DOSE CALCULATION PARAMETERS USING REDUCED SOURCE TERMS

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ABSTRACT

As convergence on more realistic source terms results from the current international analytical and experimental efforts, there is an increased interest in translation of such source terms into predicted consequences. Two difficulties in comparing source terms by historic methods emerge:

- Increased analytical sophistication allows incorporation of many plant/accident specific details which affect the calculated source terms in detail, if not in general.

- Comparison by calculation of numbers of early fatalities becomes meaningless with reduced source terms because most of these produce no calculated prompt fatalities at all.

A method of comparison based on mean whole body doses, using CRAC2 calculations, is proposed. A simplified calculation method illustrates the effects of the principal parameters and can be used to make very approximate dose calculations.

As source terms are being reduced, consequence models are becoming more important, and conservatisms in such models may prove to be just as important as conservatisms in source terms. Because of the high calculated consequences which result from the very conservative historic source terms, the results of uncertainties in consequence models have been small compared to the overall consequence analyses results. Therefore, simplifications of such models could generally be accepted. However, with the low levels of consequences associated with reduced source terms, such simplifications can lead to erroneous conclusions.

In this work, the uncertainties in two models used in consequence analyses -- plume buoyancy and dry deposition velocity -- were examined parametrically with the following results:

- The dry deposition velocity value of 1 cm/sec, recommended for use in CRAC2, is found to give conservative results for distances of interest for both historic and reduced source terms.

- Incorporation of plume buoyancy in the calculation is found to result in short distance doses markedly below those for nonbuoyant plumes. For reduced source terms, mean doses calculated with plume buoyancy are well below the severe health effects threshold range.

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FOREWORD

An important observation made on the basis of data collected at the Three Mile Island accident was that the amount of radioiodine available for release to the environment was much smaller than that which would have been predicted [1]. As a result, a large international research program was initiated to identify and provide understanding of natural processes affecting the retention of radioiodine as well as other fission products. The calculated types, quantities, and timing of releases of all these fission products, taken together, is known as the source term because it establishes the characteristics of the source of radioactivity for use in calculations of accident consequences.

INTRODUCTION

The current international analytic and experimental effort is resulting in reduced uncertainties in the physical and chemical factors affecting source terms. Additionally, the increased sophistication of the release models being developed reflect, to a greater extent than ever before, the details of individual plant design features and of specific accident sequences. The result of this is that while convergence is being approached on the magnitude of more realistic source terms, specific calculations using different computational models, different reference plants, and different accident scenarios result in source terms that differ in detail and are, therefore, difficult to compare.

A series of consequences calculations made by Stone & Webster Engineering Corporation (SWEC), using the CRAC2 computer code [2], offers a way to make comparisons among different source terms. Such comparisons will be useful in consolidating plant/accident specific source terms into categories useful for regulatory and other generalizations. In the process of making these calculations, parametric studies have been made to determine the effect of some uncertainties on the results. While some of these effects are significant for source terms in the higher ranges, they become much less so at the more realistic reduced levels.

BASIS OF COMPARISON

The mean acute whole body dose at distances to 10 miles was selected as the basis of comparison. This was calculated using CRAC2, with the following conditions:

- 2 hours decay prior to release
- 2 hours duration of release
- 10-meter release height
- 24-hour exposure to ground contamination
- Maximum individual dose (no sheltering)
- 3412 MWt PWR end of core life inventory
- 100 percent of the noble gases released
- 1 percent of all other nuclides released
- Miami typical meteorological year weather data
- Four samples per bin in CRAC2
- No heat associated with the release
- 1 cm/sec dry deposition velocity in CRAC2

Acute whole body doses have the following advantages for use in comparisons:

- They are independent of site-specific population distributions.
- They are not affected by the choice of health effect thresholds.
- They are not affected by the interdiction criteria incorporated in CRAC2.
- They allow comparison with the logic of NUREG 0396 [3].

Previous work by the authors [4] shows that the relationships between doses in the 10-mile range calculated for different source terms are not markedly affected by:

- Choice of meteorological area
- Choice of mean or 95th percentile dose
- Time of exposure between 12 and 48 hours
- Duration of release between 2 and 10 hours

Some variability over distance was found with sheltering factors.

Inclusion of the heat associated with the release and variation of the dry deposition velocity are expected to affect offsite doses and are discussed in this paper.

COMPARISON OF SOURCE TERMS

To facilitate comparison of source terms, a base case source term consisting of 100 percent of the noble gases and 1 percent of all other release groups was selected. This and other source terms used in this paper are listed below for convenient reference:

Percent of Core Inventory Released by Groups

Fission Product Group	WASH-1400 PWR2[5]	Sandia SST1[6]	SWEC IST[7]	SWEC RIST	Base Case
Noble Gases	90	100	100	100	100
Volatiles					
Iodine	70	45	1	1	1
Cs-Rb	50	67	1	1	1
Te-Sb	30	64	1	1	1
Nonvolatiles					
Ba-Sr	6	7	1	0.4	1
Ru	2	5	1	0.3	1
La	0.4	0.9	0.4	0.02	1

The "SWEC RIST" is a current revision of the Interim Source Term (IST) proposed by E. A. Warman of SWEC in 1982 [7].

The contributions to the total dose from each group of the base case were calculated individually. These are plotted in Figure 1.

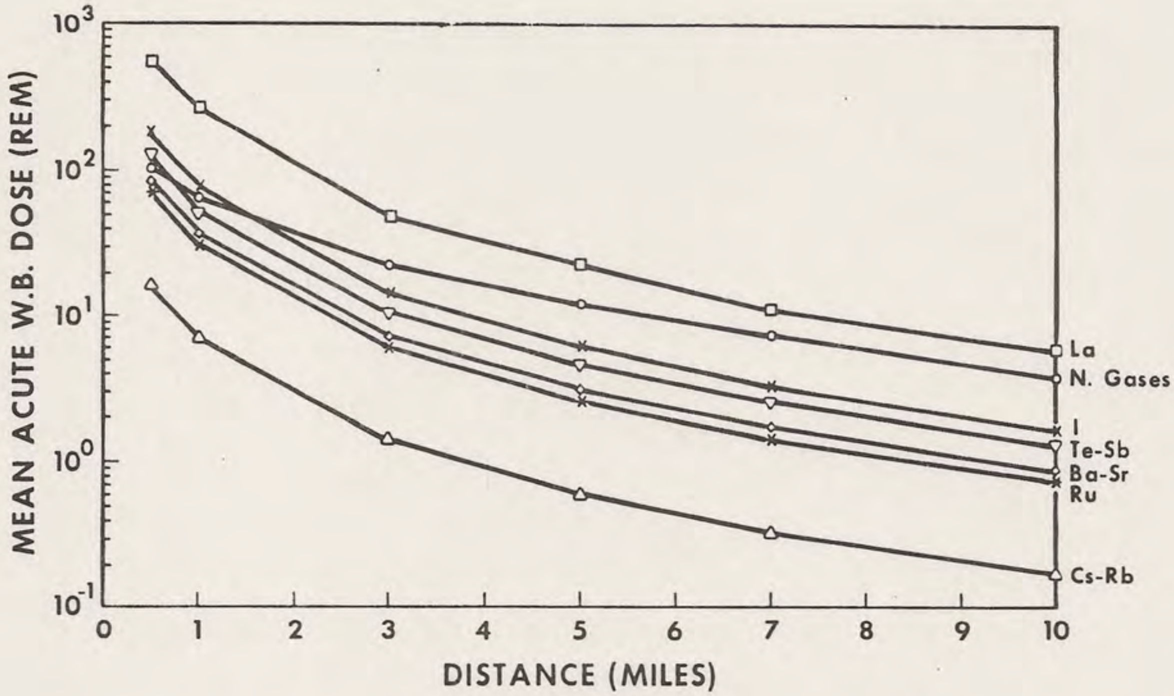

Figure 1. Dose Contribution from Each Release Group (Base Case)

Because these are based on 100 percent or 1 percent releases of each group, the curves can be used conveniently to construct a dose pattern for any source term by multiplying the calculated dose contributions by the postulated release percentages. Thus, for example, the dose contribution at 5 miles of a 2 percent iodine release would be double the (6 REM) contribution shown on the curve.

Figure 2 is a simplified calculation sheet which illustrates the effects of the principal parameters. Part A can be used to obtain approximate total 5-mile mean doses for any source term. These doses are valid for comparison of source terms at the same site and will be good to approximately a factor of 2 for a wide selection of site meteorological patterns [4].

The relatively large contribution from the noble gases (approximately 24 percent of the total 5-mile dose for the base case compared to approximately 2 percent for historical source terms such as PWR2 and SST1) should be noted. As the postulated release fractions of the other source term components shrink, the noble gases play a more prominent part. This qualitative difference will have to be considered in development of appropriate protective actions, with the acceptance of reduced source terms of similar compositions.

The very large contribution to the total from the base case release of 1 percent of the lanthanum group (including Y, La, Zr, Nb, Ce, Pr, Nd, Np, Pu, Am, and Cm) should also be noted. This is an unrealistically high release, but the 0.9 percent of SST1, and even the 0.4 percent of PWR2, will produce dose contributions which are high compared to those from 1 percent of iodine or tellurium. This is not surprising because the lanthanum group contains about 40 to 50 percent of the total curies in the core. Most source term investigators have concentrated on the volatiles, which produced the largest contributions based on the historic source terms. The sensitivity of the whole body dose to the lanthanum group release shown by this data indicates that attention should be focused on the nonvolatiles, as well as the volatiles.

Using the factors developed in a previous study [4], the 5-mile mean doses can be (again, approximately) converted to doses at other distances and for other conditions. These factors are shown in Part B of Figure 2. Figure 3 illustrates the results of a sample calculation for the 95th percentile dose at 2 miles with moderate sheltering from a source term consisting of 100 percent of the noble gases, 1.5 percent of the volatiles, and 0.1 percent of the nonvolatiles.

INVESTIGATION OF UNCERTAINTIES - DRY DEPOSITION VELOCITY

A value of 1 cm/sec for the dry deposition velocity of all the particulate matter released is generally recommended for use with CRAC2 [8]. The concept of using a single value for the dry deposition velocity, of course, is a simplification of the natural process of deposition. In reality there exists a spectrum of deposition velocities corresponding to the instantaneous spectrum of particle size distribution and particle density. Lacking a definitive basis for this value, a parametric investigation was conducted to determine the effect of using values of 0.5, 1.0, 3.0, 5.0, and 10.0 cm/sec. Mean whole body doses to 10 miles were calculated for these values using the SWEC RIST as representative of reduced source terms. The results are shown, with a series of cross curves, in Figure 4. These curves show doses as a function of dry deposition velocity at selected distances. It can be seen, as expected, that high deposition velocities generally produce high doses at short distances and lower doses at greater distances. It can also be seen that, at distances greater than about 2 to 3 miles, the deposition velocity producing the maximum dose quite rapidly approaches the CRAC2 recommended value of 1 cm/sec.

This approach is more clearly shown in Figure 5, which plots the same data in a different way and also shows that the dose profile becomes maximum around the 1 cm/sec value for the distances beyond 3 miles.

Comparable data for the PWR2 source term indicate that doses are maximized at around 1 cm/sec for the historical source terms also. Thus, it appears that in the 3 to 10-mile range, the CRAC2 assumption of a 1 cm/sec dry deposition velocity produces a conservative dose value for either historical or reduced source terms.

A. Calculate 5-mile dose from base case

GROUP	BASE CASE %	BASE CASE 5-mile dose	SPECIFIED CASE %	SPECIFIED CASE 5-mile dose
N.G.	100	12		
I	1	6		
Cs-Rb	1	0.5		
Te-Sb	1	5		
Ba-Sr	1	3		
Ru	1	2.5		
La	1	22		
TOTAL		51		

B. Apply adjustment factors

DISTANCE:	1 mile	x 11	
	2 miles	x 4	
	3 miles	x 2.2	
	10 miles	÷ 3.3	
95th PERCENTILE		x 3	
12-HOUR GROUND DOSE		÷ 1.6	
8-HOUR GROUND DOSE		÷ 2	
SHELTERING:			
Normal Activity		÷ 2	
Modest Sheltering	<3 mi	÷ 4	
	>3 mi	÷ 3	
Good Sheltering	<3 mi	÷ 6	
	>3 mi	÷ 5	
ESTIMATED DOSE (REM)			

Figure 2. Simplified Dose Calculation Sheet

A. Calculate 5-mile dose from base case

GROUP	BASE CASE %	BASE CASE 5-mile dose	SPECIFIED CASE %	SPECIFIED CASE 5-mile dose
N.G.	100	12	100	12
I	1	6	1.5	9
Cs-Rb	1	0.5	1.5	0.75
Te-Sb	1	5	1.5	7.5
Ba-Sr	1	3	0.1	0.3
Ru	1	2.5	0.1	0.25
La	1	22	0.1	2.2
TOTAL		51		32

B. Apply adjustment factors

DISTANCE:	1 mile	x 11	-
	2 miles	x 4	x 4
	3 miles	x 2.2	-
	10 miles	÷ 3.3	-
95th PERCENTILE		x 3	x 3
12-HOUR GROUND DOSE		÷ 1.6	-
8-HOUR GROUND DOSE		÷ 2	-
SHELTERING:			
Normal Activity		÷ 2	-
Modest Sheltering	<3 mi	÷ 4	÷ 4
	>3 mi	÷ 3	-
Good Sheltering	<3 mi	÷ 6	-
	>3 mi	÷ 5	-
ESTIMATED DOSE (REM)			96

Figure 3. Example of Dose Calculation at 2 Miles

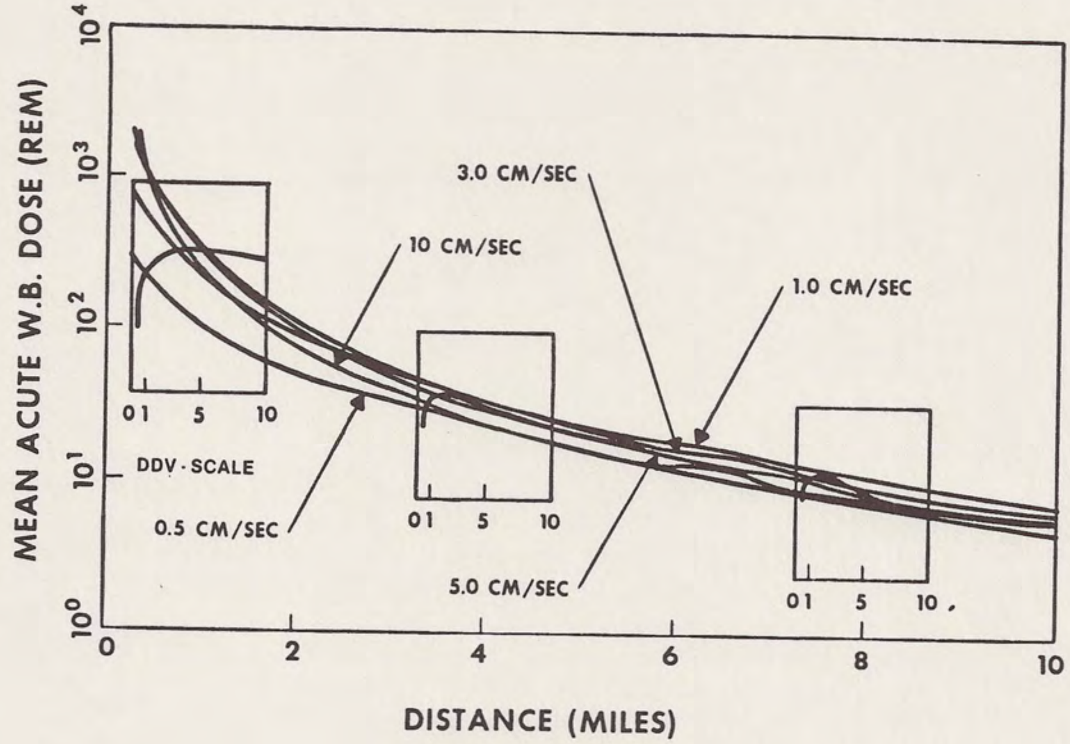

Figure 4. Effects of Assumed Dry Deposition Velocity

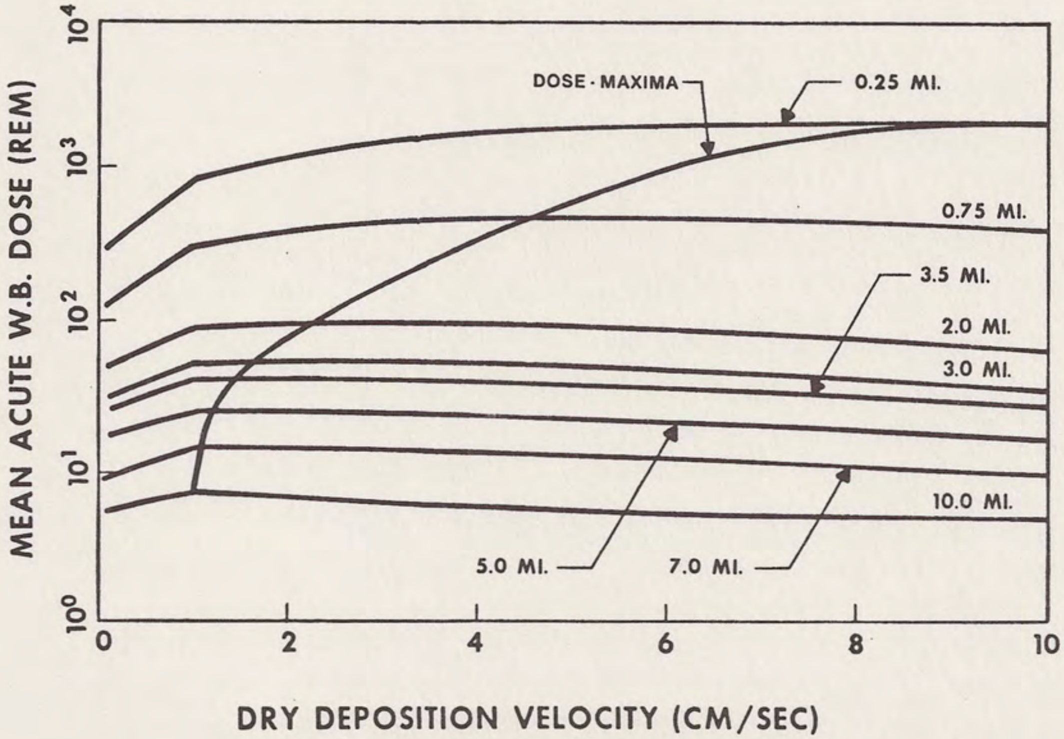

Figure 5. Dose Maxima for Assumed Dry Deposition Velocities

INVESTIGATION OF UNCERTAINTIES - PLUME BUOYANCY

For simplicity, most calculations, including those of the authors as well as such reports as the Sandia Siting Study [6], have assumed a nonbuoyant plume containing no sensible heat. Since considerable heat (on the order of 1.0 E+7 cal/sec) can accompany a release, a parametric study was also conducted to compare the effects of considering the resulting plume buoyancy on doses from historical and reduced source terms. Again, PWR2 and the SWEC RIST were selected as representative, and the effects on the calculated doses of using no energy and 1.2 E+7 cal/sec were compared. This value corresponds to the WASH-1400 value for sensible heat in PWR2 and is large compared to the decay heat energy in either historic or reduced source terms.

The results are shown in Figure 6. It can be seen that, in each case, the effect is a marked reduction in doses at short distances and some increase at larger distances. However, the values are very important. While the reduction factors to 10 miles are essentially the same, even the reduced PWR2 doses are still in the fatality/injury threshold range of 200 to 300 REM. For RIST, however, the effect of plume buoyancy is to reduce the doses, even at short distances, to levels well below the threshold values.

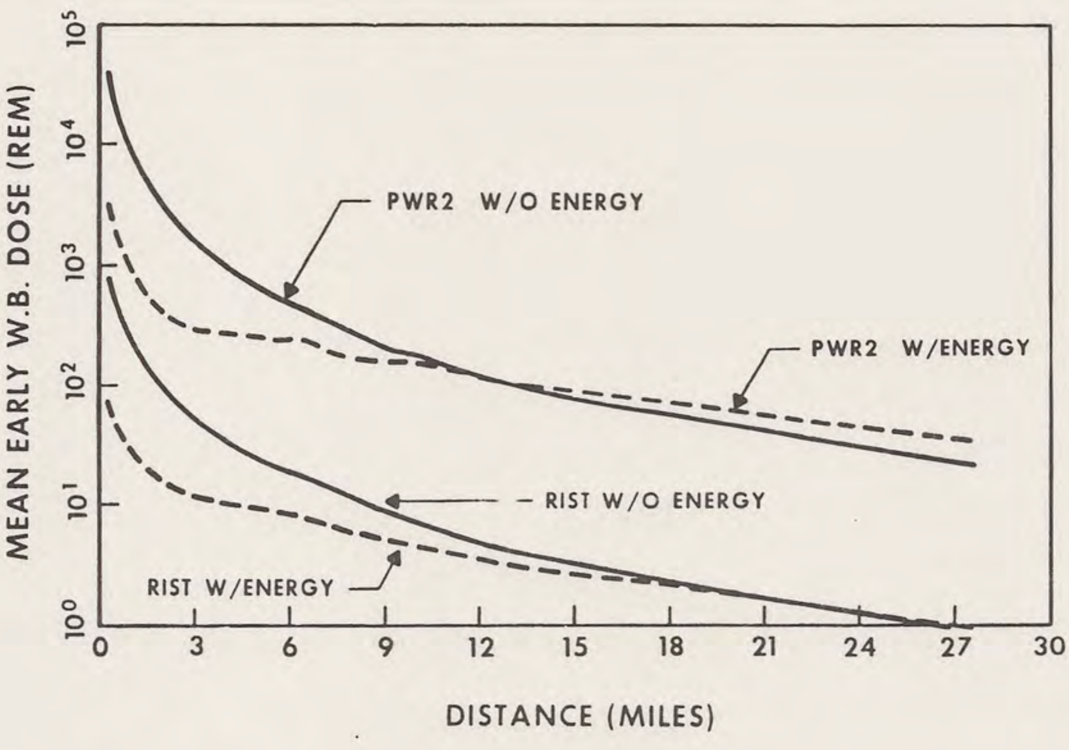

Figure 6. Effect of Plume Buoyancy

Further, it should be noted that with a PWR2 release there is sufficient activity remaining in the buoyant plume at greater distances (15 miles and more) so that dose levels at these distances are significantly (10 to 20 REM) above those calculated for the nonbuoyant plume. This increased level at extended distances may affect relatively large populations, with resultant large increases in calculated latent fatalities. With a RIST release, however, not only are the absolute values of the distant doses more than a decade lower, but the difference between the buoyant and nonbuoyant plumes is very small.

Thus, incorporation of the plume energy in the calculation for reduced source terms results in dose reductions below the threshold range at short distances without compensating increases at greater distances.

CONCLUSIONS

- A simple method has been presented which illustrates the effects of the principal parameters and can be used for comparing source terms by mean acute whole body doses.
- In source term investigations, attention should be focused on the nonvolatile as well as the volatile groups.
- Use of the CRAC2 value of 1 cm/sec for dry deposition velocity of the particulates results in conservative values of doses for both historical and reduced source terms.
- Incorporation of the plume energy in the dose calculations for reduced source terms results in dose reductions below the threshold range at short distances without the compensating increases at greater distances observed with historical source terms.

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