Fallout Radiation Dose Calculator

In October 2006, AristaTek released the latest version of the PEAC-WMD™ software application. It is referred to as the PEAC-WMD 2007 (v5.5) application and there are both the Windows and Pocket PC versions. There are several new computational tools provided in the application to assist a responder in making calculations or estimates when dealing with different types of hazards. This month I'll discuss the **Fallout Radiation Dose Calculator**, specifically when it may be useful and how the tool is used in a real situation.

The tool is designed to estimate the amount of residual radiation an individual will be exposed to when entering a radioactively contaminated area after detonation of a fission nuclear device. While the likelihood of such an occurrence is remote, having access to such a tool is only prudent for those willing to contemplate the unthinkable.

The detonation of a nuclear device is always considered an extraordinary event, and when detonated within a civilian population the event, its consequences, and the actions taken by response personnel are anticipated to be beyond the scope and guidelines that Incident Commanders (IC) follow for other events. If such an event occurs, the IC may have to make the decision(s) as to whether or not to allow response personnel to make the entry into radioactively contaminated areas. The decisions will most likely be beyond the normal pre-planning and training that most response organizations conduct. There are some states and municipalities that have developed recommended guidelines for personnel when dealing with radioactive isotopes released during an accident or in event of the detonation of an RDD (radiological dispersion device) or "dirty bomb". While these events are very different than the detonation of a fission nuclear device, the guidelines developed with respect to maximum allowable radiological dosages may still apply. The **Fallout Radiation Dose Calculator** is provided only as a tool to assist the IC in making decisions and is not intended to suggest, set, or establish an acceptable hazard level.

There are typically two different types of nuclear devices, fission and thermonuclear (fusion). The fission devices are typically smaller and have yields from less than 1 kiloton up to several hundred kilotons. Fusion devices are typically much larger, with yields up to many megatons.

The PEAC tool **Fallout Radiation Dose Calculator** provides information on fission devices of the type used at the end of World War II or detonated at the Nevada Test Site during the 1950's.

As mentioned previously, there is also the instance of a radiologically contaminated area created by detonation of a RDD or an accidental release of radioactive isotopes.

IMPORTANT: The **Fallout Radiation Dose Calculator** is designed to provide estimates of exposure after a fission device is detonated, **not** after a thermonuclear (fusion) device is detonated. Because a fission device's products consist of a very complex mixture of ~300 different isotopes, the **Fallout Radiation Dose Calculator** is **not** to be used for guidance after detonation of a radiological dispersal device (RDD) or "dirty bomb", which is typically composed of only one or a limited number of different isotopes. For the same reason, the same caution applies to accidental releases of radioactive isotopes such as might occur in a transportation accident.

The decay rates used in the **Fallout Radiation Dose Calculator** are based on the atmospheric detonation of fission devices conducted at the Nevada Test Site during the 1950's. The assumption is that the fission devices have not been "spiked" with specific materials to increase the formation of special radioactive isotopes that would exhibit different decay rates than those reported during the Nevada Test Site detonations.

Background

When a fission nuclear device is detonated, there is an initial release of radiation, primarily gamma radiation and neutrons, which is an extraordinary event far exceeding any natural event. After the initial radiation release, which is typically over in less than a minute depending on the yield of the device, the basic radiation hazard is due to residual radiation. The residual radiation results from the creation of fallout particles, which are composed of the weapon residues that are radioactive plus the radioactivity induced in the soil, water, and other materials in the vicinity of the explosion.

In general, fallout is categorized as early or delayed. The early (or local) fallout is that which reaches the ground during the first day (24 hours) after a nuclear explosion, and because of their size most of the fallout is near the source of the detonation. The delayed (or long range) fallout is that reaching the ground after the first day. The delayed fallout typically consists of very fine, almost invisible particles which tend to remain suspended in the atmosphere but which settle out in low concentrations over a considerable portion of the earth's surface. The delayed fallout location is very dependent on weather conditions.

The Early Fallout

The early fallout from a fission nuclear device is characterized radiologically by the fission products, e.g., that produced from interaction of neutrons with any surrounding materials. As the fireball cools, the fission products and other vapors gradually condense on soil and other particles that were sucked up from the surface while the fireball rises in the air. For detonations over land, where the particles consist mainly of soil minerals, the fission product vapors condense onto both solid and molten soil particles and also onto other particles that may be present.

As previously mentioned, a fission device produces a mixture of ~300 isotopes. Most of these isotopes are radioactive, decaying by the emission of beta particles, frequently accompanied by gamma radiation. The total radioactivity of the fission products initially is extremely large but it decreases at a fairly rapid rate as the result of radioactive decay.

The early fallout consists of particles that are contaminated mainly, but not entirely, with fission products. In general the dose rate from a fixed quantity of the actual mixture decreases with time using the following approximate rule: for every sevenfold increase in time after the explosion, the dose rate decreases by a factor of ten. For example, if the radiation dose rate at 1 day after the explosion is taken as a reference point, then at 7 days after the explosion the dose rate will have decreased to one-tenth.

There are complications caused by fractionation plus the presence of induced activities that make the approximate rule useful only for illustration and some planning purposes. It's important to remember that any changes in the quantity of fallout, e.g., arising from the continuing descent or the removal of particles or from multiple detonations, would affect the dose rate. In any real fallout situation, it would be necessary to perform actual measurements repeated at suitable intervals to establish the level and the rate of decay of the radioactivity.

Any neutrons liberated in the fission process, and which are not involved in the propagation of the fission chain, are ultimately captured by the weapon residues through which they must pass before they can escape, such as nitrogen and oxygen in the atmosphere, and by various materials present on the earth's surface. This happens within the first minute of detonation. As a result of capturing neutrons many substances become radioactive and emit beta particles, frequently accompanied by gamma radiation, over an extended period of time following the explosion. Such neutron-induced activity, therefore, is part of the residual nuclear radiation.

The **Fallout Radiation Dose Calculator** deals only with external radiation exposures from gamma-ray sources outside the body. A user should keep in mind that some fallout could enter the body, by inhalation and ingestion, and so give rise to internal radiation exposures.

The Delayed Fallout

There is no distinct change at 24 hours after a nuclear explosion when the early fallout ends and the delayed fallout commences. There is an important difference between the two types of fallout. The principal early fallout hazard is from exposure to gamma rays from sources outside the body, although there is also a possibility of some internal exposure. A secondary hazard would arise from beta particles emitted by fallout in contact with the skin or through ingestion or inhalation. The delayed fallout is almost exclusively a potential internal hazard that would be due to the ingestion of iodine, strontium, and cesium isotopes present in food, and especially milk. Both early and delayed fallout can have long-term genetic effects, but they are probably of less significance than other expected consequences.

Fallout Patterns

Prediction of fallout patterns is a very complicated process and the results are affected by many factors that may or may not be known. Obviously wind speed and direction at different altitudes can cause significant modification to an “expected” fallout pattern. Other factors such as the dimension of the radioactive cloud, the distribution of radioactivity within the cloud and the range of particles sizes can impact a predicted pattern.

The condensed particle sizes created as the products cool will tend to dictate the rate of decent of the particles and the pattern will depend on the size distribution of these particles. Typically, the large particles fallout the fastest and tend to carry more radioactivity, so higher contamination levels are expected near ground zero than at greater distances. But as indicated above, the variability of winds at the cloud height plus at lower levels once the particles start to descend can modify predicted fallout patterns. Precipitation in the form of rain or snow can also have a major impact on fallout patterns. Because of these different factors, there may not be an expected fallout pattern that changes from high levels to low levels of radioactivity as the distance from the detonation point increases downwind. There may be one or more localized “hot spots” where high radioactivity levels are surrounded by relatively lower levels of radioactivity.

The **Fallout Radiation Dose Calculator**

For the discussion in the article, I’ll use the Windows version of the application for the screen shots, but the tool and its associated screens in the Pocket PC version are very similar and their functions are the same.

Using the **Fallout Radiation Dose Calculator** within the PEAC-WMD software application is easy to start by clicking on the **Fallout Radiation Dose Calculator** icon [] at the top of the main data window, Figure 1.

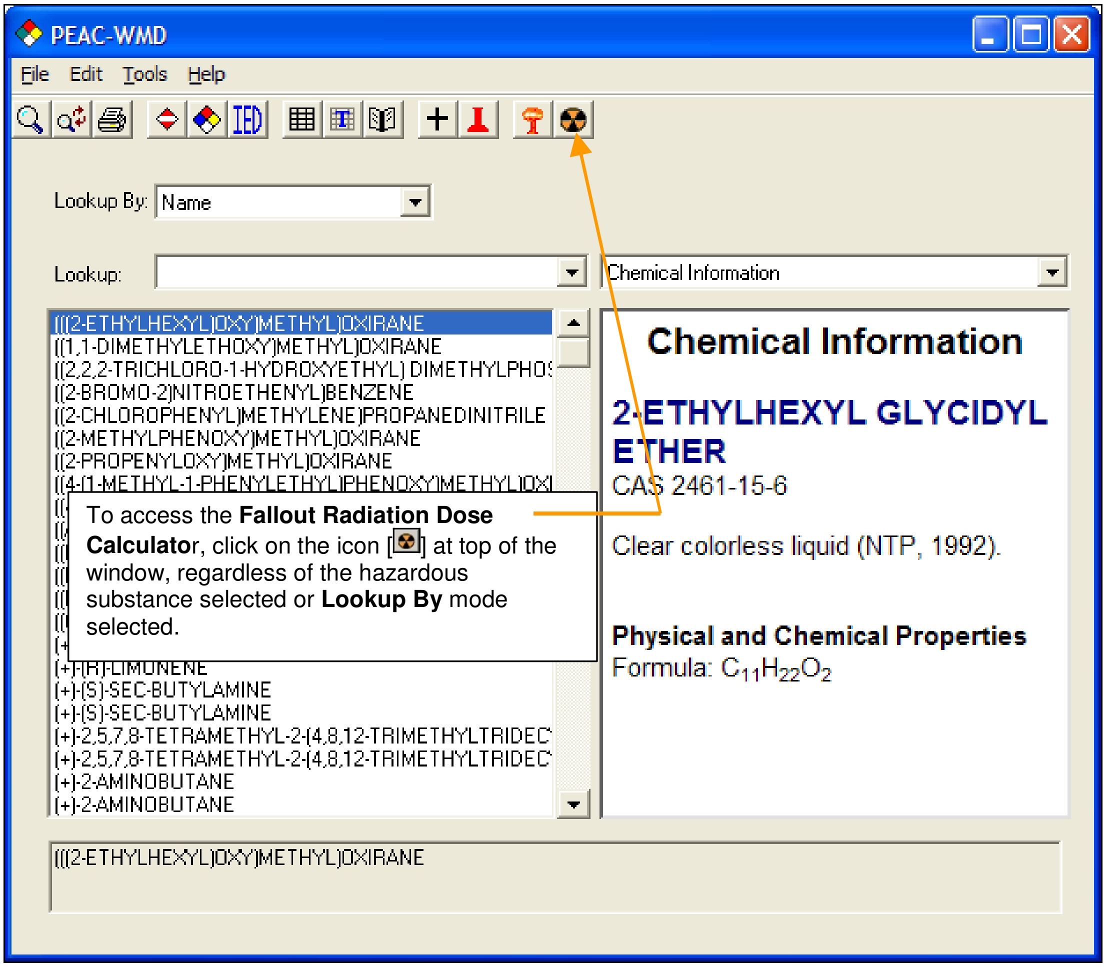


Figure 1 – Starting the Fallout Radiation Dose Calculator

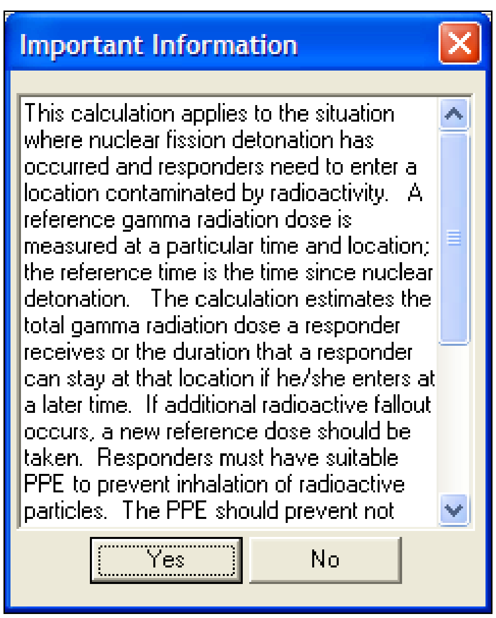


Figure 2 – Fallout Radiation Dose Calculator Disclaimer

The first time the **Fallout Radiation Dose Calculator** is executed during a session, a disclaimer window will appear (Figure 2). To continue, the user must acknowledge by clicking on the **[YES]** button. If they click on **[NO]** button, the **Fallout Radiation Dose Calculator** will not execute. The disclaimer window will not appear again if the calculator is called again. The disclaimer text is also displayed at the bottom of the report generated when the calculator is exited.

The **Fallout Radiation Dose Calculator** screen will be displayed with either the last values entered and calculated or the default values as shown in Figure 3. The user needs to provide four pieces of information for the **Fallout Radiation Dose Calculator** to estimate the radiation dose personnel will be exposed to when entering a radioactively contaminate area.

An initial radioactivity measurement must be taken before allowing personnel to enter a contaminated area. The measurement should be in the same area that personnel are expected to perform their duties. If measurements are taken at a different location than personnel will be performing duties, then the resulting estimates can be faulty. The elapsed time between the measurement for a reference radiation level and when personnel actually will be entering the contaminated region should also be considered. For instance, if a fission nuclear device is detonated and a measurement is made at 0.5 days (12 hours) after the detonation in a specific area where recovery activities may be planned, if the early fallout has not been completed, a measurement at 0.75 days (16 hours) after the detonation may indicate an increase in radiation level rather than a decrease. So timely measurement of radioactivity levels is the safest and prudent course of action. If measurements are continued and do not show an increase, particularly after 24 hours, then the early fallout phase can probably be considered completed.

The **Reference Time** is the time (days) since the detonation that the **Reference Radiation Rate (Ref Rad Rate)** is measured in the planned working area. The **Entry Time** (days) is the time since the detonation that the personnel will be entering the contaminated area to work. The **Entry Duration** is a time interval (days) that personnel are expected to be working in the contaminated area. The **Fallout Radiation Dose Calculator** will provide an estimated radiation dose (rads) based upon the typical decay rates measured in the past after detonation of a single fission nuclear device and assuming the early fallout is complete.

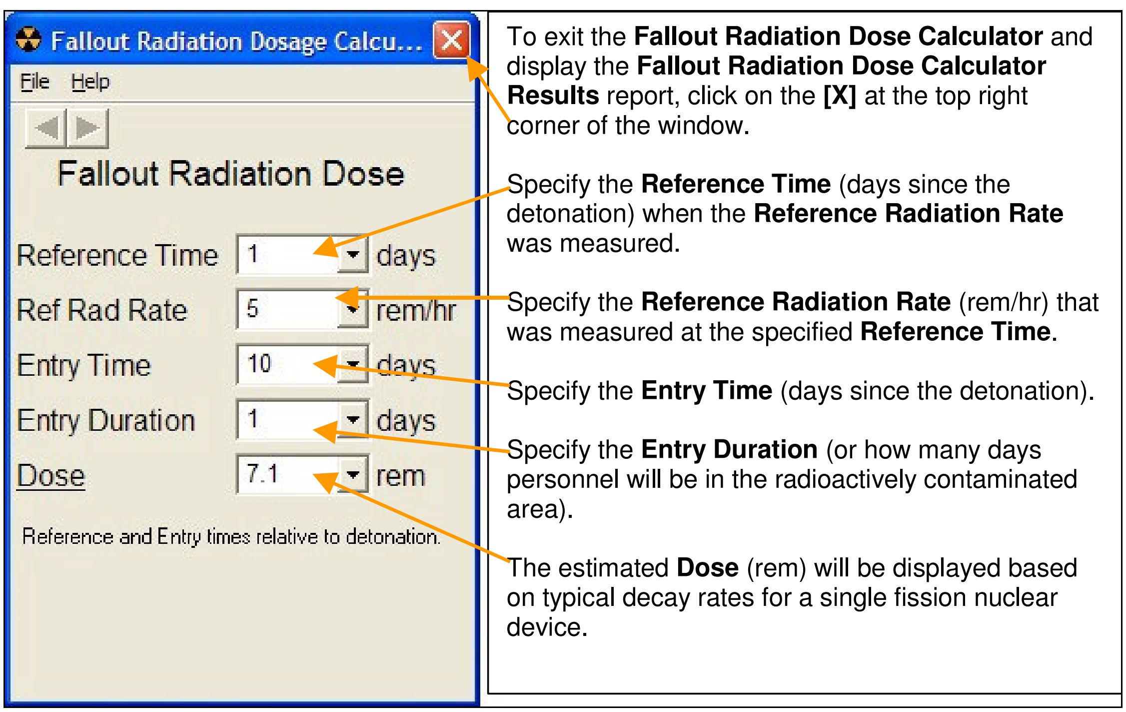
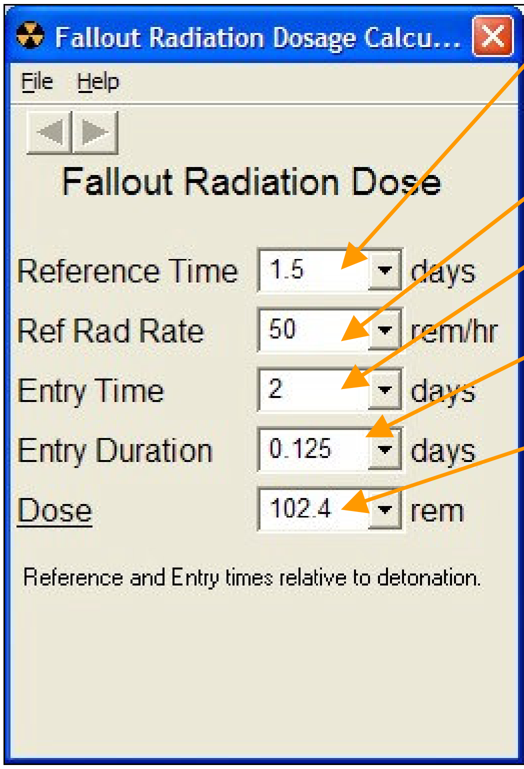


Figure 3 – Using the Fallout Radiation Dose Calculator

An example should help clarify how the calculator is used. Assume a fission nuclear device estimated to be 10 kilotons in yield was detonated at 8:00 AM (0800 hours) on day zero (0). After the initial effects (gamma radiation, neutron flux, blast wave, radiant heat flux) have subsided and the initial fallout has ceased, an aerial survey by helicopter has identified an area where fires are burning toward a structure crucial to the city's infrastructure. At 8:00 PM (2000 hours) on day one (1) the aerial survey of the area makes radiation measurements of 50 rem/hr. The decision is made to allow personnel with proper PPE ensembles into the area to perform basic fire fighting duties to save the structure within the same contaminated area. If the personnel are to enter the area at 8:00 AM (0800 hours) on day 2 and are expected to be in the area for 3 hours (this includes time for entry and exit), what is the estimated radiation dose they will be subjected to?

The key input parameters are the **Reference Time** (time in days since the detonation) which is 36 hours or 36/24=1.5 days, the **Reference Radiation Rate** which was measured at 50 rem/hr, the **Entry Time** (time in days since the detonation) which is 48 hours or 48/24=2.0 days, and the expected **Entry Duration** (in days) which is 3 hours or 3/24 = 0.125 days. Entering these values into **Radiation Dose Calculator** as shown in Figure 4 will provide the estimated radiation dose (rem) to which the personnel will be subjected.

The **Fallout Radiation Dose Calculator** can also calculate an estimated **Entry Duration Time** if the user enters a dose in rem that is allowable. When the dose value is provided, the **Fallout Radiation Dose Calculator** will solve for the estimated **Entry Duration Time** in days.



Reference Time is 36 hours or 1.5 days (detonation at 8AM on day 0 and measurement made at 8PM on day 1).

Reference Radiation Rate is 50 rem/hr.

Entry Time is 48 hours or 2 days (detonation at 8AM on day 0 and entry at 8AM on day 2).

Entry Duration is 3 hours or 0.125 days (specified by user).

Dose is calculated to be 102.4 rem.

Optionally the user can specify the allowed **Dose** and the application will calculate the appropriate **Entry Duration.**

Important: Users should remember to continue to take radiation measurements to monitor the contamination level.

Figure 4 – Example using the Fallout Radiation Dose Calculator

To exit the **Fallout Radiation Dose Calculator**, click on the **[X]** at the top right on the Calculator window, see Figure 3. A **Fallout Radiation Dose Results** report will be automatically generated and displayed in the **Data Display Field**, see Figure 5. As with all other information in the **Data Display Field**, this report can be printed or copied or be recalled at a later time as required.

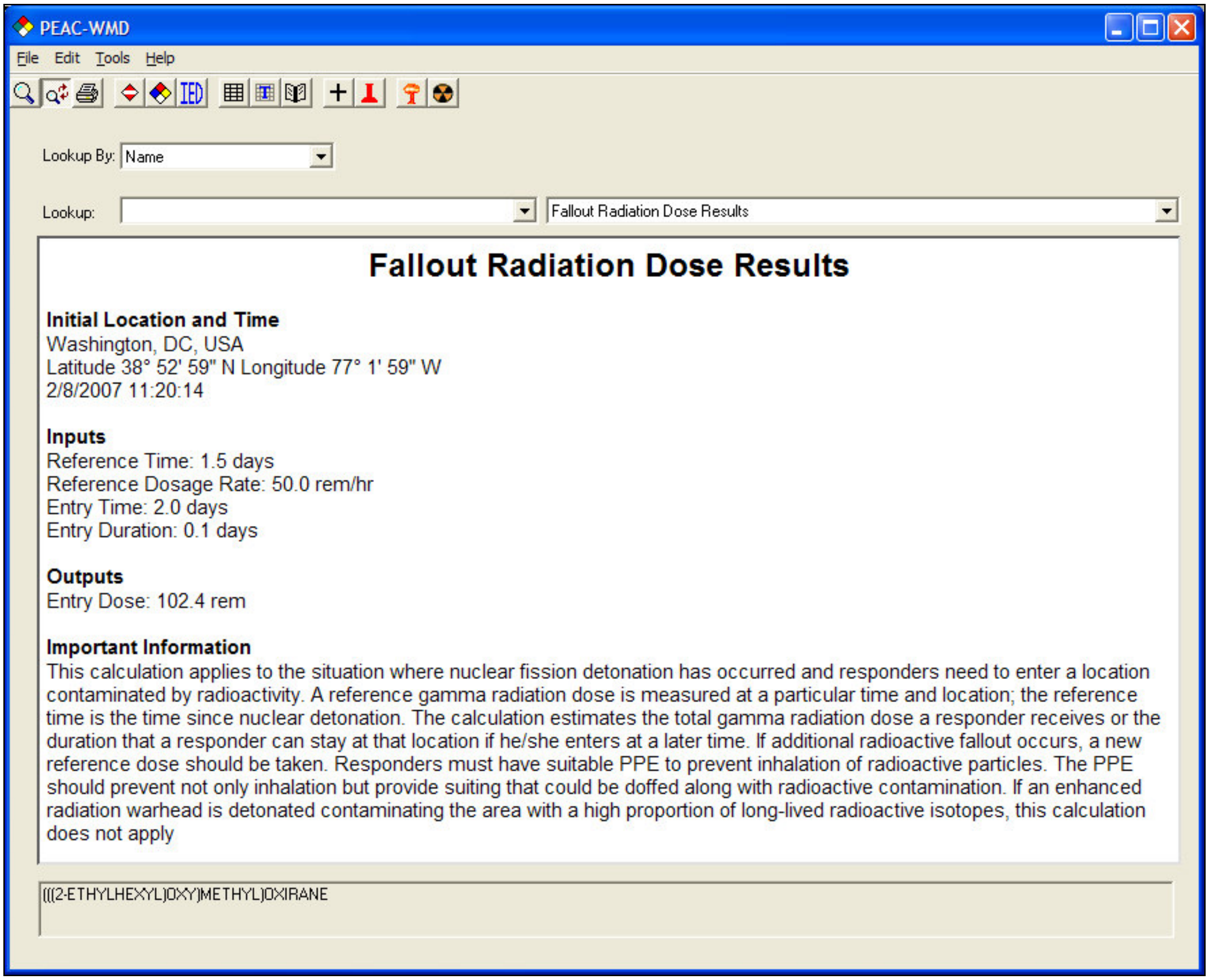


Figure 5 – Fallout Radiation Dose Calculator Results report

It is important to remember that this tool just provides estimates of expected radiation decay over a proposed time period. The individuals entering the contaminated area should be required to wear radiation dose devices and periodic radiation measurements should be made while in the contaminated area.

In this example, the estimated radiation dose may be greater than the IC or Safety Officer decides is appropriate for personnel even to protect a crucial structure to the city's infrastructure. The decision may change if lives are at stake and can be saved while being exposed to the same radiation dose. In any instance, the IC must make the decision as to whether or not the risk is acceptable considering the mission and should convey to response personnel the associated risk to which they may be exposing themselves. To that end, the following table is provided to describe the expected results from different radiation exposure levels. Also to assist the user the following relationship between the rad units, rem units, Sv units, and Gy units is provided.

100 rad = 100 cGy = 1000 mGy = 1 Gy = 1 Sv = 100 rem

Table 1 – Total Body External Doses*

Condition	mrem	mSv	rem	Sv
No observable effects	5,000	50	5	0.05
White count depression[1]	50,000	500	50	0.50
Symptom threshold[2]	100,000	1,000	100	1.00
Nearly 100% lethality[3]	600,000	6,000	600	6.00

*For brief exposures of penetrating x-ray or gamma rays to the total body
[1] Seen in circulating lymphocytes
[2] Individual variations
[3] Without treatment

Expected health effects for an adult assuming the cumulative total radiation exposure was all received within a week's time. For children, the effects can be expected at half these dose levels.

Table 2 – Exposure Symptoms

Total Exposure	Onset and Duration of Initial Symptoms and Disposition
30 to 70 Rem	From 6-12 hours: none to slight incidence of transient headache and nausea vomiting in up to 5 percent of personnel in upper part of dose range. Mild lymphocyte depression within 24 hours. Full recovery expected. (Fetus damage possible from 50R and above.)
70 to 150 Rem	From 2-20 hours: transient mild nausea and vomiting in 5 to 30 percent of personnel. Potential for delayed traumatic and surgical wound healing, minimal clinical effect. Moderate drop in lymphocyte, platelet, and granulocyte counts. Increased susceptibility to opportunistic pathogens. Full recovery expected.
150 to 300 Rem	From 2 hours to three days: transient to moderate nausea and vomiting in 20 to 70 percent; mild to moderate fatigability and weakness in 25 to 60 percent of personnel. At 3 to 5 weeks: medical care required for 10 to 50%. At high end of range, death may occur to maximum 10%. Anticipated medical problems include infection, bleeding, and fever. Wounding or burns will geometrically increase morbidity and mortality.
300 to 530 Rem	From 2 hours to three days: transient to moderate nausea and vomiting in 50 to 90 percent; mild to moderate fatigability in 50 to 90 percent of personnel. At 2 to 5 weeks: medical care required for 10 to 80%. At low end of range, less than 10% deaths; at high end, death may occur for more than 50%. Anticipated medical problems include frequent diarrhea stools, anorexia, increased fluid loss, ulceration. Increased infection susceptibility during immune-compromised time-frame. Moderate to severe loss of lymphocytes. Hair loss after 14 days.
530 to 830 Rem	From 2 hours to two days: moderate to severe nausea and vomiting in 80 to 100 percent of personnel; From 2 hours to six weeks: moderate to severe fatigability and weakness in 90 to 100 percent of personnel. At 10 days to 5 weeks: medical care required for 50 to 100%. At low end of range, death may occur for more than 50% at six weeks. At high end, death may occur for 99% of personnel. Anticipated medical problems include developing pathogenic and opportunistic infections, bleeding, fever, loss of appetite, GI ulcerations, bloody diarrhea, severe fluid and electrolyte shifts, capillary leak, hypotension. Combined with any significant physical trauma, survival rates will approach zero.
830 Rem Plus	From 30 minutes to 2 days: severe nausea, vomiting, fatigability, weakness, dizziness, and disorientation; moderate to severe fluid imbalance and headache. Bone marrow total depletion within days. CNS symptoms are predominant at higher radiation levels. Few, if any, survivors even with aggressive and immediate medical attention.

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http://media.msanet.com/NA/USA/PermanentInstruments/GasSensorsTransmitters/SafeSite/07-2095WhitePaperRadiation.pdf