OCD Work Unit No. 2525A
USNRDL-TR-67-100
14 August 1967

COUNTERMEASURE CONCEPTS FOR USE AGAINST URBAN MASS FIRES FROM NUCLEAR WEAPON ATTACK

by

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SPECIAL OCD SUMMARY FOR USNRDL-TR-67-100, 14 AUGUST 1967

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The Problem

The purpose of this report is to propose and to perform an initial evaluation of new concepts for the extinguishment and for the control of urban mass fires resulting from nuclear weapon attacks.

One of the primary objectives of civil defense is to minimize casualties and property damage from urban mass fires. Unfortunately, current metropolitan firefighting manpower, equipment and techniques will almost certainly be inadequate for extinguishing or controlling the multiple mass fires to be expected from a nuclear attack. Thus, there is merit in conceiving, evaluating and developing new procedures for dealing with these fires so that the civil defense objective may be realized.

The Findings

Possible countermeasures for extinguishing or controlling urban mass fires were investigated and evaluated. The evaluations led to some recommendations for the direction of any future physical research, development and further evaluation.

The authors conclude that firebreaks can be effective in cities, provided that they are made correctly, rapidly and in adequate width, and provided that they are diligently tended by firemen.

The probability for controlling an urban mass fire by some combination of firebreaks and then letting it burn out is greater than that for extinguishing it in toto; however, extinguishment efforts for sections of a mass fire seem hopeful, particulary in connection with control efforts. Control countermeasures and extinguishment countermeasures should be applied cooperatively when possible.

ABSTRACT

New concepts for the extinguishment or control of urban mass fires from nuclear-weapon attack are proposed and evaluated. A synoptic, illustrative modus operandi is given to illustrate application of each of these conceptual countermeasures in extinguishing or controlling fires. The generation or utilization of firebreaks seems to offer the most promise. Specific recommendations are made concerning the direction of future study.

SUMMARY

The Problem

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The authors conclude that firebreaks can be effective in cities, provided that they are made correctly, rapidly and in adequate width, and provided that they are diligently tended by firemen.

The probability for controlling an urban mass fire by creating and maintaining firebreaks and then letting the fire burn out is greater than the possibility of extinguishing the fire, either in part or in toto. Conceptual countermeasures leading to the extinguishment of mass fires resulting from nuclear attack do not seem promising.

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SECTION 1

INTRODUCTION

The purpose, background and approach of this study are given in the present section.

1.1 PURPOSE OF STUDY

The purpose of this study was to propose and to perform an initial evaluation of the effectiveness and practicality of new concepts for extinguishing and controlling urban mass fires resulting from nuclear weapon attacks.

As described, for example in a statement of OCD Task Unit 2525A, T.O. No. 65-200(43), of 30 March 1965, the work will include but not be limited to:

1. Reviewing and collating existing ideas for mass-fire control, including the use of conventional firefighting techniques as a datum.

2. Investigating other promising ideas for mass-fire control. These ideas would include those within and beyond the existing technology.

3. Conducting preliminary cost-effectiveness analyses of the possibilities and recommending promising lines of development if such are found to exist.

In this report, no attempt is made to deal exhaustively with any of the specific concepts discussed; i.e., no attempt is made to obtain a firm conclusion as to the efficacy of the countermeasure in the nuclear-warfare context. Such an effort would in fact be premature because of the state of the art in the areas treated, because of the present lack of demonstrated technical feasibility of some of the concepts treated, and because of the lack of studies of pertinent economic, political, and operational factors in other cases.

What is intended by the present report is to present a sufficient evaluation of the concepts to indicate that some possibility exists that the countermeasure will be of value, to identify the factors which must be taken into account in more detailed assessments, and to indicate specific directions for further research, development, and evaluation.

1.2 BACKGROUND

It is recognized that the civil defense, military posture, industrial capacity and wildland resources of the nation will be jeopardized by mass fires in the event of a nuclear weapon attack. One of the important goals of civil defense is to minimize casualties and property damage from these fires. The Office of Civil Defense (OCD) pursues this goal by preattack study, planning, preparation and research, and by postattack rescue and damage control. A comprehensive state of the art in such research is given by Gibbons.* Hence, OCD has sponsored studies of thermal and fire phenomena and effects, and thermal countermeasures. The present study on radical concepts for extinguishing and controlling urban mass fires from nuclear weapons is a part of the general OCD program.

Countryman[2a] has defined a "mass fire" as one characterized by large size with high rates of energy release per unit area. The term includes conflagrations and firestorms; i.e., fires showing the more violent types of behavior. In the present report, conflagrations will be conceived as fires moving as definite, violently burning fronts or "heads" which usually have a relatively shallow depth. They may be accompanied by convective columns, whirlwinds, firewhirls, and by less intensely burning fires in the wake of the moving front. Conflagrations require extensive fuel beds because they move continually into new areas. They can burn out vast areas rapidly, given optimum conditions of fuel, wind and topography. The fire spread is greatly enhanced by windblown firebrands.

Firestorms will be thought of in the classical sense as relatively stationary mass fires that violently burn out areas of high fuel density, that develop convective columns which may reach heights of 35,000 feet,[2b,3a] and that generate strong surface indrafts, destructive whirlwinds, and firewhirls.[3b,4a,5a,6a] The strong indrafts preclude moving fronts, but the whirlwinds and firewhirls are capable of scattering firebrands that can set fires in neighboring areas.[4a] Virtually complete destruction of the urban area within the firestorm perimeter will occur due to the blast-furnace effect from high indraft velocities. Firestorms develop from the union of numerous fires burning in a situation of high fuel density and only light ambient ground winds.

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* M.G. Gibbons, "State of the Art in Fire Research," USNRDL-LR-122, 15 August 1965 (UNCL).

Countryman has pointed out that a mass fire with a duration extending through major topographical, fuel and meteorological changes can change from a conflagration to a firestorm, and vice versa.[2c] Such behavior is common in wildland fires. Therefore, it is prudent to expect that a megalopolis could alternately or simultaneously exhibit conflagration and firestorm situations under certain conditions in the case of prolific ignitions from nuclear weapons.

The control of mass fires from either kiloton or megaton nuclear weapons presents an enormous problem. McNea has predicted that multimegaton nuclear weapons can subject 450 to 1200 square miles to immediate ignition and subsequent burn-out, depending upon weapon yield and burst height.[2d,7] Chandler notes that mass fires following a megaton nuclear attack may be larger and more numerous than those previously known,[5b] but believes (logically and conservatively) that their behavior and rate of spread will be governed by the same factors as have affected previous mass fires. Military evaluations of and experience from incendiary air raids of World War II have shown that the following damage-control problems can be expected in the case of urban fires from nuclear weapons:

1. The destruction or immobilization of fire-fighting personnel and equipment from blast and fire effects.[6b,8a]

2. Confusion, fear, and lack of radio, telephone, or personal communication; the ineffectiveness of fire reconnaissance because of smoke, fumes and flames.[4b,8a,9a,10a]

3. Radioactive fallout or fear thereof.

4. The simultaneous occurrence of two or more mass fires.[5b,6b,8a]

5. The blocking of access routes to fires by rubble from fire and blast, and by fleeing refugees.[4c,6b,8a,10a]

6. A nonexistent or considerably reduced water supply due to breakage of pipes, hydrants and equipment.[4d,6b,8a,10a]

7. The destruction or nonavailability of motor fuel for fire trucks.[4e]

It is considered that these and other unanticipated damage-control problems will prove to be beyond the capabilities of conventional American fire-fighting manpower and equipment, especially in the case of the larger and more numerous urban mass fires expected from megaton weapons.[9b,10b] Thus, there is merit in searching for and evaluating new concepts for dealing with mass fires.

1.3 APPROACH

Three important parameters govern the birth, duration and spread of any fire, including urban mass fires resulting from nuclear weapons. These are fuel, topography and meteorology.

Thus the approach taken in this study is to classify and present new concepts for extinguishing and controlling urban mass fires in terms of the above parameters, since a countermeasure will extinguish or control a mass fire by controlling a parameter that governs the fire. Section 2 reviews the important parameters briefly as a background for Sections 3 and 4. Section 3 concerns countermeasure concepts intended to extinguish urban mass fires thru control of the parameters. Section 4 concerns conceptual countermeasures intended only to control urban mass fires thru control of the parameters. A brief summarization of results is given in Section 5. Section 6 is a summary of conclusions and recommendations.

Conceptually, urban mass fires can be (1) prevented from occurring by minimizing ignitions from fireball radiation and blast through prefire protective measures (such as smoke screens), or (2) extinguished or controlled through postignition countermeasures. Only postignition, damage-control conceptual countermeasures are considered herein. Nevertheless, any massive postignition countermeasure requires much prefire planning, preparation and training if it is to be applied effectively in the emergency situation. Accordingly, it should not be surprising that a few of the conceptual countermeasures presented herein are a hybrid of pre- and postignition measures.

It will be noted that the concept of using backfires as a control measure is not treated in this report. Such an approach is eliminated from consideration for several reasons: (1) the magnitude of the required backfire; (2) the inability to predict the (often self-generated) meteorology within the enivronment of a mass fire; (3) the almost certain unavailability of adequate personnel for such an approach. (However, see Sections 4.1.4 and 4.3.)

The following were aids in reaching conclusions and recommendations: conferences with metropolitan fire chiefs; discussions with scientists and associates engaged in fire research; discussions with scientists of varied disciplines related to fire research; a review of the technical literature on large fires; observations of U.S. Forest Service large-scale fire tests; and a background of personal research experience in the attenuation of nuclear thermal radiation to minimize surface ignitions.[11]

SECTION 2

PARAMETERS GOVERNING URBAN MASS FIRES FROM NUCLEAR WEAPONS

This section summarizes the parameters that govern urban mass fires from nuclear weapons: fuel, topography and meteorology. It also briefly considers the important mass-fire phenomenon of ignition. It provides a background for Sections 3 and 4 which present conceptual countermeasures against urban mass fires. Taken together, the parameters define the mass-fire environment. It is noted that a much more detailed discussion of the parameters governing urban vulnerability to fire from nuclear bursts is given in Ref. 1, USNRDL-TR-1040 of 30 June 1966 "Parameters Governing Urban Vulnerability To Fire From Nuclear Bursts," (Phase I) by Renner, R.H., Martin, S.B., and Jones, R.E.

2.1 FUEL

The available fuel is obviously a major mass-fire parameter. Those who have studied mass fires of World War II have concluded that the nature and disposition of fuels in burned-out European and Japanese cities resembled those now found in various American cities closely enough so that devastating mass fires may be expected in American cities in the event of nuclear attack.[8b] For example, there is much backyard rubbish in American cities, a situation that was not tolerated in German cities which, nevertheless, still contained enough kindling for their destruction.[4f]

The nature, extent and disposition of the fuel will govern the origin, spread and behavior of a mass fire. Concerning urban mass fire, the fuel elements are the buildings themselves, gasoline stations, city gas tanks, lumber and coal yards, manufacturing and chemical plants, etc.; in brief, the entire metropolis is potentially a fuel bed. The extent and disposition of the fuel elements are complex and variable, and wide natural or emergency fire breaks in the fuel bed are obviously beneficial to fire control. The fuel in vast residential and suburban tracts consists essentially of readily combustible buildings. The fuel of hardened industrial and chemical plants is mainly the raw and manufactured products. The fuel in a central business and residential district is found largely within fire-resistive buildings and ordinary brick-concrete type buildings, but may be ignited by (nuclear) thermal radiation entering the window.

The majority of central buildings are old, have brick-concrete type exteriors, and contain much wood and combustibles within. The vulnerability of these buildings to fire is shown by the serious fires that occur in them occasionally, and by the burning of the interiors of German fire-resistive buildings during World War II from incendiaries entering the windows.[4g] Nuclear blast effects will expose combustible interiors to fire and will block streets with combustible debris. A great number of interior fires can be expected to spread rapidly to form a mass fire, due to high inside fuel densities, building congestion, blast damage, and narrow asphalt streets which will soften and could burst into flame. German wartime experience showed that the most effective way to fight a central-type mass fire was to locate and extinguish interior fires floor by floor in buildings on the perimeter of the mass fire, rather than to erect water curtains with fire hoses.[4h] Both methods would, of course, be impossible on an extensive basis in a nuclear-warfare situation.

2.2 TOPOGRAPHY

With respect to fire problems, the topography of a city properly includes its relief; the configurations and relative heights of its buildings; and the positions of water bodies, rivers and open spaces.

The largest American cities are built on relatively flat land, with a few exceptions such as San Francisco. Steep, large hills and ridges, as found in the San Francisco Bay area, are potentially capable of modifying the effects of fireball radiation and mass fire, since they obstruct the line of sight and moreover frequently determine the local weather, winds and heavy fog cover. Thus, hills and ridges could shield contiguous neighborhoods from thermal radiation, provided that the weapon is detonated low and far enough away.

Fortunately, many large American cities are adjacent to sizeable rivers or large bodies of water that may serve as hose supply, firebreaks, or (as described later) water supply for new countermeasures to extinguish or control fires.

That a conflagration accelerates uphill has been observed in some cities and in numerous wildlands.[2e,12] Forest fires roughly double their speed and intensity with each increase of 15 degrees in slope. The phenomenon is due to fire-engendered upslope winds and to greater convection-radiation heating of uphill fuels.[2e] These effects probably also enhance the upward and outward spread of fire in vicinities packed with buildings of differing heights. Conversely, downhill fires spread relatively more slowly than uphill or flat fires, except when considerable quantities of burning debris are falling or tumbling.[2e,12] For this reason, barren or only moderately developed ridge lines can serve as good firebreaks on the lee side of a conflagration.

2.3 METEOROLOGY

Meteorological conditions play a most important role in urban fire behavior.

First of all, it is noted that rainy, foggy, cloudy or smoggy conditions can attenuate fireball radiation and so decrease its kindling abilities.[13a] Intensive and prolonged rain is obviously beneficial to the extinguishment of large fires. A high atmospheric humidity causes a high moisture content in a fuel, and this increases the ignition temperature and decreases the combustion temperature until the fuel dries out in burning.

Surface wind is a particularly critical factor with mass fire. Gentle winds or a calm favor the coalescence of fires into a firestorm. For example, wind was almost totally absent shortly before the incendiary raid that caused the famous Hamburg firestorm of 27 July 1943.[3a] Strong winds develop conflagrations and determine rate, direction and distance of fire spread. For example, a wind of about 25 mph caused fire to spread across Tokyo as a flaming wall after a mass incendiary raid on 9 March 1945.[3a] Chandler[5c] has pointed out that strong winds will cause conflagrations to advance in surges, to spread by firebrands, and to traverse cities at speeds up to 3 mph. With more gentle winds, the advance will be slower and steadier, and will probably average 0.1 to 0.5 mph.

The fire parameters, meteorology, fuel and topography change their characteristics with season in many American cities. The particular nature and intensity of the change depends upon the city in question. As an example, winter brings arctic conditions to some cities. It decreases the combustibility of exterior fuels by cooling, wetting and burying them in snow and ice; increases the reflection and scattering of fireball radiation via snow cover; and increases the difficulty of firefighting due to the inclement weather, freezing water, and snowy terrain.

Mass fires frequently change local weather conditions and substitute their own. Rain frequently accompanies a firestorm, apparently resulting from the condensation of moisture on particles from the fire when they rise to a colder region. Rain resulted from the Hiroshima fire storm that resulted from atomic bombing.[13b] The association of strong indrafts, whirlwinds and firewhirls with firestorms and conflagrations was mentioned previously.

2.4 IGNITION

The ignition capabilities of both fireball radiation and mass fires are important to conceptions of urban fire defense.

Nuclear weapons can start fires directly by exposing kindling materials to thermal radiation, and indirectly by blast effects on gas facilities and electrical appliances. Concerning fireball radiation, the area density of ignitions for a given height of burst increases with exposure time (that is, with weapon yield) and decreases with distance from detonation. Fires may be expected at ranges that exceed those at which blast effects produce appreciable debris.[6c] Fuel, topography and meteorology conditions affect the ignition potential of fireball radiation as described in the above summaries.

Mass fires spread by new ignitions from firebrands, flame contact and radiation. Fire spread from firebrands scattered by wind, whirlwinds and convective columns is well known in wildland fires, and has its counterpart in urban mass fires.

The role of mass-fire radiation itself in producing new ignitions and fire spread is currently open to question. Countryman has observed that radiation had little effect on fire spread in U.S. Forest Service full-scale tests of mass fire, and has commented that this confirms observations on wildland fires and some laboratory tests.[2f] He observed, as did Evans and Tracy at other full scale tests,* that a particularly slow melting of snow close to the fire pointed to the ineffectiveness of radiation in producing ignition at those tests. However, the superb reflective capacity of granular snow may explain the slow melting at the fire tests. Another evidence of a lack of radiative effect, as observed by Evans and Tracy, was that plants near the test fire failed to char.*

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* E.C. Evans III and E.T. Tracy, "Observations of Mass Fire 460-14 at Mono Lake," USNRDL-LR-158, 24 January 1966.

SECTION 3

CONCEPTUAL COUNTERMEASURES TO EXTINGUISH URBAN MASS FIRES FROM NUCLEAR WEAPONS

Current countermeasures that extinguish ordinary urban fires will be inadequate to extinguish mass fires from nuclear weapons. Presently available firefighting manpower, equipment, and techniques cannot be expected to cope successfully with mass fires because of their size, number, violent character and damage-control problems. New concepts are required, concepts potentially capable of being developed into operating procedures through evaluation, research, engineering and experience. This section considers reasonable conceptual countermeasures to extinguish urban mass fires.

The idea of extinguishment, as contrasted with control, requires clarification. Extinguishment means to put out, whereas control means to contain and let burn out. The authors consider that the extinguishment of an entire, gigantic urban mass fire has a low probability of success with envisioned approaches, but that partial extinguishment is more hopeful and that control is much more hopeful. It would be preferable that extinguishment countermeasures and control countermeasures (firebreaks, for example) be applied together, providing as much control as possible, with a goal of ultimate extinguishment.

Any conceptual countermeasure has uncertainties with respect to feasibility, effectiveness, practicality, details of application, or dangers associated with them. Both pros and cons are considered in this study, the final judgement of the value of a concept being left to further research, testing and practical experience. Even after further study, it is expected that the acceptance or rejection of any countermeasure, new or conventional, in a given fire situation will depend upon some predetermined fire policy and upon a decision by firefighting authorities.

Since a countermeasure will extinguish (or control) a mass fire by controlling a parameter that governs the fire, it is logical to classify a countermeasure by means of the fire parameter it seeks to control. Classification becomes subjective when a countermeasure affects more than one parameter in a major way. The conceptual countermeasures considered in this study are classified as (1) those dealing with the fuel parameter, (2) those dealing with the topography parameter, and (3) those dealing with the meteorology parameter.

3.1 CONCEPTS FOR EXTINGUISHING FIRES BY CONTROLLING THE AVAILABLE FUEL

A fire may be extinguished by controlling the fuel available through cooling and suffocation. The usual way to cool and suffocate a large-scale fire is to apply water. In the case of the Hamburg firestorm, the erection of water curtains from large hose streams was found to be impractical because of the requirement for long relays and a vast number of pumpers.[4h] This problem would be even more severe in a nuclear-warfare situation. Fires extinguished with water sometimes rekindle due to the effect of adjacent fires when the fuel dries out rapidly, and so it is sometimes necessary to rewet extinguished fuels to prevent reignition.

Two conceptual countermeasures affecting the fuel parameter are discussed for extinguishing sections of an urban mass fire: (1) cooling and suffocating with liquid nitrogen, and (2) cooling and suffocating with solid carbon dioxide.

3.1.1 Cooling and Suffocating with Liquid Nitrogen

It is at least conceivable that multiton quantities of liquid nitrogen could be applied to a section of urban mass fire to extinguish it.

A refinement of this concept is the cooperative use of liquid nitrogen together with water. Liquid nitrogen alone, in sufficient quantities, can "knock out" (extinguish) fires by explosively rapid evaporation to an extensive suffocating blanket. However, experiment shows that the extinguished fuel, which remains dry, has a tendency to rekindle if the nitrogen blanket is soon breached by air.[14] Water does not extinguish fires with the suddenness of liquid nitrogen (barring actual flooding), but it has some effectiveness against rekindling because the extinguished fuel may remain moist, dry slowly, and cool efficiently due to the high heat of vaporization of the water. Ther fore, the use of massive quantities of liquid nitrogen (to extinguish rapidly) followed immediately by the use of water (to minimize rekindling) is detailed below as a conceptual countermeasure.

Both water and liquid nitrogen extinguish fires by cooling and suffocating, water having the greater cooling and expansive (suffocative) capacity on an equal weight basis, but lacking the property of "knock out" extinguishment. For example, the conversion of 28 tons of water at ordinary temperature (68°F) to gas at the boiling point (212°F) absorbs 6.2×10^7 BTU and produces at a pressure of 1 atm a volume of steam of 15.3×10^5 ft^3 (for example, 50 x 175 x 175 ft). The conversion of 28 tons of liquid nitrogen at its boiling point (-320°F) to gas at 212°F absorbs only 1.2×10^7 BTU and produces at one atmosphere a gas volume of only 9.8×10^5 ft^3 (for example, 50 x 140 x 140 ft). It should be remembered that it is not necessary to displace air completely to prevent combustion; a reduction of 4% (to about 16%) oxygen concentration is sufficient. Nitrogen has essentially the same density as air, so there is no tendency for air to displace nitrogen upward and away from a fuel.

Liquid nitrogen therefore may be considered for situations where copious quantities of hose water are not available for wetting fuel and, therefore, for which extinguishment must be rapid. For example, it might be used as an airdrop on an inaccessible section of mass fire or on an inaccessible fire burning through a firebreak. Or it might be used in a land operation where a section of urban mass fire, perhaps burning through a firebreak, is approachable for hose work, but where water must be tanked.

Let a possible air-drop procedure illustrate the use of water <u>and</u> liquid nitrogen: The C-133A military cargo plane is used since it is capable of carrying 57.5 tons of cargo and has a rear door for massive cargo drops. A cargo of 28 tons of liquid nitrogen and 28 tons of water is carried in a few liquid-nitrogen containers and water containers that are closed, adequately vented, and all tethered together so that they impact in the same vicinity. The containers are dropped on the fire to shatter and explode on impact. When extinguishment is successful, C-133A planes continue to re-bomb the area as often as necessary with water to prevent reignition. The foregoing procedure would require the design and development of suitable cryogenic containers for the liquid nitrogen, a development within the capability of current technology. The cryogenic containers would need to be cheap and expendable; they would not need the highest efficiency against evaporation since they would not contain liquid nitrogen for long; and they should not explode prematurely thru gaseous expansion while dropping thru hot air rising from the fire.

Also let a possible land procedure and situation illustrate the use of combined water and nitrogen. A section of fire is approached for hose work. Liquid nitrogen is delivered by conventional cryogenic tank trucks. Water is delivered by commandeered* 10,000-gallon tank trucks ordinarily used for transporting gasoline. Liquid nitrogen is pumped directly into the fire via a long iron pipe assembled from sections, the nitrogen gasifying in the hot end of the pipe. Extinguishment is followed by hosing with water, water trucks running relays if possible to provide water as needed to forestall drying and reignition. Equipment of the SCUBA (self-contained underwater breathing apparatus) type would be necessary to prevent possible asphyxiation of firemen.

The possibility of simply abandoning large amounts of liquid nitrogen in an area being deliberately yielded to a conflagration should

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* In the sense of the assumption of private property for civic usage. Obviously, plans for such use would have been worked out in deatil as part of preattack civil defense planning.

not be overlooked. For example, a pit might be hurriedly dug for each cryogenic tank truck at the scene, and a nitrogen-filled truck might be driven into its pit, covered with a few feet of earth for insulation (adequate venting provided), and blown up by an explosive at the propitious time to help in firefighting. Also, if railroad cryogenic tank cars with liquid nitrogen are available and cannot be used more constructively, they might be vented and abandoned in the area of retreat if railroad tracks lead there.

The conceptual countermeasure would require the ready availability of large quantities of liquid nitrogen. While the cryogenic problems of storing, handling and transporting multiton volumes are a drawback to the countermeasure, they do not make it impossible. A tank depot might be established at a facility hardened against nuclear weapon effects and located in a nearby rural area of lesser fire hazard. Conventional cryogenic tanks of 26,000-gallon capacity (87.7 tons) might be used. Because the replacement of evaporation losses (perhaps 0.5% per day) could be economically burdensome, the tanks might be filled only at the outset of a national crisis. Also, arrangements might be made with manufacturers in other localities to provide liquid nitrogen that could be picked up by C-133A cargo planes in emergencies. In addition, a sufficient number of cryogenic tank trucks would have to be kept at the tank depot, and provision made with liquid gas manufacturers for the use of their trucks in a national emergency. Furthermore, arrangements would have to be made with the military services or other agencies to have appropriate cargo planes and crews available on emergency notice. The use of liquid nitrogen, with and without water as an adjunct, as a fire-extinguishing or fire-control agent would require testing to determine its capacity and effectiveness.

3.1.2 Cooling and Suffocating with Solid Carbon Dioxide

The possibility exists for using multiton quantities of solid carbon dioxide ("dry ice") for extinguishing sections of an urban mass fire. Gaseous carbon dioxide and water vapor are the major products of carbonaceous combustion. The accumulation of either of these gases in the combustion zone tends to inhibit combustion, a few percent of carbon dioxide in air rendering it a nonsupporter of combustion of most carbonaceous material. The percent of carbon dioxide in the fire environment may be increased by the addition of solid carbon dioxide, which has the capacity for liberating gaseous carbon dioxide over a period of time, and also for cooling the fuel. While the sublimation temperature of solid carbon dioxide is -109.3°F, the solid continues to exist and slowly sublime at higher surrounding temperatures, even when contacted with flame. Its rate of gasification can be increased greatly by treating it with water, in which it dissolves and escapes with rapid bubbling. Therefore, the use of massive quantities of solid carbon dioxide, with or without water as an adjunct, is discussed as a conceptual countermeasure.

As a large-scale extinguishing agent, carbon dioxide is inferior to water in cooling and expansive (covering) capacity on an equal-weight basis. For comparison, the conversion of 28 tons of water at ordinary temperature (68°F) to gas at the boiling point (212°F) absorbs 6.2×10^7 BTU and produces at one atmosphere pressure a steam volume of 15.3×10^5 ft^3. The conversion of 28 tons of solid carbon dioxide at -109.3°F to gas at 212°F absorbs only about 2.4×10^7 BTU and produces at one atmosphere a volume of only 6.2×10^5 ft^3 (50 x 112 x 112 ft). However, other factors are undoubtedly important in extinguishment, fire behavior being imperfectly understood. For example, the ability of solid carbon dioxide to gasify over a period of time in a hot environment, coupled with its inhibitory effect on combustion, and the fact that the oxygen concentration in air need be decreased by only 4% to prevent combustion, might qualify it as a good agent for minimizing reignition. Furthermore, carbon dioxide gas is heavier than air by the factor 1.5; thus, large volumes generated at the base of a fire would tend to displace air upward and away from the fuel, unless strong winds resulted in much gaseous turbulence.

Solid carbon dioxide can be considered as an air-drop agent on inaccessible areas of mass fires. Consider a possible air drop as an illustrative procedure: The C133A military cargo plane is used. A cargo of 56 tons (essentially the cargo capacity) of granular solid carbon dioxide is carried in any convenient number of large, closed, ventilated, noncombustible boxes. The granular or snow variety of solid, rather than large chunks, is used so that there is a large surface area for sublimation. Alternately, the cargo might consist of something like 28 tons of granular carbon dioxide and 28 tons of water if experimentation shows that water is desirable to promote a faster gasification of the solid. All boxes, carbon dioxide and water, are tethered together so that they impact and shatter in the same general vicinity. If extinguishment is successful, C133A aircraft return to the area as often as necessary (perhaps just with water) to prevent reignition. Compressed-air masks would be necessary to prevent possible asphyxiation of all persons handling large amounts of solid carbon dioxide.

It would be possible to abandon massive quantities of granular carbon dioxide in any desired geometric pattern in an area that firefighters are being forced to yield to a conflagration.

The large amounts of solid carbon dioxide needed for the countermeasure could be obtained from stored liquid carbon dioxide. A tank depot for the liquid might be established as a facility hardened against nuclear weapon effects and located in a nearby rural area of lesser fire hazard. The liquid could be stored in refrigerated tanks holding 100 to 200 tons each at -4°F and 300 lbs/$in.^2$ maximum pressure. The solid would be obtained as needed by allowing the liquid to expand thru orifices into suitable containers at atmospheric pressure, the heat of vaporization being sufficient to cool about half the liquid to carbon dioxide snow. With an advanced design, the vented gas could be recycled and not wasted. Obviously, the time required for solidification (perhaps 2 hours for 200 tons), boxing, and delivery would have to be considered in firefighting plans. It is impractical to store solid carbon dioxide for emergency use on a massive scale because of sublimation losses, even in efficiently insulated rooms.

The use of carbon dioxide granules or snow, with or without water as an adjunct, as a fire extinguishing agent, will require testing to determine its capacity and effectiveness.

3.2 A CONCEPT FOR EXTINGUISHING FIRES BY CONTROLLING THE TOPOGRAPHY -- Unrestricted Flooding

Unrestricted flooding is a concept that may be applied to extinguishment or control of some urban mass fires from nuclear weapons. The control aspect is discussed in Section 4.2.1. With respect to extinguishment, the concept implies such measures as the purposeful breaching of river levees at a city to flood and extinguish a mass fire raging in the city area lying below the river level, all contiguous lowlands becoming flooded as a result. St. Louis, Memphis, and New Orleans on the Mississippi River and Louisville on the Ohio River are cities that have appreciable areas that could be flooded by breached levees. The rivers are often high enough for such flooding in spring and early summer. Ironically, in the case of New Orleans, which is entirely below the Mississippi River and Lake Pontchartrain levels, nuclear weapons could conceivably breach the levees and implement the flooding countermeasure.

This conceptual countermeasure seems logically suited to areas where most buildings are from one to a few stories high and uncongested, since flood waters would affect a large part of the bulk of such buildings. The concept would not apply to areas of tall congested buildings where fire and fire spread could largely occur high above a flood level.

The rapid inundation of a fire area of moderately sized buildings to a depth of more than 10 feet could extinguish much of the fire, cover vast amounts of potential fuel, diminish firebrand effectiveness, decrease fire spread, and decrease the combustion temperature of the remaining fire. When the fire has been sufficiently subjugated, the area could be entered with small boats and helicopters carrying portable pumps and hoses for treating the fire with the inexhaustible supply of flood water.

However, it is problematical whether flooding could occur rapidly enough to subjugate a mass fire before it could spread to adjacent areas at an elevation above the river and whether the damage caused by such flooding would not be as bad as the fire. Wide channels in the upper reaches of the levee would have to be blasted to provide rapid flooding. Floodgates especially constructed for the purpose would be a possibility.

It is recommended that the concept of unrestricted flooding for mass-fire extinguishment be evaluated in detail for specific applicable American cities to determine the expected costs versus the benefits, and the conditions where such flooding might be useful. The U.S. Army Corps of Engineers has made substantial studies of the cost of floods that might be utilized.

3.3 A CONCEPT FOR EXTINGUISHING FIRES BY CONTROLLING METEOROLOGY -- Initiation of Rain from Seeding of Mass-Fire Thunderheads and Other Clouds

A conceptual countermeasure for extinguishing an urban mass fire is the seeding of a mass-fire thunderhead or other suitable meteorologic clouds to initiate rain.

A few aspects of cloud behavior must be appreciated with respect to this countermeasure.[15] The requirements for cloud formation are warm moist air, a process for cooling the air below its saturation point (dew point), and some crystals (condensation nuclei). The cooling process may consist of both gaseous expansion and mixing with colder air as the air rises. As cooling occurs, the water vapor in the air condenses on the most hygroscopic nuclei, and eventually all the moisture at a given temperature is converted to small spherical droplets composing a cloud.

Some clouds cool below the freezing point of water without the freezing of droplets. The reason for this is not clearly understood, but may be related to the quasi-crystalline structure of the water. Such supercooled clouds are in a highly unstable state. The introduction of quite moderate numbers of condensation nuclei consisting of silver iodide, ice, or solid carbon dioxide into the cloud quickly converts the droplets they contact into ice, liberating some heat. The supercooled droplets now evaporate rapidly, only to condense upon the moderate number of neighbor ice nuclei, which thus grow. These may grow sufficiently to fall as snow, which may melt into rain. However, if the cloud is "overseeded" so that nuclei are perhaps as numerous as the droplets, a large number of small ice nuclei are rapidly produced which remain too small to fall, with precipitation consequently being delayed or prevented.

Some warm clouds never become supercooled, but they still produce rain naturally when droplets coalesce about large hygroscopic nuclei. These clouds can sometimes be triggered to produce rain by introducing salt nuclei or water droplets which cause cloud droplets to coalesce.

However, about a thousand to a million times more material is needed here to produce rain effects as compared to those produced in supercooled clouds with silver iodide or solid carbon dioxide.

Consider a mass-fire thunderhead and precipitation therefrom. Combustion produces hot gas laden with water and billions of condensation nuclei, and this mixture rises rapidly as a convective column to 20,000 to 35,000 feet.[2b,3a] The gases cool by expansion and mixing with colder air, the moisture condensing about some nuclei to form a mass-fire cloud. Considerable moisture may be absorbed by the cloud if the moisture exists in the surrounding air, and this process extends the cloud volume considerably. The cloud may produce rain if a moderate quantity of appropriate fire-generated condensation nuclei are carried high enough and the cloud becomes cold enough. Rain resulted from the Hiroshima firestorm caused by atomic bombing, and rain sometimes results from thunderheads produced by forest fires. However, as noted above, the cloud will probably not produce rain if it becomes overseeded with fire nuclei.

The conceptual countermeasure consists of the seeding of mass-fire clouds with appropriate nuclei to initiate rain for fire extinguishment:

1. If supercooled, the fire thunderhead could be seeded with a few pounds of silver iodide nuclei using pyrotechnic flares tethered to a small airplane or jettisoned therefrom. Care would be taken not to overseed, with perhaps six 6-inch flares being used.[16]

2. If it is too warm for silver-iodide seeding to work, the cloud could be seeded with massive amounts of particles of a larger size. Hundreds of pounds of sea water (which evaporates to sea salt), ammonium nitrate, borate flame-retardant slurry, or other chemicals could be sprayed in the top, middle or bottom of the cloud. A U.S. Forest Service tanker-bomber plane could be used.[16]

The conceptual countermeasure also includes the possibility of seeding appropriate clouds not originating from a mass fire in order to produce rain to extinguish the fire. If atmospheric conditions are favorable, a general rain storm might be started.

Experimental studies and additional evaluations would be required to determine the capacities and effectiveness of these procedures; for example:

1. The problem of seeding mass-fire clouds to initiate rain for fire extinguishment could be given a complete experimental evaluation, thunderheads from forest fires forming the basis of such experiments when available.

2. The problem of seeding natural clouds could be studied with respect to mass-fire extinguishment in different sections of the country.

SECTION 4

CONCEPTUAL COUNTERMEASURES TO CONTROL URBAN MASS FIRES FROM NUCLEAR WEAPONS

This section considers possible concepts to control urban mass fires from nuclear weapons. New conceptual countermeasures are presented to stimulate thought, argument and action, so that the current poor state of preparedness against mass fires may be improved.

It was pointed out in Section 3 that the probability of containing an urban mass fire and letting it burn out was presently much greater than that of extinguishing it in toto. It was also suggested that control countermeasures and extinguishment countermeasures might be applied cooperatively when possible.

The conceptual countermeasures for fire control given in this section are classified as (1) those dealing with the fuel parameter, (2) those dealing with the topography parameter, and (3) those dealing with the meteorology parameter.

4.1 CONCEPTS FOR CONTROLLING FIRES BY CONTROLLING THE FUEL SUPPLY

The following conceptual countermeasures related to the fuel parameter are considered for controlling urban mass fires:

1. The creation of firebreaks near a mass fire by bombing from military planes.

2. The creation of firebreaks near a mass fire by blasting with liquid and slurry explosives.

3. The creation of firebreaks near a mass fire by blasting with subsurface nuclear explosives.

Concerning the firebreak proposals, the usefulness of blasting city fuel into a firebreak to stop a conflagration is a highly controversial subject. The idea is not new, having been tried unsuccessfully during the San Francisco earthquake and conflagration of 1906. Opponents point to the San Francisco failure, the possibility of the firebreak debris burning, and the possible extension of the fire across the break by firebrands. The authors consider, however, that firebreaks could be as effective in cities as they are in forests, provided that they are made with correctness, skill, sufficient speed, and adequate width, and provided that they are diligently tended by firemen who will extinguish fires started by firebrands blown across the breaks. Firebreaks could also be useful in the case of a firestorm, since the inception of strong winds may change it into a conflagration. Some details of the new firebreak concepts are considered below.

4.1.1 Creation of Firebreaks by Bombing from Military Planes

The concept of making urban firebreaks by bombing from military aircraft has the advantage that long wide breaks could be made with rapidity, efficiency, and a minimum of disciplined manpower trained in the use of high explosives. Firebreaks that are miles long and a half-mile wide (more or less) could be blasted out with bombs varying from conventional Navy 500-pounders to the 12-ton blockbuster types of World War II.

Consider the creation of an operable firebreak first in general chronological terms:

1. A suitable location sufficiently distant from the conflagration or firestorm is selected.

2. Personnel evacuation of the selected area is assured.

3. Gas, electricity and water lines entering the location are shut off.

4. Air Force or Navy aircraft bomb the location into a firebreak consisting of fuel debris.

5. Fires that have started within the debris are extinguished.

6. If it is physically possible within the time available, the firebreak is modified by clearing the wide aisles free of debris; e.g., by bulldozers.

7. The firebreak and its immediately protected area are tended by firemen.

More specifically, choice of a proper location is critical for an air-blasted firebreak. The modern skyscraper section of a city would be the least promising location, since the massive construction and superior strength of the buildings would preclude efficient and rapid demolition. A section of the city would be preferable where the buildings average perhaps five floors or less and are not blast resistant; for example, some older downtown sections, congested residential areas, and suburbs. If feasible, firebreaks should be located where there are already wide streets and natural breaks. If possible, firebreaks should be located where hose water would be still available behind them to fight fires within and behind the breaks; otherwise, water tankers (or conventional 10,000-gallon gasoline tankers pressed into water service) might have to be used. As an example of initial distance from the fire, if 4 to 6 hours were needed to air-bomb out and modify a firebreak, it would have to be started at least 2 to 3 miles in advance of a conflagration moving about 0.5 mile per hour.

The nature and combustibility of the firebreak debris will depend upon firebreak location. As examples, in locations where buildings consist of non-combustible exteriors and combustible interiors, the bomb rubble may yet support combustion to some degree. In congested areas and suburbs constructed predominantly of wood, the rubble will be combustible, and an effort should be made to knock it down as flat as possible. In any event, it is to be hoped that any fire spread through a firebreak will be slow and moderate enough so that it can be coped with. Firefighting equipment should be concentrated before the bombing so that fires within and behind the break can be fought. Airplanes and helicopters dispensing chemical flame retardants would be useful for treating these fires, particularly those in inaccessible places. The chemical-retardant techniques of the U.S. Forest Service could be used, and perhaps some of their personnel, planes, equipment and retardants as well. The availability of large amounts of diammonium phosphate fertilizer as a fire inhibitor should not be overlooked if other retardants are not readily available.

If time, equipment, manpower and know-how are available before the conflagration arrives, an air-blasted firebreak might be modified to reduce its combustibility. In some areas where the debris is not too mountainous and particularly where there had been wide streets, it may be possible to clear wide lanes that are essentially free of combustibles, using bulldozers, earth-moving equipment, and large high-explosive charges detonated in a line to produce a trenching effect in the rubble. If the modified or original firebreaks contain a high proportion of noncombustible rubble, it could be beneficial to use tanker planes to spray chemical flame retardants on areas suspected of being vulnerable to ignition, expecially if they are difficult of access. If the firebreak consists principally of wood or other combustible rubble, it might be beneficial to spray chemical flame retardants on as large an area as possible.

Because so little is known about the required size and the effectiveness of urban firebreaks, further study in the following areas would be required to provide more conclusive results:

1. Detailed evaluations would be required for specific U.S. cities on how and where firebreaks, especially those from air bombing, might be employed during specific mass-fire situations.

2. The effectiveness and problems of urban firebreaks could be determined at mass-fire field tests. As one example, a prototype mass fire perhaps one mile in length could be started contiguous to an area perhaps 0.5 mile wide, containing urban rubble piled to resemble that expected from air bombing. The fire would be started when there was sufficient wind to drive the fire toward the rubble in the manner of a conflagration. Theoretical and practical observations could be made; fire-defense exercises could be performed; and new firefighting concepts and techniques could be tested and invented.

It is an obvious variation of this concept that firebreaks could be blasted by means of shelling with naval gunfire or with land-based artillery. The general size of the explosive in such cases is significantly less, but it is possible that this disadvantage could be offset by the (1) greater precision of explosive placement obtained by artillery, and (2) the larger number of shells capable of being used. This approach should be given consideration in any further analysis of the proposed countermeasure concept.

4.1.2 Creation of Firebreaks by Blasting with Liquid and Slurry Explosives

It is conceivable that liquid or slurry explosives of the low-sensitivity variety can be used advantageously in the blasting of urban firebreaks. These explosives have an advantage over solid high explosives in that they can be poured into inaccessible pipe sections and tortuous cavities for detonation. Nitromethane is a valuable liquid explosive that has been utilized as five 20-ton, simultaneously detonated charges in trenching experiments in the Atomic Energy Commission's Plowshare Program (Dugout 1964).[17a,18a] It approximates the efficiency of TNT and yet is a safe chemical to handle, store, and transport. It detonates only when set off by a small intimate charge of solid explosive which is detonated by a blasting cap.

Suppose that a city is having a conflagration and that the authorities decide to blast a firebreak across its path using nitromethane as the explosive. Civil-defense fire evaluation, preparation and training have provided a knowledge of possible sites, materiel and personnel for the job. The site selected is a long street typical of many in that city (resembling, for example, Oakland, Calif.) since (1) it is underlain by a concrete cylindrical storm drain of 4-foot diameter buried in soil (alluvium) to a depth of 6 ft at its top, and (2) has manholes spaced 440 ft apart to serve the drain, one manhole at each intersection. With these suppositions, the following synoptic procedure, subsequently elaborated, illustrates how a firebreak section one block long (440 ft) might be created, although the procedure applies equally well to any length of firebreak:

1. The operation is started as soon as possible to allow as much time for work as possible before the conflagration arrives at the firebreak site.

2. Personnel evacuation of the area is assured.

3. Gas, electricity, and water lines entering the location to be affected by the blast and fire are shut off.

4. The one-block section of storm drain under consideration is sealed off at one of its manholes (No. 1) by sandbagging or other means. The section is left open at its other manhole (No. 2) but all other drains entering manhole No. 2 are sealed off.

5. Nitromethane is pumped (poured) into manhole No. 2 until the drain section, which accommodates 195 tons of the explosive, is completely filled. The manhole will hold an additional 1.8 tons if it is assumed to be a vertical cylinder of 4-foot diameter containing a 4-foot depth of explosive.

6. A 5-to-10 lb charge of solid explosive detonator is placed at the nitromethane in each manhole, the manhole lids are replaced and weighted, and the nitromethane exploded. The explosion should blast a firebreak by demolishing buildings to perhaps 50 ft away from the street on each side; by blasting a massive trench in the street; and by ejecting about 1.2 x 10^4 yd^3 of soil potentially capable of covering or mixing with nearby blast debris to reduce its kindling tendency.

7. Fires that have started in the debris are extinguished. If necessary, the firebreak may be modified by clearing or by spraying with chemical flame retardants as described in Section 4.1.1.

The main purpose of the conceptual countermeasure is the demolition of buildings and not the mere conversion of the street into a trench. The extent of demolition is not predicted, but it would depend upon the type of buildings and the street width. Further evaluation based on experimentation is required with respect to this question. Damage should be severe since, there would be roughly one ton of explosive along each 20 foot length of the street; on this scale, the use of one 12-ton blockbuster of World War II per block would represent about 0.5 ton per 20 ft. Probably demolition by this conceptual countermeasure would be most efficient where buildings are wooden and hence easily demolished, congested, and facing each other on a relatively narrow street (such as Mission Street, San Francisco where buildings face each other at about 80 ft).

The depth and width of the massive trench can be predicted from scaling laws and results given in the Proceedings of the Third Plowshare Symposium.[19a] The laws are abbreviated in "The Effects of Nuclear Weapons."[13c] First, a section of the cylindrical nitromethane charge having equal length and diameter (4 ft) is considered to simulate a spherical point charge in a row of such charges with its center at an 8-foot depth in soil or alluvium. Values of crater depth and width are calculated for this point charge from the scaling laws which relate charge weight and depth with crater dimensions.[19b] These values are then extrapolated to the trench that would result from any number of intimate, simultaneously detonated row charges. Extrapolation involves increasing the crater values by 20% as recommended by Plowshare tests with high explosives.[19c]

On this basis, the explosion of the above synoptic procedure would replace the street with a roughly paraboloid trench one block long, about 15 ft deep and about 56 ft wide. About 6 x 10^3 yd^3 of ejecta per block would fall out on each flank of the trench, hopefully to help prevent ignitions. The ejecta blanket would be thickest in the form of a lip at the brink, and would be expected to thin to a throwout limit of about a diameter from the trench edge, or about 56 feet. For comparison, the blanket would be 6.5 ft thick if it were uniformly thick to the throwout limit.

Logistics is a critical factor. Sufficient nitromethane (or slurry explosive) would have to be stored at a depot readily available to truck tankers. The depot might be a tank facility hardened against nuclear weapons effects and located in a nearby rural area of lesser fire hazard. The large quantity of nitromethane required might be delivered to the firebreak site by 10,000-gallon tank trucks ordinarily used for transporting gasoline. The procedure used for illustration requires 41,715 gallons to produce the one-block-long firebreak, or 4.2 truck tankloads. Thus, 50 truck tankloads would be required per mile (12 blocks), and several tankers would obviously have to make a number of round trips to supply this amount.

The nitromethane charge could be reduced significantly in the illustration to ease logistics without reducing trench size significantly. For example, halving the charge would reduce trench depth and width by only 1 and 8 ft, respectively. However, this procedure would be undesirable because the major objective of the explosion is the mass demolition of buildings into firebreak rubble, and this requires as large a charge as practicable.

This conceptual countermeasure might also be used along some streets where there are sewer drains only, combined sewer and storm drains, or parallel sewer and storm drains. Such streets exist in a city such as Oakland, California. Health risks resulting from such a countermeasure would have to be evaluated in view of the seriousness of the fire emergency.

In the event of further study with respect to the concept of using liquid or slurry explosives in substreet storm drains to blast firebreaks, the following considerations are noted:

1. Individual U.S. cities could be evaluated for hypothetical mass fires to determine where firebreaks are desirable and also possible from the drain standpoint. Attention could be given to the possibility of burying special pipes for the explosive, should a drain not exist in a desirable location.

2. The concept could be tested experimentally. In the developmental sense, mock-up experiments could provide data on demolition, ground shock, trenching, mixing of trench ejecta and blast debris, and explosive handling and logistics. The possibility of participating in massive Plowshare explosions with nitromethane to obtain such data should be explored. In the opportunistic sense, the concept might be tested in a large area scheduled for redevelopment.

4.1.3 Creation of Firebreaks by Blasting with Subsurface Nuclear Explosives

The possibility of blasting a massive urban firebreak with a row of underground nuclear charges merits consideration, since nuclear explosions are much more powerful than large chemical explosions, they can break and move tremendous volumes of earth quickly, and they can demolish over a wide area. There are no thermal-radiation effects from an underground nuclear explosion. Nuclear explosives logistics seem particularly advantageous when it is realized that the explosive power of 10^3 tons of TNT, or 2.1 x 10^6 gallons of nitromethane, can be transported safely in a single device as small as one foot in diameter[13d,19d] A nuclear capability for creating a firebreak in the face of a conflagration would be useful if the military services were too preoccupied to assist by airbombing a firebreak, or if technicians and materiel for creating such a firebreak with chemical explosives were immobilized.

It could be argued that nuclear-created firebreaks are not feasible because (1) the row of underground nuclear explosions would vent some radioactivity into the habitable environment, (2) some of the radioactivity of the firebreak could be carried aloft via the convective column or firewhirls of a mass fire, and (3) radioactive firebreaks would eventually require some decontamination. On the other hand, it could be pointed out that detonation conditions may be selected to minimize the radioactivity problem; that a minimal radioactivity problem might be acceptable in the face of a serious fire threat, and that the radioactivity introduced into the environment could be marginal compared to that already introduced via the nuclear attack.

There are important matters to be considered in the case of nuclear-created firebreaks. These are (1) dimensions of the explosive device, (2) explosive yield, (3) detonation depth, (4) radiological hazard from fallout, (5) nature of the substratum, and (6) cost of explosive. These matters, except for cost, are detailed hereinafter. At this point, we note that the nuclear explosive should have small dimensions to facilitate handling, transport, and burial. Also, the explosive yield and depth must be optimized to minimize the radiological hazard from prompt fallout and prevent long-range airborne fallout, since the radioactivity escape from a nuclear cratering detonation is a function of both yield and burst depth. The radiological hazard should perhaps be minimized to the extent that a fireman could approach to within three blocks from a detonation point at two hours after detonation and work for at least one hour (dust permitting). In addition, the substratum must be readily drillable in the circumstance where the explosive must be buried quickly (or self-buriable), and ideally such that residual subcrater radioactivity would not leach to contaminate water supplies. Furthermore, a projected cost of $350,000 for a 1-KT explosive is not unreasonable in view of the fact that the saving of only fourteen homes costing $25,000 each by means of a firebreak would pay for the explosive. A sum of $1,750,000* was spent to suppress the 92,000-acre brush fire in the Los Padres National Forest in June 1966.

Two conceptual countermeasure procedures are given to illustrate the blasting of urban firebreaks with nuclear explosives:

1. One procedure (Section 4.1.3.1) assumes that it is not necessary to drill a row of burial holes for the nuclear charges during the emergency fire situation, holes 200-ft deep being available along strategic routes due to pre-attack planning and drilling. Fallout considerations permit the use of 1-KT charges.

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* San Francisco Chronicle, Newspaper, June 23, 1966.

2. The other procedure (Section 4.1.3.2) assumes that it is necessary to drill a row of burial holes for the nuclear charges during the fire, holes 80-ft deep being the deepest that can be drilled in the time available. Fallout considerations permit the use of a 0.1-KT charge.

The former procedure has the advantage of greater explosive charge which promises greater demolition capacity. The latter has the advantage of freer choice of firebreak location during the fire.

4.1.3.1 Firebreaks from Nuclear Explosives Detonated in a Row of Holes Drilled Before Attack. Let us assume that the following events occurred. An evaluation on the vulnerability of a city to hypothetical mass fires determined that wide firebreaks should ideally exist at some places. Since firebreaks did not exist at these places as long open spaces or wide freeways, and since they could not be cleared without an intolerable reduction of occupancy, a decision was reached to provide holes that could be used in a post-attack situation. Firebreak preparations were made to the extent that a row of holes to receive nuclear explosives for blasting firebreaks was drilled, cased, capped and buried under the pavement along the center of a few streets that would serve as medians of long firebreaks. Arrangements were made with the Atomic Energy Commission and other governmental agencies so that the appropriate nuclear explosives and attendant technical personnel could arrive quickly at the city when needed. The city also technically trained key employees to help, and conducted defense training exercises. Ultimately, the city faced a conflagration as a result of a nuclear attack, and it was necessary to activate a section of one of the potential firebreaks.

The following synoptic procedure, subsequently elaborated, illustrates how the firebreak might be activated:

1. The operation is started as soon as possible to allow as much time as possible for work and radioactive fallout decay before the conflagration arrives at the firebreak site. Ten hours would allow 4 hr for predetonation work and 6 hr (as recommended later) for fallout decay before fire arrival.

2. Personnel evacuation of the area is assured.

3. Gas, electricity and water lines entering the area to be affected by blast, shock and conflagration are shut off. Water lines outside the perimeter of shock damage are left on to provide water for firefighting at the break.

4. A 1-KT nuclear explosive is lowered into each hole along the distance desired for the firebreak. The holes are 200 ft deep, 1.5 to 2 ft in diameter, 233 ft apart and drilled in soil or alluvium. There are 23 charges per mile.

5. The charges are detonated simultaneously to create a massive firebreak by blasting the street, including its frontage buildings, into a gigantic trench; by demolishing buildings to an indeterminate distance away from the street; and by ejecting about 3.9 x 10^6 yd^3 of soil per mile, potentially capable of covering and mixing with nearby blast debris to reduce its kindling potential.

6. Fires that have started in the debris are extinguished as soon as possible using chemical retardants delivered by air tankers.

7. Starting at 2 hr after detonation, firemen (masked and "dressed out" against radioactive contamination) approach any firebreak area where dust (base-surge remnant) and exposure rate permit entry in order to extinguish fires that could not be extinguished by chemical-retardant aircraft.

The following discussions elaborate upon the synoptic procedure.

Plowshare studies of explosive cratering have shown that a row of subsurface nuclear charges spaced a distance apart equal to 1.5 times a single crater radius will blast a huge trench having a radius about that of a single crater.[19c] The 1-KT nuclear charge at 200-ft depth specified in the synopsis will blast, according to scaling laws,[19b] a crater in soil or alluvium having a 155-ft radius and a 70-ft depth. Thus, a row of such charges spaced 233 ft apart (1.5 radii) will blast a roughly parabolic trench having a 155-ft radius and a 70-ft depth. Approximately 1.9 x 10^6 yd^3 of ejecta per mile would fall out on each flank of the trench to mix with blast debris and help minimize ignitions. Test data suggest that the limit of throwout, if buildings were absent, would be roughly a distance of one diameter (310 ft) from the trench edge.[19e,20] For visualization, the ejecta blanket would be approximately 32-ft thick if it were uniformly thick from trench edge to throwout limit. Trench dimensions would be smaller by about 20 if the detonation occurred in rock.[13e]

Concerning building demolition by the explosion, the rows of buildings lining the street should end up as crater rubble and ejecta. A typical city street (such as Mission Street in San Francisco) is about 70 to 100 ft across from one building to another, whereas the predicted trench diameter is about 310 ft. Just how far demolition would extend away from the trench is uncertain, but demolition should be severe, since a total of 23 KT would be detonated per mile.

Charge size and burial depth must be mutually coordinated to minimize radiological hazards. According to scaling laws, a single cratering detonation from a 1-KT charge at 200 ft would distribute the radioactive products as follows: 0.4 as prompt (local) fallout; 99.6% as trench and trench-lip rubble; and 0.0 (essentially) as long-range airborne fallout.[19f] Table 1 shows that significant exposure rates are expected from the prompt fallout from a row of 1-KT charges at 200 ft depth and 1.5 radii apart, each charge venting about 0.4% as prompt fallout. Also, it will be seen later, with respect to entrance times and permissible exposures, that the exposure rates of Table 1 might be acceptable but that it would be undesirable for them to be greater. Therefore, detonating conditions for this yield would normally not be selected where a charge would vent more than 0.4% of the radioactivity as prompt fallout. Thus, a depth shallower than 200 ft would not be selected for a 1-KT charge; for example, a 160-ft depth would vent 4% of the radioactivity.[19f] Also, a charge greater than 1 KT would not normally be selected for a 200-ft depth; for example, a 10-KT charge would vent 4% of the radioactivity at this depth.[19f] A charge smaller than 1 KT was not considered for this illustrative procedure, since this would result in a diminished demolition capacity.

Nevertheless, a more detailed study of such a procedure should assess the significance of the hazard from radioactivity relative to that from the mass fire before any limitations in yield and depth of explosive are firmed up. Thus, in the illustrative examples, depths of burst have not necessarily been chosen to maximize building blowdown; it is possible that decreasing depth of burst could increase this effect at a cost of greater radioactive contamination.

Table 1

Estimated Exposure Rates at Distances from the Rim of a Trench Blasted in Alluvium by a Long Row of 1-KT Nuclear Charges 200 Ft Deep and 233 Ft Apart

Distance from Trench Rim(a)	R/HR(b)			
	1 Hr(c)	2 Hr(c)	6 Hr(c)	10 Hr(c)
2/3 City Block (Ejecta Throwout Limit)	1000	440	100	63
1-2/3 City Blocks	100	44	10	6
2-2/3 City Blocks	10	4	1	0.6

(a) One city block is assumed to be 440 ft.

(b) Wind effects are neglected.

(c) Postdetonation time

Table 1 estimates the magnitude of the prompt fallout hazard to be expected from the detonation of a row of 1-KT charges 200 ft deep and 233 ft apart. The data do not include wind effects and are estimations only. Table 1 was compiled as follows: The nuclear test DANNY BOY (0.42 KT, 110 ft deep, basalt)[19g] produced crater and throwout dimensions which, when extrapolated to alluvium by the multiplying factor 1.25,[13e] approximated to within 10 to 15% those dimensions predicted for a single firebreak charge (1 KT, 200 ft, soil or alluvium). Thus, exposure-rate contours published for the DANNY BOY crater[19h] were considered to apply to a single firebreak crater, after the contour values (at one hour postdetonation) were multiplied by the factor (1) (.004) / (.42) (.04) to correct for the difference in yield and the fact that DANNY BOY vented 4% of its radioactivity[19f] whereas a firebreak charge is expected to vent only 0.4%. The isoexposure-rate contours were taken to be approximately circles, wind effects being moderate at DANNY BOY. Next, a line of firebreak craters was considered. Adjacent and intersecting craters (i.e., a trench) were considered to give overlapping fallout patterns, and exposure rates at one hour postdetonation at various distances perpendicular to the line of craters were estimated by calculating and adding overlapping contours.

Table 1 shows that fallout radiation would be a major factor governing firefighting in the demolition area of the firebreak. It would be important to create the firebreak at the earliest possible time before fire arrival so that the process of radioactive decay could result in the lowest possible exposure rates (or longest permissible work periods possible) at the critical time of fire arrival -- hence the reason for Step 1 of the synoptic procedure. As an example, suppose that a conflagration moving at 0.3 mph is 3 miles distant and will reach the potential firebreak site in 10 hours; 4 hours are required to place and detonate nuclear charges, leaving a maximum of 6 hours for radioactive decay before fire arrival; Table 1 shows that exposure rates would be reduced by a factor greater than 10 during the 6-hour interim. Concerning permissible exposures, the National Committee on Radiation Protection has recommended that 25 R of gamma radiation ($\leq$3 Mev) be permissible once in a lifetime in a peace-time emergency situation where life and property are endangered.[21] A wartime commander might authorize a greater exposure. According to "The Effects of Nuclear Weapons,"[13f] "single doses in the range of from 25 to 100 rems over the whole body will produce nothing other than blood changes. Disabling sickness does not occur and exposed individuals should be able to proceed with their usual duties." Thus, Table 1 shows that suitably masked, "dressed out" and trained firemen could enter various firebreak areas from the radiological standpoint and work for reasonable times before receiving 25 to 50 R, as determined by self-indicating dosimeters and accompanying health-physics monitors.

One might contemplate using a smaller number of charges to decrease the radiological hazard, improve logistics, and save time by minimizing the predetonation work. However, if the number of nuclear charges used under the previously cited circumstances was approximately halved, so that there would be 12 per mile (one per 440-ft block), there would result a row of craters with rims 130 ft apart, a decreased capacity for demolition and coverage by ejecta, and only a modest improvement with respect to radiological hazard. Table 2 estimates the magnitude of the prompt fallout hazard in this case, and may be compared directly with Table 1 to see the modest gain in radiological safety. Table 2 was compiled in the same manner as Table 1, and because of the relative fractions of fallout in the ejecta, also applies to the case where a long row of 0.1-KT nuclear charges is detonated 80 ft deep and 440 ft apart.

Table 2

Estimated Exposure Rates at Distances From the Rim of a Trench Blasted in Alluvium by Either:*

1. A Long Row of 1-KT Nuclear Charges 200 Ft Deep and 440 Ft Apart, or

2. A Long Row of 0.1-KT Nuclear Charges 80 Ft Deep and 440 Ft Apart.

Distance from Trench Rim(a)	R/Hr(b)			
	1 Hr(c)	2 Hr(c)	6 Hr(c)	10 Hr(c)
2/3 City Block (Ejecta Throwout Limit)	650	280	65	39
1-2/3 City Blocks	65	28	7	4
2-2/3 City Blocks	7	3	0.7	0.4

(a) One city block is assumed to be 440 ft.

(b) Wind effects are neglected.

(c) Postdetonation time.

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* Figures apply to both cases; the factor of 10 difference in yield is compensated for by an opposing factor of 10 change in percent of the total radioactivity released in the immediate vicinity of the detonations.

With respect to the problem of blasting firebreaks with nuclear explosives placed in a row of holes drilled before attack, the following considerations apply:

1. The problem could be evaluated further. Individual U.S. cities could be evaluated for hypothetical mass fires to determine where nuclear-blasted firebreaks might be useful and where rows of holes could be drilled. Attention should be given to technical matters, such as administration, nuclear logistics, detonations in rock, and current developments in special charge-emplacement-techniques to reduce the amount of vented radioactivity.[17b,18b]

2. The possibility should be investigated for using nuclear trenching experiments when they are performed in the Plowshare Program to gain an understanding of demolition capacity and prompt fallout isoexposure-rate contours.

It is of course noted that the use of low-yield nuclear detonations to produce firebreaks does not intrinsically require pre-emplacement in holes if some sacrifice in explosive potential and increase of radioactive hazard is acceptable. They could be placed on the surface by hand, by helicopter or aircraft, or even by artillery.

4.1.3.2 Firebreaks from Nuclear Explosives Detonated in a Row of Holes Drilled After Attack and During a Conflagration. Let us assume that the following events occurred. The authorities of a city or Civil Defense Region decided to acquire the capability of blasting a firebreak with nuclear explosives at a "moment's notice" along any suitable city street. There was to be no pre-attack selection of firebreak routes nor drilling of holes. A plan was conceived and arrangements were made through appropriate channels with the Atomic Energy Commission and governmental agencies for the rapid availability of the requisite nuclear explosives and technical personnel in a fire emergency. Agency and trained city personnel practiced to achieve a competence in executing the plan. Ultimately, the city faced a wartime conflagration, and it was necessary to control it by blasting a nuclear firebreak along a street underlaid by an 80 ft depth or more of soil or alluvium.

The following synoptic procedure, subsequently elaborated upon, illustrates the approach and how the firebreak might be created:

1. The operation is started as soon as possible to allow as much time as possible for work and radioactive fallout decay before the conflagration arrives at the firebreak site. Ten hours would allow 4 hours for predetonation work and a maximum of 6 hours (as recommended later) for fallout decay before fire arrival.

2. Personnel evacuation of the area is assured.

3. Gas, electricity, and water lines entering the area to be affected by the blast, shock and conflagration are shut off. Water lines outside the perimeter of shock damage are left on to provide water for firefighting at the break.

4. A row of cased holes is drilled along the center of the street, using drilling rigs of the conventional "pick-up truck" variety. The holes are 80 ft deep, 1.5 to 2 ft in diameter, and one block (440 ft) apart. Drilling is easy because no rock is encountered.

5. A 0.1-KT nuclear explosive is lowered into each hole, giving 12 charges per mile.

6. The charges are detonated simultaneously to produce a firebreak consisting of buildings demolished to an as yet undetermined distance away from the street, and also a row of craters.

7. Fires that have started in the debris are extinguished as soon as possible using chemical retardants delivered by air tankers.

8. Starting at 2 hr after detonation, firemen (masked and "dressed out" against radioactive contamination) approach any firebreak area where dust (base-surge remnant) and exposure rate permit entry in order to extinguish fires that could not be extinguished by chemical-retardant planes.

The following discussions elaborate upon the synoptic procedure.

The drilling of the cased burial holes for the nuclear charges is a critical factor in this conceptual countermeasure. It is desirable to drill the holes as deep as possible in the time available, since the greater the depth the greater the charge that may be used (enhancing demolition) without exceeding acceptable exposure levels from prompt fallout. A hole 80 ft deep and 1 to 2 ft in diameter can be drilled in nonresistant soil in 2.5 to 3 hrs with a conventional "pick-up truck" well-drilling rig; a deeper hole requires larger equipment, extension augers and considerably more time. The 80-ft depth was accepted for the illustrative procedure because it would permit as much as a 0.1-KT charge to be used without creating an intolerable radiation field (as discussed later), and because a drilling time of greater than 3 hr for a deeper hole would be non-realistic for the urgent mass fire situation. Since one drilling rig can drill only one hole in the allotted time, the number of holes (charges) in a row would be limited by the number of drilling rigs available. The number of charges in the illustrative procedure was limited to 12 per mile, or one per block. A city would have to prepare for this countermeasure by acquiring sufficient drilling capacity during its preattack defense preparations and storing the equipment in a place safe from attack. Obviously, the conceptual countermeasure could not be used if it were necessary to drill the holes thru rock, a slow procedure. It is possible, in this context, to consider the use of high-explosive techniques for drilling the emplacement holes.

According to scaling laws, a row of 0.1-KT nuclear charges detonated at 80 foot depth in holes one block (440 feet) apart would produce a row of craters of roughly parabolic cross section with a 42-foot depth, 80-foot radius and rims 280 feet apart. Each charge would produce roughly 1.8 x 10^4 yd^3 of ejecta which would mix with demolition debris within the maximum throwout distance of roughly one diameter (160 feet) measured from the crater rim. Just how far demolition would extend away from the line of craters is uncertain. There should be severe demolition since a total of 1.2 KT would be detonated per mile. Buildings adjacent to a detonation should end up as crater rubble and ejecta. Further evaluation and experience might show that a greater number of detonations per mile is needed to increase the quality of the firebreak.

Charge size and burial depth should be coordinated to minimize radiological hazards. According to scaling laws, a single cratering detonation from a 0.1-KT charge at 80 ft would distribute the radioactive products as follows: 4.0% as prompt (local) fallout; 96.0% as trench and trench-lip rubble; and 0.0% (essentially) as long-range airborne fallout.[19f] Table 2 shows that significant exposure rates are expected from the prompt fallout from a row of 0.1-KT charges at 80 ft depth and 440 ft apart, each charge venting about 4% as prompt fallout. Table 2 exposure rates are probably acceptable and are somewhat smaller than those of Table 1. Since values greater than those of Table 1 could possibly be unacceptable (see the radiological hazard discussion of Section 4.1.3.1), and since the values of Tables 1 and 2 are very roughly equivalent, it was decided not to select detonating conditions in the present illustrations where a charge would vent more than 4% of the radioactivity as prompt fallout. Thus, a depth shallower than 80 ft was not selected for a 0.1-KT charge. Also, a charge greater than 0.1 KT was not selected for an 80 ft depth; for example, a 0.2-KT charge at a depth of 80 ft would vent 12% of the radioactivity as prompt fallout.

As noted, Table 2 gives an estimation of the prompt fallout hazard to be expected from the detonation of a row of 0.1-KT nuclear charges buried 80 ft deep and one block (440 ft) apart. The data are intended only to point out the magnitude of the radiological problem, and, hence, do not reflect wind or whirlwind effects. Like Table 1, Table 2 was compiled in the manner described in Section 4.1.3.1; because of the release fractions, it also applies to a row of 1-KT charges buried 200 ft deep and one block apart. Table 2 shows that fallout radiation would be a major factor governing firefighting in the demolition area of the firebreak. The firebreak should be made at the earliest time possible before fire arrival so that the process of radioactive decay could result in the lowest exposure rates possible at the critical time of fire arrival;

hence, the reason for Step 1 of the synoptic procedure. As an example, suppose that a conflagration moving at 0.3 mph is 3 miles distant and will reach the potential firebreak site in 10 hours; suppose 3 hours are required to drill the burial holes for the explosive and an additional hour is required to lower and detonate the charges, leaving a maximum of 6-hours for radioactive decay before fire arrival; Table 2 shows that exposure rates would be reduced by a factor greater than 10 during this 6 hour interim. Section 4.1.3.1 describes permissible radiation exposure in emergencies to save life and property.

With respect to future study of the possibility of blasting firebreaks with nuclear explosives placed in a row of holes drilled after attack and during a conflagration, the following considerations apply:

1. The problem could be evaluated in greater detail, with administration, logistics and individual U.S. cities receiving attention. Innovations for prolific and more rapid drilling of holes should be sought.

2. The possibility should be investigated for participating in nuclear trenching experiments, when they are performed in the Plowshare Program, to gain an understanding of demolition capacity and prompt fallout contours.

4.1.4 Creation of Firebreaks By Burning.

It is at least conceptually possible that a firebreak could be created through the process of independently burning a significant band of fuel in the path of an approaching mass fire. However, it is considered that before such a concept would be of value: (1) topographic or fuel-distribution conditions would be required such that with the restricted number of personnel available, the controlled fire could be limited naturally or by firefighters to the desired region, with high probability; but also (2) circumstances would have to be such that a firebreak so generated offered some clear advantage over a procedure in which an attempt was made to limit the mass fire itself in that region.

Such a combination of circumstances is considered unlikely; moreover the uncertainty of meteorology and the magnitude of the control fire involved are additional drawbacks to such an approach.

4.2 CONCEPTS FOR CONTROLLING FIRES BY CONTROLLING THE TOPOGRAPHY

Many American cities are located on rivers or large bodies of water that are potentially useful for supplying large quantities of water to control urban mass fires. This section considers two conceptual countermeasures that employ such water sources to control fires by altering the topography through flooding. These are (1) firebreaks from unrestricted flooding and (2) firebreaks from circumscribed flooding.

4.2.1 Firebreaks from Unrestricted Flooding

The use of unrestricted flooding to control or extinguish mass fires is conceivable. The extinguishment aspect was discussed in Section 3.2. With respect to fire control, the concept implies the purposeful breaching of river levees at a city to flood an area of the city below river level (and all contiguous lowland) that is threatened by an imminent conflagration. The purpose is to convert that area into a firebreak as large as the flooding boundaries in order to protect another area, and also to save the flooded buildings from any or serious burning so that they may be salvaged. Section 3.2 pointed out that areas of large American river cities can be flooded by breached levees; that the flooding concept applies logically to areas where most buildings are from one to a few stories high and uncongested; and that it does not apply to areas of tall congested buildings.

Flooding to a depth of more than 10 ft would in many cases cover a vast quantity of the fuel. Boats and helicopters carrying portable pumps and hoses could be used in the area to hose down unflooded upper floors and roofs with the inexhaustible supply of flood water. This could be done before the time of fire arrival so that everything not flooded became wet. Also, the fire might be extinguished by such hosing if it did spread into the firebreak. Also, upper floors threatened by fire, or actually on fire, could be dynamited to fall in the flood water.

The time required for flooding to an effective depth is uncertain, and could be determined only by examining and studying each city where the countermeasure applied. Wide spillways in the upper parts of the levee could be dynamited; the use of floodgates specially built for this purpose would be possible. Obviously, flooding would have to be started soon enough to be effective at the time of fire arrival. Also, flooding would have to be started even earlier if it were desired to start a backfire from the completed, irregularly shaped firebreak.

Possibly, most of the flooded buildings could be reclaimed, and the cost and inconvenience from flooding and reclaiming could be less than that of total loss thru fire. However, the relative damage expected from uncontrolled flooding compared to that expected from a mass fire would require evaluation.

Unrestricted flooding from purposefully breached levees in order to control mass fires merits further evaluation in physical and economic detail for individual American cities.

4.2.2 Firebreaks from Circumscribed Flooding

The use of circumscribed flooding during an urban conflagration in order to control it is proposed as a conceptual countermeasure.

Suppose that an evaluation of the mass-fire hazard of a city showed the wisdom of creating wide and long firebreaks along a few specific routes. Because of the city's proximity to a large body of water and its general levelness, it was decided that the breaks might well be deep strips of water, perhaps one to three blocks wide and a few miles or more long. However, it was impractical to demolish buildings along the routes and dig artificial canals or lakes. This procedure would dislocate traffic and require numerous long bridges; raise objections from property owners; cause hardship on displaced families and businesses; require purchase of highly priced, developed property; and remove land from tax rolls. Instead, it was decided to build a levee on each street bounding the firebreak route, leaving the buildings between these levees undisturbed. The artificial channel thus created would not be filled with water until after a conflagration developed that demanded the sacrificial flooding of the channel property. A conflagration might never occur, but if it did the flooded property might possibly be salvaged later. Such a firebreak would be less destructive than a blasted one, and would be more easily tended by firehosing.

As with other flooding concepts, the concept of flooding canal-like firebreaks applies only to locations where buildings can be subjected to flood wetting. Channel routes would be selected where buildings between the channels would be from one to a few floors high and (preferably) uncongested, and not where they would be tall, congested and subject to fire spread at heights far above flood level.

The conceptual countermeasure might be implemented in the following manner, considering in succession the levee system, the means of filling the channel, and emergency flooding at the time of fire.

A pair of uninterrupted levees of any desired length might be created along two parallel streets, each street supporting one of the pair. A street might be converted into a divided street with the levee composing the dividing strip, or the street might be on top of the levee. Levees could be earth fills or concrete walls with their ends joined by cross levees to produce basins. The height for a given section would depend upon the estimated volume of water that could be pumped into the section in an emergency and upon the distance between the levees. Streets crossing a levee would rise over it using an earth fill or a small bridge. Ideally, the lengthwise slope of the channel would be zero; but if a slight slope existed, cross levees could be built where needed and the canal would be built as a series of terraces.

The flood channel could be filled by pumping water from a lake, river, ocean or bay. Diesel pumps could be used having a capacity of 90,000 gallons per minute against a 100-ft head, a 1.5-ft diameter discharge, and an approximate price of $130,000 each. Such pumps are now used by the Bureau of Reclamation to pump massive volumes of irrigation water.[22] In 8 hours, a combination of four pumps could fill (neglecting friction) a basin one mile long and one block wide (440 ft) to a depth of 10 ft; or two blocks wide to 5 ft; or three blocks wide to 3.3 ft. In 16 hours, four pumps could double the width, depth or length of the basin. A detailed evaluation of the mass-fire hazard for the particular city in question would logically determine an acceptable firebreak depth and width and the required number of fire pumps to provide adequate water.

The diesel pumps could be housed horizontally in a facility not too distant from the firebreak and built to withstand nuclear attack. Such a one-story facility could be roughly 50 x 50 ft per unit of four pumps, and could be over water or on shore. It could connect with a firebreak channel by means of the requisite number of shock-resistant, durable, underground pipes of 4.5 to 6 ft diameter. The pipes could be controlled by valves near the facility so that water could be sent to the particular firebreak needing activation. The pipes could connect with the conventional storm-drain system of the firebreak channel. Obviously, this storm-drain system would have to be engineered to have large capacity, numerous street inlets, few outlets from the channel area, and controls for closing channel outlets at the time of flooding.

Large aqueducts and large artificial-lake reservoirs that provide municipal water by gravity flow would seem to be of marginal value for flooding such a firebreak channel, compared to the aforementioned pumps. For example,[23] Oakland and Berkeley, California (population over 500,000), are adjacent and served jointly by the transstate Mokelumne River Aqueduct. The aqueduct trisects at the cities, each spur having a diameter of 4.5 ft, existing under an approximate head of 300 ft, and delivering a maximum of about 38,000 gpm. This delivery is about 42% of that of a single aforementioned pump, and could only be increased by a maximum factor of two by pumping. Also, a nearby community is served by the San Pablo Reservoir which is about 150 ft above the community and has a maximum storage capacity of 1.3×10^{10} gallons; but its 5-ft-diameter outlet at a pressure head of about 150 ft would provide a flow rate of roughly the same low magnitude as one of the Mokelumne Aqueduct spurs.

It would be best to start the emergency flooding of the channel early enough so that it could be completed by the time of fire arrival. With four pumps operating per mile of firebreak, under the conditions described above, flooding could start 8 hours before the anticipated fire arrival, for example, when a fire moving at about 0.3 mph[5c] was about 2.5 miles away. Boats and helicopters carrying portable pumps and hoses could hose the area as described in Section 4.2.1 on unrestricted flooding. However, if it were desired to start a backfire from a completed firebreak, flooding would have to start much earlier than otherwise.

It is possible also that controlled flooding of a firebreak of the types discussed in Section 4.1 could be applied, thus (a) eliminating the necessity for detailed maintenance of the break once generated and (b) eliminating the necessity for working in a radioactive area (Section 4.1.3).

A detailed evaluation is merited for individual American cities with respect to this conceptual countermeasure, namely, the building of parallel levees across a city to produce a habitable flood channel to be evacuated and flooded only when necessary to control an existing conflagration. The desirability of incorporating the levees into city planning could be considered so that they could be built with a minimum adverse effect on transportation and esthetics.

4.3 A CONCEPT FOR CONTROLLING FIRES BY CONTROLLING THE METEOROLOGY -- The Use of Agricultural Wind Machines

A possible area for exploratory research at large-scale fire tests is the use of powerful, agricultural wind machines to control fires. A conceptual modus operandi for their use cannot now be given, but further investigation appears warranted. The investigation could consider, among other things, the ability of a row of wind machines to (1) retard combustion by counteracting limited areas of indrafts (allowing firemen to approach closer to a fire), (2) speed up a backfire, (3) affect whirlwinds (and even firewhirls?), and (4) extinguish by dispensing nitrogen gas (from liquid nitrogen) and carbon dioxide gas into the fire.

Wind machines are commonly used for eliminating frost in orchards and vineyards. Models of various wind-producing capabilities are available. A towable model has a 16.5-ft tower that folds to 10 ft for towing, a 14.3-ft propeller driven by a gasoline motor, and a fan rpm of 590. A large model of 280 HP can produce a wind speed of 30 mph over a test area of 1400 ft^2.[24]

It is conceptually possible that wind machines could be used on a limited scale to control a deliberately generated local fire or backfire to provide a region of exhausted fuel supply in the face of an approaching mass fire. For example, it is possible that a base of operations for some specific purpose might conceivably be generated in this way.

It has been observed that coatings of dust, particularly on vegetation, reduce the likelihood of ignition in the process of large-scale fires. It is conceptually possible that wind machines could, in specific situations, be used to generate dustclouds capable of providing limited flameproofing upon settling.

SECTION 5

SUMMARY OF INFORMATION PRESENTED

5.1 GENERAL

It has long been assumed that current metropolitan firefighting manpower, equipment and techniques will almost certainly be inadequate for extinguishment and control of the multiple mass fires to be expected from a nuclear attack (an assumption which has been borne out by the present study; see Section 6, Conclusions and Recommendations). Thus, there is merit in conceiving, evaluating, and developing new procedures for dealing with these fires. The preceding sections of this report have in a preliminary way presented some new concepts for extinguishment and control, and the following subsections summarize the results of the study.

5.2 SUMMARY OF METHODS OF EXTINGUISHMENT AND CONTROL STUDIED

Methods investigated both for extinguishment and control may be effectively grouped into three categories: (1) those involving cooling and suffocation of the fire (Sections 3.1.1 and 3.1.2); (2) those involving control of the meteorology (Sections 3.3 and 4.3), and (3) those involving generation of firebreaks by blasting (Sections 4.1.1, 4.1.2, 4.1.3), burning (Section 4.1.4), and flooding (Sections 3.2 and 4.2).

Of these radical methods, those of the latter category seem to offer greater promise of success in controlling (but not in extinguishing) mass fires in cities.

It is considered that firebreaks could be about as effective in cities as they are in forests, provided that they are made with correctness, skill, rapidity, and adequate width, and provided that they are diligently tended by firemen. Nevertheless, the use of urban firebreaks remains controversial, because of a lack of knowledge about fire parameters, limited availability of firemen and countermeasures, and environmental conditions.

Moreover, in several of the approaches considered herein, the level of damage to the city caused by firebreak production would approach the level of damage caused by the fire itself, as has been noted.

5.3 COST-EFFECTIVENESS

Because of the relatively low probability of success of the countermeasure concepts evaluated, cost-effectiveness studies have not been carried out. Such studies would be justified only if the development of the control measure indicated that a reasonable expectation of success could be expected within the present state of knowledge of firespread, physical performance of the countermeasure, and operational and political feasibility of the approach in some cases. In no specific case was this assurance achievable.

5.4 DIRECTION FOR FURTHER STUDIES

In each section, information gaps have been identified, and the direction of further analysis or development effort to fill such gaps has been noted. In general, such effort would probably not prove valuable; however, see Section 6.2 for recommendations as to three exceptions to this statement.

5.5 RELATIONSHIP OF FIRE COUNTERMEASURES TO FALLOUT HAZARD

Although it has not been treated explicitly in this report, it is apparent that some of the countermeasure concepts proposed require entry into the attack area on the ground (those of Sections 4.1.2, 4.1.3, and 4.1.4 in particular) while others do not (e.g., those of Section 3). If the nuclear attack itself generated an area of extreme fallout hazard in addition to the mass fire, the countermeasures of the latter type would assume greater significance.

SECTION 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

6.1.1 General

It is concluded that the present capability of the metropolitan fire departments is inadequate to extinguish or control the urban fires which could follow as a result of a large-scale nuclear attack upon the United States. This conclusion is based upon the anticipated widespread extent of fire and the disruption of the normally available facilities, resources, and means of communication resulting from the environment created by a nuclear attack.

When conceptual countermeasures are evaluated in the context of a postattack environment it is not enough that the countermeasure be capable of combatting the fire, it must also be consistent with the constraints of surviving facilities, resources and means of communication.

6.1.2 Extinguishment

It is concluded that the conceptual countermeasures investigated and presented in the present report would not be feasible for mass-fire extinguishment in the nuclear postattack environment. This conclusion is based upon the observation that those methods which would be capable of extinguishing a widespread well-developed fire would be either as destructive as the fire itself or would require logistic support and communications inconsistent with the post-nuclear-attack environment.

6.1.3 Control

Certain techniques presented in this report may provide some potential for controlling mass fires, particularly conflagrations, even with the postattack constraints. The most likely techniques would appear to be those dealing with the establishment of firebreaks and the control of the local meteorology in the vicinity of the fire. Even then it is considered that, if a mass fire once develops within any one major city (e.g., San Francisco), it could not be effectively controlled by any practical means, but rather could probably be brought under control before spreading to adjacent cities within an urban complex (i.e., San Francisco Peninsula).

6.2 RECOMMENDATIONS

The following recommendations are based upon the estimated feasibility of various countermeasures presented in the report to combat mass urban fire in a post-nuclear-attack environment.

6.2.1 It is recommended that firespread within cities be studied to determine the behavior of a fire at fuel interfaces, such as firebreaks. Specifically to be determined would be the required width of a firebreak under various natural and fire-caused meteorological conditions and with various levels of firebreak tending.

6.2.2 It is recommended that typical cities and urban complexes be investigated to determine the availability of natural or manmade barriers to fire which might be further augmented by other techniques, such as flooding or explosive trenching. Ultimately, this recommendation might lead to the establishment within the cities or urban complexes of a network of pre-planned fire boundaries.

6.2.3 It is recommended that further investigation be made into the practicality of cloud seeding for the formation of precipitation from either naturally occurring or fire-caused clouds in the vicinity of a mass fire.

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UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY *(Corporate author)*
U. S. Naval Radiological Defense Laboratory
San Francisco, California 94135

2a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

2b. GROUP

3 REPORT TITLE
COUNTERMEASURE CONCEPTS FOR USE AGAINST URBAN MASS FIRES FROM NUCLEAR WEAPON ATTACK

4 DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5 AUTHOR(S) *(First name, middle initial, last name)*
Wesley E. Shelberg
Edward T. Tracy

6 REPORT DATE 14 November 1967	7a. TOTAL NO. OF PAGES 59	7b. NO. OF REFS 24

8a. CONTRACT OR GRANT NO.

b. PROJECT NO.
OCD, T065-200, Work Unit 2525A

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
USNRDL-TR-67-100

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. DISTRIBUTION STATEMENT
This document has been approved for public release and sale; its distribution is unlimited.

11 SUPPLEMENTARY NOTES

12 SPONSORING MILITARY ACTIVITY
Office of Civil Defense
Washington, D. C. 20310

13 ABSTRACT

New concepts for the extinguishment or control of urban mass fires from nuclear-weapon attack are proposed and evaluated. A synoptic, illustrative modus operandi is given to illustrate application of each of these conceptual countermeasures in extinguishing or controlling fires. The generation or utilization of firebreaks seems to offer the most promise. Specific recommendations are made concerning the direction of future study.

DD FORM 1 NOV 65 1473 (PAGE 1)
S/N 0101-807-6801

UNCLASSIFIED
Security Classification

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Fire Mass fire Countermeasures Urban fire Thermal effects						

DD FORM 1 NOV 65 1473 (BACK)
(PAGE 2)

UNCLASSIFIED
Security Classification