Technical Dialogue

Dirty Bombs

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What is a Dirty Bomb?

The events of September 11, 2001, have demonstrated the need to protect the civilian population against terrorist attack. One method terrorists might use is the detonation of a dirty bomb, that is, the use of conventional explosives to disperse dangerous radioactive materials over a wide area. A dirty bomb is not the only way a terrorist may disperse radioactive materials. Other ways might be the actual detonation of a nuclear devise, crashing an aircraft into a nuclear power plant, or by blowing up a place where radioactive materials are stored or transported. Fortunately, nuclear power plants have various safety devices and backup systems, and radioactive materials being transported should have ample containerization to withstand an explosion and fire; this means that release of radioactive materials by blowing up a transport truck would be very difficult (but not impossible) to do. A more likely method chosen by terrorist might be to steal radioactive material and attach the material to an explosive devise. This way the widest possible contamination can take place using a minimum amount of material.

The next sections present some basic information about radioactive material. This information is essential in planning a response to a dirty bomb detonation, and as a reminder, that there is some natural (background) radioactivity present everywhere.

What is Radioactive Material?

All physical material on planet earth is made up of atoms. The atoms can combine with other atoms to form various chemical compounds, i.e., the whole physical world around us. An atom is made up of a central nucleus surrounded by electrons. The nucleus is made up of protons and neutrons. The nucleus of the atom hydrogen, for example, has only one proton and no neutrons; the hydrogen atom also has one electron. Hydrogen gas is made up of two atoms of hydrogen, sometimes written as H_2 (H for Hydrogen and 2 meaning there are two atoms of Hydrogen). The helium nucleus, for example, contains two protons and two neutrons; this nucleus is surrounded by two electrons. Protons are positively charged and electrons are negatively charged; neutrons do not have any charge but may be thought of like a glue that keeps the protons from flying apart.

About 98.89% of the naturally occurring carbon on planet earth has a nucleus containing six protons and six neutrons, but 1.11% of the carbon contains a nucleus with six protons and seven neutrons. Both of these carbon elements are stable (not radioactive). However a few carbon atoms contain six protons and eight neutrons. This form of carbon is unstable and is radioactive. The carbon with six protons and six neutrons is called “carbon 12” or C^{12} or C-12 (each proton and each neutron counts as one). The radioactive carbon with six protons and eight neutrons is called “carbon 14”.

About 75.53% of the naturally occurring chlorine on the earth has a nucleus containing 17 protons and 18 neutrons. Another 24.47% of the chlorine has a nucleus containing 17 protons and 20 neutrons. Both of these chlorine forms are stable and non-radioactive. They are usually found in the form of compounds such as sodium chloride. But the chlorine form with 17 protons and 19 neutrons (called “chlorine 36”) is unstable and radioactive. Chlorine atoms with fewer than 18 neutrons or more than 20 neutrons are also unstable and radioactive.

All atoms must have nuclei containing the right balance of neutrons and protons. The number of protons and neutrons in the nucleus is called the atomic mass number. If there are too few neutrons or too many neutrons to provide the proper balance, the nucleus expels some of the excess mass with release of energy. The energy is released in the form of gamma rays and x-rays plus the kinetic energy of the mass released. This mass and energy released by the nucleus is radiation. The unstable elements which release this mass and energy are called radioactive isotopes. Radioactive material contains these radioactive isotopes.

The mass released may be in the form of alpha particles or beta particles. An alpha particle emission means that the nucleus has shed two protons and two neutrons. A beta particle emission is the result of a disintegration of a neutron into a proton (which stays behind) and a beta particle (which is expelled from the atom). A beta particle has a mass and charge similar to an electron but originates in the nucleus. All this is accompanied by high-energy gamma rays and (often) x-rays. Gamma and X-rays travel at the speed of light. Another particle that can be emitted in the nucleus the positron (which has a mass similar to a beta particle but carries a positive charge); the positron does not leave the atom and annihilates itself releasing gamma radiation.

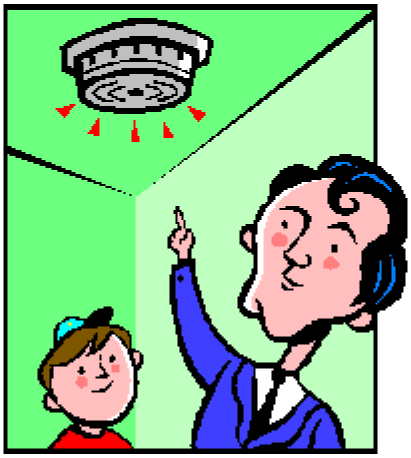
All of this radiation (alpha particles, beta particles, and gamma rays) can react with human body tissues causing havoc. The human body can withstand some radiation and recover, but if the dose is great enough, possible cancer could develop later in life, or with a large enough dose, death may follow within weeks of exposure.

Alpha particles travel only a few centimeters or less from the emitting atom. Intact human skin can stop an alpha particle. Beta particles are more penetrating; the most energetic beta particles can travel about 5 feet from the emitting atom, or through 1 inch of water (or 1-inch of human tissue). Gamma rays are the most penetrating of all; considerable lead shielding or other dense material is required to shield the radioactive material from personnel. X-rays also penetrate but because they are less energetic than gamma rays, the health hazard is much less than gamma ray emissions.

Where Do Radioactive Isotopes Come From?

Radioactive isotopes can occur naturally or may be man-made. Natural sources may be from the natural decay of uranium (and thorium) left over when the earth was created, from cosmic ray interaction with the earth elements, or carried with meteorites and cosmic dust from outer space. The largest natural source of radiation for most people is from the gas radon sometimes found in homes and in underground mines. On the average, radon accounts for 67% of a person's total dose of natural radiation. The radon originates from the radioactive decay of naturally occurring uranium and thorium isotopes in the earth's crust. Radon has several different isotopes and all are radioactive. Radium 226 (nucleus has 86 protons and 140 neutrons) is the most common isotope. Smokers are at particularly high risk from exposure to radon and other naturally occurring isotopes, and cancer is much more likely to occur in a smoker who is exposed to radiation compared with a non-smoker.

Man-made radioactive isotopes are the result of bombardment of an element (atoms) with neutrons or alpha particles. The neutron or alpha particle is absorbed by the atom nucleus creating a different element or isotope. Another way that radioactive isotopes are created is by bombardment of a heavy element with neutrons; under some circumstances the atom will break apart (fission) forming two atoms each with varying amounts of protons and neutrons and both parts are radioactive. The atom split can occur in many different ways. A tremendous amount of energy is released as the result of the fission process.



Radioactive isotopes have very useful purposes in medicine and industry. Even smoke detectors found in homes contain minute amounts of the radioactive isotope Americium 241; there is no danger of exposure even if the component containing the radioactive isotope is handled. Generation of nuclear power depends on the energy released by the fission process. When used properly, radiation exposure to the public from all man-made sources is considerably less than that from all natural sources (about one-fifth of the radiation from natural sources)

A U.S. nuclear power plant emits much less radiation to the atmosphere on a unit electricity generated basis than a coal-fired power plant. The reason for this is that coal contains minute amounts of natural radioactive isotopes which when burned is emitted to the atmosphere and appears in the ash. Even people living within a few miles of a nuclear power plant on the average receives less than 0.1% of their total radiation dosage from that power plant.

What is the Fate of Radioactive Isotopes?

As explained before, the radioactive isotope nucleus sheds some of its mass in the form of alpha or beta particles often with release of gamma radiation energy. What remains is a new element or daughter isotope with a bit less mass. The daughter isotope may also be radioactive and emit alpha or beta particles. Eventually a stable, non-radioactive isotope is formed. Science cannot predict when a particular atom will undergo decay, but can establish a half-life which is different for each radioactive isotope. The half-life is the time it takes for half of the atoms to decay.

For example, carbon 14 is a naturally occurring radioactive isotope generated by the interaction of cosmic radiation with atmospheric nitrogen. Its half life is 5715 years. Its radiation activity is 4.5 curies per gram. When it decays, the carbon 14 nucleus sheds a beta particle (a neutron is converted to a beta particle which is ejected from the nucleus and a proton which remains behind) with (for all practical purposes) no accompanying gamma radiation. The daughter isotope is nitrogen 14 which is stable and not radioactive. The kinetic energy of the beta particle ejected has a (maximum) energy of 0.15648 MeV. All this information is in the PEAC tool. A beta particle with a kinetic energy of 0.15648 MeV can travel through 10 inches of air or 0.013 inches of water.

Cesium 137 is a man-made radioactive isotope. Its half life is 30.2 years and its radiation activity is 86.7 curies per gram. When it decays, the cesium 137 nucleus sheds a beta particle with a kinetic energy (maximum) of 1.176 MeV and gamma radiation of 0.66164 MeV. Again, all of this information is in the PEAC tool. The daughter isotope is Barium 137 which is non-radioactive. A beta particle with a kinetic energy of 1.176 MeV can travel about 130 inches in air or 0.2 inches in water. Gamma radiation can theoretically travel forever unless there is some dense material in its path to absorb the radiation. Lead shielding is usually used to absorb gamma radiation. One use of cesium 137 is in the gamma radiation of food (to destroy harmful pathogens). Food subjected to gamma radiation does not contain any residual gamma radiation.

What Radiation Dose is Safe and What Radiation Dose Will Kill?

The unit of radiation dose is the "rem". "Rem" is an acronym for roentgen-equivalent-man. A "rem" is that quantity of any type of ionizing radiation which when absorbed by a person produces an equivalent to the absorption of one roentgen of x-ray or gamma radiation. Ionizing radiation includes alpha and beta particles as well as gamma and x-rays, and thermal neutrons. The term "ionizing" refers to what happens when radiation interacts with body tissue; if severe enough it could result in a later cancer or even death.

Another unit of radiation dose is the Sievert, or Sv. 100 rems = 1 sievert.

The U.S. National Council on Radiation Protection recommends a 5 rems whole body exposure limit in any one year for workers who may be in contact with radiation. This is over and above the natural background radiation which everyone is exposed. This radiation limit is accumulative. If "N" is the age of the adult (over 18 years old), the maximum accumulative whole body radiation recommended is (N-18)x5. The maximum radiation exposure for persons under 18 years old is 0.1 rems/year. For pregnant women, the maximum recommended dose is 0.5 rems during the gestation period. Higher doses are allowed for certain body parts such as skin or hands. For skin, a dose of 15 rems is allowed in one year. For hands, a dose of 75 rems is allowed in one year.

Exceptions are allowed for emergency, life-saving procedures. A person older than 45 years old might "safely" receive a 100 rems one-shot dose plus an additional 200 rems dose on the hands and forearms. This is a one-time deal. The person can't go into the contaminated zone again even at a later date and receive another 100 rem dose without adverse consequences.

The age limit is there because of uncertainties of possible cancer much later in life if a younger person went in.

Individuals receiving whole-body radiation dosages between 100 and 200 rems may experience discomfort and fatigue, with some experiencing nausea and vomiting and loss of appetite. Recovery usually occurs after two weeks, but some individuals may experience a relapse. There may be a higher risk developing a later cancer. The threshold of lethality appears to be about 200 rems of whole body radiation for the most sensitive individuals. For dosages between 200 rems and 1000 rems of whole body radiation, recovery prospects are good at the low end of the scale and poor at the upper end of the scale. Death at 1000 rems whole body exposure is almost certain, even though the person may not feel any discomfort initially (death may occur several weeks later). A person receiving a 1000 rem dose will likely experience diarrhea and vomiting for several days followed by death after a week due to circulatory collapse. Death may occur within 24 hours due to cardiac or circulatory failure for a person receiving a 3000 rem dose. A person receiving a 5000 rem dose will experience initial listlessness and prostration frequently followed by convulsions before death.

Even if the person recovers, the person may develop leukemia or other cancer many years later. The other cancers might include bone tumors, liver carcinoma, lung cancer, thyroid cancer, and skin cancer. A person receiving a 20 to 45 rem dose to the eyes will likely develop cataracts years later.

Sometimes the dose is measured in rads. A "rad" is a unit of absorbed dose imparted to matter by ionizing radiation; one rad is equivalent to 100 ergs/gram of ionizing radiation. Other terms sometime used is the "Gray" (abbreviated "Gy") and the "Roenthen" (abbreviated "R"). One Grey = 100 rads = joules/kilogram of ionizing radiation. One Roentgen = 0.88 rads. The relationship between a "rem" and a "rad" is not straightforward; it may be estimated from the factors D, Q, and N which are multiplied together as follows:

$H = D\ Q\ N$

where H = dose equivalent in "rems"

D = absorbed dose in "rads"

Q = quality factor (Q = 1 for x-rays and gamma rays; Q = 1 (approximately) for beta particles; Q = 10 for alpha particles)

N = a modifying factor which adjusts an organ receiving an uneven dose of radiation, and other factors.

In a situation where a terrorist has exploded a dirty bomb, the radiation dose which a person received will probably be unknown. Radiation measurements in the environment of the explosion can help with making an estimate. The dose which a person has received can also be estimated by the onset, duration, and severity of the nausea, diarrhea, and vomiting.

Comments on Dose a Person Receives from Natural, Background Radiation

All of us are exposed to some background radiation. The radiation comes from radon in homes, minute amounts of radioactive isotopes in the earth's crust including buildings, cosmic rays from outer space, and use of tobacco products. A background dose received by a typical non-smoker at sea level (including medical x-rays) is approximately 0.15 to 0.2 rems/year (150 to 200 mrems/year; mrems= millirems). Of that dose, cosmic radiation might account for 0.03 rems/year for a person living at sea level, or perhaps 0.09 rems/year for a person living at 7500 foot elevation. Exposure to radon gas in the home might add another 0.1 to 0.4 rem dose to the lungs, if the home has excess radon levels. Smokers might receive as much as an 8 rems/year dose to bronchial epithelium of the respiratory tract.

Examples of naturally occurring radioactive isotopes include Potassium 40, Carbon 14, Rubidium 87, Tritium (Hydrogen 3), Radium 226, Radon, and Thorium 232. They can also be man-made.

Naturally occurring radioactive isotopes as they occur in nature are extremely dilute. A terrorist seeking radioactive material would likely steal material which has been man-made and concentrated enough to do damage.

Response to a Dirty Bomb Explosion

The terrorist has struck. People need to be removed from the stricken area. Personal protection equipment can protect against radioactive isotopes from entering the body and from alpha (and to a major extent) beta particles but not gamma radiation. Gamma radiation can penetrate personal protective equipment even though the radioactive isotope is outside the protective suit. Another concern is that people may not experience adverse affects initially and may be able to walk away, but radioactive isotopes contaminate their skin and clothing. Even a person receiving a lethal dose of radiation may be able to walk away from the site. The radioactive isotopes could be spread over a broad area including the person's home exposing his family members. The person might bathe and his clothes washed, but the radioactive isotopes do not just disappear. The isotopes must go somewhere, whether down the drain, in washing machine, shower stall, and tracked in all over the floors.,

Removal of contaminated clothing and showering (using soap) might remove up to 99% of the radioactive isotopes which contaminate the person's clothing and skin. The clothing and wash water must be collected and disposed. If the radioactive isotope has already entered the person's body through breathing or injection, the isotope can continue to case harm due to alpha or beta particle emission and gamma radiation. Another concern is that rescue persons assisting with clothing removal might themselves become contaminated.

In a real-world dirty bomb detonation, a clothing and showering removal station is not going to be set up until sometime later, probably during cleanup operations or at best within hours after the detonation. People are going to walk away. They must be located. There are going to be some radioactive isotopes spread beyond the site.

Utmost care must be taken to minimize entry of the radioactive isotopes from entering the body. The U.S. Nuclear Regulatory Commission's recommendations for radioactive isotope exposure by inhalation or ingestion are codified in 10 CFR Part 20 Appendix B. Two broad categories are considered, one for a 5 rem/year exposure and the other for a 0.1 rem/year. The 5 rem/year exposure is the maximum recommended exposure for radiation workers and 0.1 rem/year exposure are for the general public including children. These numbers are reproduced in the PEAC tool for various radioactive isotopes. The 5 rem/year worker exposure calculation is based on an exposure for 2000 hours and a breathing rate of 20 liters/minute. The "general public" number is based on exposure 24 hours/day and 365 days per year, and 0.1 rem/year exposure.

Many radioactive isotopes produce gamma radiation. The radiation can penetrate the person's body even though the person as not inhaled or ingested the radioactive isotope. The person's dose will depend on the isotope. the amount of isotope, how far away the person is from the isotope, and any shielding that may be between the person and the isotope.

For example, carbon 14 does not emit any substantial gamma radiation. One gram of carbon 14 can be placed at a location 1 meter away from the person and he would not receive any radiation at all from this gram.

Cesium 137 emits beta radiation with a maximum kinetic energy of 1.176 MeV and gamma radiation of energy 0.662 MeV. A person located one meter away from one gram of Cesium 137 might receive 38 rem/hour of gamma radiation plus some beta radiation. If the person were located 10 meters away from the one-gram source, the gamma radiation exposure is estimated to be 0.4 rem/hour, and no beta radiation exposure. This estimate assumes no shielding (other than air and a person's clothing).

Only 0.1 gram of Cesium 137 dust spread evenly on a Level A protective suit might impart 200 to maybe 600 rem/hour of gamma radiation to the person inside the suit, even though the person is wearing a self contained breathing apparatus and does not inhale any Cesium 137

One of the most dangerous isotopes listed in the PEAC tool is Californium 252. A person located 1 meter away from a 1 gram source can receive a dose rate of 2540 rem/hour. At 10 meters away, the dose rate might be reduced by a factor of 100, or about 25 rem/hour.

Very roughly, the gamma radiation dose falls off according to the square of the distance from the source.

How Do You Know What Radioactive Isotopes Are in a Terrorist Bomb?

You don't, at least not initially. Perhaps there might be a reported theft of radioactive material and authorities can be placed on alert. Perhaps the only clue might be large numbers of people near the explosion experiencing nausea sometime later; subsequent investigation reveals significant radiation at the exposure site. Rescue workers may have already gone in and exposed themselves to radiation unawares.

Each radioactive isotope has its own fingerprint. Some emit alpha particles and some emit beta particles. Most emit gamma radiation of varying energies and intensities. The PEAC tool lists this information. Samples of the radioactive material may be gathered, and the isotopes identified from their pattern of gamma energies and intensities.

If significant radiation is established, personnel likely would not enter the heart of the contamination to gather samples. More likely, they would do surface wipes from the skin and clothing of people who may have been exposed at the site, or from nearby locations which are relatively safe to enter.

Once radiation contamination has been identified, there would be a tremendous effort to track down the people who may carry the radioactive isotopes on their skin and clothing.

The identification of the radioactive isotopes is important both in tracking down the source where the theft may have occurred and in tracking down people exposed to the isotopes. It is also important in treatment of people who inhaled or ingested the isotopes. Many radioactive isotopes target specific body organs (e.g. radioactive iodine to the thyroid, strontium 90 to the bone), and the exposed individuals should be monitored for many years later for possible cancer. Identification also is important in establishing a cleanup program.

What Can Be Done to Minimize the Dirty Bomb Threat?

The most important line of defense is to keep radioactive isotopes/ radioactive materials secure and protected so the theft does not occur in the first place.

The United States border needs to be secure without restricting normal commerce. The same applies to containerized material coming into the United States at seaports. Radiation detection equipment and explosive detection equipment will help here. A terrorist might minimize radiation detection using sufficient lead shielding, but now is left with an unusually heavy package. Shielding for neutrons (which are emitted from certain material such as plutonium used to make nuclear bombs) could involve barium or cadmium alloys.