Technical Dialogue

A Dirty Bomb Release Example: Cesium 137

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A van containing conventional explosives is detonated causing considerable blast damage. One ounce of radioactive isotope Cesium 137 was mixed in with the explosive, which is dispersed as a very fine dust into the atmosphere. The dust cloud is carried downwind. Assuming a wind speed of 20 mph, what radiation exposure might be expected if a person is caught in the dust cloud traveling downwind?

This question was submitted to AristaTek, Inc. by someone going through hypothetical training scenarios relating to terrorist treats. The NOVA documentary on dirty bombs aired on public television late February 2003 also covered this subject

Cesium 137

Cesium 137 is a radioactive isotope with a half-life of 30.3 years. Each disintegration results in emission of a beta particle of maximum energy of 1.176 MeV and gamma ray energy of 0.66164 MeV. The daughter isotope is Barium 137, which is stable. These disintegrations and associated energies are a signature of Cesium 137 which enable the isotope to be identified by radiation detection equipment in case of a release to the environment. The radiation activity of Cesium 137 is 86.6912 curies per gram. The number 137 means that the cesium nucleus contains 55 protons plus 82 neutrons (55 + 82 = 137); this nucleus is unstable. One of the neutrons disintegrates forming a proton (which remains in the nucleus) and an electron-like particle (called a beta particle) with release of gamma ray energy. The beta particle is ejected from the atom.

Cesium 137 is used by the food industry for food radiation. It is also used in industrial radiography. A terrorist would probably use cesium 137 in the form of cesium chloride which is a fine powder like talc and is easily dispersed. The former Soviet Union is believed to have produced a considerable quantity of cesium 137.

Modeling the Dust Cloud

We will make an assumption that all of the Cesium 137 is scooped up in the dust cloud resulting from the explosion, and that this dust cloud travels downwind. In practice, some Cesium 137 will remain near the source, and some will fall out onto the ground as the dust cloud travels downwind. If the dust is fine enough, the dust will behave similar to a gas or vapor released suddenly. Depending upon atmospheric conditions, the dust can travel a long way. Some of the atmospheric particulates seen on the west coast of North America originated in China, for example. Eventually the dust will settle or deposit with precipitation.

To describe the dust cloud, we will use one of the Gaussian Puff models applicable for a “D” atmospheric stability. The basic Gaussian puff (“instaneous”) equation calculating the centerline concentration is

$$C = [\ Q/((2)^{1/2}\ \pi^{3/2}\ \sigma_x\ \sigma_y\ \sigma_z\ )]$$

where C = dust cloud centerline concentration

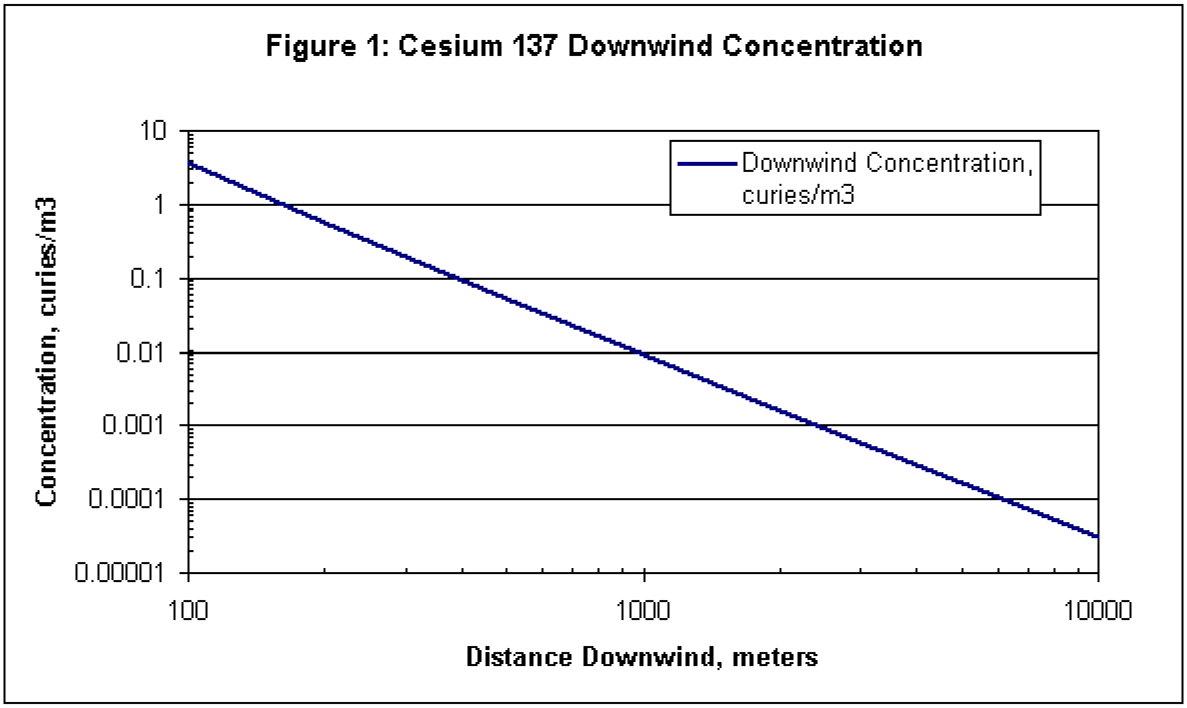
σ_x = standard deviation of the dust cloud concentration in the downwind direction

σ_y = standard deviation of the dust cloud concentration in the cross wind direction

σ_z = standard deviation of the dust cloud concentration in the vertical direction

We will express concentration in units of "curies per cubic meter", Cu/m^3 . One ounce of Cesium 137 is equivalent to 28.35(86.6912) = 2457.7 curies. This is the value of Q. The "sigmas" (σ_x , σ_y , σ_z) are empirical expressions which are a function of downwind distance X and each have units of meters. There are several different expressions for the sigmas in the literature, but we will use the ones listed in the following reference:

Spicer, T.O., and J.A. Havens, "Users Guide for DEGADIS 2.1" U.S. Environmental Protection Agency, Report EPA-450/4-89-019. ALOHA uses the DEGADIS dense gas portion described in this user's guide.



A plot of the centerline downwind concentration predicted from modeling is shown in figure 1.

However it is the radiation dose that is of most interest. We need to know the duration of the dust cloud. If concentration is plotted against time at any given location, theoretically a "bell-shaped" curve results, that is, the concentration increases as the dust starts to pass over a location, reaches some maximum, and then decreases. Figure 1 is a plot of the maximum concentration as a function of distance using a 18.3 second time average. To calculate the dust cloud duration, we need to know centerline concentrations as the cloud approaches and recedes. The calculation is,

$C = [\ Q/((2)^{1/2}\ \pi^{3/2}\ \sigma_x\ \sigma_y\ \sigma_z\ )]\ F$

where $F = \exp[0.5((X - Ut)/\sigma_x\ )^2\ ]$

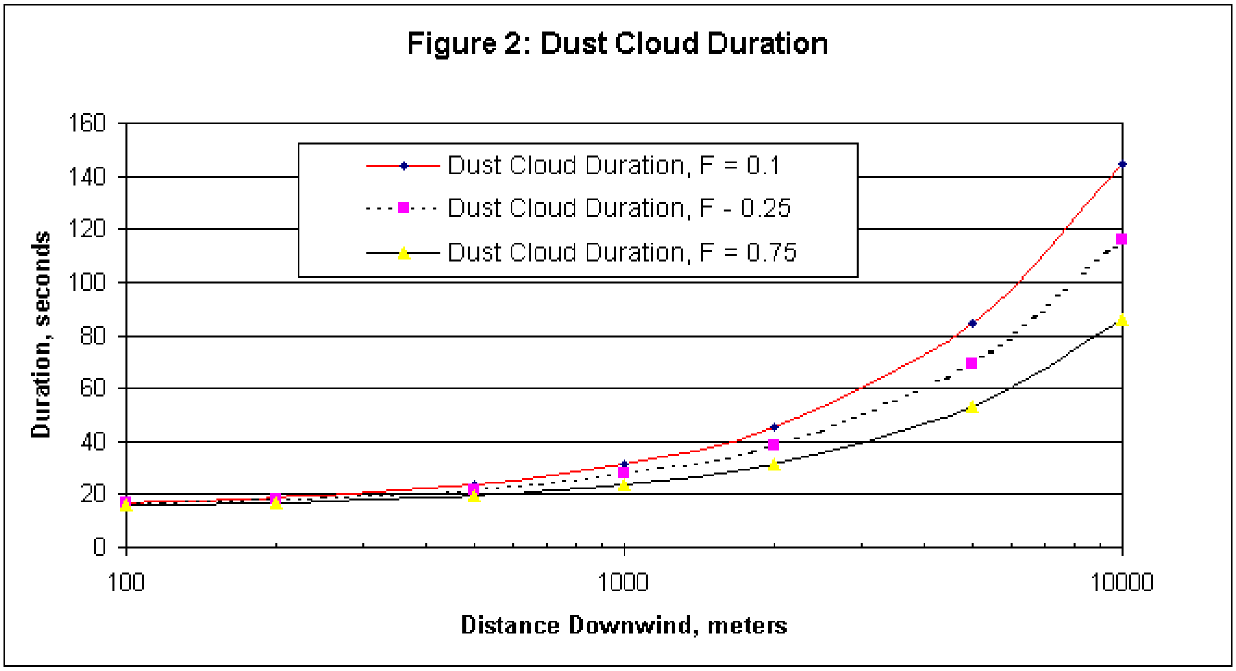
X = downwind distance, meters

U = wind speed, meters/second (20 mph = 8.943 m/s)

t = time, seconds

$\sigma_x = 0.068X^{0.9}$, the sigma expression used here

Note that when X = Ut, F = 1 which is the distance to the center of the dust cloud as it travels downwind. When the dust cloud concentration is one-fourth of the center concentration, F = 0.25. We will make a series of plots for F = 0.5, F= 0.25, and F = 0.1 where the dust cloud duration is plotted as a function of distance X downwind (figure 2). We will assume that the initial dust cloud leaving the site of the explosion lasts 15 seconds, and because of air turbulence, the dust cloud spreads out as it travels downwind. F = 0.1 means that this is the cloud duration where concentrations are between 10% and 100% of the maximum value (figure 1), F = 0.25 means the duration between 25% and 100% of the maximum concentration value.



A word of caution is required. If the initial explosion is big or if there is a fire, the initial dust cloud behavior will be different. The dust cloud duration would be much greater but downwind concentrations might be less. Tests at the Nevada Test Center (the "Kit Fox Series performed in 1995) where carbon dioxide was released in a series of 15-second puffs showed that local micrometeorology greatly influenced the cloud behavior is it traveled downwind, and that the cloud had a trailing end (i.e., it took longer for the cloud to clear out than what models predicted). It is our opinion that the model underpredicts the dust cloud duration.

Radiation Dose

We will consider the radiation dose from three sources:

- Inhaling the dust as the dust cloud passes by
- Whole body radiation from the dust cloud as it passes by
- Radiation from dust that may adhere to the body and clothing

We will not consider radiation from ingestion of food or water.

1. Inhalation:

Inhalation is particularly insidious because cesium 137 continues to undergo radioactive disintegration producing energetic beta particles and gamma radiation within the human body. These beta particles and gamma radiation ionize body tissues; if severe enough, death can occur within months from radiation burns. Even low doses of radiation have the potential for causing cancer later in life.

The U.S. Nuclear Regulatory Commission has established that inhalation of 200 microcuries of Cesium 137 results in 5 rem exposure. Numbers are also published for other radioactive isotopes in 10 CFR Part 20 Appendix B. The 5 rem exposure is the maximum annual exposure allowed for a worker who may be in contact with radioactive isotope. Lower limits are recommended for the young and for pregnant women. Assuming that the rem exposure is proportional to the microcuries inhaled, a radiation dose by inhalation might be estimated from figures 1 and 2. A normal resting breathing rate is 20 liters/minute.

Table 1. Estimated Radiation Dose from Inhaling Cesium 137 in Dust Cloud

Distance Downwind, meters	Peak Concentration in Cloud, $\mu Ci/m^3$	Cesium 137 inhaled, μCi	Radiation dose, Rem
100	3619000	21700	543
200	572000	3600	90
50	53400	360	9
1000	8900	100	2.5
2000	1550	20	0.5
5000	163	3.8	0.1
10000	30.5	1	0.025

The radiation dose by inhalation start to become significant for distances less than 1000 meters. The calculations suggest that a person located less than about 150 or 200 meters away might receive a fatal dose, but remember, that these are idealized calculations. Some of the Cesium 137 might remain at the source or a person may be lucky and escape breathing in most of the radioactive dust.

2. Whole body radiation from the dust cloud as it passes by:

There are two sources of ionizing radiation. One is from penetrating beta particles and the other is gamma radiation. Each disintegration of a Cesium 137 atom produces one beta particle of kinetic energy of 1.176 MeV and one gamma ray of energy 0.66164 MeV. A beta particle with this energy can travel a distance of 1.12 meters in air or can pass through 0.2 inches of body tissue, even if protected by clothing. Gamma rays can theoretically travel an infinite distance but gamma radiation drops off according to the square of the distance of the source.

We will make several assumptions here to come up with a rough estimate of the dose a standing adult might receive as the dust cloud passes, excluding inhalation. We will ignore quality factor and modifying factor adjustments so that the absorbed dose expressed in "rads" is the same as the dose equivalent expressed in "rems". Only the dust cloud that is within one meter of the person contributes significantly to the absorbed dose. Beta particles outside this one meter envelope can't travel to the person and penetrate the person's skin, and gamma radiation from Cesium 137 more than 1 meter away will be less than from the gamma radiation up close. We will imagine the person standing in the center of a dust cloud cylinder 2 meters in diameter and 2.8 meters high. Roughly 9 % of the beta emissions within this cylinder will be impact the human (the other 91% fly out of the cylinder envelope or impact the ground).

The calculation for gamma radiation is rather complex. It involves calculation of a photon flux (units: photons/m^2-hr) and converting to a radiation exposure at the photon energy of 0.662 MeV, and calculation of the dose for the duration of the cloud. The results are summarized in table 2.

Table 2. Estimated Radiation Dose from External Exposure to Cesium 137 as Dust Cloud Passes By

Distance Downwind, meters	Peak Concentration in Cloud, μCu/m^3	Estimated Beta Radiation Dose, Rem	Estimated Gamma Radiation Dose, Rem
100	3619000	0.03	5.6
200	572000	0.005	0.9
500	53400	<0.005	0.1
1000	8900	<0.005	0.02
2000	1550	<0.005	0.005
5000	163	<0.005	<0.005
10000	30.5	<0.005	<0.005

The passage of the dust cloud at 20 mph does not impart as much of a radiation dose because the exposure time is short. This is in contrast to the exposure resulting from inhaling cesium 137, which has a half-life of 30.2 years.

3. Radiation from dust that adheres to skin and clothing:

This is the most difficult of all to estimate. In addition, Cesium 137 dust clinging moving vehicles and people will contaminate otherwise clean areas. The dust that clings to a person's skin and clothing will continue to radiate beta particles and gamma radiation. In addition, the person may breathe some of the dust. Food and water may become contaminated. Even only 0.01 grams (10 milligrams) of Cesium 137 dust clinging to a person's skin and clothing might result in say 60 rem/hr of radiation exposure to the person.

What Radiation Dose is Safe?

The dose from normal background radiation for a non-smoker is about 0.15 to 0.2 rem/year. A person living at a high elevation (7000 to 10000 feet) might add another 0.06 to 0.12 rem/year. Excessive radon gas in the home will also boost this number (up to perhaps 0.4 rem/year). Smoking increases radiation exposure to target organs (up to 8 rem/year to bronchial epithelium of the respiratory tract).

The threshold for lethality from radiation exposure depends whether the risk for developing cancer later in life is considered. If cancer is not considered, the threshold of lethality for acute radiation exposure for the more sensitive individuals appears to be about 200 rems whole body radiation. Death is almost certain at 1000 rem dose for all individuals, even though the person may not initially feel any initial discomfort (death occurs perhaps a week or two later). The lowest radiation dose that will result in cancer many years later in life is a subject of dispute, but the NOVA documentary on dirty bombs aired on public television in February 2003 suggested an eight times normal background (15 rem dose) results in an increased one in five chance of developing cancer later in life.

The U.S. Nuclear Regulatory Commission recommends (see 10 CFR Part 20) a maximum radiation exposure of 5 rem/year for adult radiation workers and 0.1 rem/year for the general public including children. These radiation exposure numbers are above normal background.

The U.S. National Council on Radiation Protection recommends a maximum dose of 100 rem to an older person (45 years or older) engaged in emergency lifesaving operations. This radiation dose is accumulative; the person can't engage in another activity which results in a dose of 100 rem in an incident months later.

The logic of permitting a higher radiation dose for older people is that their cell division rate is lower and less likely to develop cancer from the incident during their remaining lifetime. This is also a debatable topic.

What can we learn from this analysis?

- An analysis of this type is difficult to do because of the many unknowns (such as dust cloud duration and how much dust will settle). There are really no good experimental tests (at least not available in the public domain) where models can be calibrated and assumptions verified.
- Major radiation exposure concerns are confined to within one kilometer of the explosion, at least for this hypothetical explosion.

- We do not want to breathe the radioactive dust and we don't want the dust to settle on our person or clothing. This is how the greatest exposure occurs.
- We don't want to track the dust around.

What action should be taken if an explosion occurs?

There is no way of knowing whether a suspected terrorist explosion has been seeded with radioactive isotopes. If remnants of lead shielding are seen at the site, radioactive isotopes probably are present. Use of radiation detection equipment is essential before approaching any site where an incident has occurred.

If an explosion has occurred, efforts must be made to avoid breathing in dust. Respirators designed to screen out fine particulates is essential. Unless there is danger of fire or collapsing buildings, probably the general public should be sheltered in place (inside homes and buildings). If excessive radiation is present in the dust cloud, the public should remain in place until the dust cloud has passed and an orderly evacuation can occur. Efforts must be made to keep the dust outside the buildings and homes by avoiding traffic in and out and sealing up doors and vents. The media has made fun of "duct tape and plastic sheeting", but this is serious business. When the public is evacuated, it may be necessary to send people through a decontamination station to remove dust on skin and clothing.

The original one ounce container of cesium 137 would also be very dangerous. One ounce of unshielded cesium 137 would impart a gamma radiation dose of approximately 1000 rem/hr to a person only one meters away. At 10 meters away, the unshielded radiation dose would be about 10 rem/hr. A terrorist setting this material up would be "fried" unless the material were adequately shielded with lead.