Radiological Dispersive Device; "Dirty Bomb"

Dr. John Nordin

One of the most difficult training exercises for responders is how to deal with a radiological dispersive device or "dirty bomb" incident. Unlike fires, explosions, or chemical spills, there aren't past examples where radioactive material has been actually dispersed by a terrorist where responders can learn from the experience. Furthermore, how do we even know that a radioactive material has been dispersed; if so, what radioactive material and how much? One trainer came to AristaTek and asked for a simple "widget" for converting gamma radiation counts, Curies, Becquerels, Roentgens, Rads, etc. Grays, etc. to a measure of dose, e.g. Sieverts, or Rems. The units by which radiation is measured in itself is bewildering. What are the chances of a person exposed to radiation developing cancer later in life?

Definition of a Radiological Dispersive Device: The Department of Homeland Security defines a radiological dispersive device (RDD) as a combination of a conventional explosive device with radioactive material, and is designed to scatter this radioactive material over a general area. A RDD is also called a "dirty bomb". The context is that of terrorist(s) use to cause psychological fear and economic disruption. It is also possible that a terrorist could rig up a device using an aspirator to disperse the radioactive material in the form of a fine powder or aerosol suspension into an intake air system without using an explosive, and for that reason, responders should be alert to any possibility.

How Do You Know That a Radiological Dispersive Device Has Been Deployed?

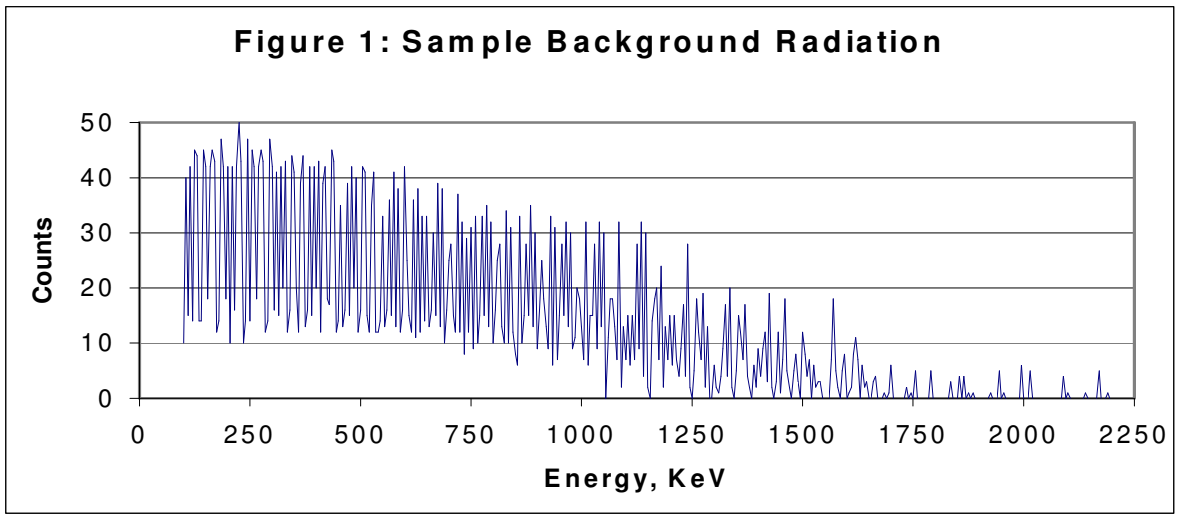
There has been a suspicious incident, perhaps resulting in an explosion, at a location where many people have gathered, or at or near a high profile target. The area has or is being secured, any injured removed or in the process of being removed, and people evacuated. There may or may not be clues (e.g. suspicious canisters or containers, maybe lead shielding) of a radiological dispersive device. Canisters could also be used to contain a chemical or biological warfare agent, or someone could have stored incompatible chemicals (e.g. a fuel and an oxidant) together without intent to harm.

Responders will not know that a radiological dispersive device has been deployed until radiation detection equipment (usually a gamma radiation counter) has been brought to the scene. Hopefully this is done quickly so that decontamination procedures and appropriate personal protection equipment implemented for responders entering and leaving the scene. An incident commander may still order these procedures, and medics may decontaminate the injured brought to the hospital before radiation exposure has been checked out. Responders should also be trained to recognize symptoms of chemical exposure, which could also account for a suspicious release.

A gamma radiation detector can be used to detect whether radioactive materials have been dispersed. The detector may simply measure total radiation count within a certain energy level range or measure radiation level counts at different energy levels.

Gamma radiation is only part of the total electromagnetic spectrum which includes radio waves, microwaves, infrared, visible light, ultraviolet radiation, x-rays, and gamma radiation. Gamma radiation is the most energetic of electromagnetic radiation and is able to penetrate human flesh; the gamma radiation energy interacts with flesh causing it to ionize at the molecular level, disrupting the cell machinery which may result in death. A sub-lethal dose may result in cancer later in life.

We are also surrounded by natural radiation. This radiation comes from many sources, including the rocks and soils, natural building materials, outer space, and trace residuals from nuclear tests conducted many years ago. Figure 1 shows natural gamma radiation counter as measured by a detector able to measure radiation at different energy levels, and has operated for a period of time. Energy levels are measured in electron volts (eV); 1000 eV = Kev; 1000 KeV = 1 MeV.



What happen if a radioactive isotope is released into the air? We would get a spike in the number of counts at certain energy levels. Each radioactive isotope has a characteristic energy level or levels representing a "fingerprint" for that isotope. For example, cesium 137 (also called Caesium 137 or Cs 137) emits gamma radiation at 660 KeV (0.66 MeV) energy level. If the gamma radiation detector measured significant radiation at 660 KeV above background, we would know Cesium 137 has been released. Cobalt 60 (Co 60) emits gamma radiation at 1173.2 KeV (1.1732 MeV) and 1332.5 (1.3325 MeV) energy levels. Americium 241 emits radiation at several energy levels: 59.5 KeV (35.9% of disintegrations), 13.9 KeV (43.5% of disintegrations), and lesser amounts at 26.3 KeV and 33.2 KeV.

Many radioactive isotopes also emit alpha particles. A few emit neutrons in the process of decay. Instrumentation can be purchased to detect alpha particles and neutrons. This is also useful in determination of the radioactive isotope released and also if a person is still contaminated with radioactive debris. Gamma radiation detectors cannot determine whether a person has been exposed to gamma radiation at some earlier time if there is no radioactive debris present when the person is checked.

Can a responder take a bunch of radiation count measurements at different locations and work backwards to estimate the total amount to radioactive material released? Theoretically yes, but there are other priorities such as determination of where contamination is located, access control, decontamination of persons entering and leaving, and locating who has been exposed. All this is required regardless of whether we know the amount released. Sampling techniques to determine air quality (e.g. measuring units Becquerels per cubic meter) and ground shine (deposited radiological material, units Becquerels per square meter) are more sophisticated and best left to specialists. A responder might best use radioactive detection equipment to determine whether there has been an incident and approximate locations of contamination and even identify the material.

Algeciras, Spain, Steel Mill Cesium 137 Release

This incident has been modeled by a number of researchers, notably from Lawrence Livermore National Laboratories and the Westinghouse Savannah River Company; the incident was also studied by several European governmental organizations. Their reports are available over the Internet (some require a subscription service to access technical publications). This was not a terrorist incident but an accidental incineration of cesium 137-contaminated material in an industrial furnace. We make mention of the incident in this newsletter because modeling was done based on ambient air quality measurements to estimate the amount of cesium 137 released at the source. In addition, the incident showed that even small quantities of radioactive material released can be detected over wide geographical areas.

Notification of the accident began on 9 June 1998, when the Swiss government announced that radiation levels up to 1000 times background had been detected in their national monitoring network and that the source was unknown. The excess radiation was also confirmed by monitoring systems in France and Italy. On 10 June 1998, a steel mill in Algeciras, Spain, notified the Spanish Nuclear Security Agency that they had detected radiation in one of their oven filtration traps. On 12 June 1998, the Spanish government announced that a medical radiotherapy source of cesium 137 was apparently melted in the steel mill scrap metal furnace and released to the atmosphere, and that the amount and time of the release was unknown, but late May was a possible release time.

Governments and researchers made available to modelers ambient air quality measurements taken during the May-June 1998 time frame. The sampling time mostly varied from 24 hours to

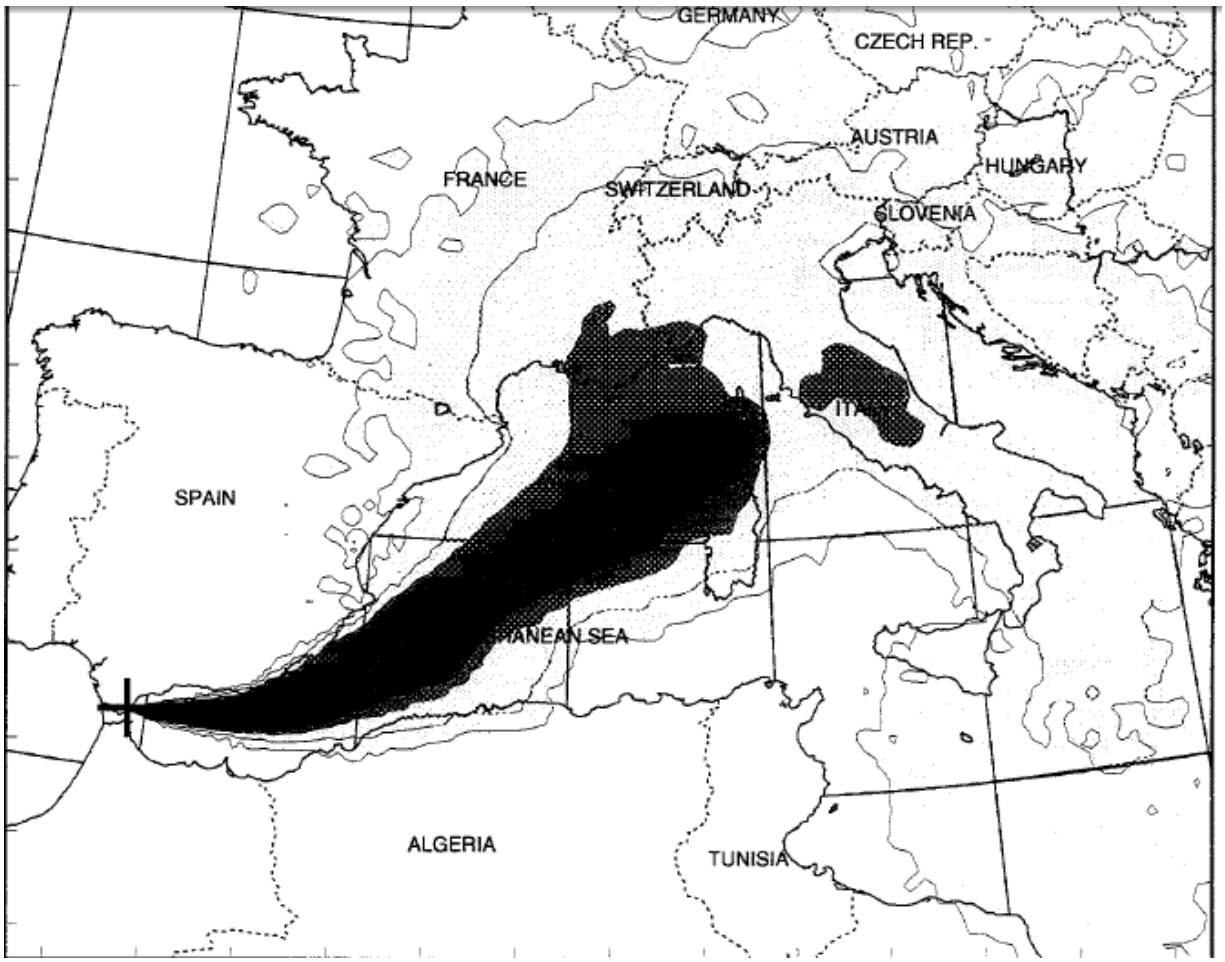
about 2 weeks depending upon the sampling location (samples from France, Spain, Germany, Austria, Czech Republic, Hungary, Slovokia). The sampling consisted of passing a measured volume of ambient air at generally a 1.5 meter height through a filter for a period of time and then measuring the radioactivity collected by the filter. Background radiation was on the order of maybe one micro Becquerels per cubic meter of air sampled ($\mu Bq/m^3$), more or less, depending upon the location and volume of air sampled (a 0.5 $\mu Bq/m^3$ limit of detection was mentioned, at least for some stations). Measurements varied from the limit of detection to over 1000 $\mu Bq/m^3$ depending upon the sampling time and location. Remember, different samplers operated for different lengths of time so the concentrations represent an average concentration during the time period sampled.

The Atmospheric Release Advisory Capability scientists, located at Lawrence Livermore National Laboratories (LLNL), took the many measurements taken in Europe and coupled this information with U.S Navy Operational Global Atmospheric Prediction System gridded data (uses a combination of measured meteorological data and high resolution forecasting) to develop a plume plot (Figure 2), which appeared in the LLNL report UCRL-JC-131330 (available on the Internet at https://e-reports-ext.llnl.gov/pdf/240649.pdf). The plume modeling methodology involved looking at different source release amounts and times and seeing which best matches what was measured at the measuring stations. The modeling and weather information suggested that the Cesium 137 plume cloud (very fine particulates) initially drifted eastward over the Mediterranean Sea , then turned north into France and Italy, and was split as it passed northward over the Alps with parts drifting into northern France, Netherlands, Germany, Austria, and Hungary.

The plume contour taken from the LLNL report is hard to read, but the solid black areas represent locations > 1000 $\mu Bq/m^3$, dark cross-hatched shading (barely distinguishable from the solid black shading) 500 to 1000 $\mu Bq/m^3$, and the unshaded areas (only the boundaries reproduced) represent 10 to 100 and 100 to 500 $\mu Bq/m^3$ contours.

Based on the modeling (figure 2), the LLNL scientists results confirmed that the Spanish government estimate of a release between 8 to 80 curies of Cesium 137 between 0300 and 0500 hours local time on 29 May was probably correct, with a 50 curie release best fitting the monitoring data. The LLNL scientists further estimated the highest dose due to 20-day ground shine exposure to be 10^{-8} Rem (= 10^{-4} μSv), well below any known health effect. We will talk about these units of measurements and what they mean later.

Figure 2: Seven-day Average Contour Plot Developed by Atmospheric Release Advisory Capability scientists at Lawrence Livermore National Laboratories.



Robert Buckley at the Westinghouse Savannah River Company in South Carolina also modeled the Cesium 137 release. His report (WSRC-MS-99-00660) is available at http://sti.srs.gov/fulltext/ms9900660/ms9900660.html.

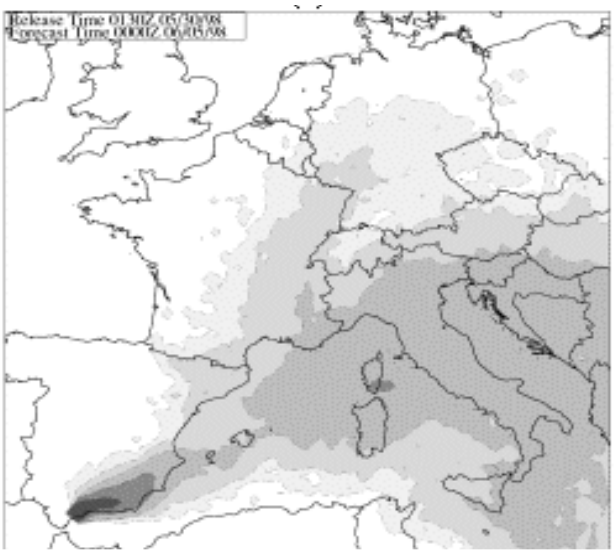
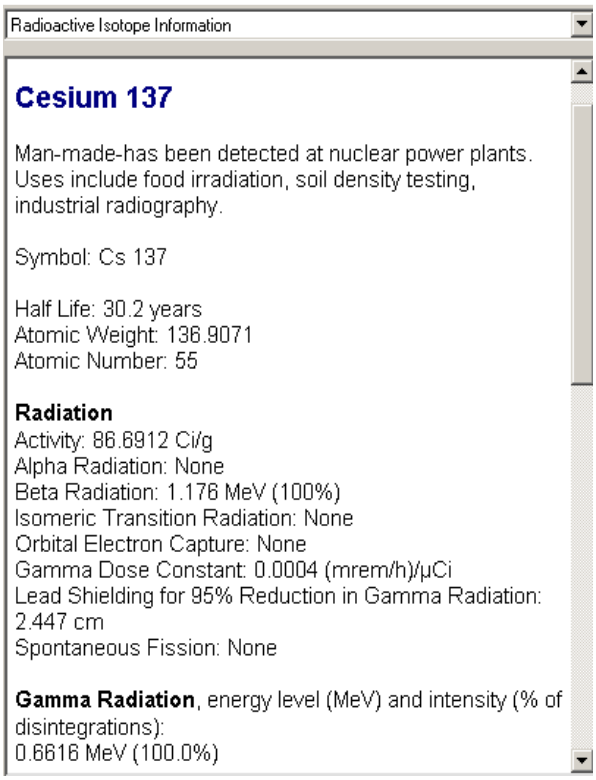


Figure 3, Left, Integrated airborne concentration near surface after six days. Black contour at southern part of Spain represents concentrations of 10^6 µBq/m^3. The shading represents decreases in order of magnitude down to 100 µBq/m^3 for the lightest shading. The modeling was based on a 80 curie release over a 30-minute period. From WSRC-MS-00-00660 report.

How much is 80 (or 50) curies of Cesium 137? From the PEAC tool, under radioactive isotopes, we can select Cesium 137.



At left is a partial view of the PEAC tool screen. Under radiation we read that Cesium 137 has an activity of 86.6912 curies per gram (Ci = curies). We are talking roughly one gram of Cesium 137 being dispersed in the atmosphere over a several hour period in the Spain incident, yet scientists were able to measure Cesium 137 concentrations hundreds of miles away.

By comparison, the weight of a one cent U.S. coin (minted after 1982) weighs 2.5 grams. We are talking about only a small quantity of cesium 137.

The gamma radiation energy is also displayed (661.6 KeV or 0.6616 MeV). The half life is 30.2 years, meaning, that after 30.2 years, Cesium 137 will have decayed to Barium 137 which is not radioactive.

Beta Particle Travel
Beta particle travel distance in air (sea level, ambient temp.): 164.8 in
Beta particle travel distance in air (6560 ft elevation, ambient temp.): 219.67 in
Beta particle travel distance into human flesh if radioactive isotope is on the skin: 0.2 in

Daughter Isotopes
Barium 137m (half life 2.55 minutes), then Barium 137 (stable)
Daughter Isotope Radiation: Ba k x-ray

Inhalation and Ingestion Exposure Limits
Annual Limit by Inhalation for 5 rem annual exposure:
2.0e+002 microcuries

Occupational Derived Air Concentration for 5 rem annual exposure:
6.0e-008 microcuries/ml (breathing rate 20 liters/minute, exposed 2000 hours/year)

Public Air Concentration for 0.1 rem annual exposure:
2.0e-010 microcuries/ml (breathing rate 20 liters/minute, exposed 24 hours/day 365 days of year, additional safety factor of 2 except for gases)

Public Water Concentration:
1.0e-006 microcuries/ml (intake 730 liters water annually,

Scrolling further down the screen, we can pull up additional information about Cesium 137. Under daughter species, Cesium 137 decays to Barium 137 which is stable (we won't count the intermediate Barium 137m which has a half life of only 2.55 minutes).

The U.S. Nuclear Regulatory Agency (and Occupational Safety and Health Administration) recommends that a person receive no more than 5 rem dose per year. This does not include normal background radiation which might be 0.15 to 0.2 rem per year for a non-smoker at sea level, and excluding radon gas exposure. The total amount of cesium 137 inhaled to result in an equivalent 5 rem dose is 2.0e-008 microcuries ($2x10^{-8}$ µCi).

Daughter Isotopes
Barium 137m (half life 2.55 minutes), then Barium 137 (stable)
Daughter Isotope Radiation: Ba k x-ray

Inhalation and Ingestion Exposure Limits
Annual Limit by Inhalation for 0.05 sievert annual exposure:
7.4e+006 Becquerels

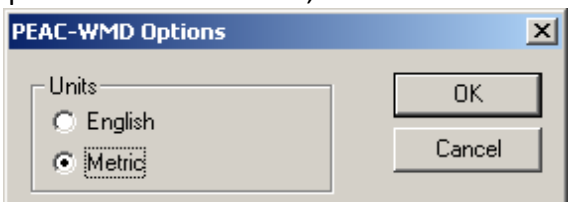
Occupational Derived Air Concentration for 0.05 sievert annual exposure:
2.2e-003 Becquerels/ml (breathing rate 20 liters/minute, exposed 2000 hours/year)

Public Air Concentration for 0.001 sievert annual exposure:
7.4e-006 Bequerels/ml (breathing rate 20 liters/minute, exposed 24 hours/day 365 days of year, additional safety factor of 2 except for gases)

Public Water Concentration:
3.7e-002 Bequerels/ml (intake 730 liters water annually, additional safety factor of 2 except for gases)

Information from 10 CFR Part 20 appendix B

Since the modeling study was done using ambient air concentration in metric units, we might select the metric rather than English option for the PEAC tool, as below:



The dose as shown in the display at left is listed in sieverts (0.05 sievert =5 rem), and the amount of cesium 137 inhaled equivalent to a 0.05 sievert dose is 7.4e+006 Becquerels [7.4 10^{6} Becquerels].

The highest concentrations modeled were on the order of 10^6 μBq/m^3 (=1 Bq/m^3) from the Westinghouse Savannah River Company in southern Spain. Assuming that the plume cloud in southern Spain lasted over say a 24-hour period and the average person breathing rate was 20 liters/minute, a person would have inhaled 28.8 cubic meters of air in a day. At concentrations of 1 Bq/m^3, we are looking at an exposure of $5x(28.8/(7.4x10^6) = 2 \times 10^{-5}$ rem, which is well below the 5 rem recommended annual exposure limit.

While the Algeciras incident in itself did not result in danger to human populations, a terrorist might release say 100 grams of Cesium 137 or multiple containers of this material resulting in a great deal of harm.

How Do You Convert Amount of Radiation to Dose?

We tossed around a bunch of different units, Curies, Becquerels, Rems, Sieverts, and added a bunch of abbreviations, and concentrations, e.g., Bq/m^3, μBq/m^3, μCi/m^3, Ci, etc., not to mention a bunch of other units and symbols that appear in print. This can be confusing to someone not familiar to terminology relating to radioactivity. Some definitions are in order:

Table 1. Definitions of Radiological Units

Unit	Abbreviation	Definition
Becquerel	Bq	A measure of activity of a radioactive material (radioactive isotope) in the International System (SI) of units. One Becquerel = 1 disintegration/second
microbecquerel	μBq	1000000 μBq = 1 Bq
megabecquerel	MBq	1000000 Bq = 1 MBq
gigabecquerel	GBq	1000 MBq = 1 GBq
Curies	Ci	A measure of activity of a radioactive material (radioactive isotope) commonly used in the United States and some other countries. One curie = 3.7×10^{10} Becquerel; 1 Ci = 37 GBq
millicuries	mCi	1000 mCi = 1 Ci
Roentgen	R	A measure of exposure (absorbed dose) due to gamma and X-rays emitted by a radioactive material in air. This unit is commonly used in the United States. One roentgen of absorbed dose equals 2.58×10^{-4} coulombs per kilogram
Rad	rad	Rad = radiation absorbed dose. A rad is the amount of radiation energy absorbed in some material, and can refer to any type of radiation, and is equal to the absorption of 100 ergs per gram of material. For X-rays and gamma radiation, one Roentgen = 0.88 rad.
Gray	Gy	A Gray is the amount of radiation energy absorbed in some material, and can refer to any type of radiation,

		and is equal to the absorption of one joule per gram of material. One Gray = 100 rads for X-rays and gamma rays. This is the International System (SI) unit for measuring absorbed radiation.
Rem	Rem	Rem = roentgen equivalent man. A rem is the amount of radiation energy absorbed by human tissue and takes into account the effective biological damage of the radiation. Rads can be converted to rems by multiplying by a quality factor which is unique to the type of radiation. Unit used commonly in the United States.
Sievert	Sv	A Sievert is the amount of radiation energy absorbed by human tissue and takes into account the effective biological damage of the radiation. Grays can be converted to Sieverts by multiplying by a quality factor which is unique to the type of radiation. One sievert = 100 rem. International System (SI) of units.

Any of these units may have prefixes which introduce some factor of ten, usually in multiples of 1000:

Prefix	Abbreviation	Factor
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	K	10^{3}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}

Curies and becquerels are measurements of amount of radiation emitted by radioactive materials. Roentgens, rads, and grays are measurements of the amount of radiation emitted which is absorbed by another material, which could be a human or animal or inanimate object and does not take into account adverse biological effects. Rems and sieverts are measurements of the dose (radiation absorbed) which takes into account the adverse biological effects.

How do you convert the amount of radiation (units of curies or becquerels) to dose received by a human (units of rems or sieverts)? The answer is lookup-up tables which have been worked out by scientists and are in the public domain.

Roentgens, rads, and grays might be thought of as an intermediate step in the conversion of curies and becquerels to dose as measured in rems or sieverts. To facilitate use of lookup tables,

this intermediate step is omitted in look-up tables allowing the user to convert the amount of radiation to dose.

To use the tables, the user must know (1) the radioactive isotope or isotopes and (2) how the person is exposed. Exposure routes may be external (e.g. by submersion, ground shine, or from a source a specified distance away from a person) or internal (by inhalation or ingestion).

Some of the published conversion factors are listed in the PEAC tool when the user pulls up a radioactive isotope. The dose due to a radioactive source a specified distance away is also available as a calculator within the PEAC tool.

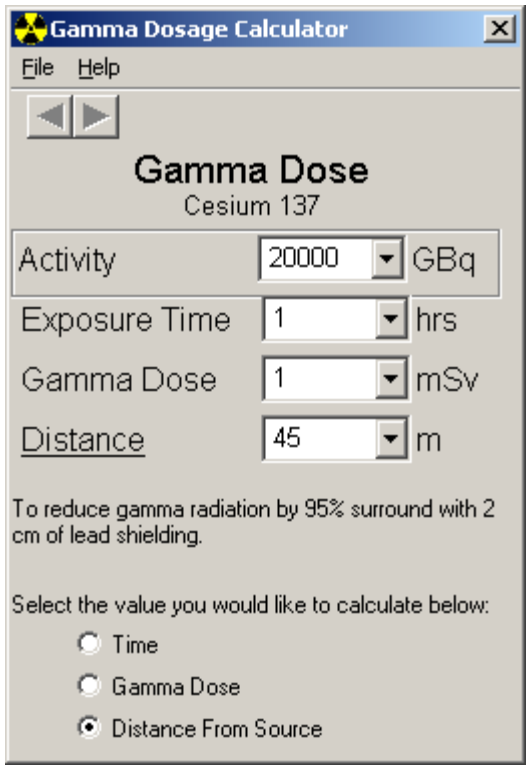
Tables presenting dose due to inhalation or ingestion are published in the U.S. Code of Federal Regulations under 10 CFR Part 20 Appendix B. The user must identify the radioactive isotope and amount, and the tables present a dose constant (which includes the effect of daughter isotopes formed through radioactive decay) which can be adjusted for exposure time, breathing rate, or ingestion, or back-calculated to give the amount equivalent to a 5 rem annual dose.

Other tables in following documents:

- U. S. Department of Energy (July, 1988), *Internal Dose Conversion Factors for Calculation of Dose to the Public*, National Technical Information Service, U.S. Department of Commerce, DE88-014297.
- L.M.; and D.K. Trubey, (1982), *Specific Gamma-Ray Dose Constants for Nuclides Important to Dosimetry and Radiological Assessment*, ORNL/RSIC-45/R1, Oak Ridge National Laboratory.
- K.F. Eckerman, A.B. Wolbarst, and A.C.B. Richardson, 1988, *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion*, Federal Guidance Report No. 11, EPA-5201/1-88-020, U.S. Environmental Protection Agency, Washington, D.C.
- Federal Guidance Report No. 13, *Cancer Risk Coefficients for Environmental Exposure to Radionuclide*, EPA 402-R-99-001, September 1999.

As an approximation, if specific radioactive isotope information is lacking, the Federal Guidance Report No. 13 report provides (assuming low dose total uniform radiation of the body over a 30-year period, estimates on the conservative side) an increased lifetime incident cancer risk factor of 0.08 per sievert, or a mortality cancer risk factor of 0.06 per sievert (recall 100 rem = 1 sievert). Short term, higher dose exposure may result in different risk factors.

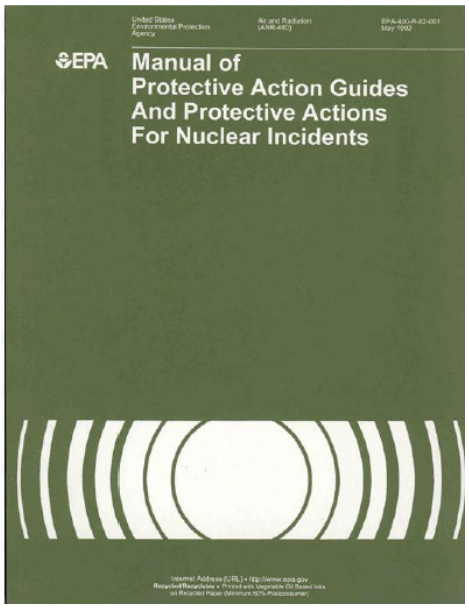
Any “widget” converting amount of radiation (curies, becquerels) to dose (rems, sieverts) and associated lifetime cancer risk would include information from these documents or its updates.



As an example, the PEAC tool contains a calculator where the user specifies the radioactive isotope and activity; in this example displayed the user is asked to calculate a distance (in meters) from a 20000 GBq source of cesium 137 in which he/she would receive a 1 mSv dose in one hour. The ORNL/RSIC-45/R1 document information cited above was used in constructing this calculator.

Protective Action Guides for Radiological Dispersive Device

The U.S. Department of Homeland Security has issued a directorate for responding to a Radiological Dispersive Device incident in the Federal Register dated January 3, 2006. The full text can be obtained at http://www.fema.gov/pdf/about/divisions/thd/repp_rdd_pag.pdf. The text also includes responding to Improvised Nuclear Device Incidents. An update is published in the Federal Register dated August 1, 2008, the full text of which is available at http://www.fema.gov/good_guidance/download/10260.



In 1992, the U.S. Environmental Protection Agency issued Protective Action Guides for responding to Nuclear Incidents. This report is no longer available in hard copy. While the emphasis of the document is on Nuclear Power Plant accidents, the Department of Homeland Security (see Jan 3, 1006 Federal Register) said that the document is appropriate for radiological dispersive devices which a terrorist might use. Updates are in the making, the status of the updates and an electronic version of the 1992 document is available at http://www.epa.gov/rpdweb00/rert/pags.html#status

The U.S. Department of Homeland Security also cites cancer risks from the Federal Guidance Report No. 13, saying that the increased cancer fatality risk for a worker is 0.0006 per rem (0.06 per sievert). This means that the fatal cancer risk for a worker exposed to 10 rem is 0.6% (six cases per 1000 persons exposed). Because the cancer may not show up until maybe 20 or 30 years later, a younger person is more likely to die a premature death from cancer than an older person. For example, 20 to 30 year olds exposed to a single 25 rem dose have a 9.1 per 1000 risk of premature cancer death while 40 to 50 year old exposed to the same dose have a 5.3 per 1000 risk of premature cancer death. Remember that doses are accumulative, meaning if the person is exposed again in an incident maybe a year later that risk of premature cancer death is added as we are looking at a total lifetime rem dose exposure.

The term "Total effective dose equivalent" or TEDE refers to the sum of exposure due to submersion, ground shine, inhalation, and ingestion.

The federal guidelines for worker response to a radiological dispersive device incident (from the the Federal Register citations are listed in table 2:

Table 2. Response Worker Guidelines

Total TEDE Guideline	Activity	Condition
5 rem	All occupational exposures	All reasonably achievable actions have been taken to minimize dose
10 rems	Protecting valuable property necessary for public welfare	Exceeding 5 rems unavoidable and all appropriate actions taken to reduce dose. Monitoring available to project or measure dose. Any Dose > 5 rem is done on a voluntary basis with responders understanding the risks involved.

25 rems	Lifesaving or protection of large populations	Exceeding 5 rems unavoidable and all appropriate actions taken to reduce dose. Monitoring available to project or measure dose. Any Dose > 5 rem is done on a voluntary basis with responders understanding the risks involved.

The problem is that especially during the early phases of an incident responders will probably not know that a radioactive dispersal devise has been used by a terrorist until the scene has been checked using a gamma radiation counter. The duty of responders is to secure the area, engage in life-saving operations, prevent public access, evacuation of the public or shelter in place, and engaging in fire-fighting operations. Responders could be exposed to doses greater than 5 rem and not even know it. These actions on the part of responders are part of a necessary response to any incident. The incident commander may elect to take precautionary actions to minimize exposure and spread of contamination even before the scene is checked out for radiation. Precautionary action might include respiratory protection to minimize inhalation of dust and maybe jump suits which are removed when the responders leave the area. If the area is found later to be contaminated, it will not be easy to determine the dose exposure, or to track down the public which may have been exposed, or to clean up radiological dust dispersed off site.

The Protective Action Guides do not provide any information to responders on how to determine levels of radiation or dose exposure, only that the exposure should not exceed guideline levels (table 2) and efforts should be made to minimize exposure and spread of contamination.

Three time phases are recognized in response to a radiological dispersive device incident.

Early Phase (Emergency Phase): The early phase takes place at the beginning of an incident when immediate decisions must be made as to effective protection actions, and before field measurements on radiation are available. If an explosive RDD is deployed, there may be no time to take protective actions to significantly reduce dust cloud plume exposure. In the case of a covert dispersal, discovery or detection may not occur for days or weeks allowing contamination to be dispersed by foot and vehicular traffic and by weather. Priority should be given to lifesaving and first-aid actions. Early protective actions should be taken very quickly which can be modified later as more information becomes available.

Expected initial protective actions will include steps common to any incident where an explosion or possible chemical release has occurred including establishing a “hot zone” , controlling public access, life saving operations, first aid, and fire-fighting if applicable. Decisions must be made whether to evacuate the public or shelter in place, fitting responders with respiratory protection, protective suits, and other actions.

The EPA Protective Action Guide recommends 1 to 5 rem maximum dose for evacuation of the public or sheltering in place, during the early phase, but again the responders will not know locations linked to dose levels.

If an incident occurs as the result of an explosion, anything that can be done to reduce inhalation of dust, even breathing through a wet cloth held to the face or moving quickly to an area outside the dust cloud will help.

The modeling for the Cesium 137 release over Europe from Algeciras, Spain, looks impressive but the concentrations and dose were many orders of magnitude less than what might cause public harm. If we are talking about a theft of radiological isotope used in industry for use in a radiological dispersive device, the quantity involved would probably be less than one gram or 100 curies. Initial public evacuation might be limited to maybe a few city blocks or even a single building for <1 rem exposure as a precaution until measurements can be taken. The use of radioactive isotopes in industry is very well controlled; it would be difficult for a terrorist to acquire a large amount of material from this source.

Intermediate Phase: This phase begins after a radiological incident has been established, the isotope(s) identified, and protective action decisions can be made based on some field measurements. The dust from any plume cloud has generally settled (although wind or other activity might resuspend dust). The period at which the intermediate phase begins might start anywhere from a few hours to days after the release and may continue for weeks or even months. Activities may include readjustment of public protective action distances based on field measurements, identify locations of contamination, refinements of control of access, reopening transportation and infrastructure, locate people which may have been exposed, cleanup of spots where radiation has been tracked off site, and possible reentry to homes and locations previously evacuated.

The EPA Protective Action Guide recommends a 5 rem per year maximum dose for response worker exposure during the intermediate phase. The public is allowed to return to occupy locations if the dose is less than 2 rem for the first year and 500 mrem (0.5 rem) per year for subsequent years. Drinking water dose should not exceed 500 mrem (0.5 rem) per year. These are the recommended guidelines in determining relocation or the public and reentry to homes.

The use of dose reduction techniques is recommended for personal property and potentially contaminated areas that continue to be occupied. This includes washing of contaminated vehicles, personal clothing before reuse, cleaning eating utensils and food preparation areas before the next use, and other personal property as appropriate.

Late Phase: The late phase involves final cleanup of areas and personal property where radioactive material is present. There will be more time to establish locations of contamination and how to clean up and locate a disposal site for the contamination. Each situation will be different, and the objective will be site restoration. No guidelines for exposure are presented in the EPA Protective Action Guide other than a general statement that the dose for the general public should not exceed 500 mrem (0.5 rem) per year.

Additional Newsletter Reading

- Issue 35, February 2005. Radioactive Substances and Illicit Materials
- Issue 21, January 2004. Radioactive Isotopes