BARTLETT

# ENGINEERING CALCULATION

Calculation Number: ENG-HB-005

Revision Number: 0

Calculation Title: Area Factors for Use with Humboldt Bay Soil DCGLs

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## 1.0 PURPOSE

The purpose of this calculation is to develop area factors (AFs) for use with derived concentration guideline levels (DCGLs) for assessing soil at the Pacific Gas & Electric (PGE) Humboldt Bay nuclear power site. This calculation is a deliverable product specified in the scope of work section in Contract No. GT012 3500895165.

## 2.0 APPLICABILITY

This calculation addresses only the development of AF values for use with soil DCGLs for the PGE Humboldt Bay site.

## 3.0 REFERENCES

3.1 ENG-HB-003, *Humboldt Bay Soil Derived Concentration Guideline Levels*

3.2 Bartlett Engineering Procedure ENG-AP-02, *Verification of Software Operability*

3.3 ANL/EAIS-8, *Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil*; U.S. Department of Energy – Argonne National Laboratory, April 1993.

3.4 NUREG/CR-5512, Volume 1, *Residual Radioactive Contamination from Decommissioning: Technical Basis for Translating Contamination Levels to Annual Total Effective Dose Equivalent*, Final Report, U.S. Nuclear Regulatory Commission, October 1992.

3.5 ANL/EAD-4, *User's Manual for RESRAD Version 6*, U.S. Department of Energy – Argone National Laboratory, July, 2001.

## 4.0 METHOD OF CALCULATION

The operability of the RESRAD Version 6.5 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].

The RESRAD computer code was developed at Argonne National Laboratory (ANL) as a multifunctional tool to assist in developing radiological criteria for unrestricted release and assessing the dose or risk associated with residual radioactive material. 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. The RESRAD software allow the user to evaluate radiation exposure through several pathways: direct external radiation, inhalation, ingestion of plants, meat, milk, aquatic foods, and drinking water, inadvertent ingestion of contaminated soil, and radon exposure. All these pathways were applied in the development of area factors.

The method applied in the calculation of area factors is the same as that applied in ENG-HB-003 [ref. 3.1] to develop the soil DCGL values. Adjustments to account for a reduced area were made to certain RESRAD input parameters, such as the size of the contaminated zone, the length of parallel to aquifer flow, plant, meat, and milk transfer factors. AFs are not determined for areas greater than 2,000 $m^2$, the maximum size for a Class 1 land survey unit. Therefore, a contaminated area equal to 2000 $m^2$ was selected as the base case.

AF values are calculated from the "peak of the mean" doses (PMD) generated in RESRAD code executions using the following equation:

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

Where

AF = the area factor (unitless)

$PMD_{2000}$ = peak of the mean dose for the base case (mrem/y), and

$PMD_i$ = peak of the mean dose for the reduced area i (mrem/y), where "i" is set at various sized areas

The above equation shows that the AF is the ratio of the base case $PMD_{2000}$ to the $PMD_i$ for the smaller area.

## 5.0 ASSUMPTIONS AND INPUT

### 5.1 Assumptions

5.1.1 Radionuclides of Concern (ROC): Am-241, C-14, Cm243/244/245/246, Co-60, Cs-137, Eu-152, Eu-154, H-3, I-129, Nb-94, Ni-59, Ni-63, Np-237, Pu-238/239/240/241, Sr-90, and Tc-99.

5.1.2 Resident Farmer Scenario: The dose model used in the development of the soil DCGL values was the Resident Farmer Scenario defined in NUREG/CR-5512 Volume 1 (Ref. 3.4). That same scenario is applied in the calculations of AFs. The pathways used to estimate human radiation exposure resulting from residual radioactivity in the soil for this scenario includes the following:

- Direct external radiation exposure pathway;
- Inhalation exposure pathway;
- Ingestion exposure pathway:
  - 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 watercontaining residual radioactivity,
  - drinking water containing residual radioactivity from a well, and
  - aquatic food from a pond containing residual radioactivity;
- Inadvertent ingestion of contaminated soil

5.1.3 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, meat, and milk originating from the site also decrease.

5.1.4 The contaminated fractions for drinking water, livestock water, irrigation water, and aquatic food 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.

5.1.5 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. A proportionate reduction in the value for this parameter is assumed as the size of the contaminated zone decreases.

## 5.2 Input

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. 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)

5.2.2 Input values for FDW, FLW, FIRW, and FR9 are held to the same values as those used in the DCGL calculation [ref. 3.1].

5.2.3 Adjustments to FPLANT were made based on information in the RESRAD User's Manual [Ref. 3.5]. The following shows how the RESRAD code determines the contamination fraction ($FA_3$) for plants:

$FA_3$ = A/2,000 when $0 \leq A \leq 1{,}000\ m^2$
$FA_3$ = 0.5 when $A > 1{,}000\ m^2$

The above equations from the RESRAD User's Manual were adjusted 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 30,000 $m^2$ (the size of the contaminated zone at the Humboldt Bay site). 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 $A < 1{,}000\ m^2$

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

In addition, the following information from the RESRAD User Manual (Ref. 3.5) shows how the RESRAD code determines the contaminated fractions for meat ($FA_4$) and milk ($FA_5$):

$FA_{4\&5}$ = A/20,000 when $0 \leq A \leq 20{,}000\ m^2$
$FA_{4\&5}$ = 1.0 when $A > 20{,}000\ m^2$

The above relationships were used to vary input values for FMEAT and FMILK in order to remain consistent with the approach used for the soil DCGLs [ref. 3.1].

Table 1 shows the values for FPLANT, FMEAT, and FMILK as a function of the area of the contaminated zone.

5.2.4 As the area of the contaminated zone decreases, the value for another RESRAD Input parameter, the length parallel to aquifer flow (LCZPAQ), also decreases. The contaminated zone is assumed to be circular, so the value

for LCZPAQ is equal to the diameter of the circle:

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

Table 1 also shows the values for LCZPAQ as a function of the size of the contaminated zone.

5.3 Results:

5.3.1 RESRAD 6.5 code was 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.

5.3.2 RESRAD code executions were made for each ROC with the input shown in Table 1. The peak of the mean doses (PMD) for reduced contaminated zone sizes are presented by ROC in Table 2.

5.3.3 AF values were generated from the PMDs using the equations described in section 4.0. The AFs by ROC are presented in Table 3. Graphic displays for area factors for the Humboldt Bay ROCs are provided in Figures 1 through 7.

Table 1: RESRAD Input Parameters Vs. Size of Contaminated Zone

| RESRAD Parameter | Input Value | | | | |
|---|---|---|---|---|---|
| Contaminated Zone ($m^2$) | 30,0000[a] | 2,000 | 1,000 | 500 | 100 |
| LCZPAQ (m) | 195[a] | 50 | 36 | 25 | 11 |
| FPLANT | 1.0[a] | 1.0 | 1.0 | 0.5 | 0.10 |
| FMEAT | 1.0[a] | 0.1 | 0.05 | 0.025 | 0.005 |
| FMILK | 1.0[a] | 0.1 | 0.05 | 0.025 | 0.005 |
| Contaminated Zone ($m^2$) | 50 | 10 | 5 | 1 | |
| LCZPAQ (m) | 8.0 | 3.6 | 2.5 | 1.1 | |
| FPLANT | 0.05 | 0.01 | 0.005 | 0.001 | |
| FMEAT | 0.0025 | 0.0005 | 0.00025 | 0.00005 | |
| FMILK | 0.0025 | 0.0005 | 0.00025 | 0.00005 | |

[a] Parameter value for DCGL modeling.

Table 2: RESRAD Dose Results for Varying Size of Contaminated Zone

| | PMD (mrem/y) for Contaminated Zone Size ($m^2$): | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ROC | 2000 | 1000 | 500 | 100 | 50 | 10 | 5 | 1 |
| Am-241 | 9.58E-01 | 9.57E-01 | 4.87E-01 | 1.10E-01 | 6.14E-02 | 1.97E-02 | 1.24E-02 | 5.09E-03 |
| C-14 | 6.04E-01 | 4.16E-01 | 1.50E-01 | 1.45E-02 | 5.43E-03 | 6.01E-04 | 2.44E-04 | 3.43E-05 |
| Cm-243 | 8.47E-01 | 8.45E-01 | 5.21E-01 | 2.47E-01 | 1.99E-01 | 1.16E-01 | 7.71E-02 | 2.65E-02 |
| Cm-244 | 5.16E-01 | 5.15E-01 | 2.59E-01 | 5.34E-02 | 2.77E-02 | 6.83E-03 | 4.14E-03 | 1.83E-03 |
| Cm-245 | 1.39E+00 | 1.39E+00 | 7.45E-01 | 2.24E-01 | 1.52E-01 | 7.15E-02 | 4.69E-02 | 1.72E-02 |
| Cm-246 | 9.63E-01 | 9.62E-01 | 4.83E-01 | 9.97E-02 | 5.16E-02 | 1.27E-02 | 7.68E-03 | 3.38E-03 |
| Co-60 | 5.76E+00 | 5.67E+00 | 5.30E+00 | 4.59E+00 | 4.16E+00 | 2.65E+00 | 1.76E+00 | 5.71E-01 |
| Cs-137 | 1.81E+00 | 1.72E+00 | 1.41E+00 | 1.06E+00 | 9.49E-01 | 5.99E-01 | 3.98E-01 | 1.31E-01 |
| Eu-152 | 2.35E+00 | 2.33E+00 | 2.28E+00 | 2.05E+00 | 1.87E+00 | 1.19E+00 | 7.92E-01 | 2.58E-01 |
| Eu-154 | 2.53E+00 | 2.50E+00 | 2.44E+00 | 2.20E+00 | 2.00E+00 | 1.27E+00 | 8.46E-01 | 2.75E-01 |
| H-3 | 1.94E-02 | 1.84E-02 | 9.22E-03 | 1.86E-03 | 9.34E-04 | 1.91E-04 | 9.74E-05 | 2.09E-05 |
| I-129 | 1.71E+00 | 1.52E+00 | 7.60E-01 | 1.55E-01 | 7.88E-02 | 1.73E-02 | 9.04E-03 | 2.06E-03 |
| Nb-94 | 3.32E+00 | 3.28E+00 | 3.21E+00 | 2.89E+00 | 2.63E+00 | 1.69E+00 | 1.12E+00 | 3.69E-01 |
| Ni-59 | 3.57E-03 | 3.06E-03 | 1.53E-03 | 3.06E-04 | 1.53E-04 | 3.07E-05 | 1.53E-05 | 3.08E-06 |
| Ni-63 | 9.71E-03 | 8.33E-03 | 4.17E-03 | 8.33E-04 | 4.17E-04 | 8.34E-05 | 4.17E-05 | 8.37E-06 |
| Np-237 | 2.19E+01 | 2.19E+01 | 1.11E+01 | 2.45E+00 | 1.34E+00 | 3.89E-01 | 2.25E-01 | 6.26E-02 |
| Pu-238 | 8.30E-01 | 8.29E-01 | 4.16E-01 | 8.59E-02 | 4.45E-02 | 1.10E-02 | 6.64E-03 | 2.92E-03 |
| Pu-239 | 9.22E-01 | 9.21E-01 | 4.62E-01 | 9.54E-02 | 4.94E-02 | 1.22E-02 | 7.35E-03 | 3.23E-03 |
| Pu-240 | 9.22E-01 | 9.21E-01 | 4.62E-01 | 9.54E-02 | 4.94E-02 | 1.22E-02 | 7.35E-03 | 3.23E-03 |
| Pu-241 | 2.87E-02 | 2.87E-02 | 1.46E-02 | 3.28E-03 | 1.83E-03 | 5.87E-04 | 3.70E-04 | 1.52E-04 |
| Sr-90 | 1.23E+01 | 1.21E+01 | 6.03E+00 | 1.21E+00 | 6.08E-01 | 1.24E-01 | 6.26E-02 | 1.28E-02 |
| Tc-99 | 1.79E+00 | 1.78E+00 | 8.90E-01 | 1.78E-01 | 8.90E-02 | 1.78E-02 | 8.91E-03 | 1.78E-03 |

Table 3: Area Factors for Soil

| ROC | Area Factor for Area Contaminated Zone ($m^2$): 2000 | 1000 | 500 | 100 | 50 | 10 | 5 | 1 |
|---|---|---|---|---|---|---|---|---|
| Am-241 | 1.0E+00 | 1.0E+00 | 2.0E+00 | 8.7E+00 | 1.6E+01 | 4.9E+01 | 7.7E+01 | 1.9E+02 |
| C-14 | 1.0E+00 | 1.5E+00 | 4.0E+00 | 4.2E+01 | 1.1E+02 | 1.0E+03 | 2.5E+03 | 1.8E+04 |
| Cm-243 | 1.0E+00 | 1.0E+00 | 1.6E+00 | 3.4E+00 | 4.3E+00 | 7.3E+00 | 1.1E+01 | 3.2E+01 |
| Cm-244 | 1.0E+00 | 1.0E+00 | 2.0E+00 | 9.7E+00 | 1.9E+01 | 7.6E+01 | 1.2E+02 | 2.8E+02 |
| Cm-245 | 1.0E+00 | 1.0E+00 | 1.9E+00 | 6.2E+00 | 9.2E+00 | 1.9E+01 | 3.0E+01 | 8.1E+01 |
| Cm-246 | 1.0E+00 | 1.0E+00 | 2.0E+00 | 9.7E+00 | 1.9E+01 | 7.6E+01 | 1.3E+02 | 2.8E+02 |
| Co-60 | 1.0E+00 | 1.0E+00 | 1.1E+00 | 1.3E+00 | 1.4E+00 | 2.2E+00 | 3.3E+00 | 1.0E+01 |
| Cs-137 | 1.0E+00 | 1.0E+00 | 1.3E+00 | 1.7E+00 | 1.9E+00 | 3.0E+00 | 4.5E+00 | 1.4E+01 |
| Eu-152 | 1.0E+00 | 1.0E+00 | 1.0E+00 | 1.1E+00 | 1.3E+00 | 2.0E+00 | 3.0E+00 | 9.1E+00 |
| Eu-154 | 1.0E+00 | 1.0E+00 | 1.0E+00 | 1.2E+00 | 1.3E+00 | 2.0E+00 | 3.0E+00 | 9.2E+00 |
| H-3 | 1.0E+00 | 1.1E+00 | 2.1E+00 | 1.0E+01 | 2.1E+01 | 1.0E+02 | 2.0E+02 | 9.3E+02 |
| I-129 | 1.0E+00 | 1.1E+00 | 2.2E+00 | 1.1E+01 | 2.2E+01 | 9.9E+01 | 1.9E+02 | 8.3E+02 |
| Nb-94 | 1.0E+00 | 1.0E+00 | 1.0E+00 | 1.2E+00 | 1.3E+00 | 2.0E+00 | 3.0E+00 | 9.0E+00 |
| Ni-59 | 1.0E+00 | 1.2E+00 | 2.3E+00 | 1.2E+01 | 2.3E+01 | 1.2E+02 | 2.3E+02 | 1.2E+03 |
| Ni-63 | 1.0E+00 | 1.2E+00 | 2.3E+00 | 1.2E+01 | 2.3E+01 | 1.2E+02 | 2.3E+02 | 1.2E+03 |
| Np-237 | 1.0E+00 | 1.0E+00 | 2.0E+00 | 9.0E+00 | 1.6E+01 | 5.6E+01 | 9.8E+01 | 3.5E+02 |
| Pu-238 | 1.0E+00 | 1.0E+00 | 2.0E+00 | 9.7E+00 | 1.9E+01 | 7.6E+01 | 1.3E+02 | 2.8E+02 |
| Pu-239 | 1.0E+00 | 1.0E+00 | 2.0E+00 | 9.7E+00 | 1.9E+01 | 7.6E+01 | 1.3E+02 | 2.9E+02 |
| Pu-240 | 1.0E+00 | 1.0E+00 | 2.0E+00 | 9.7E+00 | 1.9E+01 | 7.6E+01 | 1.3E+02 | 2.9E+02 |
| Pu-241 | 1.0E+00 | 1.0E+00 | 2.0E+00 | 8.8E+00 | 1.6E+01 | 4.9E+01 | 7.8E+01 | 1.9E+02 |
| Sr-90 | 1.0E+00 | 1.0E+00 | 2.0E+00 | 1.0E+01 | 2.0E+01 | 9.9E+01 | 2.0E+02 | 9.6E+02 |
| Tc-99 | 1.0E+00 | 1.0E+00 | 2.0E+00 | 1.0E+01 | 2.0E+01 | 1.0E+02 | 2.0E+02 | 1.0E+03 |

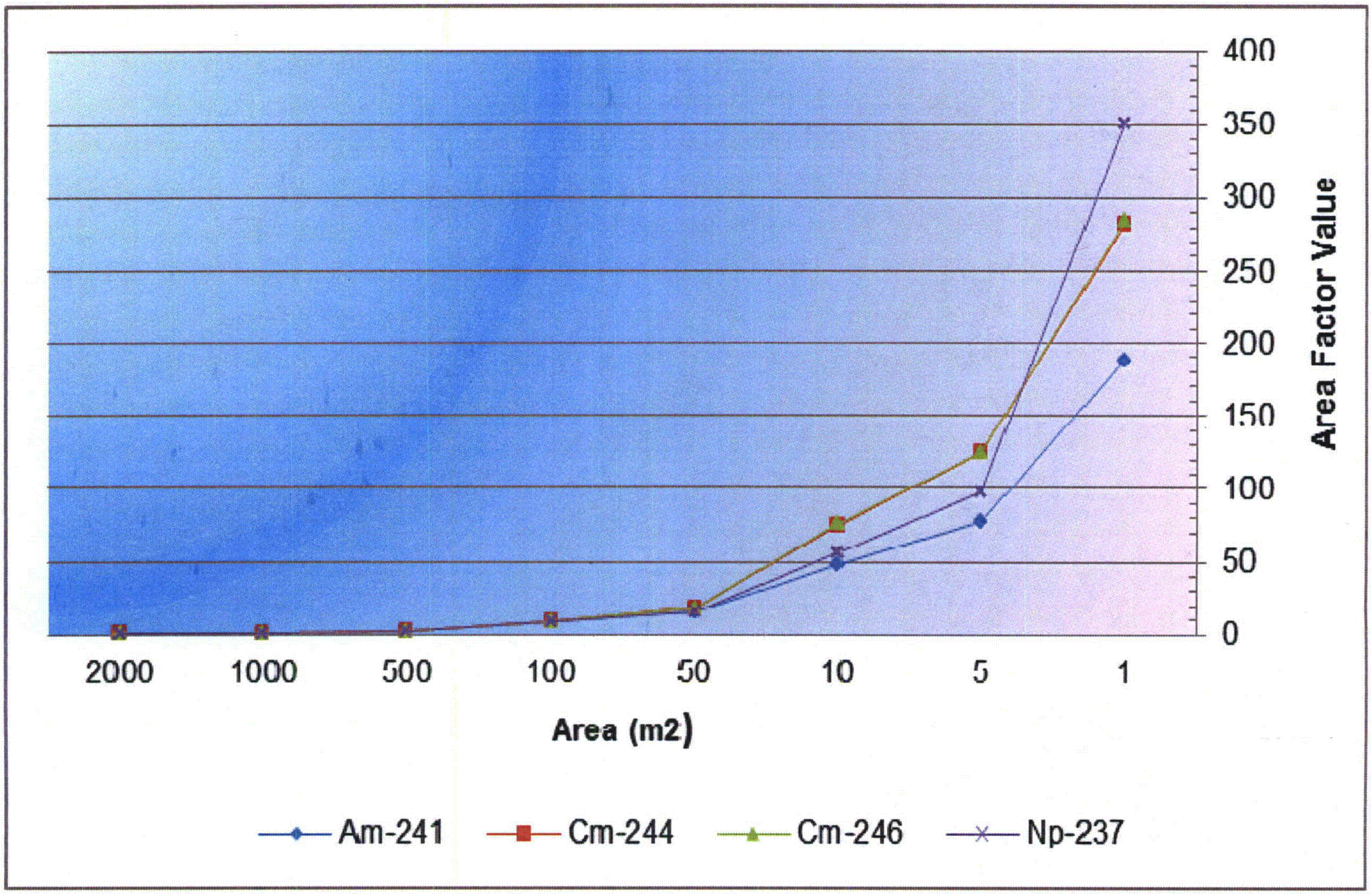


Figure 1: Area Factors for Americium-241, Curium-244, 246, and Neptunium-237

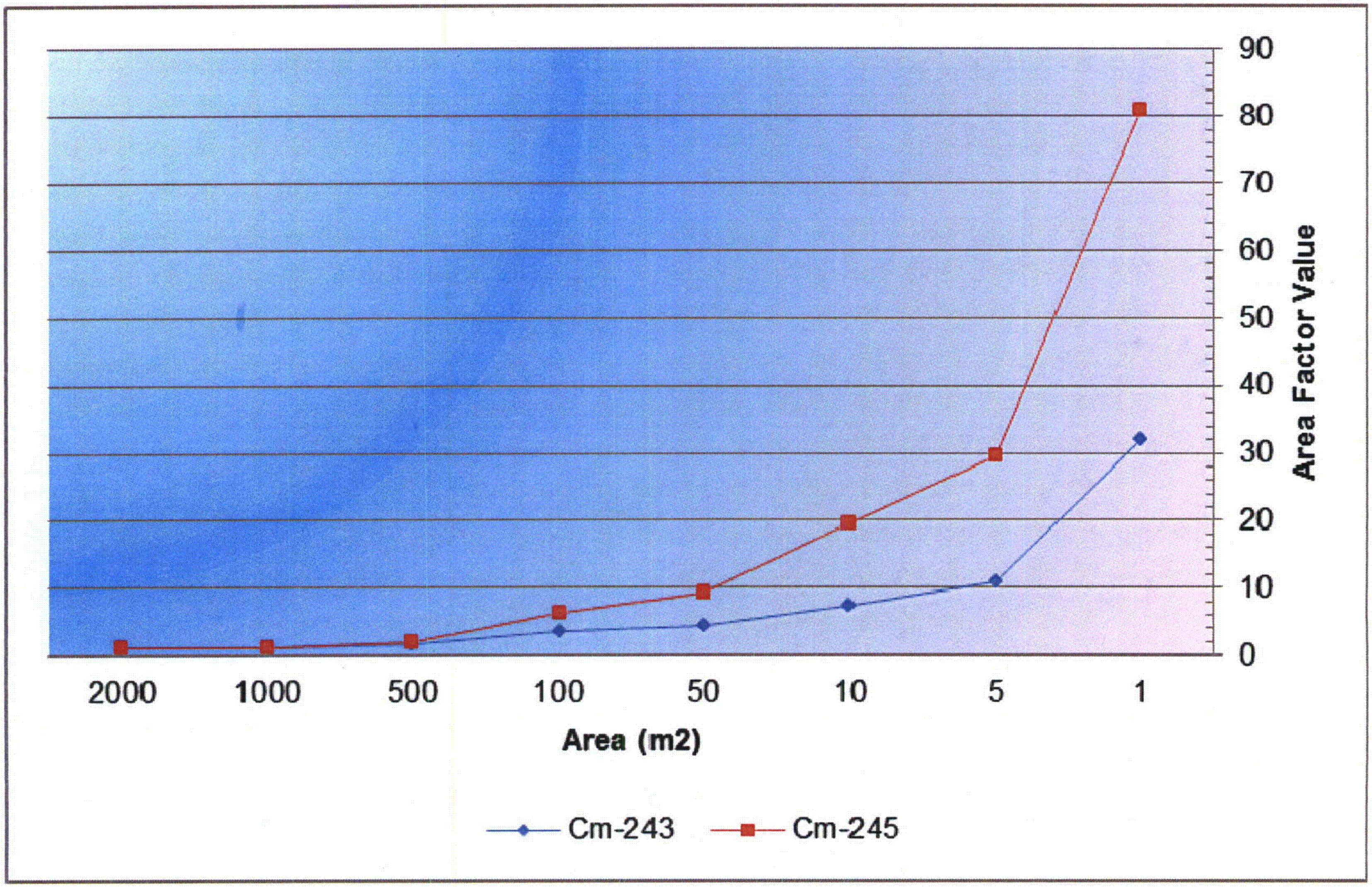


Figure 2: Area Factors for Curium-244 and 245

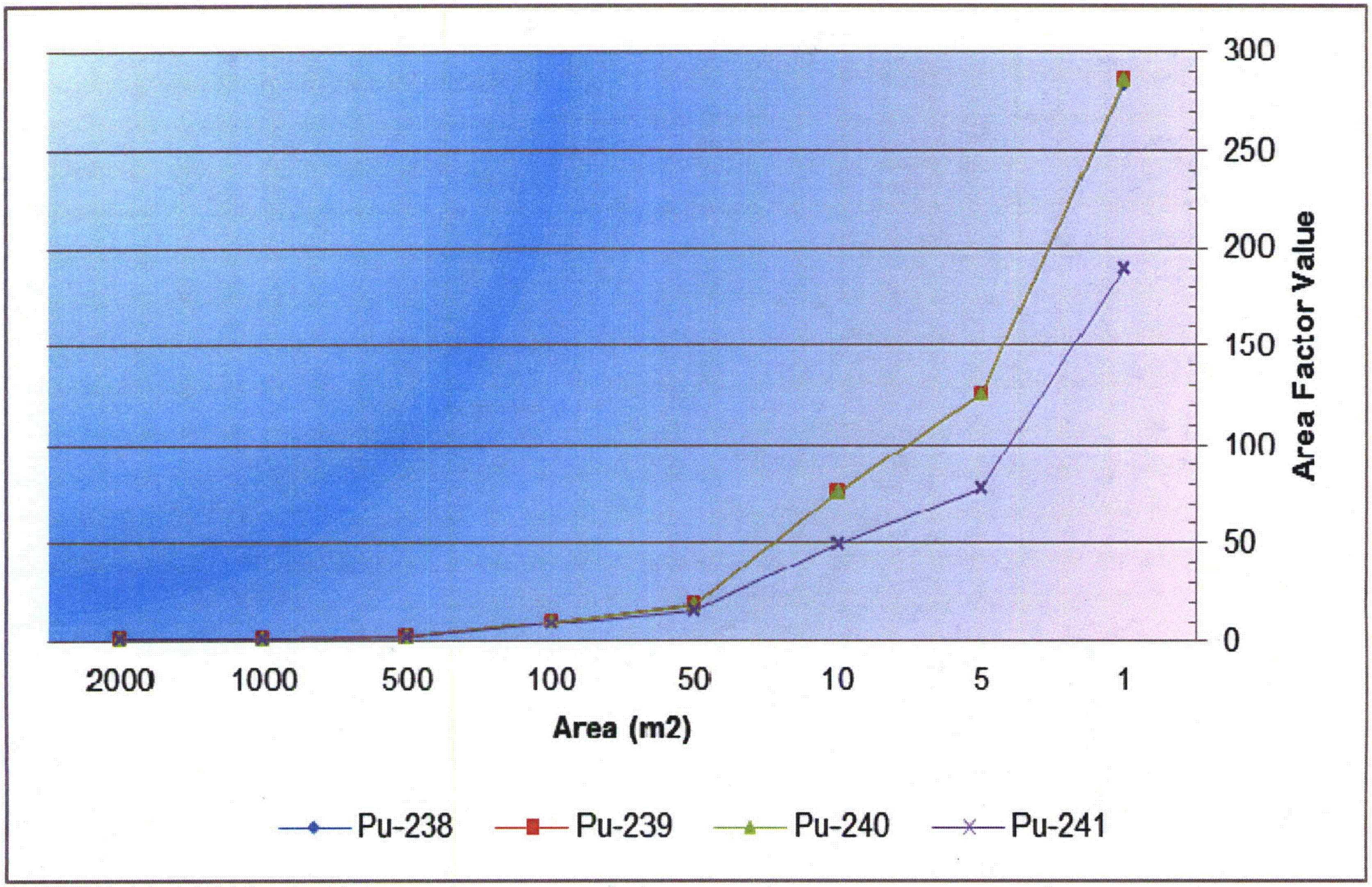


Figure 3: Area Factors for Plutonium-238, 239, 240, and 241

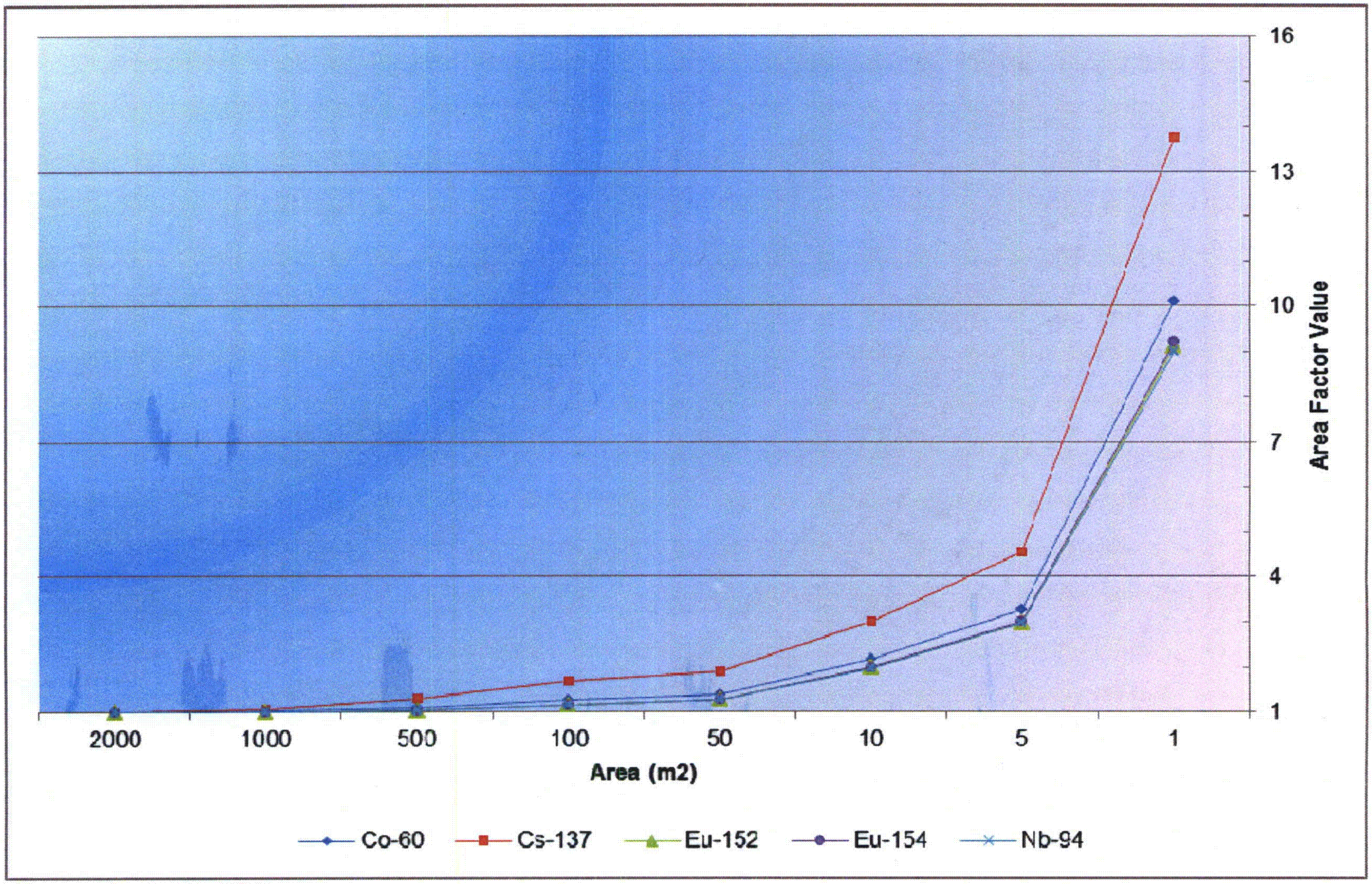


Figure 4: Area Factors for Cobalt-60, Cesium-137, Europium-152, 154, and Niobium-94

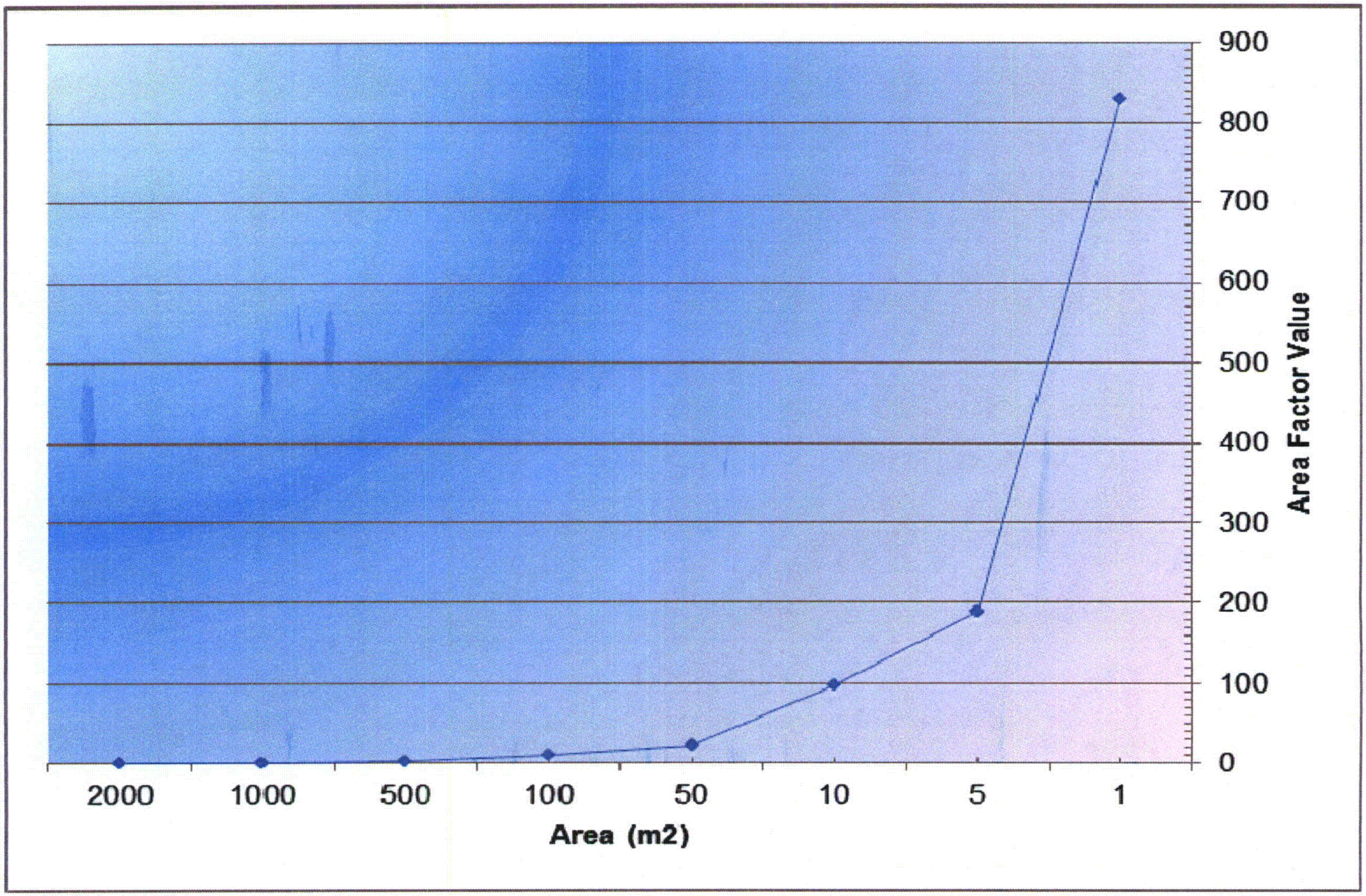


Figure 5: Area Factors for Iodine-129

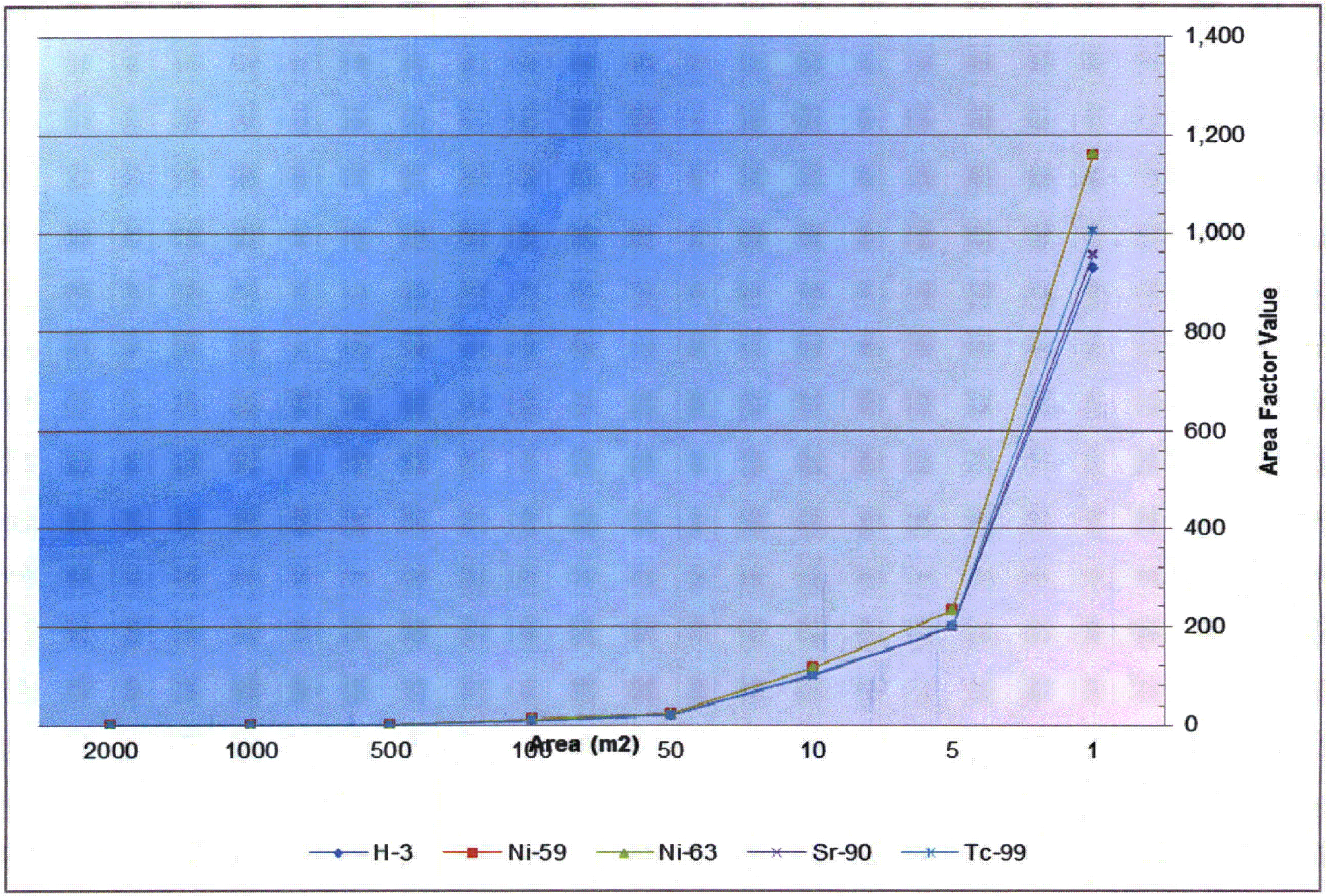


Figure 6: Area Factors for Tritium, Nickel-59, 63, Strontium-90, and Technetium-99

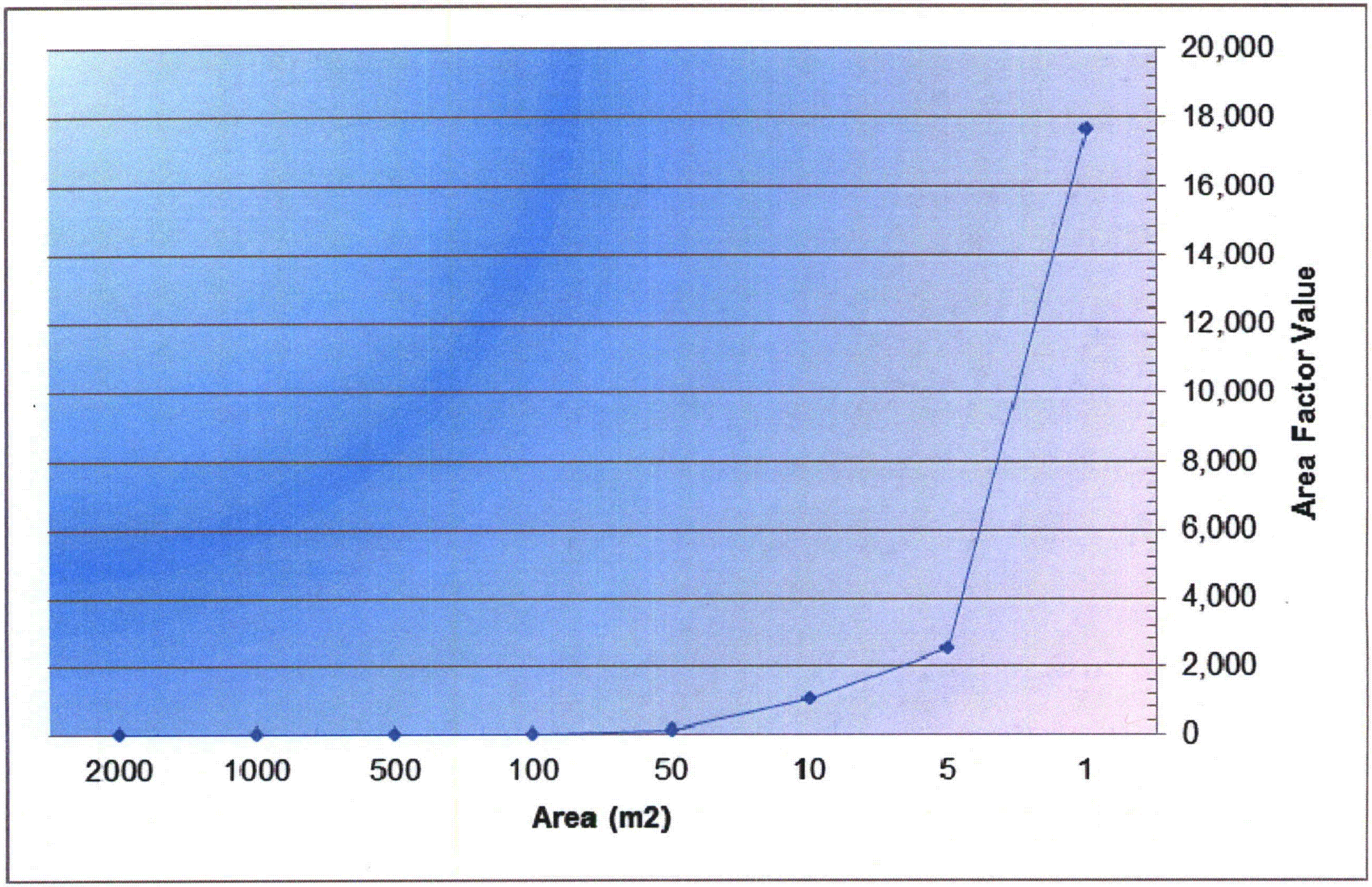


Figure 7: Area Factors for Carbon-14