western portion of the Site, bounded on the west by the Site boundary and on the east by Mississippi Avenue, formerly designated Site 18, is currently an industrial area. This portion of the Site will continue to be used for industrial purposes in the foreseeable future. However, although unlikely, future changes in land use may utilize this portion of the Site for residential property expansion.

Given the above considerations regarding current and most probable future land use, the "critical group" is determined to be a relatively small group of residents who reside at the Site and obtain a small portion of their food from a backyard garden, i.e., resident gardener. Although a majority of residents in urban areas do not maintain a garden of any size for this purpose, this "critical group" is chosen as the worst case bounding condition for determining the individual who could receive the highest hypothetical exposure at some time in the future. As such, the exposure to a majority of residents who do not maintain a garden will be lower.

Exposure pathways considered in the resident gardener model are discussed below:

- Although potable water is supplied to the Site by public water sources, the resident gardener scenario developed for the Site assumes the resident does install a well on the property to provide a source of drinking water. This is believed highly unlikely, but provides a reasonable amount of conservatism in the model. It should be noted that considering the very low thorium mobility in soil, leaving the water pathway "on" has no impact on the resulting site-specific DCGL for natural thorium compared to values generated with the water pathway suppressed.
- There are no bodies of water on the Site of sufficient size to support aquatic life to provide a source of food for a resident gardener. Therefore, the aquatic foods pathway is not considered in the Site model.
- The radon pathway is suppressed in this assessment due to its inapplicability. In a Federal Register Notice (NRC 1994), issued as a result of comments received from a radon workshop, the NRC noted that "radon would not be evaluated when developing release

criteria due to: the ubiquitous nature of radon in the general environment, the large uncertainties in the models used to predict radon concentrations; and the inability to distinguish between naturally occurring radon and that which occurs due to licensed activities."

Complete exposure pathways applicable to the resident gardener scenario include:

1. Direct radiation from radionuclides in the soil,
2. Inhalation of re-suspended contaminated dust,
3. Ingestion of home grown produce in the contaminated soil,
4. Ingestion of water from a contaminated well, and
5. Ingestion of contaminated soil.

These exposure pathways are depicted in the adjustment to the schematic representation of RESRAD pathways in Figure 2-3.

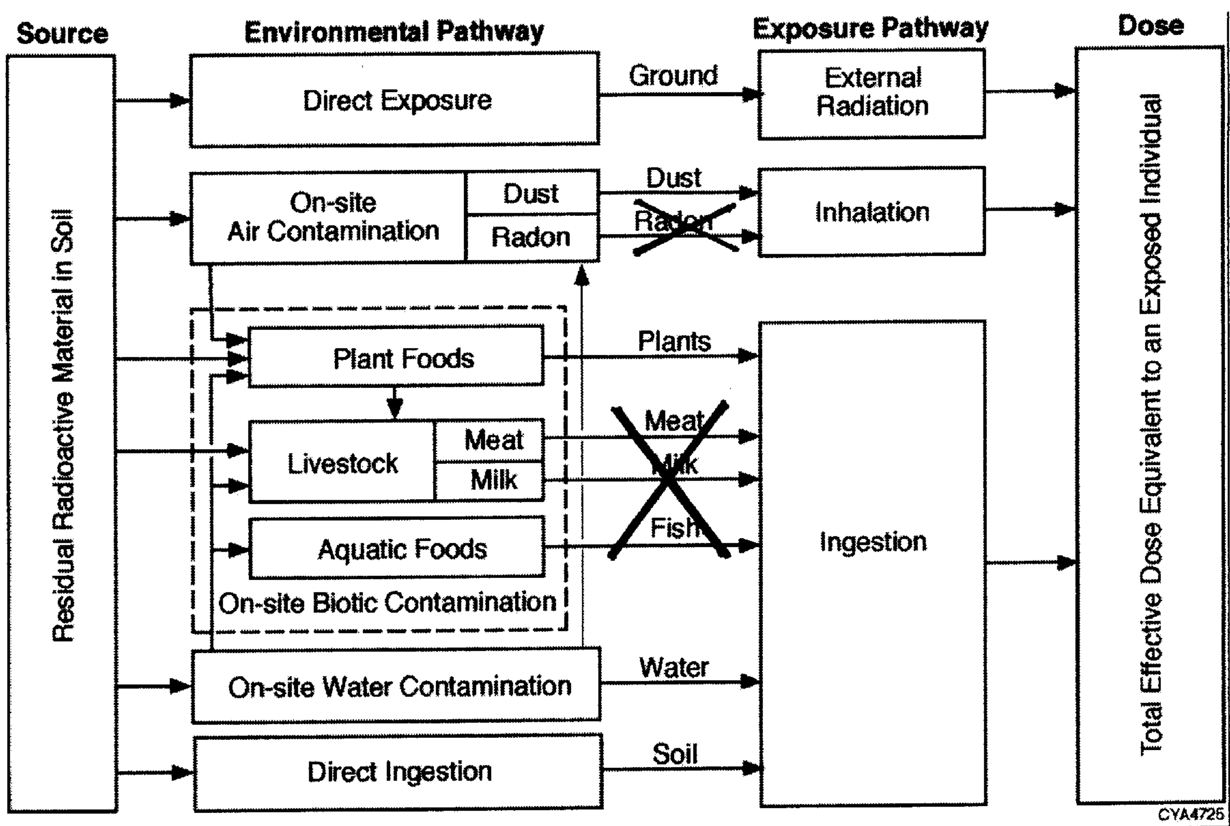

Figure 2-3: Adjusted Schematic of RESRAD Pathways for Resident Gardener

As will be shown, direct exposure to radiation from soil contamination, i.e., external radiation, results in the greatest contribution to dose. Direct ingestion of soil and foods grown in a garden contribute minimally to the dose. Consumption of water from a well placed on the resident's property has no contribution to the dose.

2.3 RESRAD Input Parameters

2.3.1 General Basis for the Dose Modeling Assessment

The following general assumptions formed the basis for the dose modeling assessments:

- The resident gardener scenario is applicable to soils at the Site.
- The DCGL for soil was derived based on a review of site surveys, sampling and prior remediation.
- Site-specific values, where available, were used as input to the RESRAD code. In lieu of site-specific values, NRC values, principally from NUREG/CR-5512, Volume 3 (NRC 1999a), NUREG/CR-5512, Volume 4 (NRC 1999b), and NUREG/CR-6697 (NRC 2000b); EPA *Soil Screening Guidance for Radionuclides: User's Guide* (EPA 2000); RESRAD default values; or information contained in the RESRAD manual (Yu 2001) were used to determine the selected inputs to the code.
- Each parameter and user input selection was evaluated individually and collectively for its appropriateness to the Site. As an example, distribution coefficients for specific elements of interest were ultimately determined based on the soil type comprising the contaminated zone. This was determined to be primarily silty clay loam (with some areas predominantly clay) (USDA 2006a). Corresponding values provided in Table 32.1 of the *RESRAD Data Collection Handbook To Support Modeling Impacts of Radioactive Material In Soil* (Yu 1993) were selected for this type of soil matrix. This same matrix and coefficient value was used for the unsaturated and saturated zones.
- The most recent version of RESRAD (Version 6.3) was used for this assessment.
- Where appropriate, parameter values were selected or determined using values provided by the EPA (EPA 2000).

2.3.2 Specific Justification for Parameter Selection

All parameters utilized in the RESRAD evaluations for natural thorium are listed with justifications for their selection in Appendix A.

The following parameters, taken from Appendix A, were specifically selected for further discussion.

2.3.2.1 Pathway Selection

Pathways applicable to the resident farmer scenario were selected. These included direct exposure from external sources, inhalation of dust, plant ingestion, water ingestion and soil ingestion. The meat, milk and aquatic food pathways were suppressed. Additionally, the radon pathway was suppressed for reasons previously discussed.

2.3.2.2 Source Term

Thorium-232 (^{232}Th), thorium-228 (^{238Th}) and radium-228 (^{228}Ra) constitute the principal radionuclides for the thorium decay chain. Secular equilibrium between the parent and decay products was assumed.

2.3.2.3 Radionuclide Concentrations

Unit concentrations of one picocurie per gram (1 pCi/g) for each of the Site radionuclides of concern were used. This approach provided dose-to-source ratios (DSRs), i.e., dose per unit concentration (mrem/y per pCi/g) which when divided into the primary dose limit resulted in a DCGL for that radionuclide in units of pCi/g.

2.3.2.4 Area of Contamination Zone

The contaminated zone is an area in which radionuclides are present in above background concentrations. The contaminated zone was modeled with no cover depth under the assumptions that contaminated silty clay loam existed to a depth of one meter. The primary case assumed a contaminated area of 10,000 square meters. Additional, smaller areas were then evaluated by reducing the contaminated area and length parallel to the aquifer while keeping all other parameters constant (in all cases the length parallel to the aquifer was assumed to be equal to the square root of the contaminated area).

2.3.2.5 Thickness of Contaminated Zone

Contamination was assumed to extent to a depth of 0.46 meters (one and a half feet). This was based on previous remediation requirements and results in a conservative approach since soil contamination in most remaining areas is expected to be found within the top 6 inches of soil (15 centimeters).

2.3.2.6 Cover Depth

The cover depth corresponds to the distance to the uppermost contaminated soil. No cover depth was assumed overlying the contaminated area for conservatism in the model.

2.3.2.7 Soil Density

The U.S. Department of Agriculture, Natural Resources Conservation Service, measured the density of soil samples obtained from many locations at the Site (USDA 2006b). For silty clay loam, which covers much of the Site, the soil density had a range of 1.2 to 1.7 grams per cubic centimeter (g/cc). This was obtained from samples from 0 to 60 inches below ground surface. Therefore, the RESRAD default of 1.5 g/cc was determined appropriate.

2.3.2.8 Elemental Distribution (partition) Coefficients (K_d)

This parameter is one of the most important to understand as it relates to contaminant migration and retardation in soil. Site-specific values for this parameter were not determined based on actual sample analysis, but were obtained from "look-up" values in Table 32.1 in the *RESRAD Data Collection Handbook To Support Modeling Impacts of Radioactive Material In Soil* (Yu 1993). Partition coefficients for elements in this table are provided for four different soil types; sand, loam, clay and organic. The following table provides the K_d values for the elements of concern at the Site for loam and clay soil types.

TABLE 2-1: ELEMENT PARTITION COEFFICIENTS (K_d)

Element	Loam K_d (cm^3/g)	Clay K_d (cm^3/g)
Thorium (Th)	3,300	5,800
Radium (Ra)	36,000	9,100

As indicated in the above Table, the K_d values for the two soil types are considerably different. However, the corresponding dose from the RESRAD model using natural thorium (and decay products) as the contaminant with K_d values for loam versus K_d values for clay do not differ. Therefore, K_d is not a sensitive parameter for natural thorium in soil at the Site.

2.3.2.9 Contaminated Zone Hydraulic Conductivity

The hydraulic conductivity, in meters per year (m/yr), for the contaminated zone (and unsaturated zone) were assumed to be a factor of 10 less than the saturated zone hydraulic conductivity for silty clay loam in Table 5.2 of the *RESRAD Data Collection Handbook To Support Modeling Impacts of Radioactive Material In Soil* (Yu 1993) or 5.36 m/yr.

2.3.2.10 Saturated Zone "b" Parameter

The soil specific exponential "b" parameter (unitless) is one of several hydrological parameters used to calculate the radionuclide leaching rate of the contaminated zone. The "b" parameters used in the Site model for the contaminated, unsaturated and saturated zones are 7.75 for silty clay loam and 11.40 for clay (Yu 1993).

2.3.2.11 Unsaturated Zone Thickness

The unsaturated zone thickness is the thickness of soil between the bottom of the contaminated zone and the water table. The unsaturated zone thickness used for the Site model is 1.54 meters. This value is derived by subtracting the contaminated zone thickness (0.46 meters) from the distance below ground surface to the water table, which for the Site is assumed to be 2 meters.

2.3.2.12 Groundwater Concentrations and Solubility Constants

The lack of site-specific groundwater and solubility data precluded the input of groundwater concentrations. The groundwater (water dependent) pathway for thorium was an "active" pathway for conservative dose modeling purposes. However, given the relatively immobile nature of thorium, groundwater contamination is not considered viable.

2.3.2.13 External Gamma Radiation Pathway

The external gamma pathway is the predominant, most significant pathway in the DCGL determination for thorium at the Site. Appendix A cites the input values selected for shielding factors and the fraction of time spent indoors/outdoors. For the resident gardener exposure scenario, these three values were obtained from the EPA (EPA 2000).

2.3.2.14 Ingestion Pathway

The significance of the dietary and non-dietary parameters on the DCGL determination is minimal for natural thorium. For the resident gardener exposure scenario, the parameter input values for the ingestion pathways were obtained from the EPA *Soil Screening Guidance for Radionuclides: User's Guide* (EPA 2000).

2.3.2.15 Radon Parameters

As noted previously, this pathway was "suppressed" in the evaluation.

3.0 RESULTS

Previous sections of this report have detailed the approach and methodology for determining the DCGL for natural thorium. This section utilizes the preceding information to provide the results of the dose assessments for natural thorium in soil at the Site.

3.1 Site-Specific DCGL

3.1.1 Radiological Parameter Inputs to the RESRAD Code

The following inputs and approach were applied to the RESRAD DCGL determination:

- Principal radionuclides and decay products are in secular equilibrium
    - natural thorium
- A normalized (unit) concentration of 1 pCi/g per radionuclide was applied.
- Doses were calculated (by radionuclide) as a function of time, up to 1,000 years.
- The peak dose over the 1,000 year time period was determined (per unit activity of the parent radionuclide).
- Resulting dose-to-source ratios (DSRs) were compared to the NRC regulatory exposure limit of 25 mrem per year, resulting in a DCGL (pCi/g), using the following equation:

DCGL (pCi/g) = 25 mrem / DSR (mrem per pCi/g)

3.1.2 RESRAD Results

3.1.2.1 Natural Thorium

Because natural thorium (^{232}Th and decay products) is the Site contaminant in soil within the areas of concern, this radionuclide, with decay products in secular equilibrium, was used in the model to investigate environmental transport and resulting exposure.

Dose Contribution from All Pathways

For the analysis of natural thorium in Site soil, the maximum (summed) dose of 6.21 mrem is delivered at time (t) = “0” years. This dose assumes a maximum contaminated area of 10,000 square meters, with a depth of contaminants in soil of 0.46 meters. Numerous additional evaluations were performed with reduced contaminated areas. As expected, the maximum (summed) dose delivered is reduced as the area is reduced. One important aspect of the evaluation is that the maximum delivered dose does not vary considerably when the contaminated area is 1,000 square meters or greater (up to the maximum of 10,000 square meters).

Significant Pathways

The external dose pathway for this model is the greatest contributor to the total dose delivered. As expected, the parameters associated with this pathway have the most significant impact on the total dose. These parameters include:

- Gamma shielding factor
- Fraction of time spent indoors (on an annual basis)
- Fraction of time spent outdoors (on an annual basis)

Natural Thorium Site-Specific DCGL

The maximum DSR for natural thorium (^{232}Th and decay products) in soil at the Site was determined to be:

5.61 mrem/yr per pCi/g

Using the equation in Section 4.1.1, the site-specific DCGL for natural thorium, determined by dividing the annual dose limit by the DSR, is:

Site-Specific DCGL = 25 mrem/5.61 mrem/yr per pCi/g = 4.46 pCi/g

As a conservative measure and in keeping with the ALARA requirement in 10 CFR 20, this has been rounded down to 4.0 pCi/g. Therefore, the final site-specific DCGL which can be applied to any portion of the Site is **4.0 pCi/g**.

This site-specific DCGL is applicable to ^{232}Th and each decay product under the assumption that all decay products are in secular equilibrium with the parent and possess radiological half-lives greater than 180 days (RESRAD recommended half-life cutoff for dose calculations). Therefore, if the ^{232}Th activity in Site soil does not exceed 4.0 pCi/g, the total dose to a future resident gardener will not exceed 25 mrem per year TEDE.

3.2 Area Factors

An area factor (A_m) is defined in NUREG-1575, *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)* (NRC 2000a), as follows:

> *A factor used to adjust $DCGL_w$ to estimate $DCGL_{EMC}$ and the minimum detectable concentration for scanning surveys in Class 1 survey units---$DCGL_{EMC} = DCGL_w \times A_m$. A_m is the magnitude by which the residual radioactivity in a small area of elevated activity can exceed the DCGLw while maintaining compliance with the release criterion.*

Area factors were generated for natural thorium in Site soil. To accomplish this, the RESRAD parameter for contaminated area size and length of contaminated area parallel to the aquifer (assumed to be equal to the square root of the contaminated area size) were adjusted while keeping all other parameters constant. The area factors were then computed by taking the ratio of the dose per unit concentration generated by RESRAD for the 10,000 square meter area to that generated for the smaller area. If the DCGL for residual radioactivity distributed over 10,000 square meters is multiplied by the area factor (for the appropriate contaminated area size), the resulting concentration distributed over the smaller area delivers the same calculated dose. Area factors for the Site are provided in Table 4-1.

TABLE 3-1: SITE AREA FACTORS

	Area Factor								
Nuclide	**1 m^2**	**5 m^2**	**10 m^2**	**50 m^2**	**100 m^2**	**300 m^2**	**1000 m^2**	**3000 m^2**	**10000 m^2**
Th-nat	10.3	3.6	2.5	1.5	1.4	1.2	1.0	1.0	1.0

An example of the use of the area factors is provided below:

> Assume that an area of interest at the Site is identified and the size of the contaminated area is 100 square meters. The adjusted natural thorium site-specific DCGL for this area is:

$$4.0 \text{ pCi/g} \times 1.4 = 5.6 \text{ pCi/g}$$

If the $DCGL_{EMC}$ is used, a final evaluation will be necessary to verify residual radioactivity within the survey unit results in a total effective dose equivalent not greater than 25 mrem year using MARSSIM Equation 8-2.

4.0 SUMMARY AND CONCLUSIONS

A site-specific DCGL for natural thorium in soil has been generated for use in remediation planning and/or verification that applicable regulatory dose requirements have been achieved at the Naval Station Great Lakes. In determining the DCGL several conservative and reasonable factors were utilized in the dose modeling assessments. These included:

- Selection of a resident gardener scenario as the conceptual site model and critical population group. Although it can't be ruled out, very few residents in urban areas actually use gardens for any significant amount of their dietary needs. Also, portions of the Site will most likely remain as industrial areas. However, the assessments performed assume the industrial area is used at some time in the future for urban residential expansion.
- No credit was taken for the potential dilution of contaminated soil with clean soil which will occur in the process of gardening, area renovations, landscaping and new construction.
- The depth of contamination in soil at the Site was assumed to be 0.46 meters. This was based on remediation performed in some areas of the Site.

Many other input parameters to the dose modeling code were used with justification for the use of all input parameters provided.

A unit concentration of 1 pCi/g for the Site radionuclides of concern (natural thorium with decay products in secular equilibrium) were used in the RESRAD evaluations. This approach provided dose-to-source ratios (DSRs) in units of mrem/yr per pCi/g, calculated for exposed individuals over a 1000 year time period. The DSRs represent the maximum dose to a member of the critical population group (resident gardener) over the 1000 year time period. A DCGL (pCi/g) for the radionuclide of concern in Site soil was determined by dividing the DSR into the primary dose limit of 25 mrem per year.

As a result of the RESRAD analysis, the site-specific DCGL for natural thorium in Site soil using resident gardener input parameters was determined to be **4.0 pCi/g**.

The site-specific DCGL represent the amount of soil contamination above background that would result in a total effective dose equivalent (TEDE) of 25 mrem to a member of the critical group in an area of 10,000 square meters uniformly contaminated with natural thorium to a depth of 0.46 meters. This DCGL is applicable to the parent, as well as each of the individual decay products associated with natural thorium.

5.0 REFERENCES

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