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Using the MACCS2 Computer Code

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PLUTONIUM EXPLOSIVE DISPERSAL MODELING USING THE MACCS2 COMPUTER CODE

U.S. Department of Energy
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C. M. Steele, T. L. Wald, and D. I. Chanin
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ABSTRACT

The purpose of this paper is to derive the necessary parameters to be used to establish a defensible methodology to perform explosive dispersal modeling of respirable plutonium using Gaussian methods. A particular code, MACCS2, has been chosen for this modeling effort due to its application of sophisticated meteorological statistical sampling in accordance with the philosophy of Nuclear Regulatory Commission (NRC) Regulatory Guide 1.145, "Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants." A second advantage supporting the selection of the MACCS2 code for modeling purposes is that meteorological data sets are readily available at most Department of Energy (DOE) and NRC sites. This particular MACCS2 modeling effort focuses on the calculation of respirable doses and not ground deposition.

More sophisticated plume modeling approaches exist for explosive dispersal modeling, such as the Explosive Release Airborne Dispersion (ERAD) code developed at Sandia National Laboratories (Boughton and DeLaurentis 1987, 1992). However, these codes are difficult to use due to the fact that meteorological data cannot be easily obtained for code input and final consequence statistics cannot be easily derived.

Once the necessary parameters for the MACCS2 modeling are developed and presented, the model is benchmarked against empirical test data from the Double Tracks shot of project Roller Coaster (Shreve 1965) and applied to a hypothetical plutonium explosive dispersal scenario. The actual amount of plutonium involved in the Double Tracks shot is still classified, so the mass of respirable plutonium used as the originating source term in the MACCS2 benchmark is 1 kg after the fashion of Dewart, Bowen, and Elder (1982).

Further modeling with the MACCS2 code is performed to determine a defensible method of treating the effects of building structure interaction on the respirable fraction distribution as a function of height. These results are related to the Clean Slate 2 and Clean Slate 3 bunkered shots of Project Roller Coaster.

Lastly a method is presented to determine the peak 99.5% sector doses on an irregular site boundary in the manner specified in NRC Regulatory Guide 1.145 (1983). Parametric analyses are performed on the major analytic assumptions in the MACCS2 model to define the potential errors that are possible in using this methodology.

I. QUALITATIVE DISCUSSION OF A PLUTONIUM EXPLOSIVE RELEASE SCENARIO

In a one-point detonation of high explosive (HE) surrounding plutonium metal, extremely high pressures and temperatures are developed in the metal as the shock wave propagates through it. The amount of energy needed to vaporize plutonium metal is approximately 2 MJ/kg. The total amount of energy available from HE is on the order of 5.5 MJ/kg. Based on these considerations and with the understanding that not all the energy will be transmitted to the metal from the HE, it is clear that a substantial fraction of this energy could be transmitted to the metal under certain circumstances of HE/plutonium mass loading and geometry.

An expert panel report by Boughton, Edwards, Hantel, Haschke, Humphrey, Luna, and Stephens (1995) of the NTS Roller Coaster data indicated some difference of opinion with respect to the fraction of material that becomes the Aerosol Release Fraction (ARF) in a conventional HE one-point detonation of metal system assemblies. The summary report states some ambiguity arises in the use of ARF in other studies where ARF is used in the context of only those particles that are essentially nonsettling. To clarify the expert panel position on this issue, ARF is defined as particles of all sizes released or projected into surrounding air including those that may have relatively high gravitational fall rates. The panel explains this definition of ARF on the basis that all sizes contribute to the spectrum of modeling issues that are of interest with respect to the radiological safety and cleanup of a nuclear-weapons accident. Despite the differences of opinion in the literature, however, all of the panel agreed that for all conventional HE one-point detonation scenarios involving metal assemblies, the ARF would be within the range of 0.75-1.00 of all material enclosed within the HE system.

After detonation, heating of all material enclosed within the explosive occurs quickly, vaporizing the material into small droplets. The fraction of droplets in the respirable (respirable fraction or RF) range of 0.1 μm -10 μm varies as a function of the expert consulted. In the panel report (Boughton et al. 1995), three experts indicated that RF = 0.2, two experts indicated RF is between 0.15-0.25, one expert indicated RF is between 0.2-0.3, and lastly, one expert indicated a range of about 0.099-0.252. In the study, Luna indicates that the ARF between 0.8-1.00 is generally used based upon the Roller Coaster data, but that some arguments for a lower ARF range could be made based upon what appear to be heuristic considerations involving qualitative understanding of the phenomena. However, Luna then states that "if one is in the position of having to defend such arguments in an unfriendly audience, the Roller Coaster assumptions will be more useful." In summary, the expert panel seems to be consistent in recommending ARFxRF values in the range 0.074-0.30 with the majority recommending the approximate range of ARFxRF between 0.11-0.25.

Mishima (1994) summarizes experimental evidence based upon the fragmentation of metals by detonations that the combined ARFxRF is a function of HE mass to enclosed metal ratios (HE/metal fraction). For HE-to-metal ratios of 0.067, 0.10, and 0.20 bounding estimates for the product ARFxRF are 0.07, 0.10, and 0.20 respectively. These data indicate that for small explosive-to-metal ratios, fracture of the material would result with insufficient energy to vaporize the metal into small droplets. In the limit of small HE/metal ratios, the amount of material that becomes respirable would be expected to be zero. Based upon the panel's consideration of the phenomenon, one would expect the amount of respirable material produced to saturate at about ARFxRF = 0.25. For the comparison that Boughton

performed (Boughton 1992) on the ERAD code against the Roller Coaster data, the particle size distribution was assumed to be a truncated log normal distribution where the minimum particle diameter was given as 0.1 μm , the maximum particle diameter was 200 μm , the median diameter was 43 μm , and the geometric standard deviation was 3.5 μm . Analysis of this distribution indicates that it is not normalized. If ERAD does not normalize the distribution, the fraction of particles in the 0.1 μm to 10 μm range would be 0.122. If ERAD does in fact normalize the distribution, the fraction of particles in the respirable range would be 0.137. In the panel report (Boughton et al. 1995), Boughton stressed that the ARFxRF applies to the total mass of metal enclosed by the explosive.

In summary, it appears that a reasonably bounding estimate of the amount of material released as a respirable fraction when a one-point detonation occurs of a metal system enclosed by HE is 0.20. A multipoint detonation of a similar configuration might under particular circumstances of geometry and materials produce a somewhat larger ARFxRF fraction. It must be emphasized that this fraction applies to all of the metal enclosed by the explosive. This paper assumes $\text{ARFxRF} = 0.20$.

Baker, Cox, Westine, Kulesz, and Strehlow (1983), indicate that the initial fireball temperatures, shortly after HE detonation and the cloud has expanded near the ground, are on the order of 5000K. The temperatures preceding this phase would of course be much higher. This thermal excursion expands the cloud to the point that a density deficit exists within the cloud bubble relative to the atmosphere far from the bubble. The cloud rises because of the density deficit and its initial ground-level momentum. For ground-level explosions of TNT equivalent, Church (1969) found that the average vertical speed of the cloud for HE masses in the 50-270 kg range was in the approximate range of 2 to 5 m/s. Aerodynamic drag as well as the increased mass of the cloud due to entrainment of surrounding air slows the cloud during the rise. Cooling of the cloud due to radiation transport and internal mixing associated with environmental air entrainment at the cloud surface reduces the density deficit and promotes cloud growth until the cloud density approximates that of the atmosphere, at which time upward motion stops due to abatement of buoyant effects. The rate of entrainment is generally assumed to be proportional to the average vertical speed of the cloud.

In a stably stratified atmosphere, it has been experimentally noted that the cloud first overshoots the maximum final cloud height. This is due to the fact that while the cloud density may have equilibrated with the atmospheric density (causing neutral buoyancy), the momentum of the cloud does not vanish when the buoyancy difference does. This results in a damped oscillation of the cloud about a buoyancy equilibrium height.

The theoretical treatment of vertical buoyant cloud rise for explosions and fires is analytically described by Morton, Taylor, and Turner (1956). In this theory, the differential equations of motion are defined and solved in closed form. Parameters that are defined in Morton et al. are determined through consideration of experimental evidence from stably stratified saline solutions. The theoretical model is then checked against other experiments to verify its validity. This paper presents a theoretical derivation similar to that of Morton et al., and compares its application to the results published by Church in 1969. The theory that is established in this paper agrees with the recommended 20% error bands applied by Church (1969) to the Cloud Top Height (CTH) formula he empirically derived for the atmospheric stability range quoted in his report. Confirmatory calculations on the data as presented by

Church (1969) were performed for this report as well. The correlation coefficient obtained in this report for the logarithmic curve fit to the data is 0.676, and the standard deviation in the data is 1.235.

Data gathered during the Project Roller Coaster Double Tracks (DT) test indicated that less than about 8% of the total plutonium (respirable and nonrespirable) was in the bottom 30% of the cloud. This is consistent with entrainment of most of the respirable plutonium by the rising cloud bubble. The centroid of the vertical total plutonium distribution appears to be located at approximately 70% of the CTH at 105 seconds (Dewart et al. 1982, and Operation Roller Coaster Technical Photography, Beasley, 1965). It would seem plausible that the very small respirable particles (1-10 μm) would have much less difficulty in maintaining their position relative to the rising bubble cloud than would the much larger particles.

Visual inspection of the cloud of the Roller Coaster DT shot indicates little correlation of the cloud diameter with height at 105 seconds after the shot. However, the typical stem and cap outline is clearly visible at 9 s, 25 s, and 57 s. Church (1969) indicates that the continuing rise of explosive clouds after about 2 minutes was caused by continuing turbulent growth due to the atmosphere as the cloud moved down range. Empirical relations for the determination of near-instantaneous (order of tens of milliseconds) cloud radii from HE explosions are summarized by Baker et al. (1983).

For the purposes of this paper the authors are interested in presenting a basis for predicting the cloud top heights and the cloud radii as a function of explosive weight. A model for the way in which the respirable plutonium in the cloud varies with range is presented and is compared against the Project Roller Coaster Double Tracks test analysis prepared by Church, Luna and Milly in 1970 and Shreve in 1965.

The defensibility of this modeling approach for open air explosions will rest upon the following considerations:

- Presenting a theoretical basis for cloud radii and cloud height as a function of explosive amount.
- Showing that the theoretical basis for cloud heights and cloud radii are supported by empirical data.
- Accurately reproducing the respirable doses over the entire range of range peak data collected during the DT test.
- Accurately reproducing the qualitative aspects of the peak dosage curve that was derived from the DT test. In particular, there is a characteristic "hump" in the DT peak experimental respirable dose data down range with a maximum at about 762 m.
- With the theoretical model, accurately reproduce the empirical time-dependent evolution of cloud top height for 118 lb. of explosive.

If it can be shown that a MACCS2 Gaussian model can reproduce the data in accordance with the criteria given in the points outlined above, the model will be considered to provide a reasonable basis for safety analysis activities.

II. THEORETICAL BASIS FOR DETERMINING CLOUD TOP HEIGHTS AND CLOUD RADII GENERATED BY EXPLOSIVE SOURCES

Morton, Turner, and Taylor (1956) address the problem of modeling instantaneous sources by setting up the simplified time-dependent conservation equations for mass, momentum, and energy for the system. The entrainment speed at which environmental air is drawn into the cloud at its surface is assumed to be proportional to the plume vertical speed (Taylor 1948). The proportionality constant for entrainment is denoted α . If $u(z, t)$ is the speed of the cloud (z is the height from the ground and t is the time since detonation), then the average speed of the velocity profile of the air through the cloud is assumed to be $ku(z, t)$. The mixing fluids are assumed to be incompressible (this assumption is later relaxed). Local variations in density are assumed to be small relative to a reference density. Frictional drag is ignored in the treatment since the speeds involved are not large. In this approximate model, the cloud geometry does not have to be spherical, however, the ratio of the surface area to the volume of the plume must vary approximately as the ratio of the square to the cube of some length scale.

Under these assumptions, the coupled linear differential equations are solved to yield the following equations for cloud top height (CTH) and cloud radius (R).

$$CTH = \frac{1}{4} \left(\frac{3}{\pi} \right)^{\frac{1}{4}} (\alpha k)^{-\frac{3}{4}} \left(\frac{gQ}{c_p \rho T} \right)^{\frac{1}{4}} \left[\frac{g}{T} \left(\frac{\partial T}{\partial z} + \Gamma \right) \right]^{\frac{1}{4}} \Psi \quad (1)$$

$$R = \left(\frac{3}{\pi} \right)^{\frac{1}{4}} (\alpha k)^{\frac{1}{4}} \left(\frac{gQ}{c_p \rho T} \right)^{\frac{1}{4}} \left[\frac{g}{T} \left(\frac{\partial T}{\partial z} + \Gamma \right) \right]^{\frac{1}{4}} \xi \quad (2)$$

Here g is the acceleration due to gravity (9.81 m/s^2), c_p is the specific heat capacity of air (1005 J/kg K), ρ is the density of air (1.225 kg/m^3), T absolute air temperature (300 K), Γ is the adiabatic lapse rate (0.0098 K/m), Q is the energy released, $\delta T/\delta z$ is the average temperature gradient in the lowest 10 km of the atmosphere (≈ -0.0065), and α is the entrainment coefficient. Ψ , ξ and are specified below.

Morton et al. (1956) present an experimental basis for choosing $\alpha k = 0.285$, and $\alpha = 0.093$ with further discussions of a data fit for $\alpha k = 0.27$, where buoyancy vanishes, and $\alpha k = 0.34$ where velocity vanishes. Boughton and DeLaurentis (1987, 1992) use an entrainment fraction of 0.18 and quote a range for large density deficits of 0.15-0.2, and a range of 0.25-0.33 for cases where lower density deficits dominate. The value of αk used in this study is 0.213, with $\alpha = 0.093$ (which yields $\alpha k/\alpha = 0.213/0.093 = k = 2.29$) in accordance with the data analysis of Morton et al. (1956). The variables Ψ and ξ are functions of functions of scaled time, t , and are defined by:

$$t_1 = \left(\frac{g}{T} \frac{\partial T}{\partial z} + \Gamma \right)^{\frac{1}{2}} \frac{1}{k} \frac{1}{2} \cdot t \quad (3)$$

$$\text{For } 0 \leq t_1 \leq \pi; \xi = (1 - \cos t_1)^{\frac{1}{4}}, \Psi = 4(1 - \cos t_1)^{\frac{1}{4}} \quad (4)$$

$$\text{For } \pi \leq t_1 \leq 2\pi; \xi = (3 + \cos t_1)^{\frac{1}{4}}, \Psi = 8 \cdot 2^{\frac{1}{4}} - 4(3 + \cos t_1)^{\frac{1}{4}} \quad (5)$$

$$\text{For } 2\pi \leq t_1 \leq 3\pi; \xi = (5 - \cos t_1)^{\frac{1}{4}}, \Psi = 8 \cdot 2^{\frac{1}{4}} - 8 \cdot 4^{\frac{1}{4}} + 4(5 - \cos t_1)^{\frac{1}{4}} \quad (6)$$

$$\text{For } 3\pi \leq t_1 \leq 4\pi; \xi = (7 + \cos t_1)^{\frac{1}{4}}, \Psi = 8 \cdot 2^{\frac{1}{4}} - 8 \cdot 4^{\frac{1}{4}} + 8 \cdot 6^{\frac{1}{4}} - 4(7 + \cos t_1)^{\frac{1}{4}} \quad (7)$$

Summation of the Ψ function at each of the time-interval end points yields:

$$\text{For } S(n) = 4(-1)^{n+1}(2n)^{\frac{1}{4}} + 8 \sum_{i=0}^{n-1} (-1)^{i+1}(2i)^{\frac{1}{4}} \quad (8)$$

Equation (8) estimates the partial sum $S_{7000} = S(7000) = 4.202$. In reality, the value that would be empirically observed for the oscillatory phenomenon theoretically predicted by Eq. 8 would average to about 4.2 within a few cycles because friction drag with the atmosphere would tend to damp the motion more quickly than the mathematical model (which does not incorporate frictional drag) indicates. Church (1969), states that analysis of the project Roller Coaster data indicates that cloud stabilization occurs at two to three minutes for HE explosions; the least-squares fit in his study was performed at two minutes to derive his CTH formula. Review of the photographic data (Beasely 1965) suggests that the growth of the cloud after two minutes was obscured due to lighting conditions and crosswind interaction with the cloud. The data further indicate that continued cloud growth occurred for up to several minutes at reduced rates. The theoretical model used in this report does not account for potential additional entrainment, or for consequent loss in buoyancy due to additional crosswind entrainment. The effect of the additional crosswind entrainment would be to stabilize the cloud at a lower level than the model would tend to support. This study uses 180 s as the time cutoff at which the cloud growth rate has decayed substantially.

Solution of the differential equations for mass, momentum, and energy in the time interval $0 \leq t_i \leq \pi$ yields the following formula for CTH vertical evolution:

$$CTH(t, w) = \left(\frac{3}{\pi} \right)^{\frac{1}{4}} (ak)^{-\frac{3}{4}} \left(\frac{gQ}{c_p \rho T} \right)^{\frac{1}{4}} \left[\frac{g}{T} \left(\frac{\partial T}{\partial z} + \Gamma \right) \right]^{\frac{1}{4}} \left[1 - \cos \left(\left(\frac{g}{T} \left(\frac{\partial T}{\partial z} + \Gamma \right) \right)^{\frac{1}{2}} k^{-\frac{1}{2}} \cdot t \right) \right] w^{\frac{1}{4}} \quad (9)$$

At this point, the variable w denotes the amount of energy instantaneously injected into the point source. This study has found that substitution of 180 s into this equation, assuming an energy release of 4.27×10^6 J/kg for TNT, and converting this into a pound (lb.) based formula by dividing the energy released by 2.204 lb./kg yields the simplified formula:

$$CTH_{TNT} = 75w^{\frac{1}{4}} \quad (10)$$

Note, that in this equation, the variable, w , stands for weight of explosive in pounds. The theoretical predictive formula (Eq. 9) was compared to the time dependent CTH evolution

empirically noted in the DT test (Beasely 1965, Church 1969). The agreement between the theoretical formula and the data is noteworthy. The comparison is presented in Fig 1.

Figure 1. Empirical and theoretically predicted time dependent cloud top heights.

For the explosive PBX-9501, the simplified theoretical formula for CTH is

$$CTH_{PBX9501} = 80W^{\frac{1}{4}} \quad (11)$$

The time dependent cloud radius formula may be found by methods similar to those employed to determine the theoretical formula for CTH. The formula is:

$$R(t,w) = \left(\frac{3}{\pi}\right)^{\frac{1}{4}} (ak)^{\frac{1}{4}} \left(\frac{gQ}{c_p \rho T}\right)^{\frac{1}{4}} \left[\frac{g}{T} \left(\frac{\partial T}{\partial z} + \Gamma\right)\right]^{-\frac{1}{4}} \left[1 - \cos\left(\left(\frac{g}{T} \left(\frac{\partial T}{\partial z} + \Gamma\right)\right)^{\frac{1}{2}} k^{-\frac{1}{2}} t\right)\right] w^{\frac{1}{4}} \quad (12)$$

The cloud radial formulae for TNT and PBX-9501 are respectively

$$R_{TNT} = 16W^{\frac{1}{4}} \quad (13)$$

and

$$R_{PBX9501} = 17W^{\frac{1}{4}} \quad (14)$$

There appears to be little analyzed data from project Roller Coaster concerning cloud radius evolution in time. The available photography (Beasely 1965) was reviewed for this

technical report from which rough measurements were made from the photographs. Approximately 60 s after the detonation, the cloud diameter was approximately 84 m, the theoretical formula in Eq. 13 predicts 63 m. At 120 s after detonation, the cloud diameter was approximately 110 m, and theoretical Eq. 13 predicts 88 m. Measurement of the cloud diameters from the pictures was difficult due to distortion of the shape of the cloud by the presence of a crosswind. However, these crude estimates serve to show that the cloud radial dimensions are a substantial fraction of the cloud height and are in approximate agreement with those made using the predictive Eq. 13.

III. REVIEW OF THE EMPIRICAL DATA ON CLOUD TOP HEIGHT AND CLOUD RADII MEASUREMENTS

Church (1969) performed a least-squares fit to 22 explosive shots that were fired at NTS in the time frame of April to June 1963. The shots ranged in TNT yield from 118 lb. to 2800 lb. The formula derived by Church (1969) for CTH (w , in lb.-TNT equivalent, CTH in m) is:

$$CTH_{TNT} = 76w^{\frac{1}{4}} \quad (15)$$

The empirical evidence for CTH prediction suffers from the fact that little data were available in the low explosive weight range. However, the formula is obviously correct in the limit of small explosive masses, and the data does appear to be well bounded by the 2σ error bands, which are in turn well bounded by the $\pm 20\%$ total formula error recommended by Church (1969) for stabilities associated with average atmospheric lapse rates. The existence of a theoretical basis (Eq. 9) for the formula that agrees well with experiment strengthens the applicability of the CTH formulae to the low explosive weight regions. The empirical formula derived by Church (1969) also compares well with theoretical equation 9 derived earlier. An independent curve fit to the data for this report yielded the plots in Fig. 2 shown below. Although the fit to the data does not extend to explosive weights below 118 lb., the applicability of the cloud radius and CTH formulae for low explosive weights is established in this report by the theoretical foundation of the time-dependent formulae presented.

Figure 2. Empirically predicted cloud to heights @ 120 seconds (Church, 1969).

In the Explosive Release Airborne Dispersion (ERAD) model, Boughton and DeLaurentis (1987, 1992) define an initial condition for the model involving a calculated explosive cloud radius. This radius is defined as that radius that gives a decayed over-pressure of

1 atmosphere. Baker et al. (1983) defines this cloud radius approximately for exploding Pentolite 50/50 (with a slightly different specific energy of 4.85×10^6 J/kg) as

$$R = 0.85 \left(\frac{E}{P_0} \right)^{\frac{1}{3}} \quad (16)$$

Within Eq. 16, E is the explosive energy (J) and P_0 is the ambient atmospheric pressure (Pa).

In the ERAD model, the mass of ambient air within a sphere of this radius is computed and the explosive energy is added to this system at ground level. Because of the instantaneous addition of energy, the heated air expands and the plume rise starts.

In an effort to determine the potential effects on the model presented in this paper, the conservation equations (Morton et al. 1956) were solved in closed form using a finite volume initial assumption consistent with the volume predicted by using Eq. 16 and a spherical volume assumption. It was determined that for this report this assumption is not necessary as an initial condition.

IV. MACCS2 AND ERAD INTERCODE COMPARISON FOR PROJECT ROLLER COASTER DT SHOT AND COMPARISON OF BOTH CODES TO PEAK DOSES AS A FUNCTION OF RANGE FOR THE DT TEST

During the time period May 15 to June 9, 1963, a joint US/UK field experiment, consisting of a series of four nonnuclear detonations of plutonium-bearing weapons occurred, to supply empirical information concerning the nature and extent of the resultant alpha contamination (Coogan 1968). The test dispersal shots were called Clean Slate 1 (CS1), Clean Slate 2 (CS2), Clean Slate 3 (CS3), and Double Tracks (DT). The test was conducted at the Tonopah Test Range in Nevada. DT and CS1 were open-air shots and CS2 and CS3 were bunkered shots. CS1 involved nine devices making interpretation of the data difficult due to the competing effects of the interacting assemblies. For open-air accident analytic purposes, DT therefore supplies the best data. DT involved 118 lb. of Cyclotol which was detonated upon an 8' x 8' steel plate. Relevant parameters of the shot include the following (Church 1969):

Shot time = 0255 hr.
CTH@120 s = 210 m-220 m
Mean Wind Speed = 8 m/s
Approximate D-Stability
Approximate Wind Speed @10 m = 5.4 m/s

Church (1969) summarizes temperature, wind speed, and wind direction analog profiles as a function of height up to 600 m that are reported in Titus (1965). These analog data were read and placed into the form required by ERAD (see Appendix A for the ERAD input file for the DT benchmark test). For this benchmark case, ERAD calculated an inverse Monin-Obukov length $(1/L) = 1.19 \times 10^{-3} \text{ m}^{-1}$. In accordance with comparative analysis of the relevant stability parameters, (Golder 1972) concludes that this value of Monin-Obukov length is consistent with D Pasquill stability class. This is further confirmation of the approximate D-stability class assumption used in the MACCS2 benchmark of the DT shot.

The total amount of plutonium released for this analysis is assumed to be 0.2 kg in accordance with the assumed release of an $\text{ARFxRF} = 20\%$ of the 1 kg MAR for both the MACCS2 and ERAD analysis. A $1 \mu\text{m}$ monodispersal particle distribution was used in both code analyses. The basis for this assumption is that this model, as described in the abstract, is designed to show that respirable doses can be accurately modeled with the MACCS2 code. This assumption would be untenable if accurate ground deposition modeling were the intent of this report. The deposition velocity used in MACCS2 was 0.01 m/s (a parametric was performed and the MACCS2 calculation was found to be relatively insensitive to this deposition velocity up to a velocity of 0.05 m/s). In MACCS2, the CTH was calculated as $75w^{1/4}$, which yielded a CTH = 247 m for an explosive weight of 118 lb. The cloud radius was calculated as $16w^{1/4}$, yielding $R = 53 \text{ m}$. The cloud center height was therefore about 194 m (see Appendix B for the MACCS2 input file). A comparison of the ERAD calculated cloud parameters was effected at $t = 180 \text{ s}$, and it was found that CTH = 251 m and $R = 54 \text{ m}$, which yields a cloud center height of 197 m. These independently calculated parameters are in excellent agreement with the methodology used in the MACCS2 calculation, with the maximum relative error in CTH and radius being bounded by 2%. Although this is not a proof, it would appear that the closed-form expressions for CTH (Eq. 9) and cloud radius (Eq. 12) derived from consideration of conservation of continuity, momentum, and energy

that form the basis for the MACCS2 model used in this paper yield essentially the same results as the numerical methods used to solve the similarly derived equations that are solved numerically in ERAD (with friction effects included).

Several analyses have been performed on the DT data in an effort to determine peak alpha airborne dosages ($\mu\text{g-s/m}^3$) as a function of radial range from the shot point. One such study is Shreve (1965). Shreve's report quotes peak activities ηCi as a function of distance. The air sampler flow rate is quoted as 17 L/min. Unloaded and filter-loaded air-sampler volumetric flow rates were recorded for each sampler before the test and some anomalies were noted (Maloney 1965). No plutonium α -only specific activity is given. Another report by Church, Luna and Milly (1970) presents peak alpha dosages as a function of downwind radius and indicates that the Casella impactors had a nominal flow rate of 18 L/min. For comparative purposes, an α -only specific activity of 0.081 Ci/g was used in the ERAD analysis used in this report. The analysis forming the basis for use of the α -only specific activity of 0.081 Ci/g is presented in Appendix D. For the MACCS2 analysis, a 3-year-old mixture was used in which the β contribution due to ^{241}Pu was removed. The specific activity of the MACCS2 mixture was 0.08107 Ci/g. The maximum value for the ERAD run was 3.73 rem cumulative effective dose equivalent (CEDE) at about 0.630 km. The maximum value obtained in the MACCS2 comparative run occurred at 0.630 km and was 2.41 rem CEDE. The analyzed data from the two reports for the DT shot are summarized in Fig. 3, where the airborne dosages have been converted to rem CEDE.

To convert the normalized Shreve (1965) data to dose in rem, a standard breathing rate of $3.33 \times 10^{-4} \text{ m}^3/\text{s}$, and a dose conversion factor of $3.08 \times 10^8 \text{ rem/Ci}$ was assumed. As can be seen from Fig. 3, the assumptions used in both the ERAD model and the MACCS2 model (both yielding a maximum at 630 m) are adequate to reproduce the characteristic maximum in the curve at the approximate correct distance (762 m) as given by Shreve (1965) and Church et al. (1970).

Figure 3. ERAD & MACCS2 code comparisons against DT empirical test data.

The equivalent peak dose presented in Church et al. (1970) is about 6.23 rem CEDE with a stated error band of approximately a factor of 2.0. The equivalent peak dose presented in Shreve (1965) is about 4.68 rem CEDE with no explicit error bars included. MACCS2 and ERAD appear to underestimate the peak approximately by factors of 2.3 and 1.5 respectively. This may be explained based upon the fact that the actual DT shot CTH ($z \approx 215$ m) was actually 87% of the theoretically predicted value of 247 m. Although this reduced cloud height is within the expected error band of 20%, the reduced altitude would have the effect of increasing the near-field doses by nearly the amount of disagreement with the empirical data. The agreement between the ERAD and MACCS2 analysis is very good across the whole range from 100 m to 11 km. Agreement between the two codes and the two different analysis of the peak dose data is also good from 100 m to about 4.5 km. While the last data point at 14 km appears to be underestimated, three other far field points in the 4.5-11 km range appear to be overestimated. This observation could be caused by variations in the meteorological parameters with range over those assumed at the shot sites in the analysis. From 4.5 km to 14 km agreement between the two codes and the two different analysis of the peak-dose data is acceptable, with both code approaches probably overestimating the far-field doses. Based upon these data, further modeling results are pursued for a hypothetical accident as shown below.

It should be noted that the agreement of the data with both the MACCS2 model and the ERAD model is very good across a broad range of distances. The reproduction of the empirical data by both codes is consistent with the assumption of a 20% ARFxRF and the stated errors in CTH and cloud radius. Use of a smaller ARFxRF would cause the calculated near-field results to be significantly underestimated in comparison to the near-field doses from the empirical data. Increasing the ARFxRF would tend to move both models toward better reproduction of the near-field empirical data. However, the authors of this paper believe that when one accounts for other potentials for errors in the plume model due to meteorological sampling, cloud heights, cloud radii, etc., an ARFxRF = 0.20 is defensible.

V. SUMMARY OF MODELING ASSUMPTIONS USED FOR HYPOTHETICAL EXAMPLE

Dewart et al. (1982) performs analysis on 20 postulated plutonium releases resulting from high-explosive, nonnuclear detonations of nuclear weapons. The mass of plutonium released varies in the range of 0.460-120 kg with the amount of explosive detonated in the range of 1.3-2000 lb. The purpose of the analysis was to support the Pantex Environmental Impact Statement through the use of the Gaussian dispersion DIFOUT code developed by Luna (1969). In a manner similar to this effort, but with the more limited scope intent of demonstrating how the method would be applied to a randomly selected energetic explosive (PBX-9501), the formulae outline below are assumed. Although Dewart et al. (1982) used explosive weights as low as 1.3 lb. and 6 lb., this report chose 6 kg of explosive as an amount representative of low cloud heights in an effort to consider bounding doses in a reasonable way, and a 1 kg respirable mass was chosen as an amount that would be easily scaleable to other dose consequences that might be considered in future uses of this report.

1. Cloud Initial Radius (PBX-9501):

$$R_{PBX9501} = 17 w^{\frac{1}{4}} = \sigma_y = \sigma_z \quad (17)$$

2. Cloud Initial Height (PBX-9501):

$$H_{PBX9501} = 80 w^{\frac{1}{4}} - R_{PBX9501} \quad (18)$$

3. Cloud Respirable Material Content: 100% of the respirable plutonium.
4. Mass of explosive is 6 kg of PBX-9501.
5. Mass of respirable ^{239}Pu released is 1 kg.
6. Meteorology: The Julich System (Vogt 1977) derived for 50 m plumes is used for determining σ_y and σ_z .
7. Upon review of the MACCS2 ATMOS input file attached as Appendix B, ATMOS might first appear to be invoking plume meander. For the purposes of minimized confusion on this issue, reference is made to the MACCS2 code manual by Chanin and Young (1997). In order to account for the effect of plume meander during transport of the plume, the linear expansion factor (EXPFAC) that operates on y is defined in the code as $\text{EXPFAC} = \{[\text{MAX}(\text{plume segment release duration, TIMBAS})] / \text{TIMBAS}\}^{\text{XPFAC}}$, where XPFAC_i is one of two empirically derived exponential factors that are used based upon whether the plume duration is less than or equal to, or greater than a breakpoint variable. For the modeling performed for this report, the plume segment release duration was chosen as 600 s while the TIMBAS constant is 3600 s. The maximum of these two constants is TIMBAS, which when divided by itself yields unity. Therefore, plume meander is not invoked except where specifically noted in this report.
8. For the ERAD benchmark, a roughness length of 10 cm was used. According to Boughton and DeLaurentis (1992), this value is appropriate to use for terrain with

roughness lengths between open pasture and agricultural land. Parametrics run with approximate 50% variations in the roughness length do not yield large variations in the dose consequences as a function of range. For the MACCS2 analysis, a roughness factor of 1.27 was used. This factor is the default value supplied with the code sample ATMOS input file. This factor was originated when scaling the Pasquill-Gifford values of σ_z up to values appropriate for prairie grass surfaces characterized by 10 cm roughness lengths (Jow et al. 1990, Hanna et al. 1982). The generic linear scale factor of 1.27 is applied in this report to the σ_z values obtained from the Julich curves which are also supplied with the code. A parametric was run to quantify the effect of using a roughness length of 1.0 in a code run with full LANL meteorologic bin sampling, and it was found that the case using a roughness length of 1.27 was conservative with the relative errors bounded by $2\sigma \approx 27\%$ in the 0-1 km range. The relative errors were found to be nonconservative ($2\sigma \approx 10\%$) in the 1-9 km range. These relative error levels are believed to be acceptable.

VI. CONSEQUENCE ERROR PARAMETRIC FOR VARIATIONS IN CLOUD RADIUS AND CLOUD MIDDLE HEIGHTS

Figure 4, shown below, applies to a 6 kg detonation of PBX-9501, with a 1 kg respirable release of 55 year old weapons-grade ^{239}Pu . It presents a parametric comparison of the effects of varying the cloud heights and cloud volumes within the expected error bands for both. Plume meander was invoked for this parametric. This plot is to be used only for qualitative relative comparisons. It has been verified that invocation of plume meander does not appreciably affect the use of these plots as a qualitative indication of relative error. However, on an absolute scale, inappropriate use of plume meander can result in significant underestimation of near and far-field dose consequences. It is not recommended by the authors of this report that plume meander be invoked for the open air explosion models because it invalidates the benchmark work performed in this report against the DT data. An exception to this recommendation would apply to sites that have empirical data, such as tracer studies, specifically applicable to their site.

Respirable release normalized to 1 kg, full LANL 1991 WEBSITE MET for TA-6 Tower

Figure 4. Effects of errors in cloud heights and cloud radii in the MACCS2 model.

VII. CONSEQUENCE ERROR PARAMETRIC FOR YEARLY VARIATIONS IN METEOROLOGICAL DATA

The graphical parametric presented below (see Fig. 5) applies to a 6 kg detonation of PBX-9501, with a 1 kg respirable release of 55 year old weapons-grade ^{239}Pu . It presents a parametric comparison of the effects of using LANL meteorological data from different years (1991-1996). In the near field an approximate maximum 30% variation occurs in the calculated doses based upon which year is selected. The year 1991 yields approximate average dose consequences. An additional plot (1991alt) is also presented. The MACCS2 meteorological file associated with these doses is the one used in the Defense Programs Safety Survey (D.I. Chanin, personal communication, May 1997). For the purposes of this study, this file was precluded from use on the grounds that it systemically underestimates dose consequences and it clearly disagrees with other data for the same meteorological tower and year. Plume meander was invoked for this parametric. This plot is to be used only for qualitative relative comparisons. It has been verified that invocation of plume meander does not appreciably affect the use of these plots as a qualitative indication of relative error. However, on an absolute scale, inappropriate use of plume meander can result in significant underestimation of near and far-field dose consequences. It is not recommended by the authors of this report that plume meander be invoked for the open-air explosion models because it invalidates the benchmark work performed in this report against the DT data.

Figure 5. Error effects on dose consequences of meteorological year selected.

VIII. CONSEQUENCE PARAMETRIC BASED UPON CONSEQUENCE PERCENTILE

Figure 6 below applies to a 6 kg detonation of PBX-9501, with a 1 kg respirable release of weapons-grade ^{239}Pu aged zero years. Plume meander was not invoked for this parametric. From the plot below, it can be seen that there is a multiplicative factor of about 3 between the mean consequences and the 95% consequences at LANL based upon use of the 1991 meteorological input file. It should be noted that the full curves for 99% and 99.5% consequences are incomplete. The MACCS2 code does not calculate the 99% and the 99.5% values in the approximate range 0-1 km. However, by using the sector peak method, the values were found for use with the NUREG 1.145 methodology.

Figure 6. Comparison of Percentile Consequences for 1 kg plutonium release.

IX. CODE COMPARISON RESULTS

A code comparison was performed with the ERAD code. To minimize errors due to mesh size choice, a fine mesh size of about 100 m was used with 10,000 Monte Carlo sampling points. Six kilograms of explosive were used with a specific energy of 5.5×10^6 J/kg. One kg of plutonium was used with the 14 "typical" meteorological cases supplied with the code by Sandia National Laboratories. It should be noted that using a small enough grid mesh size is very important; when ERAD runs were performed with a grid size on the order of 300 m, the maximum dose value was only about 0.5 of the maximum value obtained with the finer (100 m) grid. Running ERAD using the 14 generic meteorological input file approach, with grid sizes of about 100 m, was time intensive on a 130 MHz Pentium (approximately 2.3 hours) when compared with a MACCS2 run of less than five minutes.

ERAD supplies no analytic output data concerning statistical consequence confidence intervals. Figure 7 presents a comparative plot of the 95% consequences as determined from MACCS2 and averaged ERAD results + 2σ . In the near field, the 95% consequence MACCS2 dose data without regard to wind direction is judged to be about a factor of 2-3 larger than the ERAD calculation using the average of the doses at each range value and adding the 2σ value appropriate to each range value.

To ensure that the comparison was unambiguous, 1 kg of pure respirable ^{239}Pu with a mean aerodynamic diameter of $1.0 \mu\text{m}$ was used in both cases. The dose conversion factors were verified to be equivalent (3.08×10^8 rem/Ci) in the two approaches.

Figure 7. MACCS2 vs. ERAD dose 95% consequence comparison (1 kg pure ^{239}Pu).

The plot presented in Fig. 8 below is similar to the plot in Fig. 7, and compares the mean MACCS2 code analysis values to the ERAD consequence values averaged across all 14 meteorological files at each distance. In the near field, the MACCS2 appears to bound the ERAD consequence calculation by about a factor of 2.

Figure 8. MACCS2 vs. ERAD mean dose consequence comparison (1 kg pure ^{239}Pu).

Based upon the foregoing discussion, it appears that in the range of 0.2-4.0 km, use of ERAD with the 14 generic meteorological input files as a method to perform a bounding consequence analysis at other sites systematically underestimates the doses by factors as large as 2-3. It appears that the problem is related to the use of the 14 generic meteorological input files that were derived from Pantex specific data. We conclude that use of the generic 14 Pantex meteorological input files is not defensible for safety analysis report purposes. These same comments would also apply to use of the 7 generic input file approach promulgated by SNL prior to the advent of the newer 14 generic meteorological input file approach.

It is important to note that there is no indication that use of the ERAD code, with an adequate statistical sample space of actual site specific meteorological input data, and adequately chosen grid mesh size, would yield other than a fully defensible consequence analysis. However, use of ERAD in this mode would be computationally time intensive and would require the development of a statistical post-processor to determine consequence confidence intervals.

X. HEALTH PHYSICS CONSIDERATIONS

In a manner similar to that used by Sandia in the evaluation of large doses at Pantex due to the cell venting issue, this report used 55 year old weapons-grade plutonium for several of the analysis. The time-dependent isotopic composition that was used was derived from a mixture used in the HOTSPOT code (Homann 1985) initial isotopic composition (i.e., no ^{234}U initially present, no ^{241}Am initially present) and the use of the Bateman equations (see Appendix C for the details pertaining to the determination of specific activities, dose conversion factors, and specific doses for weapons-grade plutonium with the contribution of ^{241}Pu accounted for, and reference Appendix D for the analysis pertaining to α -only health physics parameters). The assumed isotopic composition for the weapons-grade plutonium is generally consistent with values summarized by Heindel, Clow, Inkret, and Miller (1995). The dose conversion factors (DCFs) used by the MACCS2 code are included and are consistent with Federal Guidance Report No. 11 (Eckerman 1988). The composition at 55 years is displayed in Table 1:

Table 1. Isotope Specifics for a Type of Weapons Grade Plutonium @ 55 years

Isotope	Mass Fraction @ 55 years	Specific Activity (Ci/g)	MACCS2 DCFs (rem/Ci)	1 kg Ci Content
^{238}Pu	2.59×10^{-4}	$1.71 \times 10^{+1}$	2.88×10^8	4.44
^{234}U	1.41×10^{-4}	6.25×10^{-3}	1.32×10^8	8.82×10^{-4}
^{239}Pu	9.32×10^{-1}	6.22×10^{-2}	3.08×10^8	58.0
^{240}Pu	5.97×10^{-2}	2.23×10^{-1}	3.08×10^8	13.6
^{241}Pu	4.10×10^{-4}	$1.03 \times 10^{+2}$	4.96×10^6	42.2
^{241}Am	5.07×10^{-3}	3.43	4.44×10^8	17.4
^{242}Pu	4.00×10^{-4}	3.93×10^{-3}	2.93×10^8	1.57×10^{-3}
^{244}Pu	0.00	1.77×10^{-5}	2.89×10^8	0.00

MACCS2 uses an actual core inventory that is entered in terms of Curies. All of the dose conversions when using MACCS2 are performed internal to the code. ERAD, however, uses an approach in which a kilogram quantity is entered into the code with one mass-fraction weighted specific activity and one mass-fraction weighted dose conversion factor. To compare the two different codes on an equal footing when using a plutonium mixture requires that the weighted specific activity and weighted dose conversion factor be carefully determined. To ensure an unambiguous code comparison, this issue is dealt with by using a pure isotope for several of the comparative analysis. In other comparisons in this report, particular weapons-grade compositions are used in which alpha only contributions to the doses are of interest when comparing to the project Roller Coaster data. It should be noted that the widespread use of alpha only specific activities in analysis is generally nonconservative. While the dose conversion factor for the beta emitter ^{241}Pu is about 62 times lower than that of ^{239}Pu , the specific activity of ^{241}Pu is about 1658 times larger than that of ^{239}Pu . Because the mass-fraction weighting of this isotope is usually a relatively small number,

the ^{241}Pu contribution to the doses does not usually dominate the consequence analysis, however its contribution can be significant and must be correctly accounted for.

Table 2. Isotope Specifics for a Type of Weapons Grade Plutonium @ 3 years.

Isotope	Mass Fraction @ 3 years	Specific Activity (Ci/g)	0.2 kg Ci Content
^{238}Pu	3.91×10^{-4}	$1.71 \times 10^{+1}$	1.34
^{234}U	9.37×10^{-6}	6.25×10^{-3}	1.17×10^{-5}
^{239}Pu	0.93	6.22×10^{-2}	11.61
^{240}Pu	0.06	2.23×10^{-1}	2.74
^{241}Pu	5.02×10^{-3}	$1.03 \times 10^{+2}$	103.5
^{241}Am	7.78×10^{-4}	3.43	0.53
^{242}Pu	4.00×10^{-4}	3.93×10^{-3}	3.14×10^{-4}

XI. BUNKERED TEST MODELING CONSIDERATIONS AND ANALYSIS

This section presents considerations applicable to the modeling of consequences due to explosive dispersal accidents inside of bunkers.

Project Roller Coaster tests CS2 and CS3 were designed to contrast weapons accidents for conditions of storage in a DASA igloo with 2 and 8 ft of earth cover respectively. The CS2 and CS3 shots each consisted of 19 units. The total HE weight in the igloo associated with the 19 units was 2242 lb. of TNT equivalent. One of the 19 units contained plutonium as the tracer isotope. The CS2 shot occurred at 0347 hr on May 31, 1963. According to Church (1969), the mean wind speed was about 4 m/s (about half of the mean wind speed of the DT shot). The meteorology for the CS2 shot was slightly more stable than the DT shot, though not as stable as CS3. The cloud top height reached 416 m at 120 s as compared to the DT shot at 120 s of 210-220 m. Ultimately the cloud top reached a height of about 457 m at about 200 s and was followed by a monotonically decreasing cloud height which at 300 s was 409 m. The cloud diameter at 120 s (Dewart et al. 1982) was about 250 m. Using the formula for the prediction of cloud radii derived in this report (Eq. 13), the cloud diameter would be 220 m, yielding an error of about 12%. This error is within the allowed 20% error bands for predicting cloud radii and is further confirmation of the adequacy of the formulas presented in this paper.

The stability class for the CS2 detonation was either D or E. Wind conditions were computed by averaging the data from the five stations/towers, yielding a wind speed at 10 m of about 2.23 m/s. Cloudiness that developed during the night inhibited radiation cooling, producing a thin inversion of approximately 1.5 °C between the surface and 30 m. Concurrently, a nearly isothermal layer existed above 30 m to 152 m above the surface, with a slight lapse in temperature through 600 m. Beasley (1965), shows the CS2 cloud venting preferentially to one side of the bunker. The bunker had 2 ft of earthen cover.

Although this technical report emphasizes CS2 data, the CS3 data also contains valuable comparative information. The total amount of explosive in the CS3 test was again 2242 lb. The earth overburden on the CS3 bunker was increased to 8 ft for this test. The shot was done at 0330 hr on June 9, 1963 and the mean wind speed at 10 m was about 2.2 m/s. An inversion of approximately 3.7 °C between the surface and 150 m existed, with a slight inversion to about 370 m, with pronounced lapse in temperature through 600 m. Stability class for this shot was assigned E. The CTH for this shot was about 517 m. Church et al. (1970), indicates that the peak respirable exposure as a function of distance parallels the exposure for CS2, but at a lower magnitude.

For a 2242 lb. shot, the cloud top height, as calculated by the formula $75w^{1/4}$, yields a predictive height of 516 m. The CS2 CTH of 416 m and the CS3 CTH of 517 m are within the expected 20% error bands for the heights. The cloud radius as calculated by the formula $16w^{1/4}$ yields a predictive radius of 110 m. This radius is within the expected 20% error band when compared to the observed radius of $250 \text{ m}/2 = 125 \text{ m}$. In the lowest 30%-40% of the CS2 cloud, the airborne plutonium was approximately doubled, and in the lowest 20% of the CS2 cloud, the airborne plutonium was about eight times greater than in the DT cloud. This is of particular importance as in the Gaussian plume methodology, effective plume height appears as a negative squared exponential.

In the reported results (Church et al. 1970) of the Clean Slate tests, it was noted that increasing the dirt overburden by a factor of four for CS3 was associated with reduced doses by a rough factor of about 3 in the near field when compared to the CS2 respirable data. Although not significant with respect to the expected errors in the cloud dimension formulas, the larger doses as a function of range for the CS2 shot when compared with the CS3 shot are consistent with the lower cloud height. Based upon these considerations, there appear to be no grounds to state that the structure or dirt overburden caused the *relative* differences in the CS2 and CS3 doses as a function of range.

As stated previously, the CTHs and radii do not appear to be affected by bunkering or observed differences in meteorology. Further, the only obvious differences between DT and the two bunkered shots (CS2 and CS3) was the presence of the dirt overburden, the number and timing of the assemblies detonated, and the building wake effects. Several investigators (Dewart et al. 1982; Luna and Church, 1969) have hypothesized that the observed difference in plutonium fraction as a function of height when comparing DT to both CS2 and CS3 was caused by interaction of the plutonium in the cloud with the dirt overburden and/or building wake effects. When the lower cloud height of CS2 is accounted for, the peak doses as a function of range for CS2 and CS3 appear similar. Therefore, the differences in dirt overburden must have to first order saturated with the 2 ft thick earth covering used in CS2. From consideration of the data, it is not clear what minimum thickness of earth overburden is required to significantly perturb the respirable plutonium fraction with height. It should be noted that because the DT shot was performed on a 8' x 8' steel plate, dirt entrainment was minimized.

In performing MACCS2 analysis applicable to bunkered tests, a first attempt was made to model the cloud using the CTH and radius formulas that worked well for the unbunkered DT test. The results of this modeling greatly under predicted the near-field peak doses and greatly over predicted the far field doses. This was consistent with the scavenging hypothesis of Dewart et al. (1982) as the far-field doses would be expected to have the greatest reduction as the scavenging process inside the cloud would have acted for the longest time. In the near field, the under predicted peak dose is consistent with the negative squared exponential weighting of the lower cloud respirable fractions.

Ultimately, it was found in a purely heuristic approach, that by reducing the CTH by half of the theoretically predicted height while retaining the predicted cloud radius, correct near-field doses could be approximated. Because MACCS2 does not allow for time or spatial varying of the cloud respirable fractions, another method was employed. The MACCS2 capability for modeling enhanced plume dispersion due to plume meander was employed in a trial and error test to fit the observed data. It was discovered that through the use of the minimum code set point of 60 s for onset of plume meander with an exponent of 0.55 a curve fit to the observed empirical data could be approximated. The results are presented graphically in Fig. 9. As a result of this analysis, it is recommended that in explosive dispersal accidents involving material in structures for which dirt entrainment is a potential analysis be performed using half of the predicted cloud height and the theoretically predicted radius.

Figure 9. MACCS2 code comparison to clean slate 2 shot data.

XII. APPLICATION OF REGULATORY GUIDE 1.145 (NRC 1983) TO A FICTITIOUS DOSE CONSEQUENCE ANALYSIS

For elevated nuclear release dose determinations, at or beyond the site exclusion boundary, NRC (1983) recommends that the χ/Q , or equivalently the dose, be determined in each of 16 compass directions (22.5-degree sectors) at the point on or beyond the exclusion area boundary where the dose consequences are a maximum for a 2-hour time period. If releases associated with a postulated event occur inside of a 20 minute interval (as in the near instantaneous release due to an explosion), the applicability of the modeling methodology should be evaluated on a case-by-case basis. The dose consequence that is exceeded 0.5 percent of the time (99.5% consequence) should be selected for each of the 16 sectors to determine the sector doses. The dose value to be used for exclusion area boundary evaluations should be the maximum of the comparison between the sector dose at or beyond the exclusion boundary for that sector and the 5 percent (95% consequence) directionally independent overall site doses at that distance.

In Fig. 10, the 99.5% sector peak doses for an unbunkered 6 kg detonation of PBX-9501 and 6 kg of weapons-grade plutonium are plotted at a fictitious site. The offsite boundary is shown for the site. Arrowed lines are drawn in between rectangular facilities to show onsite transportation paths between facilities. By creating the sector peak dose grid as an overlay, the overlay may be easily moved along the transportation path and to each of the facilities located on the map for which the maximum dose values can be easily read off of the grid. In this manner, dose consequences can be efficiently evaluated for all facility and transportation type accidents at once without separate analyses. If earth berms are present on the facilities, then the accident sequence needs to be broken up into two groups, facility and transportation. The actual data from the analysis are summarized in Appendix E.

Figure 10. Application of Regulatory Guide 1.145 to an explosion scenario involving 6 kg PBX-9501, 6 kg plutonium, and a fictitious site boundary.

XIII. CONCLUSIONS AND RECOMMENDATIONS

This report has demonstrated that defensible modeling using Gaussian plume analysis with the MACCS2 code can be performed for explosive dispersal of plutonium. The methods developed in this report are computationally efficient when compared with other codes such as ERAD and superior when statistical consequence percentile output summaries are desirable. Because the meteorological input data for MACCS2 is more generally available than the input data for other codes such as ERAD, it is easier to set up and run the MACCS2 models for explosive dispersal scenarios. Modeling of explosive dispersal scenarios with the ERAD code using either the 7 or 14 generic meteorological input file approach is not recommended by the authors of this report as this meteorological approach may systematically underestimate the consequences.

There are several potentials for error in the assessment of mean doses as a function of range, denoted $D(x, y, z)$ using the modeling methodology presented in this paper. The qualitative magnitude of these errors is assessed in this report and include the following:

- Errors due to differences in the yearly variation in the meteorological data. This error is assumed to be bounded by a multiplicative factor of 1.3.
- Errors due to statistical variation in CTHs and cloud radii. This error is assumed to be bounded by a factor of about 2.
- Errors that are possible in the original data from the project Roller Coaster data. The error is assumed to be bounded by a factor of 3.
- Lumped Errors due to use of the incorrect roughness length, slightly different ARFxRF, or another similar parameter. This error category is assumed to be bounded by a factor of about 1.5.

Assuming each of these errors is independent, the total error might be conservatively assessed to be about a factor of 4 for a mean consequence analysis. According to the data presented in Fig. 6 and Appendix E, this is slightly less than the error obtained when comparing the maximum 99.5% sector peak consequences to the maximum mean doses at a given range. Although this qualitative discussion falls far short of a proof, it does show that use of the modeling methodology outlined in the report coupled with a Regulatory Guide 1.145 approach will present accident consequences that are believed to be defensibly bounding for explosive dispersal modeling. Recommendations for future research include developing defensible methods for estimating the following:

- particulate ground deposition and resuspension with full bench marking,
- development of a theoretical fracture model for plutonium metal which will yield ARF and RF as a function of the explosive mass that surrounds the plutonium, and
- development of a theoretical entrainment, scavenging, and cloud geometry model that adequately explains how the respirable fractions in a multiple-device detonation scenario vary with height and structural interaction effects.

REFERENCES

- W. E. Baker, P. A. Cox, P. S. Westine, J. J. Kulesz, and R. A. Strehlow. Fundamental Studies in Engineering 5: Explosion Hazards and Evaluation. New York: Elsevier Scientific (1983).
- R. R. Beasley. Operation Roller Coaster: Technical Photography (POR-2519). Albuquerque, NM: Sandia Corporation (1965).
- B. A. Boughton, and J. M. DeLaurentis. Description and Validation of ERAD: An Atmospheric Dispersion Model for High Explosive Detonations (SAND92-2069). Albuquerque, NM: Sandia National Laboratories (1992).
- B. A. Boughton, and J. M. DeLaurentis. An Integral Model of Plume Rise from High Explosive Detonations. In proceedings of the 24th National Heat Transfer Conference, ASME, 27-32 (1987).
- B. A. Boughton, L. E. Edwards, L. W. Hantel, J. M. Haschke, J. R. Humphrey, R. E. Luna, and D. R. Stephens. Characterization of Plutonium Aerosols for Various Accident Scenarios by an Expert Panel (LA-CP-95-55). Los Alamos, NM: Los Alamos National Laboratory (1995).
- D. I. Chanin and M. L. Young. Code Manual for MACCS2: Volume 1, User's Guide (SAND91-0594. UC-610). Albuquerque, NM: Sandia National Laboratories (1997).
- H. W. Church. Cloud Rise from High-Explosives Detonation (SC-RR-68-903). Albuquerque, NM: Sandia National Laboratories (1969).
- H. W. Church, R. E. Luna, and S. M. Milly. Operation Roller Coaster: Near Ground-Level Air Sampler Measurements (SC-RR-69-788). Albuquerque, NM: Sandia National Laboratories (1970).
- J. S. Coogan. Operation Roller Coaster: Off-Site Survey (POR-2511). Las Vegas, Nevada: U. S. Public Health Service, Southwestern Radiological Health Laboratory (1968).
- J. M. Dewart, B. M. Bowen and J. C. Elder. Supplementary Documentation for an Environmental Impact Statement Regarding the Pantex Plant (LA-9445-PNTX-D). Los Alamos, NM: Los Alamos National Laboratory (1982).
- J. C. Elder, J. M. Graf, J. M. Dewart, T. E. Buhl, W. J. Wenzel, L. J. Walker and A. K. Stoker. A Guide to Radiological Accident Considerations for Siting and Design of DOE Nonreactor Nuclear Facilities (LA-10294-MA). Los Alamos, NM: Los Alamos National Laboratory (1986).
- K. F. Eckerman, A. B. Wolbarst, and A. C. Richardson. Limiting Values of Radionuclide Intake And Air Concentration and Dose Conversion Factors For Inhalation, Submersion, And Ingestion, Federal Guidance Report No. 11 (EPA-520/1-88-020). United States Environmental Protection Agency Office of Radiation Protection Programs, Washington, DC (1988).

D. Golder. Relations Among Stability Parameters in the Surface Layer. Boundary-Layer Meteorol, 3 :56 (1972).

S. R. Hanna, G. A. Briggs, and R. P. Hosker. Handbook on Atmospheric Diffusion (DOE/TIC-11223). Technical Information Center: U.S. Department of Energy (1982).

G. Henidel, J. Clow, B. Inkret, and G. Miller. The Radiological Hazard of Plutonium Isotopes and Specific Plutonium Mixtures (LA-13011). Los Alamos, NM: Los Alamos National Laboratory (1995).

S. G. Homan. HOTSPOT Health Physics Code: Version 8.0. Livermore, CA: Lawrence Livermore National Laboratory (1985).

H. N. Jow, J. L. Sprung, J. A. Rollstin, L. T. Ritchie, D. I. Chanin. MELCOR Accident Consequence Code System (MACCS) (NUREG/CR--4691-Vol. 2). Washington, DC: United States Nuclear Regulatory Commission (1990).

R. E. Luna, and H.W. Church. DIFOUT: A Model for Computation of Aerosol Transport and Diffusion in the Atmosphere (SC-RR-68-555). Albuquerque, NM: Sandia National Laboratories (1969).

J. C. Maloney. Operation Roller Coaster: Air Sampling Measurements (POR-2502). Edgewood Arsenal, Maryland: U.S. Army Nuclear Defense Laboratory (1965).

J. Mishima. DOE HANDBOOK: Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities (DOE-HDBK-3010-94). Washington, DC: United States Department of Energy (1994).

B. R. Morton, G. Taylor, and J. S. Turner. Turbulent Gravitational Convection from Maintained and Instantaneous Sources. In Proceedings of the Royal Society of London: Series A. Mathematical and Physical Sciences: VOL 234. (pp. 1-23). Piccadilly, London: Royal Society (1956).

NRC Atmospheric Dispersion Models for Potential Accident Consequence Assessment at Nuclear Power Plants (Reg. Guide 1.145, Rev. 1). Washington, DC: Nuclear Regulatory Commission (1983).

J. D. Shreve. Operation Roller Coaster: A joint field operation of the Department of Defense, the Atomic Energy Commission, and the United Kingdom (DASA-1644). Washington, DC: Department of Defense (1965).

G. I. Taylor. Dynamics of a Mass of Hot Gas Rising in Air (USAEC Report MDDC-919). Los Alamos, NM: Los Alamos Scientific Laboratory (1948).

R. W. Titus. Operation Roller Coaster: Micro-Meteorological Measurements (U) (POR-2504). Las Vegas, NV: United States Weather Bureau Research Station (1965).

D. B. Turner. Workbook of Atmospheric Dispersion Estimates. (PB-191 482), Cincinnati, OH: U.S. Department of Health, Education and Welfare (1970).

K. J. Vogt. Empirical Investigations of the Diffusion of Waste Air Plumes in the Atmosphere.
Nuclear Technology, (Vol. 34), 43-57 (1977).

APPENDIX A

```

<ERADInputFile>
# Title monodisperse, 6kgPBX9501, 0.2 kg Pu
Plutonium BUOYANT RELEASE
# Release - detonation -> z, massex, hdet, mit, er, vcon, capf
detonation 0.00e+00 5.35e+01 4.27e+06 .false.
# Particle Size Distribution -> dmin, dmax, dgm, sigmax, sg
monodispe 1.00e+00 1.00e+00
# Meteorology -> z0, pa0, rh, zi, prate, nt, nu, flag
1.00e-01 101325 2.00e-01 1000 0.00e+00 18 18 agl
    1 7.00E+00 3.25E+02 4.00E+00
    2 7.00E+00 3.50E+02 5.20E+00
   10 7.02E+00 3.60E+02 5.40E+00
   20 7.043+00 3.70E+02 5.60E+00
   30 7.06E+00 3.75E+02 6.62E+00
   40 7.09E+00 3.70E+02 6.81E+00
   50 7.11E+00 3.50E+02 6.40E+00
   75 7.16E+00 3.56E+02 8.81E+00
  100 7.21E+00 3.45E+02 8.69E+00
  144 7.28E+00 3.43E+02 8.20E+00
  200 7.21E+00 3.40E+02 8.14E+00
  235 7.16E+00 3.36E+02 9.70E+00
  322 7.05E+00 3.36E+02 9.80E+00
  344 7.02E+00 3.36E+02 8.14E+00
  378 6.98E+00 3.36E+02 7.54E+00
  413 6.93E+00 3.57E+02 8.14E+00
  477 6.85E+00 3.75E+02 7.03E+00
  600 6.20E+00 3.75E+02 7.54E+00
# Grid -> nx, ny, xmin, xmax, ymin, ymax
100 100 -1.00e+02 1.40E+04 -3000.0 3000.00
# Monte Carlo -> nmc, drspm
10000 1.00e+01
# Source -> src, flag, br, sa, tox
0.20e+00 .true. 3.33e-04 8.10e-02 3.08e+08

```

Comment line
Comment line
Comment line

APPENDIX B

* GENERAL DESCRIPTIVE TITLE DESCRIBING THIS "ATMOS" INPUT

*

RIATNAM1001 'Julich,0.2kgPu

resp,118lbsTNT,RLLRCSTRBCHMRK,CR=53,CTH=247,CM=194'

* GEOMETRY DATA BLOCK, LOADED BY INPGEO, STORED IN /GEOM/

*

* NUMBER OF RADIAL SPATIAL ELEMENTS

*

GENUMRAD001 35

*

* endpoints of polar-coordinate radii (km)

* 1 2** 3 4** 5 6 7** 8 9** 10

GESPAEND001 0.100 0.200 0.331 0.431 0.55 0.712 0.812 0.95 1.05 1.15

* 11 12** 13 14** 15 16 17** 18 19** 20

GESPAEND002 1.25 1.35 1.474 1.574 1.70 2.236 2.336 2.998 3.098 3.912

* 21** 22 23 24** 25 26** 27 28** 29 30**

GESPAEND003 4.012 4.65 5.484 5.584 6.10 6.20 6.80 6.90 7.113 8.213

* 31 32 33** 34 35

GESPAEND004 8.400 10.618 10.718 11.05 11.45

* NUCLIDE DATA BLOCK, LOADED BY INPISO, STORED IN /ISOGRP/, /ISONAM/

*

* Number of pseudo-stable nuclides (used to truncate the decay chains)

*

ISNUMSTB001 11

*

* List of pseudo-stable nuclides

*

ISNAMSTB001 U-235 (daughter of Pu-239)

ISNAMSTB002 U-236 (daughter of Pu-240)

ISNAMSTB003 U-237 (daughter of Pu-241)

ISNAMSTB004 Np-237 (daughter of Am-241)

ISNAMSTB005 U-238 (daughter of Pu-242)

ISNAMSTB006 Th-234 (daughter of Pu-242)

ISNAMSTB007 Pa-234 (daughter of Pu-242)

ISNAMSTB008 Th-230

ISNAMSTB009 Ra-226

ISNAMSTB010 Rn-222

ISNAMSTB011 Po-218

*

* Number of radioactive nuclides to be considered

*

ISNUMISO001 7

*

* NUMBER OF NUCLIDE GROUPS


```

*
ISMAXGRP001 1
*
* WET AND DRY DEPOSITION FLAGS FOR EACH NUCLIDE GROUP
*
* WETDEP DRYDEP
*
ISDEPFLA001 .FALSE. .TRUE.
*
* NUCNAM IGROUP
ISOTPGRP001 Pu-238 1
ISOTPGRP002 U-234 1
ISOTPGRP003 Pu-239 1
ISOTPGRP004 Pu-240 1
ISOTPGRP005 Pu-241 1
ISOTPGRP006 Am-241 1
ISOTPGRP007 Pu-242 1
*****
*****
* WET DEPOSITION DATA BLOCK, LOADED BY INPWET, STORED IN /WETCON/
*
* WASHOUT COEFFICIENT NUMBER ONE, LINEAR FACTOR
*
WDCWASH1001 0.0 (washout is being turned off for comparison to F-Canyon EIS)
*
* WASHOUT COEFFICIENT NUMBER TWO, EXPONENTIAL FACTOR
*
WDCWASH2001 1.0
*****
*****
* DRY DEPOSITION DATA BLOCK, LOADED BY INPDY, STORED IN /DRYCON/
*
* NUMBER OF PARTICLE SIZE GROUPS
*
DDNPSGRP001 1
*
* DEPOSITION VELOCITY OF EACH PARTICLE SIZE GROUP (M/S)
*
DDVDEPOS001 0.01 (dry deposition is turned on)
*****
*****
* DISPERSION PARAMETER DATA BLOCK, LOADED BY INPDIS, STORED IN
/DISPY/, /DISPZ/
*
* SIGMA = A * X ** B
*
NUM_DIST001 0
*
* Slade Parameters for instantaneous (puff) releases as quoted by Turner (1994)
* "Atmospheric Dispersion Estimates"
*

```

*P-G CLASS:	A	B	C	D	E	F
*DPCYSIGA001	0.1800	0.1400	0.1000	0.0600	0.0450	0.0300
*DPCYSIGB001	0.9200	0.9200	0.9200	0.9200	0.9100	0.9000
*DPCZSIGA001	0.7200	0.5300	0.3400	0.1500	0.1200	0.0800
*DPCZSIGB001	0.7600	0.7300	0.7200	0.7000	0.6700	0.6400

*

* Tadmor and Gur Parameterization for Distance Range 0.5 to 5.0 km
 * as taken from Atmospheric Motion and Air Pollution (Dobbins 1979).

*

P-G CLASS:	A	B	C	D	E	F
DPCYSIGA001	0.3658	0.2751	0.2089	0.1474	0.1046	0.0722
DPCYSIGB001	0.9031	0.9031	0.9031	0.9031	0.9031	0.9031
DPCZSIGA001	2.5E-4	1.9E-3	0.2	0.3	0.4	0.2
DPCZSIGB001	2.125	1.6021	0.8543	0.6532	0.6021	0.6020

*

* Tadmor and Gur Parameterization for Distance Range 5 to 50 km as taken from
 Atmospheric Motion and Air Pollution (Dobbins 1979).

P-G CLASS:	A	B	C	D	E	F
DPCYSIGA001	0.3658	0.2751	0.2089	0.1474	0.1046	0.0722
DPCYSIGB001	0.9031	0.9031	0.9031	0.9031	0.9031	0.9031
DPCZSIGA001	0.5742	0.5742	0.5742	0.9605	2.1250	2.1820
DPCZSIGB001	0.7160	0.7160	0.7160	0.5409	0.3979	0.3310

An early parameterization of the "Julich" System for 50 m release height as taken from
 (Vogt 1977). (Note: reference only provides data for classes B-F)

THIS YIELDS BEST FIT!!!

P-G CLASS:	A	B	C	D	E	F
DPCYSIGA001	0.8685	0.8685	0.7184	0.6248	1.6910	5.3820
DPCYSIGB001	0.8097	0.8097	0.7837	0.7672	0.6211	0.5778
DPCZSIGA001	0.2222	0.2222	0.2149	0.2048	0.1616	0.3960
DPCZSIGB001	0.9680	0.9680	0.9438	0.9358	0.8094	0.6183

"Karlsruhe-Julich" System for 50 m release height as taken from (Panitz 1989).

P-G CLASS:	A	B	C	D	E	F
DPCYSIGA001	1.503	0.876	0.659	0.640	0.801	1.294
DPCYSIGB001	0.833	0.823	0.807	0.784	0.754	0.718
DPCZSIGA001	0.151	0.127	0.165	0.215	0.264	0.241
DPCZSIGB001	1.219	1.108	0.996	0.885	0.774	0.662

LINEAR SCALING FACTOR FOR SIGMA-Y FUNCTION, NORMALLY 1

DPYSCALE001 1.

LINEAR SCALING FACTOR FOR SIGMA-Z FUNCTION,
NORMALLY USED FOR SURFACE ROUGHNESS LENGTH CORRECTION.
(Z1 / Z0) ** 0.2, FROM CRAC2 WE HAVE (10 CM / 3 CM) ** 0.2 = 1.27

DPZSCALE001 1.27225 (Z=10 cm; (10/3)^.2=1.27225 for surface roughness)

* EXPANSION FACTOR DATA BLOCK, LOADED BY INPEXP, STORED IN
/EXPAND/

*

* TIME BASE FOR EXPANSION FACTOR (SECONDS)

PMTIMBAS001 3600.0

(Pg2-17NUREG/CR-4691-Vol.2 states that both theoretical
(and experimental studies indicate that as sampling
(measurement times increase, the peak plume concentrations
(for continuous plume concentrations measures at a fixed
(distance decrease due to plume meander. The reference
(further states that for puff releases (which this is)
(the release duration may be equated to the sampling time
(so for a puff release, the increase in effective plume
(dimensions with release time can be modeled in MACCS2 for
(a puff release. In the case of a static model of an
(explosive release such as this, the actual release is
(already over so the TIMBAS constant could be set to
(its minimum value of 60 seconds. However this code
(Capability was not used in the DT benchmark
(Or in any open air shot consequence calculations)

* BREAK POINT FOR FORMULA CHANGE (SECONDS)

*

PMBRKPNT001 3600.00 (1 HOUR)

*

* EXPONENTIAL EXPANSION FACTOR NUMBER 1

*

PMXPFAC1001 0.2

*

* EXPONENTIAL EXPANSION FACTOR NUMBER 2

*

PMXPFAC2001 0.25

* PLUME RISE DATA BLOCK, LOADED BY INPLRS, STORED IN /PLUMRS/

*

* SCALING FACTOR FOR THE CRITICAL WIND SPEED FOR ENTRAINMENT OF
A BOUYANT PLUME

* (USED BY FUNCTION CAUGHT)

*

PRSCLCRW001 1.

*

* SCALING FACTOR FOR THE A-D STABILITY PLUME RISE FORMULA

* (USED BY FUNCTION PLMRIS)

*

PRSCCLADP001 1.

*

* SCALING FACTOR FOR THE E-F STABILITY PLUME RISE FORMULA

* (USED BY FUNCTION PLMRIS)

*

PRSCLEFP001 1.

* RELEASE DATA BLOCK, LOADED BY INPREL, STORED IN /ATNAM2/,
/MULREL/

*

RDATNAM2001 "Plutonium exp dispersal Bench Mark 1kgPu,118 lbs TNT Equivalent,'

*

* TIME AFTER ACCIDENT INITIATION WHEN THE ACCIDENT REACHES
GENERAL EMERGENCY

* CONDITIONS (AS DEFINED IN NUREG-0654), OR WHEN PLANT PERSONNEL
CAN RELIABLY

* PREDICT THAT GENERAL EMERGENCY CONDITIONS WILL BE ATTAINED

*

RDOALARM001 0.

*

* NUMBER OF PLUME SEGMENTS THAT ARE RELEASED

*

RDNUMREL001 1

*

* SELECTION OF RISK DOMINANT PLUME

*

RDMAXRIS001 1

*

* REFERENCE TIME FOR DISPERSION AND RADIOACTIVE DECAY

*

RDREFTIM001 0.00

*

* HEAT CONTENT OF THE RELEASE SEGMENTS (W)

* A VALUE SPECIFIED FOR EACH OF THE RELEASE SEGMENTS

*

RDPLHEAT001 0.00

*

* HEIGHT OF THE PLUME SEGMENTS AT RELEASE (M)

* A VALUE SPECIFIED FOR EACH OF THE RELEASE SEGMENTS:

*

RDPLHITE001 194.46 (Eff plum hght=CTH-Cloud Radius-Major Plume)

* $=75*(118)^{(1/4)}-CR$

*

* DURATION OF THE PLUME SEGMENTS (S)

* A VALUE SPECIFIED FOR EACH OF THE RELEASE SEGMENTS

*

RDPLUDUR001 600.

*

* TIME OF RELEASE FOR EACH PLUME (S AFTER SCRAM)

* A VALUE SPECIFIED FOR EACH OF THE RELEASE SEGMENTS

*

RDPDELAY001 0.0

*

* Initial value of sigma-y
 * with version 1.11: a value must be specified for each of the release segments
 *
 SIGYINIT001 52.73 (16*(118)^(1/4))
 *
 * Initial value of sigma-z
 * with version 1.11: a value must be specified for each of the release segments
 *
 SIGZINIT001 52.73 (16*(118)^(1/4))
 *
 * BUILDING HEIGHT (meters) This is now just used for plume rise entrainment
 * with version 1.11: a value must be specified for each of the release segments
 *
 WEBUILDH001 1.0
 *
 * PARTICLE SIZE DISTRIBUTION OF EACH NUCLIDE GROUP
 * YOU MUST SPECIFY A COLUMN OF DATA FOR EACH OF THE PARTICLE SIZE GROUPS
 *
 RDPSDIST001 1.
 *
 * NUCNAM CORINV (Curies)
 RDCORINV001 Pu-238 1.338E+0 (3 year old mixture designed to give)
 RDCORINV002 U-234 1.171E-5 (SA=0.81067 Ci/g to be used in ERAD)
 RDCORINV003 Pu-239 1.161E+1 (comparison and to do benchmark work)
 RDCORINV004 Pu-240 2.735E+0 (using alpha onle controbution)
 RDCORINV005 Pu-241 0.000E+0 (Pu-241 contribution therfore removed)
 RDCORINV006 Am-241 5.343E-1 (scaled to 0.2*1kg=200g)
 RDCORINV007 Pu-242 3.142E-4
 *
 * SCALING FACTOR TO ADJUST THE CORE INVENTORY
 *
 RDCORSCA001 3.7E10 (convert Curies to Becquerels)
 *
 RDAPLFRC001 PARENT (apply release fractions the same as MACCS2)
 *
 RDRELFRC001 1.00 (cloud top)

 * OUTPUT CONTROL DATA BLOCK, LOADED BY INPOPT, STORED IN /STOPME/, /ATMOPT/
 *
 * FLAG TO INDICATE THAT THIS IS THE LAST PROGRAM IN THE SERIES TO BE RUN
 *
 OCENDAT1001 .FALSE. (SET THIS VALUE TO .TRUE. TO SKIP EARLY AND CHRONC)
 *
 OCIDEBUG001 -1 (signifying that the code does not print out the 1000 odd lines of out giving the day and hour of each start time)
 *
 * NAME OF THE NUCLIDE TO BE LISTED ON THE DISPERSION LISTINGS
 *
 OCNUCOUT001 Pu-239

```

* NUM0
TYPE0NUMBER 35
*
* INDREL INDRAD
TYPE0OUT001 1 1
TYPE0OUT002 1 2
TYPE0OUT003 1 3
TYPE0OUT004 1 4
TYPE0OUT005 1 5 (this block controls air concentration printout)
TYPE0OUT006 1 6
TYPE0OUT007 1 7
TYPE0OUT008 1 8
TYPE0OUT009 1 9
TYPE0OUT010 1 10 (INDRAD IS THE NUMBER CORRESPONDING TO THE
DISTANCE)
TYPE0OUT011 1 11 (SET UO IN ATMOS)
TYPE0OUT012 1 12
TYPE0OUT013 1 13
TYPE0OUT014 1 14
TYPE0OUT015 1 15
TYPE0OUT016 1 16 (this block controls air concentration printout)
TYPE0OUT017 1 17
TYPE0OUT018 1 18
TYPE0OUT019 1 19
TYPE0OUT020 1 20
TYPE0OUT021 1 21
TYPE0OUT022 1 22
TYPE0OUT023 1 23
TYPE0OUT024 1 24
TYPE0OUT025 1 25
TYPE0OUT026 1 26
TYPE0OUT027 1 27 (this block controls air concentration printout)
TYPE0OUT028 1 28
TYPE0OUT029 1 29
TYPE0OUT030 1 30
TYPE0OUT031 1 31
TYPE0OUT032 1 32
TYPE0OUT033 1 33
TYPE0OUT034 1 34
TYPE0OUT035 1 35
*****
*****
* METEOROLOGICAL SAMPLING DATA BLOCK
*
* METEOROLOGICAL SAMPLING OPTION CODE:
*
* METCOD = 1, USER SPECIFIED DAY AND HOUR IN THE YEAR (FROM MET
FILE),
* 2, WEATHER CATEGORY BIN SAMPLING,
* 3, 120 HOURS OF WEATHER SPECIFIED ON THE ATMOS USER INPUT FILE,
* 4, CONSTANT MET (BOUNDARY WEATHER USED FROM THE START),
* 5, STRATIFIED RANDOM SAMPLES FOR EACH DAY OF THE YEAR.
*
M1METCOD001 4

```

*
 * LAST SPATIAL INTERVAL FOR MEASURED WEATHER
 *
 M2LIMSPA001 35
 *
 * BOUNDARY WEATHER MIXING LAYER HEIGHT
 *
 M2BNDMXH001 1000. (METERS)
 *
 * BOUNDARY WEATHER STABILITY CLASS INDEX
 *
 M2IBDSTB001 4 (D-STABILITY)
 *
 * BOUNDARY WEATHER RAIN RATE
 *
 M2BNDRAN001 0. (MM/HR)
 *
 * BOUNDARY WEATHER WIND SPEED at 10 m
 *
 M2BNDWND001 5.4 (M/S)
 *
 * NUMBER OF RAIN DISTANCE INTERVALS FOR BINNING
 *
 M4NRNINT001 1 (turns rain down to minimum)
 *
 * ENDPOINTS OF THE RAIN DISTANCE INTERVALS (KILOMETERS)
 *
 * NOTE: THESE MUST BE CHOSEN TO MATCH THE SPATIAL ENDPOINT
 DISTANCES
 * SPECIFIED FOR THE ARRAY SPAEND (10 % ERROR IS ALLOWED).
 *
 M4RNDSTS001 0.56 0.8 1.5 2.0 (chosen for the MEI distance range)
 *
 * NUMBER OF RAIN INTENSITY BREAKPOINTS
 *
 M4NRINTN001 2 (2=min)
 *
 * RAIN INTENSITY BREAKPOINTS FOR WEATHER BINNING (MILLIMETERS
 PER HOUR)
 *
 M4RNRATE001 1. 2.
 *
 * NUMBER OF SAMPLES PER BIN
 *
 M4NSMPLS001 24 (increased from the 4 of NUREG-1150 to 24, maximum value
 allowed)
 *
 * INITIAL RANDOM SEED
 *
 M4IRSEED001 13
 M3ISTRDY001 1
 M3ISTRHR001 1.

APPENDIX C

Calculation of total time dependent specific dose, specific activity, and dose conversion factors for an example weapons grade plutonium mixture as identified in unclassified reports LA-13011 and LA-12486-MS and in LLNL Hotspot Code.

$$N_2(t, T_1, T_2, N_1) = \left[\frac{\frac{N_1}{T_1}}{\left(\frac{1}{T_2} - \frac{1}{T_1} \right)} \right] \left(e^{-\frac{\ln(2) \cdot t}{T_1}} - e^{-\frac{\ln(2) \cdot t}{T_2}} \right)$$

Compound decay of isotope with parameters (T1, N1) to daughter (N2) with parameters (T2) then to a final isotope with a long half life relative to the daughter (or a stable third isotope). T1=half-life of parent, T2=half-life of daughter, N1=original amount of parent

$$N_1(t, T, N_{10}) = N_{10} \cdot e^{-\frac{\ln(2) \cdot t}{T}} \quad \text{decay equation} \quad NA = 6.022136736 \cdot 10^{23} \text{ Avogadro \#}$$

$$w_{238} = 0.0004 \quad w_{234} = 0.0 \quad w_{239} = 0.9334 \quad w_{240} = .06 \quad wp_{241} = 0.0058 \quad wa_{241} = 0.$$

$$w_{242} = .0004 \quad w_{244} = 0.00$$

$$\text{norm} = w_{238} + w_{234} + w_{239} + w_{240} + wp_{241} + wa_{241} + w_{242} + w_{244}$$

$$\text{norm} = 1$$

Mass Fraction Check

$$pu_{238}(t) = N_1(t, 87.74, w_{238})$$

Pu ₀	w ₂₃₈	Pu-238 mass fraction at t=0 for weapons grade pu	$u_{234}(t) = N_2(t, 87.74, 2.445 \cdot 10^5, w_{238})$
	w ₂₃₄	U-234 mass fraction at time t=0 decay product of Pu-238	$pu_{239}(t) = N_1(t, 2.4065 \cdot 10^4, w_{239})$
	w ₂₃₉	Pu-239 mass fraction at t=0	
	w ₂₄₀	Pu-240 mass fraction at t=0	$pu_{240}(t) = N_1(t, 6538, w_{240}) + N_2(t, 8.26 \cdot 10^7, 6537, w_{244})$
	wp ₂₄₁	Pu-241 mass fraction at t=0	$pu_{241}(t) = N_1(t, 14.4, wp_{241})$
	wa ₂₄₁	Am-241 mass fraction at t=0, decay product of Pu-241	$am_{241}(t) = N_2(t, 14.4, 432.2, wp_{241})$
	w ₂₄₂	Pu-242 mass fraction at t=0	$pu_{242}(t) = N_1(t, 3.763 \cdot 10^5, w_{242})$
	w ₂₄₄	Pu-244 mass fraction at t=0	$pu_{244}(t) = N_1(t, 8.26 \cdot 10^7, w_{244})$

$$SA(T, A)$$

$$\frac{\ln(2) \cdot NA}{T \cdot 365 \cdot 24 \cdot 60^2 \cdot A} \cdot 3.7 \cdot 10^{10}$$

Specific activity (Ci/g), T in years, A=atomic number

$$SA_{pu} = \begin{bmatrix} SA(87.74, 238.049553) \\ SA(2.445 \cdot 10^5, 234.040945) \\ SA(2.4065 \cdot 10^4, 239.052156) \\ SA(6537, 240.053808) \\ SA(14.4, 241.0568) \\ SA(432.2, 241.056822) \\ SA(3.763 \cdot 10^5, 242.058737) \\ SA(8.26 \cdot 10^7, 244.06420) \end{bmatrix}$$

$$Pu(t) = \begin{bmatrix} pu_{238}(t) \\ u_{234}(t) \\ pu_{239}(t) \\ pu_{240}(t) \\ pu_{241}(t) \\ am_{241}(t) \\ pu_{242}(t) \\ pu_{244}(t) \end{bmatrix}$$

pu mass fractions as a function of time (yrs)

From a health physics point of view, if the release that is predicted is given in mass of material, the most bounding number to be used will come from consideration of the product of the specific activity and the dose conversion factor. This is because the specific activity is used in conjunction with the mass to arrive at the activity which is then converted to a dose using the dose conversion factor.

$$V(x) = (P_u(x) \cdot SA)_{pu} \cdot DCF$$

$$DCF = 10^4 \text{ dose conversion factor in rem/Ci}$$

$$k = 1.8$$

$$P_u(0) =$$

0
0.0004
0
0.0058
0.06
0.9334
0
0.0004

DCF

2.88
1.32
3.08
3.08
0.496
4.44
2.93
2.89

Dose Conversion Factors
(NACCS2 and USEPA-420/1-88
-826, 1988)

SA_{pu}

17.1278457
0.0062517
0.0621855
0.2279716
103.0589855
3.4337095
0.0039275
1.7745311 · 10 ⁻⁵

Pu-238
U-234
Pu-239
Pu-240
Pu-241
Am-241
Pu-242
Pu-244

$$SD_{mix}(t) \frac{d}{dt} SD_{mix}(t)$$

$$t = 80$$

Given
Given value (used in years)

$$SD_{mix}(t) = 0$$

$$t = \text{Find}(t)$$

t = 51.59697
time in years that specific dose is maintained for material

$$j = 0, 1, \dots, 10$$

$$SD_{mix}(t) = 3.126 \cdot 10^7 \text{ rem/g}$$

$$M = 1000$$

Mass of Pu mix (g)

$$SD_{mix}(0) = 2.703 \cdot 10^7 \text{ rem/g}$$

$$SD_{mix}(1) = 2.729 \cdot 10^7 \text{ rem/g}$$

$$SD_{mix}(j)$$

$2.70288 \cdot 10^7$
$2.72882 \cdot 10^7$
$2.75341 \cdot 10^7$
$2.77672 \cdot 10^7$
$2.79879 \cdot 10^7$
$2.8197 \cdot 10^7$
$2.8395 \cdot 10^7$
$2.85824 \cdot 10^7$
$2.87597 \cdot 10^7$
$2.89273 \cdot 10^7$
$2.90859 \cdot 10^7$

rem/g

$$CK(t) = (M \cdot Pu(t) \cdot SA_{pu})$$

$$CK(55.0) =$$

4.44
$8.81 \cdot 10^{-4}$
$5.8 \cdot 10^1$
$1.36 \cdot 10^1$
$4.23 \cdot 10^1$
$1.74 \cdot 10^1$
$1.57 \cdot 10^{-3}$
0

Pu-238

U-234

Pu-239

Pu-240

Pu-241

Am-241

Pu-242

Pu-244

CI equivalent of M kg

$$SA_{mix}(t) = Pu(t) \cdot SA_{pu} \text{ mix specific activity (Ci/g)}$$

$$DCF_{mix}(t) = Pu(t) \cdot DCF \text{ mix dose conversion factor (rem/Ci)}$$

$$dSA_{mix}(t) = \frac{d}{dt} SA_{mix}(t)$$

$$t = 10$$

guess value (used in years)

Given

$$dSA_{mix}(t) = 0$$

t Find(t)

$$t = 3.0989 \cdot 10^7 \quad \text{time in years that specific activity is maximum}$$

$$SA_{mix}(t) = 0 \quad \text{maximum specific activity of Pu mix used}$$

SD_{mix}(j)

2.70288 · 10 ⁷
2.72882 · 10 ⁷
2.75341 · 10 ⁷
2.77672 · 10 ⁷
2.79879 · 10 ⁷
2.8197 · 10 ⁷
2.8395 · 10 ⁷
2.85824 · 10 ⁷
2.87597 · 10 ⁷
2.89273 · 10 ⁷
2.90859 · 10 ⁷

t=0 years

Specific Dose (rem/g)

t=10 years

SA_{mix}(j)

0.67632
0.6491
0.62317
0.59844
0.57488
0.55242
0.53101
0.5106
0.49115
0.47261
0.45494

t=0 years

Specific activity (Ci/g)

t=10 years

APPENDIX D

Calculation of alpha-only time-dependent specific dose, specific activity, and dose conversion factors for an example weapons grade plutonium mixture as identified in unclassified reports LA-13011 and LA-12846-MS and in LLNL Hotspot Code.

$$N_2(t, T_1, T_2, N_1) = \left(\frac{N_1}{T_1} \right) \left(\frac{1}{T_2} \right) \left(e^{-\frac{\ln(2)t}{T_1}} - e^{-\frac{\ln(2)t}{T_2}} \right)$$

Compound decay of isotope with parameters (T1,N1) to daughter (N2) with parameters (T2) then to a final isotope with a long half life relative to the daughter (or a stable third isotope). T1=half-life of parent, T2=half-life of daughter, N1=original amount of parent

$$N_1(t, T, N_{10}) = N_{10} e^{-\frac{\ln(2)t}{T}} \quad \text{decay equation} \quad NA = 6.022136736 \cdot 10^{23} \text{ Avogadro \#}$$

w238 0.0004 w234 0.0 w239 0.9334 w240 0.06 wp241 0.0058 wa241 0

w242 .0004 w244 0.00

norm w238 + w234 + w239 + w240 + wp241 + wa241 + w242 + w244

norm = 1

Mass Fraction Check

pu238(t) = N₁(t, 87.74, w238)

w238	Pu-238 mass fraction at t=0 for weapons grade pu	u234(t) = N ₂ (t, 87.74, 2.445·10 ⁵ , w238)
w234	U-234 mass fraction at time t=0 decay product of Pu-238	pu239(t) = N ₁ (t, 2.4065·10 ⁴ , w239)
w239	Pu-239 mass fraction at t=0	
w240	Pu-240 mass fraction at t=0	pu240(t) = N ₁ (t, 6538, w240) + N ₂ (t, 8.26·10 ⁷ , 6537, w244)
wp241	Pu-241 mass fraction at t=0	pu241(t) = N ₁ (t, 14.4, wp241)
wa241	Am-241 mass fraction at t=0, decay product of Pu-241	am241(t) = N ₂ (t, 14.4, 432.2, wp241)
w242	Pu-242 mass fraction at t=0	pu242(t) = N ₁ (t, 3.763·10 ⁵ , w242)
w244	Pu-244 mass fraction at t=0	pu244(t) = N ₁ (t, 8.26·10 ⁷ , w244)

$$SA(T, A) = \frac{\ln(2) \cdot NA}{T \cdot 365 \cdot 24 \cdot 60^2 \cdot A} \cdot 3.7 \cdot 10^{10}$$

Specific activity (Ci/g), T in years, A=atomic number

SA _{pu}	SA(87.74, 238.049553)
	SA 2.445·10 ⁵ , 234.040945
	SA 2.4065·10 ⁴ , 239.052156
	SA(6537, 240.053808)
	0
	SA(432.2, 241.056822)
	SA 3.763·10 ⁵ , 242.058737
	SA 8.26·10 ⁷ , 244.06420

Note: Pu-241 contribution set to zero

Pu(t)	pu238(t)
	u234(t)
	pu239(t)
	pu240(t)
	0
	am241(t)
	pu242(t)
	pu244(t)

Pu mass fractions as a function of time (yrs), note the Pu-241 beta contribution has been set to zero, but the contribution to the production of Am-241 is still calculated from the t=0 initial amount of Pu-241

Pu(0) =	0.0004	DCF	2.88	Dose Conversion Factors (MACCS2, and USEPA-626/1-88 -626, 1988), note DCF for Pu-241 not to zero	SA _{pu} =	17.1278457	Pu-238
	0		1.32			0.0062517	U-234
	0.9334		3.08			0.0621855	Pu-239
	0.06		3.08			0.2279716	Pu-240
	0		0			0	Pu-241
	0		4.44			3.4337095	Am-241
	0.0004		2.93			0.0039275	Pu-242
	0		.289			1.7745311·10 ⁻⁵	Pu-244

DCF DCF·10⁸ dose conversion factors in rem/Ci

k = 1..8

$$v(x) = (Pu(x) \cdot SA_{pu} \cdot DCF)$$

From a health physics phone modeling perspective, if the release that is postulated is given in mass of material, the most bounding number to be used will evolve from consideration of the product of the specific activity and the dose conversion factor. This is because the specific activity is used in conjunction with the mass to arrive at the activity which is then converted to a dose using the dose conversion factor.

$$SD_{mix}(t) = \sum_{k=1}^8 v(t)_k \quad \text{mix mass Specific Dose (rem/g)} \quad z = 0, 1..200$$

$$dSD_{mix}(t) = \frac{d}{dt} SD_{mix}(t)$$

t = 80 guess value (used in years)

Given

$$dSD_{mix}(t) = 0$$

t Find(t)

t = 60.5 time in years that ALPHA-ONLY specific dose is maximized for material

j = 0, 1, ..., 10

$$SD_{mix}(t) = 3.106 \cdot 10^7 \text{ rem/g}$$

M = 1000

Mass of Pu mix (g)

$$SD_{mix}(0) = 2.406 \cdot 10^7 \text{ rem/g}$$

$SD_{mix}(j)$

$2.4064 \cdot 10^7$
$2.44628 \cdot 10^7$
$2.48414 \cdot 10^7$
$2.5201 \cdot 10^7$
$2.55424 \cdot 10^7$
$2.58664 \cdot 10^7$
$2.61739 \cdot 10^7$
$2.64657 \cdot 10^7$
$2.67424 \cdot 10^7$
$2.70049 \cdot 10^7$
$2.72538 \cdot 10^7$

rem/g

$$C(t) = \frac{M \cdot Pu(t) \cdot SA_{pu}}{SA_{mix}(t)}$$

$C(55.0) =$

4.44
$8.81 \cdot 10^{-4}$
$5.8 \cdot 10^1$
$1.36 \cdot 10^1$
0
$1.74 \cdot 10^1$
$1.57 \cdot 10^{-3}$
0

Pu-238

U-234

Pu-239

Pu-240

Pu-241

Am-241

Pu-242

Pu-244

Cl equivalent of M kg

$$SA_{mix}(t) = Pu(t) \cdot SA_{pu} \text{ mix ALPHA-ONLY specific activity (Ci/g)}$$

$$DCF_{mix}(t) = Pu(t) \cdot DCF \text{ mix ALPHA-ONLY dose conversion factor (rem/Ci)}$$

$$dSA_{mix}(t) = \frac{d}{dt} SA_{mix}(t)$$

t = 10

guess value (seed in years)

Given

$$dSA_{mix}(t)=0$$

t Find(t)

t = 55.61317 time in years that specific activity is maximum

SA_{mix}(t) = 0.09339 maximum specific activity of Pu mix used

SD_{mix}(j)

2.4064 · 10 ⁷
2.44628 · 10 ⁷
2.48414 · 10 ⁷
2.5201 · 10 ⁷
2.55424 · 10 ⁷
2.58664 · 10 ⁷
2.61739 · 10 ⁷
2.64657 · 10 ⁷
2.67424 · 10 ⁷
2.70049 · 10 ⁷
2.72538 · 10 ⁷

t=0 years

Mix specific dose (rem/g) over j years

t=10 years

SA_{mix}(j)

0.07857
0.07945
0.08029
0.08108
0.08183
0.08254
0.08321
0.08385
0.08445
0.08502
0.08557

t=0 years

Mix Specific activity over j years

t=10 years

APPENDIX E

0 year old weapons grade Pu used in paper (from HOTSPOT mix) @ T=0
normalized to 1 kg respirable Pu in air @ 1.0 um particle size (Sv)

MEAN	50th	90th	95th	99th	99.5th	RANGE (Km)
0.1158	0.0794	0.2442	0.4392			0.05
0.4475	0.3167	0.9333	1.7333			0.15
0.6033	0.4267	1.4167	1.9500			0.25
0.6158	0.4375	1.4500	1.9583			0.35
0.5742	0.3950	1.3000	1.8667			0.45
0.5208	0.3617	1.0667	1.4417			0.55
0.4692	0.3325	0.9750	1.2583			0.65
0.4233	0.2992	0.9167	1.1833			0.75
0.3842	0.2775	0.7950	1.0917			0.85
0.3500	0.2667	0.7058	0.9000			0.95
0.2858	0.1967	0.5433	0.7233	1.2083		1.20
0.2183	0.1375	0.4417	0.5858	0.9417	1.2917	1.60
0.1625	0.1050	0.3283	0.4375	0.7108	0.8333	2.00
0.1283	0.0801	0.2792	0.3642	0.5167	0.5817	2.50
0.1058	0.0671	0.2475	0.3067	0.4500	0.4925	3.00
0.0875	0.0599	0.1942	0.2517	0.3567	0.4142	3.50
0.0745	0.0488	0.1733	0.2042	0.3192	0.3975	4.00
0.0650	0.0413	0.1417	0.1825	0.2725	0.3617	4.50
0.0568	0.0328	0.1183	0.1542	0.2608	0.3375	5.00
0.0507	0.0294	0.1100	0.1392	0.2058	0.2350	5.50
0.0452	0.0263	0.1008	0.1233	0.1925	0.2292	6.00
0.0412	0.0229	0.0950	0.1142	0.1733	0.2117	6.50
0.0371	0.0210	0.0892	0.1058	0.1567	0.1925	7.00
0.0335	0.0190	0.0768	0.0933	0.1367	0.1608	7.50
0.0311	0.0171	0.0699	0.0867	0.1450	0.1742	8.00
0.0289	0.0159	0.0649	0.0798	0.1383	0.1692	8.50
0.0268	0.0151	0.0619	0.0743	0.1242	0.1575	9.00
0.0248	0.0139	0.0601	0.0702	0.1100	0.1375	9.50
0.0233	0.0131	0.0556	0.0668	0.0950	0.1083	10.00
0.0217	0.0128	0.0487	0.0603	0.0883	0.1008	10.50
0.0203	0.0120	0.0455	0.0541	0.0753	0.0867	11.00
0.0190	0.0115	0.0438	0.0511	0.0660	0.0718	11.50
0.0181	0.0106	0.0425	0.0473	0.0611	0.0687	12.00
0.0172	0.0095	0.0401	0.0460	0.0599	0.0678	12.50
0.0162	0.0093	0.0394	0.0449	0.0553	0.0628	13.00

2-3 km

DOSE FOUND AT (R,THETA) LOCATION (Sv)

		DIR	RANGE	PROB	MEAN DOSE	90th DOSE	95th DOSE	99th DOSE	99.5th DOSE
Compass Sector	1	(N)	0.25 km	0.3034	1.60E-01	5.43E-01	7.60E-01	1.80E+00	2.23E+00
Compass Sector	2	(NNE)	0.25 km	0.3570	1.51E-01	5.28E-01	7.35E-01	1.63E+00	2.00E+00
Compass Sector	3	(NE)	0.25 km	0.3831	1.25E-01	4.38E-01	6.62E-01	1.54E+00	1.95E+00
Compass Sector	4	(ENE)	0.25 km	0.3741	1.05E-01	3.44E-01	6.00E-01	1.57E+00	1.88E+00
Compass Sector	5	(E)	0.25 km	0.3719	9.98E-02	3.08E-01	5.54E-01	1.57E+00	2.03E+00
Compass Sector	6	(ESE)	0.25 km	0.3685	1.00E-01	3.10E-01	5.64E-01	1.57E+00	1.91E+00
Compass Sector	7	(SE)	0.25 km	0.3433	9.42E-02	2.80E-01	5.74E-01	1.50E+00	1.89E+00
Compass Sector	8	(SSE)	0.25 km	0.2980	8.79E-02	2.13E-01	5.85E-01	1.55E+00	1.93E+00
Compass Sector	9	(S)	0.25 km	0.2268	8.79E-02	2.08E-01	6.16E-01	1.57E+00	1.96E+00
Compass Sector	10	(SSW)	0.25 km	0.1704	9.21E-02	2.78E-01	6.36E-01	1.62E+00	1.99E+00
Compass Sector	11	(SW)	0.25 km	0.1474	9.42E-02	2.79E-01	6.36E-01	1.73E+00	2.18E+00
Compass Sector	12	(WSW)	0.25 km	0.1402	9.83E-02	2.59E-01	6.47E-01	1.89E+00	2.43E+00
Compass Sector	13	(W)	0.25 km	0.1431	1.07E-01	3.09E-01	6.88E-01	1.98E+00	2.54E+00
Compass Sector	14	(WNW)	0.25 km	0.1670	1.20E-01	4.15E-01	7.24E-01	2.04E+00	2.59E+00
Compass Sector	15	(NW)	0.25 km	0.1998	1.32E-01	4.70E-01	7.60E-01	2.11E+00	2.63E+00
Compass Sector	16	(NNW)	0.25 km	0.2514	1.47E-01	5.23E-01	7.60E-01	2.09E+00	2.64E+00

5-.6km

DOSE FOUND AT (R,THETA) LOCATION (Sv)

		DIR	RANGE	PROB	MEAN DOSE	90th DOSE	95th DOSE	99th DOSE	99.5th DOSE
Compass Sector	1	(N)	0.55 km	0.2736	1.05E-01	3.63E-01	5.33E-01	1.24E+00	1.51E+00
Compass Sector	2	(NNE)	0.55 km	0.2941	1.05E-01	3.58E-01	5.43E-01	1.17E+00	1.42E+00
Compass Sector	3	(NE)	0.55 km	0.2959	9.05E-02	3.04E-01	4.86E-01	1.15E+00	1.45E+00
Compass Sector	4	(ENE)	0.55 km	0.3078	7.97E-02	2.78E-01	4.40E-01	1.08E+00	1.31E+00
Compass Sector	5	(E)	0.55 km	0.3313	7.92E-02	2.44E-01	4.07E-01	1.13E+00	1.53E+00
Compass Sector	6	(ESE)	0.55 km	0.3394	8.07E-02	2.58E-01	4.21E-01	1.09E+00	1.36E+00
Compass Sector	7	(SE)	0.55 km	0.3088	7.66E-02	2.65E-01	4.36E-01	1.09E+00	1.37E+00
Compass Sector	8	(SSE)	0.55 km	0.2324	6.78E-02	2.06E-01	4.25E-01	1.13E+00	1.40E+00
Compass Sector	9	(S)	0.55 km	0.1626	6.47E-02	1.87E-01	4.39E-01	1.15E+00	1.43E+00
Compass Sector	10	(SSW)	0.55 km	0.1455	6.47E-02	1.87E-01	4.43E-01	1.16E+00	1.42E+00
Compass Sector	11	(SW)	0.55 km	0.1316	6.10E-02	1.59E-01	4.19E-01	1.18E+00	1.48E+00
Compass Sector	12	(WSW)	0.55 km	0.1216	6.00E-02	1.20E-01	3.95E-01	1.26E+00	1.62E+00
Compass Sector	13	(W)	0.55 km	0.1311	6.41E-02	1.40E-01	4.19E-01	1.29E+00	1.64E+00
Compass Sector	14	(WNW)	0.55 km	0.1544	7.04E-02	2.40E-01	4.38E-01	1.33E+00	1.69E+00
Compass Sector	15	(NW)	0.55 km	0.1683	7.76E-02	2.74E-01	4.64E-01	1.36E+00	1.68E+00
Compass Sector	16	(NNW)	0.55 km	0.2155	9.00E-02	3.16E-01	4.97E-01	1.36E+00	1.70E+00

9-1.0

DOSE FOUND AT (R,THETA) LOCATION (Sv)

		DIR	RANGE	PROB	MEAN DOSE	90th DOSE	95th DOSE	99th DOSE	99.5th DOSE
Compass Sector	1	(N)	0.95 km	0.2428	5.28E-02	1.70E-01	2.81E-01	6.67E-01	8.54E-01
Compass Sector	2	(NNE)	0.95 km	0.2570	5.54E-02	1.74E-01	3.05E-01	6.67E-01	8.69E-01
Compass Sector	3	(NE)	0.95 km	0.2803	5.28E-02	1.48E-01	2.87E-01	7.09E-01	9.88E-01
Compass Sector	4	(ENE)	0.95 km	0.2986	5.11E-02	1.52E-01	3.10E-01	6.21E-01	8.33E-01
Compass Sector	5	(E)	0.95 km	0.3262	5.23E-02	1.37E-01	2.49E-01	6.98E-01	1.07E+00
Compass Sector	6	(ESE)	0.95 km	0.3336	5.38E-02	1.49E-01	2.79E-01	6.31E-01	8.79E-01
Compass Sector	7	(SE)	0.95 km	0.3040	5.28E-02	1.55E-01	3.16E-01	6.73E-01	9.36E-01
Compass Sector	8	(SSE)	0.95 km	0.2268	4.30E-02	1.21E-01	2.42E-01	6.78E-01	9.11E-01
Compass Sector	9	(S)	0.95 km	0.1496	3.82E-02	1.09E-01	2.28E-01	6.83E-01	9.31E-01
Compass Sector	10	(SSW)	0.95 km	0.1258	3.47E-02	1.01E-01	2.13E-01	6.57E-01	9.16E-01
Compass Sector	11	(SW)	0.95 km	0.1083	3.03E-02	5.54E-02	1.93E-01	6.10E-01	8.23E-01
Compass Sector	12	(WSW)	0.95 km	0.0966	2.84E-02		1.77E-01	6.31E-01	8.38E-01
Compass Sector	13	(W)	0.95 km	0.0924	2.94E-02		1.92E-01	6.31E-01	8.07E-01
Compass Sector	14	(WNW)	0.95 km	0.1033	3.16E-02	6.31E-02	2.01E-01	6.47E-01	8.28E-01
Compass Sector	15	(NW)	0.95 km	0.1341	3.59E-02	1.12E-01	2.16E-01	6.47E-01	7.97E-01
Compass Sector	16	(NNW)	0.95 km	0.1870	4.34E-02	1.41E-01	2.44E-01	6.47E-01	8.07E-01

2.0km

DOSE FOUND AT (R,THETA) LOCATION (Sv)

		DIR	RANGE	PROB	MEAN DOSE	90th DOSE	95th DOSE	99th DOSE	99.5th DOSE
Compass Sector	1	(N)	2 km	0.2389	1.61E-02	5.01E-02	8.79E-02	2.33E-01	3.25E-01
Compass Sector	2	(NNE)	2 km	0.2470	1.89E-02	5.38E-02	1.06E-01	3.00E-01	4.02E-01
Compass Sector	3	(NE)	2 km	0.2413	2.06E-02	4.53E-02	1.07E-01	3.99E-01	5.02E-01
Compass Sector	4	(ENE)	2 km	0.2533	2.44E-02	6.00E-02	1.29E-01	3.96E-01	4.89E-01
Compass Sector	5	(E)	2 km	0.3053	2.56E-02	6.73E-02	1.17E-01	3.93E-01	4.98E-01
Compass Sector	6	(ESE)	2 km	0.3164	2.78E-02	7.40E-02	1.31E-01	3.91E-01	4.87E-01
Compass Sector	7	(SE)	2 km	0.2597	2.75E-02	6.93E-02	1.52E-01	4.18E-01	5.23E-01
Compass Sector	8	(SSE)	2 km	0.1804	1.90E-02	4.14E-02	9.98E-02	4.04E-01	4.99E-01
Compass Sector	9	(S)	2 km	0.1315	1.57E-02	3.15E-02	8.07E-02	3.82E-01	4.75E-01
Compass Sector	10	(SSW)	2 km	0.1182	1.20E-02	2.75E-02	6.52E-02	2.61E-01	3.64E-01
Compass Sector	11	(SW)	2 km	0.1022	9.00E-03	1.36E-02	5.23E-02	1.89E-01	2.94E-01
Compass Sector	12	(WSW)	2 km	0.0934	7.50E-03	4.42E-02	1.52E-01	2.67E-01	
Compass Sector	13	(W)	2 km	0.0914	7.60E-03	4.91E-02	1.47E-01	2.44E-01	
Compass Sector	14	(WNW)	2 km	0.1029	7.97E-03	2.01E-02	5.13E-02	1.43E-01	2.35E-01
Compass Sector	15	(NW)	2 km	0.1333	9.00E-03	2.96E-02	5.54E-02	1.47E-01	2.30E-01
Compass Sector	16	(NNW)	2 km	0.1848	1.18E-02	3.85E-02	6.67E-02	1.69E-01	2.62E-01

3.0km

DOSE FOUND AT (R,THETA) LOCATION (Sv)

		DIR	RANGE	PROB	MEAN DOSE	90th DOSE	95th DOSE	99th DOSE	99.5th DOSE
Compass Sector	1	(N)	3 km	0.2305	8.33E-03	2.37E-02	4.75E-02	1.26E-01	1.86E-01
Compass Sector	2	(NNE)	3 km	0.2299	1.01E-02	2.50E-02	5.79E-02	1.75E-01	2.74E-01
Compass Sector	3	(NE)	3 km	0.2074	1.16E-02	1.62E-02	6.31E-02	2.75E-01	3.44E-01
Compass Sector	4	(ENE)	3 km	0.2201	1.53E-02	3.73E-02	9.11E-02	2.78E-01	3.41E-01
Compass Sector	5	(E)	3 km	0.2534	1.67E-02	5.23E-02	9.21E-02	2.70E-01	3.44E-01
Compass Sector	6	(ESE)	3 km	0.2661	1.85E-02	5.79E-02	1.04E-01	2.75E-01	3.41E-01
Compass Sector	7	(SE)	3 km	0.2200	1.78E-02	4.79E-02	1.14E-01	2.92E-01	3.64E-01
Compass Sector	8	(SSE)	3 km	0.1385	1.14E-02	1.18E-02	6.73E-02	2.82E-01	3.48E-01
Compass Sector	9	(S)	3 km	0.1131	9.31E-03	7.35E-03	5.08E-02	2.67E-01	3.34E-01
Compass Sector	10	(SSW)	3 km	0.1059	6.47E-03	5.95E-03	3.04E-02	1.48E-01	2.24E-01
Compass Sector	11	(SW)	3 km	0.0976	4.64E-03		2.26E-02	1.09E-01	1.57E-01
Compass Sector	12	(WSW)	3 km	0.0907	3.75E-03		1.90E-02	8.23E-02	1.36E-01
Compass Sector	13	(W)	3 km	0.0894	3.86E-03		2.32E-02	7.97E-02	1.26E-01
Compass Sector	14	(WNW)	3 km	0.1011	4.05E-03	5.64E-03	2.55E-02	7.71E-02	1.23E-01
Compass Sector	15	(NW)	3 km	0.1308	4.54E-03	1.19E-02	2.77E-02	8.07E-02	1.22E-01
Compass Sector	16	(NNW)	3 km	0.1813	5.95E-03	1.61E-02	3.39E-02	9.42E-02	1.38E-01

4.0km

DOSE FOUND AT (R,THETA) LOCATION (Sv)

		DIR	RANGE	PROB	MEAN DOSE	90th DOSE	95th DOSE	99th DOSE	99.5th DOSE
Compass Sector	1	(N)	4 km	0.2304	5.23E-03	1.30E-02	3.04E-02	8.33E-02	1.26E-01
Compass Sector	2	(NNE)	4 km	0.2298	6.52E-03	1.40E-02	3.84E-02	1.23E-01	1.81E-01
Compass Sector	3	(NE)	4 km	0.2074	7.71E-03	8.90E-03	4.19E-02	1.80E-01	2.30E-01
Compass Sector	4	(ENE)	4 km	0.2199	1.09E-02	2.68E-02	6.41E-02	1.99E-01	2.41E-01
Compass Sector	5	(E)	4 km	0.2533	1.23E-02	3.68E-02	7.55E-02	1.86E-01	2.30E-01
Compass Sector	6	(ESE)	4 km	0.2660	1.38E-02	4.45E-02	8.54E-02	1.91E-01	2.36E-01
Compass Sector	7	(SE)	4 km	0.2198	1.29E-02	3.36E-02	8.74E-02	2.07E-01	2.52E-01
Compass Sector	8	(SSE)	4 km	0.1383	7.92E-03	5.69E-03	4.51E-02	1.87E-01	2.38E-01
Compass Sector	9	(S)	4 km	0.1129	6.36E-03	3.57E-03	3.17E-02	1.72E-01	2.23E-01
Compass Sector	10	(SSW)	4 km	0.1056	4.18E-03	2.73E-03	1.67E-02	1.02E-01	1.55E-01
Compass Sector	11	(SW)	4 km	0.0973	2.88E-03		1.15E-02	6.67E-02	9.83E-02
Compass Sector	12	(WSW)	4 km	0.0903	2.28E-03		9.57E-03	5.38E-02	8.28E-02
Compass Sector	13	(W)	4 km	0.0889	2.37E-03		1.20E-02	5.38E-02	7.81E-02
Compass Sector	14	(WNW)	4 km	0.1008	2.49E-03	2.20E-03	1.36E-02	5.28E-02	7.76E-02
Compass Sector	15	(NW)	4 km	0.1305	2.80E-03	5.90E-03	1.58E-02	5.54E-02	7.86E-02
Compass Sector	16	(NNW)	4 km	0.1811	3.69E-03	8.17E-03	2.07E-02	6.36E-02	9.05E-02

5.0km

DOSE FOUND AT (R,THETA) LOCATION (Sv)

		DIR	RANGE	PROB	MEAN DOSE	90th DOSE	95th DOSE	99th DOSE	99.5th DOSE
Compass Sector	1	(N)	5 km	0.1736	3.63E-03	8.59E-03	2.04E-02	6.00E-02	9.83E-02
Compass Sector	2	(NNE)	5 km	0.1651	4.62E-03	9.88E-03	2.63E-02	9.78E-02	1.58E-01
Compass Sector	3	(NE)	5 km	0.1431	5.59E-03	5.23E-03	2.91E-02	1.55E-01	1.83E-01
Compass Sector	4	(ENE)	5 km	0.1672	8.17E-03	1.80E-02	4.51E-02	1.60E-01	1.89E-01
Compass Sector	5	(E)	5 km	0.2013	9.52E-03	2.64E-02	6.31E-02	1.58E-01	1.88E-01
Compass Sector	6	(ESE)	5 km	0.2207	1.08E-02	3.25E-02	6.93E-02	1.62E-01	1.92E-01
Compass Sector	7	(SE)	5 km	0.1771	9.78E-03	2.36E-02	6.47E-02	1.66E-01	1.96E-01
Compass Sector	8	(SSE)	5 km	0.1043	5.90E-03	2.03E-03	3.15E-02	1.62E-01	1.90E-01
Compass Sector	9	(S)	5 km	0.0833	4.68E-03		2.05E-02	1.54E-01	1.81E-01
Compass Sector	10	(SSW)	5 km	0.0802	2.96E-03		1.18E-02	7.45E-02	1.28E-01
Compass Sector	11	(SW)	5 km	0.0748	1.97E-03		7.50E-03	4.68E-02	7.50E-02
Compass Sector	12	(WSW)	5 km	0.0731	1.53E-03		6.26E-03	3.76E-02	6.16E-02
Compass Sector	13	(W)	5 km	0.0791	1.61E-03		7.60E-03	3.84E-02	5.95E-02
Compass Sector	14	(WNW)	5 km	0.0905	1.69E-03		8.59E-03	3.79E-02	5.90E-02
Compass Sector	15	(NW)	5 km	0.1118	1.91E-03	3.38E-03	9.88E-03	4.07E-02	6.16E-02
Compass Sector	16	(NNW)	5 km	0.1393	2.51E-03	5.33E-03	1.41E-02	4.75E-02	7.09E-02

6.0km

DOSE FOUND AT (R,THETA) LOCATION (Sv)

		DIR	RANGE	PROB	MEAN DOSE	90th DOSE	95th DOSE	99th DOSE	99.5th DOSE
Compass Sector	1	(N)	6 km	0.1743	2.81E-03	6.00E-03	1.62E-02	5.12E-02	8.64E-02
Compass Sector	2	(NNE)	6 km	0.1660	3.59E-03	6.73E-03	1.93E-02	8.28E-02	1.20E-01
Compass Sector	3	(NE)	6 km	0.1443	4.26E-03	3.66E-03	2.03E-02	1.14E-01	1.39E-01
Compass Sector	4	(ENE)	6 km	0.1682	6.31E-03	1.34E-02	3.19E-02	1.24E-01	1.44E-01
Compass Sector	5	(E)	6 km	0.2024	7.50E-03	1.96E-02	5.64E-02	1.21E-01	1.44E-01
Compass Sector	6	(ESE)	6 km	0.2217	8.54E-03	2.26E-02	6.26E-02	1.24E-01	1.47E-01
Compass Sector	7	(SE)	6 km	0.1784	7.55E-03	1.79E-02	5.59E-02	1.28E-01	1.50E-01
Compass Sector	8	(SSE)	6 km	0.1056	4.51E-03	1.52E-03	2.10E-02	1.20E-01	1.45E-01
Compass Sector	9	(S)	6 km	0.0844	3.60E-03		1.49E-02	1.12E-01	1.37E-01
Compass Sector	10	(SSW)	6 km	0.0810	2.30E-03		8.59E-03	6.31E-02	1.06E-01
Compass Sector	11	(SW)	6 km	0.0752	1.53E-03		5.28E-03	3.61E-02	6.26E-02
Compass Sector	12	(WSW)	6 km	0.0734	1.20E-03		4.33E-03	2.84E-02	4.80E-02
Compass Sector	13	(W)	6 km	0.0792	1.27E-03		5.15E-03	2.93E-02	4.57E-02
Compass Sector	14	(WNW)	6 km	0.0907	1.32E-03		5.90E-03	2.89E-02	4.47E-02
Compass Sector	15	(NW)	6 km	0.1119	1.50E-03	2.30E-03	7.19E-03	3.19E-02	4.71E-02
Compass Sector	16	(NNW)	6 km	0.1398	1.96E-03	3.75E-03	1.09E-02	3.81E-02	5.33E-02

7.0km

DOSE FOUND AT (R,THETA) LOCATION (Sv)

		DIR	RANGE	PROB	MEAN DOSE	90th DOSE	95th DOSE	99th DOSE	99.5th DOSE
Compass Sector	1	(N)	7 km	0.1741	2.26E-03	5.23E-03	1.21E-02	4.41E-02	6.52E-02
Compass Sector	2	(NNE)	7 km	0.1658	2.88E-03	5.74E-03	1.45E-02	6.26E-02	9.05E-02
Compass Sector	3	(NE)	7 km	0.1440	3.42E-03	2.59E-03	1.53E-02	8.69E-02	1.14E-01
Compass Sector	4	(ENE)	7 km	0.1679	5.04E-03	1.06E-02	2.41E-02	9.98E-02	1.17E-01
Compass Sector	5	(E)	7 km	0.2022	6.10E-03	1.37E-02	4.95E-02	1.01E-01	1.18E-01
Compass Sector	6	(ESE)	7 km	0.2214	6.98E-03	1.57E-02	5.59E-02	1.04E-01	1.19E-01
Compass Sector	7	(SE)	7 km	0.1782	6.10E-03	1.27E-02	5.09E-02	1.06E-01	1.22E-01
Compass Sector	8	(SSE)	7 km	0.1053	3.60E-03	1.06E-03	1.55E-02	9.98E-02	1.18E-01
Compass Sector	9	(S)	7 km	0.0842	2.89E-03		1.07E-02	8.54E-02	1.13E-01
Compass Sector	10	(SSW)	7 km	0.0809	1.84E-03		6.88E-03	5.38E-02	7.76E-02
Compass Sector	11	(SW)	7 km	0.0751	1.23E-03		4.30E-03	2.98E-02	5.33E-02
Compass Sector	12	(WSW)	7 km	0.0733	9.67E-04		3.27E-03	2.41E-02	4.02E-02
Compass Sector	13	(W)	7 km	0.0792	1.02E-03		4.40E-03	2.59E-02	3.82E-02
Compass Sector	14	(WNW)	7 km	0.0907	1.07E-03		5.28E-03	2.59E-02	3.75E-02
Compass Sector	15	(NW)	7 km	0.1119	1.21E-03	1.59E-03	6.05E-03	2.75E-02	3.98E-02
Compass Sector	16	(NNW)	7 km	0.1396	1.57E-03	2.71E-03	8.33E-03	3.15E-02	4.73E-02

8.0km

DOSE FOUND AT (R,THETA) LOCATION (Sv)

		DIR	RANGE	PROB	MEAN DOSE	90th DOSE	95th DOSE	99th DOSE	99.5th DOSE
Compass Sector	1	(N)	8 km	0.1731	1.86E-03	4.27E-03	9.83E-03	3.66E-02	5.79E-02
Compass Sector	2	(NNE)	8 km	0.1646	2.39E-03	4.97E-03	1.18E-02	5.64E-02	7.04E-02
Compass Sector	3	(NE)	8 km	0.1425	2.80E-03	2.05E-03	1.20E-02	6.73E-02	8.74E-02
Compass Sector	4	(ENE)	8 km	0.1666	4.15E-03	6.88E-03	2.16E-02	7.81E-02	9.78E-02
Compass Sector	5	(E)	8 km	0.2008	5.16E-03	1.04E-02	4.24E-02	7.92E-02	9.88E-02
Compass Sector	6	(ESE)	8 km	0.2200	5.90E-03	1.28E-02	4.90E-02	8.17E-02	1.00E-01
Compass Sector	7	(SE)	8 km	0.1766	5.04E-03	9.11E-03	4.04E-02	8.28E-02	1.04E-01
Compass Sector	8	(SSE)	8 km	0.1035	2.91E-03	6.73E-04	1.16E-02	7.19E-02	9.36E-02
Compass Sector	9	(S)	8 km	0.0828	2.34E-03		7.55E-03	6.57E-02	8.59E-02
Compass Sector	10	(SSW)	8 km	0.0795	1.50E-03		5.59E-03	4.81E-02	6.47E-02
Compass Sector	11	(SW)	8 km	0.0742	9.83E-04		3.39E-03	2.65E-02	4.74E-02
Compass Sector	12	(WSW)	8 km	0.0728	7.60E-04		2.36E-03	1.84E-02	3.20E-02
Compass Sector	13	(W)	8 km	0.0788	8.02E-04		3.46E-03	1.95E-02	3.12E-02
Compass Sector	14	(WNW)	8 km	0.0902	8.48E-04		4.13E-03	1.94E-02	3.14E-02
Compass Sector	15	(NW)	8 km	0.1115	9.47E-04	1.13E-03	5.17E-03	2.17E-02	3.18E-02
Compass Sector	16	(NNW)	8 km	0.1388	1.27E-03	1.96E-03	6.78E-03	2.78E-02	3.79E-02

9.0km

DOSE FOUND AT (R,THETA) LOCATION (Sv)

		DIR	RANGE	PROB	MEAN DOSE	90th DOSE	95th DOSE	99th DOSE	99.5th DOSE
Compass Sector	1	(N)	9 km	0.1713	1.61E-03	3.71E-03	8.12E-03	3.40E-02	5.48E-02
Compass Sector	2	(NNE)	9 km	0.1636	2.06E-03	4.02E-03	1.02E-02	5.28E-02	6.52E-02
Compass Sector	3	(NE)	9 km	0.1418	2.38E-03	1.66E-03	1.02E-02	6.21E-02	7.97E-02
Compass Sector	4	(ENE)	9 km	0.1659	3.56E-03	5.90E-03	1.74E-02	7.24E-02	9.36E-02
Compass Sector	5	(E)	9 km	0.2001	4.46E-03	8.59E-03	3.83E-02	7.14E-02	9.00E-02
Compass Sector	6	(ESE)	9 km	0.2192	5.13E-03	1.04E-02	4.13E-02	7.40E-02	9.31E-02
Compass Sector	7	(SE)	9 km	0.1759	4.33E-03	7.55E-03	3.65E-02	7.71E-02	9.93E-02
Compass Sector	8	(SSE)	9 km	0.1028	2.45E-03	4.44E-04	9.47E-03	6.62E-02	8.59E-02
Compass Sector	9	(S)	9 km	0.0821	1.98E-03		5.79E-03	6.16E-02	7.86E-02
Compass Sector	10	(SSW)	9 km	0.0786	1.28E-03		4.40E-03	4.00E-02	5.95E-02
Compass Sector	11	(SW)	9 km	0.0730	8.43E-04		2.61E-03	2.09E-02	3.99E-02
Compass Sector	12	(WSW)	9 km	0.0712	6.52E-04		2.01E-03	1.59E-02	2.64E-02
Compass Sector	13	(W)	9 km	0.0769	6.93E-04		2.55E-03	1.65E-02	2.59E-02
Compass Sector	14	(WNW)	9 km	0.0879	7.29E-04		3.53E-03	1.65E-02	2.58E-02
Compass Sector	15	(NW)	9 km	0.1091	8.17E-04	9.78E-04	4.07E-03	1.75E-02	2.69E-02
Compass Sector	16	(NNW)	9 km	0.1369	1.10E-03	1.66E-03	5.59E-03	2.20E-02	3.47E-02