FINAL

SITE-SPECIFIC
DERIVED CONCENTRATION GUIDELINE LEVEL

ADDENDUM

NAVAL STATION GREAT LAKES
RADIOLOGICAL REMEDIATION
GREAT LAKES, ILLINOIS

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LIST OF ACRONYMS

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.

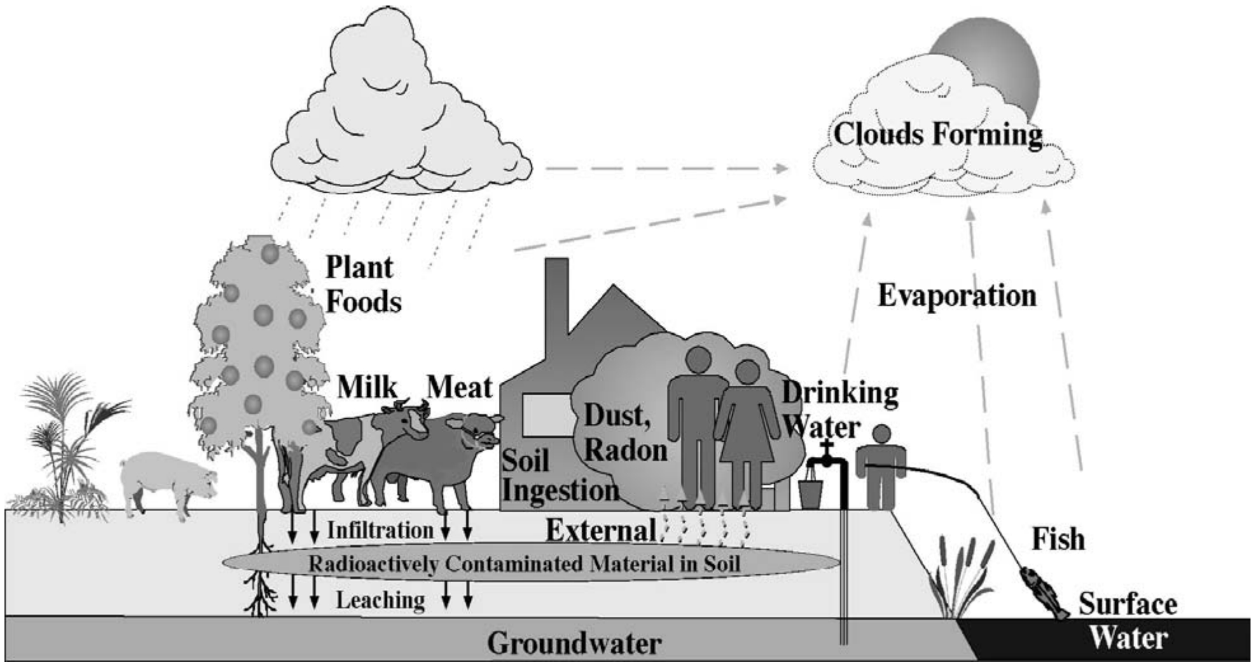

Figure 2-1: Exposure Pathways Considered in RESRAD

This is also presented schematically in Figure 2-2.

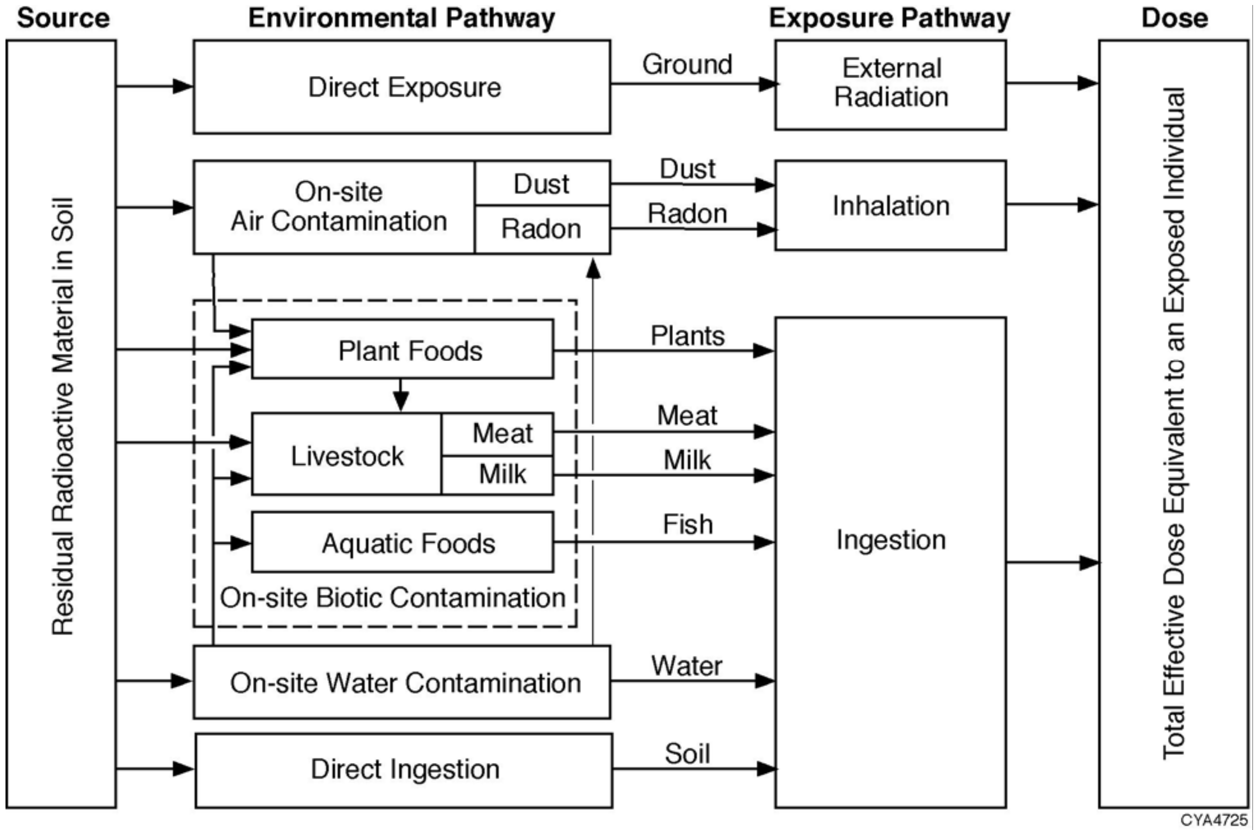

Figure 2-2: Schematic Representation of RESRAD Pathways

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.

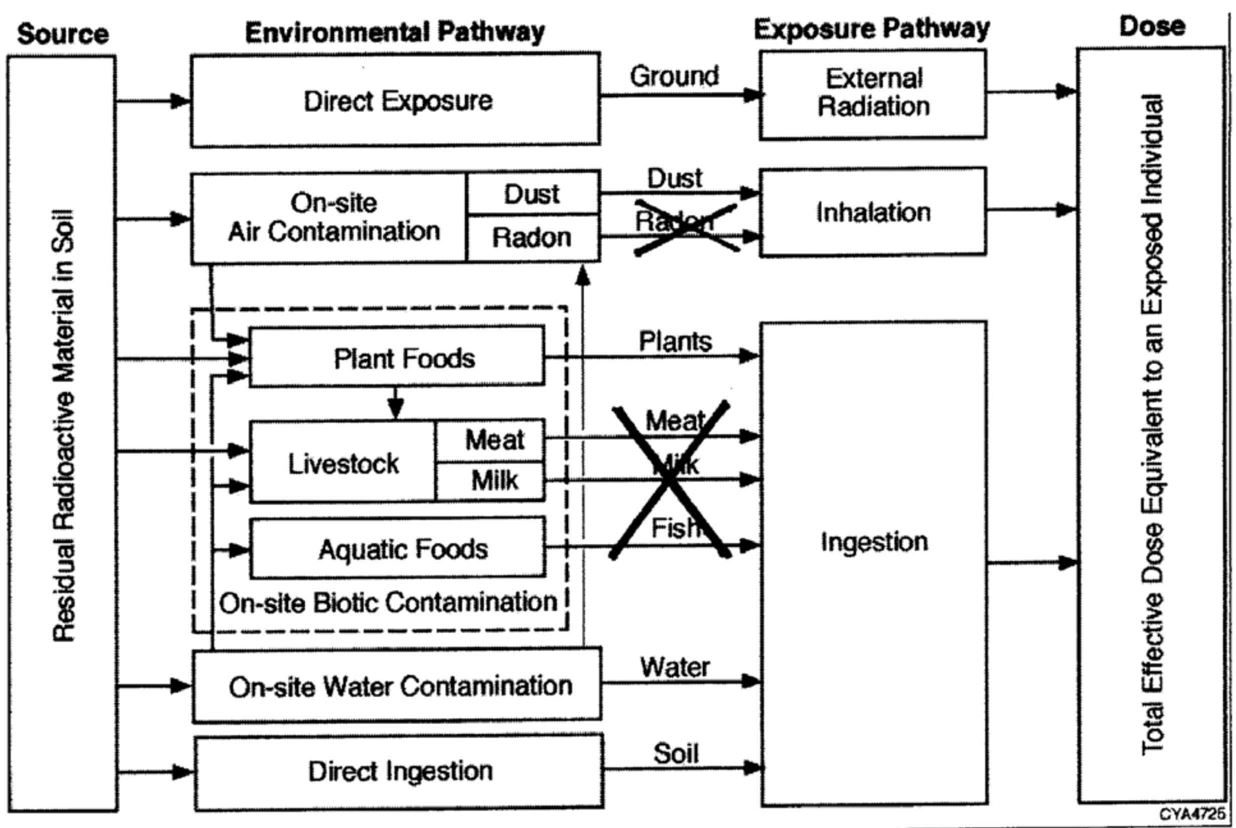

Figure 2-3: Adjusted Schematic of RESRAD Pathways for Resident Gardener

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 gardener 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 3.1.1, 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 3-1.

TABLE 3-1: SITE AREA FACTORS

Nuclide	Area Factor								
	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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ALARA	as low as reasonably achievable
bgs	below ground surface
CABRERA	Cabrera Services, Inc.
cc	cubic centimeter
CFR	Code of Federal Regulations
cm	centimeter
cm^3	cubic centimeter
CTA	center tank area
DCGL	derived concentration guideline level
DRMO	Defense Reutilization and Marketing Office
DSR	dose-to-source ratio
EPA	U. S. Environmental Protection Agency
EMC	elevated measurement comparison
g	gram
IL	Illinois
K_d	element partition coefficient
m	meter
m^2	square meter
MDC	minimum detectable concentration
NAVSTA	Naval Station
NFA	north fence area
NRC	U.S. Nuclear Regulatory Commission
pCi/g	picocurie per gram
PPV	Public Private Venture
RCOC	radiological contaminant of concern
TEDE	total effective dose equivalent
UIRB	Upper Illinois River Basin
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
yr	year
^{228}Ra	radium-228
^{228}Th	thorium-228
^{232}Th	thorium-232
U.S.	United States

EXECUTIVE SUMMARY

This report presents the site-specific derived concentration guideline level (DCGL) for the radiological contaminant of concern (RCOC) in soil at the Naval Station Great Lakes within an area designated for industrial use. The RCOC in soil within the industrial area, natural thorium and decay products in secular equilibrium, resulted from storage of monazite sand prior to 1974. The industrial use DCGL was developed to provide a realistic, site specific clean-up level based on reasonable site specific conditions. In determining the DCGL several conservative and reasonable factors were utilized in the dose modeling assessments.

As a result of the evaluations and RESRAD analysis presented in this report, the site-specific DCGL for natural thorium in soil within the Site industrial area for the scenario evaluated was determined to be **5 pCi/g**.

The site-specific DCGL represent the amount of soil contamination above background in the Site industrial area that would result in a total effective dose equivalent (TEDE) of 25 mrem to a member of the critical group (industrial worker) in an area of 10,000 square meters (m^2) uniformly contaminated with natural thorium to a depth of 1 meter. This DCGL is applicable to the parent, as well as each of the individual decay products associated with natural thorium.

Area factors have also been generated to account for areas of contaminated soil smaller than the area used in the model (10,000 m^2) as shown below.

SITE AREA FACTORS

Nuclide	Area Factor								
	1 m^2	**5 m^2**	**10 m^2**	**50 m^2**	**100 m^2**	**300 m^2**	**1000 m^2**	**5000 m^2**	**10000 m^2**
Th-nat	10.1	3.3	2.2	1.4	1.2	1.1	1.0	1.0	1.0

1.0 INTRODUCTION

This report presents the site-specific derived concentration guideline level (DCGL) for the radiological contaminant of concern (RCOC) in soil at the Naval Station Great Lakes (hereafter referred to as the Site) within an area designated for industrial use. The RCOC in soil within the industrial area resulted from storage of monazite sand prior to 1974. The industrial use DCGL was developed to provide a realistic, site specific clean-up level based on reasonable site specific conditions.

1.1 Purpose

The purpose of the analyses is to provide a site-specific, realistic DCGL in support of decisions regarding the need for additional remediation in the Site industrial area and demonstrating the industrial area is suitable for restricted use. Specifically, when the DCGL is applied to the final status survey and the survey data demonstrates that the DCGL has been satisfied, the requirements of Title 10, Code of Federal Regulations (CFR), Part 20, Paragraph 1403 (10 CFR 20.1403) for restricted release of the Site industrial area are achieved.

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

1.2 Site Description, Radiological History and Contaminants

1.2.1 Site Description

The Site is located in Lake County, Illinois, 36 miles north-northwest of Chicago and slightly west of the Lake Michigan shore, occupying an area of approximately 1,600 acres. The location of Lake County is presented in Figure 1-1.

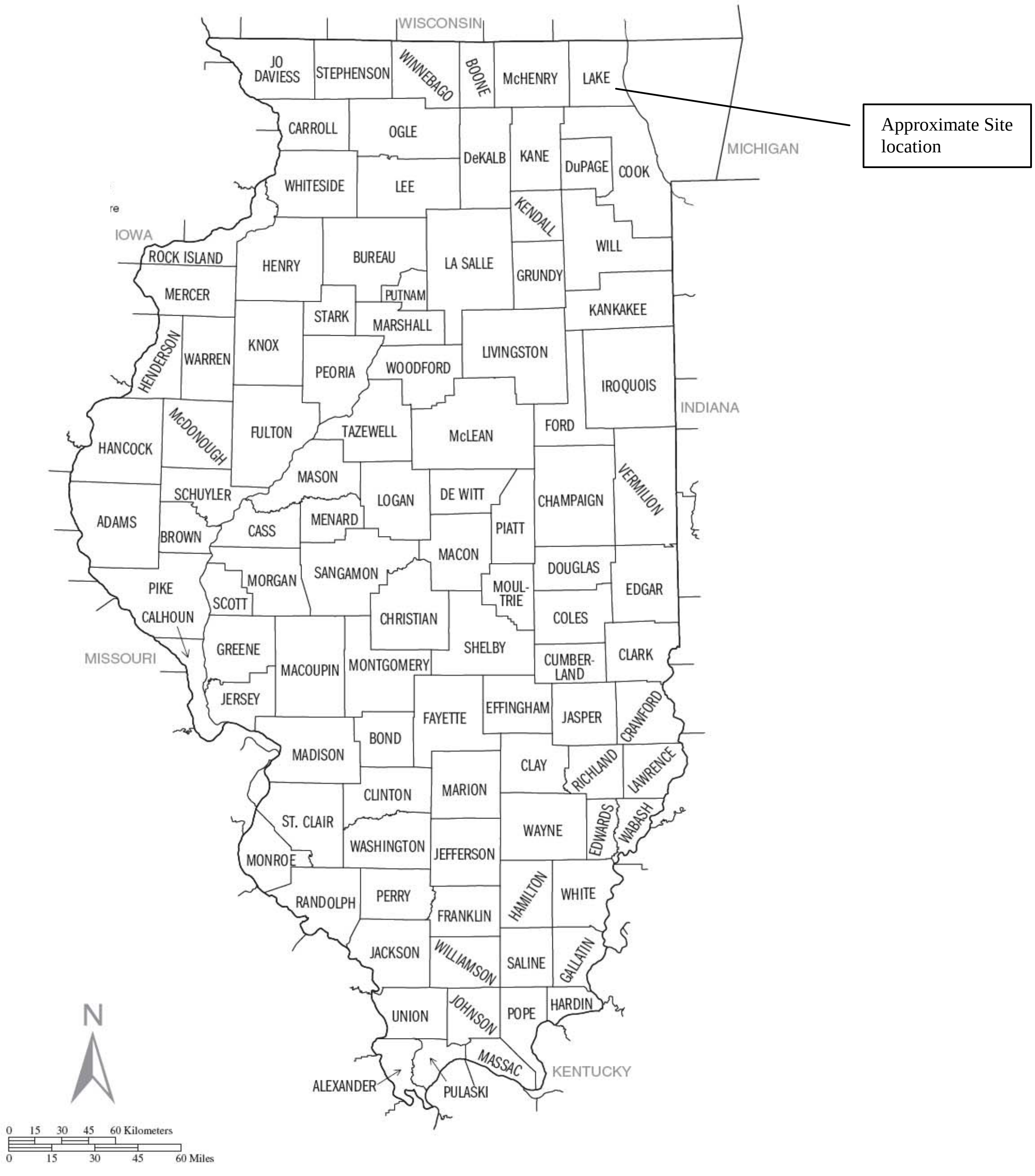

FIGURE 1-1: ILLINOIS COUNTY MAP

The Site is located in an urbanized area of the county, on the eastern edge of the Upper Illinois River Basin (UIRB) (USGS 1999). The U.S. Census Bureau estimated the Lake County population in 2005 to be 702,680. Like many urban areas in proximity to Lake Michigan, the Site obtains potable water from a public water supply. An aerial photograph of the Site, with the industrial area highlighted, is presented in Figure 1-2. As indicated in this figure, the Site industrial area boundaries generally coincide with the Site property boundaries to the north, west and south, and Mississippi Street to the east (Mississippi Street turns into Superior Street south of Ontario Court).

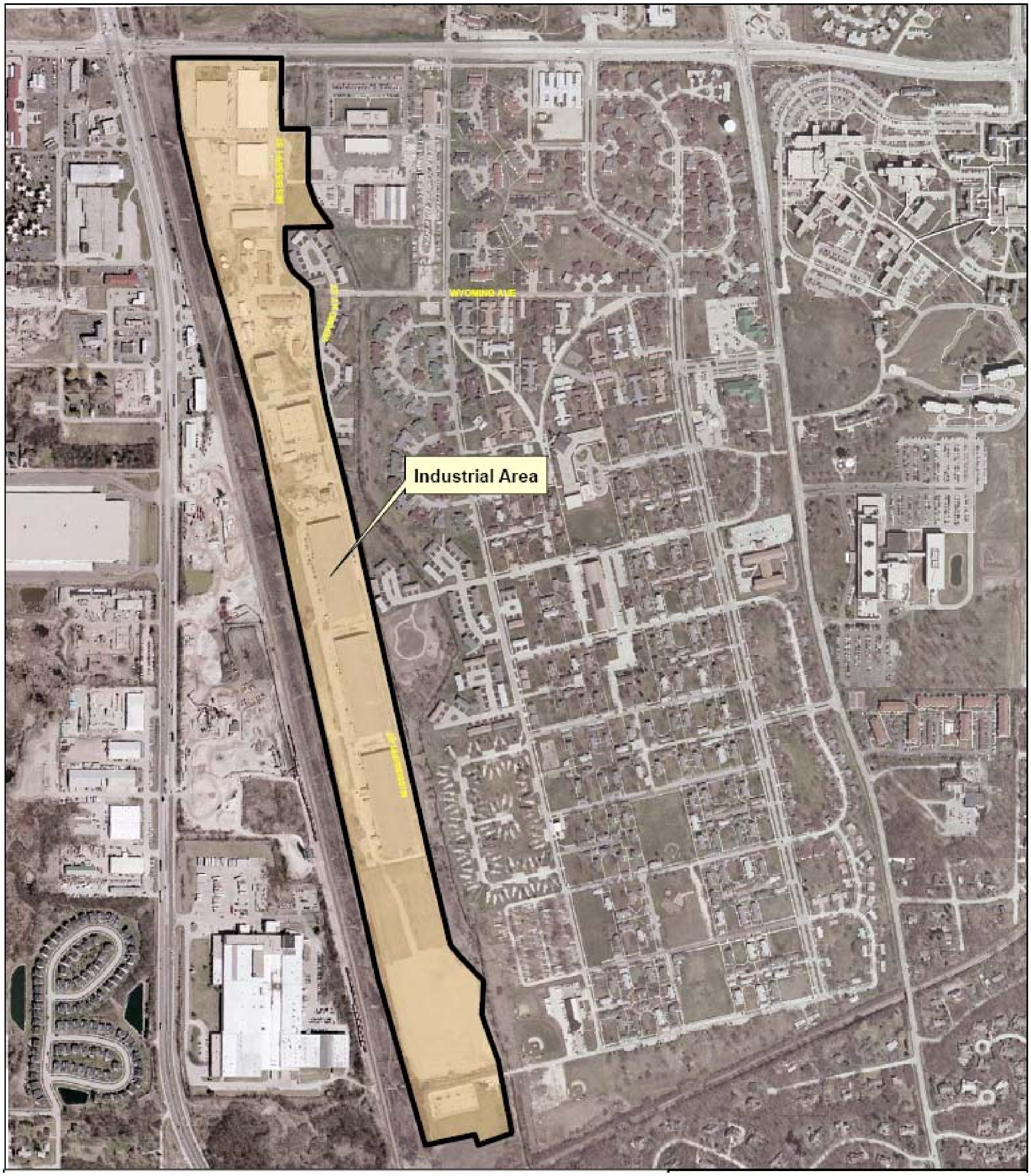

FIGURE 1-2: AERIAL VIEW OF NAVAL STATION GREAT LAKES

1.2.2 Radiological History

In 1974 the U.S. Atomic Energy Commission (AEC) granted a license (license number STE-8179) to Engelhard Minerals & Chemicals to package and ship a strategic stockpile of monazite sand from the Site. This sand was reportedly shipped to Holland in 1974. In January 2000, the NRC found residual monazite sand during a confirmatory survey of the previous AEC decommissioning of the Site. The NRC found elevated areas of gamma activity on the north side of the former monazite sand storage area along the fence near the Defense Reutilization and Marketing Office (DRMO) facility (North Fence Area). In the spring of 2000, CABRERA Services, Inc. (CABRERA) performed a detailed site characterization of the North Fence Area (NFA) that confirmed the NRC findings and identified several other areas of elevated concentrations of thorium-232 (^{232}Th). The final characterization report identified a monazite sand area of concern approximately 90,000 square meters (m^2) in the tank farm area of the Site (Center Tank Area).

In 2004, as part of a removal action, CABRERA characterized the remainder of this portion of the Site, with results published in a technical memorandum. It was estimated that an additional 1,526 cubic yards of material required remediation. As part of Phase III and Phase IV, CABRERA performed remediation in the NFA, Center Tank Area (CTA) and the area just south of the CTA referred to as the Recreation Area. Final status surveys in the CTA performed by CABRERA and scoping surveys completed by the NRC showed additional areas of contamination above the existing clean-up goal of 1 picocurie per gram (pCi/g) above background (NRC default surface soil screening value). This included some areas at the boundary of the original footprint remediated under Phase IV at a greater depth than anticipated and over a larger area than previously identified. Additionally, the NRC identified contamination up to 20 pCi/g at the headwall of a drainage pipe that empties into Skokie ditch. The headwall is in the northern portion of the Site industrial area.

The former monazite sand storage area, NFA, CTA, recreation area and the headwall discussed above are all contained within the Site industrial area.

1.2.3 Radiological Contaminants of Concern

The RCOC associated with monazite sand is natural thorium and the decay products from natural thorium. Since the monazite sand was stored in its natural, unprocessed form at the Site, the decay products associated with natural thorium remain in the same concentrations as would be found in locations where these sands occur in nature. Therefore, the decay or daughter products for natural thorium would remain in secular equilibrium with the parent radionuclide.

The parent radionuclide in the natural thorium decay chain, ^{232}Th, decays by emitting alpha particles. The daughter products in the natural thorium decay chain decay by emission of alpha or beta particles, some with accompanying emission of gamma rays. The decay scheme for natural thorium is provided in Figures 1-3.

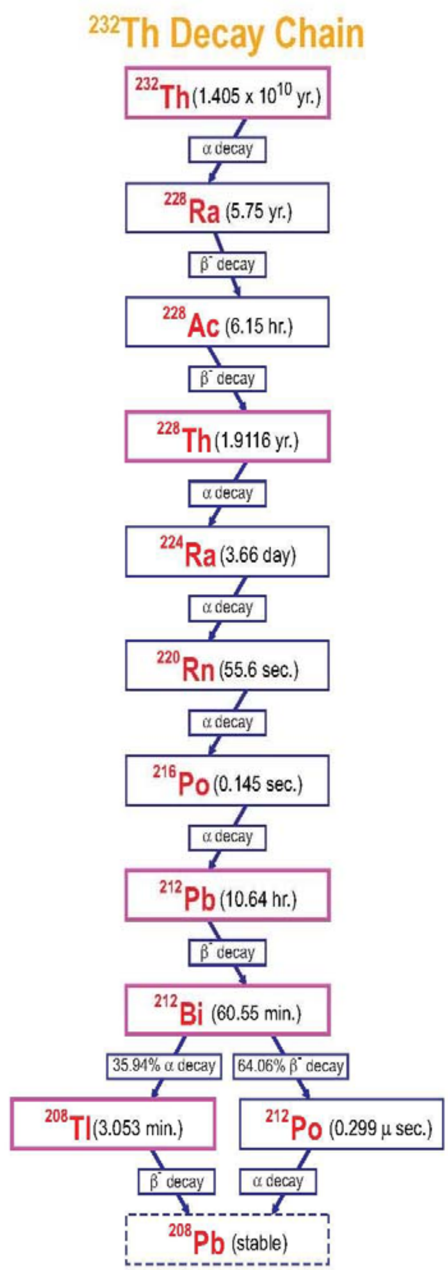

FIGURE 1-3: THORIUM 232 DECAY CHAIN

1.2.4 Radionuclides Present in Monazite Sand[1]

Thorium is a naturally occurring radioactive element commonly found in very small amounts in rocks, soil, sand, water, plants and animals, including humans. The radioactivity of thorium in the environment is typically very low and contributes to low levels of natural background radiation. A higher concentration of natural thorium (^{232}Th) is found in certain sands, such as monazite sand. Table 1-1 provides the specific activity and radiological half-life of ^{232}Th.

TABLE 1-1: THORIUM 232 RADIOLOGICAL INFORMATION

Specific Activity (Ci/g)	**Half-life (years)**
1.10E-07	1.405E10

Monazite sand differs from most other environmental media in that it contains much higher concentrations of natural thorium, specifically ^{232}Th. The percentage of ^{232}Th in monazite sand has a range of 3 to 10 percent.

1.2.5 Potential or Known Contaminated Media

The following environmental media at the Site have been identified as contaminated through sampling or evaluated for potential contamination: surface soil, subsurface soil, surface water, groundwater, and structures.

1.2.5.1 Soil

Surface soil is defined as the top layer (15 centimeters) of soil on the Site. Subsurface soil is any solid materials not considered to be surface soil. Soil contamination has resulted from the storage of monazite sand, migration of the contaminated material by natural methods (wind, rain, etc) and the possible use of monazite sand or soil mixed with monazite sand as fill material, although there are no records indicating this occurred. Extensive surveys and sampling have been performed at the Site. As a result, several areas have been remediated by removal and disposal of contaminated soil. Since prior remediation in some areas required excavation below the surface soil layer, the thickness of the contaminated soil is assumed to be 1 meter for the purpose of site-specific DCGL determination. Although soil contamination in most areas is limited to surface soil, a contaminated soil thickness of 1 meter results in a conservative approach to DCGL determination.

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[1] Throughout this section, natural thorium refers to ^{232}Th.

1.2.5.2 Surface Water and Groundwater

There is no evidence of surface water or groundwater contamination at the Site and is not expected due to a lack of significant source term. Also, because of the low mobility of thorium in soil, the contamination of surface water and groundwater is considered an unlikely current or future event.

1.2.5.3 Structures

Monazite sand was stockpiled in outdoor areas at the Site. This material was not processed, handled or stored within structures, other than tanks. Therefore, there is no evidence to indicate that any structure on the Site may contain residual surface contamination.

2.0 GENERAL ENVIRONMENTAL AND PHYSICAL SITE CHARACTERISTICS

As discussed in Section 1.0, the Site is located in Lake County, Illinois. Lake County, with an area of 301,435 acres or about 471 square miles, is in the northeast corner of Illinois. Lake County is bordered by Cook County on the south, McHenry County on the west, Kenosha County, Wisconsin on the north and Lake Michigan on the east. Lake County has a temperate, humid continental climate, which has had an important influence on the characteristics of the soils. However, the climate is essentially uniform throughout the county and has not caused any major differences among the soils (USGS 1999).

Lake County is overlain by a thick (mostly greater than 250 feet) succession of Quaternary deposits that resulted from the multiple glacial advances of the last glaciation (Wisconsian period, approximately 17,000 to 12,000 years ago). Each time glaciers of the Lake Michigan lobe advanced out of and retreated into the Lake Michigan basin a layer of glacial, fluvial and lacustrine materials was deposited. Because the ice from earlier advances did not completely melt from the area before subsequent ice advanced, the sediment layers were modified by dead-ice sedimentation during deglaciation.

The Site is located in the southeastern portion of Lake County, in close proximity to Lake Michigan, with portions set aside for industrial use. The terrain is generally flat, with minimal slopes. The land surface is approximately 585 feet above sea level, covering an area of approximately 1,600 acres. The annual average precipitation is 35.82 inches per year (0.91 meters per year) and the annual average wind speed is 10.4 miles per hour (4.65 meters per second). In winter, the average temperature is 23.9 degrees Fahrenheit (F) and, in summer, the average temperature is 69.1 degrees F, with an annual average temperature of 49.8 degrees F.

The U.S. Geological Survey (USGS) has established numerous study areas as part of the National Water Quality Assessment Program. One of these study areas is the Upper Illinois River Basin (UIRB), which is subdivided into four sub-basins: the Kankakee, Illinois, Fox and Des Plaines River Basins. The Site lies on the northeastern edge of the Upper Illinois River Basin (UIRB), at the edge of the Des Plaines sub-basin (USGS ND). A depiction of the UIRB is provided in Figure 2-1.

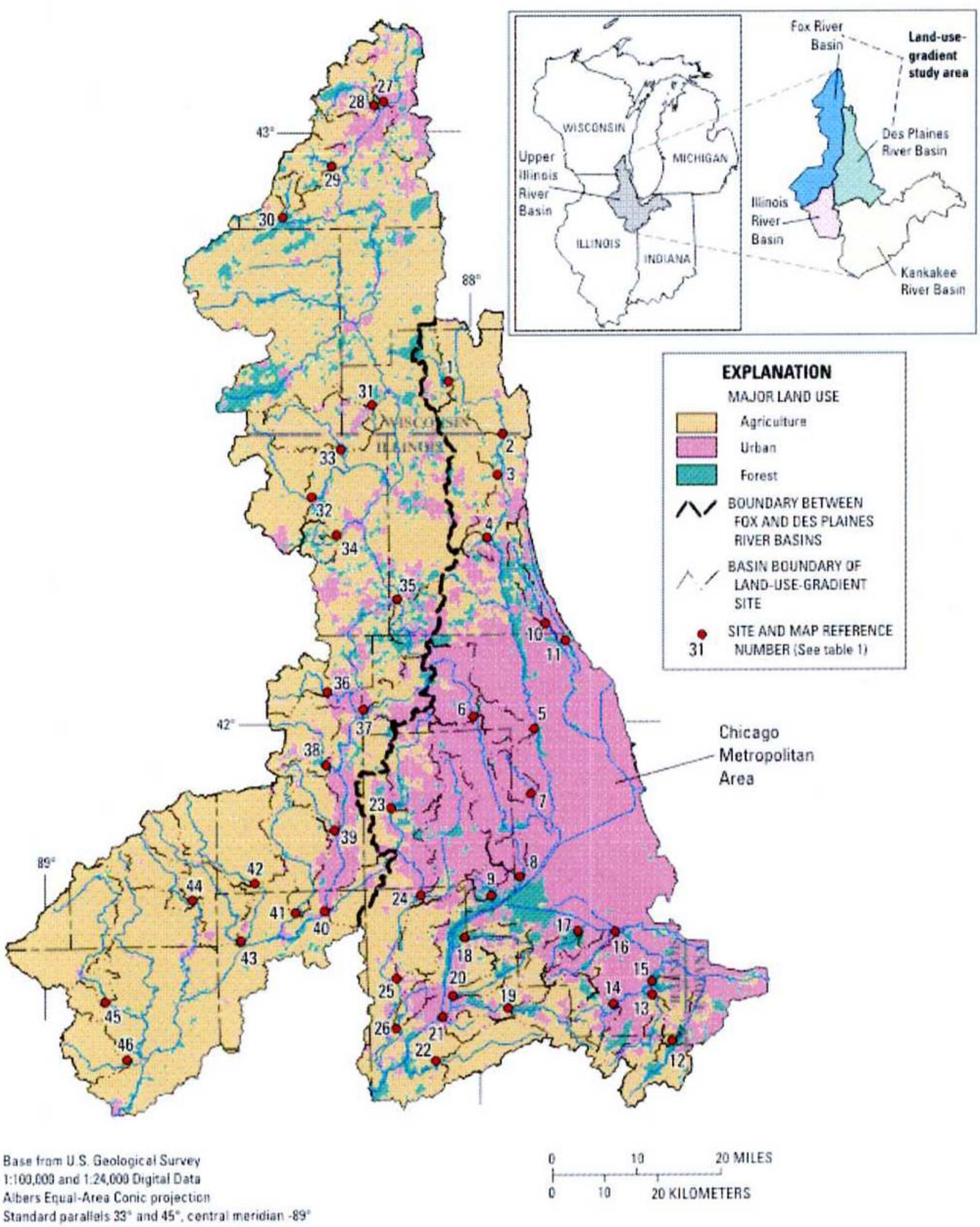

FIGURE 2-1: UPPER ILLINOIS RIVER BASIN AND SUB-BASINS

The entire UIRB is underlain by Precambrian granite rocks at depths of about 1,000 feet below land surface in the northern part of the basin. The Precambrian rocks are overlain by sedimentary rocks of the Cambrian System. These sedimentary rocks are predominantly sandstone. The Cambrian rocks are about 1,000 feet thick in the northern part of the UIRB. Ordovician-aged rocks overlie the Cambrian rocks and are composed predominantly of limestone and dolomite. The Ordovician rocks are less than 1,000 feet thick in the northern portion of the UIRB. The uppermost bedrock units of the Des Plaines River Basin are predominantly undifferentiated Silurian-Devonian dolomite and limestone.

Overlying soil at the Site is predominantly silty clay loam, with 0 to 4 percent slopes. The western portion of the site, however, is predominantly clay (USDA 2006a). Both soil types exhibit very low permeability and water infiltration rates (USDA 2006b).

Groundwater level is estimated to be 2 meters below ground surface at the Site. This is a conservative estimate since site-specific data is not available.

3.0 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 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, including decay products; and
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 20.1403. Microsoft Excel was utilized to generate additional output results based on the dose assessment model results.

3.1 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 specified in 10 CFR 20.1403, *Criteria for license termination under restricted conditions*, 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 industrial area.

3.2 Conceptual Site Model

The conceptual site model has been developed on the basis of Site review, how the industrial portion of the Site is currently used and the most probable use of this area of the Site once released for restricted use, and a complete understanding of the most relevant exposure pathways to the critical group at the Site, defined as an industrial worker.

Figure 3-1, from the *Users Manual for RESRAD Version 6* (Yu 2001), presents all potential exposure pathways, using a worst case, resident farmer exposure scenario.

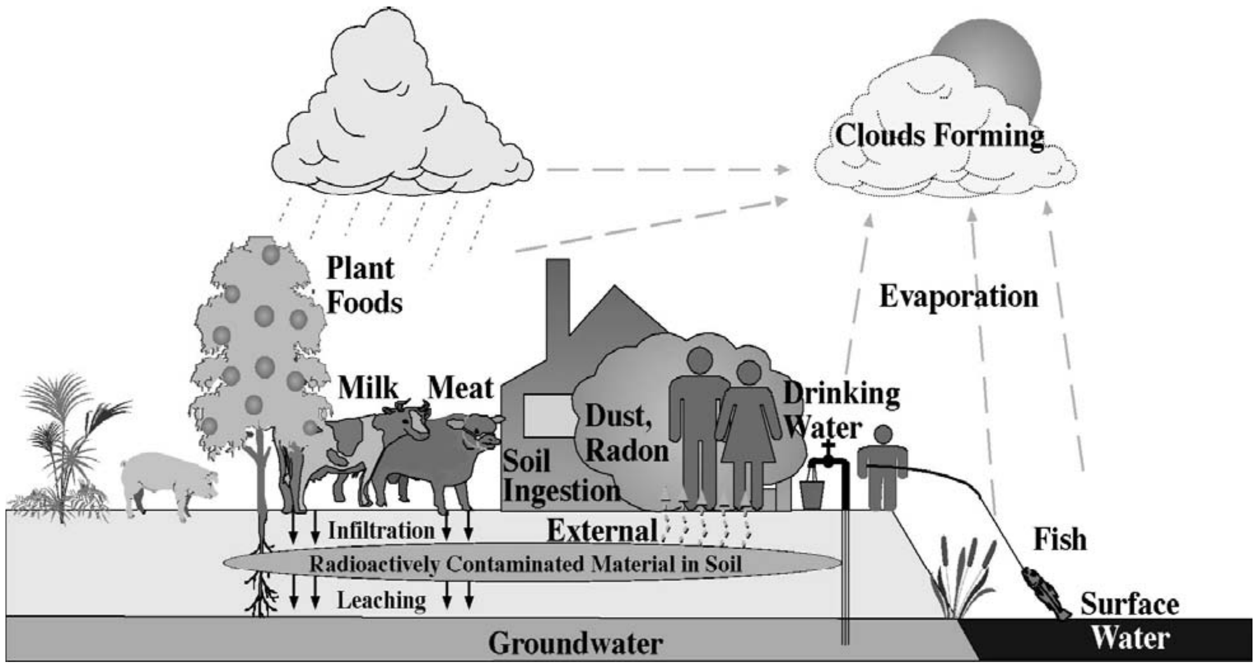

FIGURE 3-1: EXPOSURE PATHWAYS CONSIDERED IN RESRAD

This is also presented schematically in Figure 3-2.

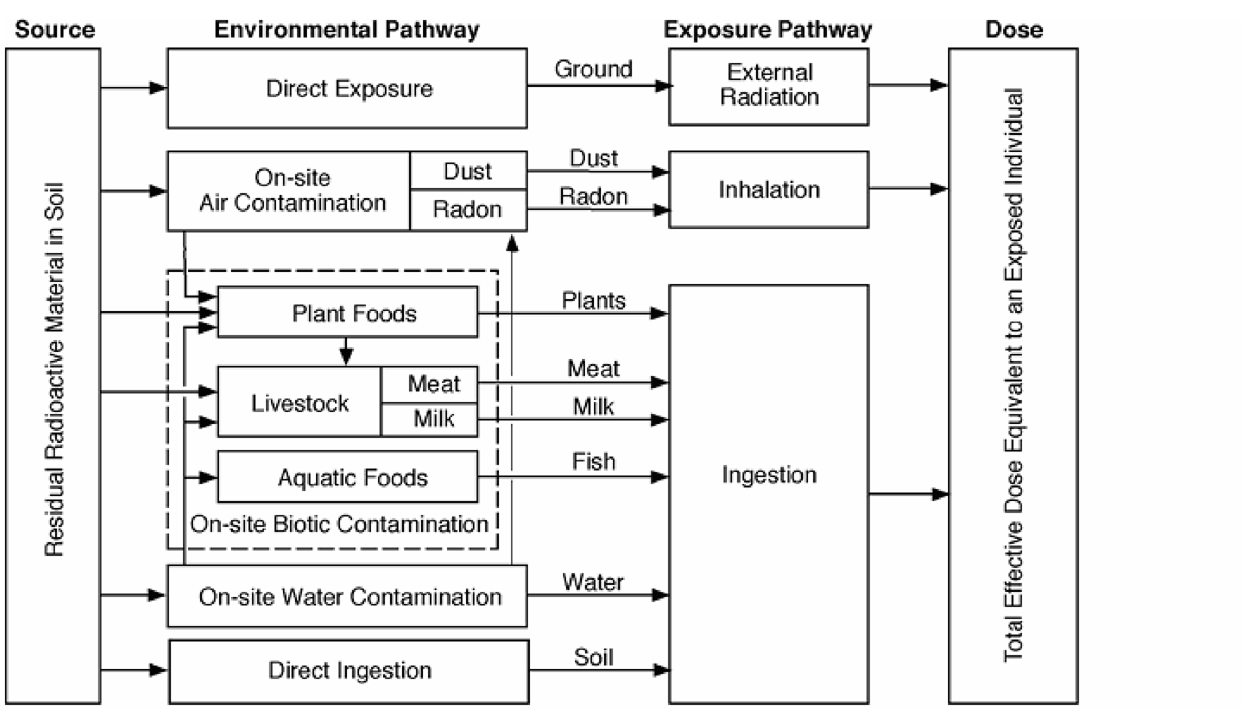

FIGURE 3-2: SCHEMATIC REPRESENTATION OF RESRAD PATHWAYS

As mentioned previously, Figures 3-1 and 3-2 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. Section 1.0 of this report provides a discussion of the Site location and current use. As discussed, the Site is currently federally owned and designated for industrial use and will continue to be used for industrial purposes in the foreseeable future. Hence, the industrial worker scenario was selected as the receptor scenario for the site.

Under this scenario, the industrial worker is assumed to work at the Site following restricted release. An industrial worker is modeled as a typical site worker who spends most of the time outdoors. The worker will be at the site for 25 years (EPA 1991a). A typical industrial worker usually spends 250 days per year at the site. As a conservative approach, the site specific DCGL is derived assuming an industrial worker will spend 300 days per year at this site, with a 10-hour work day. During the 10-hour working day, the worker is assumed to spend 2 hours indoors and 8 hour outdoors. Based on EPA guidance document, the indoor and outdoor soil ingestion rates for a worker are 50 and 480 milligrams (mg) per day, respectively (EPA 1991b). Therefore, the time-weighted soil ingestion rate for the worker is 143.8 grams (g) per day. Based on NUREG/CR 5512, the indoor and outdoor inhalation rates for the receptor are 0.9 and 1.4 cubic meters (m^3) per hour respectively, so the weighted inhalation rate for the receptor is 11,388 m^3 per year (yr) (NRC 1999).

Also, there are no bodies of water on the Site of sufficient size to support aquatic life to provide a source of food for an industrial worker scenario. Therefore, the aquatic foods pathway is not considered in the Site model. In addition, plant ingestion pathways are not considered for the industrial worker scenario. Although potable water is supplied to the Site, including the industrial area, by public water sources, as a conservative approach, the industrial worker scenario developed for the Site assumes the receptor 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. Additionally, sufficient restrictions are in place at the Site to prohibit installation of wells for the purpose of obtaining potable water. However, it will be shown that leaving the water pathway "on" in the analysis has no impact on the resulting site-specific DCGL for natural thorium compared to values generated with the water pathway suppressed.

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 industrial worker scenario include:

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

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

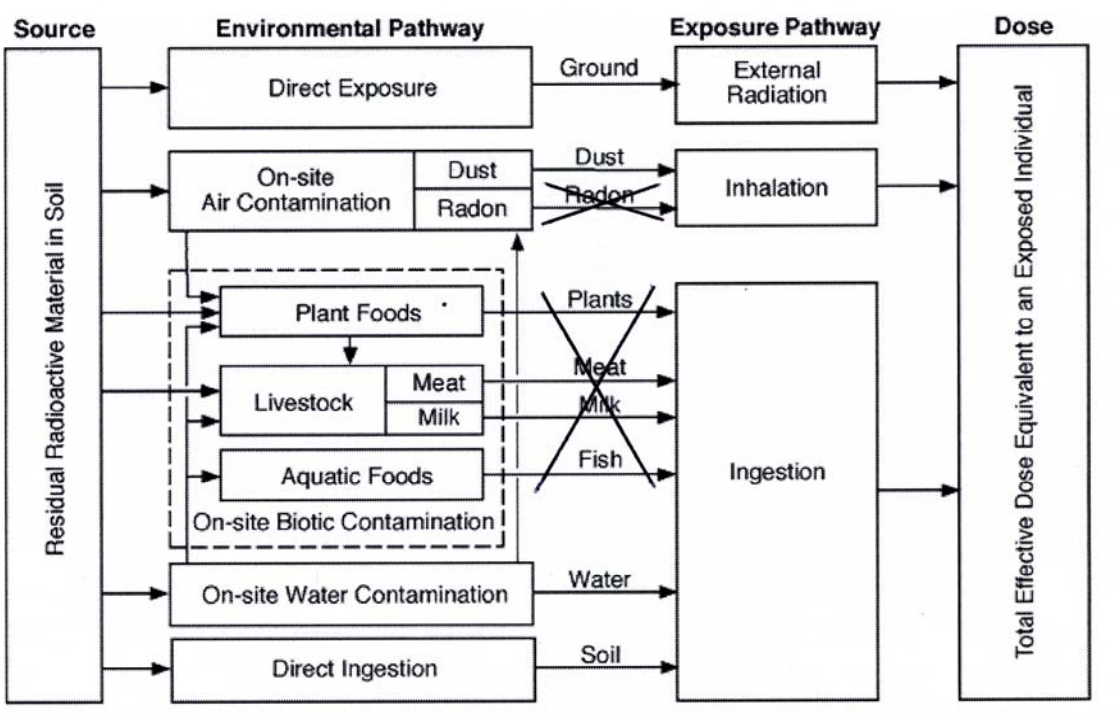

FIGURE 3-3: ADJUSTED SCHEMATIC OF RESRAD PATHWAYS FOR INDUSTRIAL WORKER

As will be shown, direct exposure to radiation from soil contamination, i.e., external radiation, results in the greatest contribution to dose. Consumption of water from a well placed on the property has no contribution to the dose.

3.3 RESRAD Input Parameters

3.3.1 General Basis for the Dose Modeling Assessment

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

- The industrial worker scenario is applicable to soils at the Site within the industrial area;
- 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); *Risk Assessment Guidance for Superfund: Volume I - Human Health Evaluation Manual* (Part B, Development of Risk-based Preliminary Remediation Goals) (EPA 1991a), *Risk Assessment Guidance for Superfund, Volumes 1: Human Health Evaluation Model* (EPA 1991b); *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; and
- Where appropriate, parameter values were selected or determined using values provided by the EPA (EPA 2000).

3.3.2 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 input/output reports for the RESRAD results are provided in Appendix B.

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

3.3.2.1 Pathway Selection

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

3.3.2.2 Source Term

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

3.3.2.3 Radionuclide Concentrations

A unit concentration of 1 pCi/g for the Site RCOC was 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.

3.3.2.4 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 m^2. 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).

3.3.2.5 Thickness of Contaminated Zone

Contamination was assumed to extend to a depth of one meter. 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).

3.3.2.6 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.

3.3.2.7 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.

3.3.2.8 Elemental Distribution (partition) Coefficients (Kd)

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 3-1: 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 Table 3-1, 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.

3.3.2.9 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.

3.3.2.10 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).

3.3.2.11 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 meter. This value is derived by subtracting the contaminated zone thickness (1 meter for the Site) from the distance below ground surface to the water table, which for the Site is assumed to be 2 meters.

3.3.2.12 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. Additionally, sufficient restrictions are in place at the Site to prohibit installation of wells for the purpose of obtaining potable water.

3.3.2.13 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 industrial worker exposure scenario, these three values were obtained from the NRC guidance document (NRC 2000).

3.3.2.14 Ingestion Pathway

The significance of the dietary and non-dietary parameters on the DCGL determination is minimal for natural thorium. For the industrial worker 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).

3.3.2.15 Radon Parameters

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

4.0 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.

4.1 Site-Specific DCGL

4.1.1 Radiological Parameter Inputs to the RESRAD Code

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

- The RCOC (natural thorium) and decay products are in secular equilibrium;
- 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); and
- 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)

4.1.2 RESRAD Results

4.1.2.1 Natural Thorium

Because natural thorium (^{232}Th and decay products) is the Site RCOC in soil within the industrial area, 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 4.99 mrem is delivered at time (t) = “0”. This dose assumes a maximum contaminated area of 10,000 m^2, with a depth of contaminants in soil of 1 meter. 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 m^2 or greater (up to the maximum of 10,000 m^2).

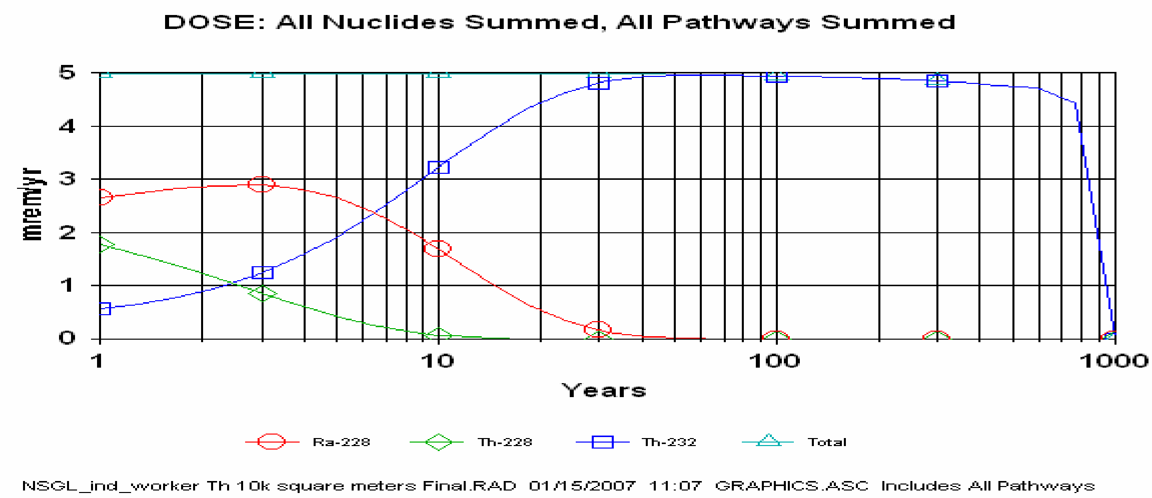

FIGURE 4-1: TOTAL DOSE FOR NATURAL THORIUM, ALL NUCLIDES SUMMED, ALL PATHWAYS SUMMED

Significant Pathways

The external dose pathway clearly drives the DCGL for this environmental model and therefore has the most significant impact on the potential dose to the critical group, as depicted in Figure 4-2.

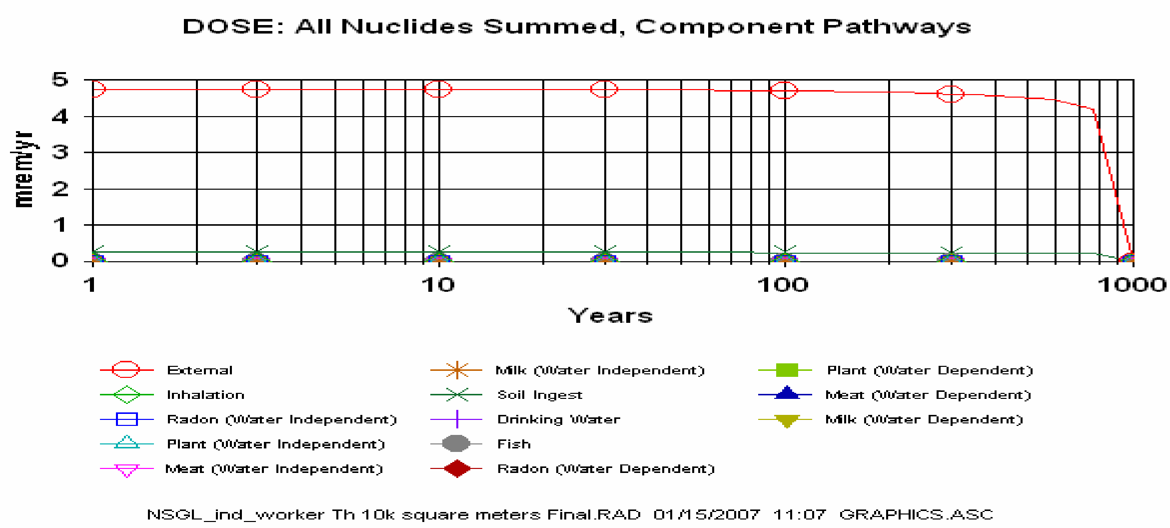

FIGURE 4-2: TOTAL DOSE ALL NUCLIDES (THORIUM CHAIN) SUMMED, COMPONENT PATHWAYS

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); and
- 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 for the industrial scenario was determined to be:

4.99 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/4.99 mrem/yr per pCi/g = 5 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 5 pCi/g, the total dose to a future industrial worker will not exceed 25 mrem per year TEDE.

4.2 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 m^2 area to that generated for the smaller area. If the DCGL for residual radioactivity distributed over 10,000 m^2 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 4-1: 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**	**5000 m^2**	**10000 m^2**
Th-nat	10.1	3.3	2.2	1.4	1.2	1.1	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 m^2. The adjusted natural thorium site-specific DCGL for this area is:

$$5 \text{ pCi/g} \times 1.2 = 6 \text{ pCi/g}$$

5.0 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 for the industrial area at the NAVSTA Great Lakes. In determining the DCGL several conservative and reasonable factors were utilized in the dose modeling assessments. These included:

- Selection of an industrial worker scenario as the conceptual site model and critical population group. The industrial worker scenario selected during this evaluation is much more conservative than a typical industrial worker (300 days/year versus 250 days/year, 10 hours/day versus 8 hours workday). An industrial worker typically spends most of the time indoors. However, this evaluation assumed that the industrial worker scenario for this site will spend most of the time outdoors (even more than typical residential receptor) to take account for the dose related to external gamma pathway as external gamma pathway is the predominant dose contributor for the site;
- 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; and
- The depth of contamination in soil at the Site was assumed to be 1 meter. 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 RCOC (natural thorium with decay products in secular equilibrium) was used in the RESRAD evaluations. This approach provided a dose-to-source ratio (DSRs) in units of mrem/yr per pCi/g, calculated for exposed individuals over a 1000 year time period. The DSR represent the maximum dose to a member of the critical population group (industrial worker) over the 1000 year time period. A DCGL (pCi/g) for the RCOC 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 soil within the Site industrial area for the scenario evaluated was determined to be **5 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 (industrial worker) in an area of 10,000 m^2 uniformly contaminated with natural thorium to a depth of 1 meter. This DCGL is applicable to the parent, as well as each of the individual decay products associated with natural thorium.

Area factors have also been generated to account for contaminated soil areas smaller in size than the area used in the model (10,000 m^2). These area factors are presented in Table 4-1.

6.0 REFERENCES

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(NRC 1999a) NUREG/CR-5512, Vol. 3, *Residual Radioactive Contamination from Decommissioning, Parameter Analysis, Draft Report for Comment*, U.S. Nuclear Regulatory Commission, August 1999.

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(USDA 2006b) *Physical Soil Properties, Lake County, Illinois*, Tabular Data, U.S. Department of Agriculture, National Resources Conservation Service, obtained November, 2006

(USGS 1999) Water-Resources Investigations Report 98-4268, *Environmental Setting of the Upper Illinois River Basin and Implications for Water Quality*, U.S. Geological Survey, 1999

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(Yu 2001) ANL/EAD-4, *User's Manual for RESRAD Version 6*, Argonne National Laboratory, C. Yu, et. al., July 2001.

(Yu 2005) *RESRAD for Windows*, Version 6.3, Computer Code, Argonne National Laboratory, Environmental Assessment Division, C. Yu, et. al., August 25, 2005.

APPENDIX A

RESRAD INPUT PARAMETERS

NAVAL STATION GREAT LAKES
DEFAULT AND RECOMMENDED VALUES FOR RESRAD INPUT PARAMETERS

RESRAD Version 6.3					Parameter Justification	
Parameter	**Code**	**Default Value**	**User Input Value**	**Units**	**Comments**	**Reference**
PATHWAY SELECTIONS						
External Gamma	N/A	Active	Active	N/A	N/A	N/A
Inhalation (without radon)	N/A	Active	Active	N/A	N/A	N/A
Plant Ingestion	N/A	Active	Active	N/A	N/A	N/A
Meat Ingestion	N/A	Active	**Inactive**	N/A	Not applicable for resident gardener	N/A
Milk Ingestion	N/A	Active	**Inactive**	N/A	Not applicable for resident gardener	N/A
Aquatic Foods	N/A	Active	**Inactive**	N/A	Not applicable for resident gardener	N/A
Drinking Water	N/A	Active	Active	N/A	N/A	N/A
Soil Ingestion	N/A	Active	Active	N/A	N/A	N/A
Radon	N/A	Inactive	Inactive	N/A	Not applicable per Federal Register, 1994, p. 43210	NRC 1994
CONTAMINATED ZONE PARAMETERS						
Area of contaminated zone	AREA	10,000	10,000	m^2	The RESRAD default is used as the base case for natural thorium.	Yu 1993 (Section 30)
Thickness of contaminated zone	THICK0	2	**0.46**	m	A conservative approach was selected to define this parameter. The thickness was determined based on previous remediation history at portions of the facility.	Yu 1993 (Section 39)
Length parallel to the aquifer	LCZPAQ	100	100	m	For all cases, the length parallel to the aquifer was calculated as the square root of the contaminated zone area.	Yu 1993 (Section 16)
Times for calculations	TI	1, 3, 10, 30, 100, 300, 1000	1, 3, 10, 30, 100, 300, 1000	yr	RESRAD defaults for calculation times.	Yu 2001
COVER AND CONTAMINATED ZONE HYDROLOGICAL DATA						
Cover depth	COVER)	0	0	m	As a conservative approach for dose modeling, no cover depth was assumed.	Yu 1993 (Section 31)
Density of cover material	DENSCV	1.5	**N/A**	g/cm^3	Lack of cover depth precludes an assigned value for this parameter.	Yu 1993 (Section 2)
Cover erosion rate	VCV	0.001	**N/A**	m/yr	Lack of cover depth precludes an assigned value for this parameter.	Yu 1993 (Section 14)

NAVAL STATION GREAT LAKES
DEFAULT AND RECOMMENDED VALUES FOR RESRAD INPUT PARAMETERS

RESRAD Version 6.3					Parameter Justification	
Parameter	**Code**	**Default Value**	**User Input Value**	**Units**	**Comments**	**Reference**
Density of contaminated zone	DENSCZ	1.5	1.5	g/cm^3	Soil density range from samples obtained by USDA at the site was 1.2 to 1.7. The RESRAD default was chosen as a reasonable average.	USDA 2006b Yu 1993 (Section 2)
Contaminated zone erosion rate	VCZ	0.001	0.001	m/yr	RESRAD default used.	Yu 1993 (Section 14)
Contaminated zone total porosity	TPCZ	0.4	0.4	unitless	RESRAD default used as an estimate of the total porosity	Yu 1993 (Section 3)
Contaminated zone field capacity	FCCZ	0.2	0.2	unitless	RESRAD default used as an estimate of field capacity	Yu 2001
Contaminated zone hydraulic conductivity	HCCZ	10	**5.36**	m/yr	Assumed to be a factor of 10 less than the saturated zone hydraulic conductivity for silty clay loam from Table 5.2 of the reference.	Yu 1993 (Section 5)
Contaminated zone b parameter	BCZ	5.3	**7.75**	unitless	The contaminated zone b parameter was selected from Table 13.1 of the reference for silty clay loam.	Yu 1993 (Section 13)
Humidity in air	HUMID	8	**N/A**	g/m^3	Humidity input is only required in RESRAD when tritium is a radionuclide of concern.	Yu 2001
Evapotranspiration coefficient	EVAPTR	0.5	0.5	unitless	No site-specific data available. RESRAD default used.	Yu 1993 (Section 12)
Wind speed	WIND	2	**4.65**	m/sec	Per city-data.com, the wind speed for the Chicgao, IL area averages 10.4 miles per hour (4.65 m/sec).	Yu 1993 (Section 21) Internet search
Precipitation	PRECIP	1	**0.91**	m/yr	Site-specific value based on reported 35.82 inches per year (0.91 m/yr)	Yu 1993 (Section 9) Internet search
Irrigation	RI	0.2	0.2	m/yr	No site-specific data available. RESRAD default used.	Yu 1993 (Section 11)
Irrigation mode	IDITCH	Overhead	Overhead	unitless	The “Overhead” and “Ditch” designations are independent of the depth of contaminated zone and have no significant impact on the RESRAD evaluation. The RESRAD default designation was selected.	Yu 2001
Runoff coefficient	RUNOFF	0.2	0.2	unitless	The RESRAD default value was selected based on reference value for intermediate combinations of clay and loam.	Yu 1993 (Section 10)

NAVAL STATION GREAT LAKES
DEFAULT AND RECOMMENDED VALUES FOR RESRAD INPUT PARAMETERS

RESRAD Version 6.3					Parameter Justification	
Parameter	**Code**	**Default Value**	**User Input Value**	**Units**	**Comments**	**Reference**
Watershed area for nearby stream or pond	WAREA	1.00E6	1.00E6	m^2	RESRAD default used.	Yu 1993 (Section 17)
Accuracy for water/soil computations	EPS	0.001	0.001	unitless	RESRAD default used.	Yu 2001
SATURATED ZONE HYDROLOGICAL DATA						
Density of saturated zone	DENSAQ	1.5	1.5	g/cm^3	Soil density range from samples obtained by USDA at the site was 1.2 to 1.7. The RESRAD default was chosen as a reasonable average.	USDA 2006b Yu 1993 (Section 2)
Saturated zone total porosity	TPSZ	0.4	0.4	unitless	RESRAD default used. Equivalent to contaminated zone total porosity.	Yu 1993 (Section 3)
Saturated zone effective porosity	EPSZ	0.2	0.2	unitless	RESRAD default used.	Yu 1993 (Section 4)
Saturated zone field capacity	FCSZ	0.2	0.2	unitless	RESRAD default used.	Yu 2001
Saturated zone hydraulic conductivity	HCSZ	100	**53.6**	m/yr	Saturated zone hydraulic conductivity for silty clay loam taken from Table 5.2 of the reference.	Yu 1993 (Section 5)
Saturated zone hydraulic gradient	HGWT	0.02	0.02	unitless	RESRAD default used. Potable water at the Site is obtained via public water supply. Groundwater contamination is not considered a significant exposure pathway, though this parameter is “active” for conservatism.	Yu 1993 (Section 15)
Saturated zone b parameter	BSZ	5.3	**7.75**	unitless	The contaminated zone b parameter was selected from Table 13.1 of the reference for silty clay loam.	Yu 1993 (Section 13)
Water table drop rate	VWT	0.001	0.001	m/yr	RESRAD default used. Groundwater contamination is not considered a significant exposure pathway, though this parameter is “active” for conservatism.	Yu 1993 (Section 18)
Well pump intake depth (meters below water table)	DWIBWT	10	10	m	RESRAD default used. Groundwater contamination is not considered a significant exposure pathway, though this parameter is “active” for conservatism.	Yu 1993 (Section 19)
Model for Water Transport Parameters [Non-dispersion (ND) or Mass-Balance (MB)]	MODEL	ND	**MB**	unitless	Per NRC guidance, the MB model is an acceptable approach and provides a potentially more conservative dose estimate relative to the ND model. The MB model assumes a well is located at the center of the site rather than on the down gradient side of the Site boundary.	NUREG-1757, Vo. 2, App. I, page I-40

NAVAL STATION GREAT LAKES
DEFAULT AND RECOMMENDED VALUES FOR RESRAD INPUT PARAMETERS

RESRAD Version 6.3					Parameter Justification	
Parameter	**Code**	**Default Value**	**User Input Value**	**Units**	**Comments**	**Reference**
					In addition, all radionuclides released from the contaminated zone are withdrawn through the well. Groundwater contamination is not considered a significant exposure pathway, though this parameter is "active" for conservatism.	NRC 1999b
Well pumping rate	UW	250	250	m^3/yr	RESRAD default used. Groundwater contamination is not considered a significant exposure pathway, though this parameter is "active" for conservatism.	Yu 2001
UNCONTAMINATED UNSATURATED ZONE PARAMETERS						
Number of unsaturated zone strata	NS	1	1	unitless	RESRAD default used.	Yu 1993 (Section 25)
Unsaturated zone thickness	H(1)	4	**1.54**	m	Determined by subtracting the contaminated zone thickness (0.46 m) from the assumed saturated zone depth below ground surface (2 m).	Yu 1993 (Section 25)
Unsaturated zone soil density	DENSUZ(1)	1.5	1.5	g/cm^3	Soil density range from samples obtained by USDA at the site was 1.2 to 1.7. The RESRAD default was chosen as a reasonable average.	USDA 2006b Yu 1993 (Section 2)
Unsaturated zone total porosity	TPUZ(1)	0.4	0.4	unitless	RESRAD default used (equivalent to saturated and contaminated zone total porosity inputs).	Yu 1993 (Section 3)
Unsaturated zone effective porosity	EPUZ(1)	0.2	0.2	unitless	RESRAD default used.	Yu 1993 (Section 4)
Unsaturated zone field capacity	FCUZ(1)	0.2	0.2	unitless	RESRAD default used.	Yu 2001
Unsaturated zone hydraulic conductivity	HCUZ(1)	100	**5.36**	m/yr	Assumed to be a factor of 10 less than the saturated zone hydraulic conductivity for silty clay loam from Table 5.2 of the reference.	Yu 1993 (Section 5)
Unsaturated zone b parameter	BUZ	5.3	**7.75**	unitless	The unsaturated zone b parameter was selected from Table 13.1 of the reference for silty clay loam.	Yu 1993 (Section 13)
NATURAL THORIUM						
ELEMENTAL DISTRIBUTION (PARTITION) COEFFICIENTS AND LEACH RATES: THORIUM						
Contaminated zone	DCNUCC(2 & 3)	60,000	**3,300**	cm^3/g	Site is predominantly silty clay loam. Value from Table 32.1 of the reference for loam selected as the input. However, for thorium, the value selected has no impact on the DCGL determination.	Yu 1993 (Section 32)

NAVAL STATION GREAT LAKES
DEFAULT AND RECOMMENDED VALUES FOR RESRAD INPUT PARAMETERS

RESRAD Version 6.3					Parameter Justification	
Parameter	**Code**	**Default Value**	**User Input Value**	**Units**	**Comments**	**Reference**
Unsaturated zone	DCNUCU(2 & 3,1)	60,000	**3,300**	cm^3/g	Site is predominantly silty clay loam. Value from Table 32.1 of the reference for loam selected as the input. However, for thorium, the value selected has no impact on the DCGL determination.	Yu 1993 (Section 32)
Saturated zone	DCNUCS(2 & 3)	60,000	**3,300**	cm^3/g	Site is predominantly silty clay loam. Value from Table 32.1 of the reference for loam selected as the input. However, for thorium, the value selected has no impact on the DCGL determination.	Yu 1993 (Section 32)
Leach rate	ALEACH(2 & 3)	0	0	y^{-1}	RESRAD default used.	Yu 2001
Solubility constant	SOLUBK(2 & 3)	0	0	unitless	RESRAD default used.	Yu 2001
ELEMENTAL DISTRIBUTION (PARTITION) COEFFICIENTS AND LEACH RATES: RADIUM						
Contaminated zone	DCNUCC(1)	70	**36,000**	cm^3/g	Site is predominantly silty clay loam. Value from Table 32.1 of the reference for loam selected as the input.	Yu 1993 (Section 32)
Unsaturated zone	DCNUCU(1,1)	70	**36,000**	cm^3/g	Site is predominantly silty clay loam. Value from Table 32.1 of the reference for loam selected as the input.	Yu 1993 (Section 32)
Saturated zone	DCNUCS(1)	70	**36,000**	cm^3/g	Site is predominantly silty clay loam. Value from Table 32.1 of the reference for loam selected as the input.	Yu 1993 (Section 32)
Leach rate	ALEACH(1)	0	0	y^{-1}	RESRAD default used.	Yu 2001
Solubility constant	SOLUBK(1)	0	0	unitless	RESRAD default used.	Yu 2001
OCCUPANCY, INHALATION AND EXTERNAL GAMMA DATA						
Inhalation rate	INHALR	8,400	8,400	m^3/y	RESRAD default used.	Yu 1993 (Section 43)
Mass loading for inhalation	MLINH	0.0001	0.0001	g/m^3	RESRAD default used.	Yu 1993 (Section 35)
Exposure duration	ED	30	30	yr	RESRAD default used. DCGL calculations not influenced by exposure duration.	Yu 2001
Inhalation shielding factor	SHF3	0.4	0.4	unitless	RESRAD default used.	Yu 1993 (Section 36)
External gamma shielding factor	SHF1	0.7	**0.4**	unitless	EPA value from Equation 4 in reference used.	EPA 2000

NAVAL STATION GREAT LAKES
DEFAULT AND RECOMMENDED VALUES FOR RESRAD INPUT PARAMETERS

RESRAD Version 6.3					Parameter Justification	
Parameter	**Code**	**Default Value**	**User Input Value**	**Units**	**Comments**	**Reference**
Indoor time fraction	FIND	0.5	**0.683**	unitless	EPA value from Equation 4 in reference used.	EPA 2000
Outdoor time fraction	FOTD	0.25	**0.073**	unitless	EPA value from Equation 4 in reference used.	EPA 2000
Shape of the contaminated zone (circular or non-circular)	FS	Circular	Circular	unitless	RESRAD default used.	Yu 1993 (Section 50)
INGESTION PATHWAY (DIETARY DATA)						
Fruits, vegetables and grain consumption	DIET(1)	160	**42.7**	kg/yr	EPA value from Equation 5 in reference used.	EPA 2000
Leafy vegetable consumption	DIET(2)	14	**4.66**	kg/yr	EPA value from Equation 5 in reference used	EPA 2000
Milk consumption	DIET(3)	92	**N/A**	L/yr	Pathway not active	N/A
Meat and poultry consumption	DIET(4)	63	**N/A**	kg/yr	Pathway not active	N/A
Fish consumption	DIET(5)	5.4	**N/A**	kg/yr	Pathway not active	N/A
Other seafood consumption	DIET(6)	0.9	**N/A**	kg/yr	Pathway not active	N/A
Soil ingestion rate	SOIL	36.5	**43.8**	g/yr	EPA value from Equation 1 in reference used.	EPA 2000
Drinking water intake	DWI	510	**730**	L/yr	EPA value from Attachment D (paragraph D.2) in reference used.	EPA 2000
Contamination fraction of drinking water	FDW	1	1	unitless	Maximum NRC value used.	NRC 1999b Yu 2001
Contamination fraction of household water	FHHW	1	**NA**	unitless	Radon pathway is not selected; hence this parameter is not applicable	N/A
Contamination fraction of livestock water	FLW	1	**N/A**	unitless	Pathway not active.	N/A
Contamination fraction of irrigation water	FIRW	1	1	unitless	Maximum NRC value used.	NRC 1999b
Contamination fraction of aquatic food	FR9	0.5	**N/A**	unitless	Pathway not active.	N/A
Contaminated fraction of plant food	FPLANT	-1	**0.1**	unitless	0.1 chosen to more accurately represent the limited available residential garden area and much shorter growing period in this region.	EPA 2000
Contaminated fraction of meat	FMEAT	-1	**N/A**	unitless	Pathway not active	N/A

NAVAL STATION GREAT LAKES
DEFAULT AND RECOMMENDED VALUES FOR RESRAD INPUT PARAMETERS

RESRAD Version 6.3					Parameter Justification	
Parameter	**Code**	**Default Value**	**User Input Value**	**Units**	**Comments**	**Reference**
Contaminated fraction of milk	FMILK	-1	**N/A**	unitless	Pathway not active	N/A
INGESTION PATHWAY (NON-DIETARY DATA)						
Livestock fodder intake for meat	LP15	68	**N/A**	kg/day	Pathway not active	N/A
Livestock fodder intake for milk	LP16	55	**N/A**	kg/day	Pathway not active	N/A
Livestock water intake for meat	LW15	50	**N/A**	L/day	Pathway not active	N/A
Livestock water intake for milk	LW15	160	**N/A**	L/day	Pathway not active	N/A
Livestock intake of soil	LS1	0.5	**N/A**	kg/day	Pathway not active	N/A
Mass loading for foliar deposition	MLFD	0.0001	0.0001	g/m^3	RESRAD default used.	Yu 1993
Depth of soil mixing layer	DM	0.15	0.15	m	RESRAD default used.	Yu 1993 (Section 35)
Depth of roots	DROOT	0.9	0.9	m	RESRAD default used.	Yu 1993 (Section 37)
Groundwater fractional usage: Drinking water	FGWDW	1	1	unitless	RESRAD default used.	Yu 1993
Groundwater fractional usage: Household water	FGWHH	1	**N/A**	unitless	Radon pathway not active	N/A
Groundwater fractional usage: Livestock water	FGWLW	1	**N/A**	unitless	Pathway not active	N/A
Groundwater fractional usage: Irrigation water	FGWIR	1	1	unitless	RESRAD default used.	Yu 1993
PLANT TRANSPORT FACTORS						
Wet weight crop yield: non-leafy vegetables	YV(1)	0.7	0.7	kg/m^2	RESRAD default used.	Yu 1993 NRC 2000b
Wet weight crop yield: leafy vegetables	YV(2)	1.5	1.5	kg/m^2	RESRAD default used.	Yu 1993 NRC 2000b

NAVAL STATION GREAT LAKES
DEFAULT AND RECOMMENDED VALUES FOR RESRAD INPUT PARAMETERS

RESRAD Version 6.3					Parameter Justification	
Parameter	**Code**	**Default Value**	**User Input Value**	**Units**	**Comments**	**Reference**
Wet weight crop yield: fodder	YV(3)	1.1	**N/A**	kg/m^2	Pathway not active.	N/A
Length of growing season: non-leafy vegetables	TE(1)	0.17	0.17	years	RESRAD default used.	Yu 1993 NRC 2000b
Length of growing season: leafy vegetables	TE(2)	0.25	0.25	years	RESRAD default used.	Yu 1993 NRC 2000b
Length of growing season: fodder	TE(3)	0.08	**N/A**	years	Pathway not active	N/A
Translocation factor: non-leafy vegetables	TIV(1)	0.1	0.1	unitless	RESRAD default used.	Yu 1993 NRC 2000b
Translocation factor: leafy vegetables	TIV(2)	1	1	unitless	RESRAD default used.	Yu 1993 NRC 2000b
Translocation factor: fodder	TIV(3)	1	**N/A**	unitless	Pathway not active	N/A
Weathering removal constant	WLAM	20	20	y^{-1}	RESRAD default used.	Yu 1993 NRC 2000b
Wet foliar interception fraction: non-leafy vegetables	RWET(1)	0.25	0.25	unitless	RESRAD default used.	Yu 1993 NRC 2000b
Wet foliar interception fraction: leafy vegetables	RWET(2)	0.25	0.25	unitless	RESRAD default used.	Yu 1993 NRC 2000b
Wet foliar interception fraction: fodder	RWET(3)	0.25	**N/A**	unitless	Pathway not active.	N/A
Dry foliar interception fraction: non-leafy vegetables	RDRY(1)	0.25	0.25	unitless	RESRAD default used.	Yu 1993 NRC 2000b
Dry foliar interception fraction: leafy vegetables	RDRY(2)	0.25	0.25	unitless	RESRAD default used.	Yu 1993 NRC 2000b
Dry foliar interception fraction: fodder	RDRY(3)	0.25	**N/A**	unitless	Pathway not active.	N/A
STORAGE TIMES BEFORE USE						
Fruits, non-leafy vegetables and grain	STOR_T(1)	14	14	days	RESRAD default used.	Yu 2001 Yu 1993

NAVAL STATION GREAT LAKES
DEFAULT AND RECOMMENDED VALUES FOR RESRAD INPUT PARAMETERS

RESRAD Version 6.3					Parameter Justification	
Parameter	**Code**	**Default Value**	**User Input Value**	**Units**	**Comments**	**Reference**
Leafy vegetables	STOR_T(2)	1	1	days	RESRAD default used.	Yu 2001 Yu 1993
Milk	STOR_T(3)	1	**N/A**	days	Pathway not active.	N/A
Meat	STOR_T(4)	20	**N/A**	days	Pathway not active.	N/A
Fish	STOR_T(5)	7	**N/A**	days	Pathway not active.	N/A
Crustacea and mollusks	STOR_T(6)	7	**N/A**	days	Pathway not active.	N/A
Well water	STOR_T(7)	1	1	days	RESRAD default used.	Yu 2001 Yu 1993
Surface water	STOR_T(8)	1	1	days	RESRAD default used.	Yu 2001 Yu 1993
Livestock fodder	STOR_T(9)	45	**N/A**	days	Pathway not active.	N/A

APPENDIX B

RESRAD INPUT/OUTPUT FILES FOR THORIUM

(Provided on Accompanying Electronic Compact Disc)