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ENERGY FIELDS FOR FIRE EXTINGUISHMENT

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Previous studies of the interactions between flames and energy fields were found, reviewed and analyzed for the purposes of enhancing or causing fire extinguishment. Thirty-three publications were analyzed in this project and ten types of energy fields were evaluated The electrostatic field is the optimum field for enhancing fire extinguishment. It is technically feasible to apply an electrostatic field to a fire using modified firefighting equipment. It is recommended that the project be continued with the development of this equipment and its testing on standard pool fires. The results of these tests may indicate a substantial improvement in the capability of firefighting equipment.

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EXECUTIVE SUMMARY

This work is primarily an analysis and review of previous work in the interactions between energy fields and fire. The intent of the work was to find an energy field which would be beneficial in firefighting. Some firefighting chemicals (halons and foaming agents) have adverse environmental effects, and an energy field might reduce the need for these chemicals.

Thirty three technical publications on related topics were found, reviewed and analyzed. Ten types of energy fields were studied, and the electrostatic field was selected as offering the best chance of successful application in enhancing firefighting. The other fields were rejected because they were dangerous, expensive or otherwise impractical for general use.

A special nozzle which imparts negative electric charges to water drops may enhance the ability of fire-fighters to extinguish burning hydrocarbons. This should be verified experimentally before proceeding further. However, this nozzle could be used without substantial modification of present equipment and techniques.

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PREFACE

This report was prepared by Hughes Associates, Inc., Wheaton MD under Contract number F08635-89-C-0381 for the Air Force Engineering and Services Center (HQ AFESC/RDCF), Tyndall Air Force Base, Florida 32403-6001. Mr. Joseph L. Walker, Mr. Charles W. Risinger, and Mr. Douglas B. Schwartz were the technical program managers.

This report has been reviewed by the Public Affairs Office and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be availiable to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication.

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SECTION I

INTRODUCTION

A. OBJECTIVE

The objective of this Phase I SBIR contract was to identify and analyze the adjustment of flames by energy fields to increase the fire extinguishment potential.

B. BACKGROUND

Burning involves changes such as the relationship of atoms, arrangements of electrons and electron clouds, states for the various energy modes, temporary formation of intermediate transition state complexes, chemical ionization reactions, and quantity of magnetic moment. Some of these known changes have been quantified for use in flame diagnostics. For example, the chemical ionization process, which produces ions in a flame, is the basis of flame ionization detection for gas chromatography; radiation (laser) absorption is used to change the state of reactants during saturated fluorescence diagnostics. The Phase I effort would review, analyze, and evaluate the application of electric, magnetic, microwave, and electromagnetic energy fields for causing or enhancing fire extinguishment. Existing applications and research of the various energy fields toward flames would be reviewed and interpreted, in relation to new efficient energy technologies (e.g., superconductivity), to identify the optimal techniques for potential applications to fire extinguishment. The Phase II effort would involve the design and construction of a laboratory device to study the identified optimal energy fields and the conduct of experiments to quantify the efficiencies of energy fields for fire extinguishment with, and without, the addition of fire extinguishing agents.

C. APPROACH

The approach to this effort was an in-depth literature search of energy fields, fires, and their interactive effects so that the research, analysis, and evaluation of theory and application would lead to the identification of an optimal energy field for fire extinguishment. The five tasks, developed for the technical work plan were accomplished both sequentially and concurrently under the 6-month duration of the Phase I contract.

Descriptions of these five tasks are as follows:

1. Task 1: Literature Search

A literature search was made of the scientific literature, as well as Department of Defense and contractor manuals and reports for background enrichment to provide a baseline for the research and analyses required in this program.

2. Task 2: Application of Theories of Flame and Extinguishment

Review of theories of the initiation, propagation, and termination or extinguishment of various types of flame was in terms of the most applicable model and the role of a critical reaction step in its life cycle.

3. Task 3: Study and Analysis of Energy Fields and Their Interactions with Fire

A compilation of various energy fields and their possible interactions with or effects on fires. The orthodox places for interactions between fire and "energy fields" are:

a. Interference in the chemistry by perhaps changing molecular energy levels,

b. Separating the flame into components where one part is affected by the field,

c. Adding energy to the combustion process, usually increasing the overall rate of heat release,

d. Mechanically interfering with the flame, and

e. Reacting with one of the flame components in such a way as to stop combustion.

A study and analysis was made of these energy fields and their possible interaction with fires.

4. Task 4: Identification of Optimal Energy Field

On the basis of the applicable theories, as well as on the study and analysis of the various energy fields and their interaction with fire, the type of energy field which is optimal for fire extinguishment was identified.

SECTION II

RESULTS OF ENERGY FIELD STUDY

A. CONCEPTS

A meeting was held with Chuck Risinger from Tyndall AFB on 30 August 1989 who provided guidance for the Phase I study to be undertaken.

A meeting was held with personnel from the Fire, Science and Engineering Division of the Center for Fire Research at NIST (National Institute of Standards and Technology), Gaithersburg, MD on 30 August 1989. Suggestions on possible leads on energy fields for fire extinguishment centered on the 3-5 Hz normal frequency of flames. It was suggested that exposing a flame to a 3-5 Hz frequency which is 180 degrees out of phase might quench the flame. Another suggestion was that a higher frequency source directed at a flame might distort and levitate the flame sufficiently to extinguish it.

B. RESULTS

The results are summarized in the four tasks described in the proposal and the same format is used to present the results.

1. Task 1: Literature Search

a. Electrostatic Fields

A literature search was initiated. Much information was found in two journals: Combustion, Explosion, and Shock Waves, and Progress in Energy Combustion Science. The former journal is an English translation of Russian papers in Fiz. Goreniya Vzryva, covering the period 1976 to 1987. Many Russian papers reported the electrostatic effects of electrical fields on flame extinguishment. Their studies were performed on a laboratory scale using a tube burner and a propane-butane fuel mixture. A transverse field was produced by applying a DC voltage, up to 10 kV, to a metal grid electrode installed coaxially with respect to the burner. The cylindrical metal grid was negative and the ground wire was positive. At voltages of about 1 kV, the flame began to distort and "flower," the phenomena becoming more pronounced as the voltage increased until extinguishment occurred (Reference 1-2). An AC voltage on a flame served merely to increase the rate of combustion (Reference 3).

b. Acoustical Fields

The journal Progress in Energy Combustion Science contained papers discussing chemical-acoustic interactions in combustion processes, as well as a survey of recent studies on flame extinction. In general, it was shown that "sound waves tend to accelerate exothermic reactions"; therefore, one would expect an increased combustion rate of flammable components when exposed to sound waves (Reference 4). Recent studies on flame extinction, although differing on the physical processes controlling flame extinction, agree that flame extinction results from heat outflow from the flame, causing a decrease in flame temperature (Reference 5).

c. Magnetic Fields

Using a composition of ammonium perchlorate and a rubbery binder as the fuel, to which different ferromagnetic substances had been added, Lesnikovich et al (Reference 6) found that a strong magnetic field (approx. 1000 Oersteds), developed by a mild-steel core in a solenoid and located 35 mm from the flame front, had "a retarding influence on the burning rate at atmosphere pressure" at temperatures below the Curie Point (temperature at which ferromagnetic properties of materials is lost).

d. Turbulence Fields

The influence of turbulence as an energy input to a laminar flame was studied by Jarosinski et al (References 7-8) at zero mean air flow. The experimental apparatus consisted of a standard tube for flammability tests with a turbulence generator mounted on top. It was reported that the "initially undisturbed flame" propagating into the region of the tube, where it encountered a region of gradually increasing turbulent velocity, increased its propagation velocity until it experienced a "sudden collapse" in the propagation velocity and the flame was quenched." Fuel mixtures used were methane-air, propane-air, and ammonia-air. Two generators of turbulence were used, having turbulent scales of 2.14 and 6 mm and variability ranges of the rms turbulent velocity of 0.1-1.2 and 0.5-3.4 m/sec, respectively. Conditions for flame quenching of homogeneous gas mixtures by turbulence were correlated with the Karlovitz-Kovasznay criterion which is the ratio of the chemical reaction time to the characteristic eddy breakup time in turbulent flow. It was concluded that the "flame is quenched by the turbulence if the time scale of the chemical process is... at least one order of magnitude larger than the characteristic eddy break-up time."

e. Gravitational Fields

Gravitational acceleration of flames was also studied and was shown (Reference 8) to manifest itself in the effect of buoyancy forces. Characteristics of near lean limit 5.7 percent methane-air flames were studied by Jarosinski et al (Reference 9) under standard or 1 g gravity conditions. The major conclusion of the study was that the extinction mechanism of an upward-propagating flame was markedly different than that of a downward-propagating flame. The upward-propagating flame is extinguished "by a stretch mechanism in which the holding region is stretched to extinction and the extinction wave then washes down the skirt of the flame..." Extinction of the downward-propagating flame, however, was triggered by heat loss to the wall and the flame was finally driven to extinction by differential buoyancy which forced cooler product gases ahead of the flame.

In other studies the effect of flames under high centrifugal accelerations was studied with regard to flammability limits. Jarosinski reports (Reference 8) that Krivulin et al (Reference 10) found the dependence of the flammability limits on acceleration for a flame propagating in the direction of the acceleration (downward) and in the opposite direction (upwards). The difference between the flammability limits for an upward- and downward-propagating flame is greater for higher values of the acceleration. If the acceleration g is more than 97 times greater than normal g then "downward flame propagation becomes impossible."

Under conditions of external acceleration Rakib et al (Reference 11) found that upward-propagating flames were extinguished by the "classical effect of Rayleigh-Taylor instability" brought on by thermal expansion of the flame.

The behavior of near-limit flames under zero gravity conditions was studied by Strehlow et al (Reference 12) and by Krivulin et al (Reference 13). They concluded that the flammability limits under zero gravity conditions were intermediate between the limits for an upward- and downward-propagating flame in a one-g field.

Microgravity experiments on the behavior of freely flowing propagating premixed gas flames near the flammability limit were reported by Ronney (Reference 14) who attributed the primary mechanism of heat loss from these flames to be by nonluminous radiation from the burned gases.

f. Charged Particles

The role played by charged particles in flames was studied by various groups. Olsen and Calcote studied acetylene and benzene flames (Reference 15) and reported that the positive ions CHO^+ and $C_3H_3^+$ were the key ions produced by the flames and that these ions led to the growth of molecular species and polycyclic aromatic ions which ultimately became soot particles. A critical review of the mechanisms of soot nucleation in flames was published by Calcote (Reference 16). The development of mechanisms of ion formation in a flame was detailed by Fialkov (Reference 17), differentiating those ionic reactions taking place in the preparation region from those in the chemiluminescent zone, as well as indicating those chain reactions and recombinations which form larger neutral products. More recent studies on the role of charged particles on the combustion mechanism have been reported by Botova and Fialkov (Reference 18).

g. Plasmas

Plasmas, developed in air by arc pyrolysis of a fraction of a natural gas flow, enhanced flames (Reference 19) since the pyrolysis generated both carbon seed-particles and hydrogen from the gas. Since plasmas developed in gas/air systems consist of mixtures of active species of ions and radicals, the study by Fialkov and coworkers (Reference 20) on the ion content of propane and butanes flames has confirmed the important role played by primary ion formation in the combustion process. The various ions formed in the preparation region of the combustion process, and which lead to the flow of charged particles in the reaction zone of the flame, are positively charged.

h. Air Blast

Air blast has been a recognized method of extinguishing certain types of fires. Martin (Reference 21) reported on flame "blowout tests with simulated nuclear air-blast waves" in a special "shock-tube facility on Class B fires both in a flat-plate geometry and stabilized behind barriers". The results of these tests "support the concept of flame displacement as a mechanism of extinguishment."

i. Lasers

The effect of lasers, as a source of energy input to a flame, has not been reported in terms of a possible method of flame extinguishment. Rather, since high energy intensities can be created with coherent radiation, Tewari and Wilson reported (Reference 22) that "sparks with energies as low as 1 mJ were produced at atmospheric pressure by focusing a single 3-4 msec wide laser pulse generated by the ruby oscillator-amplifier system" to ignite a 13 percent methane/air mixture. These sparks were caused by electrical breakdown of the gas mixture by the high electrical field associated with the high intensity of the ruby laser's light. The special advantage of this technique is that no electrodes are present in the gas mixture, so no corrections need be made for the effects of the electrodes. Phuoc and Maloney (Reference 23) have also used laser energy for ignition, specifically to pyrolyze single coal particles.

In addition to the use of laser energy for ignition, Penner and coworkers (Reference 24) have reported on the use of lasers for fire diagnostics, such as for applications in measurement of population temperatures, pressures, densities, etc., of combustion systems.

No confirmation was found in the literature for the reference in the Report No. 3 that some lasers may be generated with a low frequency, in the range of 10 Hz. This must refer to the frequency of the modulation of the laser output, not the basic frequency of the laser itself. (A frequency of 10 Hz would require the laser to have wave length of 3×10^7 meters whereas Penner (Reference 24) describes low power infrared lasers with wave lengths only in the order of 10^{-5} meters.) If laser radiation is absorbed by vapor over a pool fire, then it is likely that the flames will respond to modulation of the radiation at the flicker frequency.

j. Microwave Energy

In a study for NAVAIR, Peschel showed (Reference 25) that microwave radiation will ignite and sustain a flame front rather than extinguishing it.

Since microwaves and infrared radiation are overlapping categories of radiant energy, the use of modulated microwaves at the flicker frequency of a pool fire may affect the process. This effect will depend upon the wavelength of the radiation, its intensity and the absorbtion by the gases in the fire.

Although not considered part of energy fields the following two observations are included here since they may form a theoretical basis for methods which successfully extinguish flames.

k. Water as an Extinguishing Agent

Cooling by water is the predominant method by which fires are extinguished, as indicated by Drysdale (Reference 26), particularly because of water's high latent heat of evaporation (2.4 kJ/g or 2.28 BTU/g at 25°C). With regard to the physical state of the water as a coolant, Drysdale indicates that water "can extinguish a diffusion flame per se, if it can be introduced into the flame in the form of a fine mist or as steam."

l. Oscillation Frequency of Flames

The oscillation frequency of 3 Hz for fires, as reported in Progress Report No. 3, was confirmed by Drysdale (Reference 26) who states that "the 0.3 m square gas burner used by McCaffrey (1979) and Chitty and Cox (1979) gave flames with an oscillation frequency of 3 Hz... similar to that observed by Rasbash et al (1956) for a 0.3 m diameter petrol fire. The oscillations are generated by instabilities at the boundary layer between the fire plume and the surrounding air."

2. Task 2: Application of Theories of Flame and Extinguishment

The literature revealed well-defined theories of flame and its extinguishment.

a. Flame

With regard to theories of flame, Shebeko (Reference 3) states that combustion of organic compounds in air takes place in two stages: (1) oxidation of the original fuel to carbon monoxide and water, and (2) burning of the carbon monoxide to carbon dioxide. The first process takes place in the preflame front zone and the second in the reaction zone. Although other workers in the field also characterize a flame as having two zones, their naming or labeling of the zones differ somewhat; Salamandra and Maiorov (Reference 27) refer to the flame formation and burnout zones, Fialkov (Reference 17) refers to the preparation and chemiluminescent zones, and Cottrell refers to the fuel and combustion reaction zones (Reference 28).

b. Extinguishment

As a corollary to the theories of flame zones and their chemical reactions, there are six theories of extinguishment: ion wind hypothesis, action of convection, flame stretch, chemical kinetics, preferential diffusion, and instability. Jarosinski, however, indicates (Reference 5) that the "mechanisms of flame extinction currently suggested by different authors (i.e., the action of convection, flame stretch, chemical kinetics) are all based on the assumption of a decrease in flame temperature."

- The ion wind hypothesis was used to explain flame extinction by distortion of the geometry of a flame in the presence of an electric field (References 1 and 3).

- The action of convection was meant to describe the phenomenon of the mass transfer of heat from the region of chemical reaction in the reaction zone of the flame or from the preheat zone to the surrounding walls (Reference 5). Flame stretch was considered to result from the existence of a velocity gradient.

- The theory of chemical kinetics emphasized the influence of chemical reaction rates on the resultant exothermic heat release due to reaction.

- Preferential diffusion, leading to flame extinguishment, is described by Bregeon and coworkers (Reference 29) as occurring in hydrogen and methane flames in oxygen-nitrogen mixtures because of the high molecular diffusivity of these low-molecular-weight gases. Because of the "large ratio of fuel to oxidizer diffusivities, cellular phenomena were highly pronounced in the... flame," and then "heat loss by conduction occurs from the cells to their noncombustible boundaries... eventually causes complete extinction."

- Instability of the flame, and the factors leading to such instability, are described by Kydd and Foss (Reference 30). Three separate mechanisms by which real flames are extinguished before the intrinsic flammability limit is reached, which can be ascribed to flame instability, are described. Two of these mechanisms involve the formation of holes in the flame: one in which the holes "originate from the Taylor instability due to negative temperature gradient in the burnt gas," leading to flow reversal, flame lifting, and, with lean mixtures, terminating in extinction; the other in which small mobile holes are formed in flames of near stoichiometric mixtures, leading to instability but not necessarily extinction. The third mechanism or type of instability occurs in a flame inside a tube, and when the flow velocity of a strong mixture of propane or carbon monoxide in air was reduced "the flame inside the tube was observed to undergo a sudden rapid fluttering in the vertical direction, and an additional decrease in velocity extinguished it."

3. Task 3: Study and Analysis of Energy Fields and Their Interactions with Fire

The study and analysis of energy fields and their interaction with fire can be considered the key task in the contract. Tuve (Reference 31) defines fire as a "rapid, self-sustaining oxidation process accompanied by the evolution of heat and light of varying intensities." Following up on this definition, Tuve shows that the old characterization of fire as a triangle of fuel, oxygen, and heat has been superseded by the "tetrahedron of fire," consisting of fuel (reducing agent), an oxidizing agent, temperature, and uninhibited chain reactions. Thus, he indicates four basic methods of fire extinguishment exist:

a. Removal or dilution of air or oxygen to a point where combustion ceases.

b. Removal of fuel to a point where there is nothing remaining to oxidize.

c. Cooling of the fuel to a point where combustible vapors are no longer evolved or where activation energy is lowered to the extent that no activated atoms or free radicals are produced.

d. Interruption of the flame chemistry of the chain reaction of combustion by injection of compounds capable of quenching free radical production during their residence time.

The latter two methods, cooling a flame and quenching free radical production, are particularly applicable to the study of energy fields for fire extinguishment.

It is conceivable that cooling a flame, or the fuel feeding the flame, can be accomplished by more efficient methods of water evaporation, by conduction or convection, and by causing incomplete combustion due to instability of the flame or holes within the flame. Interruption of the flame chemistry of the chain reaction and quenching of free radical production could be achieved by drawing off or neutralizing the free positively charged radicals so that chemical extinguishment of the flame is possible. In effect, causing flame instability with an accompanying decrease in the efficiency of the flame combustion chemistry should result in fire extinguishment.

When water is used to cool a flame, Layman (Reference 32) states that the "maximum cooling action of a given volume of water is obtained only when the entire volume has been converted into steam." A gallon of water can absorb 9330 B.t.u. from its surroundings, 1250 B.t.u. in the process of raising its temperature from 62 to 212°F and 8080 B.t.u. in the process of vaporization. However, the "rate of heat absorption can be increased by increasing the surface exposure of a heat absorbing substance in ratio to its volume." Layman (Reference 32) continues by stating that the "surface exposure of a given volume of water can be increased by breaking the water into finely divided particles," so that the water droplet can vaporize instantaneously upon contact with the combustion material. This methodology produces an increased extinguishing efficiency for the water. In another publication (Reference 33), Layman states that a "high percentage of vaporization is the key to the successful employment of water as a controlling and extinguishing agent."

With regard to the extinguishment of a fire by quenching free radical production, thereby interrupting the chemistry of the chain reaction in combustion, Tuve (Reference 31) mentions that the addition of chemicals to a fire is done to capture and neutralize the free radicals. No other method of neutralizing the free radicals is offered by Tuve.

In summary, the analysis of energy fields and interaction with fire reveals two methods by which fires can be extinguished: (1) by cooling the fire by using very small droplets of an extinguishing liquid to enhance heat removal by vaporization, and (2) by quenching free radical production which will interrupt the chemistry of the chain reactions in combustion.

4. Task 4: Identification of Optimal Energy Field

Identification of the optimal energy field for fire extinguishment was initiated by a review and analysis of all energy fields reported as having a positive effect on fire extinguishment.

Table 1 shows that of the ten energy fields listed, five have been identified as having a positive effect on fire extinguishment. These five fields are magnetic, turbulence, gravitational, air blast, and electrostatic. Magnetic fields

TABLE 1. ENERGY FIELD EFFECTS ON FIRE EXTINGUISHMENT

Energy Field	Effect on Fire Extinguishment	Remarks
Electrostatic	Positive	Requires negative space charge
Acoustical	Negative	Tends to accelerate exothermic reactions
Magnetic	Positive	Requires very strong field
Turbulence	Positive	Requires physical coupling to obtain turbulence
Gravitational	Positive	Requires large gravitational field
Charged Particles	Not determined	Forms soot particles
Plasma	Negative	Enhances flame
Air Blast	Positive	Blows out flame
Lasers	Negative	Causes ignition or used for diagnostics, however, modulation frequency might induce flame instability
Microwave	Negative	Ignites and sustains a flame, modulation might induce flame instability

have been shown to extinguish a flame, however, only at very high field strengths. Turbulence energy was also shown capable of flame extinguishment but only when directly coupled to the flame. A gravitational field 97 times that of our normal earth field also extinguished a flame but generation of such a field is highly impractical. Although air blast as an energy field has long been used to extinguish underground oil fires its methodology is not practical for aboveground pool type fires characteristic of buildings and equipment such as aircraft.

The optimal energy field for fire extinguishment investigated under this SBIR Phase I contract is the electrostatic field. The theory of its operation is the "ion wind hypothesis" which indicates that attraction of the positively charged particles by the negative field near the flame removes one of the four essential characteristics in the "tetrahedron" of a fire and by preventing the fire from sustaining itself actually extinguishes the flame.

5. Lagniappe: Demonstration of Energy Field in Extinguishment

A demonstration apparatus was constructed, patterned on the apparatus used by Salamandra and Maiorov (Reference 27). This apparatus successfully extinguishes a small diffusion flame.

The apparatus consisted of a miniature Bunsen burner, a gas supply, a screen and a high voltage supply. The burner's air inlet control was removed and the air inlet closed off using rubber hose. The gas supply to the burner was the tank and valve from a propane torch. The screen was cylindrical in form, with an inside diameter of about 32 mm and a height of about 130 mm. This screen was made of expanded metal (steel) lath, which is normally used in the construction of wet plaster walls. The high voltage supply was constructed from a transformer from an office copying machine and a high voltage diode. The transformer is rated at 7300 volts a. c. so the voltage applied to the screen was about 10,000 volts peak half wave rectified d. c. The burner was connected to ground, and the screen was at a negative potential with respect to ground. A second grounded screen surrounded the first. This had no effect upon the operation of the device, but was installed to prevent anyone from touching the inner screen. (The transformer is easily capable of delivering a lethal current to a person touching the exposed high voltage screen. The apparatus has since been partially disassembled as a safety precaution.)

In this apparatus, the mechanism for extinguishing the fire seems to be the transfer of electrical charge into the flame, rather than the action of an electrostatic field, per se. It is technically feasible to transfer electrical charge into a large pool-type fire if mechanical methods are used. Several techniques may be used to charge water drops, which are then sprayed into a fire. It is hoped that the transfer of charge will greatly improve the extinguishing qualities of water spray.

If negatively-charged water spray is effective for extinguishing fires, special nozzles can be designed, based on the Kelvin water dropper electric machine. These nozzles could use electrets, rather than the charged rings typical of the water dropper. The resulting current will flow to ground through a conductor attached to the fire hose. This will eliminate any shock hazard to bystanders and to persons using the nozzle. Special advantages of this technique include:

- Minimal modifications to standard equipment
- Not polluting
- Reliable
- Compact
- Easily learned
- Safety

Methods of direct charge transfer into a flame (e.g. electron beams) are not practical. Not only are the energy requirements excessive, but the apparatus would be hazardous and cumbersome.

SECTION III

CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSION

On the basis of the investigation performed under this SBIR Phase I contract on Energy Fields For Fire Extinguishment it is concluded that, of the ten energy fields studied, the electrostatic field is the optimal energy field for fire extinguishment.

B. RECOMMENDATIONS

The study and development of electrostatic fields for fire extinguishment should be continued under a Phase II SBIR contract in order to develop a practical method of creating an electrostatic field for the extinguishment of pool type fires which will be in accord and compatible with standard AF firefighting equipment, procedures, and tactics.

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