**Effects of Nuclear Explosions**

Nuclear explosions produce both immediate and delayed destructive effects. Immediate effects (blast, thermal radiation, prompt ionizing radiation) are produced and cause significant destruction within seconds or minutes of a nuclear detonation. The delayed effects (radioactive fallout and other possible environmental effects) inflict damage over an extended period ranging from hours to centuries, and can cause adverse effects in locations very distant from the site of the detonation.

The three categories of immediate effects are: blast, thermal radiation (heat), and prompt ionizing or nuclear radiation. Their relative importance varies with the yield of the bomb.

The underlying principles behind these scaling laws are easy to explain. The fraction of a bomb's yield emitted as thermal radiation, blast, and ionizing radiation are essentially constant for all yields, but the way the different forms of energy interact with air and targets vary dramatically.

Air is essentially transparent to thermal radiation. The thermal radiation affects exposed surfaces, producing damage by rapid heating. A bomb that is 100 times larger can produce equal thermal radiation intensities over areas 100 times larger. Blast effect is a volume effect. The blast wave deposits energy in the material it passes through, including air. When the blast wave passes through solid material, the energy left behind causes damage. When it passes through air it simply grows weaker. The more matter the energy travels through, the smaller the effect. The amount of matter increases with the volume of the imaginary sphere centered on the explosion. Blast effects thus scale with the inverse cube law which relates radius to volume.

The intensity of nuclear radiation decreases with the inverse square law like thermal radiation. However nuclear radiation is also strongly absorbed by the air it travels through, which causes the intensity to drop off much more rapidly.

In the Hiroshima attack (bomb yield approx. 15 kt) casualties (including fatalities) were seen from all three causes. Burns (including those caused by the ensuing fire storm) were the most prevalent serious injury (two thirds of those who died the first day were burned), and occurred at the greatest range. Blast and burn injuries were both found in 60-70% of all survivors. People close enough to suffer significant radiation illness were well inside the lethal effects radius for blast and flash burns, as a result only 30% of injured survivors showed radiation illness. Many of these people were sheltered from burns and blast and thus escaped their main effects. Even so, most victims with radiation illness also had blast injuries or burns as well.

With yields in the range of hundreds of kilotons or greater (typical for strategic warheads) immediate radiation injury becomes insignificant. Dangerous radiation levels only exist so close to the explosion that surviving the blast is impossible. On the other hand, fatal burns can be inflicted well beyond the range of substantial blast damage. A 20 megaton bomb can cause potentially fatal third degree burns at a range of 40 km, where the blast can do little more than break windows and cause superficial cuts.

**Radioactive Contamination**

The chief delayed effect is the creation of huge amounts of radioactive material with long lifetimes (half-lives ranging from days to millennia). The primary source of these products is the debris left from fission reactions. A potentially significant secondary source is neutron capture by non-radioactive isotopes both within the bomb and in the outside environment.

A useful rule-of-thumb is the ‘rule of sevens’. This rule states that for every seven-fold increase in time following a fission detonation (starting at or after 1 hour), the radiation intensity decreases by a factor of 10. Thus after 7 hours, the residual fission radioactivity declines 90%, to one-tenth its level of 1 hour. After 7x7 hours (49 hours, approx. 2 days), the level drops again by 90%. After 7x2 days (2 weeks) it drops a further 90%; and so on for 14 weeks. The rule is accurate to 25% for the first two weeks, and is accurate to a factor of two for the first six months. After 6 months, the rate of decline becomes much more rapid.

These radioactive products are most hazardous when they settle to the ground as ‘fallout’. The rate at which fallout settles depends very strongly on the altitude at which the explosion occurs and to a lesser extent on the size of the explosion.

If the explosion is a true air-burst (the fireball does not touch the ground), when the vaporized radioactive products cool enough to condense and solidify, they will do so to form microscopic particles. These particles are mostly lifted high into the atmosphere by the rising fireball, although significant amounts are deposited in the lower atmosphere by mixing that occurs due to convective circulation within the fireball. The larger the explosion, the higher and faster the fallout is lofted, and the smaller the proportion that is deposited in the lower atmosphere. For explosions with yields of 100 kt or less, the fireball does not rise above the troposphere where precipitation occurs. All of this fallout will thus be brought to the ground by weather processes within months at most (usually much faster).

In the megaton range, the fireball rises so high that it enters the stratosphere. The stratosphere is dry, and no weather processes exist there to bring fallout down quickly. Small fallout particles will descend over a period of months or years. Such long-delayed fallout has lost most of its hazard by the time it comes down, and will be distributed on a global scale.

An explosion closer to the ground (close enough for the fireball to touch) sucks large amounts of dirt into the fireball. The dirt usually does not vaporize, and if it does, there is so much of it that it forms large particles. The radioactive isotopes are deposited on soil particles, which can fall quickly to earth. Fallout is deposited over a time span of minutes to days, creating downwind contamination both nearby and thousands of kilometers away. The most intense radiation is created by nearby fallout, because it is more densely deposited, and because short-lived isotopes haven't decayed yet. Weather conditions can affect this considerably of course. In particular, rainfall can ‘rain out’ fallout to create very intense localized concentrations. Both external exposure to penetrating radiation and internal exposure (ingestion of radioactive material) pose serious health risks.

Explosions close to the ground that do not touch it can still generate substantial hazards immediately below the burst point by neutron-activation. Neutrons absorbed by the soil can generate considerable radiation for several hours.

The megaton class weapons that were developed in the US and USSR during the fifties and sixties have been largely retired, being replaced with much smaller yield warheads. The yield of a modern strategic warhead is, with few exceptions, now typically in the range of 200-750 kt. Recent work with sophisticated climate models has shown that this reduction in yield results in a much larger proportion of the fallout being deposited in the lower atmosphere, and a much faster and more intense deposition of fallout than had been assumed in studies made during the sixties and seventies. The reduction in aggregate strategic arsenal yield that occurred when high yield weapons were retired in favor of more numerous lower yield weapons has actually increased the fallout risk.

**Effects on the Atmosphere and Climate**

The high temperatures of the nuclear fireball followed by rapid expansion and cooling, cause large amounts of nitrogen oxides to form from the oxygen and nitrogen in the atmosphere (very similar to what happens in combustion engines). Each megaton of yield will produce some 5000 tons of nitrogen oxides. The rising fireball of a high kiloton or megaton range warhead will carry these nitric oxides well up into the stratosphere, where they can reach the ozone layer. A series of large atmospheric explosions could significantly deplete the ozone layer. The high yield tests in the fifties and sixties probably did cause significant depletion, but the ozone measurements made at the time were too limited to pick up the expected changes out of natural variations.

**Nuclear Winter**

The famous Turco, Toon, Ackerman, Pollack, and Sagan proposal regarding a potential ‘nuclear winter’ is a possible occurrence. This effect is caused by the absorption of sunlight when large amounts of soot are injected into the atmosphere by the widespread burning of cities and petroleum stocks destroyed in a nuclear attack. Soot is far more efficient in absorbing light than volcanic dust, and soot particles are small and hydrophobic and thus tend not to settle or wash out as easily.

Additional studies predict that the amount of soot that would be produced by burning most of the major cities would severely disrupt climate on a world-wide basis. The major effect would be a rapid and drastic reduction in global temperature, especially over land. All recent studies indicate that if large scale nuclear attack occurs against urban or petrochemical targets, average temperature reductions of at least 10 degrees C (50 degrees F) would occur lasting many months. This level of cooling far exceeds any that has been observed in recorded history, and is comparable to that of a full scale ice age.

Smaller attacks would create reduced effects. But it has been pointed out that most of the world's food crops are subtropical plants that would have dramatic drops in productivity if an average temperature drop of even one degree were to occur for even a short time during the growing season. Since the world maintains a stored food supply equal to only a few months of consumption, a war during the Northern Hemisphere spring or summer could still cause deadly starvation around the globe from this effect alone even if it only produced a mild ‘nuclear autumn’.

**Air Bursts**

When an explosion occurs it sends out a shock wave like an expanding soap bubble. If the explosion occurs above the ground the bubble expands and when it reaches the ground it is reflected. The shock front bounces off the ground to form a second shock wave traveling behind the first. This second shock wave travels faster than the first, or direct shock wave since it is traveling through air already moving at high speed due to the passage of the direct wave. The reflected shock wave tends to overtake the direct shock (Mach Effect) wave and when it does, they combine to form a single reinforced wave.

The Mach Effect produces a skirt around the base of the shock wave bubble where the two shock waves have combined. This skirt sweeps outward as an expanding circle along the ground with an amplified effect compared to the single shock wave produced by a ground burst.

The higher the burst altitude, the weaker the shock wave is when it first reaches the ground. On the other hand, the shock wave will also affect a larger area. Air bursts therefore reduce the peak intensity of the shock wave, but increase the area over which the blast is felt. For a given explosion yield, and a given blast pressure, there is a unique burst altitude at which the area subjected to that pressure is maximized. This is called the optimum burst height for that yield and pressure.

All targets have some level of vulnerability to blast effects. When some threshold of blast pressure is reached the target is completely destroyed. Subjecting the target to pressures higher than that would accomplish nothing. By selecting an appropriate burst height, an air burst can destroy a much larger area for most targets than can surface bursts.

The Mach Effect enhances shock waves with pressures below 50 psi. At or above this pressure the effect provides very little enhancement. As result, air bursts have little advantage if very high blast pressures are desired.

An additional effect of air bursts is that thermal radiation is also distributed in a more damaging fashion. Since the fireball is formed above the earth, the radiation arrives at a steeper angle and is less likely to be blocked by intervening obstacles and low altitude haze.

**Surface Bursts**

Surface bursts are useful if local fallout is desired, or if the blast is intended to destroy a buried or very hard structure like a missile silo or dam. Shock waves are transmitted through the soil more effectively if the bomb is exploded in immediate contact for ground bursts to destroy buried command centers and the like. Some targets like earth-fill dam require actual cratering to be destroyed and would be ground burst targets.

**Sub-Surface Bursts**

Exploding a bomb below ground level can be even more effective for producing craters and destroying buried structures. It can also eliminate thermal radiation and reduce the range of blast effects substantially. The problem, of course is getting the bomb underground. Earth-penetrating bombs have been developed that can punch over one hundred feet into the earth.

**Thermal Damage and Incendiary Effects**

Thermal damage from nuclear explosions arises from the intense thermal (heat) radiation produced by the fireball. The thermal radiation (visible and infrared light) falls on exposed surfaces and is wholly or partly absorbed.

The heat is absorbed by the opaque surface layer of the material on which it falls, which is usually a fraction of a millimeter thick. Naturally dark materials absorb more heat than light colored or reflective material. The heat is absorbed much faster than it can be carried down into the material through conduction, or removed by radiation or convection. As result, very high temperatures are produced in this layer almost instantly.

**Thermal Injury**

The result of very intense heating of skin causes burn injuries. The burns caused by the sudden intense thermal radiation from the fireball are ‘flash burns’. The more thermal radiation absorbed, the more serious the burn. The following equation indicates the amount of thermal radiation required to cause different levels of injury, and the maximum ranges at which they occur, for different yields of bombs. The unit of heat used is measured in gram-calories, equal to 4.2 joules (4.2 watts for 1 sec). Skin color significantly affects susceptibility, light skin being less prone to burns.

First degree flash burns are not serious, no tissue destruction occurs. They are characterized by immediate pain, followed by reddening of the skin. Pain and sensitivity continues for some minutes or hours after which the affected skin returns to normal without further incident.

Second degree burns cause damage to the underlying dermal tissue, killing some portions. Pain and redness is followed by blistering within a few hours as fluids collect between the epidermis and damaged tissue. Sufficient tissue remains intact however to regenerate and heal the burned area quickly, usually without scarring. Broken blisters provide possible infection sites prior to healing.

Third degree burns cause tissue death into the skin, including the stem cells required to regenerate skin tissue. The only way a 3rd degree burn can heal is by skin growth from the edges, a slow process that usually results in scarring, unless skin grafts are used. Before healing 3rd degree burns present serious risk of infection, and can cause serious fluid loss. A 3rd degree burn over 25% of the body (or more) will typically precipitate shock in minutes, which itself requires prompt medical attention.

Even more serious burns are possible, which have been classified as fourth (even fifth) degree burns. These burns destroy tissue below the skin: muscle, connective tissue etc. They can be caused by thermal radiation exposures substantially in excess of 3rd degree burns. Many people close to the hypocenter of the Hiroshima bomb suffered these types of burns. At the limit of the range for 3rd degree burns, the time lapse between suffering burns and being hit by the blast wave varies from a few seconds for low kiloton explosions to a minute of so for high megaton yields.

**Incendiary Effects**

Despite the extreme intensity of thermal radiation, and the extraordinary surface temperatures that occur, it has less incendiary effect than might be expected. This is mostly due to its short duration, and the shallow penetration of heat into affected materials. The extreme heating can cause pyrolysis (the charring of organic material, with the release of combustible gases), and momentary ignition, but it is rarely sufficient to cause self-sustained combustion. This occurs only with tinder-like, or dark, easily flammable materials: dry leaves, grass, old newspaper, and thin, dark flammable fabrics, tar paper, etc. The incendiary effect of the thermal pulse is also substantially affected by the later arrival of the blast wave, which usually blows out any flames that have already been kindled.

The major incendiary effect of nuclear explosions is caused by the blast wave. Collapsed structures are much more vulnerable to fire than when intact. The blast reduces structures to piles of kindling, the many gaps opened in roofs and walls act as chimneys, gas lines are broken open, storage tanks for flammable materials are ruptured. The primary ignition sources appear to be flames and pilot lights in heating appliances (furnaces, water heaters, stoves, ovens, etc.). Smoldering material from the thermal pulse can be very effective at igniting leaking gas.

Although the ignition sources are probably widely scattered a number of factors promote their spread into mass fires. The complete suppression of fire fighting efforts is extremely important.

The effectiveness of building collapse, accompanied by the disruption of fire fighting, in creating mass fires were observed in the San Francisco earthquake (1906), the Tokyo-Yokahama earthquake (1923), and the recent Kobe earthquake (1995). In these disasters there was no thermal radiation to ignite fires, and the scattering of combustible materials did not occur, but huge fires still resulted. In San Francisco and Tokyo-Yokohama these fires were responsible for most of the destruction that occurred.

**Eye Injury**

The brightness and thermal output of a nuclear explosion presents an obvious source of injury to the eye. Injury to the cornea through surface heating, and injury to the retina are both possible risks. A number of factors act to reduce the risk. First, eye injury occurs when vision is directed towards the fireball. People spend relatively little time looking up at the sky so only a very small portion of the population would have their eyes directed at the fireball at the time of burst. Second, since the bomb exploded in bright daylight the eye pupil would be expected to be small.

The most common eye injury is flash blindness, a temporary condition in which the visual pigment of retina is bleached out by the intense light. Vision is completely recovered as the pigment is regenerated, a process that takes several seconds to several minutes. This can cause serious problems though in carrying out emergency actions, like taking cover from the oncoming blast wave.

Retinal injury is the most far reaching injury effect of nuclear explosions, but it is relatively rare since the eye must be looking directly at the detonation. Retinal injury results from burns in the area of the retina where the fireball image is focused. The brightness per unit area of a fireball does not diminish with distance (except for the effects of haze), the apparent fireball size simply gets smaller. Retinal injury can thus occur at any distance at which the fireball is visible, though the affected area of the retina gets smaller as range increases. The risk of injury is greater at night since the pupil is dilated and admits more light. For explosions in the atmosphere of 100 kt and up, the blink reflex protects the retina from much of the light.

**Blast Damage and Injury**

Blast damage is caused by the arrival of the shock wave created by the nuclear explosion. Shock waves travel faster than sound, and cause a virtually instantaneous jump in pressure at the shock front. The air immediately behind the shock front is accelerated to high velocities and creates a powerful wind. The wind in turn, creates dynamic pressure against the side of objects facing the blast. The combination of the pressure jump (overpressure) and the dynamic pressure causes blast damage.

Both the overpressure and dynamic pressure jump immediately to their peak values when the shock wave arrives. They then decay over a period ranging from a few tenths of a second to several seconds, depending on the strength of the blast and the yield. Following this there is a longer period of weaker negative pressure before the atmospheric conditions return to normal. The negative pressure has little significance as far as causing damage or injury is concerned. A given pressure is more destructive from a larger bomb, due its longer duration.

There is a definite relationship between the overpressure and the dynamic pressure. The overpressure and dynamic pressure are equal at 70 psi, and the wind speed is 1.5 times the speed of sound (1140 miles per hour). Below an overpressure of 70 psi, the dynamic pressure is less than the overpressure; above 70 psi it exceeds the overpressure. Since the relationship is fixed it is convenient to use the overpressure alone as a yardstick for measuring blast effects. At 20 psi overpressure the wind speed is still 500 mph, higher than any tornado wind.

As a general guide, city areas are completely destroyed (with massive loss of life) by overpressures of 5 psi, with heavy damage extending out at least to the 3 psi perimeter. The dynamic pressure is much less than the overpressure at blast intensities relevant for urban damage, although at 5 psi the wind speed is still 162 mph - close to the peak wind speeds of the most intense hurricanes.

Humans are actually quite resistant to the direct effect of overpressure. Pressures of over 40 psi are required before lethal effects are noted. This pressure resistance makes it possible for unprotected submarine crews to escape from emergency escape locks at depths as great as one hundred feet (the record for successful escape is actually an astonishing 600 feet, representing a pressure of 300 psi). Loss of eardrums can occur, but is not a life threatening injury.

The danger from overpressure comes from the collapse of buildings that are generally not as resistant. The violent implosion of windows and walls creates a hail of deadly missiles, and the collapse of the structure above can crush or suffocate those caught inside.

The dynamic pressure causes creates injury by hurling large numbers of objects at high speed. Urban areas contain many objects that can become airborne, and the destruction of buildings generates many more. Serious injury or death can also occur from impact after being thrown through the air. Blast effects are most dangerous in built-up areas due to the large amounts of projectiles created, and the presence of obstacles to be hurled against. The blast also magnifies thermal radiation burn injuries by tearing away severely burned skin. This creates raw open wounds that readily become infected.

These many different effects make it difficult to provide a simple rule of thumb for assessing the magnitude of harm produced by different blast intensities. A general guide is:

1 psi - Window glass shatters. Light injuries from fragments occur.

3 psi - Residential structures collapse, serious injuries are common. Fatalities may occur.

5 psi - Most buildings collapse, injuries are universal. Fatalities are widespread.

10 psi - Reinforced concrete buildings are severely damaged or demolished, killing most people.

20 psi - Heavily built concrete buildings are severely damaged or demolished, fatalities approach 100%.

**Radiation Injury**

Ionizing radiation produces injury primarily through damage to the chromosomes. Since genetic material makes up a very small portion of the mass of a cell, the damage rarely occurs from the direct impact of ionizing radiation on a genetic molecule. Instead the damage is caused by the radiation breaking up other molecules and forming chemically reactive free radicals or unstable compounds. These reactive chemical species then damage DNA and disrupt cellular chemistry in other ways - producing immediate effects on active metabolic and replication processes, and long-term effects by latent damage to the genetic structure.

Cells are capable of repairing a great deal of genetic damage, but the repairs take time and the repair machinery can be overwhelmed by rapid repeated injuries. If a cell attempts to divide before sufficient repair has occurred, the cell division will fail and both cells will die. As a consequence, the tissues that are most sensitive to radiation injury are ones that are undergoing rapid division. Another result is that the effects of radiation injury depend partly on the rate of exposure. Repair mechanisms can largely offset radiation exposures that occur over a period of time. Rapid exposure to a sufficiently large radiation dose can thus cause acute radiation sickness, while a longer exposure to the same dose might cause none.

By far the most sensitive are bone marrow and lymphatic tissues (blood and immune system forming organs of the body). Red blood cells, which provide oxygen to the body, and white blood cells, which provide immunity to infection, only last a few weeks or months in the body and so must be continually replaced. The gastrointestinal system is also sensitive, since the lining of the digestive tract undergoes constant replacement. Although they are not critical for health, hair follicles also undergo continual cell division resulting in radiation sickness' most famous symptom is hair loss. The tissues least sensitive to radiation are those that never undergo cell division (i.e. the nervous system). This also means that children and infants are more sensitive to injury than adults, and that fetuses are most sensitive of all.

If the individual survives, most chromosome damage is eventually repaired and the symptoms of radiation illness disappear. The repair is not perfect however. Latent defects can show up years or decades later in their effects on reproductive cells, and in the form of cancer. These latent injuries are a very serious concern and can shorten life by many years. They are the sole form of harm from low level radiation exposure.

**Acute Radiation Sickness**

This results from exposure to a large radiation dose to the whole body within a short period of time (no more than a few weeks). There is no sharp cutoff to distinguish acute exposures from chronic (extended). In general, higher total doses are required to produce a given level of acute sickness for longer exposure times. Exposures received over a few days do not differ substantially from instantaneous, except that the onset of symptoms is correspondingly delayed or stretched out. Nuclear weapons can cause acute radiation sickness either from prompt exposure at the time of detonation, or from the intense radiation emitted by early fallout in the first few days afterward.

The effects of increasing exposures are described below. A notable characteristic of increasing doses is the non-linear nature of the effects. That is to say, a threshold exists below which observable effects are slight and reversible (about 300 rems), but as exposures rise above this level the possibility of mortality (death) begins and increases rapidly with dose. This is believed to be due in part to the saturation of cellular repair mechanisms. The total energy absorbed by a 75 kg (165 lb) individual with a whole body exposure of 600 rads (fatal in most cases) is 450 joules.

Below 100 REMS:  
In this dose range no obvious sickness occurs. Detectable changes in blood cells begin to occur at 25 rems, but occur consistently only above 50 rems. These changes involve fluctuations in the overall white blood cell count (with drops in lymphocytes), drops in platelet counts, and less severe drops in red blood cell counts. These changes set in over a period of days and may require months to disappear. They are detectable only by lab tests. At 50 rems atrophy of lymph glands becomes noticeable. Impairment to the immune system could increase the susceptibility to disease. Depression of sperm production becomes noticeable at 20 rems, an exposure of 80 rems has a 50% chance of causing temporary sterility in males.

100-200 REMS  
Mild acute symptoms occur in this range. Tissues primarily affected are the hematopoietic (blood forming) tissues, sperm forming tissues are also vulnerable. Symptoms begin to appear at 100 rems, and become common at 200 rems. Typical effects are mild to moderate nausea (50% probability at 200 rems), with occasional vomiting, setting in within 3-6 hours after exposure, and lasting several hours to a day. This is followed by a latent period during which symptoms disappear. Blood changes set in and increase steadily during the latency period as blood cells die naturally and are not replaced. Mild clinical symptoms return in 10-14 days. These symptoms include loss of appetite (50% probability at 150 rems), malaise, and fatigue (50% probability at 200 rems), and last up to 4 weeks. Recovery from other injuries is impaired and there is enhanced risk of infection. Temporary male sterility is universal. The higher the dosage in this range, the more likely the effects, the faster symptoms appear, the shorter the latency period, and the longer the duration of illness.

200-400 REMS  
Illness becomes increasingly severe, and significant mortality sets in. Hematopoietic tissues are still the major affected organ system. Nausea becomes universal (100% at 300 rems), the incidence of vomiting reaches 50% at 280 rems. The onset of initial symptoms occurs within 1-6 hours, and last 1-2 days. After this a 7-14 day latency period sets in. When symptoms recur, the may include epilation (hair loss, 50% probability at 300 rems), malaise, fatigue, diarrhea (50% prob. at 350 rems), and hemorrhage (uncontrolled bleeding) of the mouth, subcutaneous tissue and kidney (50% prob. at 400 rems). Suppression of white blood cells is severe, susceptibility to infection becomes serious. At 300 rems the mortality rate without medical treatment becomes substantial (about 10%). The possibility of permanent sterility in females begins to appear. Recovery takes 1 to several months.

400-600 REMS  
Mortality rises steeply in this dose range, from around 50% at 450 rems to 90% at 600 (unless heroic medical intervention takes place). Hematopoietic tissues remain the major affected organ system. Initial symptoms appear in 0.5-2 hours, and last up to 2 days. The latency period remains 7-14 days. The symptoms listed for 200-400 rems increase in prevalence and severity, reaching 100% occurrence at 600 rems. When death occurs, it is usually 2-12 weeks after exposure and results from infection and hemorrhage. Recovery takes several months to a year. Blood cell counts may take even longer to return to normal. Female sterility becomes probable.

600-1000 REMS  
Survival depends on stringent medical intervention. Bone marrow is nearly or completely destroyed, requiring marrow transfusions. Gastrointestinal tissues are increasingly affected. Onset of initial symptoms is 15-30 minutes, last a day or two, and are followed by a latency period of 5-10 days. The final phase lasts 1 to 4 weeks, ending in death from infection and internal bleeding. Recovery, if it occurs, takes years and may never be complete.

Above 1000 REMS  
Very high exposures can sufficient metabolic disruption to cause immediate symptoms. Above 1000 rems rapid cell death in the gastrointestinal system causes severe diarrhea, intestinal bleeding, and loss of fluids, and disturbance of electrolyte balance. These effects can cause death within hours of onset from circulatory collapse. Immediate nausea occurs due to direct activation of the chemo receptive nausea center in the brain.

In the range 1000-5000 rems the onset time drops from 30 minutes to 5 minutes. Following an initial bout of severe nausea and weakness, a period of apparent well-being lasting a few hours to a few days may follow (called the ‘walking ghost’ phase). This is followed by the terminal phase which lasts 2-10 days. In rapid succession prostration, diarrhea, anorexia, and fever follow. Death is certain, often preceded by delirium and coma. Therapy is only to relieve suffering.

Above 5000 rems metabolic disruption is severe enough to interfere with the nervous system. Immediate disorientation and coma will result; onset is within seconds to minutes. Convulsions occur which may be controlled with sedation. Victim may linger for up to 48 hours before dying.

The U.S. military assumes that 8000 rads of fast neutron radiation (from a neutron bomb) will immediately and permanently incapacitate a soldier.

Note:

Some of the preceding information is extracted with stated authorization by its author Carey Sublette from the website link: http://nuclearweaponarchive.org/Nwfaq/Nfaq5.html, titled ‘Nuclear Weapons Frequently Asked Questions, Version 2.14: 15 May 1997, Copyright Carey Sublette.