Nuclear Detonation Calculator

In last month's newsletter, February 2007, I discussed the **Fallout Radiation Dose Calculator** that was a new feature in the in the latest version of the PEAC-WMD™ software released in October 2006. Another computational tool in the new version is the **Nuclear Detonation Consequences Calculator**. The calculator provides estimates of different types of damages associated with the detonation of a nuclear device. This month I'll discuss this tool, specifically when it may be useful, the type of information provided, and how the tool is used for exercises or a real situation.

The **Nuclear Detonation Calculator** is provided to assist users in three areas. The first area is in the planning, training and exercises targeted at how a response organization will react and utilize resources in a scenario involving the after effects of the detonation of a nuclear device. The second area is in the event of the discovery of a possible nuclear device prior to detonation and emergency management agencies have time and facilities available to warn the public with protective actions that may save lives and/or reduce injuries. The third area is dealing with the aftermath of a nuclear detonation by estimating the size of different damage areas and the injuries to be expected in those areas. 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.

There are multiple factors to be considered, e.g., the type of device, the yield of the device, and the location of the detonation of a nuclear device (ground level, elevated, sub-surface). For the **Nuclear Detonation Calculator** the assumption is that the device is a terrorist device and not a thermonuclear device delivered by some nation state via a missile or aircraft. While not completely an unrealistic scenario, the detonation effects of a thermonuclear device on the order of megatons are substantially greater than those of a smaller fission device that might be concealed in a smaller package and have a realistic chance of being smuggled into the country without being detected. The **Nuclear Detonation Calculator** assumes a fission device in the 0.5-1,000 kiloton yield range and it assumes the device is detonated at the ground level or at a low elevation, i.e., in an upper level of a tall building. A radiological dispersal device (RDD) or "dirty bomb" is not considered to be a nuclear device and the **Nuclear Detonation Calculator** would not be applicable to the detonation effects of such a device.

<u>Background</u>

Most of the material damage caused by a nuclear explosion at the surface or at a low or moderate altitude in the air is due primarily to the shock wave that accompanies the explosion. For comparison, a nuclear device will be contrasted to "high explosives," by convention; the energy released from a nuclear device is expressed in terms of equivalent TNT (a conventional "high explosive"). There are differences between blast damage from a TNT explosive and a nuclear device with a TNT energy equivalent. In general terms an explosion, whether a conventional "high explosive" or a nuclear explosion, results from the very rapid release of a large amount of energy within a limited space. The sudden release of energy causes a substantial increase in temperature and pressure, so that all the materials present are converted into hot, compressed gases. In conventional explosives the maximum temperatures may be 9,000°F while in a nuclear device the maximum temperature may be in excess of 10,000,000°F. At these high temperatures all the bomb materials are vaporized to gases. These gases, at the instant of explosion, are confined to the space occupied by the original weapon components and tremendous pressures are produced. These pressures are most likely on the order of millions of pounds per square inch. The gases expand rapidly and thus initiate a pressure wave (called a "shock wave") in the surrounding medium whether it is air, water, or earth. The magnitude of the shock wave and speed at which it travels are much greater than those produced by conventional explosives.

This is not the only difference between a conventional explosive device and a nuclear device.

Immediately after detonation, the nuclear device emits primarily X-rays that are absorbed within a few feet of the air (or other surrounding medium) and then reemitted from the fireball as thermal radiation (ultraviolet, visible, and infrared rays). The temperature of the interior immediately after the detonation reaches perhaps 10 million degrees and then begins to decrease, but the surface temperature of the fireball will rise emitting a short pulse (less than one second) of ultraviolet radiation. Afterwards, there will be a longer pulse of several seconds of ultraviolet, visible, and infrared radiation. The radiation from the second pulse causes fires and skin and eye damage to individuals some distance away from the source. The peak radiation emission from the second pulse occurs about 1 second after the detonation, and about 99% of the total thermal energy is emitted after 10 seconds. The heat and light flash essentially occurs in the first second. The peak light flash causing a retinal burn occurs faster than the eye can blink (about 0.25 seconds) for lower yield nuclear devices.

The initial nuclear radiation consists of gamma rays and neutrons produced during the first minute of a nuclear explosion. Neutron radiation is essentially completed during the first second. While the energy of gamma radiation and neutrons may make up only 3% of the total energy released, it can still account for a significant number of deaths. Essentially all of the neutrons reach their target within the first second of the detonation; therefore the evasive action of dropping to the ground probably would not help for neutrons because everything happens too fast.

Shielding is more complex; the neutrons must first be slowed down (an elastic scattering material such as one containing barium or iron which are best) and then adsorbed (water is good for this purpose). The density of shielding material should be considered, and in general the following indicates the relative shielding ability for some common materials: *lead > concrete > dirt > water > wood*. Any one of these may be used to provide an effective shield against gamma radiation and are sometimes rated with the “tenth-value” thickness, in inches. This means that the gamma radiation that passes through the specified thickness is reduced to 1/10th as much gamma as what was exposed to the barrier. The 1/10th thickness values for the most common materials are:

Concrete = 12
Earth = 16
Damp earth = 18
Water = 24
Wood = 38

The neutron capture is accompanied by gamma emission. Both gamma radiation and neutrons also undergo scattering in the air so that the shielding must be provided in all directions.

Twelve inches of concrete (on all sides) should reduce gamma radiation intensity by a factor of 10; twenty four inches by a factor of 100. Therefore, the interior lower floors of reinforced buildings may provide a 50 to 300-fold protection from radiation compared with an individual outside. A basement in a one-story house could offer a 15-fold protection factor. The subbasement of multistory building could offer a 1,000-protection factor.

The **Nuclear Detonation Calculator**

The **Nuclear Detonation Calculator** within the PEAC-WMD software application is easy to use by clicking on the **Nuclear Detonation Calculator** icon [ ] at the top of the window, Figure 1, which is always displayed, regardless of what **Lookup By** mode is selected or what hazardous substance is selected.

The first time the **Nuclear Detonation Calculator** is executed during a session, a warning window will appear (Figure 2). To continue, the user must acknowledge by clicking on the **[YES]** button. If they click on **[NO]** button, the **Nuclear Detonation 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.

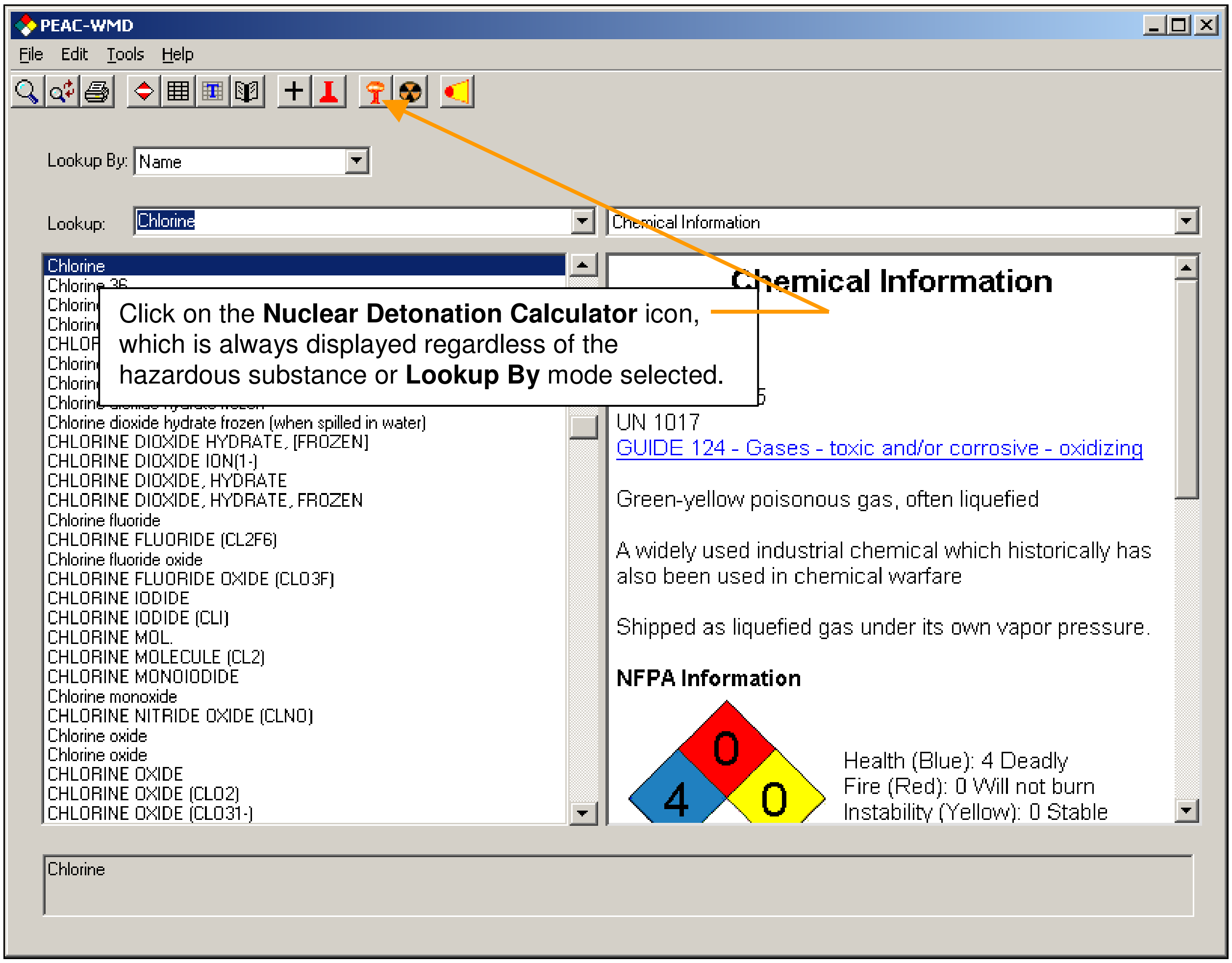


Figure 1 – Starting the Nuclear Detonation Calculator

A window similar to Figure 3 will appear which allows the user to estimate the **Yield** of the nuclear device that has detonated by using different methods.

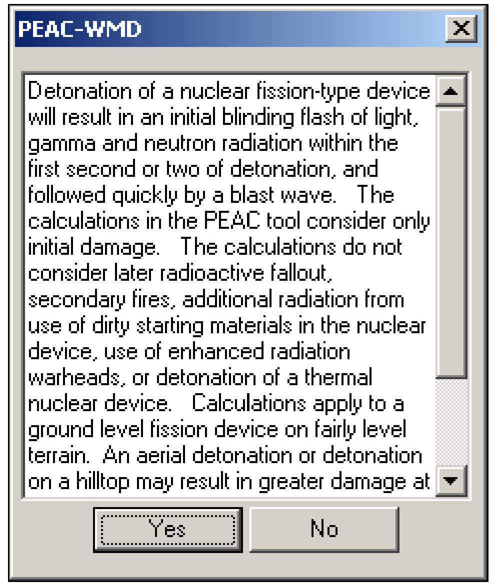
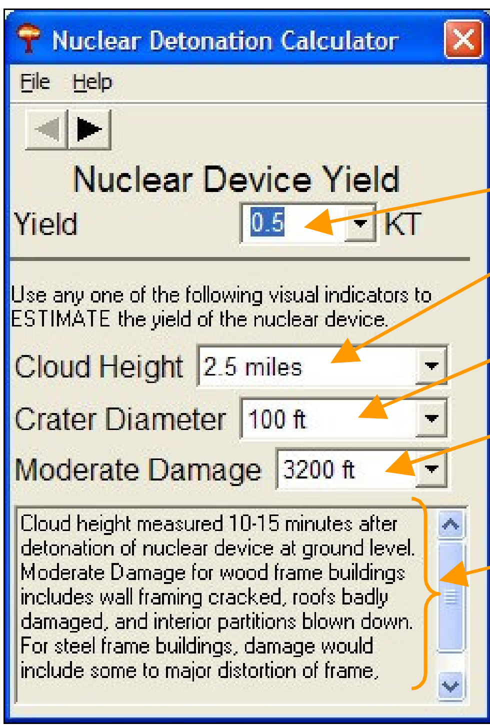


Figure 2 – Nuclear Detonation Calculator Disclaimer

To assist the user in estimating the yield of the detonated nuclear device, the **Nuclear Detonation Calculator** has for five (5) different default yields built into the application. The default values are for 0.5, 1, 10, 100 and 1,000 kiloton devices. The yield of the detonated nuclear device can be estimated by one of three methods as denoted in Figure 3.



The user must first provide an estimate of the yield of the nuclear device that was detonated. This can be done by either:

1. Selecting a yield from the drop-down list or entering a value in the Yield field, or
2. Selecting an observed Cloud Height (typically defined at maximum which is 10-15 minutes after detonation), or
3. Selecting an approximate crater diameter created by the detonation, or
4. Selecting the distance from ground zero where moderate damage to buildings are encountered.

The Cloud Height estimation time and the description of moderate damage is provided below the Moderate Damage input field.

Figure 3 – The Nuclear Detonation Calculator input screen

The user can estimate the approximate **Cloud Height** obtained after the detonation of the nuclear device. The **Cloud Height** is typically obtained within approximately 10-15 minutes after the detonation. As shown in Figure 4, there are five default **Cloud Height** values provided for the five default **Yields**. If the user is going to use **Cloud Height** to estimate the **Yield** of the nuclear device, one of these values must be selected. The application will not allow intermediate **Cloud Heights** to be entered.

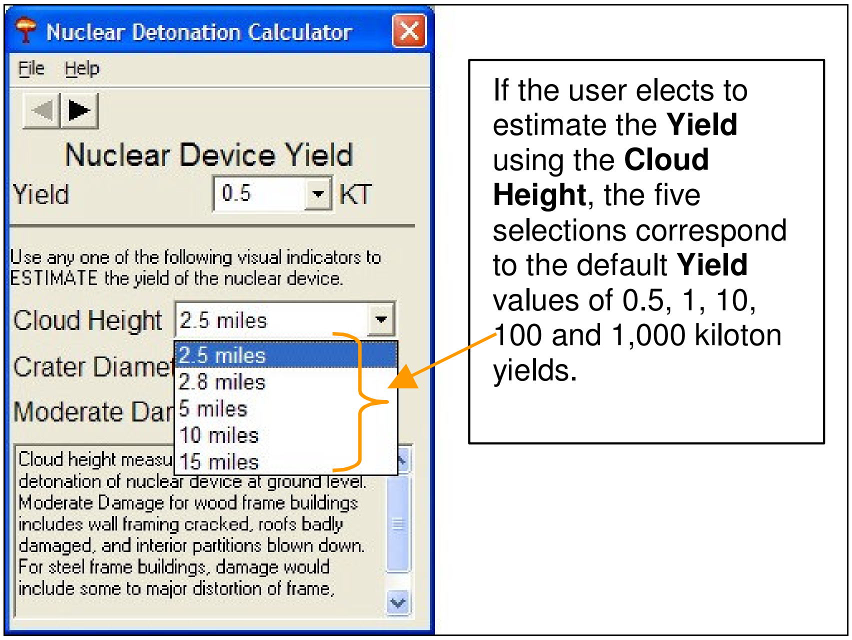


Figure 4 – Estimating the Yield using the Cloud Height

A second method for estimating the **Yield** of a nuclear device is by the **Crater Diameter** created when the device is detonated. This information may be unavailable or unobservable for some time period after the detonation due to high radiation levels, and immediate damage (fires and blast effects) in the ground-zero area. As shown in Figure 5, there are five default **Crater Diameter** values provided for the five default **Yields**. If the user is going to use **Crater Diameter** to estimate the **Yield** of the nuclear device, one of these values must be selected. The application will not allow intermediate **Crater Diameters** to be entered.

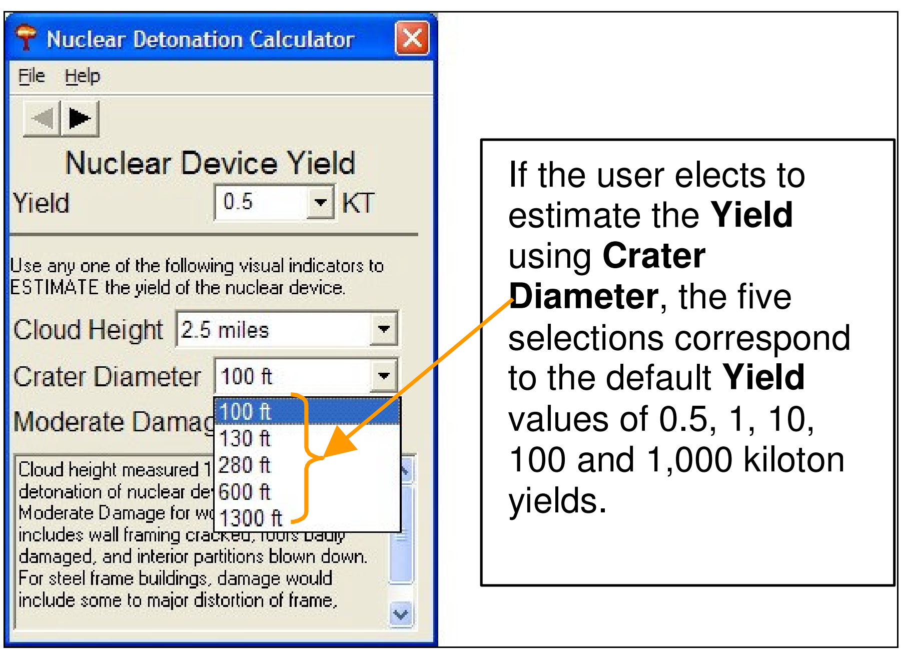


Figure 5 – Estimating the Yield using the Crater Diameter

A third method for estimating the **Yield** of a nuclear device is by the distance from ground-zero to the observed **Moderate Damage** created when the device is detonated. This information may be observable shortly after the detonation since it is observed at a greater distance from ground-zero. As shown in Figure 6, there are five default **Moderate Damage** distance values provided for the four default **Yields**. If the user is going to use **Moderate Damage** to estimate the **Yield** of the nuclear device, one of these values must be selected. The application will not allow intermediate **Moderate Damage** distances values to be entered.

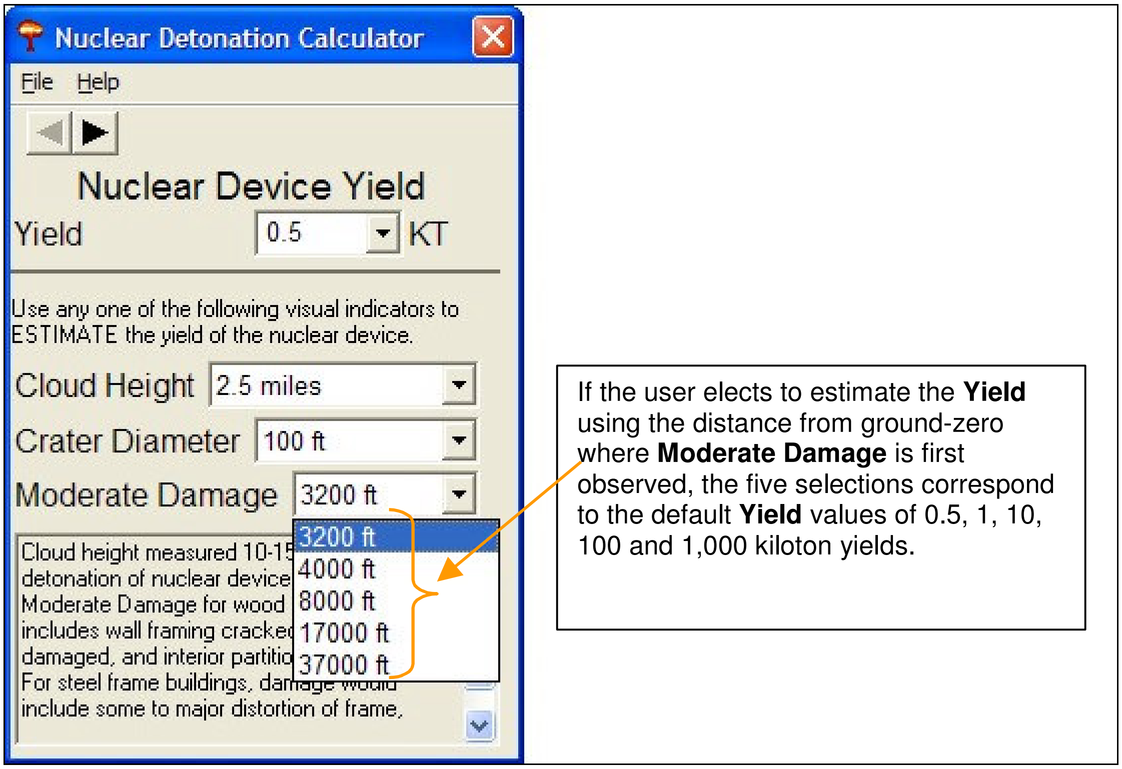


Figure 6 – Estimating the Yield using the distance from ground-zero to Moderate Damage

The **Nuclear Detonation Calculator** will accept and then calculate post-detonation effects using the **Yield** value. Which of these three methods is used is up to the user, but the possible **Yields** are the default values of 0.5, 1, 10, 100 or 1,000 kilotons. A fourth method is available when the user enters a **Yield** value between 0.5 and 1,000 kilotons in the entry field for **Yield**. The Incident Commander may also obtain this value from Department of Energy or the military that have access to additional information or sensor systems that can provide a reliable **Yield** value, e.g., a Nuclear Emergency Search Team (NEST) manned by the Department of Energy/National Nuclear Security Administration Laboratories personnel.

If a **Yield** value different than the default values is entered by the user, the **Nuclear Detonation Calculator** will display the value and blank out the **Cloud Height, Crater Diameter** and **Moderate Damage** values as shown in Figure 7.

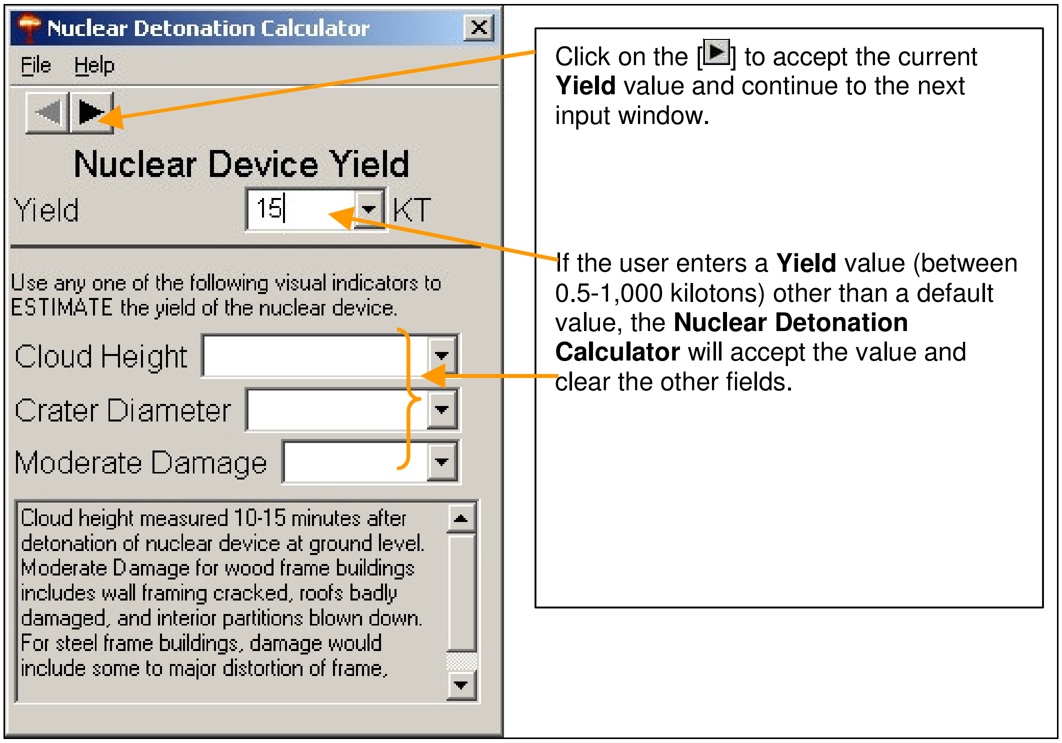


Figure 7 – Accepting a non-default Yield value

Regardless of which method is used, the user clicks on the [▶] arrow at the top left of the **Calculator** window to display the next input window, see Figure 8.

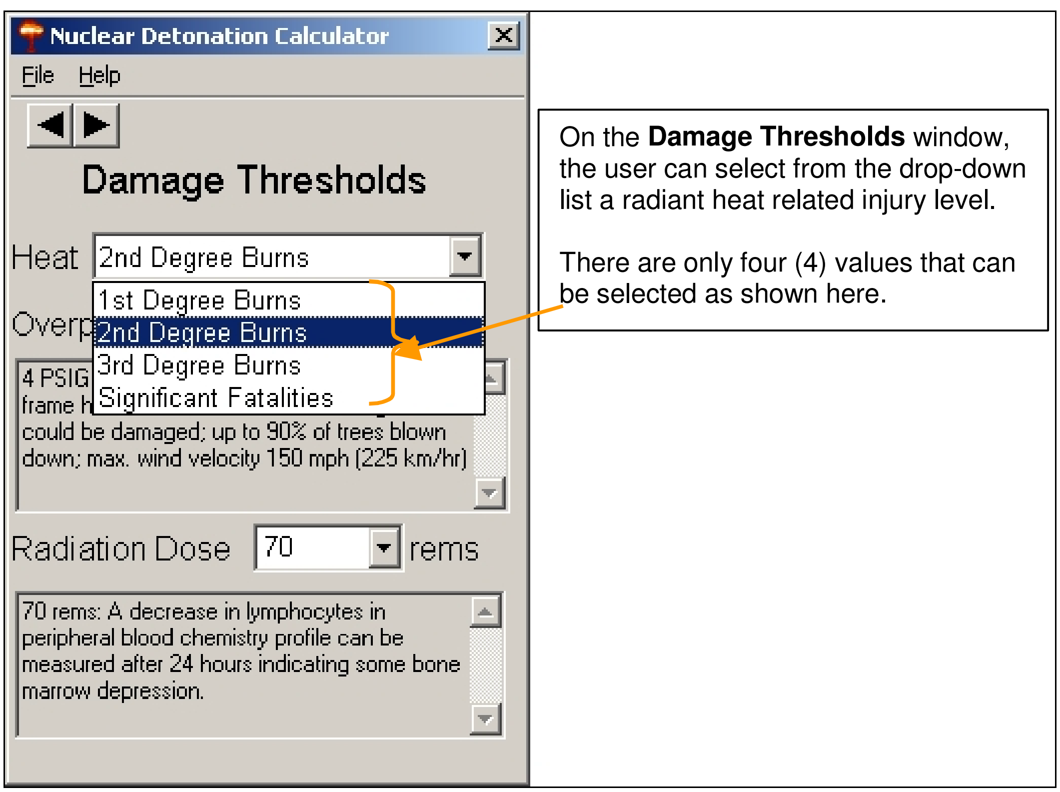


Figure 8 – Entering a Radiant Heat Injury

The next window requests input for Levels of Concern for each of three areas: expected **Radiant Heat** injuries**; Overpressure** value associated with the blast wave (shock wave); and total **Radiation Dose** level from the gamma radiation and neutrons released during the initial detonation of the nuclear device (does not include radiation dose from fallout). Based on these values provided and the estimated **Yield** provided on the previous input window, the application calculates a conservative maximum distance from ground-zero where each of these effects would occur.

The first value requested is the type of **Radiant Heat** related injuries observed on individuals. As shown in Figure 8, the user has four selections available from the drop-down list of selections.

For **Overpressure** selection the user has the option of selecting values from a drop-down list or entering a value in the field (valid values are from 0.5 to 100 psig). When the user selects a value from the list, a description of the type of damage expected from that overpressurization level will be displayed in the bottom of the **Nuclear Detonation Calculator** window, see Figure 9.

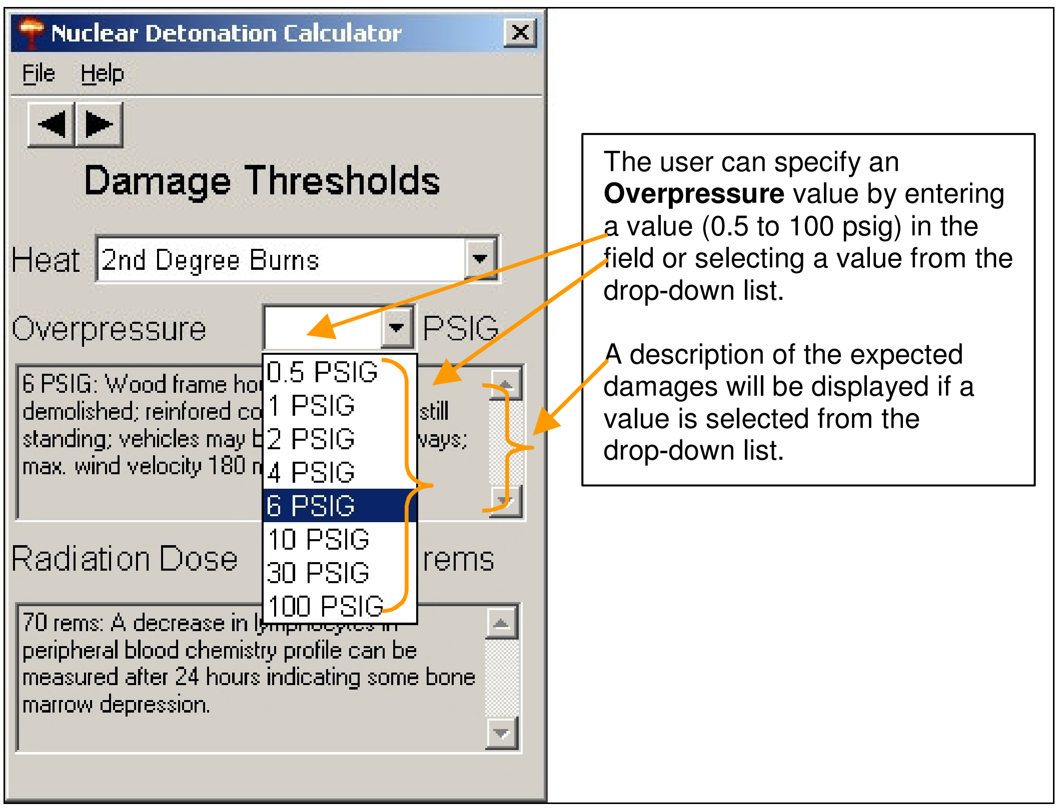


Figure 9 – Selecting an Overpressure Level of Concern

The last user selection is the Level of Concern for the total **Radiation Dose** received from the initial detonation of the nuclear device, Figure 10. The assumption is that the total **Radiation Dose** includes both the gamma radiation and neutrons released during the first minute after the detonation and does not include any radiation dose from fall out which may be delayed from minutes to hours to days after the detonation. The calculation also assumes there is no shielding involved although a user could assume individuals in shielded areas would receive a lower total **Radiation Dose** depending on their location and type of structure and the associated shielding it provided.

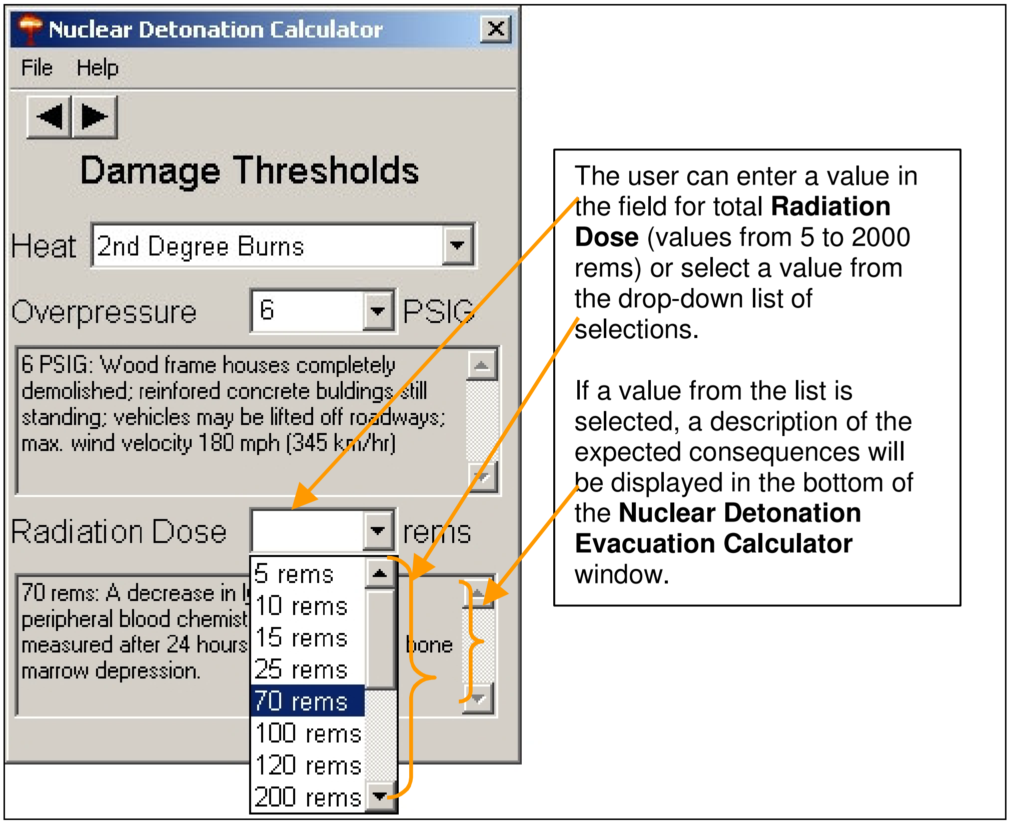


Figure 10 – Selecting a Radiation Dose value

At this point, the user can click on the [▶] at the top of the window (Figure 11) and the next window will be displayed.

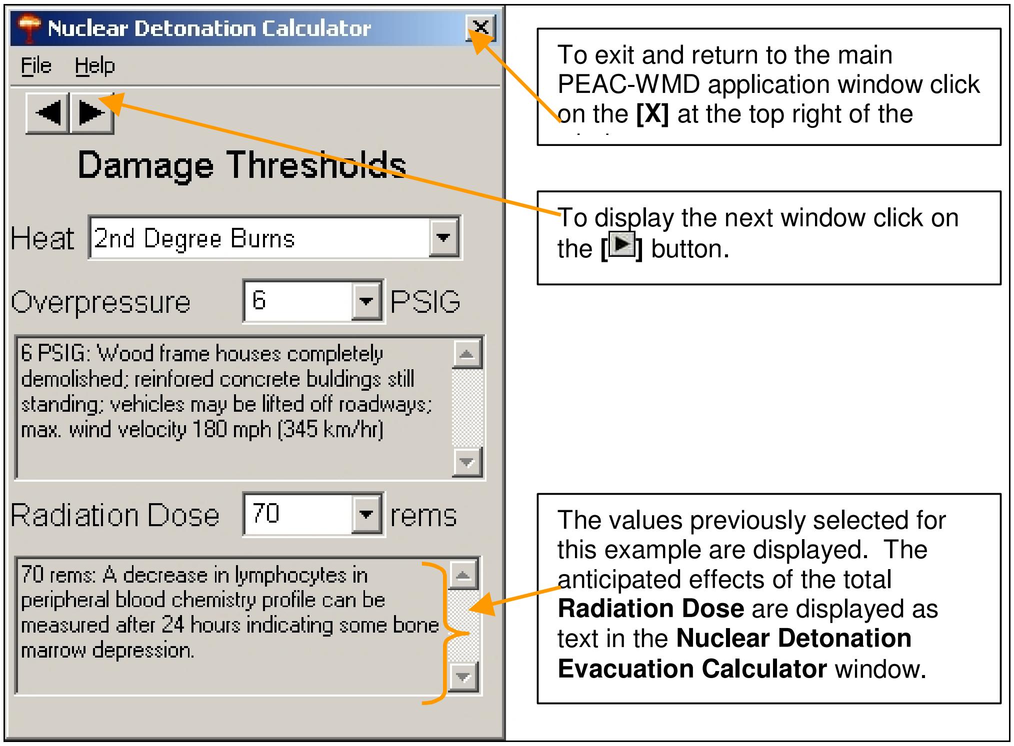


Figure 11 – Moving to the results of Nuclear Detonation Calculator

Since the **Nuclear Detonation Calculator** calculates appropriate distances based on the radiant heat, overpressure, and radiation dose values, it is possible to generate a SHAPE file for display on a GIS or mapping application. If a GPS is connected or available for entering a latitude and longitude a window similar to one of those shown in Figure 12 will be displayed.

Please Note: - For a nuclear device detonation the distance to ground zero may be on the order of miles or kilometers. There are 5280 feet/mile or 1000 meters/kilometer.

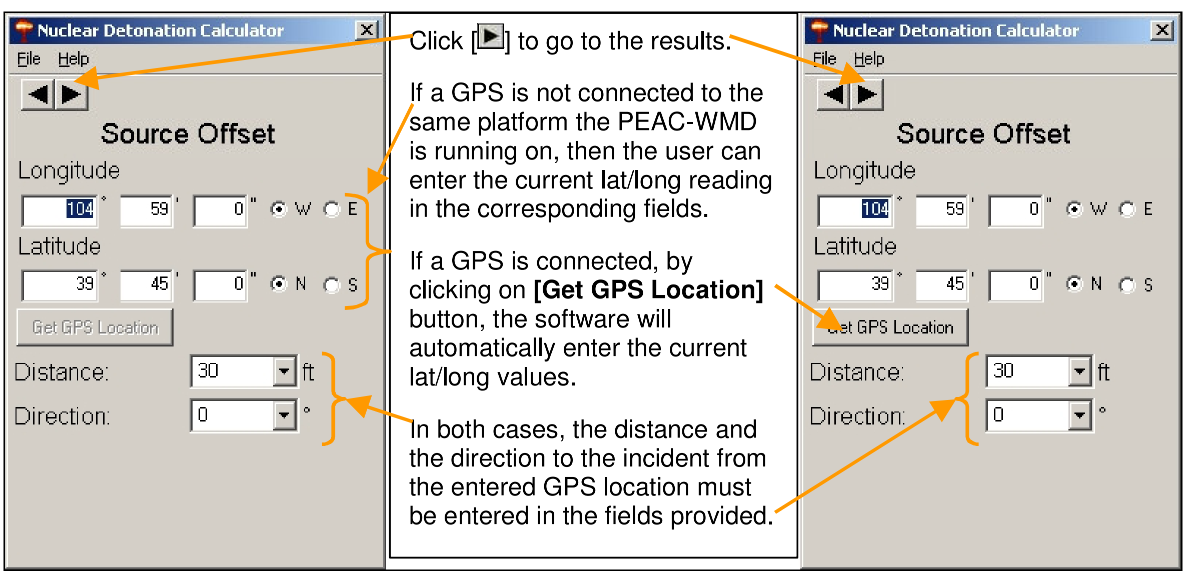
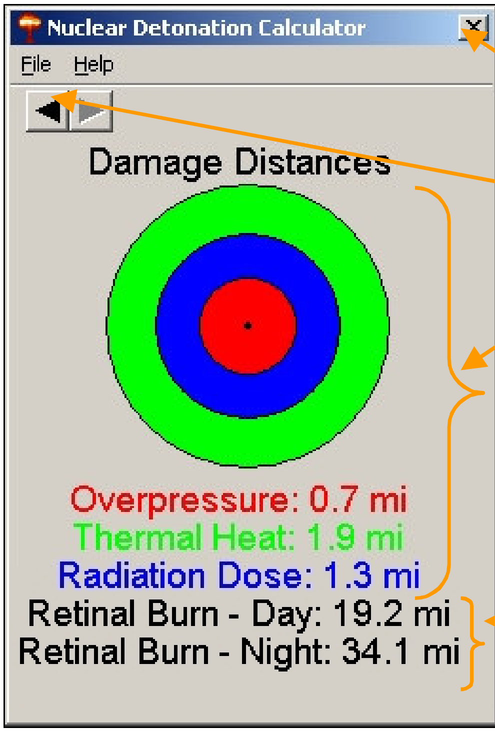


Figure 12 - Providing a location of the incident for a SHAPE file

If there is not GPS connected or available, then a window similar to Figure 12 will not appear and the **Nuclear Detonation Calculator** results window will appear (Figure 13).



Click on the **[X]** at the top right to return to the main PEAC-WMD window and display the **Nuclear Detonation Calculator Results** report.

Click on the [◄] button to return to the input windows to modify an input value.

The calculated distances from ground-zero to the outside edge of the zone where the specific Level of Concerns for damages related to **Overpressure**, thermal **Heat** injury, total **Radiation Dose** are displayed in the three different colors. The calculated distances are displayed next to each category of damage.

In addition, distances for retinal burns for day and night conditions are also displayed.

Figure 13 – The results of the Nuclear Detonation Calculator for different damage types

The information shown in Figure 13 are the results from the calculations based on the specified **Yield** (15 kilotons), and the Levels of Concern specified for the **Overpressure** (6 psi), thermal **Heat** injury (2^{nd} degree burns), and the total **Radiation Dose** (70 rems) from gamma radiation and neutrons exposure during the first minute after the nuclear detonation. The results are presented in both a graphical format and the associated distances with the values being color coded to assist the user in relating the various distances to the different damage assessments. The distances for expected retinal burns (both day and night conditions) are provided as a text value only, since the retinal burns are expected to extend an order of magnitude or more beyond the other effects.

Immediately and automatically after the results of the **Nuclear Detonation Calculator** are displayed as shown in Figure 13, another window is displayed with the same concentric circles to scale overlaid on a local street map, Figure 14. There are icons on the **PEAC Map Tool** that allow the user to zoom in/out or re-center the ground-zero location on the map.

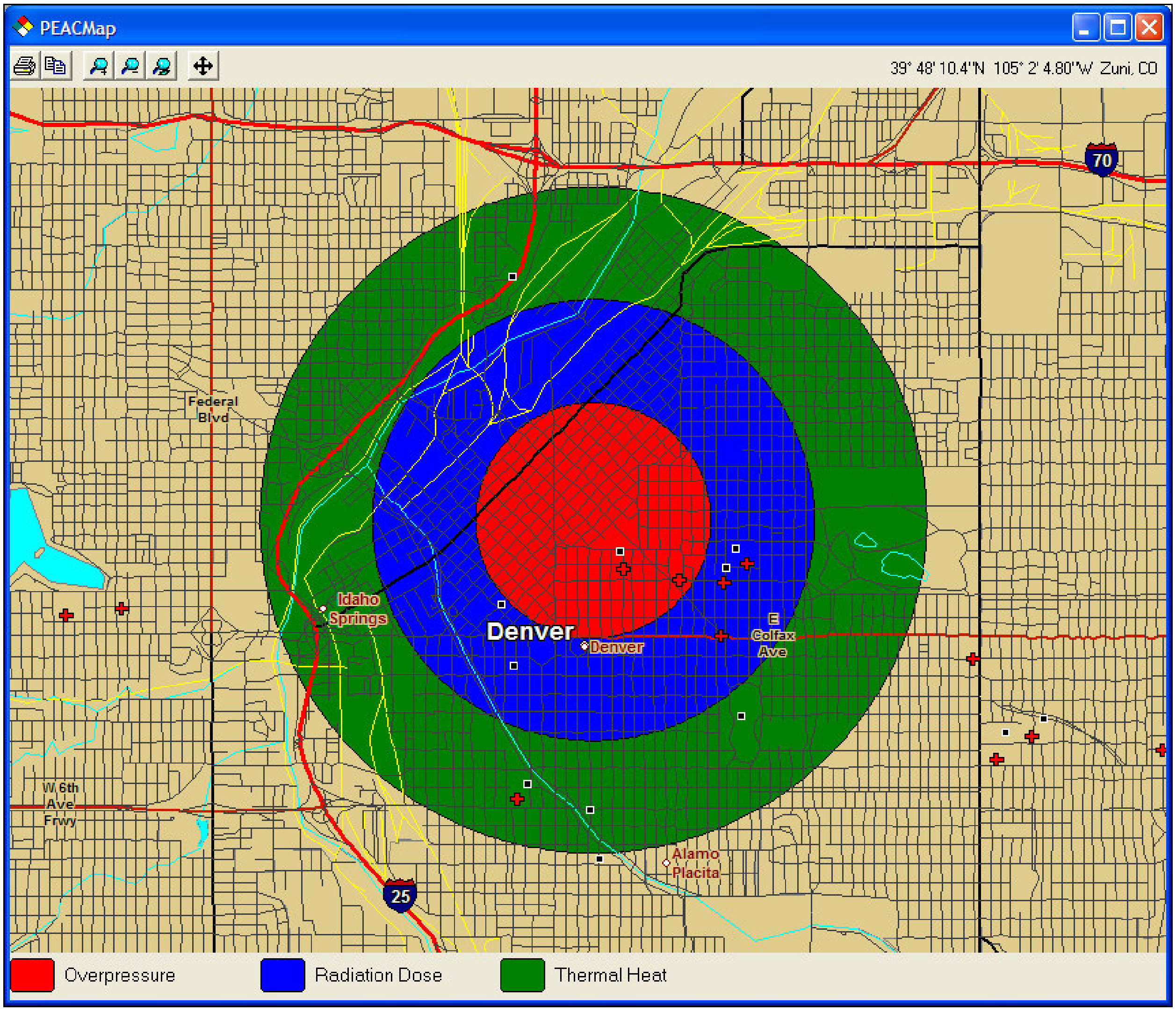


Figure 14 – Results displayed on the PEAC Map Tool

The user can return to an earlier input window to change a value by clicking on the **[◄]** button. To return to the main PEAC-WMD window, the user clicks on the **[X]** button at the top right of the window. This action will display a **Nuclear Detonation Results** report in the **Data Display** portion of the PEAC-WMD window, see Figure 15. Similar to the **Explosion** and **Fireball Calculators** there is also a table appended to the end of the **Results Report** that provides estimated distances to other damage thresholds. This report can be printed or recalled later using the **Prior Results** selection from the **Data Display** selection list.

When the **Nuclear Detonation Calculator Results** report is generated, there is also a SHAPE file created that can be imported into a GIS or mapping application that accepts an ESRI standard SHAPE file. The SHAPE files are created on the local hard drive of the PC the PEAC-WMD application is running on. The path name is *My Documents\PEAC\Results\Shapes* and the files have a prefix of ND (for Nuclear Detonation) on the time stamped name using the date and time formatted as yyyy*mmdd_hhmmss*.

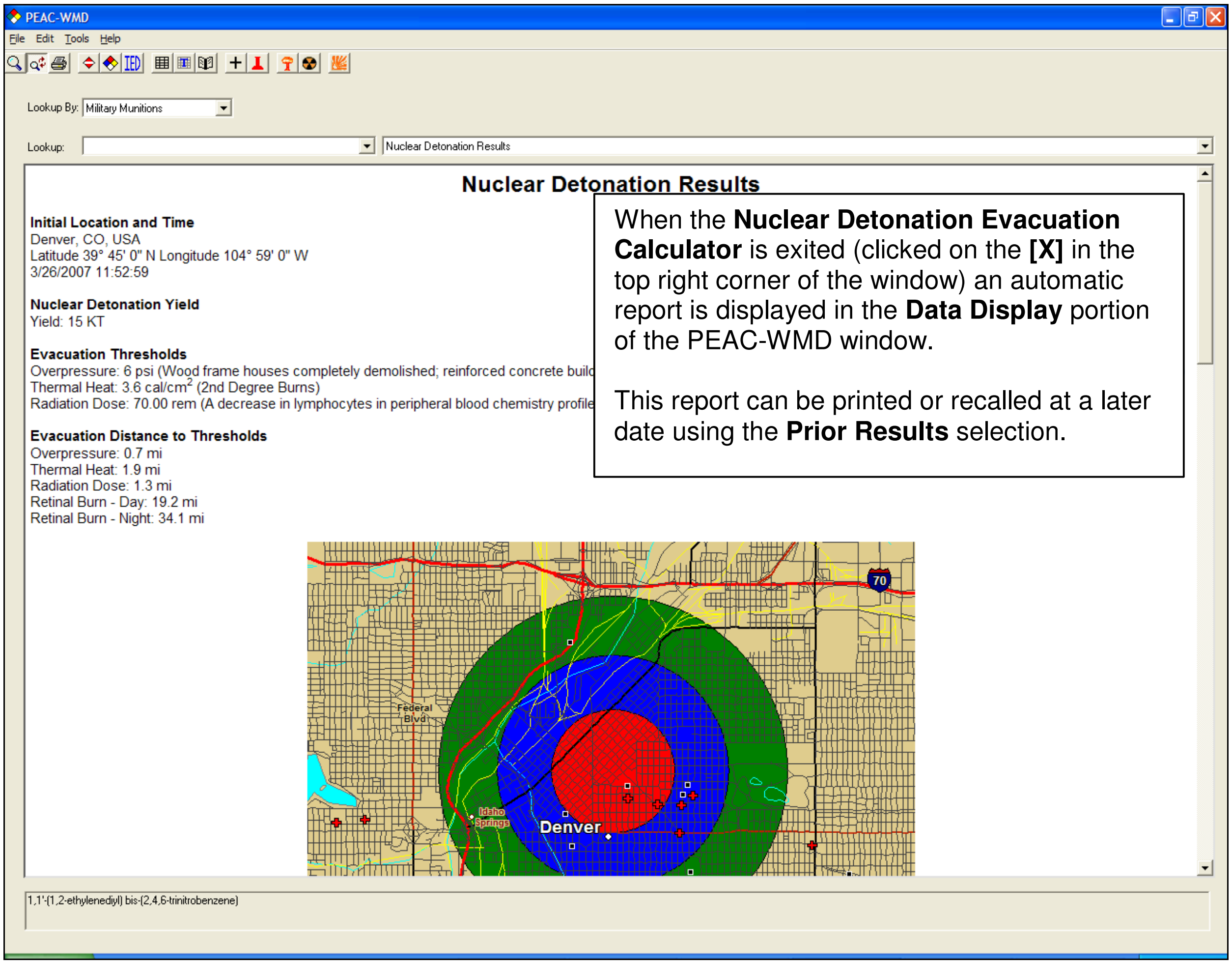


Figure 15 – Automatic report that can be printed or recalled later

The tool is designed to provide the user with critical information quickly and in a useable and understandable format with a minimal amount of input. From a training or exercise viewpoint it provides participants with information that may not be easily produced from other means or sources and can provide valuable input when planning for the unthinkable.