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FIRE AND THE RELATED EFFECTS OF NUCLEAR EXPLOSIONS

1982 Asilomar Conference

Proceedings of the Conference

Edited by: Stanley B. Martin
Raymond S. Alger

Prepared for:

FEDERAL EMERGENCY MANAGEMENT AGENCY
Office of Mitigation and Research
Washington, D.C. 20472

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Vice President
Physical Sciences Division

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report summarizes the proceedings of a FEMA-sponsored Conference (organized and arranged by SRI International under subcontract to Lawrence Livermore National Laboratory) on fire and the related effects of nuclear explosions (with passing attention to earthquakes and other nonnuclear mishaps). This conference, the fifth of an annual series (formally called Blast/Fire Interaction Conferences), was held during the week of April 25, 1982, again at Asilomar, California.

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The meeting was international with representation from the United Kingdom, Sweden, and Japan in addition to representatives from government, industry, and academe in the United States.

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This report summarizes the proceedings of a FEMA-sponsored Conference (organized and arranged by SRI International under subcontract to Lawrence Livermore National Laboratory) on fire and the related effects of nuclear explosions (with passing attention to earthquakes and other nonnuclear mishaps). This conference, the fifth of an annual series (formally called Blast/Fire Interaction Conferences), was held during the week of 25 April 1982, again at Asilomar, California.

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I INTRODUCTION

Background

The 1982 Conference on Fire and Related Effects is the fifth in an annual series dealing with research on nuclear weapon effects and their interactions. The first four conferences focused on blast/fire interactions research. However, several noteworthy events since the previous conference altered both the form and content of this year's conference.

Lawrence Livermore National Laboratory (LLNL) became "lead laboratory" for a portion of the Federal Emergency Management Agency (FEMA) research program; hence, the conference sponsor is now LLNL. Also, within the past year, the fledgling fire program in the Defense Nuclear Agency (DNA), announced during last year's conference, expanded to include experimental studies of blast/fire interactions. By the time of this year's conference, the program had achieved sufficient reportable results to qualify for a major session in the conference proceedings. In addition, the MILL RACE high-explosive event was conducted in September 1981, providing new data, some of it fire relevant, and planning was already under way for the next such event (DIRECT COURSE) in 1983. Finally, reconsideration of the so-called ENCORE anomaly* brought into question the relevance of current fire-start models in nuclear explosion applications, prompting a reexamination of the basis for current estimates of fire threat, and suggesting the possible need for appropriate large-scale experiments.

Conference Format

Although much of the subject matter of the 1982 Conference remained in the mold of the previous conferences, with fire effects dominating attention and providing the common ingredient, two basic differences in

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*See proceedings of 1981 Conference, Appendix, "Fire in an Airblast Environment," p. C-9.

format were intentionally introduced. First, unlike the previous conferences, which concentrated on program planning, the 1982 conference was designed to be free of any such distractions from the review of technical subject content. Second, as a consequence of the first change, workshops became discussion groups.

Otherwise, the format was the familiar one, similar in most respects to the previous four conferences. Much of the time (evenings as well as mornings and portions of the afternoons) were spent in generally attended sessions, including plenary lectures. The remaining time was available for group discussions on various subjects derived from the general-session subject matter.

On the following pages, the conference agenda is reproduced along with a listing of the conferees and conference staff members.

This report, although it contains only a portion of the material presented at the Conference, is designed to stand alone. Material whose relevance to a general audience was not such as to warrant its inclusion here has been reproduced (where possible) and sent to attendees separately.

Agenda

1982 CONFERENCE ON FIRE AND RELATED EFFECTS

(Conference Coordinator,* S. Martin, SRI)

25 April

Evening Session:

Welcome by Conference Co-chairmen

Keynote--FEMA and the Status of Civil Defense, J. Kerr, Director, FEMA Office of Research

26 April

Session on FEMA Research Program, Chairman, J. Kerr

1. Preview of Pilot Video Presentation "Incendiary Threat in Airblast Environment" (SRI)
2. "Prediction of Fire and Blast Effects in Urban Areas Due to Nuclear Attack: Preliminary Observations on Blast/Fire State of the Art," T. Reitter, S. Kang, D. McCallen (LLNL)
3. Work Unit Reviews:
   - 2564E "Predictive Modeling of Large Area Fires," R. Small, PSR
   - 2564 B "Thermal Pulse Accessory for B/F Shock-tube," S. Martin for J. Cockayne (SAI)
   - 2564A "Experimental Extinction of Fire by Blast," J. Backovsky (SRI)
   - 2564H "Blast/Fire Response Mechanism," M. Kanury (UND)
   - 2563G "Flame Extinction of Char Formers," F. Fendell (TRW)
   - 2564I "Secondary Fire Analysis," C. Wilton (SSI)
   - 2564D "Assessment of Combined Effects of Blast and Fire on Personnel Survivability," H. Napadensky (IITRI)

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*Conference staff included:

- Ray Alger, technical program arrangements, documentation.
- John Nichols, audio visuals, administrative assistance.
- Mary Jean Felts, housing arrangements.
- Fred LaVigna, video services.

4. "FLAMBEAU Revisited," T. Palmer (SWETL)
5. "Training with Video," H. Ryland (RRI)

Evening Session:

International Programs, Chairman, S. Martin (SRI)

1. "Scandinavian Fire Research," V. Sjölin (SFRB), G. Arbman (FOA)
2. "Japanese Research on Earthquake Fires," Y. Aoki (BRI)
3. "Activities in the U.K.," P. Thomas (FRS)

27 April

Conclusion of Session of FEMA Research, Chairman, J. Kerr

6. Remaining Work Units:
   - 1128D "Construction, Instrumentation, and Testing of Shelter Design and Industrial Hardening Concepts at the MILL RACE Event," J. Zaccor (SSI)
   - 2563I "MILL RACE Event: Experiments in B/F Interactions," J. Rempel (CPR), S. Martin (SRI)

Program at NBS Center for Fire Research, Chairman, R. Levine (NBS)

1. "Introduction and Overview of Facilities, Exploratory Research Program, and Grants Program," R. Levine
2. "Programs of the Fire Safety Engineering Division," A. Fowell
   a) Combustion Toxicology
   b) Fire Growth Modeling
   c) Fire Protection Systems
   d) Design Concepts
   e) Hazard Analysis
3. Other Programs, R. Levine
   - Product Flammability
   - Fire Test Methods
   - Anti-Arson Research

"Fire Loss Following Earthquakes," I. Oppenheim, Carnegie Mellon

After the Oppenheim lecture, the following discussion groups were organized and began development of summaries for presentation during the final session of the conference:

1. "Blast/Fire Interactions: Relevance of Existing and Proposed Research to FEMA Goals," Discussion Leader, T. Reitter
2. "Importance and Status of Secondary-Fire Assay," Discussion Leader, I. Oppenheim
3. "MILL RACE Results/DIRECT COURSE Plans," Discussion Leader, R. Peterson
4. "Mass Fires," Discussion Leader, T. Palmer
5. "How to Translate Threat to Risk," Discussion Leader, L. Schmidt

28 April

Session on DNA Fire Program, Chairman, M. Frankel (DNA)

1. Introduction by Session Chairman
2. On-Going Research Contracts:
   - "Historical Fire Data Review," M. McKay (SAI)
   - "Extinction of Fires by Blast Waves," T. Goodale (SRI)
   - "Fire Damage Vulnerability and Methodology," [illegible] Brode (PSR)
   - "Urban Fire Dynamics," D. Larson (PSR)
   - "Urban Fire Damage Simulation Development," J. Ball (MRC)
   - "Firestorm Modeling," F. Fendell (TRW)

Discussion Groups reconvened in afternoon.

The evening session included (1) a film on fire and explosion hazards due to spills of liquefied natural gas (presented by Paul Urtiew of LLNL), (2) a concept for simulation of combined damaging effects of nuclear explosions (introduced by Peter Hughes of LATA), and (3) "Whiskey on the Rocks," an illustrated, anecdotal review of the international incident, during the fall of 1981, when a Soviet Whiskey-class submarine, allegedly armed with nuclear torpedos, went aground and foundered within a restricted area of Swedish coastal fortification (retold by Vilhelm Sjölin and Gunnar Arbman who were personally involved in the tense moments of the confrontation).

29 April

Wrap-up session, Chairman, J. Kerr

1. Discussion Group summaries
2. Acknowledgment of contributors, announcement of plans for 1983 conference, and send-off by conference co-chairman.

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II PROGRAM OVERVIEW

Preliminaries

At the opening session, attendees were welcomed by the Conference Coordinator and the FEMA/LLNL Cochairmen. Special attention was given to foreign visitors and representatives of government agencies not previously in attendance. The Conference keynote was presented for the sponsoring agency by James Kerr.

The first morning session began with a showing of a pilot version of a video presentation "Incendiary Threat in Airblast Environment," produced by SRI for LLNL. Critical comments were solicited. Then to stimulate thought and discussion of issues, Tom Reitter presented tentative results of a study conducted at LLNL to identify and compare the importance of missing information in the analytical forecasting of fire and blast effects of nuclear explosion.*

Status of Civil Defense in FEMA+

The ups and downs of U.S. funding for civil defense, a core FEMA program, have all related to world events or political program shifts. It is easy to note from Table 1 the impact of the Berlin crisis of 1962, or the Cuban missile crisis, for example, Of particular interest now (April 1982) is the President's announced intention, as confirmed by his pending budget, to "get serious" about civil defense--to implement the evacuation policy, backed up with the research and development needed to make it possible and credible. This could exceed $20 million in FY 1983.

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*The final LLNL report, Literature Survey of Blast and Fire Effects of Nuclear Weapons on Urban Areas, is in preparation.

+Based on comments by Jim Kerr, Director, FEMA Office of Research, to the conference--opening session (April 25, 1982).

Table 1

CIVIL DEFENSE RESEARCH

BUDGET HISTORY
($)
(000's)

FY	Actual $	Constant* $	FY	Actual $	Constant* $
62	16,008	54,800	72	3,451	9,320
63	6,098	20,815	73	3,161	7,580
64	11,390	38,900	74	2,304	4,660
65	10,576	37,000	75	1,596	2,960
66	9,262	30,100	76	1,631	2,725
67	10,001	32,600	77	1,263	2,150
68	6,861	21,700	78	7,475	11,480
69	4,814	14,620	79	5,047	6,600
70	3,846	11,270	80	3,918	4,360
71	2,997	8,450	81	5,339	5,339
			TOTALS	$117,108	$327,429

*1981

The implementing agency is FEMA, whose latest organization chart appears as Figure 1. The focal point for plans and policies is the National Preparedness Programs, detailed in Figure 2. It is important to note that the Research Office manages "basic" science and coordinates the "applied" science or technology funded by the program offices. For this case, it is the Civil Defense Division of the Office of Civil Preparedness that will fund most of the applied work.

In order to learn from the accomplishments and problems of other nations, FEMA has carried out studies of--and maintains strong ties with--a number of countries. This conference includes people from Sweden, Japan, and the United Kingdom. Invitations were sent to Canada, Switzerland, Australia, and the German Federal Republic; they were unable to send representation.

There are many points of view to choose from in analyzing foreign civil defense activities for relevance to U.S. needs. One is funding level. The U.S. spends less than $0.50 per capita per year. USSR and Swiss expenditures are probably something like 100 times that amount ($50 per capita). Most European nations fall somewhere between these extremes.

Other approaches compare programs, hardware, or research. Perhaps the most significant is the basic operating assumption on the part of the Soviets that something of value will remain after a nuclear exchange. Their priorities stress restoration of vital capabilities, with concern for the general population secondary. Evacuation remains their key pre-attack strategy.

It is interesting to compare U.S. expenditures for civil defense R&D with those of other countries.

- We know very little about USSR budgets.
- Only the U.S. has had a concentrated civil defense R&D effort.
- Most nations make executive decisions as to emphasis and fund rather modest R&D efforts in the perceived key areas.

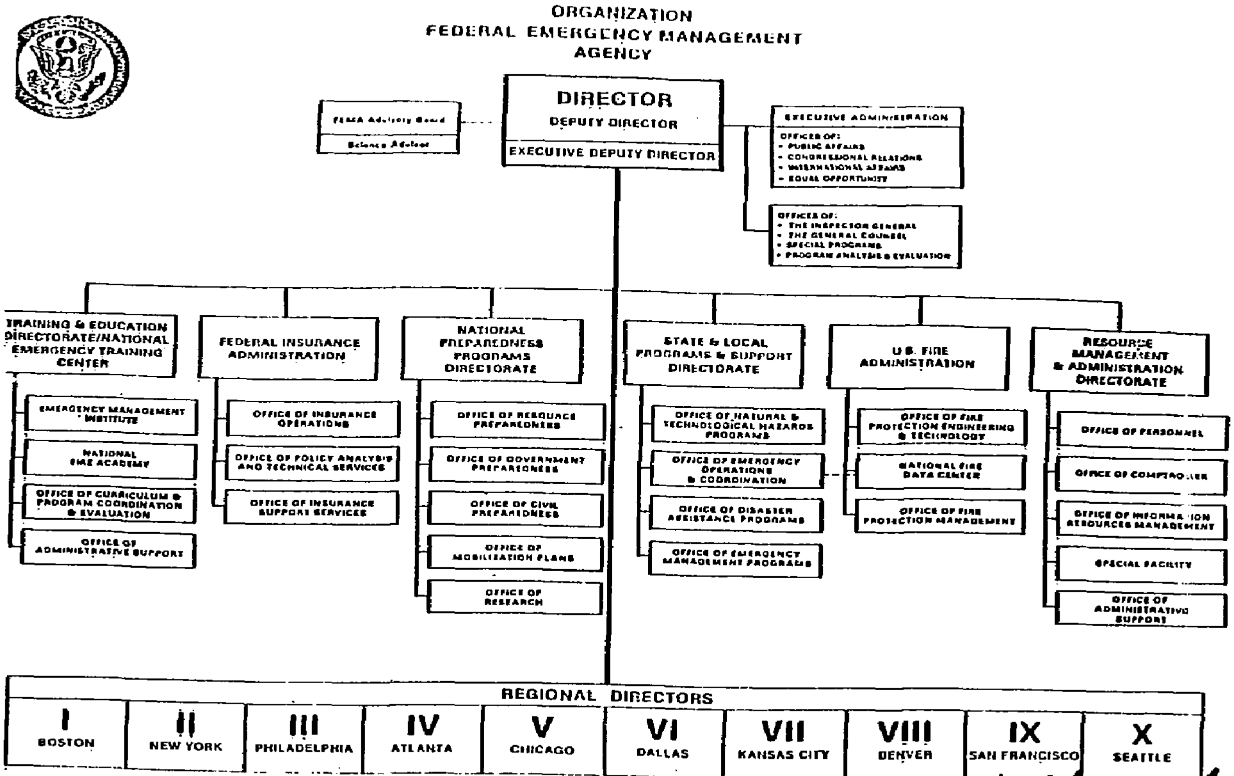


Figure 1 Organization, Federal Emergency Management Agency

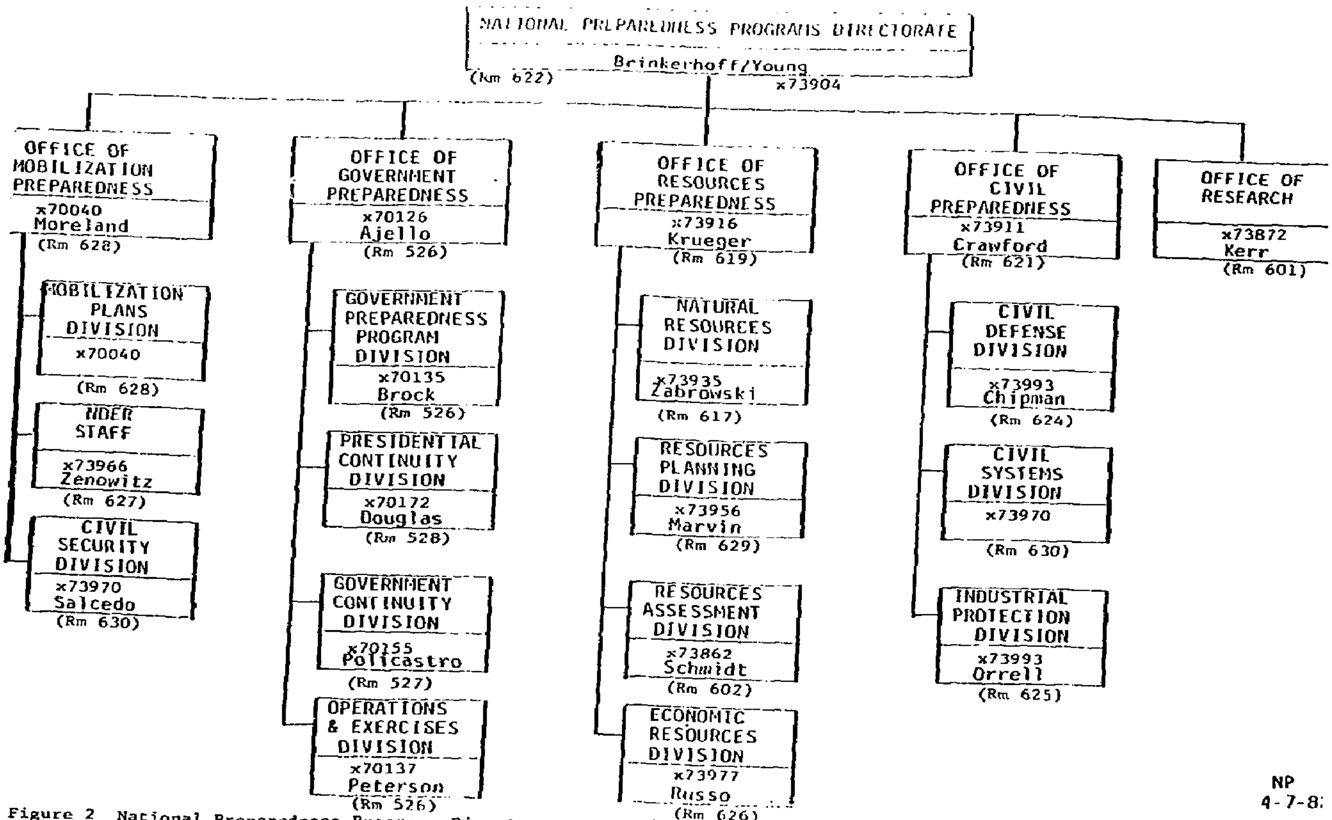


Figure 2. National Preparedness Programs Directorate

NP
4-7-8:

The chairman ended his remarks by saying: "There are several tasks I hope the group will address this week.

- How can we most wisely use a major increase in funds?
- What can we learn from our foreign contacts?
- What should the next U.S. CD program be, assuming evacuation planning will take some years to implement?"

The following summarizes the interim report of the Lawrence Livermore National Laboratory literature survey of fire and blast effects on urban areas.

State of Knowledge Survey

This is intended to identify gaps in understanding required for predictive capability. No priorities are implied by ranking into three categories. The rankings are relative: "2" means sufficient understanding for current general state of the art; "1" means some work has been found, more is probably necessary; "0" means nothing has been found, work is almost certainly necessary at some time. The work may be theoretical, experimental, done for civil defense or other purposes. The caveats are that the results are interim, based on what we found during six months of literature and limited mostly to U.S. work.

	Relative State of Knowledge		
	2	1	0
Attack Scenario			
1. Target Identification for Various Strategic choices	X		
2. Yields, Height of Burst, CEP for Individual Targets	X		
3. Timing of Bursts for Individual Targets		X	
4. Weapon Output Characteristics	X		
Transmission and Shadowing of Thermal Radiation			
1. Transmission of Thermal Pulse Through a Clear Atmosphere	X		
2. Effects of Clouds, Precipitation (deterministic)		X	
3. Methodology to Account for Realistic Atmospheric Conditions			X
4. Shadowing Effects of Terrain, Structures (deterministic)	X		
5. Methodology to Account for Shadowing Effects in a Realistic Fashion			X
Blast Propagation			
1. Blast Wave Propagation in Free-Field, Clear, Still Atmosphere	X		
2. Effects of Other Atmospheric Conditions		X	
3. Shielding Effects of Specified Terrain	X		
4. Shielding Effects of Specified Structures and barriers		X	
5. Methodology for Shielding Effects in an Urban Environment		X	

	Relative State of Knowledge		
	2	1	0
Radiative Ignition Criteria			
1. Identification of Relevant Parameters for Sustained and Transient Ignition by Thermal Radiation	X		
2. Understanding of the Effects of Wind, Sample Orientation		X	
3. Geometrically-Complex, Mixed Fuel, and Enclosure Effects		X	
4. Criteria for a Variety of Common Materials with Clean Surfaces	X		
5. Same for Materials Which Have Come Into Common Use in the Past 20 Years			X
6. Criteria for a Variety of Common Materials with Surfaces Representative of Use Conditions (Dirty, Weathered, Condensation)			X
Blast Effects on Fires			
1. Understanding of Conditions for which Blast Extinguishes Incipient Fires		X	
2. Understanding of Conditions for which Blast Promotes Incipient Fires			X
3. Effects of Blast on an Established Structural or Debris Fire			X
4. Effects of Blast on an Established Wildland Fire			X
Secondary Fire Ignition			
1. Probabilities of Secondary Fire Ignition as a Function of Blast Loading, Building Type and Use, for Non-Residential Buildings		X	
2. Same, But for Residential Buildings			X
3. Effects on Burn Characteristics of Structures for Secondary vs. Primary Ignition.			X
Fire Spread Within Relatively-Intact Structures			
1. Time from Ignition to Total Room Involvement for Various Types of Buildings (Classical Flashover)	X		
2. Time from Single-Room Involvement to Total Building Involvement for Various Types of Buildings	X		
3. Burn Characteristics for Single-Building Fires, for Various Types of Buildings	X		
4. Effects of Light-to-Moderate Blast Damage (Missing Windows, Roofs) on Burn Characteristics		X	

	Relative State of Knowledge 2	1	0
Fire Spread Between Relatively-Intact Structures			
1. Understanding of How Fire Spreads from One Structure to Others, Including Effects of Wind, Humidity, and Precipitation, for Various Combinations of Adjacent Structural Types	X		
2. Synergistic Effects of Adjacent Burning Structures on Their Burn Characteristics		X	
3. Firebrand Production, Transport, and Ignition Threat		X	
Convective Ignition Criteria			
1. Identifiction of Relevant Parameters for Sustained and Transient Ignition by Convective Heating, Including Effects of Wind	X		
2. Data for a Variety of Common Materials			X
3. Flammability Data for Materials Exposed to Mixed Convective and Radiative Sources		X	
Single-Building Response to Blast			
1. External Loading History of Isolated Structure	X		
2. Internal Room Filling:			
Single Room		X	
Multiple Rooms, Complex Geometry			X
3. Methodology for Modeling Dynamic Response and Collapse of Individual Structural Elements (e.g., walls floors)		X	
4. Experimental Data for Collapse of Structural Elements		X	
5. Dynamic Response and Collapse Models of Various Types of Structures		X	
6. Experimental Data for Collapse of Various Types of Structures			X
Multiple-Building and Multiple-Burst Response			
1. Effects of Shielding on Blast Loading of a Specified Structure in an Urban Area			X
2. Experimental Data on Blast Wave Shielding		X	
3. Effects of Multiple Bursts on Dynamic Response of Structures			X
4. Effects of Fire on Structural Response			X

	Relative State of Knowledge 2	1	0
Debris Formation and Transport			
1. Understanding of Debris Formation Mechanisms		X	
2. Modeling of Debris Production for Various Types of Buildings as a Function of Blast Loading		X	
3. Ultimate Debris Distribution from Various Types of Buildings as a Function of Blast Loading		X	
4. Experimental Data on Debris Translation and Distribution for Various Building Types			X
Fire Spread Through Debris and Collapsed Structures			
1. Effects of Severe Blast Loading on Subsequent Burn Characteristics of Various Types of Structures		X	
2. Fire Spread Rates Across Various Types of Debris Fields		X	
3. Effects of Wind, Humidity, and Precipitation on Fire Spread Rates Across Debris Fields			X
Mass Fires			
1. Understanding of Conditions Under which Individual Fires Merge, and the Effects of Merging on Burn Characteristics of Structures		X	
2. Conditions for Existence of Firestorms		X	
3. Conditions for Existence of Mass Conflagrations		X	
4. Physical Conditions Within a Firestorm		X	
5. Physical Conditions Within and Near a Conflagration			X
Fire Spread Through Wildland Areas			
1. Understanding of Fire Spread in Wildland Areas	X		
2. Rates of Fire Spread Through Various Fuels	X		
3. Effects of Wind, Humidity, and Precipitation on Rates of Fire Spread	X		

Priorities

The priorities given below are tenative, based on the state of knowledge survey and their perceived relative importance to predictive capability, with some consideration given to the perceived feasibility of obtaining information. There is no ranking implied within the categories, nor is there any implied recommendation for funding by anyone.

	High	Moderate	Low
Initial Conditions			
1. Thermal radiation propagation: effects of non-clear atmospheres, obstructions		X	
2. Blast wave propagation: effects of atmospheric conditions, shielding		X	
3. Development of methodologies for non-deterministic representation of weather, target areas	X		
Ignition			
1. Radiative ignition phenomenology: effects of target orientation, wind, and humidity			X
2. Radiative ignition data for non-ideal surfaces, newer materials	X		
3. Geometrically complex and mixed fuel arrangements	X		
4. Enclosure effects (abrupt flashover)	X		
5. Convective ignition criteria for common materials		X	
Structural Response			
1. Blast wave room filling, especially multiple room and complex geometry		X	
2. Modeling of dynamic response and collapse of individual structural elements and buildings	X		
3. Experimental data for collapse of various structural elements	X		
4. Experimental data for collapse of various typesof buildings		X	
5. Effects of multiple bursts on dynamic response of structures		X	
6. Effects of fire on structural response			X

	High	Moderate	Low
Blast and Fire			
1. Blast effects on incipient fires			X
2. Blast effects on established fires			X
3. Secondary fire ignition probabilities as a function of blast loading, building type and use			X
4. Effects of light-to-moderate blast damage on burn characteristics of various types of buildings	X		
Fire Spread			
1. Fire spread between structures, including effects of wind, humidity, and precipitation	X		
2. Firebrand production, transport, and ignition threat		X	
3. Analysis of urban fire spread data from the past 20 years	X		
4. Fire spread rates across various types of debris fields	X		
5. Effects of wind, humidity, and precipitation on rates of fire spread across various types of debris fields		X	
Debris			
1. Understanding of debris formation phenomena	X		
2. Empirical modeling of debris production as a function of blast loading for various types of buildings	X		
3. Analytical modeling of same			X
4. Ultimate debris distribution from various types of buildings as a function of blast loading	X		
Mass Fires			
1. Conditions for the existence of firestorms, conflagrations	X		
2. Physical conditions within a firestorm			X
3. Physical conditions within and near a mass fire conflagration		X	

III REVIEW OF CURRENT FEMA WORK UNITS

Weapon effect Work Units, having pertinence to fire effects and blast/fire interactions are summarized below. These summaries were provided in advance of the conference by the responsible principal investigator and reproduced here as received. Additional material was presented at the conference; to the extent practical, copies have been provided separately to the conference attendees.

SUMMARY

<u>FEMA Work Unit No:</u> 2564E

<u>FEMA Work Unit Title:</u> Predictive Modeling of Large Area Fires

<u>Objective and Scope:</u> Analytical description of the physics of a large area fire and calculation of the fluid mechanics and thermodynamics for given burning rates and city sizes.

<u>Contractor:</u> Pacific-Sierra Research Corporation
1456 Cloverfield Boulevard
Santa Monica, California 90404
(213) 828-7461

<u>Contractor Personnel:</u> R. D. Small, D. A. Larson, H. L. Brode

<u>Approach:</u>

The research focuses on modeling of the combustion layer (the burning area and region immediately above it) of a large area fire. This enables calculation of the temperature and velocity fields in the burning city.

<u>Status:</u>

The analytical formulations have been completed and computations for varying city sizes and burning rates are currently being performed.

<u>Significant Results:</u>

Asymptotic expansions have been used to formulate the combustion layer boundary value problem. The burning processes are modeled using a spatially dependent volume heat addition. The resulting strongly buoyant flow is compressible with arbitrary changes in temperature and density allowed. The induced firewinds are related to the burning induced flow through jump conditions derived for the inlet region. Calculations for an experimental *Flambeau* fire and the Hamburg firestorm event show agreement with documented observations. Calculations for larger area fires are currently being performed.

FEMA Work Unit No: 2564A

FEMA Work Unit Title: Blowout of Fires by Shockwaves

Objective and Scope: The overall objective of this experimental program is to determine and evaluate the physical variables that govern airblast extinction of sustained burning, in representative fuels, using a specially designed shocktube facility to simulate pressure pulses that are characteristic of nuclear explosions in air. The experiments are also selected to provide both an empirical base for analytical models being developed concurrently elsewhere and data for direct validation in high-explosive field tests such as MILL RACE. This year's efforts were aimed toward (1) establishing experimentally the scaling rules of blast extinguishment of fires for various fuels and geometries, (2) installing and testing a thermal radiation source (accessory to the shocktube at Camp Parks), and (3) employing the thermal source in full simulation (thermal/blast) shocktube tests duplicating MILL RACE conditions in preparation for and validation of the blast/fire field experiments.

Contractor: SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025
(415) 859-4009

Contractor Personnel: S. Martin, R. McKee, J. Backovsky, and T. Goodale

Approach: Because the components of the thermal source that we expected to use and its design specifications were not delivered in full by another FEMA contractor during the term of the present SRI project, our experiments were performed by substituting low-power thermal fire-initiation sources.

On the basis of results and understanding obtained from previous (1980) shocktube tests, wood cribs of two different element thickness were used as a vehicle to investigate the scaling of preblast burning time and the role of fuel-element thickness in heat-retentive, charring fuels. Crib dimensions were kept the same as in the 1980 study, but the fuel elements (sticks) making up the new crib were scaled down by a factor of 2 in thickness (to 3/8-in.) and thus reduced by a factor 4 the fuel-element cross-sectional area. Theory predicts a 41% increase (i.e., $\sqrt{2}$) in specific burning rate (weight loss per unit fuel surface area) during steady burning, and a shortened fire-time scale to 70% of the characteristic times for the thicker element crib; a 43.5% increase in specific burning rate was observed in verification tests.

The dependence of blast/fire effects on scale (fire size) was established for hexane in a previous SRI study. Of interest, this year, has been the determination of the role played by fuel type--notably, the pertinent physico-chemical properties--compared with the significant role played by wakes and eddies in the airblast flowfield, as previously observed. The fuels (kerosene, n-pentane, and acetone) were chosen to emphasize this variability when tested as 3-ft long pool fires for extinction by unobstructed, zero-angle-of-incidence airblast waves.

Status: All experimental work on the present contract has been completed and the final report prepared. It will be published and distributed in May 1982 pending FEMA approval.

Significant Results: The shortening of the preburn times (preselected delays between ignition and shock firing) at which the crib fires resist permanent extinction by airblasts of given overpressures was well confirmed by experiments with the new cribs. Comparison of the limiting preburn times--limits of extinguishability by airblast--suggests a 40% reduction in time scale from the 3/4-in. to the 3/8-in. stick cribs. Below the limiting preburn time the extinction overpressure threshold increases with preburn time. Both crib types become unextinguishable when comparable percentage weight loss has been reached (23.5% and 28% for the 3/4 and 3/8-in. stick cribs, respectively) and correlations of extinction thresholds in terms of percent crib weight loss at airblast arrival are quite similar.

Shocktube experiments with Class B fuels provide some surprising new information. The surprising aspect of these tests is the relatively low extinction blast-overpressure thresholds observed for the fuels tested: kerosene (1.5-2.0 psi mean overpressure); n-pentane (2.8-3.0 psi); acetone (1.5-1.9 psi). These thresholds are between the values for n-hexane (5.1 psi) and methanol (less than 1 psi) obtained previously. Except for hexane, the thresholds correlate with the effective fuel volatility (heat required to gasify the fuel). High-speed photographic records suggest the mechanism by which volatile fuels resist blast extinction in the shocktube tests, placing the flame displacement concept into better perspective.

In a typical class B fuel shocktube experiment, the arriving shock displaces the flame off the fuel bed cleanly and sweeps it downstream at near the particle velocity of the airblast. The displaced flame survives downstream of the test section for up to 150 ms--or the full extent of the positive phase duration in short duration tests. The displaced flame becomes essentially a wake flame and is fueled by vapors swept from the still-volatilizing fuel bed. The intense, turbulent mixing of the fuel-vapor/air mixture and the hot combustion gases in the shear mixing layer downstream of the fuel bed and of the test stand (rather than flow recirculation as in the case with flow obstacles) substantially increases the fuel burning velocity. When the particle velocity drops near the end of the positive phase, the high burning velocity provides for flashback upstream to the fuel bed and for eventual reestablishment of flame of the fuel bed. Fuel volatility plays a part in the amount of fuel vapor supplied to the wake: if the fuel volatility is low, the mixture in the wake is lean and the burning velocity drops too low for combustion to persist until flow particle decreases sufficiently for flashback.

<u>Reports:</u>

1. J. Backovsky, S. Martin, R. McKee, "Experimental Extinguishment of Fire by Blast," Final Report, FEMA Work Unit 2564A, SRI International, Menlo Park, CA (to be released May 1982).

2. S. Martin, J. Backovsky, and R. G. McKee, "Blast Effects on Fires," Final Report, FEMA Work Unit 2564A, SRI International, Menlo Park, CA (December 1980).

3. S. Martin, "Experiments on Extinction of Fires by Airblast: Flame Displacement as an Extinction Mechanism," Annual Report, FEMA Work Unit 2564A, SRI International, Menlo Park, CA (January 1980).

4. J. Backovsky, T. C. Goodale, S. B. Martin, and R. G. McKee, "Shocktube for Blast/Fire Interaction Studies," paper presented at and included in Proceedings of the Seventh International Symposium on Military Applications of Blast Simulation, Medicine Hat, Alberta, Canada, 13-17 July 1981.

FEMA Work Unit No: 2564H

FEMA Work Unit Title: Response Mechanisms: Blast/Fire Interactions

Objective and Scope: To deduce nondimensional parameters which capture the mechanisms of blast/fire interaction. To correlate, on the basis of these parameters, the SRI shock-tube data on both Class A and Class B fuel fires.

Contractor: University of Notre Dame, Department of Aerospace and Mechanical Engineering, Notre Dame, IN 46556. (219) 239-5635.

Contractor Personnel: Professor A.M. Kanury, Principal Investigator; Mr. P. D. Gandhi, Graduate Research Assistant.

Approach: The steps involved are: (a) identification of potential candidate mechanisms of blast/fire interaction; (b) formulation of the mechanisms to deduce nondimensional parameters and the expected overall features of the interaction; (c) correlation of SRI data; refinement of the mechanistic models; (d) continued correlations and identification of areas in which data and/or information is lacking.

Status: The Work Plan calls for simultaneous development of mechanisms, parameters and correlations. The following schedule was originally planned.

Preliminary correlations	May 31, 1981
Liquid (B) fires	Aug 31, 1981
Barrier & Enclosure effects	Dec 31, 1981
Charring effects	Mar 31, 1982
Radiant Pulse effects	May 31, 1982
Final Report	Aug 31, 1982

The project is approximately on schedule at the milestone of charring effects. Due to considerable unavailability of information on property values of partially charred wood, we are about a month or so behind schedule.

Significant Results: To date, we succeeded in correlating the liquid-fuel extinction data on a blast strength versus flame strength map. Although the kinetic parameters for the overall oxidation of liquids such as hexane and methanol are not well-known, the ambiguities are found to be not serious. The mechanism indicates that upstream barriers tend to render flames blast-proof. The barrier data of SRI, however, appear to be not adequate to test this hypothesis mainly because these barriers are not tall enough to cause significant recirculation.

Mechanisms are postulated for the extinction (and the possibility of reignition) of charring-fuel fires. Parameters are currently being developed with correlations to follow.

Reports: Six progress reports. The final report is due August 1982.

FEMA Work Unit No: 2563G

FEMA Work Unit Title: Flame Extinction for Char-Forming Objects

Objective and Scope: Identification of the mechanisms, and quantification (by approximate analysis) of the criteria, which determine whether or not radiation-precursor-initiated burning of a char-forming object is extinguished by arrival of the post-blast-wave gases. Attention is confined to cases of objects in the modest-peak-overpressure far field for a moderately strong thermonuclear yield, such that quasisteady burning has been established by the time of blast-front arrival. Also, the matter of flame stabilization in the wake of a bluff body that emits combustible vapor is outside the scope of the investigation.

Contractor: Engineering Sciences Laboratory
TRW Space and Technology Group
One Space Park
Redondo Beach, CA 90278
(213) 536-2438)

Contractor Personnel: George Carrier
Francis Fendell
Phillip Feldman
Stanton Fink

Approach: Approximate-analytic and simple-numeric treatment of appropriate boundary/initial-value problems.

Status: Project completed; final report issued May 1981.

Significant Results: The heat-storage properties of the porous carbonaceous matrix (char layer) formed between the pristine inner material and the surrounding atmosphere distinguishes the burning of most (non-sublimating) solids from the burning of liquid fuels that evaporate upon heating. If a flame is displaced completely off a fuel-vapor source (in the thermonuclear context because blast arrival introduces flow rates in excess of reaction rates, during the duration of the positive phase), then convective cooling would soon reduce the surface temperature of a liquid fuel below the evaporation temperature; even after the speed of the relative gaseous flow slowed at the end of the positive phase, evaporation (and, as a consequence, burning) would not be resumed. However, for a char-forming solid, provided the duration of the positive phase were not too long, outgassing of combustible vapor still warm enough for gas-phase ignition would be resumed, and exothermic combustion could be resumed. Additional considerations for char-forming objects involves radiative transfer from the surface of the carbonaceous matrix: unless surrounding objects can counter radiative cooling of the charring body, heat transfer in excess of that associated with convection causes the hot surface of the char to be cooled more rapidly; on the other hand, after the enveloping gas-phase diffusion flame is displaced off the body, oxygen may reach the body surface and react heterogeneously and exothermically with the surface of the carbonaceous char layer, such that convective cooling is at least partially countered.

Thus, interaction of blasted gas with a body enveloped by flame owing to ignition by the precursor radiation primarily entails forced-convective extinction of burning of unpremixed gaseous reactants; the overpressure and oxygen-reduction effects can alter chemical-kinetic rates, but seem less important considerations. Furthermore, forced-convective extinction may occur equally well for a liquid hydrocarbon pool (not a typical urban setting) as for a char-forming solid (i.e., for any synthetic or natural polymer, and both cellular plastics and wood are used extensively in contemporary Western construction); however, while the flame over a pool is very likely to be <u>permanently</u> extinguished, the flame over a char-forming solid is likely to be <u>only temporarily</u> extinguished. This is especially the case since geometric and fluid-dynamic considerations may reduce the relative flow. Thus experiments with liquid fuels may be misleading because, for practically interesting construction materials, fire/blast interaction <u>cannot</u> be relied upon to eliminate primary fires in the far field (for civil defense planning in a postnuclear environment).

The general analytic apparatus constructed for treating a broad class of blast/fire interaction problems consists of two parts. First, the heat stored in the porous carbonaceous matrix for quasisteady, well-established burning is calculated; the thickness of the char layer, and its temperature as a function of depth from the surface of the body to the pristine core material, are obtained. Then, in a subsequent time-dependent calculation, the reduction of temperature at the outer surface of the char layer after flame blow-off is obtained; unless the balance of radiative transfer, conductive transfer, convective cooling, and heterogeneous-chemistry exothermicity leads to reduction of this surface temperature below an ignition temperature for gas-phase burning over a temporal span of the duration of the positive phase, flaming is likely to be resumed at the end of the positive phase. The problem of a thin, incompletely developed char layer owing to small temporal separation between radiative-precursor arrival and blast-front arrival in the low-peak-overpressure annulus (for a smaller-yield thermonuclear weapon) has not been treated, but would appear to constitute a tractable generalization of the analysis already executed.

Finally, experimental verification of the theory would seem to be adequately and inexpensively executed in a low-speed wind tunnel, with provision for rapid insertion and removal of samples. Such a facility would seem to be adequate to provide the large number of test runs required for this multiparameter problem; a large number of tests are also needed because of the inevitable scatter in the data, a scatter that should not be too quickly interpreted as significant for purposes of the sponsor.

Reports: G. Carrier, F. Fendell, P. Feldman, and S. Fink: Forced-convection extinction of a diffusion flame sustained by a charring body. TRW Defense and Space Systems Group Report 37503-6001-UT-00 (to be published in revised and abbreviated form in the journal Combustion Science and Technology).

FEMA Work Unit No.: 2564 I

FEMA Work Unit Title: Secondary Fire Analysis

Objective and Scope:
To examine the potential for secondary fires in or near structures, with emphasis on critical facilities and industries. (Secondary fires are defined as fires caused by blast effects, or other nonthermal effects, of a nuclear detonation, in contrast with primary fires, which are those resulting from the thermal radiation of a nuclear detonation.) Assessment of the potential for secondary fires is critical to many aspects of civil defense planning, including protection against ignitions in critical/key industries, protection from fire spread, assessment of expected damage, and for locating or for determining the survivability of key worker shelters.

Contractor: Scientific Service, Inc.,
517 East Bayshore, Redwood City, CA 94063
(415) 368-2931

Contractor Personnel: C. Wilton, D.J. Myronuk, J.V. Zaccor

Approach: To review and assess a broad range of available data on fire ignitions from secondary (nonthermal) causes encompassing nuclear explosions (Hiroshima, Nagasaki, and the Nevada tests), natural disasters (earthquakes, hurricanes, tornadoes, etc.), explosions (high explosive tests and accidents), and available research documents. To analyze these data and develop a model for predicting the incidence of secondary fires.

Status: Project completed September 1981.

Significant Results:
The major findings of this study were that there are significant differences between the secondary ignitions caused by nuclear blasts and those caused by other mechanical stimuli such as earthquakes. This fact greatly reduces the data base available to apply to the development of a prediction method. The study indicated that, in the 2 to 5 psi range, secondary ignitions from megaton weapons are probably inconsequential compared with primary ignitions, while in the 0.5 to 3 psi range (a vastly larger area than the 2 to 5 psi range), secondary ignitions may prove to be very important.

A model was developed, using the data base available. This model was designed for use by civil defense planners, and the input provided includes all information required to determine the key parameters: the building type, its structural characteristics, a use classification, damage as a function of overpressure, and the probability this will lead to secondary fires. A copy of the model is detachable from the report for easy use in field surveys.

Reports: Wilton, C., D. J. Myronuk, and J.V. Zaccor, **Secondary Fire Analysis**, AD # A105 723, SSI Report No. 8048-6, Scientific Service, Inc., Redwood City, California, September 1981.

FEMA Work Unit No.: 2564D

FEMA WORK UNIT TITLE:

Assessment of Combined Effects of Blast and Fire on Personnel Survivability.

Objective and Scope:

Develop a methodology for evaluating personnel survivability in three types of shelters when subjected to a blast/fire environment.

Contractor:

IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616
312/567-4782

Contractor Personnel:

A. Longinow, T. Waterman and A. Takata
(Work unit results summarized by H. Napadensky)

Approach:

1. Building plans for four types of structures were acquired. Details of the damage and failure modes when subjected to selected blast overpressures were determined.

2. The distribution of debris produced by a two story, frame, single family residential structure and contents was determined at the blast overpressure from the near surface burst of a one megaton weapon producing incipient collapse. This included the physical description of the debris piles and the amount of combustible material as a function of spatial location.

3. Modelling of blast/fire interaction was done for a hypothetical city consisting solely of the frame residences at a building density of 15 percent of ground area and extending far beyond all weapon effects in all directions.

4. Local areas of the city were reexamined within the hypothetical city to evaluate the influence of a variety of fire prevention and/or fire fighting activities. Studies included areas of the high (15 percent) building density; and, regions of lesser density (5 percent).

5. Estimates were made of people survivability in three types of personnel shelters located within the modelled city.

Status:

Draft final report submitted December 1981.

Significant Results:

A portion of a city consisting of identical, single-family frame residences and three types of below-grade personnel shelters located in selected areas was modelled. A single 1-MT nuclear weapon detonation near the ground, which subjected the city to thermal radiation and overpressure was postulated. Zones of various levels of structural damage were identified and debris final location and distribution was determined both for initial conditions of the blast normal to the structure and at 30 degrees. Debris piles were described in spatial coordinates and composition (combustible, non-combustible) at various locations on the city blocks. Time dependent fire effects were determined using existing fire ignition and fire spread computer programs developed at IITRI (these models also included various levels of fire fighting). Hazards were quantified and the probability of people survival was estimated in terms of shelter effectiveness when located in different zones of blast damage.

The expedient, pole type below-grade shelter proved to be the most effective in all blast damage zones and fire environments considered in this study. (The other types of personnel shelters considered were a conventional wood framed basement upgraded to provide additional blast resistance and a conventional basement with a reinforced concrete overhead slab).

Reports:

A. Longinow, T. Waterman, A. Takata, et al. "Assessment of Combined Effects of Blast and Fire on Personnel Survivability", Final Report, FEMA Work Unit 2564D, IITRI, Chicago, IL Dec., 1981 (Draft).

FEMA Work Unit No.: 1128 D

FEMA Work Unit Title: Construction, Instrumentation and Testing of Shelter Design and Industrial Hardening Concepts at the MILL RACE Event

Objective and Scope:

(1) To evaluate various upgrading methods for strengthening different types of floors to compare response under actual blast loading with static laboratory tests.

(2) To evaluate the performance of basement walls when subjected to an overpressure surcharge.

(3) To obtain information on the bracing and upgrading of walls.

(4) To evaluate the performance of a dimensioned lumber version of a pole shelter.

(5) To obtain information on debris translation and distribution for casualty evaluation.

(6) To assess selected simple hardening options for their effectiveness in restricting motions of industrial equipment under drag forces.

(7) To verify scaling relations applied to shock tube models by evaluating two scales in the field.

(8) To observe the effects of a 40 psi air shock on underground utility vaults.

Contractor: Scientific Service, Inc.
517 East Bayshore, Redwood City, CA 94063
(415) 368 2931

Contractor Personnel: R. S. Tansley, J. V. Zaccor, Principal Investigators

Approach:

Structure Upgrading Studies:

Four structures were built to represent common "existing" structures (and common elements of existing structures) so that upgrading techniques presented in SSI reports 7719-4 and 7910-5 could be evaluated. One structure was built at the 40 psi ground range and three at the 2 psi ground range.

Expedient Key Worker Shelters Studies:

At the 40 psi ground range, a dimensioned lumber version of the pole shelter was placed below grade. No upgrading was required for this structure as it represented an expedient shelter designed for 40 psi. Two additional expedient shelters were tested in conjunction with the industrial hardening studies. These shelters were standard utility vaults of the sort found below grade at many street intersections in urban areas. One of these vaults was placed at the 40 psi ground range and one at the 20 psi ground range, to evaluate the effects of ground shock on passive gauges and anthropomorphic dummies and to observe the overall effect in terms of structure distress. The vault placed at the 40 psi ground range was upgraded with two telephone pole shores at the third points of the long axis of the vault and centered on the other axis. Posttest photographs and observations were the principal means for evaluating performance.

Industrial Hardening:

For these experiments, full-scale industrial equipment would have been far too large and massive to evaluate effects of strategic weapons. Consequently, home power tools and drums were chosen as scaled representations of industrial equipment. Identical units were obtained so different conditions could be compared. The equipment and the arrays represented acceleration coefficients α ($\alpha = AC_d/m$, where A is the area perpendicular to the flow in ft^2, C_d is the appropriate drag coefficient, and m is the object weight in lbs; from Ref. 1*) in the range from 0.001 $ft^2\ lb^{-1}$ to 0.07 $ft^2\ lb^{-1}$. Items were placed in the free-field, as well as protected, to compare displacements under several different circumstances. Predictions regarding expectations of free-field displacements and overturning were of major interest. Ref. 1 was used to predict displacements, and a concept developed at SSI was used to predict overturning. In addition to the full-scale drums, one-tenth scale models of drums were tested in which the mass "m" was made ten times larger than for the full-scale drums (so that α would be the same at both scales). These scale model drums were identical to drums tested in the SSI 12-inch shock tube using pulses scaled to 1 kt.

* Bowen, I. Gerald, et al., "A Model Designed to Predict the Motion of Objects Translated by Classical Blast Waves," CEX-58.9 U.S. Atomic Energy Commission, June 1961.

One additional experiment was conducted to evaluate an expedient blast anchor concept that uses side-on overpressure to help secure a package against the dynamic pressure pulse. These anchors were oriented to restrain packages with restraints in the direction of, as wells as at right angles to, the blast wave. Again, direct observation measurements and photographs were the principal means of assessing performance.

Status: This particular study is completed. However, it relates to ongoing studies being conducted for FEMA in which analyses and laboratory, shock-tube, shock-tunnel, and field tests, all are being employed to test and evaluate both structure upgrading and industrial hardening concepts for technical validity and practical feasibility.

Significant Results:

Structures:

The most significant results were the non-failure of the unreinforced concrete masonry wall below grade at 40 psi, and the early failure of the wood joist and plywood sheathed overhead floor in the unshored section of the below grade structure at 2 psi. The former was significant because it was expected the backfill and soil cover would tax the strength without allowance for a blast wave surcharge. The pretest failure of a section of the overhead flooring in the unshored portion of the below grade structure at the 2 psi ground range had been predicted at SSI; the event was significant in that many people continued to disbelieve that a progressive deterioration under a static load of slightly over 1 psi could lead to failure.

Analysis subsequent to MILL RACE has shown that the non-failure of the unreinforced concrete masonry walls might have been predicted if all factors were considered. More important, subsequent shock tube experiments suggest these walls would not have survived had the weapon had a yield of 1 Mt instead of 1 kt. This points out a lesson learned long ago -- that is, that damage from strategic weapons can be markedly greater than from tactical weapons at the same overpressure. Complete destruction with a 1.3 Mt weapon at a lower overpressure versus partical destruction with an 18 kt weapon at a higher overpressure, on identical structures, was reported in Ref. 2, page 329.*

* CEX-68.3, "Nuclear Weapons Effects Tests of Blast Type Shelters," compiled by C. Beck, U.S. Atomic Energy Commission, June 1969.

Industrial Hardening:

Two observations were of significance. Again, one was an anomaly, while the other was an observed agreement with concept. The anomaly was the failure of the drums standing on a soil surface to displace as far as Ref. 1 theory would predict. The drums standing on a concrete surface behaved very well according to Ref. 1 theory, but those standing on soil acted as if they had a much larger effective mass. This behavior would be expected if the side-on pressure on top surface of the stable drum arrays were to increase the effective normal force, thereby reducing the sliding that could occur (this would be likely to occur only on soft surfaces where the lip of the drums could bite in and effect a seal). Such behavior is entirely compatible with the concept of utilizing the side-on pressure of the air blast to increase the holding power of the expedient anchors (which were observed to work effectively). The other item of significance was the successful testing of banding items into clusters to increase the package size and decrease the acceleration coefficient. This proved a very effective method to reduce the maximum velocities and total displacement. Finally, the scaling studies conducted in the SSI 12-inch shock-tube were verified in the field with the one tenth scale models of the drums.

Reports: Tansley, R.S. and J.V. Zaccor, **Testing of Shelter Design and Industrial Hardening Concepts at the MILL RACE Event**, AD # A110 919, SSI Report No. 8115-4, Scientific Service, Inc., Redwood City, California, January 1982.

FEMA WORK UNIT SUMMARY

Work Unit No. 2563I

Project Title: MILL RACE Event: Experiments in Blast/Fire Interactions.

Objective and Scope: The purpose of the experiment was to bracket threshold airblast conditions for fire extinction as a test of the predictive validity of shocktube data, and to explore the effect of fuel-bed orientation with respect to the advancing shock.

Contractor: SRI International, 333 Ravenswood Ave., Menlo Park, CA 94025, (415) 859-3578.

Contractor Personnel: Stanley B. Martin, Robert G. McKee, Jr., and Jana Backovsky.

Approach: Idealized material specimens (trays of shredded filter-paper stock), intended to represent ignitable debris, were placed at the three TRS stations of MILL RACE in locations where they were expected to be ignited by the thermal pulse. Expected overpressures were approximately 3½ and 7 psi. Trays were oriented to provide cases of grazing, normal, and intermediate shock incidence, and both horizontal and vertical aspects. The principal observations (high framing-rate cine photography) were visual evidence of (1) ignition during TRS exposure, (2) persistence of fire until shock arrival, and (3) whether or not, flames were extinguished by the passing blast wave. Secondary observations of possible rekindle of extinguished flames was provided by time-lapse photography. Passive fluence gages were placed with each specimen as a backup diagnostic. The experimental variables were:

- Peak overpressure
- Orientation
- Height above grade
- Preburn duration
- Specimen moisture content and bulk density.

Preliminary tests were run in the Camp Parks Blast Simulator to ensure that thresholds of extinction could be bracketed at MILL RACE.

Status: The experiments have been performed; the contract is concluded. Results have been reported.

Significant Results: The basic objectives of the experiment were not met. None of the debris-tray targets was consumed by fire; few showed even significant scorching. It appears that the TRS exposures were insufficient to cause ignition in every case. While the possibility exists that some specimens were ignited and the fire then promptly blown out by the shock with little residual effect, the motion pictures fail to provide any compelling evidence of this having occurred.

Reports: S. Martin and R. McKee, "Airblast Extinction of Fires," Experiment Report Prepared for MILL RACE Results Symposium, 16-18 March 1982, Harry Diamond Labs (January 1982).

FEMA Work Unit No: 4113

FEMA Work Unit Title: MILL RACE Event: Structural Response and Debris Distribution

Objective and Scope: To relate structural response and debris dispersal to interaction of structural elements

Contractor: Center for Planning and Research, Inc.
2483 East Bayshore Road
Palo Alto, CA 94303
(415) 858-0252

Contractor Personnel: John Rempel
James E. Beck

Approach: Three near full size buildings were erected at three different ranges from the MILL RACE ground zero. (MILL RACE was the detonation of approximately 500 tons of ammonium nitrate-fuel oil mixture on the ground surface at White Sands Missile Range, New Mexico.) Two buildings were unreinforced masonry (at 10 and 30 psi) and the third was reinforced concrete tilt-up (at 25 psi). Collapse was observed with accelerometers, displacement gauges and cine cameras; airblast loading was recorded with static pressure gauges. Structural components were coded and their post-shot distribution measured.

Significant Results: During the early phases of the response all the electronic gauges performed as expected and we have excellent information on the relations among the movements of individual components such as walls and ceilings as well as concurrent airblast pressures. Very little useful information came from the cameras, which failed for one reason or another. The flexure of the front walls of the unreinforced buildings clearly led to upward acceleration of the ceiling and to increased stabilization of the front wall, although the results do not follow a simple rigid model. The behavior of the side and rear walls is more complex but there is evidence of interaction both with the ceiling and with other walls, particularly in the debris patterns.

Collapse of the reinforced building was by flexure in the front wall and ceiling, followed by loss of embeddment of connectors in the sidewalls. The rear wall remained in place, although subject to motion, most notably under debris impact. Front wall flexure predictions were found to be quite accurate.

Data from these experiments will provide guidance for much needed improvement of structural response and airblast loading models, particularly for the unreinforced buildings.

Reports: Rempel, J. R., J. E. Beck and R. G. McKee, "Structural Response and Debris Distribution at MILL RACE," SRI International, to be published.

FEMA Work Unit No.: EMW-C-0743

FEMA Work Unit Title: Emergency Management for the Fire Service

Objective and Scope: The objective of the study is to update and upgrade the document entitled "A System for Local Assessment of the Conflagration Potential for Urban Areas" developed by Gage-Babcock & Associates, Inc. in 1965. This involves modifying and expanding, where appropriate, the computation variables and systematic methodology used in the current Conflagration Block Rating Formula published in the original study.

Contractor: International Association of Fire Chiefs, Inc., 1329 18th Street, N.W., Washington, D.C. 20036, (202) 833-3420.

Contractor Personnel: Harry E. Hickey, Dennis H. McCune, Lee M. Feldstein.

Approach: The initial task involves reviewing relevant literature published since 1965. The following subject areas have been delineated for purposes of impact analysis:

1. Fire Development in Structures
2. Fire Development in Multiple Structures (Mass Fires)
3. Conflagration Development
4. Risk Assessment
5. Fire Load Measurement
6. Radiation Measurement and Exposure Analysis
7. Weather Analysis
8. Fire Flow Analysis
9. Fire Suppression Manning Levels for Large Scale Fires
10. Effectiveness of Internal Protection.

The review of the reported literature and the quantitative methods analysis will be used to modify the computation variables, if necessary, in the Current Conflagration Block Rating Formula published in the original study.

Examples of the block rating analysis will be prepared using the original formula and the modified formula. Block configurations in Alexandria, Virginia, were used to test the original formula, so the modified formulas will be tested there as well. Topographical maps identifying these block configurations can be used for contructing comparative analysis.

On the basis of completing the first analysis, an application quide will be prepared to describe the conflagration assessment methodology. This guide is necessary for the first pilot study of the revised methods. Additional built-up blocks in Alexandria will be selected for this test. It will be implemented by the following groups:

1) Ten Fire Officers - Alexandria Fire Department
2) Ten Fire Protection Engineers
3) Ten Civil Defense Personnel
4) Twenty Fire Protection Engineering Students from the University of Maryland.

Results of the pilot test will be analyzed for method clarity, consistency of application and method validity. An assessment will be conducted on the individual and combined ability of the identified groups to apply the methodology and the variance of the final Block Rating by each method. Results of the pilot study will also be used to further restructure the Block Rating Model if necessary. The Block Rating application guide will also be revised as appropriate.

The above described pilot test will provide a proper foundation for an applications study in Alexandria, Virginia. The city blocks selected for the pilot study will be used for the applications study. To obtain a limited validation of the application methodology, a new group of individuals will be selected to apply the revised Block Rating Model. However, the general composition of the study group will follow the outline of individuals above.

The applications analysis of the Block Rating Model(s) will be used to finalize the methodology. The structure including the methodology statements and situation examples will be incorporated into a new Manual titled: System II for the Local Assessment of the Conflagration Potential of Urban Areas. A support document will also be prepared concerning the entire study process and the supporting literature. This work is scheduled for completion by August 15, 1982.

Status: At this time thirty relevant literature sources have been annotated and reported in separate literature research papers. A bibliography sheet has been prepared on the applicable literature to date. Of course, literature review will continue throughout the project as new reference items are constantly being identified.

A summary of the literature review has been completed. This paper discusses the significance of the literature in relation to potential modification of the original conflagration analysis methodology.

Significant Results: Generally, a wealth of research has been conducted and reported for the past fifteen years in the evaluation areas of fire development risk assessment, fire load measurement and radiation measurement in relation to exposure analysis. This is in contrast to the paucity of work in other critical areas; i.e., impact analysis of weather on structures.

A number of new quantitative measures have been identified for computing relative impact of the stated measures on conflagration potential. To compare and contrast other measures, an interim paper is being prepared to evaluate each methodology and to appraise the potential impact of alternatives on the block rating assessment.

IV REVIEW OF NBS FIRE PROGRAM

The following presentation, provided by Drs. R. Levine and A. Fowell, was included in the 1982 Asilomar Conference proceedings, to round out a review of the scope of fire research activities undertaken by federal agencies. While the character and application of the fire research at the Center for Fire Research at the National Bureau of Standards is by and large very different from that specifically directed to assessing the incendiary threat of nuclear explosions, many of the results are believed to be relevant, and the skills and special facilities are in some degree adaptable to such assessment.

OUTLINE OF PRESENTATION

PROGRAM OF THE NBS CENTER FOR FIRE RESEARCH

I. INTRODUCTION: - U.S. FIRE LOSSES

II. CFR GOAL & STRATEGY

III. EXPLORATORY FIRE RESEARCH

IV. GRANTS PROGRAM

V. FIRE SAFETY TECHNOLOGY DIVISION
   1) SUPPRESSION & EXTINGUISHMENT
   2) FIRE GROWTH PROCESSES
   3) SMOKE & TOXIC GASES, TOXICITY
   4) FACILITY FIRE SAFETY PERFORMANCE

VI. FIRE MEASUREMENT & RESEARCH DIVISION
   1) FIRE PERFORMANCE & EVALUATION
   2) MATERIALS FIRE PROPERTIES

VII. ANTI-ARSON

VIII. SUMMARY

A. INTRODUCTION

FIRE LOSSES - $7 BILLION/YEAR
7500 LIVES/YEAR
120,000 INJURIES/YEAR

OTHER COSTS - ~5% OF CONSTRUCTION COSTS
$16 BILLION FOR FIRE FIGHTING

PROTECTION METHODS - PRESCRIPTIVE CODES
EMPIRICAL FIRE TESTS AND STANDARDS

PROBLEMS - MORE COST/EFFECTIVE PROTECTION
FORESTALL BAD EFFECTS OF NEW MATERIALS

CENTER FOR FIRE RESEARCH

GOAL: Provide Scientific and Technical Basis to:

°Reduce fire loss and cost of fire protection

°Remove fire as barrier to other national needs

CENTER FOR FIRE RESEARCH

STRATEGY:

A. Contribute Directly to Reduction of Fire Loss and Cost of Fire

B. Promote Scientifically-Based Fire Protection Engineering Practices

C. Promote Advance of Fire Science

EXPLORATORY FIRE RESEARCH

OBJECTIVE: DEVELOP SCIENTIFIC KNOWLEDGE OF FIRE PROCESSES.

RECENT INVESTIGATIONS:

- °MEASURED & MODELED 2D SMOLDERING IN CELLULOSIC INSULATION
- °2-WAVELENGTH LASER HOLOGRAPHIC STUDY OF PRE-IGNITION
- °LASER-INDUCED SCATTERING STUDY OF SOOT PRECURSORS IN FLAMES
- °ROLE OF RETARDANTS IN PLASTICS - SOLID PHASE EFFECTS

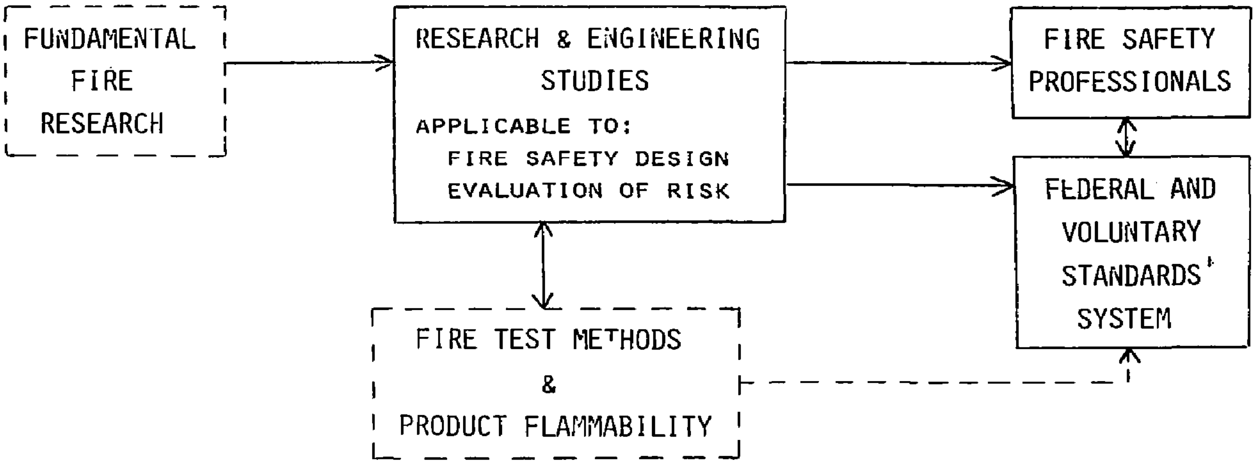
C. RESEARCH PROJECTS (II)

GRANT RESEARCH

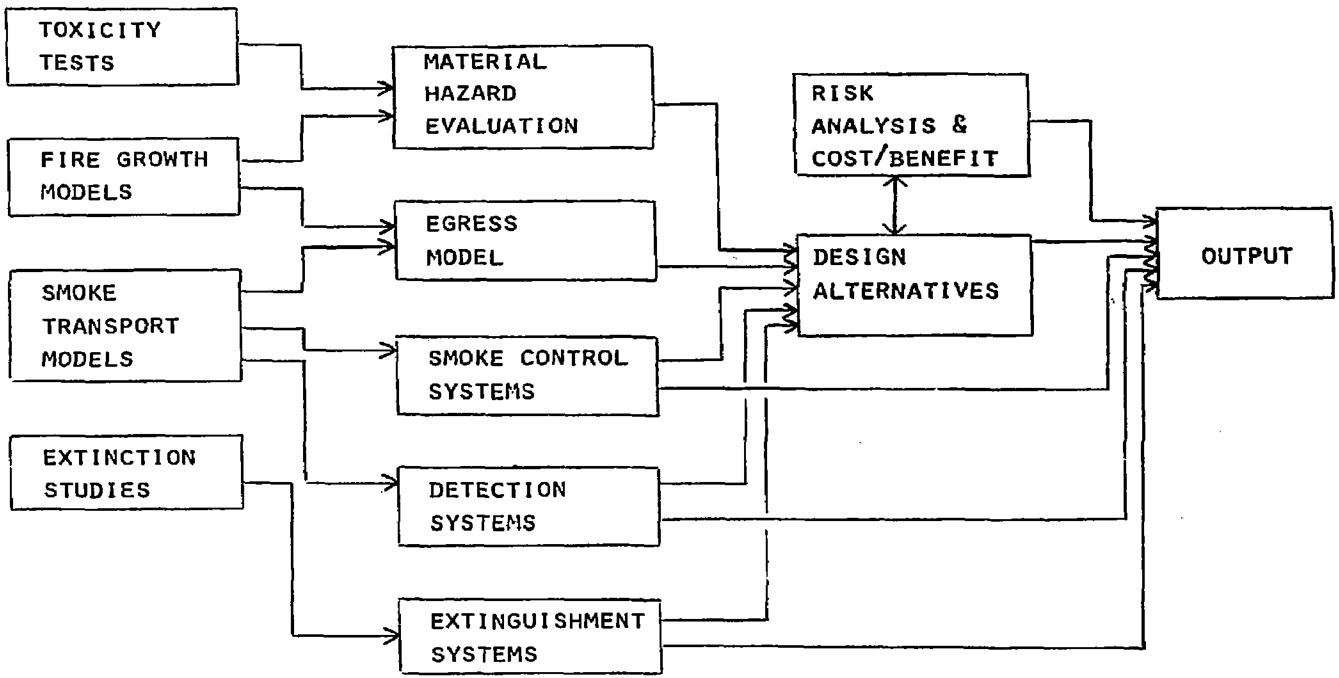
HARVARD	• RESEARCH FIRE GROWTH MODEL • RESEARCH SMOKE FLOW MODEL • CEILING LAYER REACTION
FACTORY MUTUAL	• FIRE & PLUME RADIATION • PLUME COMBUSTION EFFICIENCY • MATERIAL FIRE PROPERTIES
PENN STATE CAL TECH	• VERTICAL SURFACE BURNING • ENTRAINMENT • CEILING HEAT TRANSFER • ROOM TO ROOM SMOKE TRANSFER

U OF C BERKELEY	• POLYMER FIRE PLUMES • FLAME SPREAD • SOOT RADIATION
NOTRE DAME	• FIELD MODEL OF FIRE IN A LONG NARROW CORRIDOR
CASE WESTERN	• HORIZONTAL FLAME SPREAD
BROWN	• RADIATION & VITIATION ON FLAMES
PRINCETON	• FLAME SPREAD • EXTINCTION • SOOT FORMATION

FIRE SAFETY TECHNOLOGY DIVISION



PROGRAM INTERRELATIONSHIPS



PROGRAM AREAS 1981

- ° COMBUSTION TOXICOLOGY
- ° FIRE MODELING
- ° FIRE PROTECTION SYSTEMS
- ° DESIGN CONCEPTS
- ° FIRE HAZARD ANALYSIS

ACCOMPLISHMENTS 1981

COMBUSTION TOXICOLOGY

- TOXICITY TEST METHOD FOR COMBUSTION PRODUCTS.
- ANALYSIS OF TISSUE AND BLOOD SAMPLES--MGM FIRE.
- EXAMINED TOXICITY OF MATTRESSES AND PAINT FOR SOUTH CAROLINA PRISONS.
- DEVELOPED A STANDARD TEST METHOD FOR SNIFFERS (FOR LOCATING ARSON SAMPLES).

ACCOMPLISHMENT 1981

FIRE MODELING

- DEVELOPED UNSTEADY 2-DIMENSIONAL ENCLOSURE FIRE MODEL WITH SMOKE COAGULATION.
- MEASURED WINDOW AND DOOR FLOWS VS FIRE SIZE AND LOCATION.
- DEVELOPED TECHNIQUE TO MEASURE DOWNWARD AND LATERAL FLAME SPREAD.
- MODELED MULTIROOM FIRE GROWTH WITH FUEL AND SPECIE TRANSPORT.
- MODELED GENERATION OF CO IN ENCLOSURE SMOLDERING FIRE.
- VALIDATED CORRIDOR SMOKE FILLING MODEL.

ACCOMPLISHMENTS 1981

FIRE PROTECTION SYSTEMS

- FULL SCALE STUDY ON SMOKE PENETRATION OF CEILING SYSTEMS (VA).
- REVIEWED APPLICABILITY CONVENTIONAL SMOKE CONTROL TO MERCHANT SHIPS (U.S.C.G.).
- STARTED LAB STUDY ON WATER EXTINGUISHMENT OF OIL AND GAS WELL FIRES (U.S.G.S.).
- STUDIED RESPONSE OF SIDEWALL SPRINKLERS (HHS).

ACCOMPLISHMENTS 1981

DESIGN CONCEPTS

- SUBMITTED TO NFPA LIFE SAFETY CODE, FIRE SAFETY EVALUATION SYSTEMS FOR:
  - BOARD AND CARE HOMES (HHS)
  - HEALTH CARE FACILITIES (HHS)
  - PRISONS (DEPT. OF JUSTICE)
- DEVELOPED TECHNIQUE FOR COMPUTING AVAILABLE EGRESS TIME.

ACCOMPLISHMENTS 1981

FIRE HAZARD ANALYSIS

- STUDY ON CAUSES OF FIRE FATALITIES IN RURAL AREAS (U.S.F.A.).
- DEMONSTRATION OF LIFE CYCLE COSTING TO HOSPITALS (HHS).
- STUDY OF HAZARDS OF RAIL PASSENGER TRAINS (D.O.T.).
- STUDY OF ALTERNATIVES FOR THE TRANSPORTATION OF EXPLOSIVES (D.O.T.).

FIRE TOXICITY

OBJECTIVE: TO IDENTIFY POTENTIALLY HARMFUL COMBUSTION PRODUCTS AND MEASURE THEIR EFFECT ON LIVING ORGANISMS.

FIRE GROWTH PROCESSES

OBJECTIVE: PREDICT FIRE GROWTH PROCESSES INSIDE AND OUTSIDE OF BUILDINGS, FACILITIES, VEHICLES, ETC.

SUPPRESSION & EXTINGUISHMENT

OBJECTIVE: ESTABLISH BASIS FOR TECHNOLOGIES OF SUPPRESSION AND EXTINGUISHMENT INCLUDING CRITERIA, PERFORMANCE DATA AND TEST METHODS.

MITIGATION OF SMOKE AND TOXIC GASES

OBJECTIVE: PREDICT PRODUCTION, PROPERTIES AND SPREAD OF SMOKE AND TOXIC GASES: AND ESTABLISH TECHNICAL BASIS REDUCTION OF IMPACTS.

FACILITY FIRE SAFETY PERFORMANCE

OBJECTIVE: ENGINEERING MODELS TO PREDICT PERFORMANCE OF FACILITIES AND PEOPLE TO POTENTIAL FIRE.

FIRE RISK ASSESSMENT

OBJECTIVE: QUANTITATIVE MEANS TO MEASURE AND MANAGE FIRE RISK TO PEOPLE, PROPERTY OR SYSTEMS.

FIRE PERFORMANCE & VALIDATION

OBJECTIVE: To design and conduct tests to evaluate fire performance of systems, components and structures.

RECENT INVESTIGATIONS:

- °Time-Temperature Characteristics of Basement Recreation Room Fires
- °Quarter-Scale Modeling to Evaluate Interior Finish
- °Evaluation of Materials Used by AMTRAC
- °Use of Oxygen Depletion Calorimetry in Large Scale Experiments
- °Validation of Computer Model to Predict Temperatures and Deflections of Restrained Steel Structures Exposed to Fire
- °Standard Room Fire Test Development
- °Furniture Calorimeter

MATERIALS FIRE PROPERTIES

OBJECTIVE: DEVELOP AND VALIDATE MEASUREMENT METHODS AND DATA NECESSARY TO CHARACTERIZE THE FIRE PERFORMANCE OF MATERIALS, COMPONENTS, OR ASSEMBLIES.

RECENT INVESTIGATIONS:

- °DEVELOPMENT OF FLOORING RADIANT PANEL TEST METHOD, AND ITS APPLICATION TO ATTIC INSULATION
- °EASE OF IGNITION TEST METHOD
- °ISO FLAME SPREAD TEST METHOD
- °CIGARETTE IGNITION TEST FOR UPHOLSTERED FURNITURE AND ATTIC INSULATION
- °TEST METHOD FOR RATING INSTITUTIONAL MATTRESSES
- °SAFETY MEASURES FOR WOOD-BURNING APPLIANCES

ARSON PROGRAM

* 1. Fire Investigators' Handbook

* 2. Sniffer Calibrator

* 3. Sniffer Evaluation and LESL Standard

4. Accelerant Analysis Standard

5. Improved Laboratory Techniques

6. Decision Analysis - Investigation & Prosecution

** 7. Psychology of Arsonists

*Current Programs

**Done

V FIRE PROGRAM FUNDED BY THE DEFENSE NUCLEAR AGENCY

The renewal of fire research support by the Defense Nuclear Agency seems to spring from nuclear targeting applications, primarily. Although high-level Defense Department directives are occasionally given DNA to support the civil defense elements of national security, prospects for continued support of the DNA program can be expected to depend heavily on the perceived extent to which fire effects can impact the methodology of strategic targeting and the choice of triad options.

Intuitively, at least, fire has long been regarded as a major damage-producing result of nuclear attack on urban centers. The history of aerial war supports this view. In the targeting of nuclear warheads, however, planners have been unwilling to count on fire to inflict damage, choosing to regard it as an unreliable "bonus" effect. From time to time, this virtual neglect of a potentially great effect has haunted the scientific advisors of targeting methodology, causing them to raise questions about the state of fire technology. DNA is supportive of this concern; its priority has, however, been low and will remain low in relation to the agency's more traditional concerns about weapon systems and their vulnerabilities until a clear demonstration can be made that fire effects are reliable (i.e., predictable and plannable) as a damage-causing mechanism of first rank.

Several technical uncertainties remain that seriously interfere with any reliable forecast of fire consequences. Clearing up uncertainties about fire initiation and spread will require research investment. The justification for DNA to invest in such research must, however, be continuously reappraised in the light of the best available knowledge. This understanding can be expected to improve with time and investment.

A five-year projection of the DNA Fire program is illustrated in Figure 3. Summaries of the ongoing projects follow.

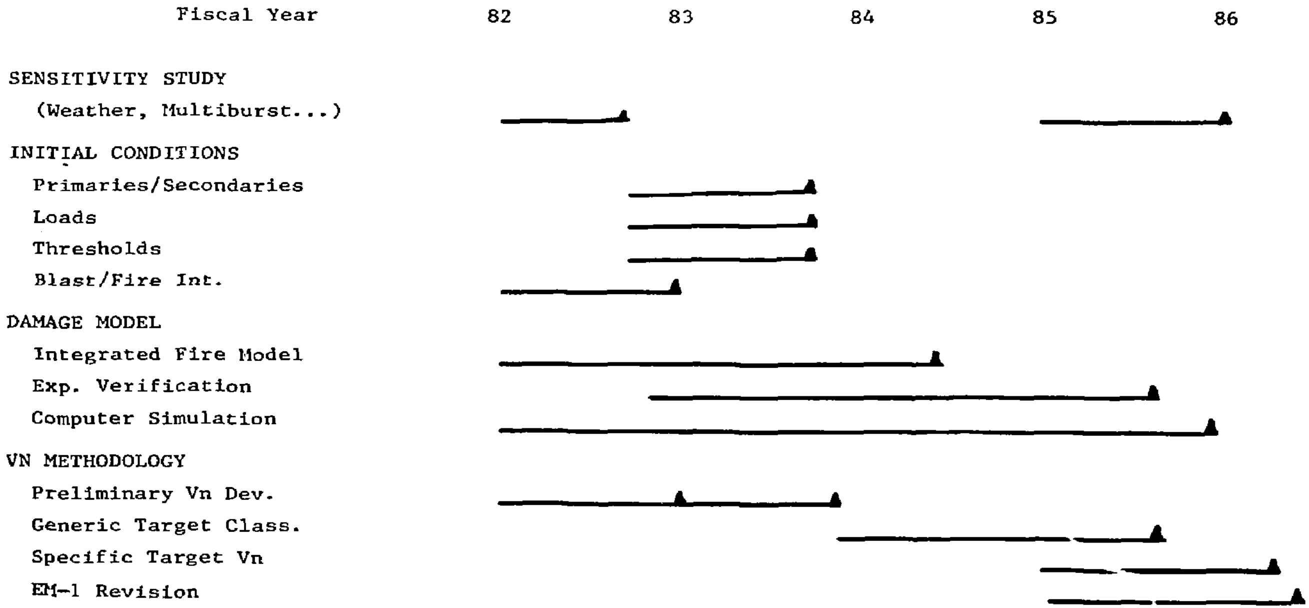


Figure 3 DNA Fire Program

Contract No. DNA001-81-C-0165

Project Title: Review of Historical Fire Data

Objective and Scope: To review and summarize data from past mass fire experiences in order to provide a better understanding of mass fire phenomenology, to provide data for fire prediction and assessment models, and to help understand the possible role of fire damage in strategic targeting.

Contractor: Science Applications, Inc.
1200 Prospect Street
P.O. Box 2351
La Jolla, California 92038
(714) 454-3811

Contractor Personnel: Michael W. McKay
David E. Groce

Status: The contract calls for 1) preparing a list of the key fire parameters for which data is needed; 2) locating the reference documents and determining the availability of the data from historical fire sources; and 3) extracting, summarizing and documenting the data. The first two tasks have been accomplished and the third is in progress. The project is on schedule.

Significant Results: This project has concentrated on obtaining mass fire data from the World War II incendiary bombings in Germany and Japan, the atomic bombings at Hiroshima and Nagasaki, natural disaster fires such as those in Chicago, San Francisco and Texas City, and experimental mass fires such as Flambeau. In the process of obtaining this data, a fairly extensive computerized bibliography has been developed containing more than 1100 fire-related references. A draft version of this bibliography has been submitted to DNA and has been made available to the participants in the DNA Fire Program.

As might be expected, it has been difficult to extract scientifically precise information from what is, for the most part, non-scientific literature. In most cases the observations and descriptions come from people who are not trained fire observers. Much of the information is anecdotal and some is conflicting. Some is unreferenced and its accuracy is somewhat suspect. However, several sources have provided good information. In particular the U.S. Strategic Bombing Survey reports provide a large amount of useful information about the mass fires from World War II incendiary bombings in both Germany and Japan and the fires produced by the atomic bombs at Hiroshima and Nagasaki. From these reports, supplemented by other sources, we have been able to compile data on such key parameters as fuel loading, pre-attack weather, areal extent and density of ignitions, fire spread, fire conditions (such as induced winds, fire plume, etc.) and fire damage. Because we are still in the process of extracting and compiling this data, we are not prepared to present any conclusions at this time. However, some preliminary information is provided in the oral presentation.

Reports: D. E. Groce and M. W. McKay, "Historical Fires Bibliography," Draft Topical Report, SAI-133-82-038-LJ, 16 February 1982.

DNA PROJECT
SUMMARY FORMAT

Contract No. DNA 001-81-C-0118

Project Title: Extinction of Fires by Blast Waves

Objective and Scope: Indentify the important phenomena involved in blast/fire inte · ·ion physics

Contractor: SRI International, 333 Ravenswood Ave., Menlo Park, 94025

Contractor Personnel: Stanley B. Martin, Thomas C. Goodale, Jana Backovsky

Approach: Experimental data will be obtained, using the Blast Wave Simulator at USAG Camp Parks and other facilities, to serve as an empirical basis for the development of theoretical models of the interaction of blast waves with fires.

Status: The initial contracted effort is complete. A continuation effort was started in March of this year.

Significant Results: Means have been devised to observe, separately, the effect on fires of fast-rising air flow velocity and of the pressure jump associated with blast waves. Preliminary results indicate the presence of recirculating flame-holding configurations of the fuel bed to be of major importance to the survival of ''res in fast-rising flows. The principal effect on fires identified to date as due to the pressure jump associated with blast waves is the turbulence induced in the flow by diffraction of the shock front in passing through the fire.

Reports: None

Project Title: Fire Damage Vulnerability and Methodology

Objective: Many factors influence the fires generated by nuclear bursts in urban areas. In an effort to evaluate the relative importance of various fire factors, a simple targeting study was undertaken. The aim of this study is to identify parameters most in need to further refinement and thereby to focus research attention.

Contractors: R & D Associations
P.O. Box 9695
Marina del Rey, CA 90291

and

Pacific-Sierra Research Corp.
1456 Cloverfield Blvd.
Santa Monica, CA 90404
(213) 828-7461

Contractor Personnel: R. Port and H. L. Brode

Approach: This initial targeting study used very approximate fire damage estimators. Variations in the recognized parameters were used to provide a measure of their relative importance. Among the variables included were some having to do with primary (thermal radiation caused) fire initiation and some having to do with secondary (blast caused) fire initiation; others were associated with blast/fire interactions, fire spread, fire-induced winds, multiple bursts, and civil-defense countermeasures.

In the targeting exercise, two yields were considered, 50 Kt and 1 Mt. Burst heights of 700, 500, and 300 feet (scaled to 1 Kt) as well as surface bursts were included, along with visibilities ranging from 1 to 50 miles (a mean of 6 miles was commonly used). The effects of clouds were considered.

Estimates of fire damage were compared with blast effects. The relative importance of primary and secondary fires was evaluated. The additional damage due to fire spread was estimated in gross.

Status: An initial exploration of parameters has been completed. Most major parameters have been identified and their sensitivities roughly quantified. More refined estimates are anticipated from further efforts.

Significant Results: Fire appears to be a dominant damage-causing mechanism in nuclear attack on urban centers for a wide range of scenario variables. Results to date suggest that more accurate accounting of major variables would allow reliability in targeting to optimize fire effects. Such conclusions rest heavily on assumptions about a few remaining technical uncertainties. These include the frequency of secondary fire starts, airblast extinction of primary fire starts, the likelihood of mass fires, and the importance of fire-induced winds as a damage mechanism.

SUMMARY

Contract Number: NDA001-82-C-0046

Title: Urban Fire Dynamics

Objective and Scope: Prediction of the meso-scale wind patterns generated by large-area fires.

Contractor: Pacific-Sierra Research Corporation
1456 Cloverfield Boulevard
Santa Monica, California 90404
(213) 828-7461

Contractor Personnel: H. L. Brode, D. A. Larson, R. D. Small

Approach:

Use an implicit hydrodynamics numerical method to explore the transient nature of the induced winds for a large-area fire.

Status:

Code modification has been completed, and a sample simulation of the winds generated by a fire twenty kilometers in diameter has been made. As a qualitative check on the predictive accuracy of the code, a simulation of the winds generated by the large multiple-fuel-bed *Flambeau* experiment is currently being performed.

Significant Results:

Preliminary results of the twenty-kilometer-fire simulation support the hypothesis that significant wind damage may occur at appreciable distances beyond the fire perimeter as well as in and around the fire itself. A seemingly periodic cycle of strong vortex generation and dissipation is observed to occur near the fire periphery, with a resultant pumping of ambient air into the fire and the induction of hurricane-force surface winds. During some phases of the cycle (15-20 min), these winds extend out to regions well away from the fire, and structural damage due to the high velocity winds must be expected. Additionally, during one phase of the cycle, portions of the high-velocity winds are directed away from the fire. Outward fire spread -- via heat transport and/or branding -- and hence direct fire damage may also then occur in regions outside the basic fire zone.

DNA PROJECT SUMMARY

for

1982 Conference on Fire and Related Effects

Sponsored by Federal Emergency Management Agency

Asilomar Conference Grounds, Pacific Grove, CA

25-29 April 1982

Contract No.: DNA 001-82-C-0071

Project Title: Urban Fire Damage Simulation Development

Objective and Scope:

1. Define the events and modules to be used in the Urban Fire Demonstration Model along with appropriate data elements, control and data interfaces and grid systems. Demonstrate the simulation from weapon detonation to burnout. As far as possible, the simulation is to be built in machine independent format to facilitate ultimate conversion to the DNA computer system.

2. Develop methods for calculating urban wind fields and analyze significance of wind/fire interaction for fire-spread modeling. Incorporate results in Urban Fire Demonstration Model.

3. Define parametric variables for the set of Demonstration Urban Fire Model runs to be executed. Execute runs.

Contractor: Mission Research Corporation
P.O. Drawer 719
Santa Barbara, CA 93102
(805) 963-8761

Subcontract: Los Padres Research Corporation
(805) 736-1920

Contractor Personnel: J. A. Ball/L. E. Ewing (MRC)
J. C. Sanderlin (LPR)

Approach:

Previous work has defined a concept for simulation of the development of urban mass fires. The important features of the concept are: (1) a specific control structure to sequence and organize the various computational elements of an interactive simulation, and (2) emphasis upon atmospheric motion, both as ambient conditions and in response to the fire itself, as the most important mechanism of fire-spread, either through branding or convective ignition. A demonstration model was constructed and run to illustrate the concept.

Ongoing work will: (1) adapt the simulation control structure to the entire event sequence from detonation to burnout, (2) develop computational methods of determining the effect of wind on fire-spread as well as the wind environment produced by mass fire, and (3) determine the sensitivity of fire-development to the underlying parameters of the simulation.

Status and Results:

Progress to date in the current project has consisted primarily in the examination and verification of the feasibility of the approaches to firespread and wind modeling. Model structure development and examination of parametric sensitivity has just begun.

Reports: J. C. Sanderlin, J. A. Ball, and G. A. Johanson, "Mass Fire Model Concept," Final Report, DNA Contract No. DNA 001-80-0351, Mission Research Corporation, Santa Barbara, CA, May 1981.

Contract No.: DNA001-81-C-0111

Project Title: Firestorms

Objective and Scope: To elucidate quantitatively, in order of priority, (1) prequisites for the onset of a firestorm, (2) the time scale for the onset, and (3) the properties of a firestorm; a firestorm is identified as a very severe mesoscale incendiary event, persisting for about 6-9 hours or so, characterized by radial influx (at ground level) from all directions of air flowing at 25-50 m/s, by a convective column rising 10-13 km into the troposphere, and by a thoroughly burned over area of about 12 km^2 or more. Particular attention is to be paid to corroboration of theory with observation of the 27-28 July 1943 event at Hamburg, Germany, probably the most extensively documented firestorm on record.

Contractor: Engineering Sciences Laboratory
TRW Space and Technology Group
One Space Park
Redondo Beach, CA 90278
(213) 536-2438

Contractor Personnel: George Carrier
Francis Fendell
Phillip Feldman

Approach: Approximate-analytic and simple-numeric treatment of boundary/initial-value problems.

Status: First stage completed and final report issued.

Significant Results: Review [of the firestorm events associated with World War II bombings at Hamburg, Dresden, and Hiroshima (with Kassel, Darmstadt, Leipzig, Brunswick, etc., being sometimes cited as additional sites of firestorms); of exceptional behavior observed during two Meteotron experiments in the central French Pyrenees Mountains; and of the Tokyo Military Clothing Depot incident after the earthquake of 1 September 1923] suggests that a firestorm is a mesocyclone engendered by massive release of combustion heat in a dry, unstable atmosphere, not involving too strong a cross-wind. An intense cyclonic mesolow is engendered on the scale of two-to-three hours, reaches peak strength in about six hours, and decays on the scale of nine-to-twelve hours. Briefly, convectively induced advection results in a spin-up through the depth of much of the troposphere, such that entrainment of cooler air into the sustained central convective column is reduced and hence buoyant ascent of smoke and ash persists to exceptional height before the altitude of neutral stability is attained. Although there is a preponderantly swirling character to the airflow in and surrounding the buoyant plume throughout most of the troposphere, in the near-ground "boundary layer" (only) there is high-speed radial influx toward the center of the vortex. The strong inflow from all directions near ground level is a known property of intense atmosphere vortices: while a radial pressure gradient is counterbalanced by a centrifugal acceleration at most heights, near the ground the centrifugal force is modified by the no-slip boundary condition. Owing to the positive (accelerating) pressure gradient, the role of friction becomes confined to a very thin sublayer (of the surface inflow layer), a sublayer located immediately contiguous to the ground; hence, in the absence of friction, exceptionally large influx arises near ground level under the high-speed portion of the vortex.

The firestorm is of particular significance in the context of incendiary effects from thermonuclear events in an urban environment. Whereas modest winds may precede the event, the high-speed low-level radial inflow spawned by the event itself leads to devastating wind-aided flame spread, such that a sea of fire can consume totally tens of square kilometers. Comparable fire devastation is usually associated with the spread of flame by a pre-existing wind. In contrast to such a propagating fire (e.g., the Tokyo fire of March 1945), recorded firestorms have not spread outside the region of initial ignitions. However, tall swirling columns engender long-range firebrands in other fire contexts, so exception to the confined character of recorded firestorms seems quite possible.

Quantitative analysis initiated in this investigation has entailed generalization of the Morton-Taylor-Turner integral theory for buoyant convection over a maintained source to encompass conservation of angular momentum, thermodynamic stratification of the ambient atmosphere, radial variation of the pressure field, and time evolution of spin-up. A simplistic characterization of atmospheric stability, incorporation of the rate of release of chemical exothermicity (as implied by fuel loading and areal extent, and by fuel exothermicity), and accounting for ambient atmospheric circulation permit parameterization of a particular setting without requiring unavailable details. Further desirable analytic development are (1) an improved nonlinear treatment of the conservation of angular momentum in the spatial domain outside the convective plume, since the present treatment is linear and inadequate; and (2) explicit inclusion of the mass and momentum efflux from the surface inflow layer to the vertical central plume, to complement the heat source for which provision is already made. Without incorporation of such nonlinear effects, the present theory does not describe the full intensity to which the firestorm can evolve.

A further desirable experimental activity is identified to be quantitative measurement in a large laboratory firewhirl apparatus of the reduction of turbulent entrainment (into a buoyant plume) of air surrounding a rising convective column, as a function of the swirling speed (or angular momentum) of that surrounding air.

<u>Reports</u>: G. F. Carrier, F. E. Fendell, and P. S. Feldman: Firestorms. TRW Document 38163-6001-UT-00, April 1982. Redondo Beach, CA: TRW Space and Technology Group.

VI DISCUSSION GROUP SUMMARIES

The discussion group summaries provided at the conclusion of the conference by discussion group leaders are reproduced here without substantial modification. Because of the limited time available to this group activity, summaries representing a consensus did not always result, and more than one written contribution was supplied. Wherever such "minority reports" of factional opinions were provided to the Editors, we have included them, and they are so labeled.

Discussion Group 1

BLAST/FIRE INTERACTIONS: RELEVANCE OF EXISTING AND PROPOSED RESEARCH TO FEMA GOALS

This discussion group included (but was not necessarily limited to) Tom Goodale, Tom Reitter, Jerry Carpenter, Jana Backovsky, Murty Kanury, Frank Fendell, Craig Chandler, and Sang-Wook Kang. The discussion leader was Tom Reitter of LLNL.

The initial discussions centered on the list of priorities Mr. Reitter had presented at the beginning of the Conference. Subsequent discussions concerned the question of blowout of fires by airblast and the recent research efforts directed thereto.

Priorities in Blast/Fire Research

Two basic research philosophies were expressed in the discussion group. One emphasized the understanding of the environment and consequent risk to lives and resources in an urban area subjected to nuclear attack. The other stresses work on mitigation in general and hardening of key resources in particular.

There was general agreement that the two paths must be pursued in parallel. There was some disagreement about what level of understanding of the trans- and post-attack environment is necessary for civil defense purposes. There was agreement that the end result--improvement of civil defense--should be kept constantly in mind to avoid too much emphasis on less important, albeit technically interesting areas. Support for investigation of conceptually simple and inexpensive mitigation measures was expressed. In the longer term, it was suggested that the policy makers should be provided a choice of mitigation measures and their expected effectiveness.

As an exercise, the group went over the items identified in the presentation of T. Reitter (LLNL). Those of particular interest were discussed, and a few others were added. The participants were asked to rank them from 1 (lowest to 5 (highest) priority. The results were averaged and categorized as follows:

2.25 < A	Low
2.25 ≤ A < 3.00	Low-Medium
3.00 ≤ A < 3.75	Medium-High
A ≤ 3.75	High

There were 11 participants in the exercise. Some did not respond to all items; however, any item receiving fewer than eight responses was discarded. The items ranked High were (in no particular order):

- Qualitative definition of thermal and blast environment due to multiple bursts, with emphasis on identification of differences from single-blast environment.
- Radiative ignition data for nonideal surfaces and newer materials.
- Radiative ignition data for geometrically complex and mixed fuel arrangements. ("Mixed fuel" means a mixture of thick and thin fuels, or composite materials.)
- Enclosure effects ("ENCORE effect") on flashover.
- Blast effects on incipient fires.
- Fire spread rates across various types of debris fields.
- Understanding of debris formation phenomena.
- Empirical modeling of debris production as a function of blast loading for various types of buildings.
- Ultimate debris distribution from various types of buildings as a function of blast loading.
- Conditions for the existence of firestorms and conflagrations.

Although it was not on the list for ranking, the discussion suggested that another highly ranked item might be a survey of simple and relatively inexpensive mitigation measures.

The items ranked in the Medium-High category were:

- Development of methodologies for nondeterministic representation of weather, target areas, etc.
- Blast-wave room filling, especially multiple room and complex geometry.

- Modeling of dynamic response and collapse of individual structural elements and of buildings formed from these elements.
- Experimental data for collapse of various structural elements.
- Effects of multiple bursts on dynamic response of structures.
- Blast effects on established fires.
- Effects of light-to-moderate blast damage on burn characteristics of various types of buildings.
- Fire spread from one structure to others, including effects of wind, humidity, and precipitation.
- Firebrand production, transport, and ignition threat.
- Effects of wind, humidity, and precipitation on rates of fire spread across various types of debris fields.
- Physical conditions within a firestorm.
- Physical conditions within and near a mass fire conflagration.

It is recognized that the sample size was small and that the assignment of priorities is basically subjective, especially when done quickly and in the absence of funding considerations. It does appear to have value as a means of focusing attention and stimulating discussion.

<u>Blast/Fire Interaction</u>

Due to the very limited amount of time available, and the complexity of the subject, it was not possible to reach agreement on the status or importance of the collection of questions referred to as "blast/fire interaction." After the Conference, brief statements were invited from Professor Murty Kanury and Dr. Frank Fendell. These are given below,* following a list of points made in the discussion group.

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*After reading these contributions by Kanury and Fendell, representing the views of investigators engaged in the more theoretical/analytical aspects of the study, the editors took the liberty of inviting an analogous contribution from the investigators engaged in the experimentation. This view is also included.

Comments from the discussion group:

- It is important to bear in mind the distinction between extinguishment of flame and the extinction of fire.
- Mention of the work performed by T. Goodale and others in the late 1960's at Ft. Cronkhite evoked interest as being particularly relevant for civil defense purposes. Propane-ignited contents of various types of room occupancies were subjected to blast waves of 1-5 psi overpressure. An overpressure of 2.5 psi was found sufficient to extinguish all flames. However, smoldering materials generally reignited after about 20 minutes. (Ref.: T. Goodale, Effects of Air Blast on Urban Fires, AD-723429, Dec. 1970).
- It was suggested that pressure effects should be investigated by closing off the end of a shock tube and placing burning targets as close as possible to the end. The suggestion was also made that pressure effects on porous materials may be different for other types of materials, based on the Ft. Cronkhite results.
- It was suggested that Ft. Cronkhite experiments would be repeated, but at lower overpressures to find the minimum required for extinction. Also, a study of scorching, such as would result from short exposures of smoldering materials, was suggested.
- It was suggested that simple calculations be done to see whether the approximate temperature in a room after the incipient burn and blastwave filling is high enough for ignition.

(It should perhaps be noted that no mention of possible effects of multiple bursts on the blast/fire interaction problem was made during the discussion.)

Statement by A. M. Kanury (Notre Dame)

Mechanistic (or Correlative) Models of Blast/Fire Interaction

All that is known of the nature of a nuclear detonation leads one to conclude that fire is an issue of major concern in any viable civil defense strategy. The primary fires are those initiated by exposure of combustibles to the intense thermal radiation pulse of the fireball. Most of the combustibles fall into either Class A (solids) or Class B (liquid fuel) categories. Both are important to civil defense concerns, and any theoretical development should give attention to both. No theory should ignore the role of the noncharring thermoplastics that are so common in urban use today.

Likewise, the important interactions are many, and should not be represented in the theory as a single response--such as flame displacement. Depending upon the nature and size of the fuel bed, strength of the blast wave, time of blast arrival, and other factors, (1) the fire may be blown out by the blast; (2) the blown-out fire may reflash as soon as the blast winds subside; or (3) the glowing firebrands from the fuel bed may get scattered around to serve as ignition sources for secondary fires.

The current knowledge of how the blast interferes with fire is mainly empirical. Simulation tests employing shock tubes have been conducted at SRI and elsewhere over the past decade and a half. High explosive field test set-ups have not always been successful due to spurious artifacts and experimental difficulties. Because of the inherent cost constraints, parametric limitations, and controllability of secondary variables, the number of good simulations and field tests will be limited. The empirical base alone, therefore, cannot be expected to yield a complete and reliable understanding of the blast/fire interaction.

In order to optimize the information, the limited experimental data and observations have to be analyzed and interpreted on the basis of generalized concepts. These concepts may be developed by theoretical work at two distinct levels of detail: (i) correlative and (ii) predictive. In the correlative models, a concept mechanism is postulated and the directions of expected trends estimated. The variables of the experiments are regrouped into nondimensional ratios of definite meaning embodying the mechanism. These ratios and the expected trends then serve to correlate the experimental data in a unified framework. The outcome is twofold: on the one hand, the correlations substantiate the inherent consistencies underlying different experimental observations and data; on the other hand, these correlations would also point out the most crucial ranges of the experimental variables to be tested.

Consider extinction as an occurrence in which the combustion chemical kinetics fail to keep pace with the physical processes (of heat loss, reactant supply,...) which are generally enhanced by the blast through its attendant winds, adiabatic heating, and pressure histories. A simple description of this thermochemical state through the principles of conservation of mass, momentum, energy, and species leads to a mechanism which is reasonably successful in correlating liquid-fuel pool-fire data involving fuels ranging from methanol to n-hexane, pool lengths ranging from 1 ft to 3 ft and blast overpressures ranging from about 1 psi to 11 psi.

Recent SRI observations suggest the definition of extinction in Class B fuels is a permanent displacement of the flame from the fuel bed. As the flame is displaced, the fuel bed cools down, fuel vapor production ceases, and the combustion chemical kinetics slow down to result in the extinction. It thus appears that no matter whether extinction is defined as (a) disappearance of flame; or as (b) failure of the flame to rekindle, the correlative mechanism is valid.

It appears feasible to extend the same mechanism to correlate the blowing away of flames supported by wood-like solid fuels, but glowing combustion should be included in any theory of extinguishment of charring solids. Heat storage in the char layer is at least an order of magnitude too small to supply the heat requirements of pyrolysis.

In conclusion, this problem, though complex, is important and should receive appropriate support. First-principle theories, not regularly checked against the realities of the physical problem, are far less likely to deliver their promises than empirically guided but mechanistically based correlative models. Since we cannot expect to get enough data to cover all situations, a general, mechanistically based correlation of the existing data is all the more important. As the program progresses, we have to keep checking to ensure that the research is physically realistic and relevant, and that the level of detail in the work is consistent with the practical application.

Statement by F. Fendell (TRW)

Status of Understanding of Blast/Fire Interactions

"Blast/fire interaction" in contemporary civil-defense research concerns the consequences of blasted-gas arrival at the site of a primary (i.e., radiation-precursor-initiated) fire in the region of one- to two-psi peak overpressure. For a megaton-TNT-equivalent-yield thermonuclear weapon there is likely to be (very crudely) about a 10-second interval prior to blast arrival during which radiatively ignited solid fuels may be brought to pyrolysis condition, such that the exothermic gas-phase combustion of fuel vapor with atmospheric oxygen furnishes the heat for further pyrolytic degradation. Attention here is limited to char-forming solid fuels; virtually all synthetic polymers (plastics) and natural polymers (woods) form a porous carbonaceous matrix (char layer) that envelops the pristine core material. The significance of the char is as a means of significant heat storage by the object. (Liquid fuels that gasify by vaporization, and those very exceptional solid fuels that gasify by sublimation, are ignored here as of no practical interest to civil-defense-sponsored research, since liquid fuels are not used in urban construction and/or furnishings.)

Since the blasted gas may be flowing up to around 70 mph at the 2-psi-peak-overpressure site, and since the positive phase (interval of finite overpressure) may last (very roughly) 6 seconds, fire may well be blown off the body such that a temporary extinction occurs. In aerothermochemical parlance, there is forced-convective extinction of diffusion-flame burning because flow rates exceed reaction rates (the first Damkoehler number is reduced below the critical value pertinent for extinction). However, despite radiative and convective cooling subsequent to flame blow-off, the char layer retains heat such that pyrolysis continues for a finite interval; furthermore, exothermic heterogeneous oxidation of the char may furnish further heat. Thus, at the end of the positive phase, there may have persisted outgassing of combustible vapor, in sufficient quantity and at sufficient temperature, for (spontaneous) autoreignition to occur. The depth of the char, its heat storage, the duration and intensity of the enhanced flow past the object, the exothermicity of the surface burning, the radiative exchange with surrounding objects, etc., all influence whether reignition of homogeneous burning can occur in this multiparametric phenomenon.

Incidentally, after flame blow-off, the surface of a pool of liquid fuel is immediately convectively cooled below its vaporization temperature, so such autoreignition is usually impossible. An exception occurs when the duration of overpressure is held to milliseconds (implausibly brief, for practical interest), such that the vapor pressure maintains a non-negligible supply of fuel vapor over the pool for the brief interval of extinction involved. Indeed, the rather peripherally related subjects of wake-stabilized flames, blast-wave-splintered objects, and of reignition by "flashover" are not being discussed. However, it is the enhanced speed (as opposed to the enhanced pressure and altered oxygen content) of the blasted gas that is primarily pertinent to blast-fire interaction.

Significance of the Problem and Recommendations for Further Research

First, blast/fire interaction is a relatively well-defined, tractable civil-defense-related fire problem. If the research community feels the need to recommend substantial continued work on this problem into 1983, after having devoted significant effort since 1978 (see FEMA Research Summaries of Mitigation & Research, FY 1979, p. 20), then the prognosis for the contribution contemporary fire science and technology can make to the civil-defense needs of FEMA is not favorable. The blast/fire interaction problem should have been solved for FEMA needs with the time span and resources already allotted. Also, solution seems tractable enough that there ought to be no need to distinguish between correlative and mechanistic approaches; a competent mechanistic approach should correlate experimental results adequately.

Second, it seems self-evident that the incendiary consequences of a thermonuclear event may be modestly mitigated, but will not be eliminated, by fire/blast interaction (are not the events at Hiroshima and Nagasaki suggestive?). Some primary and all secondary fires will persist, not to mention incendiary consequences of multiburst scenarios. A plethora of other technical problems and a very limited availability of resources combine to urge that new subjects become the focus of FEMA-sponsored fire research.

Third, if any further research is devoted to blast/fire interaction, what seems needed immediately is many experimental data points, with redundancy, owing to the multiparametric nature of the problem. Neither shock tunnels nor periodic large TNT events have been able, or are likely to be able, to furnish the requisite large amount of data. A low-speed wind tunnel, equipped with a moveable object support and designed for high-enthalpy conditions, should suffice to furnish the data needed. Then, and only then, the matter of corroboration via a few large-scale tests ought to be considered. If the laboratory experimental data corroborates the discussion of physics given in Section A, the main motivation for field tests would seem to be (radiative) interaction between objects too large for wind-tunnel testing.

Statement of The Experimentalists' View*

Displacement of flames is a mechanism of extinguishment of flaming combustion; it is a necessary step but does not always result in a condition sufficient to ensure permanent extinction. In experiments with Class B fuels, we observe reinitiation by flashback of flames that have been blown downstream and separated from the liquid fuel by distances several times the length of the fuel bed. This reinstatement is apparently enhanced by turbulence and/or recirculation in the air/vapor stream. In Class A fuels (those that pyrolyze to a char capable of interface combustion), flames may rekindle when glowing combustion is intensified by air flow, showing an enhanced tendency to relight with higher velocity air blasts. In either case, the displacement of flame from the fuel bed may be an almost trivial consequence of the interaction of the air blast with the fire and its fuel source, the ultimate outcome being determined mostly

*Contribution from the SRI Fire Research Program.

by whether the flame can reestablish itself. This suggests that the Damkoehler-number correlations of experimental data may turn out to be unsuccessful in any generally useful way. Moreover, it argues that, since the mechanism of flame reestablishment in Class A fuels is apt to be totally unlike that for Class B fuels, no single parameter group can be expected to apply universally.

We believe it would be unwise to ignore the Class B fuels in the belief that only solids are of civil defense interest. Although the furnishings of urban interiors are commonly solids composed of char-forming polymerics, many of the fires resulting from nuclear attack (especially those of secondary origins in industrial occupancies) are likely to be fueled by fluids (hydrocarbons and other organic liquids, vapors, and gases). Their threat to critical resources may be far greater than fire in Class A fuels, while the reverse may be true as a threat to survival of the unrelocated, unprotected civilian population.

Because of its complexity, this multiparametric, dichotomous, but practically important problem cannot be "laid to rest" in two or three years of study at the modest level of funding it has received to date. In truth, we have been able thus far only to explore the nature of the problem--enough to know that it is not just a disguised version of the steady-flow blowout situation already addressed by Spalding and others, but not yet enough to have confidently discovered what other parametric groups will apply, or to know whether we can simplify our experimental simulation without losing essential ingredients from the physics of the process.

The specialized experimental facilities and approaches thus far developed to deal with this unique problem are proving their worth. Any reservations we may have about accelerated application of these developments toward an early resolution of the blowout problem, as it is currently perceived, derives from the long-standing, unresolved question of the importance of the urban enclosure itself in the fire initiation process, as raised by the ENCORE experiment of the days of atmospheric nuclear testing. Until the ENCORE response can be finally categorized as either anomalous or the expected norm, the practical context of the blowout problem remains somewhat obscure.

Report of Discussion Group 2

Importance and Status of Secondary-Fire Assay

(30 April 1982)

Introduction

The main themes developed during the discussion of the importance of secondary fires and the present status of the understanding of them included: the inadequacy of currently available data relevant to secondary fires, the availability of techniques to prevent the occurrence or mitigate the effects of secondary fires, and some possible approaches to obtaining a better understanding of the potential for secondary fires resulting from nuclear attack. The chairman of this discussion group was I. Oppenheim. Participants in the discussion were: Y. Aoki, H. Brode, S. W. Kang, and C. Wilton.

Importance of Secondary Fires

Secondary fires are significant because they have the potential for extending the fire effects zone significantly beyond the radius of primary ignitions, all the way out to low overpressures (0.5 psi) where ignitions may be caused even though there may be little structural blast damage.

Secondary fires can be caused by numerous influences including:

(1) Gross structural damage, at moderate-to-high psi levels, in ways comparable to earthquake effects.

(2) Generation of interior debris at low-to-moderate psi levels, not accompanied by gross structural damage.

(3) Numerous special (surprise) effects, including:

(a) Arcing from conductors because of voltages induced by the extraordinary electromagnetic field.

(b) The electro-static discharge in the uncommonly violent debris production process.

(c) Explosions in dust clouds released in older facilities.

(d) Automobiles "rolled" at moderate (5 psi) levels of blast.

Conclusions and Recommendations

A series of pertinent observations follows:

(1) One portion of the secondary ignitions will be analogous to earthquake effects, and such existing data sets are appropriate. (See SSI Report, 1981, and original papers of Mizuno and Horiuchi.) Further treatment of earthquake data is at present underway by Aoki et al., and will provide some more guidance on ignition frequency by occupancy.

(2) Presence of utility (natural gas and electricity) sources will increase ignition frequency.

(3) Industrial processes can be protected against ignition if shut down and cleaned up; if unprepared, ignition probability approaches one.

(4) Hazardous materials and the "surprise" effects may contribute substantial ignitions.

(5) There will be a zone around GZ in which ignition frequency is so high (i.e., >0.1) that full loss should be assumed in that zone. Rather than measure ignition frequency proper, it may be more reasonable to estimate instead the radius (or psi level) at which the frequency falls below some threshold (0.001 perhaps?).

(6) Much can be gained by performing an "expert inventory" of ignition mechanisms for typical facilities of interest. The inventory could be performed by a two-man team consisting of a fire-cause expert responding to debris scenarios pointed out (on the site) by a blast specialist.

(7) It is important to identify these mechanisms, and establish a data base as to their prevalence, and for data about their normal occurrence, if that latter is available.

(8) Once identified, the ignition mechanisms may be more easy to control than to quantify.

(9) When plausible and populous mechanisms are identified, laboratory tests may be recommended to study them.

(10) At present the ranking scheme proposed by SSI (1981) is useful, and leads to an estimate of one portion of the secondary ignition effect.

References

1. Wilton, C., D.J. Myronuk, and J.V. Zaccor, **Secondary Fire Analysis,** SSI Report No. 8048-6, Scientific Service Inc., Redwood City, CA, September 1981.

2. McAuliffe, John, and Kendall Moll, **Secondary Ignitions in Nuclear Attack,** Stanford Research Institute, Menlo Park, CA, July 1965.

3. Karter, Michael J., "Fire Loss in the United States During 1979", **Fire Journal,** National Fire Protection Association, Boston, MA, September 1980.

4. **Fire in the United States,** National Fire Data Center, U.S. Fire Administration, U.S. Department of Commerce, Washington, D.C., December 1978.

Report of Discussion Group 3

MILL RACE Results/DIRECT COURSE Plans

Introduction

The discussion topics suggested in the conference agenda for the discussion group on MILL RACE Results/DIRECT COURSE Plans were as follows:

- B/F extinction experiments
- Structures and debris
- Future opportunities
- Requirements for DIRECT COURSE

We began our discussion with the structures experiments, as requested by the conference coordinator, and deferred discussion of blast/fire field testing. Initially, we discussed the MILL RACE results from the standpoint both of accomplishments and of areas where furtl :r work is needed. Then we considered the DIRECT COURSE experiments as described in the Proposed Experiment writeups provided by Waterways Experiment Station.

MILL RACE Experiments

The various FEMA MILL RACE experiments were discussed, except for the blast/fire experiment. Significant comments and conclusions were as follows:

Key Worker Shelter - The behavior of the floors was as predicted within about 4-5 psi. The resistance of the concrete floors to punching shear from the telephone poles used as shoring was better than predicted. Better closure designs than the type used in the MILL RACE shelters need to be tested in future field tests. The understanding of the soil/structure interaction as it related to the survival of the unreinforced walls is inadequate. Further field tests with a variety of well characterized soils and backfill conditions are needed.

The practical problems of safely installing post and beam shoring were severe and this type should be avoided where possible. Also, lateral bracing of shoring is advisable for safety. Furthermore, use of buildings with hollow concrete plank floors for upgrading for key worker shelters should be avoided, if other types are available.

Host Area Shelter - The floor predictions for the basement shelter were good. However, the floor joists in the unshored basement portion of the structure failed prior to the blast test from the weight of soil added for fallout protection. This shows the need for shoring of this type of structure, just to prevent failure from this dead weight.

The MILL RACE host area shelters also demonstrated that we need more knowledge on soil/structure interaction as well as more adequate closures. For the aboveground buildings, the walls appear to have been shored more extensively than was necessary to assure their survival.

Industrial Hardening - The utility vaults included in the industrial hardening experiment as improvised key worker shelters made good shelters and were put in place rapidly at MILL RACE. The only problem was that 24-inch diameter entrances used were too small, but the 28-inch entrance used previously when this type of shelter was tried out at San Jose is satisfactory.

The clustering, banding and anchoring of pieces of industrial equipment to protect them was shown to be effective. This sort of protective measure is appropriate for the many situations when other demonstrated industrial equipment hardening techniques such as burial in earth are not feasible.

Expedient Key Worker Shelter - As designed for MILL RACE, this dimensioned lumber version of the previously tested pole shelter used an excessive amount of lumber and man-hours and was not a practical alternative.

Debris Distribution - This experiment provided verification and improved understanding of collapse and debris translation models. The air blast measurements provided new insight into exterior and interior loading at high pressures. Interactions of the ceiling slab and walls, and of the walls with each other, were demonstrated. Effects of these interactions on the resulting debris distribution were also shown. However, quantitative understanding of this experiment requires further data analysis. The analysis of this experiment and other MILL RACE experiments has been impeded by the lack of the high-speed motion picture coverage that was supposed to have been provided.

Blast Fire Interactions - Not discussed.

Other Comments - We recommend that FEMA and WES consider including sheep or other large animals in the DIRECT COURSE shelter experiments. Among other things, dust inhalation by these animals could be studied. Dust inhalation by shelter occupants may be a significant casualty mechanism.

We also noted that there are no host area shelter experiments included in the currently approved FEMA-sponsored DIRECT COURSE tests. We believe that shelter upgrading for abovegrade shelters in host areas still needs to be improved and verified in tests such as DIRECT COURSE.

We also think that shelter ventilation components should be included in both of the key worker shelter experiments. If this is done, perhaps combustible material simulating building debris can be burned near and upwind of the shelters at some time following the blast test to provide a fairly realistic test of shelter ventilation considerations in a fire situation.

Footnote: The members of Group 3 were:

Pete Peterson
Don Bettge
Stan Woodson
John Rempel
Gabe Gabrielsen
Jim Zaccor
H. L. Murphy

DIRECT COURSE Experiments

A summary listing of the experiments proposed for DIRECT COURSE is given in Table 1. Present planning is for Waterways Experiment Station to field the approved experiments, with assistance from other organizations. The Proposed Experiment descriptions for the five approved experiments are included as Attachments 1 through 5. The discussion group recommendations and comments on these experiments and on other aspects of DIRECT COURSE are as follows:

Development of Design Criteria for Basic Shelter - The members of the discussion group agreed with the scope and objectives of this experiment. The need to improve the capability to scale DIRECT COURSE results to the planned 10 kT DNA test and to MT yields was noted. Preliminary shock tunnel testing of scaled models of portions of this experiment, well prior to DIRECT COURSE, was recommended.

Test and Evaluation of 50-psi Key Worker Shelter - We basically also agreed with this experiment. However, we believe that a variety of dissimilar designs, including modular as well as cast-in-place concrete, should be fielded.

Blast/Fire Interaction - Apparently the 30 psi requirement is to be deleted and an environment of 1.5 to 2 psi added. Otherwise, we had no comment.

Industrial Hardening - We noted that the three free-field pressure gauges may not be required as part of this experiment, depending on what other measurements are to be made nearby that could be used to determine the environment. It was also suggested that testing of drag and overturning characteristics of various types and configurations of industrial equipment should be accomplished in the shock tunnel prior to DIRECT COURSE.

Debris Distribution as a Function of Collapse Mode - We recommend that the possibility of partially combining the frame response portion of the Basic Shelter experiment with the Debris Distribution experiment be considered. Also, we would like to see concrete blocks and bricks used as well as cubes and spheres in the part of the experiment dealing with verifying computer code predictions for the translation of heavy objects. It was suggested that extensive wall debris measurements, including high speed motion picture coverage, are available from previous tests in the Fort Cronkhite shock tunnel. Analysis of these data could result in more accurate debris distribution modeling and thus could be used to advantage in designing the DIRECT COURSE Debris Distribution experiment.

Table 1

DIRECT COURSE EXPERIMENTS

Priority	Title
1	Development of Design Criteria for Basic Shelter
2	Test and Evaluation of 50-psi Risk Area Personnel Shelter
3	Blast/Fire Interaction
4	Industrial Hardening
5	Debris Distribution as a Function of Collapse Mode

Attachment 1

DIRECT COURSE
Proposed Experiment

Title: Development of Design Criteria for Basic Shelter

Project Officer: Mr. Donald Bettge, Federal Emergency Management Agency, 500 C Street, S.W., Room 634, Washington, D. C. 20472
Telephone No. (202) 287-0026

Mr. William L. Huff, USAE Waterways Experiment Station, P. O. Box 631, Vicksburg, MS 39180
Telephone No. (601) 634-2755

Funded by: Federal Emergency Management Agency (proposed funding for FY 83)

Experiment Objective: The general objective of this experiment is to gather data for the development of design criteria for key worker shelters located in existing buildings. The specific objectives are: (a) to obtain experimental data to evaluate an analytical model for predicting the response of basement walls to airblast-induced soil loadings, (b) to determine the effect of aboveground structural collapse on the integrity of a basement shelter, and (c) to evaluate closure designs.

Experiment Description: All details of the experiments have not been finalized at this time. Presently three structures are proposed for studying soil-structure interaction on basement walls. A single structure for evaluation of closure designs; and depending on funding, one or two multistory models to study the interaction of the collapsing aboveground structure and basement shelter. All models will be instrumented to define the shelter environment and people survivability.

Instrumentation Requirements: Data recording will be provided by the experimenter.

Type of instrumentation:

20 displacement
15 soil stress
15 soil motion
3 free-field overpressure
3 total head gages
10 accelerometers

Photographic requirements:

internal high-speed movie cameras
external high-speed movie cameras

Special/Unusual Requirements: None.

Environment Required: 25, 40, and 100 psi.

TRS Required: None.

Attachment 2

DIRECT COURSE
Proposed Experiment

Title: Test and Evaluation of 50-psi Risk Area Personnel Shelter

Project Officer: Mr. Donald Bettge, Federal Emergency Management Agency,
500 C Street, S.W., Room 634, Washignton, D.C. 20472
Telephone No. (202) 287-0026

Mr. William L. Huff, USAE Waterways Experiment Station.
P.O. Box 631, Vicksburg, MS 39180
Telephone No. (601) 634-2755

Funded by: Federal Emergency Management Agency (proposed funding for FY 83)

Experiment Objectives: The objective of this experiment is to evaluate designs for a 50-psi risk area personnel shelter system. In addition to evaluating structural components of the main shelter, closure and entranceway details will be evaluated, data will be collected on the shelter environment for development of people survivability functions, and the use of soil arching to produce the most economical shelter design will be investigated.

Experiment Description: It is anticipated that an area approximately 200 ft by 200 ft at the 50 psi ground range would contain five or six shelter designs to be evaluated. In addition, a small area would be required at the 100 psi ground range to obtain collapse data on one of the shelter systems.

Instrumentation Requirements: Data recording will be provided by the experimenter.

Type of recorded instrumentation:

6 free-field pressure
8 accelerometers
10 deflection gages
15 soil stress

Photography requirements:

6 interior high-speed movie cameras

Special/Unusual Requirements: None.

Environment Required: 50 and 100 psi.

TRS Requirement: None.

Attachment 3

DIRECT COURSE
Proposed Experiment

Title: Blast/Fire Interaction

Project Officer: Mr. Donald Bettge, Federal Emergency Management Agency, 500 C Street, S.W., Room 634, Washington, D. C. 20472
Telephone No. (202) 287-0026

Mr. William L. Huff, USAE Waterways Experiment Station, P. O. Box 631, Vicksburg, MS 39180
Telephone No. (601) 634-2755

Funded by: Federal Emergency Management Agency (proposed funding for FY 83)

Experiment Objective: To provide data on the effects of airblast on fires which are inside structures in various stages between ignition and flashover and to gather data on the extinction threshold for open debris fires.

Experiment Description: Scaled models of rooms in various stages of fire growth between ignition and flashover will be located at several overpressure levels to bracket responses of interest to FEMA. The scale will be chosen to provide filling times and shock diffraction effects representative of full-scale structures exposed to the effects of megaton-yield explosions. In addition, there will be three test stations located at 3, 7, and 10 psi, each containing five debris trays in various orientations to the blast. The debris trays would be similar in size to those used in the MILL RACE Event. In both the room filling and debris tray experiments, an ignition source other than a TRS would be used.

Instrumentation Requirements: Data recording will be provided by the experimenter.

Type instrumentation:

30 passive calorimeters
10 pressure gages

Photographic requirements:

9 high-speed movie cameras (3 with IR film)

Special/Unusual Requirements: The area directly behind the debris trays should be left open since burning debris may be scattered.

Environment Required: 3, 7, 10, and 30 psi.

TRS Required: None.

Attachment 4

DIRECT COURSE
Proposed Experiment

Title: Industrial Hardening

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Funded by: Federal Emergency Management Agency (proposed funding for FY 83)

Experiment Objective: To assess hardening concepts for equipment inside structures where the equipment would be subjected to missile impact and to initiate the first phase of a scaling check for banding or strapping together irregular-shaped pieces of industrial equipment. The second phase of this study would take place in the first nuclear simulation event larger than 1 kt. This data is necessary for the preparation of a self-help manual for industry.

Experiment Description: Two pads will be located at the 20-psi range for equipment packages. Each pad will be 25 ft by 40 ft with the 25 ft dimension in the radial direction. One will be a concrete pad flush with the ground surface and the other will be a cleared spot on the ground. A third 15-ft-diameter pad will be located inside the WES steel frame building. Various pieces of industrial equipment will be placed on each pad in both hardened and nonhardened configurations.

Instrumentation Requirements: Data recording will be provided by the experimenter.

Type of recorded instrumentation:

3 free-field pressure

Photography requirements:

3 high-speed movies

Special/Unusual Requirements: None.

Environment Required: 20 psi and inside WES structure.

TRS Requirement: None.

Attachment 5

DIRECT COURSE
Proposed Experiment

Title: Debris Distribution as a Function of Collapse Mode

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Funded by: Federal Emergency Management Agency (proposed funding for FY 83)

Experiment Objective: To determine the collapse mode of supported walls and the influence of collapse mode on debris distribution and to determine the effects of soil and surface conditions on over-the-ground translation of heavy objects by airblast. This information is necessary to further develop techniques used to predict debris fields for fire spread models and civil defense planning.

Experiment Description: A building having a load bearing wall without openings facing GZ will be constructed at the 30 psi overpressure. The structure will be about 15 ft square and about 8 ft high. Collapse mode of all walls of the structure will be documented along with the debris distribution. In addition, cubes and spheres of varying size and density will be placed at several overpressure levels to obtain data to verify computer code prediction for the translation of heavy objects.

Instrumentation Requirements: Data recording will be provided by the experimenter.

Type of recorded instrumentation:

3 displacement gages
4 accelerometers
5 pressure gages

Photography requirements:

3 high-speed movie cameras, exterior

Special/Unusual Requirements: None.

Environment Required: 30 psi.

TRS Requirement: None.

Discussion Group 4

MASS FIRES

I MODELING

Three different efforts were reported to be in progress and a fourth was proposed.

In terms of level of sophistication they were

(1) The potential-theory, fire-spread model of Joe Ball

(2) The two-dimensional models, steady-state and time-dependent of Hal Brode

(3) The three-dimensional, time-dependent model reported by Frank Fendell. The application proposed by Bill Kreiss was based on a three-D, time-dependent model of winds.

II EXPERIMENTAL

The primary sources of experimental data are Projects Flambeau and Euroka. The fires of Dessens at the French Meteotron facility are probably too small to simulate a large fire of the "fire storm" or conflagration class.

The Flambeau data have not been analyzed in a comprehensive fashion, particularly with reference to the use of computer simulations developed in the past 5 years and turbulence theory. The design of these fires and the instrumentation placement lend themselves to this kind of a study. Tom Palmer has been slowly reducing these data on an independed. Tom Palmer has been slowly reducing these data on an independent, unsupported basis.

III ANALYSIS

A. Computer Models

The potential theory model is of very limited value, except as a systems module. It represents the technology of the 19th century. Its main utility has been to provide an extremely rough and approximate input to a fire-spread model which may in turn be used in other civil defense applications. It is simple to calculate (on a computer) and relatively cheap to use, but should be discarded as soon as a validated model is available.

The two-dimensional model (both steady state and time dependent) is unrealistic. In the outputs displayed by the investigators, there is evidence of model artifacts such as Donner self-differences, self-diffusion, boundary-value matching, and computational cell limitations. It also is impossible to handle the vertical component of atmosphere and fire vorticity. Its future applicability looks limited. This model represents the technology of the 1960 to mid-1170 hydro-modeling community. The 3-D, time-dimensional models presented by Fendell and Kreiss represents a quandary. As described, the model of Fendell has conceptually incorporated the major elements of the fire storm problem (although his hurricane analogy is strained) but has yet to incorporate the higher-order mathematical terms. This is potentially a major problem. Further, the computer on which he has programmed this (the 7600) is too small for the problem, but he has put fire physics into the model.

The three-dimensional time-dependent model proposed by Kreiss has the higher order terms, has the necessary conservation, radiation and other calculation capability, but has not yet been tried on the fire problem.

B. Fire Storms and Conflagration

First, definitions- Frank Fendell's (as modified) definition of a fire storm is a good starting point, as it is based on what is believed to have happened in the past.

(1) The convection column should reach 30 Kilofeet (10 kilometers)

(2) Velocites should reach or exceed the storm level defined by Admiral Beaufort (120 km/hr or 75 mph). Flow may be radial near the fire but should have a significant tangential velocity component farther out.

(3) The area actively burning at once should cover from 12 to 28 km^2.

(4) The fire (as described above) should take about 2 hours to build up to "fire storm" intensity, last 5 to 6 hours, and take 9 to 12 hours to die out. So-called firestorm conditions may not, however, apply over the entire burning area.

Conflagration. An intense, wind-driven fire in which ambient winds exceed 25 mph (40 km/hr). Fuel-bed loadings may be light in this type of fire. It does not advance on a completely uniform front but in a series of rapidly moving bursts. Winds in the flame area are 75 mph (120 km/hr) but are much lighter (twice ambient) in nearby (to 100 meters distant) areas.

C. Damage Potential

The most damaging event is the fire storm, but it is unlikely to occur on a random basis. The probability of occurrence can be significantly raised if there is a choice of weather conditions and sites.

The most potentially damaging event in terms of area burned is the wind-driven conflagration. The local conditions for this kind of event (mostly weather) are easily identified and an assessment of risk should be easy to make. The "Fire Danger Rating System" of the U.S. Forest Service is suggested as a possible point of departure for further development. A joint risk assessment of many targets might be appropriate.

IV EXPERIMENTAL DATA

Comparative studies between computer simulations of Mass Fires and real fires have apparently been limited to the fires of wartime experience. However, there is poor to no quantitative measurements of wartime fires such as Hamburg, Dresden, Tokyo, and other "firestorms." Consequently comparisons are difficult and depend heavily upon interpretation of verbal and written descriptive accounts.

It is apparent that advantage has not been taken of experimental data from Project FLAMBEAU and Project EUROKA which were heavily instrumented. This is primarily because the data reduction on Project FLAMBEAU is incomplete and the results have not been presented in a manner conducive to such comparisons.

To quote Lord Kelvin: "When you can measure what you are speaking about and express it in numbers, you know something about it; but when you cannot express it in numbers your knowledge is of a meagre, unsatisfactory kind: it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the state of science."

Recommendations (not necessarily in order of priority)

(1) Computer simulations should continue but there should be thorough coordination.

(2) DNA should have lead-agency responsibility for fire storm research because of its potential targeting application and its unlikely occurrence outside of wartime.

(3) Conflagrations should be a FEMA responsibility because wind-driven fires occur in many civilian contexts as well as during incendiary and nuclear attack.

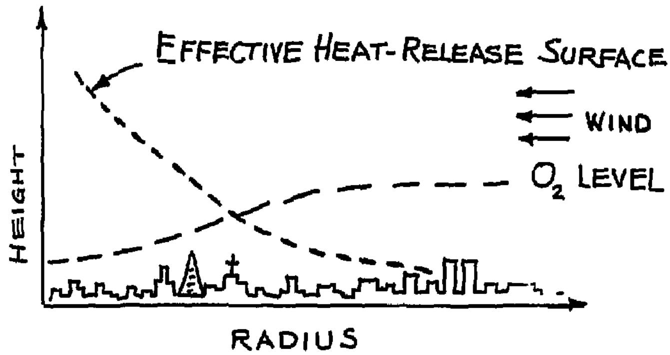
(4) A joint probability risk assessment of conflagrations, based on the extension of past Forest Service fire research and climatology, should be made.

(5) The FLAMBEAU data should be analyzed and put into usable form.

V ADDITIONAL COMMENTS ON MASS FIRES

Progress in understanding is encouraging. The application of ideas and models including large scale meteorology appears productive.

One missing part of the large-scale models is the point that in such fires it seems likely that the heat release will occur at varying altitudes (with radius) while fuel release will be at ground level. The feedback is presumably dominantly radiation. The system could become oxygen depleted at the center and the coupling may induce "breathing" fluctuations conneceted with combustion rate, which could in some areas be O_2 limited but in other areas limited by radiation feedback.



Some computations should be done to see if the energy storage in the atmosphere by water vapor production is sufficient to yield a hurricane for every city burned and what the total atmospheric energy load due to a full-scale attack might do to world meteorology (if anything).

Information from volcanic eruptions might be useful for plume-meteorological interruption estimates.

Some of the missing information on new materials may exist in reports of the Products Research Committee.

Coriolis interactions with fire storms and conflagrations should be explicitly included in the models as soon as practical.

In the large-scale models, the tropopause could act as a natural boundary for the computation.

Some of the chemistry may be useful to estimate whether evolved fuel burns completely and to try to estimate areas of oxygen depletion.

Discussion Group 5

REPORT OF DISCUSSION GROUP ON THREAT, RISK, AND COUNTERMEASURES

I INTRODUCTION

This report summarizes the proceedings of a combined discussion group addressing two subjects: "How Do We Translate Threat into Risk" and "Fire Countermeasures."

The time available was not adequate for a full discussion of all the issues raised. Thus, much of the following presentation represents separate viewpoints of one (or at most a few) of the discussion group members, rather than a consensus. Again, due to lack of time for discussion, much of the presentation is not as specific as it might have been. The following discussion is divided into three major sections: A) A Summary of Group Discussion, B) The Translation of Threat and Risk, and C) Fire Countermeasures.

II SUMMARY OF GROUP DISCUSSION

An attempt was made in this group to address one of the major questions posed by Mr. Kerr: What should the future civil defense (CD) program be? Before any discussion of the assigned topics began, each member of the group stated his views on the current status of the CD program in general. A number of these were advanced in explanation of the program's weaknesses and as constructive suggestions for improvement. Broadly, these may be grouped under (1) credibility problems and (2) inflexible planning.

A. Credibility Problems

Civil defense planning suffers from a credibility gap. The source documents cited by those opposing civil defense preparation are often poorly done or poorly understood. There is a belief, now strong, and getting stronger, that nothing can really be done in the event of a nuclear war and, in any case, that the government isn't really serious about what it has been telling people because it talks only about casualties, says nothing about what (beside evacuation) can be done to reduce them, and suggests nothing about what a post-attack environment might be like (Can the goernment survive? Will resources be adequate? What are the economic consequences of a nuclear war? Will the survivors envy the dead?) While it was noted that CD had indeed addressed these questions, (e.g., in addition to planning for relocation of people, plans are being developed for survival both in a "relocated" world, and in a recovering world) it was the group perception that people have little or no knowledge of these plans.

The group generated a number of approaches to overcoming this credibility gap:

1) It was noted that people still don't want to think about the biggest unthinable, but they are willing to think about smaller unthinables, such as tsunamis, hurricanes, earthquakes, toxic material spills, etc. Many plans made for these events (in which people have trust) fit well into various forms of crisis planning, and the sense of trust could be transmitted. (Population evacuation in advance of hurricanes, for example involves host areas, supply, security, etc.).

2) Since lack of public understanding accounts for a good part of the credibility gap, attempts should be made to improve understanding by referring to conditions that people do understand because they've experienced them. Specifically cited was the fact that Labor Day weekend traffic exceeds anything contemplated for crisis relocation. Also, Washington, D.C. empties itself of about one-third of its daytime population in 3 hours every working day, a far greater movement density than any expected in crisis relocation.

3) What might be termed an internal credibility gap was also noted. Many civil defense plans are based on single weapon attacks, but ". . . no one will accept a single burst (hypothesis) anymore." Thus, many current plans and analyses must be updated before the CD community itself can believe them.

B. Inflexible Planning

Civil defense must include more than just crisis planning. This opinion was put forth in a number of ways, most generally as suggestions about what might be done. One suggestion was to provide incentives for new construction. This was enlarged on by noting that improved National Codes might have the same, or even more, effect. Certain actions taken at present for things other than nuclear war (e.g., the construction of underground schoolhouses to minimize tornado damage and to protect against inclement weather) could be encouraged. Incentives could also be adopted to disperse critical industries, most particularly the electronics industry, now concentrated in a few centers.

Two other important and related observations were made which, though little discussed, were clearly accepted by the group. First, crisis relocation planning is highly scenario dependent. Its effectiveness clearly depends on how closely scenarios might fit actual events (or vice versa). Second, on a somber note, effective countermeasures can be taken against any known civil defense system. One question posed was: What *if* the Soviets don't cooperate, e.g., in helping you to define the crisis period?

III TRANSLATION OF THREAT INTO RISK

A. Arsenals

The specific details of estimates by the United States of the nuclear arsenals of potential nuclear adversaries are highly classified. Nevertheless, sufficient information has been released into the public domain so that the current threat can be described with adequate accuracy for this discussion, and reasonable projections of possible directions of threat development in the future can be made.

The original planning for crisis relocation was done on the basis of an attack felt to be consistent with the Soviet Union nuclear arsenal of about a decade ago. This attack consisted of about 2600 aim-points and contained about 6600 megatons of yield. Of these 2600 aimpoints, about half were military targets and half nonmilitary targets, the latter being primarily industrial targets in urbanized areas.

Current public estimates give the Soviet Union a somewhat larger total yield capability, and a considerably larger number of total warheads, (8000 to 10,000) due to the switch to multiple warheads on missiles. Thus, the number of warheads targeted against nonmilitary targets in the United States could readily be estimated at several thousand.

B. Scenarios

For civil defense, the purpose of a scenario of a future nuclear war is to define the nature of strategic and tactical warning of an attack, the timing of an attack, and the types of targets attacked. That is, the scenario provides the assumptions necessary so that the effectiveness of the implementation of a possible civil defense program can be assessed. A scenario can be limited to the few assumptions necessary for a particular evaluations, or can be embellished with narratives to provide a judgmental context within which assumptions can be developed.

The selection of appropriate scenarios requires a political judgments. Different people have different subjective views of the sets of possible circumstances that could lead to a future nuclear war, and will come up with different sets of circumstances to be used as a basis of planning. Planning by the government, which could lead to possible policy decision, should be based on scenarios selected through some governmental decision process.

At the time of the original crisis relocation planning, two pairs of alternatives provided the basic planning scenarios. These were:
For warning,

1) An attack with tactical warning and no strategic warning

or

2) An attack with adequate tactical warning and strategic warning. (Adequate strategic warning was considered to provide at least 3 days for evacuation.)

For targeting,

1) A counterforce attack. (This was defined as an attack against strategic delivery forces. The targets were missile silos, bomber airbases, and ballistic-missile submarine bases.)

2) A countervalue attack. (To the counterforce attack was added those targets whose destruction was judged to be of most interest to the Soviet Union.)

The timing of the attack was assumed to be simultaneous arrival of all weapons.

Some members of this discussion group felt that the larger Soviet arsenals and an increased technical capability to control attacks warrants consideration of additional scenarios beyond the two conventional scenarios above. Thus, two further scenarios should be added:

1) A scenario which includes attacks on urban areas where the number of weapons delivered on each urban area is limited to one, or a very few.

2) Scenarios where the duration of the attack is extended in time.

Especially in considering fire problems, it is deemed important to consider such scenarios since the nature of fire effects is quite sensitive to the number and sequence of weapons explosions on each urban area.

C. Definition of Risk Areas

In the original crisis relocation planning, the definition of risk areas was based upon a specific attack using the arsenals and weapons mentioned. For urban areas, the attack was developed to maximize damage against a set of industrial targets. No attempt was made to avoid killing people. Some targets were added to ensure that every urbanized area, as defined by the Census Bureau, was attacked with at least one weapon. The defined resolution of areas was a "minor Civil Division," again as defined by the Census Bureau. An area was considered to be at risk if, at the centroid of its population, either:

1) It had greater than a 50% chance of receiving greater than 2 psi overpressure

or

2) It had greater than a 50% chance of receiving greater than 10,000 Roentgens total biological dose from fallout radiation.

The stochastic variations for blast were primarily due to weapons reliability and delivery error and for fallout primarily due to wind variability. The stochastic effects had practically no effect on the definition of those areas at risk from blast, but a profound effect on those areas at risk from fallout.

Host areas were defined as counties or parts of counties not at risk from blast. In some planning, two-criteria risk levels were defined, and counties subjected to blast or fallout levels between the two critical values were taken as neither the host nor risk areas.

The risk due to fire has not been used in the definitions of risk areas but some of this working group judge that the magnitude of changes in risk area definition resulting from such inclusion should at least be defined.

At one time a civil defense program designed to defend primarily against counterforce attack was considered. The above process was repeated for a counterforce-only attack and a restricted set of risk areas were developed. At this time, a combined in-place/relocation defense strategy was considered.

D. Prediction of Blast and Fire Damage

As a result of an extensive amount of analytical and experimental research, the prediction of blast damage from nuclear explosions is a highly developed science. To achieve the best possible prediction of damage to a specific building, a large array of tools can be used; however, this requires rather extensive knowledge of the details of the building and its surroundings. In predictions of damage to large areas, the limitations of available data preclude making detailed predictions and do, in fact, dictate the methodology used.

Available national data bases have specific vulnerability estimates in terms of a mean lethal overpressure or vulnerability number for a limited number of buildings, a classification of buildings into broad categories for a rather more extensive set (e.g., those in the National Fallout Shelter Survey) and no data at all for most buildings. In the last case for assessment some value is assumed which is taken as typical.

Give a data base, a probability of damage as a function of distance can be computed. With good description of individual structures, this function decreases rather sharply from unity to zero. When none of the statistical variation has been estimated, a much more gradual decrease is assigned.

Given an attack on an urban area, prediction of blast damage now becomes a simple counting exercise. Given only overall attacker intentions, the predictions are much less certain. Typically, for counter value attacks such attack predictions lead to heavy attack intensities in urban areas. For most urban areas, damage probabilities over almost all of the urban area are typically computed to be in excess of, say, 80 percent.

The assessment of fire effects in an urban area is often considered in relation to a single weapon. If such a weapon is surface burst, there is a region near ground zero where nothing is left, followed by regions of successively lighter damage. The central region (the hole in the doughnut) has no fire potential since the surface is swept clear and covered with dirt from the crater. It is surrounded by a toroidal region of heavy ignitions and high fire likelihood. The boundary of this region is determined by the level of thermal radiation that will cause primary ignitions.

For large attacks, the regions of damage overlap in a rather unpredictable fashion. For fire assessment purposes, a better model of urban blast damage might be a large uniform region of heavy damage surrounded by a ring at the fringe of the urban area where the damage decreases to to that produced by successively lower levels of overpressure. In counterforce attacks only, relatively few cities would have weapons exploded close enough for direct effects to be significant, and for those the center of the explosion would be adjacent to the urbanized area. In these cases, blast effects would be estimated as relatively small, and fire effects could dominate the risk.

Unlike blast, the development of many individual fires can give rise to synergistic mass-fire effects. A large region of heavy blast damage covering the entire interior of a city will certainly heavily influence mass fire development. Estimates of the magnitude of these risk effects would be most desirable.

This discussion has concentrated on the immediate direct effects of an attack. Other more indirect or long term effects may be of importance but are not explicitly considered here.

E. Relation to Civil Defense Planning

A specification of risk that includes estimates of the intensity of damage is of most use for optimal civil defense planning. if defense resources are more than adequate, then all areas of possible risk can be given adequate resources. If resources are limited, then for optimal use they should be employed where they are of maximum benefit. Here a procedure analogous to the medical procedure of triage is suggested. Defensive resources are neither applied to those areas where the damage expected is so heavy that little benefit is expected from their application, nor to those areas where the damage expected is so light that recovery is expected even without use of defensive resources. Rather, they are saved for application in sufficient volume to as many moderately damaged areas as possible. In each of these moderately damaged areas, such application may aid significantly in the area's ultimate recovery.

The following three possible risk areas are candidates for fire defense measures:

a) The fringes of urbanized areas expected to receive slightly less than the blast overpressure requiring evacuation, which is 2 psi. The risk to the areas from mass fires should be evaluated.

b) High overpressure blast shelters for critical workers remaining in risk areas after a crisis relocation. The cost of acheiving high assurance protection should be estimated.

c) Industrial facilities. The cost of achieving fire protection for various types of facilities at various thermal risk levels is needed before optimal selection of specific plants to protect can be made.

IV FIRE COUNTERMEASURES

The discussion group presentation of fire countermeasures at the last Asilomar Conference presented a survey of this area which is still considered applicable. This presentation will amplify a few issues which were identified in the present group discussion. Each of the following sections addresses one such question.

A. Improve Firefighting Procedures

Several papers presented at the Asilomar Conference indicate that fire prevention/suppression countermeasures offer significant potential for reducing fire losses resulting from attack. This potential is especially significant for scenarios which do not preclude all suppression activities subsequent to attack.

A number of valuable projects in the fire countermeasures area were conducted by DCPA/OCD. However, additional effort is needed in this area for the following reasons:

1) Generally, fire protection personnel are not motivated to address the attack-induced fire problem.

2) Fire personnel do not have up-to-date information, in the appropriate form and format, to help them understand the attack environment.

3) Fire personnel do not have current procedures to use in planning and implementing a prevention/suppression program.

Therefore, a fire countermeasures program is needed that includes:

1) Education and motivation for local government officials and fire personnel.

2) Operational procedures for a prevention/suppression program at the local level

   - Facility design, construction, and use
   - Expedient measures
   - Post-attack suppression, rescue, salvage operations
   - Protection of fire fighters and their equipment

B. Improve Fire-Fighting Equipment

In a post-nuclear environment, limited fire-fighting manpower, equipment, and suppressant resources may be required (in addition to passive protection) to protect key structures housing essential resources related to post-attack recovery. Research is needed to both identify these structures (discussed under a separate task) and to improve fire-fighting equipment to achieve rapid fire knock-down and extinguishment with smaller suppressant expenditure over a wide range of building and fire conditions.

To achieve this goal, computer models are needed to predict the amount of extinguishing agent required to control fires of various types and intensities and to identify directions for performance improvements. Figure 4 illustrates the type of results one can expect. This figure shows the extinguishing effect of hose-nozzle systems emitting water spray at various flow rates and droplet sizes for high intensity post-flashover solid-fuel compartment fires. The calculations are based on a heat and mass balance accounting for gas and surface cooling, steam-induced smothering and direct extinguishment of fuel. Figure 4 also identifies what combination of water-flow rate and droplet size achieves effective fire control with minimum water usage. Equipment manufacturers can measure these spray characteristics and seek improvements accordingly. FEMA would provide the direction. Computer models used to produce graphs similar to Figure 4 are required for other fire conditions (pre-flashover, liquid fuels), extinguishing agents (foam, CO_2, powder), and delivery equipment types (fixed in place, portable).

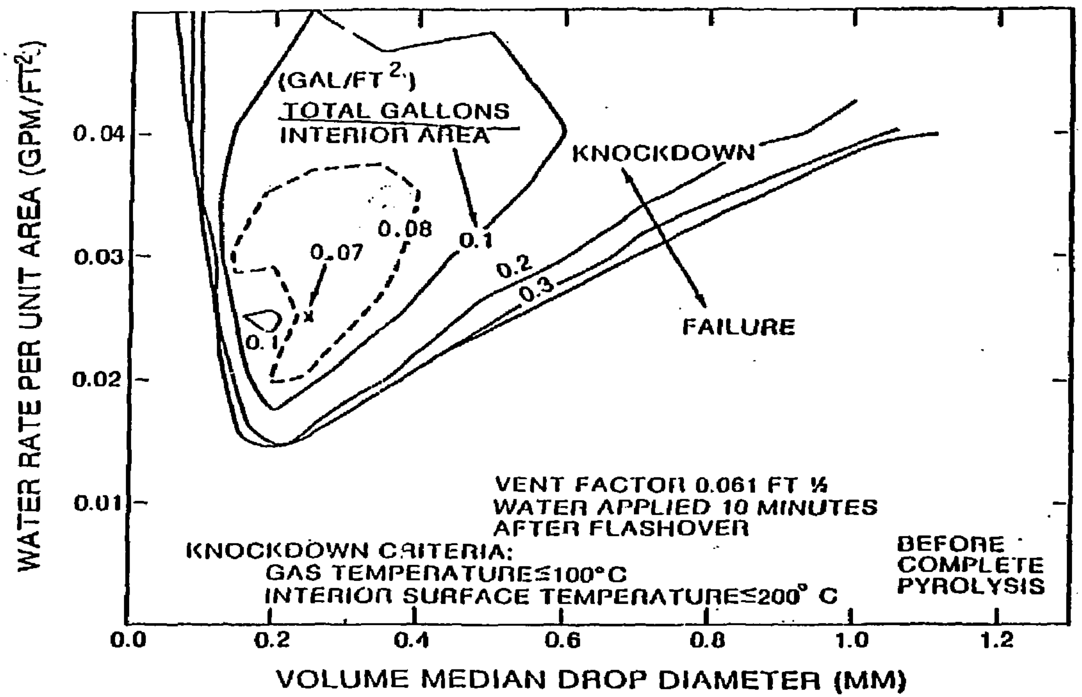


Figure 4 Fire Demand Chart (Post-Flashover Fire)

C. Passive Fire Countermeasures

In the crisis relocation situation, not enough people will be in residence to do much active fire fighting. Therefore, their efforts should be focused on a few critical situations where they might be effective. Most pre-attack efforts should focus on passive fire protection, by training architects and engineers to incorporate such protection in their designs. For example, the following measures would be of value:

- Training city planners and building permit offices to encourage passive fire protection features in plans for new construction. Where fire department opinion is required on the building permit, train the firemen to take such considerations into account.
- Emphasize design features that will protect from more than just the nuclear threat if one feature is good for both.
- Devise an incentive to stimulate the use of such designs such as tax incentives or quick amortizations.
- If the training information is not available in suitable form, FEMA should have it prepared.

Communities and individuals can do many things to reduce their vulnerability to fire and blast damage in a nuclear attack. FEMA could provide architectural colleges with structure design and construction techniques that provide blast and fire resistant structures. It would not be surprising to find many cases in which a slight change in building design or materials could result in a significant change in blast or fire resistance.

Individuals might be given tax incentives to include certain approved construction materials, design techniques or furnishings when either remodeling or building. Good examples are low-flammability roof materials, and reflective or nonflammable window coverings. Outside the range of devastating overpressures, the primary source of damage is fire. Except for ignitions in exterior kindling fuels, most of the materials that will ignite are interior--window coverings, carpets, tablecloths, newspaper, etc. Eliminating these ignitions is possible and the effect can be significant. Many other similar incentives are possible. A brief investigation of the extent and (cost effective) utility of possible incentives would be appropriate.

D. Active Fire Countermeasures

In most attack situations, the capabilities of normal firefighting organization appear likely to be inadequate to deal with the requirements. A selection of those facilities most critical to protect would assist in applying such limited resources in the best fashion. For each one an estimate should be made of the number of resources that could be protected with the capability available.

A systematic investigation is needed to establish what industries are most critical to post attack recovery, to assess their current vulnerability down to the specific key facilities involved and to establish the most cost-effective combination of passive and active measures for protecting them.

We are emphasizing here key industries in the civil sector that affect survival, not those necessary for convenience or comfort. For example, the petroleum industry is required to provide fuel for heating, transport, construction and food production. Key industries may be identifiable with the help of economic input-output models developed for the United States.

Once key industries have been identified, surveys are needed to establish where key facilities of these industries are physically located, and how many there are. Studies are also needed to establish the minimum number required to support the post-attack population for various attack scenarios and threat postulations. Finally, studies are needed to identify and apply the most cost-effective combination of passive and active measures for protecting these facilities against blast and fire effects.