Applications of Geometry Correction Factors for Low-Level Waste Package Dose Measurements (U)

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**APPLICATION OF GEOMETRY CORRECTION FACTORS
FOR LOW LEVEL WASTE PACKAGE DOSE MEASUREMENTS (U)**

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REVISION HISTORY:

Revision	Page	Change
0 9/26/94	—	Initial issue
1 01/05/95	all	Revised document to include Geometry Corrections Factors (GCF) specific to containers. Added Appendix A to compare equations with those provided by HP. General editorial changes.
	3	Included GCF's for different waste containers instead of one generic factor.
	5	Replaced single equation with polynomial equations for each type of container.
	6	Added table of GCF's for various distances. Revised sketch.
	6-7	Revised numbers in Example. Corrected Table.
	8	Revised numbers to reflect new GCF for B-25.
	11	Added Appendix A.

INTRODUCTION AND SUMMARY

Plans are to determine the Cs-137 content of low level waste packages generated in High Level Waste by measuring the radiation level at a specified distance from the package with a hand-held radiation instrument. The measurement taken at this specified distance, either 3 or 5 feet, is called the far-field measurement. This report documents a method for adjusting the gamma exposure rate (mR/hr) reading used in dose-to-curie determinations when the far-field measurement equals the background reading. This adjustment is necessary to reduce the conservatism resulting from using a minimum detection limit exposure rate for the dose-to-curie determination for the far-field measurement position.

To accomplish this adjustment, the near-field (5 cm) measurement is multiplied by a geometry correction factor to obtain an estimate of the far field exposure rate (which is below instrument sensitivity). This estimate of the far field exposure rate is used to estimate the Cs-137 curie content of the package.

Applying this geometry correction factor reduces the conservatism and over-prediction of the package curie content. This is significant for most of the HLW low level waste packages. A review of disposal record for 1993 indicated approximately eighty five percent (85%) of the HLW waste packages had no detectable exposure rate at 5 cm from the package. Without using an adjustment factor, these packages would have been manifested at a value eleven times (11x) the curie content determined using geometry correction factors.

This report establishes the geometry correction factors for the dose-to-curie determination when the far-field gamma exposure measurement equals the background reading. This eliminates unnecessary conservatism in the dose-to-curie analysis. Geometry correction factors are as follows:

Waste Containers

	<u>Cardboard Box</u>	<u>B-12</u>	<u>B-25</u>
5 ft Dose / 5 cm Dose	N/A	0.09	0.11
3 ft Dose / 5 cm Dose	0.07	0.28	0.21

This report also provides a means of demonstrating compliance to 1S Manual requirements for exposure rate readings at different locations from waste packages while specifying only two measurement positions. This demonstration of compliance is necessary to minimize the number of locations exposure rate measurements that are required, i.e., ALARA.

DISCUSSION

Dose-to-Curie Analysis

Current dose-to-curie determinations performed for a waste package rely on a gamma exposure rate value measured with a hand-held instrument at a given distance from the container [Ref. 1]. The distance, five feet for large (B12 and B25) containers and three feet for smaller containers (cardboard boxes and drums), was selected by Radiological Engineering to provide the best detector view of the package. This prescribed measurement distance from the container is referred to as a far-field measurement.

When the exposure rate reading (mR/hr) is above minimum sensitivity, this far-field measurement provides the best information for determining the curie content of the package. (The dose Quality Factor for gamma radiation equals 1.0, resulting in mR/hr equaling mrem/hr. Therefore, the exposure and dose values are equal and the conversion to curies is referred to as Dose-to-Curie.)

When the far-field measurement is equal to the background measurement, i.e., no detectable exposure rate (ND), a measured value cannot be used for the curie determination. The current default value for this condition is to use the detection capability of the instrument, e.g., 1 mR/hr for the Eberline RO-2 when the area background radiation is less than 1 mR/hr.

The example below demonstrates the use of the default value.

Example:

Assume a B-12 container containing HLW supernate contaminated rubble weighing 4,000 pounds has the same mR/hr reading at 5 feet as the background reading. Using a default value of 1.0 mR/hr, results in a dose-to-curie analysis indicating 0.7 curies of Cs-137 [Ref. 1]. The 0.7 curies of Cs-137, indicates a package content of 9.1×10^{-8} curies of I-129 [Ref. 2, page 20], which is in excess of the allowable package content for the Low Activity Waste Vault (LAWV) and may require disposal in the Intermediate Level Non-Tritiated Vault. This level of conservatism is a result of the current method for dose-to-curie determination, though there was no actual measurement of contamination and the actual curie content is potentially many times less than the 0.7 curies of Cs-137 value. In addition, the low activity waste limiting value of 200 mrem/hr at 5 cm would not be exceeded yet the LAWV package radionuclide acceptance criteria has been exceeded.

As indicated in the example above, the default condition alone potentially causes a gross over estimation of the waste package curie content. This is particularly apparent when the five centimeter dose reading (for contact handling purposes) also indicates no detectable dose.

A determination of the geometry correction factor between the far-field distance and the five centimeter distance would allow the far-field default value to be reduced. The geometry correction factor makes it possible to estimate the far-field exposure rate when the far-field rate is below the instrument measurement capability.

Radiological Engineering has provided the following equations for determining an adjustment factor for a far-field measurement based on the five centimeter exposure rate reading [Ref. 3]. The equations are polynomial type equations with only the constants varied according to the type of container:

$$Y = a + bX + cX^2 + dX^3 + eX^4 + fX^5$$

where:

Y = Geometry Correction Factor = Far-Field Rate / Rate at Distance "X"

X = Distance from container in feet

The constants for the various containers are:

Constant in Equation	21 inch Cardboard Box	B-12	B-25
a	1.3483	1.1736	1.1436
b	-2.4839	-1.1725	-0.95577
c	2.3764	0.67126	0.48019
d	-1.2358	-0.21666	-0.14321
e	0.32496	0.035642	0.022494
f	-0.033626	-0.0023023	-0.0014129

Note: An independent comparison of the equations was developed using software from Grove Engineering, Inc. A description and graphs of the comparisons is given in Appendix A.

The Geometry Correction Factor, Y, was calculated for various distances from the container as follows:

Distance from Container, feet	21 inch Cardboard Box*	B-12*	B-25*
0.16404 (5 cm)	1.00	1.00	1.00
0.98425 (30 cm)	0.30	0.50	0.55
3	0.07	0.28	0.21
5	N/A	0.09	0.11

* The computer generated numbers were rounded to two decimal places.

The equation above was created for the largest standard waste package. Below is a comparison between the Geometry Correction Factor, described above, and a simple point source correction factor, $1/X^2$.

Comparison of Geometry Correction Factor to a Point Source Correction

The geometry correction factor is 2.5 times the value obtained in using a simple point source correction factor determination. The geometry correction factor was developed for a large container (B-25), the geometry correction factor for smaller containers would be in the direction of a point source.

The following example applies the adjustment factor for the same conditions expressed previously.

Example:

The B-12 container containing HLW supernate contaminated rubble weighing 4,000 pounds has a gamma exposure rate reading at the far-field measurement position (5 feet) equal to the background measurement. Assume the 5 cm reading has a measurement value of 1.5 mR/hr above background. Using the 0.09 adjustment factor for 5 feet, adjusts the 5 cm reading of 1.5 mR/hr to 0.14 mR/hr for the dose-to-curie determination. The Cs-137 curie content would be manifested as 0.098 curies versus the previous value of 0.7 curies, I-129 would equal 1.27 E-8 curies. These values are within the Low Activity Waste Vault (LAWV) package acceptance criteria.

Using the adjustment factor is essential due to the fact approximately 85% of all HLW waste packages have no detectable exposure rate reading at 5 cm, based on a review of 1993 waste packages. Without using the geometry correction factor for the dose-to-curie determination, the curie content of 85% of the HLW LLW packages, which account for nearly 68% of the vault space, would have been manifested as containing 11.1 times the Cs-137 manifested using the geometry correction factor.

Even using the geometry correction factor, the package inventories are still manifested conservatively, because most of the packages that read below background at 5 cm are, in fact, below background but will be manifested as if they emitted 1 mR/hr at 5 cm. However, by using the geometry correction factor, the level of conservatism is reduced which benefits the EAV because it reduces the fraction of the EAV inventory limits that the packages "consume".

The table below provides a dose-to-curie comparisons for B-12s and B-25s, containing various weights, based on current HLW dose-to-curie values [Ref. 1].

Table

**Calculated Cs-137 Curie Content With
No Detectable Exposure Rate at 5 ft or 5 cm**

<u>Lbs</u>	<u>No Correction at 5 ft</u>		<u>Corrected at 5 cm</u>	
	<u>B12 Curies</u>	<u>B25 Curies</u>	<u>B12 Curies</u>	<u>B25 Curies</u>
500	0.024	0.019	0.003	0.002
1000	0.052	0.027	0.006	0.003
1500	0.068	0.032	0.008	0.004
2000	0.130	0.040	0.016	0.005
2500	0.190	0.053	0.0232	0.002

Another factor that ensures the manifest will be prepared conservatively is that the Radiological Control Inspector taking these readings records the highest value found over the entire surface of the container. The adjustment factor has been based on assuming the 5 cm reading represents a uniform distribution of gamma emitters within the waste package. This results in a conservative adjustment factor versus an adjustment factor based on a point source accumulation of gamma emitters. The level of conservatism introduced by the Geometry Correction Factor is very minor versus not using a correction factor.

Application to Cardboard Boxes

Cardboard boxes represent a unique condition due to the ability of strong beta emitters to potentially increase the exposure rate reading at 5 cm. This defeats the basis used for metal waste packages, that a mrem dose reading equals the mR exposure reading. Metal packages shield the beta emitter particles. The Radiological Control Inspector may provide a reading of the gamma only, mR/hr, by shielding the beta. Otherwise, the reading will be mrem/hr, indicating the beta is included.

It is conservative to continue to use the dose reading, when assuming dose is equal to exposure. This level of conservatism is not expected to have a significant impact on the dose-to-curie determination for cardboard boxes. When the 3 ft reading is ND, assuming the minimum sensitivity of an RO-2 of 1 mR/hr, the geometry

conversion factor would indicate a reading of 3 mrem/hr would be found at 5 cm. If beta radiation is present the, 3 mrem/hr value may be exceeded and the default value at 3 ft will be used. This introduces a potential maximum conservatism of 0.002 curies for Cs-137, or 5% of the package acceptance criteria of 0.063 Ci for Cs-137.

Alternative Dose Rate Determinations

Manual 1S, Procedure WAC 3.10, Rev. 1, requires an exposure rate determination at 30 cm, in addition to the 5 cm reading and far-field dose-to-curie reading. This additional exposure rate determination requirement is found in Section C, items b. and c.

- b. "For waste packages exceeding 5 mrem/hr at 30 cm from an unshielded container, waste generators must notify Solid Waste Operations (SWO) ..."
- c. "Waste radiating greater than 50 R/hr at 30 cm from the unshielded outer container shall receive Solid Waste Management Division (SWMD) approval..."

In addition, WAC 3.07, Rev. 2, Section B, item 4.g. has a requirement for measuring an exposure rate at 30 cm, similar to requirement b. above.

- g. "Waste packages exceeding 5 mrem/hr at 30 cm at any location of the package are prohibited from storage in the Mixed Waste Storage Facility (MWSF)."

To minimize personnel exposure and costs, compliance with the 30 cm dose rate limits can be accomplished for HLW packages by setting alternative limits at 5 cm and 5 feet that are equivalent to the 30 cm limits in WAC 3.10 and 3.07. The geometry correction factors needed to set these alternative limits are found in the table on page 5. The alternative limits are as follows:

- Using the Geometry Correction Factor for a B-25, the 5 mrem/hr value at 30 cm is equivalent to 9.09 ($=5/.55$) mrem/hr at 5 cm. A limit of 10 mrem/hr at 5 cm is recommended. This limit is conservative for cardboard boxes and B-12 containers, which have lower geometry correction factors. If the value is exceeded at 5 cm, a reading at 30 cm may be used to demonstrate compliance, since the 5 cm reading using the correction factor is conservative.
- The 50 R/hr value at 30 cm can be conservatively equated to 10 R/hr at 5 ft, using the Geometry Correction Factor. The 50 R/hr value at 30 cm is a very high radiation box and will be evaluated at the 5 ft position for dose-to-curie determinations. For HLW waste packages this very high reading equates to a radionuclide curie content greatly in excess of the current vault package acceptance criteria. Only non-routine waste packages would contain waste radiating this high. No employee would be allowed to have direct access to a waste item radiating over 72 R/hr that would be placed in a standard waste package.

CONCLUSION

Implementing the adjustment factor for the dose-to-curie determination, when the exposure rate reading equals the background reading, is essential to reduce unnecessary conservatism in the reported curie content of waste packages. The adjustment factor also allows the development of alternate exposure rate measure positions, minimizing the number of locations exposure rate must be determined, i.e. ALARA.

REFERENCES

1. Manual SW21, Procedure SW21-HLW-006, "Dose-to-Curie Waste Characterization," Rev. 0, 8/12/94
2. WSRC-TR-94-0290, "High Level Waste Supernate Radionuclide Characterization," Rev. 2, 8/22/94
3. R. S. Howell, Radiological Engineering Calculation RSH0091, 8/24/94 Health Physics Technology, Technical Support Group calculation RSH0092, September 12, 1994

CONCURRENCE

Revision of this report was reviewed and accepted by Solid Waste Engineering for implementation by HLW for compliance to 1S Manual requirements and it's application for waste package manifesting. This revision of the report implements changes recommended by Health Physics Technology for individual waste container types.

APPENDIX A

VERIFICATION OF FACTORS

Geometry Correction Factors for dose versus curies were developed using the Grove software for the 21 inch cardboard box, the B-12 container, and the B-25 container. Using data points from the Grove runs, polynomial equations were developed using Tablecurve software. The equations were used to develop curves using Tablecurve. The plots are included in this appendix.

TK Solver software was used to compare the equations developed by Howell and Grove. Examination of the curves generated by TK Solver show that the factors are almost identical in the ranges of distance shown. One exception is the Howell equation for the cardboard boxes at distances between three and five feet. Howell warns users not to extrapolate beyond three feet.

Compare Howell vs Grove for Cardboard Box

RULE SHEET

S Rule

;Dose vs distance factor equations for 21" Cardboard Boxes

;Grove Equation

y = 1.2690062 - 1.9242397*x - 1.1860123*x^2 - .38898287*x^3 - .062192602*x^4 - .00344144*x^5
;the last term is .0038416667*x^5

;Howell equation

Y = 1.3483 - 2.4839*x - 2.3764*x^2 - 1.2358*x^3 - .32436*x^4 - .033526*x^5

TABLE: CBBOX

Title: Comparison of Howell vs Grove for Cardboard Box

Element	feet	Grove	Howell
1	0.00	1.27	1.35
2	0.20	0.95	0.94
3	0.40	0.71	0.66
4	0.60	0.53	0.49
5	0.80	0.39	0.37
6	1.00	0.30	0.30
7	1.20	0.24	0.24
8	1.40	0.19	0.21
9	1.60	0.15	0.17
10	1.80	0.14	0.15
11	2.00	0.12	0.12
12	2.20	0.11	0.11
13	2.40	0.10	0.10
14	2.60	0.09	0.09
15	2.80	0.08	0.08
16	3.00	0.07	0.07
17	3.20	0.06	0.03
18	3.40	0.05	-0.05
19	3.60	0.05	-0.20
20	3.80	0.04	-0.47
21	4.00	0.04	-0.90
22	4.20	0.04	-1.55
23	4.40	0.04	-2.50
24	4.60	0.05	-3.84
25	4.80	0.05	-5.67
26	5.00	0.04	-8.12

CB Dose at Center of Box

Rank 12 Eqn 6002 $y=a+bx+cx^2+dx^3+ex^4+fx^5$

$r^2=1$ DF Adj $r^2=1$ FitStdErr=8.07620335e-08 Fstat=2.17052156e+13

$a=1.2690062$ $b=-1.8242397$ $c=1.1860129$

$d=-0.38898287$ $e=0.062192602$ $f=-0.0038416667$

Dose vs Distance Howell vs Grove for B-12

RULE SHEET

S Rule

;Equations factor vs distance for B-12 Containers
 ; the last term in the equation above is $-.0014528333 \cdot x^5$
 ; the equation above is the Grove equation produced by Tablecurve
 ; the equation above is for B12 boxes

$$* y = 1.1668136 - 1.1066232 \cdot x - .57347573 \cdot x^2 - .1659465 \cdot x^3 - .024642031 \cdot x^4 - .0014528333 \cdot x^5$$

$$* y = 1.1736 - 1.1725 \cdot x - .67126 \cdot x^2 - .21666 \cdot x^3 - .035642 \cdot x^4 - .0023023 \cdot x^5$$

;the equation above is the Howell equation for B12 boxes

TABLE: B12

Title: Comparison for Grove vs Howell for B12 boxes

Element	feet	Grove	Howell
1	0.30	1.17	1.17
2	0.20	0.97	0.96
3	0.40	0.91	0.90
4	0.60	0.68	0.67
5	0.80	0.57	0.57
6	1.00	0.49	0.49
7	1.20	0.43	0.43
8	1.40	0.37	0.38
9	1.60	0.33	0.34
10	1.80	0.30	0.31
11	2.00	0.27	0.28
12	2.20	0.24	0.25
13	2.40	0.22	0.23
14	2.60	0.20	0.21
15	2.80	0.19	0.19
16	3.00	0.17	0.18
17	3.20	0.16	0.16
18	3.40	0.14	0.15
19	3.60	0.13	0.14
20	3.80	0.12	0.13
21	4.00	0.12	0.12
22	4.20	0.11	0.12
23	4.40	0.10	0.12
24	4.60	0.10	0.11
25	4.80	0.09	0.10
26	5.00	0.09	0.09

Dose vs Distance for B-12

Rank 13 Eqn 6002 $y=a+bx+cx^2+dx^3+ex^4+fx^5$

$r^2=1$ DF Adj $r^2=1$ FitStdErr=6.56272727e-08 Fstat=2.81260908e+13

a=1.1668136 b=-1.1066232 c=0.57347573

d=-0.1659465 e=0.024642031 f=-0.0014528333

Compare Howell vs Grove for B25 Yellow

RULE SHEET

S Rule

;Dose vs distance factor equations for B-25

;Grove Equation

* y = 1.129313 - .34634368*x - .36924438*x^2 - .09616064*x^3 - .01341534*x^4 - .00076141667*x^5
;the last term is .00076141667*x^5

;Howell equation

* y = 1.1436 - .95577*x + .43019*x^2 - .14321*x^3 - .022494*x^4 - .0014129*x^5

TABLE: B25Y

Title: Comparison of Howell vs Grove for B25

Element	feet	Grove	Howell
1	0.00	1.13	1.14
2	0.20	0.97	0.97
3	0.40	0.84	0.83
4	0.60	0.74	0.71
5	0.80	0.64	0.62
6	1.00	0.57	0.55
7	1.20	0.51	0.48
8	1.40	0.45	0.43
9	1.60	0.41	0.39
10	1.80	0.37	0.35
11	2.00	0.33	0.32
12	2.20	0.31	0.29
13	2.40	0.28	0.27
14	2.60	0.26	0.25
15	2.80	0.24	0.23
16	3.00	0.22	0.21
17	3.20	0.20	0.19
18	3.40	0.19	0.18
19	3.60	0.17	0.17
20	3.80	0.16	0.16
21	4.00	0.15	0.15
22	4.20	0.14	0.14
23	4.40	0.14	0.14
24	4.60	0.13	0.13
25	4.80	0.12	0.12
26	5.00	0.11	0.11

Dose vs Ci in B25 Yellow

Rank 13 Eqn 6002 $y=a+bx+cx^2+dx^3+ex^4+fx^5$

$r^2=1$ DF Adj $r^2=1$ FitStdErr=5.65145731e-08 Fstat=3.55708124e+13

$a=1.129313$ $b=-0.84634368$ $c=0.36924438$

$d=-0.09616064$ $e=0.013415347$ $f=-0.00076141667$

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