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WORST SOURCE TERM DETERMINATION FOR RADIONUCLIDES OF GIVEN RANGES (U)

by

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Section A

WORST SOURCE TERM DETERMINATION FOR RADIONUCLIDES OF GIVEN RANGES

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In determining the source term for radiological consequence analysis of non-reactor operations, safety analysts sometimes are given a range of weight or curie fractions for the radionuclides in a process stream. Because the worst radiological dose is of most interest to safety analysts, the worst source term from the given ranges of radionuclide composition must be determined.

This paper presents a methodology which can be used by safety analysts for the determining the isotopic distribution to yield the maximum radiological consequences when a range of weight or curie compositions are possible. Use of this methodology eliminates any unnecessary safety and/or environmental concerns because safety analysts no longer have to make overly conservative assumptions to simplify the worst source term determination.

The method uses a relative-dose concept which overcomes the tediousness of the traditional trial-and-error approach. Depending on the location of receptors, two relative-dose equations are derived: one for the operating personnel inside a building and the other for workers outside the building. Example problems will be used to illustrate the methodology for the determination of the worst source term.

WORST SOURCE TERM DETERMINATION FOR RADIONUCLIDES OF GIVEN RANGES

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INTRODUCTION: In determining the source term for radiological consequence analysis of non-reactor operations, safety analysts sometimes are given a range of weight or curie fractions for the radionuclides in a process stream. Because the worst radiological dose is of most interest to safety analysts, the worst source term from the given ranges of radionuclide composition must be determined. This paper presents a methodology which can be used by safety analysts for the determining the isotopic distribution to yield the maximum radiological consequences when a range of weight or curie compositions are possible. Use of this methodology eliminates any unnecessary safety and/or environmental concerns because safety analysts no longer have to make overly conservative assumptions to simplify the worst source term determination. The method uses a relative-dose concept which overcomes the tediousness of the traditional trial-and-error approach. An example problem will be used to illustrate the methodology for the determination of the worst source term.

DISCUSSION: The worst source term is the source term which yields the worst inhalation dose given all other conditions are constant. A simple approach for determining the worst source term is the use of relative dose calculations. Depending on the location of receptors, two relative-dose equations are derived: one for the operating personnel inside a building and the other for workers outside the building. These two methods using relative dose approach are proposed for determining the worst source term when radionuclide composition is expressed as a range of weight or curie fraction. When radionuclide composition is expressed by a range of curie fraction, the SA (specific activity) term should be removed from the equations below.

A. Source Term Yielding the Worst Inhalation Dose to the Operating Personnel:
Considered in this category are indoor spills or leaks causing an inhalation dose to operating personnel in the area. The following equation is used to determine the relative dose to the individual.

$$RD = (SA)(CEDE)(PF) \qquad (1)$$

RD = the relative dose
SA = the specific activity
CEDE = the comitted effective dose equivalent factor
PF = the partition factor

Values for CEDE for a specific radionuclide can be found in "Internal Dose Conversion Factors for Calculation of Dose to the Public", DOE/EH-0071, U.S. Department of Energy, Washington, D.C. (July 1988). The partition factor is a measure of how readily particulates become entrained in the vapor escaping from a liquid spill. Approximate values for partition factors are as follows: 10^{-4} for particulates, 10^{-2} for semi-volatiles (such as Ru, Se, Tc, etc.), and 1 for gases (such as H^3, noble gases, Iodine, etc.). If the spill is in powder form, the partition factor is removed from the above equation.

B. Source Term Yielding the Worst Inhalation Dose to the Persons Outside the Building:
Considered in this category are indoor spills or leaks causing an inhalation dose to persons outside the building. The following equation is used to determine the relative dose to the individual.

$$RD = (SA)(CEDE)(PF)(\text{Penetration factor}) \qquad (2)$$

The penetration factor is a measure of the fraction of particulates not removed from the effluent due to emission control devices such as HEPA filters,etc. If the spill is in powder form, the partition factor (PF) is removed from the above equation.

EXAMPLE PROBLEM: Given the following information, the safety analyst is to determine the worst source term when the radionuclides are released to the environment such that an inhalation dose could occur to persons outside the building. The effluent passes through a single HEPA filter.

RADIONUCLIDE	% WEIGHT FRACTION	
	MINIMUM	MAXIMUM
H-3	2	6
Ru-103	4	10
Ru-106	8	15
U-234	12	18
U-235	15	20
U-236	8	15
U-238	20	45

The following table summarizes the input data and results of the calculation.

NUCLIDE	SA Ci/gm	CEDE rem/µCi	PARTITION FACTOR	PENETRATING FACTOR	RELATIVE DOSE	WORST SOURCE TERM
H-3	9.67E+03	6.30E-05	1	1	6.09E-01	6%
Ru-103	3.22E+04	7.80E-03	10^{-2}	4.9E-03	1.23E-02	10%
Ru-106	3.35E+03	4.40E-01	10^{-2}	4.9E-03	7.22E-02	15%
U-234	6.15E-03	1.30E+02	10^{-4}	4.9E-03	3.92E-07	18%
U-235	2.20E-06	1.20E+02	10^{-4}	4.9E-03	1.29E-10	20%
U-236	6.32E-05	1.20E+02	10^{-4}	4.9E-03	3.72E-09	15%
U-238	3.36E-07	1.20E+02	10^{-4}	4.9E-03	1.98E-11	16%
					total	100%

The relative dose for each radionuclide is calculated using equation 2 because the effluent passes through a HEPA filter. The worst source term is determined in the following manner. The radionuclide contributing the highest relative dose (H-3 at 6.09E-01) is assigned its maximum weight percentage (6%). The radionuclide contributing the second highest relative dose (Ru-106 at 7.22E-02) is assigned its highest weight percentage (15%). The combined total for the worst case source term is noted following each radionuclide so that the total does not exceed 100%. The total thus far is 21%. Continuing in this manner, the third highest relative dose (Ru-103 at 1.23E-02) is assigned its maximum weight percentage (10%). The total is now 31%. The radionuclide with the next highest relative dose (U-234 at 3.92E-07) is assigned its maximum weight percentage (18%) bringing the total to 49%. The radionuclide with the next highest relative dose (U-236 at 3.72E-09) is assigned its maximum weight percentage (15%) bringing the total to 64%. The radionuclide with the next highest relative dose (U-235 at 1.29E-10) is assigned its maximum weight percentage (20%), bringing the total to 84%. If the radionuclide with the next highest relative dose (U-238 at 1.98E-11) is assigned its maximum weight percentage (45%) the total would exceed 100%. Therefore, the source term for U-238 is assigned 16%. The weight fractions of radionuclides thus derived and shown in the last column of the above table constitute the worst source term for the example problem. For cases in which a total of 100% is reached by radionuclides with higher relative doses, the remaining radionuclides with lower relative doses can be neglected.

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OBJECTIVE

To present a simple approach for the determination of the source term which yields the worst inhalation dose when the radionuclide composition in the process stream is expressed by a range of weight or curie fractions.

WORST SOURCE TERM

Radionuclide	% Weight Fraction
R_1	$(f_1)_s - (f_1)_b$
R_2	$(f_2)_s - (f_2)_b$
R_3	$(f_3)_s - (f_3)_b$
.	.
.	.
.	.
R_n	$(f_n)_s - (f_n)_b$

The worst source term is the source term which yields the worst inhalation dose given all other factors are constant.

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Source Term Yielding the Worst Inhalation Dose to Operating Personnel

Considered in this category are indoor spills or leaks causing an inhalation dose to operating personnel in the area.

$$RD = SA * CEDE * PF$$

RD = the relative dose

SA = the specific activity

CEDE = the comitted effective dose equivalent factor

PF = the partition factor

The partition factor is a measure of how readily particulates become entrained in the vapor escaping from a liquid spill.

Source Term Yielding the Worst Inhalation Dose to the Persons Outside the BUildiung

Considered in this category are indoor spills or leaks causing an inhalation dose to persons outside the building.

RD = SA * CEDE * PF * Penetration factor

The penetration factor is a measure of the fraction of particulates not removed from the effluent due to emission control devices such as HEPA filters, etc.

- When radionuclide composition is expressed by a range of curie fraction, the SA (specific activity) term should be removed from the relative dose equactions equations.

- If the spill is powder form, the partition factor is removed from the relative dose equations.

Example Problem #1

- Determine the worst source term when the radionuclides are released to the environment such that an inhalation dose could occur to persons outside the building.

- Assume the effluent passes through a single HEPA filter (penetration factor of 4.9E-03 for particulates)

- Assume the following partition factors:
  - 1 for gases
  - 1.0E-2 for semi-volatiles
  - 1.0E-4 for particulates

Example Problem #1

- The following minimum and maximum weight fractions are given:

Radionuclide	% Weight Fraction Minimum	% Weight Fraction Maximum
H-3	8	6
Ru-103	4	10
Ru-106	5	15
U-234	12	18
U-235	15	20
U-236	8	15
U-238	20	45

Example Problem #1

Since the receptor of interest is a person outside the building, the following equation is used to determine relative dose:

$$RA = SA * CEDE * PF * \text{Penetration factor}$$

Example Problem #1

The following table summarizes the input data:

Nuclide	SA Ci/gm	CEDE rem/μCi	Partition Factor	Penetration Factor
H-3	9.67E+03	6.30E-05	1	1
Ru-103	3.22E+04	7.80E-03	1.0E-02	4.9E-03
Ru-106	3.35E+03	4.40E-01	1.0E-02	4.9E-03
U-234	6.15E-03	1.30E+02	1.0E-04	4.9E-03
U-235	2.20E-06	1.20E+02	1.0E-04	4.9E-03
U-236	6.32E-05	1.20E+02	1.0E-04	4.9E-03
U-238	3.36E-07	1.20E+02	1.0E-04	4.9E-03

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Example Problem #1

The following table summarizes the results of the relative dose calculation:

Nuclide	Relative Dose
H-3	6.09E-01
Ru-103	1.[illegible]E-02
Ru-106	7.22E-02
U-234	3.92E-07
U-235	1.29E-10
U-236	3.72E-09
U-238	1.98E-11

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Example Problem #1

Nuclide	Maximum Weight Fraction	Worst source Term
H-3	6%	
Ru-103	10%	
Ru-106	15%	
U-234	18%	
U-235	20%	
U-236	15%	
U-238	45%	

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Example Problem #1

The worst source term is determined in the following manner:

- The radionuclide contributing the highest relative dose (H-3 at 6.06E-01) is assigned its maximum weight percentage (6%).

- The radionuclide contributing the second highest relative dose (Ru-106 at 7.22E-02) is assigned its highest weight percentage (15%).

- The combined total for the worst case source term is noted following each radionuclide so that the total dose does not exceed 100%.

- The total is now 21%.

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Example Problem #1

- Continuing in this manner, the third highest relative dose (Ru-103 at 1.23E-02) is assigned its maximum weight percentage (10%).

- Bringing the total to 31%.

- The radionuclide with the next highest relative dose (U-234 at 3.92E-07) is assigned its maximum weight percentage (18%) .

- Bringing the total to 49%.

Example Problem #1

- The radionuclide with the next highest relative dose (U-236 at 3.72E-09) is assigned its maximum weight percentage (15%).

- Bringing the total to 64%.

- The radionuclide with the next highest relative dose (U-235 at 1.29E-10) is assigned its maximum weight percentage (20%).

- Bringing the total to 84%.

Example Problem #1

If the radionuclide with the next highest relative dose (U-238 at 1.98E-11) is assigned its maximum weight percentage (45%) the total would exceed 100%.

Therefore, the source term for U-238 is assigned 16%, bringing the total to 100%.

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Example Problem #1

The following table summarizes the results of the calculation

Nuclide	Relative Dose	Worst Source Term
H-3	6.09E-01	6%
Ru-103	1.23E-02	15%
Ru-106	7.22E-02	10%
U-234	3.92E-07	18%
U-235	1.29E-10	20%
U-236	3.72E-09	15%
U-238	1.98E-11	16%
	Total	100%

Example Problem #2

- Determine the worst source term when the radionuclides are released such that an inhalation dose could result to the operating personnel.

- Given the following information:

Nuclide	% Weight Fraction Minimum	% Weight Fraction Maximum
Pu-238	70	84
Pu-239	10	15
Pu-240	1	8
Pu-241	2	10
Pu-242	0.5	2

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Example Problem #2

The following table summarizes the input data

Nuclide	SA Ci/gm	CEDE rem/μCi	Partition Factor
Pu-238	1.71E+01	4.60E+02	1.0E-04
Pu-239	6.20E-02	5.10E+02	1.0E-04
Pu-240	2.27E-01	5.10E+02	1.0E-04
Pu-241	1.03E+02	1.00E+01	1.0E-04
Pu-242	3.93E-03	4.80E+02	1.0E-04

Example Problem #2

The following table summarizes the results of the calculation

Nuclide	Relative Dose	Worst Source Term
Pu-238	7.87E-01	84%
Pu-239	3.16E-03	-
Pu-240	1.16E-02	6%
Pu-241	1.03E-01	10%
Pu-240	1.89E-04	-
	Total	100%

Example Problem #2

In this example, a total of 100% is reached by the radionuclides with higher relative doses; therefore, the remaining radionuclides with lower relative doses can be neglected.

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