BARTLETT

**ENGINEERING CALCULATION**

Calculation Number: ENG-006

Revision Number: 001

Calculation Title: Calculation of DTE EF- 1 Area Factors for Soil

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| Preparer: | Bruce Dionne<br>Bruce J Dionne | Date | 12-17-09 |
| Reviewer: | J. W. Brown | Date | 12/17/09 |
| Approval: | Corporate Project Manager | Date | 12-17-09 |
| Approval: | R E Full<br>Director of Quality Assurance | Date: | 12/17/09 |

**Bartlett.**
**60 Industrial Park Road**
**Plymouth, MA 02360**

## 1. PURPOSE

The purpose of this calculation is to develop Area Factors (AF) that will be used with soil-based derived concentration guideline levels (DCGLs) for Detroit Edison's (DTE) Enrico Fermi 1 (EF-1) Fast Breeder Reactor located in Newport, Michigan. This calculation is part of the scope of work defined in the DTE Contract No. 4400001090 associated with DTE Fermi 1 DCGL Development.

Revision 1 is being performed in order to correct the nuclide used in the Area Factor RESRAD input file for Nb-94. The Revision 0 input file used Nb-95 instead of Nb-94. This revision used Nb-94 and corrected the associated Peak of the Mean Doses/DCGLs for each of the eleven (11) areas.

## 2. APPLICABILITY

This calculation addresses only the development of AF for soils at the DTE EF 1 site using the resident farmer scenario and the RESRAD Version 6.4 software. The AF is defined as the magnitude by which the concentration within the small area of elevated activity can exceed $DCGL_w$ while maintaining compliance with the release criteria.

## 3. REFERENCES

3.1. Bartlett Engineering Calculation ENG-004, Calculation of Enrico Fermi 1 Derived Concentration Guidelines Levels for Soil, Rev 1, December 16, 2009.

3.2 Bartlett Engineering Procedure ENG-AP-02, Verification of Software Operability, Rev. 0.

3.3. NUREG-1757, Multi-Agency Radiation Survey and Site Investigation Manaual (MARSSIM), Rev. 1, August 2000.

3.4. NUREG-1727. NMSS Decommissioning Standard Review Plan, September 2000.

3.5. Yu, C., et. al., Users Manual for RESRAD Version 6, ANL-EAD-4, July 2001.

3.6. NUREG/CR-6692, Probabilistic Modules for the RESRAD 6.0 and RESRAD-BUILD 3.0 Computer Codes, LePoire, D., et. al., US Department of Energy- Argonne National Laboratory, November 2000.

3.7. NUREG/CR-6676, Probabilistic Dose Analysis Using Parameter Distributions Developed for RESRAD and RESRAD-BUILD Codes, Kamboj S., et. al., US Department of Energy-Argonne National Laboratory, May 2000.

3.8. NUREG/CR-6697, Development of Probabilistic RESRAD 6.0 and RESRAD-BUILD 3.0 Computer Codes, Yu, C. et. al., US Department of Energy- Argonne National Laboratory, November 2000.

3.9 NUREG-1757. Consolidated NMSS Decommissioning Guidance, Volume 2: Characterization, Survey and Determination of Radiological Criteria, September 2006.

# 4. METHOD OF CALCULATION

4.1 The operability of the RESRAD Version 6.4 code was verified on each computer used for code executions in accordance with Bartlett Engineering procedure ENG-AP-02, Verification of Software Operability (Ref. 3.2). The RESRAD User's Manual (Ref. 3.5) provided guidance for code operation and execution. The RESRAD code has undergone extensive review, benchmarking, verification, and validation. Details on reviews, benchmarking, verification, and validation for the RESRAD code are summarized in Sections 5.1–5.4 of RESRAD User's Manual (Ref. 3.5).

4.2 The RESidual RADioactivity (RESRAD) Version 6.4 computer code developed by Scientists and Engineers at Argonne National Laboratory (ANL) was used. The RESRAD computer code is a pathway analysis model designed to evaluate the potential radiological dose associated with residual radioactive material for a defined receptor scenario: in this case resident farmer. Eight environmental pathway models are considered in this software application: 1) direct radiation exposure, 2) inhalation of airborne dust, 3) ingestion of plants, 4) ingestion of meat, 5) ingestion of milk, 6) ingestion of groundwater, and 7) ingestion of aquatic foods, and 8) inadvertent ingestion of soil contaminants. All these pathways were applied for the DTE EF-1 AF computer runs.

4.3 Similar to the Bartlett calculation of DTE EF-1 DCGLs (Ref. 3.1), the conceptual model underlying the development of AFs is based on the resident farmer scenario. The hydro-geological model is comprised of a contaminated zone underlain by an unsaturated zone underlain by a saturated zone. The contaminated zone is assumed to be the top 15 cm of topsoil with no cover material. The ground water is assumed to be uncontaminated initially. The area of the contaminated zone in the top 15 cm was varied from 2000 $m^2$ down to 1 $m^2$. RESRAD 6.4 enables site modeling through its many input parameters, and includes probabilistic modules (Ref. 3.6, 3.7, and 3.8) that provide peak-of-the-mean doses (PMD) as discussed in NUREG-1727 (Ref. 3.4) and NUREG-1757(Ref. 3.9).

4.4 The method that was used in ENG-004 (Ref. 3.1) to calculate the nuclide-specific DCGLs is similar to the method utilized here to calculate nuclide-specific AFs. The values listed in Table 1 for the area of the contaminated zone, the length of parallel to aquifer flow, plant transfer factor, meat transfer factor and milk transfer factors were substituted into the nuclide specific DCGL data set that was used to compute the DCGLs. The PMD for an area of 2,000 $m^2$ ($PMD_{2000}$) served as base case in the area factor calculations. This area was selected because it is the maximum area for a Class 1 land survey unit. In a Class 2 or 3 land survey unit, contamination levels greater than the value would result in the classification for survey unit being revised to a Class 1 survey unit. For mixtures of radionuclides, if the sum of the fractions of the concentration over the $DCGL_w$ is greater than 1 than the survey unit would be revised to a Class 1 survey unit

4.5 DCGL values can be adjusted through the use of area factors to obtain a DCGL that represents the same dose from residual radioactivity over a smaller area within a survey unit (Ref. 3.4). The adjusted value is designated as $DCGL_{EMC}$, where EMC stands for elevated measurement comparison. The $DCGL_{EMC}$ is the product of the AF and the DCGLw shown in Equation (1) (Equation 8-1 in Ref. 3.3)

$DCGL_{EMC}$ = (AF) * (DCGLw) (1)

From this relationship it follows that, for a small area of elevated concentration within a survey area, the area factor is the ratio of the nuclide concentration in the smaller area that results in the same dose as the dose from a concentration equal to the DCGL for 2000 $m^2$. Therefore, for the DTE EF-1 Area Factor calculations $DCGL_w$ is equal to the DCGL for 2000 $m^2$.

$AF = (DCGL_{EMC})/ (DCGL_w)$ (2)

AF values calculated here are computed directly from the Peak of the Mean Dose (PMD mrem/yr per pCi/g) results instead of the DCGL (pCi/g) values. Therefore, a variation of Equation (2) is used. The DCGL values were calculated using the relationship shown in Equation (3):

$DCGL_w = DL_{TEDE} / PMD_{2000}$ and $DCGL_{EMC} = DL_{TEDE} / PMD_i$ (3)

Where the Dose Limit $DL_{TEDE}$ = 25 mrem/yr.

Substitution of terms allows Equation (1) to be re-written as follows:

$(25/PMDi) = (AF) * (25/PMD_{2000})$ (4)

Further re-arrangement shown in Equation (4) demonstrates that the AF is the ratio of the base case $PMD_{2000}$ to the PMDi for the smaller area zone shown in Equation (5).

$AF = (PMD_{2000} / PMD_i)$ (5)

# 5 ASSUMPTIONS AND INPUT

## 5.1 Assumptions

5.1.1. The resident farmer scenario is assumed as a reasonably conservative scenario for establishing DTE EF-1 DCGL values for residual radioactivity in soil (Ref. 3.1). The same exposure scenario is assumed for the AF calculations.

In the resident farmer scenario, residual radioactivity is contained in a soil layer on the property that can be used for residential and light farming activities. A residential farming family is postulated to live onsite, raise crops and livestock for consumption and drink water from a ground water source onsite. The dose from residual radioactivity in the soil is evaluated for the average member of the critical group as required by 10CFR Part 20, Subpart E and described in NUREG-1727 (Ref. 3.4). The critical group represents the group reasonably expected to receive the greatest exposure to residual radioactivity.

The potential pathways used to estimate human radiation exposure resulting from residual radioactivity in the soil for this scenario includes the following:

- Direct exposure to external radiation from soil containing residual radioactivity;
- Internal dose from inhalation of airborne radionuclides;
- Internal dose from ingestion of:

- Plant foods grown in the soil material containing residual radioactivity;
- Meat and milk from livestock fed with fodder grown in soil containing residual radioactivity and water containing residual radioactivity;
- Drinking water containing residual radioactivity from a well;
- Aquatic food from a pond containing residual radioactivity; and
- Soil containing residual radioactivity.

5.1.2. As the area of the contaminated zone decreases from the area used in the base case (2,000 $m^2$), it is assumed that the values for the contaminated fractions of plant food (FPLANT), meat (FMEAT) and milk (FMILK) originating from the site also decrease (Equations 6 – 13).

Where:

FPLANT is the contaminated fraction of plant food,
FMEAT is the contaminated fraction of meat, and
FMILK is the contaminated fraction of milk.

5.1.3. The contaminated fractions for drinking water (FDW), livestock water (FLW), irrigation water (FIRW), and aquatic food (FR9) are assumed not to decrease as the size of the contaminated zone decreases. Setting the values for these input parameters equal to 1.0 incorporates the assumption that all water used by the resident farmer comes from the site (i.e., residential well), regardless of the size of the contaminated area.

Where:

FDW is the contaminated fraction of drinking water,
FLW is the contaminated fraction of livestock water,
FIRW is the contaminated fraction of irrigation water, and
FR9 is the contaminated fraction of aquatic food.

5.1.4. Another input parameter that is influenced by changes in the size of the contaminated zone is the length parallel to aquifer flow in the contaminated zone (LCZPAQ). A proportionate reduction in the value for this parameter is assumed as the size of the contaminated zone decreases (see Equation 14).

5.1.5. The year in which the maximum dose occurs may vary depending on the nuclide. The time which the peak mean dose occurs will be selected for the purpose of calculating AFs to be the time of the peak of the mean dose. It should be noted that the year of occurrence of the peak of the mean dose for the all but one nuclides (for Pu-241 the time for the peak of the mean dose ranges from 30 to 41.25 years) is at time = 0 years.

5.1.6 Twenty-five nuclides of concern were assumed for the DTE EF-1 site: Ag-108m, Am-241, C-14, Co-60, Cm-242, Cm-243, Cs-134, Cs-137, Eu-152, Eu-154, Eu-155, Fe-55, H-3, Mn-54, Na-22, Nb-94, Ni-59, Ni-63, Pu-238, Pu-239, Pu-240, Pu-241, Sb-125, Sr-90, and Tc-99. This list of nuclides of concern was provided by the client for this contract i.e., DTE.

5.1.7. An initial soil concentration of 1 pC/g is assumed for each nuclide.

## 5.2 Inputs

5.2.1 In the RESRAD executions for AFs, the input parameter values used were the same values as those used to calculate DCGLs, except for the input parameters discussed below and shown in Table 1. As the area of the contaminated zone decreases, it is reasonable to assume that the fraction of a person's diet from the contaminated zone will also decrease in proportion to the size (assumptions 5.1.2 and 5.1.3 above). The RESRAD contamination fractions are:

- Fraction of drinking water from site (FDW)
- Fraction of livestock water from site (FLW)
- Fraction of Irrigation water from site (FIRW)
- Fraction of aquatic food from site (FR9)
- Fraction of plant food from site (FPLANT)
- Fraction of meat from site (FMEAT)
- Fraction of milk from site (FMILK)

Input values for FDW, FLW, FIRW, and FR9 are held to the same values as those used in the DCGL calculation (see assumption 5.1.3 above).

Adjustments to FPLANT, FMEAT, and FMILK are made using equations from the RESRAD User's Manual (Ref. 3.3). Equation D.5 in Section D.2.1.2 of the RESRAD User's Manual (Ref. 3.5) varies the contamination fraction ($FA_3$) for plants as follows:

$$FA_3 = A/2{,}000 \text{ when } 0 \leq A \leq 1{,}000\ m^2 \quad (6)$$
$$FA_3 = 0.5 \text{ when } A > 1{,}000\ m^2 \quad (7)$$

In addition, Equation D.5 of the RESRAD User Manual (Ref. 3.5) varies the $FA_{4\&5}$ values for meat and milk as follows:

$$FA_{4\&5} = A/20{,}000 \text{ when } 0 \leq A \leq 20{,}000\ m^2 \quad (8)$$
$$FA_{4\&5} = 1.0 \text{ when } A > 20{,}0000\ m^2 \quad (9)$$

Modified versions of Equation D.5 are used here to vary the input values for FPLANT, FMEAT, and FMILK in order to remain consistent with the approach used for the soil DCGLs (Ref. 3.1). The soil DCGLs were developed using a value of 1.0 for each of the contamination fractions, which incorporated the assumption that 100% of plant food, meat, and milk is obtained from an area equal to 7,855 $m^2$ (the size of the contaminated zone at DTE EF-1).

As applied to plants, use of a FA value equal to 1.0 in the calculation of the soil DCGLs effectively multiplied Equation D.5 by a factor of 2 to yield a FA value of 1.0 for areas equal to or greater than 1,000 $m^2$

Input values for FPLANT used in this calculation are determined as follows:

FPLANT = A/1,000 when $A \leq 1{,}000\ m^2$ (10)

FPLANT = 1.0when $A > 1{,}000\ m^2$ (11)

As applicable to meat and milk, Equation D.5 was adjusted for the size of the contaminated zone used in the calculation of the soil DCGLs, (i.e., FA = 1.0 when the contaminated area was 7,855 $m^2$). Input values for FMEAT and FMILK used in this calculation are determined as follows:

FMEAT or FMILK = A/ 7,855 when $A \leq 7{,}855\ m^2$ (12)

FMEAT or FMILK = 1.0 when $A > 7{,}855 m^2$ (13)

Table 1 shows the values for FPLANT, FMEAT, and FMILK as a function of the area of the contaminated zone that were calculated using Equations 10, 11, 12 and 13.

5.2.2 As the area of the contaminated zone decreases, the value for another RESRAD Input parameter, the length parallel to aquifer flow (LCZPAQ), also decreases (see assumption 5.1.4 above). The contaminated zone is assumed to be circular, so the value for LCZPAQ is equal to the diameter of the circle:

Area of a Circle $A = \pi r^2$

Rearranging and substituting for $r = \frac{LCZPAQ}{2}$

$$LCZPAQ\ (m) = 2\sqrt{\frac{A}{\Pi}} \quad (14)$$

Table 1 has the values for LCZPAQ vs. of the area of the contaminated zone using Equation 14.

**Table 1: Contaminated Fractions vs. Area of Contaminated Zone**

| RESRAD Parameter | Input Value | | | |
|---|---|---|---|---|
| **Area Contaminated Zone ($m^2$)** | **2000** | **1000** | **500** | **250** |
| LCZPAQ (m) | 50 | 36 | 25 | 18 |
| FPLANT | 1.0E+00 | 1.0E+00 | 5.0E-01 | 2.5E-01 |
| FMEAT | 2.5E-01 | 1.3E-01 | 6.4E-02 | 3.2E-02 |
| FMILK | 2.5E-01 | 1.3E-01 | 6.4E-02 | 3.2E-02 |
| **Contaminated Zone Area ($m^2$)** | **100** | **50** | **25** | **10** |
| LCZPAQ (m) | 11 | 8.0 | 5.6 | 3.6 |
| FPLANT | 1.0E-01 | 5.0E-02 | 2.5E-02 | 1.0E-02 |
| FMEAT | 1.3E-02 | 6.4E-03 | 3.2E-03 | 1.3E-03 |
| FMILK | 1.3E-02 | 6.4E-03 | 3.2E-03 | 1.3E-03 |
| **Contaminated Zone Area ($m^2$)** | **5** | **2** | **1** | |
| LCZPAQ (m) | 2.5 | 1.6 | 1.1 | |
| FPLANT | 5.0E-03 | 2.0E-03 | 1.0E-03 | |
| FMEAT | 6.4E-04 | 2.5E-04 | 1.3E-04 | |
| FMILK | 6.4E-04 | 2.5E-04 | 1.3E-04 | |

5.2.3 The RESRAD 6.4 analyses are executed using 2000 observations and 1 repetition. The Latin Hypercube Sampling (LHS) technique is used to sample the probability distributions for each of the stochastic input parameters. The correlated or non-correlated grouping option is used to preserve the prescribed correlation, and a random seed of 1000 is used to preserve the prescribed sampling technique.

# 6 CALCULATIONS AND RESULTS

## 6.1 Calculations

6.1.1 Running the probabilistic modules in version 6.4 of the RESRAD computer code provided the PMDs for the eleven area values, which were then used to calculate AF for residual radioactivity in soil. A total of 275 RESRAD runs were made, for each of the 25 nuclides that may present a significant dose impact for license termination at DTE EF-1. The RESRAD data sets used to calculate the AF were similar to those used to calculate nuclide-specific, soil-based DCGLs (Ref. 3.1). Attachment 1 of the Bartlett Engineering Calculation ENG-004 provides a complete listing of parameter values used for DCGL derivation (Ref. 3.1).The difference in the two data sets is that in the AF data set the values listed in Table 1 were substituted into the DCGL data set for each nuclide and for each of the areas analyzed.

In Revision 1, the input files for the Area Factor RESRAD runs for Nb-94 were corrected to replace Nb-95 with Nb-94.

## 6.2 Results

6.2.1 Table 2 summarizes the RESRAD results, namely, the base case $PMD_{2000}$ and the PMDi for the desired areas (1000 $m^2$ down to 1 $m^2$) for the twenty-five nuclides of concern at DTE EF-1. Table 2A provides a cross reference between the PMD results in Table 2 and the associated filenames for the RESRAD Uncertainty Analysis Reports.

In Revision 1, Table 2 was revised to replace the peak of the mean doses for the eleven (11) areas used for Nb-94 Area Factor calculations.

6.2.2 Tables 3, 4 and 5 provide the AFs listed by gamma, beta and alpha emitters, respectively. The AFs given in Tables 3, 4 and 5 are relative to base case, $PMD_{2000}$.

In Revision 1, Table 3 was revised to replace the eleven (11) area factors that were calculated for Nb-94.

6.2.3 The AF results are also displayed graphically in Figures 1, 2 and 3 for gamma, beta and alpha emitters, respectively. The nuclide specific AF curves are shown by the major radiation type emitted in Figures 1, 2 and 3.

In Revision 1, Figure 1 was revised to update the graph with the revised area factors for Nb-94.

**Table 2 Peak Mean Dose (mrem/yr per pCi/g) vs Area ($m^2$)**

| Area | Ag-108m | Am-241 | C-14 | Co-60 | Cm-242 | Cm-243 | Cs-134 | Cs-137 |
|---|---|---|---|---|---|---|---|---|
| 2000 | 3.135E+00 | 1.813E-01 | 1.604E-02 | 4.703E+00 | 3.141E-03 | 3.155E-01 | 2.741E+00 | 1.176E+00 |
| 1000 | 3.101E+00 | 1.798E-01 | 1.008E-02 | 4.638E+00 | 3.118E-03 | 3.128E-01 | 2.677E+00 | 1.143E+00 |
| 500 | 3.015E+00 | 9.928E-02 | 3.627E-03 | 4.475E+00 | 1.621E-03 | 2.528E-01 | 2.547E+00 | 1.071E+00 |
| 250 | 2.879E+00 | 5.859E-02 | 1.318E-03 | 4.251E+00 | 8.688E-04 | 2.170E-01 | 2.394E+00 | 9.982E-01 |
| 100 | 2.640E+00 | 3.344E-02 | 3.527E-04 | 3.876E+00 | 4.125E-04 | 1.868E-01 | 2.184E+00 | 9.060E-01 |
| 50 | 2.367E+00 | 2.410E-02 | 1.318E-04 | 3.448E+00 | 2.558E-04 | 1.652E-01 | 1.950E+00 | 8.073E-01 |
| 25 | 1.972E+00 | 1.821E-02 | 5.045E-05 | 2.838E+00 | 1.729E-04 | 1.382E-01 | 1.617E+00 | 6.689E-01 |
| 10 | 1.420E+00 | 1.307E-02 | 1.482E-05 | 2.021E+00 | 1.167E-04 | 1.015E-01 | 1.160E+00 | 4.798E-01 |
| 5 | 9.362E-01 | 9.336E-03 | 6.074E-06 | 1.330E+00 | 9.133E-05 | 6.759E-02 | 7.650E-01 | 3.163E-01 |
| 2 | 5.068E-01 | 6.180E-03 | 1.990E-06 | 7.166E-01 | 7.144E-05 | 3.763E-02 | 4.144E-01 | 1.713E-01 |
| 1 | 2.904E-01 | 4.618E-03 | 9.104E-07 | 4.075E-01 | 6.175E-05 | 2.255E-02 | 2.377E-01 | 9.823E-02 |
| **Area** | **Eu-152** | **Eu-154** | **Eu-155** | **Fe-55** | **H-3** | **Mn-54** | **Na-22** | **Nb-94** |
| 2000 | 2.141E+00 | 2.306E+00 | 6.072E-02 | 1.971E-04 | 4.144E-04 | 1.132E+00 | 3.837E+00 | 3.095E+00 |
| 1000 | 2.117E+00 | 2.279E+00 | 6.027E-02 | 1.117E-04 | 3.470E-04 | 1.119E+00 | 3.779E+00 | 3.059E+00 |
| 500 | 2.055E+00 | 2.211E+00 | 5.883E-02 | 5.512E-05 | 1.794E-04 | 1.082E+00 | 3.657E+00 | 2.973E+00 |
| 250 | 1.960E+00 | 2.107E+00 | 5.675E-02 | 2.757E-05 | 9.463E-05 | 1.028E+00 | 3.482E+00 | 2.830E+00 |
| 100 | 1.795E+00 | 1.927E+00 | 5.310E-02 | 1.118E-05 | 4.198E-05 | 9.427E-01 | 3.183E+00 | 2.599E+00 |
| 50 | 1.603E+00 | 1.717E+00 | 4.872E-02 | 5.528E-06 | 2.573E-05 | 8.395E-01 | 2.842E+00 | 2.320E+00 |
| 25 | 1.325E+00 | 1.416E+00 | 4.192E-02 | 2.772E-06 | 1.808E-05 | 6.934E-01 | 2.352E+00 | 1.921E+00 |
| 10 | 9.483E-01 | 1.011E+00 | 3.192E-02 | 1.133E-06 | 1.093E-05 | 4.955E-01 | 1.684E+00 | 1.376E+00 |
| 5 | 6.245E-01 | 6.656E-01 | 2.136E-02 | 5.665E-07 | 7.142E-06 | 3.263E-01 | 1.109E+00 | 9.067E-01 |
| 2 | 3.371E-01 | 3.592E-01 | 1.199E-02 | 2.303E-07 | 3.097E-06 | 1.762E-01 | 5.990E-01 | 4.904E-01 |
| 1 | 1.923E-01 | 2.047E-01 | 7.271E-03 | 1.248E-07 | 1.452E-06 | 1.006E-01 | 3.418E-01 | 2.806E-01 |
| **Area** | **Ni-59** | **Ni-63** | **Pu-238** | **Pu-239** | **Pu-240** | **Pu-241** | **Sb-125** | **Sr-90** |
| 2000 | 8.130E-04 | 2.226E-03 | 1.495E-01 | 1.660E-01 | 1.659E-01 | 4.585E-03 | 7.103E-01 | 1.640E+00 |
| 1000 | 5.755E-04 | 1.576E-03 | 1.477E-01 | 1.641E-01 | 1.640E-01 | 4.543E-03 | 7.029E-01 | 1.560E+00 |
| 500 | 2.858E-04 | 7.824E-04 | 7.581E-02 | 8.420E-02 | 8.413E-02 | 2.480E-03 | 6.828E-01 | 7.825E-01 |
| 250 | 1.429E-04 | 3.912E-04 | 3.973E-02 | 4.408E-02 | 4.407E-02 | 1.439E-03 | 6.517E-01 | 3.943E-01 |
| 100 | 5.757E-05 | 1.576E-04 | 1.791E-02 | 1.989E-02 | 1.984E-02 | 8.033E-04 | 5.977E-01 | 1.612E-01 |
| 50 | 2.860E-05 | 7.828E-05 | 1.050E-02 | 1.166E-02 | 1.162E-02 | 5.735E-04 | 5.361E-01 | 8.281E-02 |
| 25 | 1.431E-05 | 3.916E-05 | 6.687E-03 | 7.416E-03 | 7.383E-03 | 4.300E-04 | 4.468E-01 | 4.311E-02 |
| 10 | 5.773E-06 | 1.580E-05 | 4.246E-03 | 4.701E-03 | 4.676E-03 | 3.064E-04 | 3.221E-01 | 1.862E-02 |
| 5 | 2.875E-06 | 7.864E-06 | 3.320E-03 | 3.669E-03 | 3.652E-03 | 3.390E-04 | 2.124E-01 | 9.797E-03 |
| 2 | 1.147E-06 | 3.134E-06 | 2.637E-03 | 2.909E-03 | 2.898E-03 | 1.460E-04 | 1.150E-01 | 4.203E-03 |
| 1 | 5.904E-07 | 1.610E-06 | 2.319E-03 | 2.556E-03 | 2.470E-03 | 1.097E-04 | 6.595E-02 | 2.186E-03 |
| **Area** | **Tc-99** | | | | | | | |
| 2000 | 1.927E-01 | | | | | | | |
| 1000 | 1.894E-01 | | | | | | | |
| 500 | 9.470E-02 | | | | | | | |
| 250 | 4.736E-02 | | | | | | | |
| 100 | 1.897E-02 | | | | | | | |
| 50 | 9.494E-03 | | | | | | | |
| 25 | 4.757E-03 | | | | | | | |
| 10 | 1.911E-03 | | | | | | | |
| 5 | 9.583E-04 | | | | | | | |
| 2 | 3.850E-04 | | | | | | | |
| 1 | 1.933E-04 | | | | | | | |

## Table 2A: Cross References for RESRAD Report Files

| Area (m2) | RESRAD Uncertainty Analysis Report file name: Ag-108m | Am-241 | C-14 | Cm-242 | Cm-243 | Co-60 |
|---|---|---|---|---|---|---|
| 1 | MCSUMMARAg108mAF1 | MCSUMMARAm241AF1 | MCSUMMARC14AF1 | MCSUMMARCm242AF1 | MCSUMMARCm243AF1 | MCSUMMARCo60AF1 |
| 2 | MCSUMMARAg108mAF2 | MCSUMMARAm241AF2 | MCSUMMARC14AF2 | MCSUMMARCm242AF2 | MCSUMMARCm243AF2 | MCSUMMARCo60AF2 |
| 3 | MCSUMMARAg108mAF3 | MCSUMMARAm241AF3 | MCSUMMARC14AF3 | MCSUMMARCm242AF3 | MCSUMMARCm243AF3 | MCSUMMARCo60AF3 |
| 4 | MCSUMMARAg108mAF4 | MCSUMMARAm241AF4 | MCSUMMARC14AF4 | MCSUMMARCm242AF4 | MCSUMMARCm243AF4 | MCSUMMARCo60AF4 |
| 5 | MCSUMMARAg108mAF5 | MCSUMMARAm241AF5 | MCSUMMARC14AF5 | MCSUMMARCm242AF5 | MCSUMMARCm243AF5 | MCSUMMARCo60AF5 |
| 6 | MCSUMMARAg108mAF6 | MCSUMMARAm241AF6 | MCSUMMARC14AF6 | MCSUMMARCm242AF6 | MCSUMMARCm243AF6 | MCSUMMARCo60AF6 |
| 8 | MCSUMMARAg108mAF8 | MCSUMMARAm241AF8 | MCSUMMARC14AF8 | MCSUMMARCm242AF8 | MCSUMMARCm243AF8 | MCSUMMARCo60AF8 |
| 10 | MCSUMMARAg108mAF10 | MCSUMMARAm241AF10 | MCSUMMARC14AF10 | MCSUMMARCm242AF10 | MCSUMMARCm243AF10 | MCSUMMARCo60AF10 |
| 15 | MCSUMMARAg108mAF15 | MCSUMMARAm241AF15 | MCSUMMARC14AF15 | MCSUMMARCm242AF15 | MCSUMMARCm243AF15 | MCSUMMARCo60AF15 |
| 25 | MCSUMMARAg108mAF25 | MCSUMMARAm241AF25 | MCSUMMARC14AF25 | MCSUMMARCm242AF25 | MCSUMMARCm243AF25 | MCSUMMARCo60AF25 |
| 50 | MCSUMMARAg108mAF50 | MCSUMMARAm241AF50 | MCSUMMARC14AF50 | MCSUMMARCm242AF50 | MCSUMMARCm243AF50 | MCSUMMARCo60AF50 |
| 100 | MCSUMMARAg108mAF100 | MCSUMMARAm241AF100 | MCSUMMARC14AF100 | MCSUMMARCm242AF100 | MCSUMMARCm243AF100 | MCSUMMARCo60AF100 |
| Area (m2) | RESRAD Uncertainty Analysis Report file name: Cs-134 | Cs-137 | Eu-152 | Eu-154 | Eu-155 | Fe-55 |
| 1 | MCSUMMARCs134AF1 | MCSUMMARCs137AF1 | MCSUMMAREu152AF1 | MCSUMMAREu154AF1 | MCSUMMAREu155AF1 | MCSUMMARFe55AF1 |
| 2 | MCSUMMARCs134AF2 | MCSUMMARCs137AF2 | MCSUMMAREu152AF2 | MCSUMMAREu154AF2 | MCSUMMAREu155AF2 | MCSUMMARFe55AF2 |
| 3 | MCSUMMARCs134AF3 | MCSUMMARCs137AF3 | MCSUMMAREu152AF3 | MCSUMMAREu154AF3 | MCSUMMAREu155AF3 | MCSUMMARFe55AF3 |
| 4 | MCSUMMARCs134AF4 | MCSUMMARCs137AF4 | MCSUMMAREu152AF4 | MCSUMMAREu154AF4 | MCSUMMAREu155AF4 | MCSUMMARFe55AF4 |
| 5 | MCSUMMARCs134AF5 | MCSUMMARCs137AF5 | MCSUMMAREu152AF5 | MCSUMMAREu154AF5 | MCSUMMAREu155AF5 | MCSUMMARFe55AF5 |
| 6 | MCSUMMARCs134AF6 | MCSUMMARCs137AF6 | MCSUMMAREu152AF6 | MCSUMMAREu154AF6 | MCSUMMAREu155AF6 | MCSUMMARFe55AF6 |
| 8 | MCSUMMARCs134AF8 | MCSUMMARCs137AF8 | MCSUMMAREu152AF8 | MCSUMMAREu154AF8 | MCSUMMAREu155AF8 | MCSUMMARFe55AF8 |
| 10 | MCSUMMARCs134AF10 | MCSUMMARCs137AF10 | MCSUMMAREu152AF10 | MCSUMMAREu154AF10 | MCSUMMAREu155AF10 | MCSUMMARFe55AF10 |
| 15 | MCSUMMARCs134AF15 | MCSUMMARCs137AF15 | MCSUMMAREu152AF15 | MCSUMMAREu154AF15 | MCSUMMAREu155AF15 | MCSUMMARFe55AF15 |
| 25 | MCSUMMARCs134AF25 | MCSUMMARCs137AF25 | MCSUMMAREu152AF25 | MCSUMMAREu154AF25 | MCSUMMAREu155AF25 | MCSUMMARFe55AF25 |
| 50 | MCSUMMARCs134AF50 | MCSUMMARCs137AF50 | MCSUMMAREu152AF50 | MCSUMMAREu154AF50 | MCSUMMAREu155AF50 | MCSUMMARFe55AF50 |
| 100 | MCSUMMARCs134AF100 | MCSUMMARCs137AF100 | MCSUMMAREu152AF100 | MCSUMMAREu154AF100 | MCSUMMAREu155AF100 | MCSUMMARFe55AF100 |

**Table 2A (continued): Cross References for RESRAD Report Files**

| Area (m2) | RESRAD Uncertainty Analysis Report file name: H-3 | Mn-54 | Na-22 | Nb-94 | Ni-59 | Ni-63 |
|---|---|---|---|---|---|---|
| 1 | MCSUMMARH3AF1 | MCSUMMARMn54AF1 | MCSUMMARNa22AF1 | MCSUMMARNb94AF1 | MCSUMMARNi59AF1 | MCSUMMARNi63AF1 |
| 2 | MCSUMMARH3AF2 | MCSUMMARMn54AF2 | MCSUMMARNa22AF2 | MCSUMMARNb94AF2 | MCSUMMARNi59AF2 | MCSUMMARNi63AF2 |
| 3 | MCSUMMARH3AF3 | MCSUMMARMn54AF3 | MCSUMMARNa22AF3 | MCSUMMARNb94AF3 | MCSUMMARNi59AF3 | MCSUMMARNi63AF3 |
| 4 | MCSUMMARH3AF4 | MCSUMMARMn54AF4 | MCSUMMARNa22AF4 | MCSUMMARNb94AF4 | MCSUMMARNi59AF4 | MCSUMMARNi63AF4 |
| 5 | MCSUMMARH3AF5 | MCSUMMARMn54AF5 | MCSUMMARNa22AF5 | MCSUMMARNb94AF5 | MCSUMMARNi59AF5 | MCSUMMARNi63AF5 |
| 6 | MCSUMMARH3AF6 | MCSUMMARMn54AF6 | MCSUMMARNa22AF6 | MCSUMMARNb94AF6 | MCSUMMARNi59AF6 | MCSUMMARNi63AF6 |
| 8 | MCSUMMARH3AF8 | MCSUMMARMn54AF8 | MCSUMMARNa22AF8 | MCSUMMARNb94AF8 | MCSUMMARNi59AF8 | MCSUMMARNi63AF8 |
| 10 | MCSUMMARH3AF10 | MCSUMMARMn54AF10 | MCSUMMARNa22AF10 | MCSUMMARNb94AF10 | MCSUMMARNi59AF10 | MCSUMMARNi63AF10 |
| 15 | MCSUMMARH3AF15 | MCSUMMARMn54AF15 | MCSUMMARNa22AF15 | MCSUMMARNb94AF15 | MCSUMMARNi59AF15 | MCSUMMARNi63AF15 |
| 25 | MCSUMMARH3AF25 | MCSUMMARMn54AF25 | MCSUMMARNa22AF25 | MCSUMMARNb94AF25 | MCSUMMARNi59AF25 | MCSUMMARNi63AF25 |
| 50 | MCSUMMARH3AF50 | MCSUMMARMn54AF50 | MCSUMMARNa22AF50 | MCSUMMARNb94AF50 | MCSUMMARNi59AF50 | MCSUMMARNi63AF50 |
| 100 | MCSUMMARH3AF100 | MCSUMMARMn54AF100 | MCSUMMARNa22AF100 | MCSUMMARNb94AF100 | MCSUMMARNi59AF100 | MCSUMMARNi63AF100 |
| Area (m2) | RESRAD Uncertainty Analysis Report file name: Pu-238 | Pu-239 | Pu-240 | Pu-241 | Sb-125 | Sr-90 |
| 1 | MCSUMMARPu238AF1 | MCSUMMARPu239AF1 | MCSUMMARPu240AF1 | MCSUMMARPu241AF1 | MCSUMMARSb125AF1 | MCSUMMARSr90AF1 |
| 2 | MCSUMMARPu238AF2 | MCSUMMARPu239AF2 | MCSUMMARPu240AF2 | MCSUMMARPu241AF2 | MCSUMMARSb125AF2 | MCSUMMARSr90AF2 |
| 3 | MCSUMMARPu238AF3 | MCSUMMARPu239AF3 | MCSUMMARPu240AF3 | MCSUMMARPu241AF3 | MCSUMMARSb125AF3 | MCSUMMARSr90AF3 |
| 4 | MCSUMMARPu238AF4 | MCSUMMARPu239AF4 | MCSUMMARPu240AF4 | MCSUMMARPu241AF4 | MCSUMMARSb125AF4 | MCSUMMARSr90AF4 |
| 5 | MCSUMMARPu238AF5 | MCSUMMARPu239AF5 | MCSUMMARPu240AF5 | MCSUMMARPu241AF5 | MCSUMMARSb125AF5 | MCSUMMARSr90AF5 |
| 6 | MCSUMMARPu238AF6 | MCSUMMARPu239AF6 | MCSUMMARPu240AF6 | MCSUMMARPu241AF6 | MCSUMMARSb125AF6 | MCSUMMARSr90AF6 |
| 8 | MCSUMMARPu238AF8 | MCSUMMARPu239AF8 | MCSUMMARPu240AF8 | MCSUMMARPu241AF8 | MCSUMMARSb125AF8 | MCSUMMARSr90AF8 |
| 10 | MCSUMMARPu238AF10 | MCSUMMARPu239AF10 | MCSUMMARPu240AF10 | MCSUMMARPu241AF10 | MCSUMMARSb125AF10 | MCSUMMARSr90AF10 |
| 15 | MCSUMMARPu238AF15 | MCSUMMARPu239AF15 | MCSUMMARPu240AF15 | MCSUMMARPu241AF15 | MCSUMMARSb125AF15 | MCSUMMARSr90AF15 |
| 25 | MCSUMMARPu238AF25 | MCSUMMARPu239AF25 | MCSUMMARPu240AF25 | MCSUMMARPu241AF25 | MCSUMMARSb125AF25 | MCSUMMARSr90AF25 |
| 50 | MCSUMMARPu238AF50 | MCSUMMARPu239AF50 | MCSUMMARPu240AF50 | MCSUMMARPu241AF50 | MCSUMMARSb125AF50 | MCSUMMARSr90AF50 |
| 100 | MCSUMMARPu238AF100 | MCSUMMARPu239AF100 | MCSUMMARPu240AF100 | MCSUMMARPu241AF100 | MCSUMMARSb125AF100 | MCSUMMARSr90AF100 |

**Table 2A (continued): Cross References for RESRAD Report Files**

| Area (m2) | RESRAD Uncertainty Report file name: Tc-99 |
|---|---|
| 1 | MCSUMMARTc99AF1 |
| 2 | MCSUMMARTc99AF2 |
| 3 | MCSUMMARTc99AF3 |
| 4 | MCSUMMARTc99AF4 |
| 5 | MCSUMMARTc99AF5 |
| 6 | MCSUMMARTc99AF6 |
| 8 | MCSUMMARTc99AF8 |
| 10 | MCSUMMARTc99AF10 |
| 15 | MCSUMMARTc99AF15 |
| 25 | MCSUMMARTc99AF25 |
| 50 | MCSUMMARTc99AF50 |
| 100 | MCSUMMARTc99AF100 |

## Table 3 - Area Factors for Gamma Emitters

| | Area ($m^2$) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Gamma | 1 | 2 | 5 | 10 | 25 | 50 | 100 | 250 | 500 | 1000 | 2000 |
| Ag-108m | 10.80 | 6.19 | 3.35 | 2.21 | 1.59 | 1.32 | 1.19 | 1.09 | 1.04 | 1.01 | 1.00 |
| Co-60 | 16.19 | 6.56 | 3.54 | 2.33 | 1.66 | 1.36 | 1.21 | 1.11 | 1.05 | 1.01 | 1.00 |
| Cs-134 | 11.53 | 6.61 | 3.58 | 2.36 | 1.70 | 1.41 | 1.26 | 1.14 | 1.08 | 1.02 | 1.00 |
| Cs-137 | 11.97 | 6.87 | 3.72 | 2.45 | 1.76 | 1.46 | 1.30 | 1.18 | 1.10 | 1.03 | 1.00 |
| Eu-152 | 11.13 | 6.35 | 3.43 | 2.26 | 1.62 | 1.34 | 1.19 | 1.09 | 1.04 | 1.01 | 1.00 |
| Eu-154 | 11.27 | 6.42 | 3.46 | 2.28 | 1.63 | 1.34 | 1.20 | 1.09 | 1.04 | 1.01 | 1.00 |
| Eu-155 | 8.35 | 5.06 | 2.84 | 1.90 | 1.45 | 1.25 | 1.14 | 1.07 | 1.03 | 1.01 | 1.00 |
| Mn-54 | 11.25 | 6.42 | 3.47 | 2.28 | 1.63 | 1.35 | 1.20 | 1.10 | 1.05 | 1.01 | 1.00 |
| Na-22 | 11.23 | 6.41 | 3.46 | 2.28 | 1.63 | 1.35 | 1.21 | 1.10 | 1.05 | 1.02 | 1.00 |
| Nb-94 | 11.03 | 6.31 | 3.41 | 2.25 | 1.61 | 1.33 | 1.19 | 1.09 | 1.04 | 1.01 | 1.00 |
| Sb-125 | 10.77 | 6.18 | 3.34 | 2.21 | 1.59 | 1.32 | 1.19 | 1.09 | 1.04 | 1.01 | 1.00 |

## Table 4
## Area Factors for Beta Emitters

| | Area ($m^2$) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Beta Emitters** | **1** | **2** | **5** | **10** | **25** | **50** | **100** | **250** | **500** | **1000** | **2000** |
| **H-3** | 285.40 | 133.81 | 58.02 | 37.91 | 22.92 | 16.11 | 9.87 | 4.38 | 2.31 | 1.19 | 1.00 |
| **C-14** | 17618.63 | 8060.30 | 2640.76 | 1082.32 | 317.94 | 121.70 | 45.48 | 12.17 | 4.42 | 1.59 | 1.00 |
| **Fe-55** | 1579.33 | 855.84 | 347.93 | 173.96 | 71.10 | 35.65 | 17.63 | 7.15 | 3.58 | 1.76 | 1.00 |
| **Ni-59** | 1377.03 | 708.81 | 282.78 | 140.83 | 56.81 | 28.43 | 14.12 | 5.69 | 2.84 | 1.41 | 1.00 |
| **Ni-63** | 1382.61 | 710.27 | 283.06 | 140.89 | 56.84 | 28.44 | 14.12 | 5.69 | 2.85 | 1.41 | 1.00 |
| **Sr-90** | 750.23 | 390.20 | 167.40 | 88.08 | 38.04 | 19.80 | 10.17 | 4.16 | 2.10 | 1.05 | 1.00 |
| **Tc-99** | 996.90 | 500.52 | 201.09 | 100.84 | 40.51 | 20.30 | 10.16 | 4.07 | 2.03 | 1.02 | 1.00 |

**Table 5**
**Area Factors for Alpha Emitters**

| | Area ($m^2$) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Alpha Emitters** | **1** | **2** | **5** | **10** | **25** | **50** | **100** | **250** | **500** | **1000** | **2000** |
| **Am-241** | 39.26 | 29.34 | 19.42 | 13.87 | 9.96 | 7.52 | 5.42 | 3.09 | 1.83 | 1.01 | 1.00 |
| **Cm-242** | 50.87 | 43.97 | 34.39 | 26.92 | 18.17 | 12.28 | 7.61 | 3.62 | 1.94 | 1.01 | 1.00 |
| **Cm-243** | 13.99 | 8.38 | 4.67 | 3.11 | 2.28 | 1.91 | 1.69 | 1.45 | 1.25 | 1.01 | 1.00 |
| **Pu-238** | 64.47 | 56.69 | 45.03 | 35.21 | 22.36 | 14.24 | 8.35 | 3.76 | 1.97 | 1.01 | 1.00 |
| **Pu-239** | 64.95 | 57.06 | 45.24 | 35.31 | 22.38 | 14.24 | 8.35 | 3.77 | 1.97 | 1.01 | 1.00 |
| **Pu-240** | 67.17 | 57.25 | 45.43 | 35.48 | 22.47 | 14.28 | 8.36 | 3.76 | 1.97 | 1.01 | 1.00 |
| **Pu-241** | 41.80 | 31.40 | 13.53 | 14.96 | 10.66 | 7.99 | 5.71 | 3.19 | 1.85 | 1.01 | 1.00 |

**Figure 1 - Area Factors for Gamma Emitting Radionuclides**

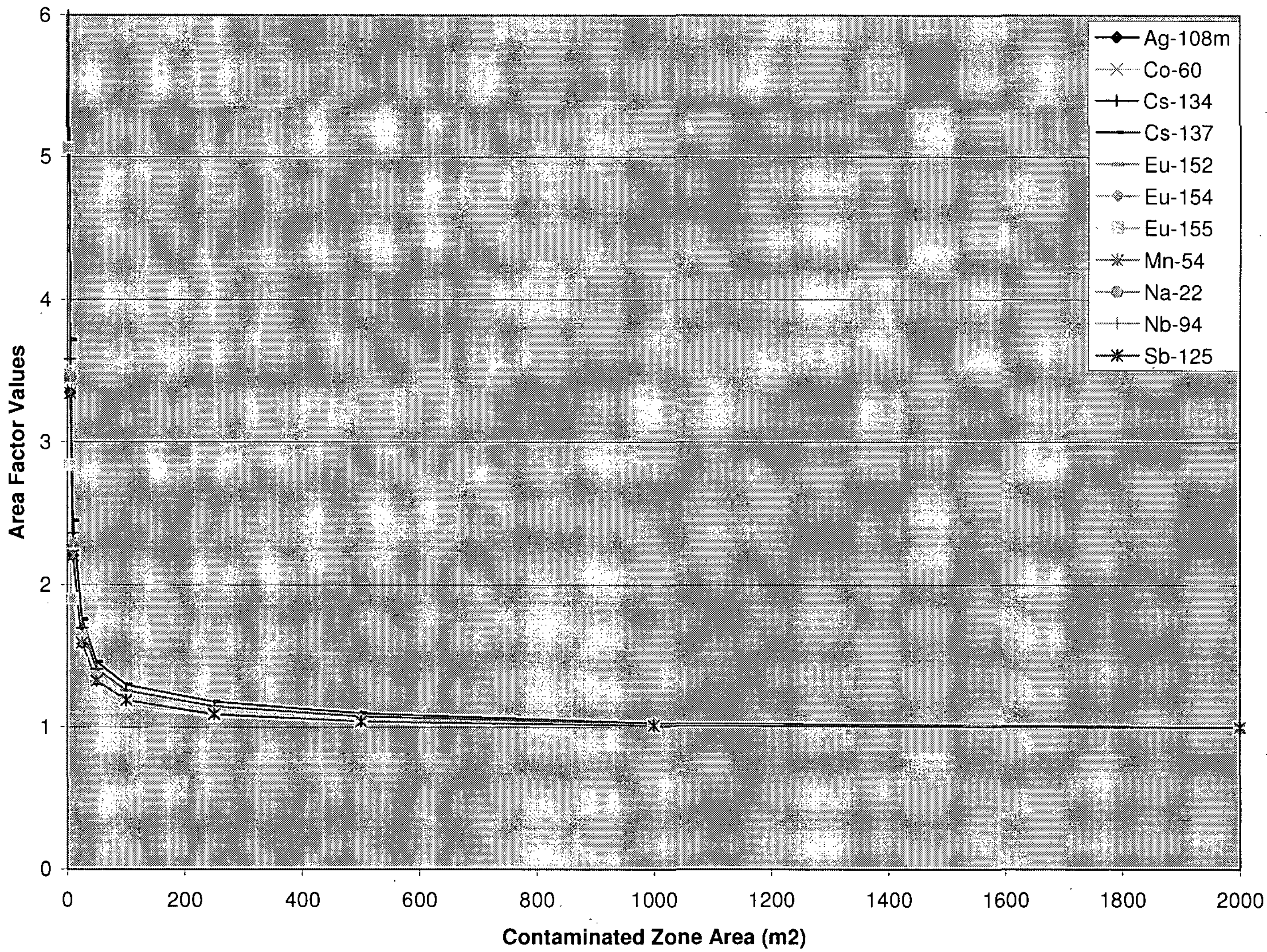

**Figure 2 - Area Factors for Beta Emitting Radionuclides**

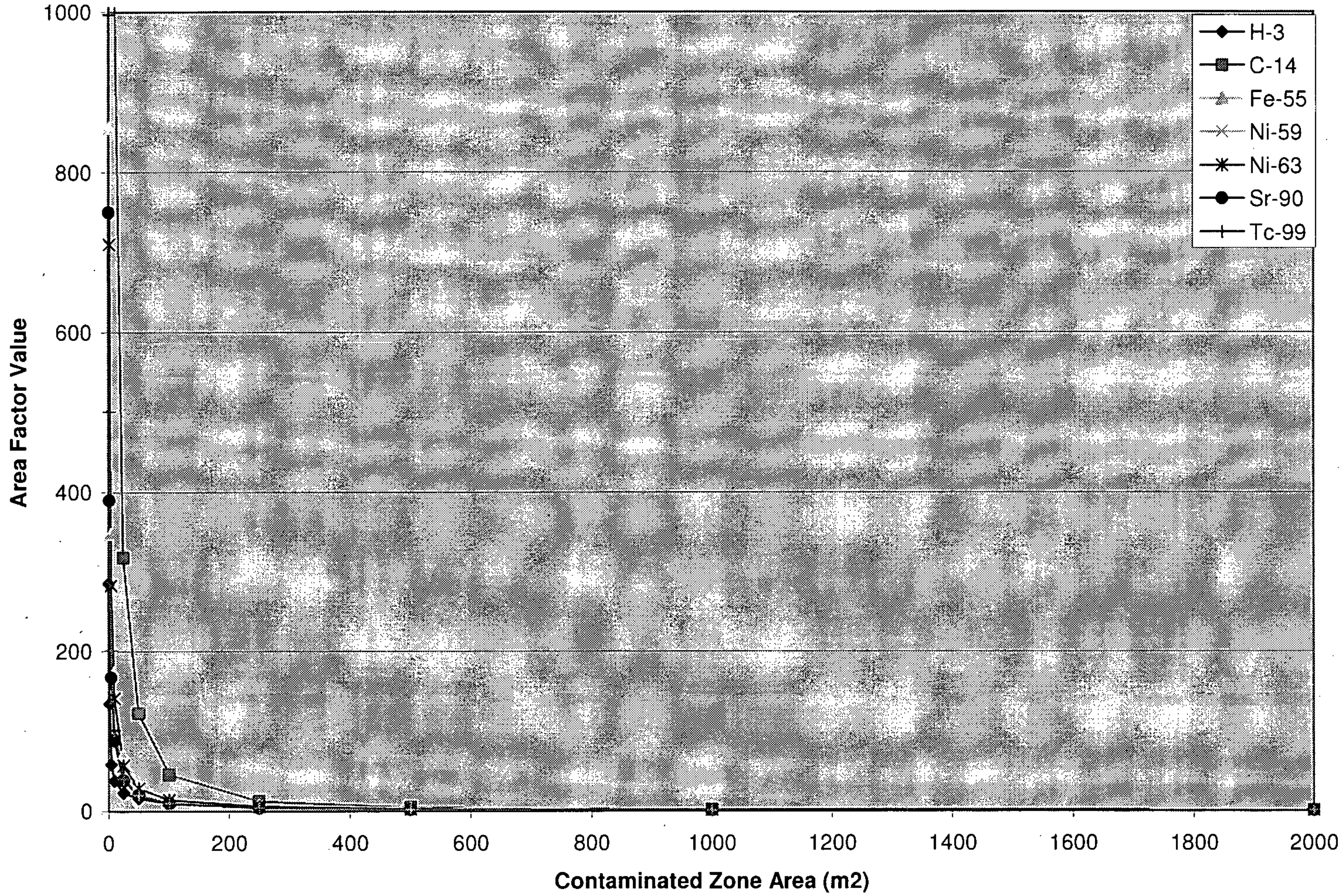

**Figure 3 - Area Factors for Alpha Emitting Radionuclides**