PART 3. RISK DEFINITIONS

A. Direct Effects Risk

1. General Overview - Blast overpressures generated by a nuclear weapon detonation present the greatest risk to human life and health in a nuclear effects environment because achieving effective protection is so difficult. The destruction, death, and injury that can result from the blast generated overpressures of modern nuclear weapons are awesome compared to those from the atomic weapons used against Hiroshima and Nagasaki, Japan, in World War II. Although current thermonuclear weapons have diminished in yields (principally because of greater accuracy), the power generated is still magnitudes above that released by the earlier weapons.

Protective measures against direct effects of weapons have been researched and are possible but generally impractical due to the enormous expenditures entailed in the construction of a comprehensive blast shelter system. Over the years, proposals to initiate a combined blast and fallout shelter program have been submitted to the Congress but not accepted. In some areas close to the point of detonation (which can never be predicted accurately) even extensive protective measures may be inadequate and, even if successful in mitigating initial effects, may be insufficient to support continued habitation of the area.

Fire generated by the thermal pulse of the weapon and by damage-induced ruptures in gas and electric lines also could present a formidable risk for survivors close in to the target aim point. The fire risk is discussed in C., below.

Even in areas far enough from the point of detonation to escape severe damage, the population still faces unique survival problems to protect their lives and continued health in the direct effects environment.

2. Extent of Risk - The extent and range affected by this risk are determined by:

- The altitude at which the weapon is detonated (see the discussion of this in Part 2.D., "Targeting Considerations"). The altitude at which the weapon is detonated determines the range of given overpressures.

- The yield of the weapon. The range of a given blast overpressure increases with the cube root of the weapon yield in kilotons and is directly correlated to the height of burst.

- The accuracy of the weapon (see the discussion of this in Part 2.D., "Targeting Considerations"). Weapons used in NAPB-90 were assumed to have extremely small CEP's. CEP's, therefore, have little effect on the extent of the damage area and influence only the location of the damage.

- The probability of arrival of the weapon (see the discussion of this in Part 2.D., "Targeting Considerations"). Weapons used in NAPB-90 were assumed to have a probability of arrival of 66 percent or greater.

3. Statistical Overview - NAPB-90 defines the potential risk from nuclear weapon blast overpressures as the total area affected by 0.5 pound per square inch (psi) or more. This represents 727,112 square miles of U.S. territory with an estimated resident population of 175.11 millions. Approximately 66.54 million people, therefore, are not considered to be at risk from blast overpressures although some of this number (approximately 2.47 million) reside in areas immediately outside of the 0.5 psi boundary and may experience low levels of blast overpressure (i.e., less than 0.5 psi). Since NAPB-90 does not target population per se, the persons affected by blast overpressures reside in areas which are peripheral to or collocated with potential military and industrial targets (see Part 2.B., "Target Selection").

The magnitude of this potential risk is represented with maps and statistics in Annex A.

4. Methodology Employed - The selection and methodology employed for arriving at potential aim points included in NAPB-90 are discussed in detail in Part 2., "Project Development," and will not be repeated here. In general, direct effects risk areas are the result of considerations discussed in Part 2.D., "Targeting Considerations." Specific criteria used to select critical psi demarcations are included in discussions of these areas.

NAPB-90 defines four levels of potential risk from blast overpressure. Each definition is driven by the degree of influence a specific blast overpressure has on the continued life and health of the resident population. In this context, the following considerations were used in determining the degrees of direct effects risk:

- The severity of short-term risk posed by the blast wave itself in terms of its potential to kill or injure directly, or through damage or destruction of homes and buildings. This short-term risk may include the immediate effects of the weapon's thermal pulse.

- The potential long-term severity of the risk to survivors within the area by entrapment in damaged or destroyed buildings and by fires created by thermal pulse generated and damage-caused ignitions. Fire risk is discussed in C., below.

- The kind, degree, and practicality of in-place and/or crisis-generated preparedness measures necessary to mitigate initial blast, thermal pulse, and initial reation risks as well as measures necessary to assure continued life support for long-term habitation in the area. Also included in this consideration is the cost of such measures in total effort, time of preparation, and efficacy.

The potential risk from initial radiation released at the time of detonation is considered by NAPB-90 to be reciprocal with the risk from blast generated overpressure. As an example, at a distance of one mile from a one megaton air-burst detonation, initial radiation would probably prove fatal to a large portion of persons in the area even if they were shielded by 24 inches of concrete. These same people would simultaneously be exposed to blast overpressures of from 50 to 60 psi. Thus, the specific level of risk from initial radiation is difficult to define since population at risk to lethal levels of initial radiation is at double jeopardy from blast overpressure.

a. Very High Direct Effects Risk

(1) Definition - A Very High Direct Effects Risk Area is defined as the area surrounding a target aim point which has the potential to experience blast overpressures equal to or greater than 10.0 pounds per square inch (psi) from a nuclear weapon detonation.

(2) Criteria - In a Very High Direct Effects Risk Area death or severe injury from blast overpressure is certain without specially constructed protection against the blast wave and initial radiation. Survivors in this area might also face probably fatal fires generated by the thermal pulse of the weapon as well as damage-caused ignitions from ruptured gas and electric lines. This 10.0 psi limit marks the approximate median (50-50) point of lethal overpressure for persons inside homes as well as the threshold (beginning point) of possible lung damage. Beyond this demarcation, probable death and severe injury increase as overpressures increase exponentially toward the point of detonation.

While blast effects could be mitigated through specially constructed blast shelter, shelter occupants would also require protection from highly debilitating if not lethal levels of ionized radiation (neutrons and gamma rays) produced at the instant of the detonation of weapon. This initial radiation is extremely more difficult to protect against than fallout radiation produced by the fission reaction of the weapon.

In short, potential Very High Direct Effects Risk Areas are extremely dangerous for the continued protection and maintenance of human life.

(3) Overview - The total potential Very High Direct Effects Risk Areas in the U.S. cover approximately 46,352 square miles, with a resident population of 47.25 millions. Of the total U.S. area and population defined by NAPB-90 at risk from direct effects, 1.3 percent of the land area and 27.0 percent of the population fall under this risk definition. As a population group, those in potential Very High Direct Effects Risk Areas represent 19.6 percent of the total population of the U.S.

b. High Direct Effects Risk

(1) Definition - A High Direct Effects Risk Area is defined as the area around a target aim point which has the potential to experience

blast overpressures from a nuclear weapon detonation of equal to or greater than 5.0 psi but less than 10.0 psi.

(2) Criteria - A High Direct Effects Risk Area is a distinctly hazardous nuclear effects environment. Within this area lies the demarcation point of the median (50/50) probability of injury to persons within homes (approximately 7.0 psi). This is illustrative of the need for population protection measures of a prodigious nature in this area (measures which may still prove to be insufficient and impractical). Depending upon the type of construction, a large majority of homes within this area could be severely damaged or totally destroyed. Continued habitation in the area --even if survival of the initial blast overpressures were attained--would probably be impractical.

(3) Overview - The total potential High Direct Effects Risk Areas in the U.S. cover approximately 49,896 square miles with a resident population of 32.19 millions. Of the total U.S. area and population defined by NAPB-90 at risk from direct effects, 1.4 percent of the land area and 18.4 percent of the population fall under this threat definition. As a population group, those in potential High Direct Effects Risk Areas represent 13.3 percent of the total population of the U.S.

c. Medium Direct Effects Risk

(1) Definition - A Medium Direct Effects Risk Area is defined as the area surrounding a target aim point which has the potential to experience blast overpressures from a nuclear detonation of equal to or greater than 2.0 psi but less than 5.0 psi.

(2) Criteria - Unprotected and poorly protected populations in a Medium Direct Effects Risk Area have a sure probability of becoming injured or killed from either the dangers created by the blast overpressure or from the thermal pulse of a weapon. The impact lethality threshold, or the overpressure at which death could result from a body thrown by the blast, occurs within this area at approximately 3.3 psi. At approximately 2.3 psi and up, the likelihood of skull fractures increases from the same phenomenon and shattered glass and other debris impelled by the blast can be very dangerous and potentially fatal.

This area poses a risk to populations due to direct structural damage of homes and buildings. Persons caught outdoors when the detonation occurs may receive potentially severe and possibly fatal burns from the thermal pulse of the weapon. Without a detailed analysis of the specific characteristics of each area in this risk category, it must be assumed that there is a very high potential for fires that could result from the thermal pulse of the weapon or from damage-caused ignitions (see C., below). Protective measures to mitigate the immediate effects within this area are possible but time consuming and complex. Depending on the type of construction, homes and other buildings in this area would suffer moderately high to severe damage and may not be repairable. Morever, continued habitation of undamaged or repaired homes may prove difficult and impractical except for emergency reasons. Long-term preparations to sustain surviving populations may also have to take into consideration the potential lack of water pressure or electricity, as well as the complete failure of other vital community services. Finally, if downwind from a ground-burst weapon, the risk from fallout radiation may exacerbate and override the direct effects risk in this area.

(3) Overview - The total potential Medium Direct Effects Risk Areas in the U.S. cover approximately 151,535 square miles, which have a resident population of 50.3 millions., Of the total U.S. area and population defined by NAPB-90 as at risk from direct effects, 4.3 percent of the land area and 28.7 percent of the population fall under this risk definition. As a population group, those in potential Medium Direct Effects Risk Areas represent 20.8 percent of the total population of the U.S.

d. Low Direct Effects Risk

(1) Definition - A Low Direct Effects Risk Area is defined as the area surrounding a target aim point which has the potential to experience blast overpressures from a nuclear detonation of equal to or greater than 0.5 psi but less than 2.0 psi.

(2) Criteria - Blast overpressures in a Low Direct Effects Risk Area are not lethal in themselves, but serious injury or death can occur from flying debris if protection measures are not taken. In addition, the thermal pulse of the weapon in this area could result in significant first and second degree burns on exposed skin. Damage to homes and other buildings could range from low to moderately high depending upon the type of construction but would, generally, be limited to repairable damage. Repair of the area for continued long-term habitation could be a serious problem. Small but controllable fires are possible through thermal pulse ignitions of curtains, furniture, and other light flammable substances in and about homes. If uncontrolled initially, however, fires in this area might become a significant risk.

If downwind from a ground-burst weapon, this area could, within a short period of time, receive a significant amount of fallout radiation requiring additional protective measures.

(3) Overview - The total potential Low Direct Effects Risk Areas in the U.S. cover approximately 479,329 square miles, which have a resident population of 45.37 millions. Of the total U.S. area and population defined by NAPB-90 as at risk from direct effects, 13.5 percent of the land area and 25.9 percent of the population fall under this risk definition. As a population group, those in potential Low Direct Effects Risk Areas represent 18.8 percent of the total population of the U.S.

B. Fallout Radiation Risk

1. General Overview - The risk to U.S. population from gamma radiation given off from fallout particles produced by ground burst nuclear weapons is vast and far-reaching. None of the continental U.S. land area can be considered categorically secure from this risk. The two types of fallout from

a ground burst detonation are "early" (within 24 hours of the detonation) and "delayed" (after 24 hours of the detonation). Approximately 80 percent of the total radioactivity generated by a ground-burst weapon will be in the form of early fallout, with the remaining 20 percent reaching earth in the form of delayed fallout hundreds or thousands of miles from the point of detonation of the weapon. Heavier radioactive particles constitute the bulk of early fallout and fall closer in to the detonation point, while smaller, lighter particles are carried downwind eventually to fall earthward as delayed fallout. Delayed fallout, therefore, can cause radioactive contamination far beyond the range of the direct effects of the weapon detonation producing it. Given seasonal changes in weather patterns plus unpredictable local occurrences such as rain and showers, fallout must be regarded as a potential risk to all U.S. land areas.

The risk derives from human exposure to the gamma and beta radiation emitted by the fallout particles. Of these two types of radiation, protection from gamma rays is the more difficult to achieve since it requires extensive shielding ("mass") to reduce the radiation.

Gamma radiation is measured in units of roentgen (R) energy. The risk to human health and life is the amount of such energy absorbed by the body over time, called the "total dose." In most cases, a very high percentage of the total dose received will occur within the first hours after fallout arrival. In assessing the degree of risk from fallout, the total dose accumulated during a 1-week period provides an efficient standard of measurement. Table B-1 shows this and other exposure criteria for estimating the risk to human life and health from gamma radiation exposure.

Table B-1. OUTCOMES OF EXPOSURE TO GAMMA RADIATION

Persons Needing Medical Care	Accumulated R Dose Within: One Week	One Month	Four Months
NONE	150	200	300
SOME (5% may die)	250	350	500
MOST (50% may die)	450	600	---

NAPB-90 based threat assessments on the potential effect of fallout radiation on the resident population of an area over a period of 1 week following the deposition of fallout and on the efficacy of various levels of shelter protection to mitigate such exposure. While Table B-1 is useful as a guide for judging potential acute radiation penalties in a nuclear attack environment, longer term biological effects should also be considered. Using shelter offering the highest protection possible in any fallout area to limit exposure to the lowest possible level will reduce the risk of medical care for acute radiation sickness as well as the risk of longer term biological effects. In NAPB-90, assessments of longer term effects for additional survivor deaths from radiation-induced cancers as well as deaths in future progeny caused by genetic damage were calculated for a range of total exposures. These assessments were based on the assumption that exposures in a post-shelter environment (beyond 1 week) were the same as the exposure in the first week, i.e., the 1-week shelter exposure was essentially doubled to account for exposures over the longer term from remaining lower level radiation.

Estimations of potential increases in cancer deaths due to radiation exposures were based on work done by Dr. Warren Sinclair, President of the National Council on Radiation Protection and Measurements. He calculated that the cancer deaths resulting from exposures to 100R or more (but less than lethal) would be 3 percent per 100 person-roentgen (a 100 person-roentgen exposure would result if each of 100 persons were exposed to 1 roentgen, or if 50 people were exposed to 2 roentgens each, etc.). To calculate the cancer deaths for lower exposure levels, it was assumed that the percentage would decrease linearly from 3 percent per 100 person-roentgen at 100R exposure to 1.25 percent per 100 person-roentgen at 1 R exposure. Table B-2 shows these and other calculations made for other exposure levels.

The basis for data on genetic damage affecting future generations was taken from a document written by Sir Edward Pochin, former President of the International Commission on Radiation Protection as well as the British representative on the United Nations Scientific Committee on the Effects of Atomic Radiation. Dr. Pochin estimated that the increase in future deaths due to genetic damage would be 0.35 percent for each 100 person-roentgen. Calculations for other exposure levels were made accordingly as shown on Table B-2.

TABLE B-2. CANCER AND GENETIC CONSEQUENCES OF ONE-WEEK RADIATION DOSES

One-Week Acute R Dose	Assumed Total R Dose	Percent Cancer Deaths	Percent Genetic Deaths
6R	12R	0.18	0.04
12R	24R	0.40	0.08
15R	30R	0.53	0.10
30R	60R	1.40	0.21
38R	76R	2.00	0.27
50R	100R	3.00	0.35
75R	150R	4.50	0.53
100R	200R	6.00	0.70
150R	300R	9.00	1.10
188R	376R	11.00	1.30
200R	400R	12.00	1.40
250R	500R	15.00	1.80
300R	600R	18.00	2.10
375R	750R	23.00	2.60
500R	1000R	30.00	3.50
600R	1200R	36.00	4.20

These calculations are reflected in tables illustrating the consequence of shelter use for each of the risk levels discussed below.

2. Extent of the Risk. Residual radiation comes from the radioactive by-products of a nuclear detonation. The radioactive elements created by the detonation are joined with materials scoured from the crater of a ground burst weapon to form "fallout particles" which give off gamma radiation (as well as other less harmful forms of radiation). The extent of the risk portrayed by NAPB-90 was determined by:

- The fission-fusion ratio of the weapon. In a nuclear detonation, over 300 different radioactive isotopes are formed by the atomic fission ("splitting") of the uranium or plutonium used in the weapon. Atomic fusion ("joining") actions within the weapon create no harmful radioactive substances. The amount of fission products produced by the weapon is a function of the percentage of the weapon yield which results from fission. The fission-fusion ratio of an NAPB-90 weapon was assumed, for planning purposes, to be a 50-50 ratio (although fission-fusion ratios higher and lower than 0.5 are possible).

- The amount of fallout produced. Each megaton of fission energy yield (equivalent to 1 million tons of TNT explosive force) produces about 125 pounds of radioactive by-products. At the same time, a surface burst weapon vaporizes and draws upward an enormous amount of surface material (weighing up to 500,000 tons depending upon the weapon yield). This vaporized material, as it cools, combines with the fission by-products of the explosion to form fallout particles. NAPB-90 fallout risk was determined by analysis of weapons employed in a ground-burst mode.

- The altitude at which the weapon is detonated. (See the discussion of this in Part 2.D., "Targeting Considerations"). Generally, the more the fireball of a surface-burst weapon makes contact with the ground, from merely touching the surface to below-ground detonations, the more ground material will be lofted and be available for combination with fission by-products to produce fallout particles. Weapons employed by NAPB-90 in this mode were also analyzed for contribution to the fallout risk.

- The distribution of fallout. The wind direction and speed in the layers of the atmosphere up to the height reached by the mushroom cloud determines the area coverage of fallout. The height of the cloud is a function of the heat generated by the weapon yield. For very large weapons the cloud could reach 15 to 20 miles in altitude. The cloud drifts away from the target in relation to the speed and direction of the winds in each atmospheric layer through which the cloud has risen. Distribution of the fallout particles to the ground is a function of wind speed and gravity. The heavier particles will fall first, while lighter particles may be carried hundreds or thousands of miles from the target area before returning to earth. (See 4., below, for a discussion of the methodology employed by NAPB-90 to determine the distribution of the fallout risk.)

° The decay rate of the radioactivity in fallout. Each of the radioactive substances produced by fission exhibits a continuous and regular decrease or decay in the amount of radiation it gives off over time. The rate of decay is expressed as the "half-life" of the element, or the amount of time necessary for its radiation intensity to be reduced by one-half the original intensity. Two fission by-products are illustrative: the half-life of radioactive iodine-131 is 8 days, while the half-life for radioactive strontium-90 is 28 years. NAPB-90 used a decay rate of radioactivity for the mix of fission by-products which is generally expressed as a ten-fold reduction in intensity for every seven-fold increment of time after detonation (e.g., the radiation intensity at some location on the ground 7 hours after detonation would be one-tenth as much as it was 1 hour after detonation if all the fallout had been deposited within the first hour).

3. Statistical Overview - NAPB-90 defined the total potential risk from fallout from its ground-burst weapons to encompass the entire U.S. land area. While it is recognized that specific nuclear attack scenarios and specific weather patterns will result in little or no fallout radiation in some land areas, NAPB-90 makes no attempt to predict such an outcome.

The magnitude of this potential risk is represented with maps and statistics in Annex B.

4. Methodology Employed - Predicting the potential distribution of delayed fallout is a difficult and uncertain task. NAPB-90 employed the GUISTO-DNAF-1 fallout model to determine potential distribution patterns. This model is efficient in determining potential fallout distribution patterns for the small-yield, ground-burst weapons (high kiloton to low megaton ranges), characteristic of weapons used in NAPB-90 (see Part 2.C., "Weapon Inventory Base"). The model incorporates wind speeds and directions ("wind shears") for various altitudes up to the height reached by the weapon's mushroom cloud, integrating all data necessary to estimate unidirectional downwind fallout distributions.

To calculate potential fallout distributions "most probable" winds for each month of the year were used. The wind patterns were developed by the U.S. Air Force Environmental Technical Applications Center following analysis of the period January 1977 through September 1981. Within this period, a specific day for each month was chosen which represented the most typical surface and upper air flow patterns, together with wind patterns for the day preceding and following the date chosen. These wind patterns are those which could most probably be expected to occur any day of a month barring unseasonal weather or future atmospheric changes to current weather patterns.

In addition to calculations described above, the results of a Defense Nuclear Agency study which assessed fallout shelter protection factors was incorporated. This study used a simulated U.S. attack with ground-burst weapons corresponding closely with the pattern used in NAPB-90. The study simulated fallout distribution using 40 randomly selected wind patterns from weather data over a 5-year period.

Both of these probable fallout distributions were used to determine the highest dose reading reached within each county unit in the U.S. This reading was recorded as the degree of potential risk for that county. The probability of the county receiving this dose over a 1-week period was not considered, but it can be said to range from "greater than zero" to 100 percent. The depicted potential risk areas in Annex B should, therefore, not be interpreted as a prediction of the fallout risk resulting from any nuclear attack. The distribution of actual fallout would be driven by weather conditions extant at the time of the attack.

As pointed out earlier, predicting potential fallout distribution is a difficult and uncertain task. Within the current state-of-the-art, there are distinct possibilities of *a priori* errors in calculations. In addition, there is the possibility of abherent, unseasonal weather patterns on any day of the year.

NAPB-90 defines four degrees of potential fallout risk. Each definition is determined by the degree of influence specific protection measures would have on mitigating human exposures to gamma radiation. In this context, the following considerations were examined to determine the degrees of potential fallout risk:

- The mitigation of a 1-week, unprotected[1/] exposure in relation to the protection factor (PF)[2/] afforded by various shelters; and

- The kind, degree, and utility of in-place or crisis-generated shelter necessary to permit continued life support in the area; and the cost, total effort, preparation time, and efficacy of such shelter.

Specific criteria used in choosing risk level demarcations are included in discussions of these areas.

a. Very High Fallout Risk

(1) Definition - A Very High Fallout Risk Area is defined as an area which has the potential to receive a 1-week unprotected radiation dose of equal to or greater than 15,000R (nominally up to 100,000R).

(2) Criteria - If the radiation levels identified as characterizing a Very High Fallout Risk Area should actually occur, death for the resident population without very high quality protection would be almost certain. Because such high quality shelter protection factors (PF's) would be

1/ Outdoor fallout doses were calculated with no consideration for natural reductions in that dose which could be provided by the environment such as nearby buildings, lakes, ponds, streams, and surface irregularities. Average dose reductions for many outside locations might easily be half or more of the NAPB-90 levels calculated.

2/ The protection factor (PF) of a shelter is an expression of the effectiveness of the mass or shielding provided by the structure to attentuate gamma radiation (e.g., in a PF 100 shelter, the dose rate of gamma radiation would be .01 of the outside dose rate).

needed, adequate protection in the area may be difficult, if not impossible, to find.

Chart B-3a and B-3b illustrate the consequences of selecting protection levels ranging from PF 5 through PF 500. It should be pointed out that exact radiation levels can never be determined for specific points within this area in advance of fallout arrival. Hence, a minimum PF level for the entire area cannot (and should not) be defined. Shelter with the highest PF possible should always be used in planning.

Chart B-3a. PROBABLE CONDITION OF MAJORITY OF SURVIVORS IN VERY HIGH FALLOUT RISK AREAS*

Using Shelter Protection Factor	Potential In-Shelter One Week Dose Range	Medical Care Needed	Able to Work	Probable Death Rate	Comments
PF 5 PF 10 PF 20	3000R + 1500R + 750R +	Yes	No	100%	Deaths would probably occur in two weeks or less
PF 30	500R +	Yes	No**	More than 50%	Deaths would occur in about one month
PF 40 PF 60	375R + 250R +	Yes	No**	Less than 50%	Deaths would occur in 30 to 60 days
PF 80 PF 100 PF 200	188R + 150R + 75R +	No	Yes	Less than 5%	Deaths would occur in 60 or more days
PF 500	30R +	No	Yes	None	No symptoms

* Based on the lowest potential doses; at the practical upper limit of this area (approximately 100,000R dose), only shelter with a PF of 2000 or more can mitigate against probable illness and death.

** Except during illness-free latent period.

Survivors in an area of this type face the possibility of continuing to mitigate the radiation risk beyond 1-week in order to sustain life and health. Outdoor radiation levels in this area may still be high enough at the end of 1-week to severely limit outdoor activity and may require frequent and continued stay within shelter to limit additional exposures through the end of the first month. This longer in-shelter period and limited time for outdoor activity would require advance preparations to sustain life (stocking of food, water, sanitation equipment, etc.).

Chart B-3b. POTENTIAL LONG-TERM EFFECTS ON SURVIVORS IN VERY HIGH FALLOUT RISK AREAS*

Using Shelter Protection Factor	Potential In-Shelter One Week Dose Range	Additional Survivor Cancer Deaths	Additional Deaths From Genetic Damage in Future Generations
PF 5	3000R +	No survivors	No progeny
PF 10	1500R +		
PF 20	750R +		
PF 30	500R +	23 to 30%	2.6 to 3.5%
PF 40	375R +	15 to 23%	1.8 to 2.6%
PF 60	250R +		
PF 80	188R +	4.5 to 11%	.53 to 1.3%
PF 100	150R +		
PF 200	75R +		
PF 500	30R +	0 to 1.4%	0 to .21%

* Based on assumption that sheltered survivors receive an additional dose over the longer term equal to that received in shelter, i.e., double the shelter dose received in 1 week.

The very high PF ratings needed in this area are generally found only in buildings of massive construction, mines, caves, tunnels, and the like. These facilities would have to be prepared in advance for occupancy.

(3) Overview - The total potential Very High Fallout Risk Areas cover approximately 421,835 square miles of the U.S., with a resident population of 9.582 millions. This constitutes 12.1 percent of the total U.S. land area, and 4.2 percent of the national population.

b. High Fallout Risk

(1) Definition - A High Fallout Risk Area is defined as an area which has the potential to receive a 1-week total radiation dose of equal to or greater than 6,000R but less than 15,000R.

(2) Criteria - If the radiation levels that characterize a High Fallout Risk Area should occur, eventual death from radiation is almost certain for resident populations unless they find shelter with relatively high protection factors (PF's).

Charts B-4a and B-4b illustrate the consequences of selecting PF levels ranging from PF 5 through PF 500. It should be pointed out that exact radiation levels can never be determined for specific points within this area in advance of fallout arrival. Hence, a minimum PF level for the entire area cannot (and should not) be defined. Shelters with the highest PF possible should always be used in planning.

Chart B-4a. PROBABLE CONDITION OF MAJORITY OF SURVIVORS IN HIGH FALLOUT RISK AREAS*

Using Shelter Protection Factor	Potential In-Shelter One Week Dose Range	Medical Care Needed	Able to Work	Probable Death Rate	Comments
PF 5 PF 10 PF 20	1200R-3000R 600R-1500R 300R-750R	Yes	No	100%	Deaths would probably occur in two weeks or less
PF 30	200R-500R	Yes	No**	More than 50%	Deaths would occur in about one month
PF 40 PF 60	150R-375R 100R-250R	Yes	No**	Less than 50%	Deaths would occur in 30 to 60 days
PF 80 PF 100 PF 200	75R-188R 60R-100R 30R-75R	No	Yes	Less than 5%	Deaths would occur in 60 or more days
PF 500	12R-30R	No	Yes	None	No symptoms

* Based on the highest potential doses; further mitigation of illustrated conditions would occur at lower dose ranges.

** Except during illness-free latent period.

Chart B-4b. POTENTIAL LONG-TERM EFFECTS ON SURVIVORS IN HIGH FALLOUT RISK AREAS*

Using Shelter Protection Factor	Potential In-Shelter One Week Dose Range	Additional Survivor Cancer Deaths	Additional Deaths From Genetic Damage in Future Generations
PF 5 PF 10 PF 20	1200R-3000R 600R-1500R 300R-750R	No survivors	No progeny
PF 30	200R-500R	23 to 30%	2.6 to 3.5%
PF 40 PF 60	150R-375R 100R-250R	15 to 23%	1.8 to 2.6%
PF 80 PF 100 PF 200	75R-188R 60R-100R 30R-75R	4.5 to 11%	.53 to 1.3%
PF 500	12R-30R	0 to 1.4%	0 to .21%

* Based on assumption that sheltered survivors receive an additional dose over the longer term equal to that received in shelter, i.e., double the shelter dose received in 1 week.

Survivors in areas of this type may face the possibility of continuing mitigation of the radiation risk beyond 1 week in order to sustain life and health. Outdoor radiation levels could be high enough at the end of 1 week to place a limit on time for outdoor activities and may require continued use of the shelter to limit additional exposures through the end of the first month. The longer in-shelter period which may be required in this area would mean advance preparations to sustain life (stocking of food, water, etc.) are a necessary measure.

(3) Overview - The total potential High Fallout Risk Areas cover approximately 614,508 square miles of the U.S., with a resident population of 48.712 millions. This constitutes 18.0 percent of the total U.S. land area, and 21.3 percent of the national population.

c. Medium Fallout Risk

(1) Definition - A Medium Fallout Risk Area is defined as an area which has the potential to receive a 1-week unprotected radiation dose of equal to or greater than 3,000R but less than 6,000R.

(2) Criteria - If the fallout levels that characterize a Medium Fallout Risk Area should actually occur, death or debilitating illness from radiation is certain for resident populations without adequate shelter. Charts B-5a and B-5b illustrate the consequences of selecting PF

Chart B-5a. PROBABLE CONDITION OF MAJORITY OF SURVIVORS IN MEDIUM FALLOUT RISK AREAS*

Using Shelter Protection Factor	Potential In-Shelter One Week Dose Range	Medical Care Needed	Able to Work	Probable Death Rate	Comments
PF 5	600R-1200R	Yes	No	100%	Deaths would occur in two weeks or less
PF 10	300R-600R	Yes	No**	More than 50%	Deaths would occur in about one month
PF 20	150R-300R	Yes	No**	Less than 50%	Deaths would occur in 30 to 60 days
PF 30 PF 40 PF 60 PF 80	100R-200R 75R-150R 50R-100R 38R- 75R	No	Yes	Less than 5%	Deaths would occur in 60 or more days
PF 100 PF 200 PF 500	30R-60R 15R-30R 6R-12R	No	Yes	None	No symptoms

* Based on the highest potential doses; further mitigation of illustrated conditions would occur at lower dose levels.

** Except during illness-free latent period.

levels ranging from PF 5 through PF 500. It should be pointed out that exact radiation levels can never be determined for specific points within this area in advance of fallout arrival. Hence, a minimum PF level for the entire cannot (and should not) be defined. Shelter with the highest PF possible should always be used in planning.

Chart B-5b. POTENTIAL LONG-TERM EFFECTS ON SURVIVORS IN MEDIUM FALLOUT RISK AREAS*

Using Shelter Protection Factor	Potential In-Shelter One Week Dose Range	Additional Survivor Cancer Deaths	Additional Deaths From Genetic Damage in Future Generations
PF 5	600R-1200R	No survivors	No progeny
PF 10	300R-600R	23 to 30%	2.6 to 3.5%
PF 20	150R-300R	15 to 23%	1.8 to 2.6%
PF 30 PF 40 PF 60 PF 80	100R-200R 75R-150R 50R-100R 38R-75R	4.5 to 11%	.53 to 1.3%
PF 100 PF 200 PF 500	30R-60R 15R-30R 6R-12R	0 to 1.4%	0 to .21%

* Based on assumption that sheltered survivors receive an additional dose over the longer term equal to that received in shelter, i.e., double the shelter dose received in 1 week.

Survivors in this area may face the possibility of continuing to use shelters beyond 1 week in order to sustain life and health. Potential outdoor radiation levels may be moderately high enough at the end of 1 week to require careful area monitoring to limit additional exposure from outdoor activity. Continued use of shelter beyond 1 week following outdoor activity may also be required through the end of the first month and would require modest preparations to sustain life (stocking of food, water, etc.).

(3) Overview - The total potential Medium Fallout Risk Areas cover approximately 578,616 square miles of the U.S., with a resident population of 62.702 millions. This constitutes 16.9 percent of the total U.S. land area, and 27.4 percent of the national population.

d. Low Fallout Risk

(1) Definition - A Low Fallout Risk Area is defined as an area which has the potential to receive a 1-week unprotected radiation dose of less than 3,000R.

(2) Criteria - If the fallout levels that characterize a Low Fallout Risk Area should occur, debilitating illness and possible death are certain for resident populations without adequate shelter. Charts B-6a

and B-6b illustrate the consequences of selecting protection levels ranging from PF 5 through PF 500. It should be pointed out that exact radiation

Chart B-6a. PROBABLE CONDITION OF MAJORITY OF SURVIVORS IN LOW FALLOUT RISK AREAS*

Using Shelter Protection Factor	Potential In-Shelter One Week Dose Range	Medical Care Needed	Able to Work	Probable Death Rate	Comments
PF 5	600R or less	Yes	No**	More than 50%	Deaths would occur in about one month
PF 10	300R or less	Yes	No**	Less than 50%	Deaths would occur in 30 to 60 days
PF 20 PF 30 PF 40	150R or less 100R or less 75R or less	No	Yes	Less than 5% than	Deaths would occur in 60 or more days
PF 60 PF 80 PF 100 PF 200 PF 500	50R or less 38R or less 30R or less 15R or less 6R or less	No	Yes	None	No symptoms

* Based on the highest potential doses; further mitigation of illustrated conditions would occur at lower dose levels.

** Except during illness-free latent period.

Chart B-6b. POTENTIAL LONG-TERM EFFECTS ON SURVIVORS IN LOW FALLOUT RISK AREAS*

Using Shelter Protection Factor	Potential In-Shelter One Week Dose Range	Additional Survivor Cancer Deaths	Additional Deaths From Genetic Damage in Future Generations
PF 5	600R or less	23 to 30%	2.6 to 3.5%
PF 10	300R or less	15 to 23%	1.8 to 2.6%
PF 20 PF 30 PF 40	150R or less 100R or less 75R or less	4.5 to 11%	.53 to 1.3%
PF 60 PF 80 PF 100 PF 200 PF 500	50R or less 38R or less 30R or less 15R or less 6R or less	0 to 1.4%	0 to .21%

* Based on assumption that sheltered survivors receive an additional dose over the longer term equal to that received in shelter, i.e., double the the shelter dose.

levels can never be determined for specific points within this area in advance of fallout arrival. Hence, a minimum PF level for the entire area cannot (and should not) be defined. Shelter with the highest PF possible should always be used in planning.

Continued use of shelter in this type of area beyond 1 week might not be necessary. As a precaution, however, unnecessary outdoor work should be avoided until all necessary radiological monitoring and decontamination has been completed.

(3) Overview - The total potential Low Fallout Risk Area covers approximately 1,803,733 square miles of the U.S., with a resident population of 107.867 millions. This constitutes 52.8 percent of the total U.S. land area, and 47.1 percent of the national population.

C. Thermal and Secondary Blast Fire Risk

1. General Overview - This risk accompanies the direct effects risk discussed in A., above. There are two principal causes of fire in direct effects risk areas: primary fires ignited directly by the thermal pulse or "heat flash" of a nuclear detonation; and secondary fires started by blast effects damage on electrical connections, gas lines, heating units, etc.

About 35 percent of the energy of an air-burst nuclear weapon is released as thermal energy or "heat flash." In weapon yields in hundreds of kilotons the duration of this period of energy radiation is very short (a flash of light) and the heat from the fireball is translated almost instantly to the surrounding area. In larger weapons (a megaton or greater) the fireball is slower in forming and is of somewhat longer duration. Therefore, in large weapons, the heat from the fireball is prolonged in areas of high overpressure but is proportionally less than the energy transmitted at low overpressure distances by the smaller-yield weapons. (Note: for determination of the fire risk, NAPB-90 assumed weapon yields characteristic of the 1985-1990 strategic inventories, i.e., weapons in the 500 kiloton to 1.5 megaton range.)

Thermal energy is measured in the number of calories per square centimeter (abbreviated "cal/cm^2") delivered to exposed areas. A calorie is the amount of heat necessary to raise the temperature of 1 gram of water 1 degree Celsius. The rate at which the calories are transmitted over time is also an important aspect of ignition. For weapons characteristic of the NAPB-90 inventories, it was assumed that thermal energy of the explosion is delivered almost "instantaneously" to exposed areas, i.e., at a very high rate.

The extent of the thermal effect of a nuclear weapon is subject to natural variations in the atmospheric conditions as well as the shielding ("shadow") provided by adjacent buildings, trees, hills, and the like. Likewise, any windows facing away from the fireball would receive little or no thermal energy. In addition to shielding, atmospheric conditions (such as rain or fog) would markedly reduce the transmission of the thermal energy and, thus, subsequent primary fire starts. Even minor shielding can have a mitigating effect on the amount of heat transmitted beyond the shielding: ordinary window glass and screens can reduce heat transmission into a room by as much as 20 percent or more.

Secondary fires may result from the disruption of building furnaces, gas lines, electric lines, and the like, and are independent of those influences mentioned above affecting the number of primary fire starts, since secondary fires are generated by damage and destruction from blast overpressure.

All NAPB-90 discussions in this section on the risk of potential primary and secondary fires are based on the assumption of a nuclear weapon detonated at its optimum height of burst to maximize the area covered by a blast overpressure of 10.0 psi or more, and under clear weather conditions which allow a visibility of 10 miles or more.

2. Composition of the Fire Risk - Factors influencing the magnitude of the fire risk are:

- The type of blast damage within the area;
- The number of primary and secondary fires originating (and not suppressed) within the area;
- The density of construction of the fire area, usually defined as the fraction of ground covered by buildings;
- The number of buildings within the area which are burning at the same time (usually expressed as a percentage of buildings);
- The amount of immediate fuel available to the fire;
- The weather conditions at the time of burning; and,
- The season of the year.

An example of the relationship of these factors is presented below. It must be stressed that such examples are illustrative of the potential fire risk and are based upon certain assumptions of the factors influencing the magnitude of the fire risk. Emergency planning requires an assessment of the actual values of the factors which influence the fire potential of tracts within a Direct Effects Area. A comprehensive assessment can be conducted only by fire professionals who have a working knowledge of the technology of fire and who can define the "real-world" fire risk to an area. Fire risk definitions in NAPB-90 are illustrative of the potential risk and are not predictive.

a. Origination

(1) Relationship to Overpressure - There is close relationship between the level of blast overpressures from air-burst weapons and the thermal energy received at any given overpressure. For example, the rationale

designating 2.0 psi overpressure limit as the practical limit of major thermal-induced primary fires is based on the fact that for most air-burst weapons, the 2.0 psi boundary coincides with a delivered thermal energy about 12.0 cal/cm^2--approximately the level of energy at which nearly all exposed easily flammable substances would ignite. This relationship, however, does not hold true between low air-bursts and surface-bursts of the same weapon yield.

Although little research has been done at low overpressure ranges on levels of thermal energy transmission, it is almost certain that primary fire ignitions could occur within the entire area of 0.5 psi and greater overpressure.

The level of damage produced by certain blast overpressures can affect fire growth and spread. For example, damage from blast overpressures in the 2.0 to 5.0 psi range is generally characterized by damaged but standing buildings amid a debris field--conditions favoring the spread, growth, and severity of fire. On the other hand, blast overpressures above 5.0 psi tend to result in a large debris field within which fire spread and growth could be much slower, and the severity of fires could be less intense.

(2) Primary Fire Starts - For all easily flammable materials exposed ("unshielded") to the thermal flash, the possibility exists that a primary fire may start if the material:

- Receives sufficient calories per square centimeter at a sufficient rate (i.e., over a very short period of time);
- Is not extinguished by the following blast wave or by immediate fire suppression actions; and,
- Is collocated with other, "heavier" fuel to sustain the initial ignition.

Ignition of commonly found outdoor "trash"--such things as newspapers, cardboard cartons, dried leaves--will usually occur at relatively low thermal exposures (about 5 to 7 cal/cm^2). By themselves, however, these fuels rarely can generate a sustained fire. Of much greater concern are ignitions of materials most commonly found indoors where a thermal ignition of things like curtains or drapes may spread to other material within the room. The risk from primary ignitions is highest when both the "tinder" with which to begin the fire, and substantial, heavier fuel with which to provide for continued fire growth are present. While weapon testing has indicated that this type of fire rarely occurred below 2.0 psi overpressure, primary ignitions cannot be categorically ruled out for this area.

Table C-1 shows extrapolated weapons test data on the estimated primary fire starts which might be expected to occur in exposed rooms from an air-burst, 1.0 megaton weapon on a clear day. Note that primary fire starts below 2.0 psi could occur but are considered the exception.

Table C-1. Estimated Primary Fire Starts Per 1000 Exposed Rooms

Blast Overpressure	Fires in Commercial Buildings	Fires in Private Residences
0.5 psi	Possible but Rare	Possible but Rare
1.0 psi	Probably None	Probably None
2.0 psi	Approximately 1%	Less than 1%
3.0 psi	Approximately 20%	Approximately 10%
5.0 psi	Approximately 38%	Approximately 21%

Some visual evidence suggested at Hiroshima and Nagasacki that the blast wave which followed thermal radiation may have extinguished some primary ignitions (although no firm proof was found to support this assumption). However, subsequent shock tunnel tests of room fires similar to primary ignitions seemed to suggest that some proportion of primary fires will be extinguished by the blast wave and it will slow, but not stop, fire growth.

(3) Secondary Ignitions - As stated earlier, the damage and destruction of the blast wave can create secondary fires from a variety of causes. At Hiroshima, for example, a great number of fires were caused by the overturning of hot charcoal cooking braziers commonly found in Japanese homes.

Secondary fires present a potential risk regardless of local weather conditions which might inhibit primary ignitions and could also be more extensive in the case of ground-burst weapons. Advance preparations (such as shutting off electrical power and gas supplies) could significantly reduce, but probably not eliminate, secondary fires.

Studies and research suggest that statistically in the area receiving 2.0 psi to 5.0 psi overpressure up to six significant secondary fire starts might be expected for every million square feet of building floor space. In a predominantly residential area, however, the number of such starts might be half as many. Theoretically, this assessment suggests an important functional relationship between the degree of blast damage and potential secondary fire starts.

b. Growth - As noted previously, there are a number of factors which influence fire growth. These are discussed below in illustrative applications of fire growth factors of various combinations. The potential growth of individual fires into large group or mass fires, as well as "firestorms," is also discussed. In the example presented, influences of weather and the season of the year on the growth and severity of fire are not factored.

(1) Area Density - Probably one of the most important factors influencing fire growth and severity is the amount of open space between construction in a given area. This is usually expressed as the percent of land area which is under roof (streets, parks, parking lots, yards, and the like, are considered open space). Suburban single family residential areas,

for example, typically are 20 percent or less "built up," while an inner city tenement district may be built up 50 percent or more.

Table C-2 shows illustrative area coverages for some types of construction.

Table C-2. Illustrative Area Coverage

General Type of Area Construction	Illustrative Area Covered by Buildings[1/]
Tenement/Townhouse	10 to 50 percent
Industrial	20 to 40 percent
High Rise Commercial	20 to 40 percent
Public Use Buildings	20 to 40 percent
Apartments (Fire Resistant)	10 to 25 percent
Warehousing/Storage	10 to 25 percent
Industrial Park	Up to 25 percent
Single Homes (All Types)	Up to 20 percent

1/ Percent of square mile covered by roof

The less open space between burning buildings, the more likely that fires will spread to buildings not previously ignited. Spread is achieved by three means of energy transfer: convection, radiation, and firebrands.

- Convection raises the temperature of nearby combustibles by the contact of flame or hot gases and is most likely to occur when buildings are immediately adjacent or very close to each other, as in a highly built-up area.
- Radiation from a burning structure raises the temperature of nearby combustibles in a manner similar to the thermal radiation of the weapon but at a very much lower rate.
- Firebrands from a burning building when carried aloft by wind or hot air convection currents can cause ignitions in other buildings and in other combustible material (such as debris) over a wide, downwind area.

It is not known how fire spreads in large debris fields with little or no structures standing.

(2) Simultaneous Burning - Another important influence on the growth and severity of fires is the number of standing buildings burning at the same moment within the area. Usually this is expressed as the percentage of total buildings within a square mile which are burning simultaneously. The importance of this influence was demonstrated in World War II and subsequently verified by controlled fire experiments.

(3) Fuel Load - The fuel in a building is measured in pounds of combustible material per square foot of floor space. This figure would represent the combined fuel of a building and its contents. For example, the fuel load of the contents of a single family residence might average

about 3.5 pounds per square foot of floor, while the combined fuel load of both contents and building might be 10 to 20 pounds or more per square foot for each floor of the structure.

The heat of combustion of the fuel is measured in kilowatt hours per pound of fuel. Each pound of available, burned fuel can be expected to release about 2.3 kilowatt-hours of energy (although many synthetic substances have a higher potential for energy release).

Table C-3 shows <u>illustrative</u> ranges of fuel loading for various types of building construction.

Table C-3. <u>Illustrative Ranges of Fuel Loading</u>

General Type of Area Construction	Illustrative Fuel Load Per Square Foot, Per Floor*
Warehousing/Storage	20 to 80 pounds
High Rise Commercial	10 to 40 pounds
Tenement/Townhouse	10 to 30 pounds
Industrial	5 to 30 pounds
Industrial Park	10 to 30 pounds
Frame or Brick Single Homes	10 to 20 pounds
Public Use Buildings	5 to 10 pounds
Single Homes (Fire Resistant)	5 to 10 pounds
Apartments (Fire Resistant)	3 to 5 pounds

*Building and sum of contents

c. <u>Severity</u> - Predicting the severity of fires is an uncertain science despite extensive research on World War II mass fires which occurred in German and Japanese cities. Some of the very large mass fires called "firestorms" by a German journalist had characteristics which were new to previous fire experience. In broad qualitative terms, fire research and study of the firestorm events following attacks on Heilbronn, Hamburg, Dresden, and Darmstadt, Germany, show that a firestorm event is accompanied by:

° High-velocity, in-rushing winds at the periphery of the fire area;

° A well-developed convection or smoke column; and,

° Little spread beyond the area containing the initial, merged fires.

Research also indicated that large fires, including firestorm events, will not develop without adequate fuel within the area of initial fires, coupled with a very high rate of fuel consumption. Most importantly, the studies showed that the <u>level of damage</u> from high-explosive bombs used before incendiary bombs played a significant role in the formation of the firestorm. The damage environment created was conducive to the rapid burning which took place. Four basic criteria were determined to be present in the firestorm events listed above. In each of these events:

- The average fuel loading per square foot of the entire fire area was at least 8 pounds (buildings and their contents);

- At least half of the standing, damaged buildings within the area were burning simultaneously and vigorously within a short time following initial fire starts;

- Initial surface winds at the time of the attack were less than 8 miles per hour; and,

- The firestorm area was greater than 0.5 square miles.

Illustrative examples on severity given below will address all of these criteria except weather (which is assumed to be "ideal").

(1) Relationship to Overpressures - As stated earlier, there is a close relationship between blast overpressure levels and characteristics which seem to replicate the German firestorm experiences. But while mass fire experiments in the 1960's tended to confirm much of the criteria for a firestorm occurrence (particularly those dealing with fuel consumption and burn rate), it is not at all clear whether fires in a nuclear effects environment would develop in the same manner.

Weapon test data show that buildings within the 2.0 to 5.0 psi overpressure range of a nuclear weapon would generally be heavily damaged but standing. Portions of this blast area might include certain of the necessary requirements for the generation of a firestorm. On the other hand, damage in the area experiencing 5.0 psi and more overpressure would be more severe with few buildings remaining standing. This area could be expected to consist largely of rubble and debris from destroyed buildings and their contents. Here, the necessary criteria for mass fires or firestorms may not be present (which is not to say that fires could not occur).

(2) Burn Time - Fire can be said to have three burn stages--all related to time: initial ignition; vigorous burning, when a large amount of the fuel energy is expended; and residual burning, which consumes the remaining fuel. Of the three, vigorous burning is the most important in determining the severity of fires following a nuclear detonation since it usually occurs over a relatively shorter period of time than the growth and residual stages. While not totally adequate as a measure, the vigorous burn stage can be used to define a burn "rate" for comparative purposes.

Weapon tests as well as research have shown that the vigorous burn stage of a damaged but standing structure generally releases a higher proportion of the available energy than the vigorous burn stage of rubble or debris of the same fuel density.

Table C-4 shows illustrative vigorous burn rates for various types of area construction for both damaged and destroyed building modes.

Table C-4. Illustrative Vigorous Burn Rates

General Type of Area Construction	Damaged Buildings[1/] Energy Released Over Time	Damaged Buildings[1/] Percent of Fuel	Damaged Buildings[1/] Burn Rate[3/]	Rubble and Debris[2/] Energy Released Over Time	Rubble and Debris[2/] Percent of Fuel	Rubble and Debris[2/] Burn Rate[3/]
Frame or Brick Single Homes	20 min	70%	2.10	40 min	75%	1.13
Single Family (Fire Resistant)	20 min	70%	2.10	40 min	75%	1.13
Tenement/Townhouse	25 min	60%	1.44	50 min	70%	.84
Apartments (Fire Resistant)	25 min	60%	1.44	50 min	70%	.84
Warehousing/Storage	40 min	60%	.90	80 min	70%	.53
High Rise Commercial	40 min	60%	.90	80 min	70%	.53
Industrial	60 min	30%	.30	60 min	30%	.30
Industrial Park	60 min	30%	.30	60 min	30%	.30
Public Use Buildings	60 min	30%	.30	60 min	30%	.30

1/ Damage characteristic in Medium Direct Effects Risk Areas (2.0 to 5.0 psi).

2/ Damage characteristic in High and Very High Direct Effects Risk Areas (greater than 5.0 psi).

3/ Relative burn rate given by the fraction of the available energy released per hour of vigorous burn time.

(3) Potential Energy - Previous illustrations concerning area coverage of various types of construction and corresponding fuel loads gave high-low ranges for these figures. To simplify further discussion, potential energies will be determined using only the high ranges of illustrative figures previously shown. Potential energies will be calculated for both the areas identified in Table C-4., above.

The severity of mass fire is expressed in terms of the average energy output per hour of vigorous burn time measured in millions of kilowatts of energy per square mile of fire area.

Table C-5 shows illustrative energies for various types of construction. Note that to determine such potential energy, it is necessary to assume an average number of stories for buildings in each category of construction. Fire severity assessments for specific areas require estimates based on the composition of construction in these areas.

Table C-5. Illustrative kW Energy (Millions) in Construction

General Type of Area Construction	Ave Sty[1/]	Area Cvrg[2/]	Fuel Load[3/]	Millions kW Energy Per: Sq Ft	Bldg	Sq Mile
High Rise Commercial	6	40%	40 lbs	94 kW	564 kW	6263 kW
Tenement/Townhouse	3	50%	30 lbs	141 kW	423 kW	2936 kW
Warehousing/Storage	2	25%	80 lbs	117 kW	235 kW	2610 kW
Industrial	2	40%	30 lbs	240 kW	47 kW	1566 kW
Public Use Buildings	4	40%	10 lbs	8 kW	31 kW	1044 kW
Industrial Park	2	25%	30 lbs	15 kW	29 kW	979 kW
Frame or Brick Homes	1.5	20%	20 lbs	55 kW	55 kW	392 kW
Apartments (Fire Res)	3	25%	5 lbs	12 kW	35 kW	245 kW
Single Homes (Fire Res)	1.5	20%	10 lbs	27 kW	41 kW	190 kW

1/ Assumed average height (stories) of all buildings in the area.

2/ Highest illustrative square mile area coverage by roof.

3/ Highest illustrative per square foot fuel load for building and contents.

To obtain an average rate of kilowatt energy release per hour per square mile, the burn rate for each type of construction must be considered.

Carrying over data illustrated in Table C-5, Table C-6a illustrates the potential kilowatt energy in a Medium Direct Effects Risk Area (2.0 to 5.0 psi overpressure) assuming 100 percent of the damaged, standing buildings are burning simultaneously at a vigorous burn rate, an extremely unlikely situation.

Table C-6a. Illustrative Energy Release With All Buildings Burning in Medium Direct Effects Risk Area (2.0 to 5.0 psi)

General Type of Area Construction	Millions of kW Potential Sq Mile Energy[1/]	Burn Rate	Millions of kW Energy Release Per Sq Mile[2/]
High Rise Commercial	6263 kW	.90	5736 kW
Tenement/Townhouse	2936 kW	1.43	4198 kW
Warehousing/Storage	2610 kW	.90	2349 kW
Frame or Brick Single Homes	392 kW	2.12	831 kW
Industrial	1566 kW	.30	470 kW
Single Homes (Fire Resistant)	196 kW	2.12	416 kW
Apartments (Fire Resistant)	245 kW	1.43	350 kW
Public Use Buildings	1044 kW	.30	313 kW
Industrial Park	979 kW	.30	294 kW

1/ All buildings; data carried from Table C-5.

2/ Potential average rate of kW energy per square mile (in millions of kW) if all buildings in the area are in vigorous burn stage.

Table C-6b illustrates the same calculations of potential energy release in kilowatts in the High and Very High Direct Effects Risk Areas (greater than 5.0 psi overpressure) if 100 percent of the rubble and debris from this construction are burning simultaneously at a vigorous burn rate, again, an extremely unlikely situation.

Both Table C-6a and C-6b will serve as a base for determining the average kilowatt energy release for more realistic assumptions of the numbers of buildings in simultaneous, vigorous burn stages which will allow an assessment of the possibility of mass fire or firestorm events.

Table C-6b. Illustrative kW Energy With Simultaneous Rubble and Debris Burning in High and Very High Direct Effects Risk Area (greater than 5.0 psi)

General Type of Area Rubble or Debris	Millions of kW Potential Sq Mile Energy[1/]	Burn Rate	Millions of kW Energy Release Per Sq Mile[2/]
High Rise Commercial	6244 kW	.53	3309 kw
Tenement/Townhouse	2940 kW	.83	2440 kW
Warehousing/Storage	2604 kW	.53	1380 kW
Industrial	1568 kW	.30	470 kW
Frame or Brick Single Homes	392 kW	1.14	447 kW
Public Use Buildings	1036 kW	.30	311 kW
Industrial Park	980 kW	.30	294 kW
Single Family (Fire Resistant)	196 kW	1.14	223 kW
Apartments (Fire Resistant)	252 kW	.83	209 kW

1/ All rubble and debris from buildings.

2/ Potential average energy release in millions of kW per square mile if all rubble and debris from buildings are in vigorous burn stage.

(4) Mass Fire/Firestorm Potential - Analyses of World War II mass fires concluded that the severity of fires can be expressed as an average kilowatt energy release per square mile of fire area. Many such fires were classified as group fires since the area covered by the conflagration was characterized by isolated city blocks burning simultaneously and vigorously but not merging. Group fires of this kind were estimated to generate energy releases of from 25 to 300 million kilowatts. Included in this category were the fires which followed the atomic bomb attacks on Hiroshima and Nagasaki. While extremely dangerous to life, the severity of fires in both of these cities was less than that generated by conventional bombing in the Tokyo fire raids carried out some weeks before the dropping of the atomic bombs.

The chief factors involved in estimating potential fire severity have been covered before and will not be repeated here. An illustration of the effect of these factors is, however, pertinent. The Hamburg firestorm event provides an example case:

- The average fuel load of the area (including all buildings and contents and considering the density of construction) was estimated to be 70 pounds per square foot of fire area. At 2.3 kilowatt-hours per pound this translated into 163 potential kilowatt-hours per square foot or about 4567 million kilowatt-hours per square mile.

- It was estimated that about 45 percent of the buildings were in a vigorous burn stage simultaneously during the firestorm; therefore, about 2055 million kilowatt-hours were released per square mile of burn area.

- The firestorm lasted about three hours and, therefore, the hourly average release was about 676 million kilowatt-hours.

From the above, an estimate of the possibility of a firestorm would be a combination of contributing factors which could lead to an average energy release of at least 650 million kilowatt-hours or more per square mile. However, potential energy releases lower than this level have also been shown to be extremely dangerous. Estimates derived from large burn tests show that extreme life-threatening situations can develop from a combination of extremely high air temperatures, smoke and combustion-generated gases, and the rapid rise in carbon monoxide when the average energy release approaches 300 million kilowatt-hours per square mile. Fatality rates also increase sharply as this level is approached.

Table C-7a illustrates the changes in per square mile energy release rates when various percentages of buildings are burning simultaneously within the Medium Direct Effects Threat Area (2.0 to 5.0 psi). Likewise, Table C-7b illustrates the changes in per square mile energy release rates when various percentages of building rubble and debris are burning simultaneously within the High and Very High Direct Effects Threat Areas (greater than 5.0 psi).

Table C-7a. Illustrative Results of Simultaneous Burning in Medium Direct Effects Risk Area (2.0 to 5.0 psi)

General Type of Area Construction	Average Square Mile Rate of Energy Release (Millions of kW) 50% Burning	40% Burning	30% Burning	20% Burning
High Rise Commercial	2819 kW*	2255 kW*	1691 kW*	1127 kW*
Tenement/Townhouse	2099 kW*	1679 kW*	1259 kW*	840 kW*
Warehousing/Storage	1175 kW*	940 kW*	705 kW*	470 kW*
Frame or Brick Single Homes	416 kW**	332 kW**	249 kW	166 kW
Industrial	235 kW	188 kW	141 kW	94 kW
Single Family (Fire Resistant)	208 kW	166 kW	125 kW	83 kW
Apartments (Fire Resistant)	175 kW	140 kW	105 kW	70 kW
Public Use Buildings	157 kW	125 kW	94 kW	63 kW
Industrial Park	147 kW	118 kW	88 kW	59 kW

* Firestorm theoretically possible at this average energy release rate given all previous illustrative assumptions on fuel, coverage, average stories, and burn rate.

** Level of energy release would make area extremely dangerous for survivors.

Table C-7b. Illustrative Results of Simultaneous Burning in High and Very High Direct Effects Risk Areas (greater than 5.0 psi)

General Type of Area Construction	Average Square Mile Rate of Energy Release (Millions of kW) 50% Burning	40% Burning	30% Burning	20% Burning
High Rise Commercial	1644 kW*	1315 kW*	986 kW*	658 kW**
Tenement/Townhouse	1233 kW*	986 kW*	740 kW*	493 kW**
Warehousing/Storage	685 kW*	548 kW**	411 kW**	274 kW
Industrial	235 kW	188 kW	141 kW	94 kW
Frame or Brick Single Homes	221 kW	176 kW	132 kW	88 kW
Public Use Buildings	157 kW	125 kW	94 kW	63 kW
Industrial Park	147 kW	118 kW	88 kW	59 kW
Single Homes (Fire Resistant)	113 kW	90 kW	68 kW	45 kW
Apartments (Fire Resistant)	103 kW	82 kW	62 kW	41 kW

* A firestorm is theoretically possible at this energy release rate given all previous illustrative assumptions on fuel, coverage, average stories, and burn rate.

** The level of energy release would make this area extremely dangerous for survivors.

3. Statistical Overview of Risk - NAPB-90 defines the potential risk from fire following a nuclear explosion as the total area covered by blast overpressure, i.e., any area which has the potential to experience 0.5 pounds per square inch (psi) or more. This represents 727,112 square miles of U.S. territory with an estimated resident population of 175.11 millions.

The magnitude of this risk is represented in Annex A.

4. Methodology Employed - NAPB-90 defines three levels of potential risk from fire. Each definition is driven by the likely effects of the potential fire on the life and health of the resident population. In this context, the following considerations were used in determining the degrees of fire risk:

- The potential long-term severity of the threat to survivors within a blast-damaged area through entrapment in damaged or destroyed buildings by fires of whatever origin and of whatever severity; and,

- The kind, degree, and practicality of fire suppression actions.

It should be evident from prior discussions that there must be many factors present before mass fire or firestorm can result. If, in the entire area, such factors are not found to be present following a detailed fire assessment, the defined risks will be less severe than presented below.

The defined NAPB-90 fire risks, therefore, do not predict the severity or extent of the threat itself but do point out the potential for the risk to occur if necessary factors in the entire area (or in portions of the area) support such a conclusion.

a. Very High Fire Risk

(1) Definition - A Very High Fire Risk Area is defined as the area corresponding to the High and Very High Direct Effects Risk Areas, i.e., the area which has the potential to experience blast overpressures from a nuclear detonation equal to or greater than 5.0 psi.

(2) Criteria - In a Very High Fire Risk Area survivors would probably face life-threatening fires generated by the thermal pulse of a weapon as well as damage-caused ignitions from ruptured gas and electric lines. In this area, it will be virtually impossible to initiate fire-fighting procedures because of rubble and debris, severed waterlines, damaged or destroyed firefighting equipment, and the like. For this reason--more than for the potential severity of fires--any survivors of blast effects face death unless evacuated from this area.

In short, residents in potential Very High Fire Risk Areas face extremely dangerous blast overpressures as well as the possibility of death from ensuing fires of whatever origin or severity.

(3) Overview - The total potential Very High Fire Risk Areas in the U.S. cover approximately 96,248 square miles, with a resident population of 79.44 millions. Of the total U.S. area and population defined by NAPB-90 as under fire risk, 2.7 percent of the land area and 45.4 percent of the population fall under this risk definition. As a population group, those in Very High Fire Risk Areas represent 42.9 percent of the total population of the U.S.

b. High Fire Risk

(1) Definition - A High Fire Risk Area is defined as the area corresponding to the Medium Direct Effects Risk Area, i.e., the area which has the potential to experience blast overpressures from a nuclear detonation equal to or greater than 2.0 psi but less than 5.0 psi.

(2) Criteria - A High Fire Risk Area has the potential to experience large fires following weapon detonation which could prove fatal to survivors unless they were evacuated. The potential for such fires to originate and develop depends on the number of structures and construction type within the area and their propensity to fire growth and spread. Should a detailed fire analysis of this area reveal such characteristics, large group fires and even firestorms are possible, posing the possibility of sure death for survivors unable to evacuate the area.

Initial and subsequent firefighting procedures for large fires in this area will be difficult, if not impossible, due to limited mobility imposed by rubble and debris, the potential lack of water, and damaged or destroyed fire-fighting equipment. Self-help fire fighting of initial ignitions (from whatever cause) may be possible but extremely difficult.

(3) Overview - The total potential High Fire Risk Areas in the U.S. cover approximately 151,535 square miles, with a resident population of 50.3 million. Of the total U.S. area and population defined by NAPB-90 as under fire risk, 4.3 percent of the land area and 28.7 percent of the population fall under this risk definition. As a population group, those in High Fire Risk Areas represent 20.8 percent of the total population of the U.S.

c. Medium Fire Risk

(1) Definition - A Medium Fire Risk Area is defined as the area corresponding to the Low Direct Effects Risk Area, i.e., the area which has the potential to experience blast overpressures from a nuclear detonation equal to or greater than 0.5 psi but less that 2.0 psi.

(2) Criteria - The most probable cause of fire in a Medium Fire Risk Area will be from indoor primary ignitions caused by the thermal radiation of the weapon. These indoor ignitions, if unchecked, have the potential to grow into larger, more threatening fires. Secondary fires in this area are possible, but not very likely. Since protective measures in this area can be effective against blast overpressures, firefighting in this area is possible (if extensive preattack preparations and training have been accomplished), but shortages or lack of water for such purposes may prove a serious problem.

Fires in this area, even though individually intense, will probably not merge into a mass fire or firestorm.

(3) Overview - The total potential Medium Fire Risk Areas in the U.S. cover approximately 479,329 square miles, with a resident population of 45.37 millions. Of the total U.S. area and population defined by NAPB-90 as under fire risk, 13.5 percent of the land area and 25.9 percent of the population fall under this risk definition. As a population group, those in Medium Fire Risk Areas represent 18.8 percent of the total population of the U.S.