Proceedings

International Wildland Fire Foam Symposium and Workshop

Compiled by G.S. Ramsey
Petawawa National Forestry Institute • PI-X-123

Natural Resources Canada | Ressources naturelles Canada
Canadian Forest Service | Service canadien des forêts

Canada

Proceedings

International Wildland Fire Foam Symposium and Workshop

Thunder Bay, Ontario
3-5 May 1994

Compiled by G.S. Ramsey[1]

Natural Resources Canada
Canadian Forest Service
Petawawa National Forestry Institute
Information Report PI-X-123

1996

[1]Project Leader, Equipment Development and Technology Transfer, Canadian Forest Service, Petawawa National Forestry Institute, Chalk River, Ontario.

This Publication was printed with funds provided by the Canadian Forest Service, Petawawa National Forestry Institute, Chalk River, Ontario, the USDA Forest Service, Intermountain Fire Sciences Laboratory, National Wildfire Suppression Technology Program, Missoula, Montana, USA, and the Canadian Committee on Forest Fire Management, Forest Fire Equipment Working Group, Winnipeg, Manitoba.

Catalogue No. Fo46-11/123-1994E
ISBN 0-662-24069-3
Printed in Canada

Copies of this publication may be obtained free of charge from the following address:

Forestry Canada
Publications Distribution Centre
Petawawa National Forestry Institute
Chalk River, Ontario
K0J 1J0

Telephone: 613-589-2880

A microfiche edition of this publication may be purchased from:

Micromedia Ltd.
240 Catherine St.
Suite 305
Ottawa, Ontario
K2P 2G8

Canadian Cataloguing in Publication Data

International Wildland Fire Foam Symposium and Workshop
(1994 : Thunder Bay, Ont.)

International wildland fire foam symposium and workshop :
proceedings, Thunder Bay, Ontario, 3-5 May 1994

(Information report ; PI-X-123)
Includes an abstract in French.
ISBN 0-662-24069-3
Cat. no. Fo46-11/123-1994E

1. Wildfires -- Prevention and control -- Congresses.
2. Forest fires -- Congresses.
I. Ramsey, G. S.
II. Petawawa National Forestry Institute.
III. Title.
IV. Series: Information report (Petawawa National Forestry Institute) ; PI-X-123.

SD420.6I57 1996 363.37'9 96-980014-2

Contents

v Preface

vi Agenda

ix Biographical Sketches

1 Keynote Address – *Karan Aquino*

2 In order to know where we are going - it is helpful to know where we have been – A brief history of the International Foam Task Group – *Hiram B. "Doc" Smith*

4 International wildland fire foam specification and NFPA 298 - foam chemicals for fire control – *Chuck George*

9 TECHNICAL SESSION I : PROPERTIES AND EFFECTIVENESS

10 Efforts in characterizing wildland fire foams – *Cecilia Johnson*

16 NFPA recent and future studies – *Rich Bielen*

19 Army fire research and development Class A foam evaluation – *Samuel Duncan*

21 Class A foam research projects – *William M. Carey*

25 Preliminary investigation of the fire extinguishment effectiveness of compressed air foam – *Daniel Madrzykowski*

26 Performance of Class A compressed-air-foam from a fixed system – *Andrew K. Kim, Bogdan Z. Dlugogorski, George P. Crampton,* and *Jack R. Mawhinney*

31 Evaluation of enhanced water fire suppression - Class "A" foam crib burns – *C. Bruce Edwards*

40 Evaluating the effectiveness of retardant and foam composites – *Judi Beck, Jeff Berry,* and *Kevin Wallinger*

45 TECHNICAL SESSION II: APPLICATION AND USE

46 A brief history of Class A fire control foam in Canada – *R.R. Lafferty*

50 National survey of use of Class "A" foam for wildland fire management – *R.P. Bailey* and *Wm. Mawdsley*

82 The use of foaming agents in forest firefighting in Spain – *Ricardo Velez*

84 The use of wildland fire foam in the Province of Québec – *François Lefebvre*

87 Evaluating foam: A systems level perspective – *David L. Martell*

91 Indirect applications with foam – *Paul Schlobohm*

94 CAFS power systems and proportioning equipment performance – *Dan W. McKenzie*

97 The utilization of foam with water scooping aircraft in Ontario – *Gordon Luke*

101 **Technical Session III: Environmental**

102 The ecological impact of fire protection and its role in forest ecosystem management – *Luc C. Duchesne* and *T. Hinrichs*

106 Human health and ecological risk assessments: Wildland fire suppression chemicals – *Christine Boivin* and *Cyndi Bailor*

114 Toxicity, health, and safety of wildland foams – *Robert J. Sabol*

119 Environmental implications of fire-fighting chemicals: A summary of current research by the national biological survey – *Susan E. Finger*

123 Effects of fire suppressant foam on vegetation in North Dakota Prairie – *Diane L. Larson* and *Wesley E. Newton*

128 Toxicity of fire retardant chemicals and fire suppressant foams to vertebrate and invertebrate wildlife species – *Nimish B. Vyas* and *Elwood F. Hill*

132 Toxicity of fire retardant chemicals to aquatic organisms: Progress report – *Steven J. Hamilton, Susan F. McDonald, Mark P. Gaikowski,* and *Kevin J. Buhl*

145 Effects of fire suppressant foams on a Prairie wetland ecosystem - A study of a North Dakota prairie wetland community – *Barry C. Poulton* and *Susan E. Finger*

152 Wildland fire extinguishing foams in Québec: The environmental aspect – *Robert Langevin* and *Pierre-M. Marotte*

157 Group Recommendations

161 List of Participants

166 Appendix 1

169 Appendix 2

DISCLAIMER

Preface

An International Wildland Fire Foam Symposium and Workshop was held 3-5 May 1994, in Thunder Bay, Ontario, Canada. The Symposium and Workshop was hosted by the Ontario Ministry of Natural Resources and sponsored by the National Wildfire Coordinating Group (NWCG) through its Fire Equipment Working Team (FEWT) and by the Canadian Committee on Forest Fire Management (CCFFM) through its Forest Fire Equipment Working Group (FFEWG). The stated objectives of the Symposium were to:

1. Review the state-of-the-art in wildland fire foam research, development, and application
2. Assess progress that has been made in R & D and application since the International Symposium held in Denver, Colorado, in 1988
3. Identify and prioritize needs and/or areas for future work
4. Make appropriate recommendations for action

The Proceedings begin with a short history of the Task Group for International/Interagency Foams and Applications Systems by its Chairperson, "Doc" Smith. It includes professional papers presented during the Symposium and biographical sketches of the presenters.

Based on the information obtained from the professional papers presented, the participants broke into five groups to make recommendations for guidance of future efforts in foam application and use. The participant groups were assigned the topics of Foam Properties, Foam Effectiveness, Foam and the Environment, Foam Application and Use – Ground, and Foam Application and Use – Air. The group's recommendations are included on pages 167-170.

The Symposium was followed by a Foam Tactics and Applications Workshop, 5-7 May, 1994, sponsored by the Canadian Committee on Forest Fire Management, Forest Fire Equipment Working Group and was dedicated to an exchange of information between forest fire management agencies and industry representatives. After vendor presentations, session participants had the opportunity to view company displays and talk with company representatives individually.

The second part of this Workshop included presentations by Canadian and American agencies on individual foam programs, several field demonstrations, and a panel discussion. These discussions led to the view that it is now up to individual agencies to explore the future use of foam within their fire management program.

The International Wildland Fire Foam Symposium and Workshop was jointly chaired by Bob Joens and Gordon Ramsey. Other members of the organizing Steering Committee were Bob Bailey, Ed Bons, Chuck George, Doug Higgins, Paul McBay, Sig Palm, "Doc" Smith, Jim Stumpf, and Reidar Vollebekk.

The Steering Committee would like to extend its sincerest appreciation to Karan Aquino, Director, Aviation, Flood and Fire Management Branch, Ontario Ministry of Natural Resources, whose organization hosted and whose staff coordinated the numerous activities required for a successful meeting. We wish to thank the speakers (and their co-authors, as applicable) and moderators for their obvious contribution. We would also like to acknowledge the support and give much deserved credit to the following who contributed so much to the success of the Symposium:

- Dianne Trethewey and Julie Uchida, USDA Forest Service, Intermountain Fire Sciences Laboratory, NWST, Missoula, Montana.
- Nancy Steward, USDA Forest Service, Fire and Aviation Management, Washington, D.C.
- April Donak, Janet Margarit, and Wilma Bodnar, Ontario Ministry of Natural Resources, Northwest Regional Office, Thunder Bay, Ontario.
- Eliza Andersen and Margo Strachan, Canadian Forest Service, Petawawa National Forestry Institute, Chalk River, Ontario.

International Wildland Fire Foam Symposium and Workshop

Thunder Bay, Ontario, 3-5 May, 1994

AGENDA

Monday, May 2

1900 - 2200 Registration and Icebreaker - Scandia I

Tuesday, May 3

0730 - 0830 Late Registration

0830 Symposium Opening – *Gordon Ramsey*, CFS/PNFI

Official Welcome – *Cam Clark*, NW Regional Director, OMNR

Keynote Address – *Karen Aquino*, Director of Aviation, Flood, and Fire, OMNR

Introductions – *Gordon Ramsey*, CFS/PNFI

General Symposium Information – *Ed Bons*, OMNR

Overview of Symposium – *Bob Joens*, USDA Forest Service, WO

Background
(Unit Leader, *Bob Joens*)

Review of Denver Meeting: Identified Needs and Direction, Post-Denver Meeting accomplishments – *Doc Smith*, USDA Forest Service, Kaibab, NF

Status: International Wildland Fire Foam Specification and NFPA 298-Foam Chemicals For Fire Control - Revision Update – *Chuck George*, USDA Forest Service, NWST

1000 Break

1015 **Properties and Effectiveness**
(Unit Leaders: *Bob Bailey*, NWT, DRR and *Cecilia Johnson*, USDA Forest Service, NWST)

Efforts in Characterizing Wildland Fire Foams – *Cecilia Johnson*, USDA Forest Service, NWST

Suppression /Extinguishing Effectiveness (Water/Foam Comparison)

NFPA Recent and Future Studies – *Rich Bielen*, NFPA

U.S. Army Studies (Ft. Belvoir) – *Sam Duncan*, U.S. Army

Underwriter Laboratories (UL) Studies – *Bill Carey*, UL

1130 Lunch

1245 NIST Studies – *Dan Madrzykowski*, NIST

NRC Studies: Performance of Compressed Air Class A Foam in Fixed Systems – *Andrew K. Kim*, *Bogdan Dlugogorski*, *George F. Crampton*, and *Jack R. Mawhinney*

Quantative Evaluation of Enhanced Water Fire Suppression

Past and Future Class A Foam Crib Burns and Natural Fuel Burn Tests – *Bruce Edwards*, Fire Tech Engineering, BC

Foam Enhanced Retardants - Operational Burns Trials – *Judy Beck*, British Columbia, Ministry of Forests

1415 Break

1430 **Application and Use**
(Unit Leaders: *Sig Palm*, USDA Forest Service, SDTDC and *Doug Higgins*, CFS, PNFI)

History of Foam Use In Canada – *Randy Lafferty*, C.O.F.I. of BC

Summary of Wildland Fire Foam in Canada – *Bob Bailey*, NWT, DRR

Effectiveness and Application of Foam in Spain – *Ricardo Velez* Munoz, ICONA (Spain)

Acceptance of Foam Use in Fire Suppression in British Columbia – *Bob Beck*, BC, Ministry of Forests

Foam Use in the Province of Québec – *François Lefebvre*, SOPFEU Quebec

Cost-Effectiveness Analysis in Considering Fire Suppression – *Dave Martell*, University of Toronto

Indirect Tactical Applications with Foam – *Paul Schlobohm*, BLM, NIFC

CAFS Power Systems and Proportioning Equipment Performance – *Dan McKenzie*, USDA Forest Service, SDTDC

1700 Close of Day

1830 Banquet

Wednesday, May 4

0800 **Application and Use**

Utilization of Foam from Water Scooping Aircraft in Ontario – *Gordon Luke*, OMNR

Environmental
(Unit Leaders: *Paul McBay*, OMNR and *Chuck George*, NWST)

The Ecological Impact of Fire Protection – *Luc Duchesne*, CFS, PNFI

FS Risk Assessment Study/Labat-Anderson, Inc.
- Human Health Risk Assessment – *Chris Boivin*, LAI
- Ecological Risk Assessment – *Cyndi Bailor*, LAI

Toxicity, Health and Safety of Wildland Fire Foams – *Bob Sabol*, Stillmeadow Laboratories

0940 Break

1000	Toxicity of Foams to Plant and Animal Communities	
		Overview of NBS Recent and Planned Studies – *Susan Finger*, USDI, NBS, NFCRC
		Terrestrial Vegetation Response to Silv-Ex Application – *Diane Larson*, USDI, NBS, NPWRC
		Toxicity of Fire Retardant Chemicals to Wildlife Species – *Nimish B. Vyas*, USDI, NBS, PWRC
		Toxicity of Fire Retardant Chemicals to Aquatic Organisms – *Steven J. Hamilton*, USDI, NBS, NFCRC
		Toxicity of Fire Suppressant Foams to the Aquatic Community – *Barry C. Poulton*, USDI, NBS, NFCRC
1130		Quebec Ecotoxicological Study On Fire Extinguishing Foams – *Robert Langevin*, Quebec Ministère des Ressources Naturelles
1150	Lunch	
1300	**Symposium Committee Workshops** (Unit Leaders: *Bob Joens* and *Gordon Ramsey*)	
	Properties and Effectiveness	
	Environmental	
	Application and Use	
	Others as Needed	
1700	End of Day	

Thursday, May 5

0800	Reports from Symposium Workshop Committees
	Discussion
	Recommendations/Conclusions
	Wrap Up and Evaluation
1130	End of International Wildland Fire Foam Symposium and Workshop
	Post Symposium Activities
1330-1800	Vendor Displays and Presentations

Biographical Sketches

KARAN AQUINO Karan was appointed Director of the Aviation, Flood and Fire Management Branch in January, 1994. She had recently returned from a one year educational leave of absence to complete her post-graduate studies in Developmental Economics at the London School of Economics in London, England.

Karan has 16 years of administrative and management experience with the Ontario Ministry of Natural Resources, most of it in communities across Northern Ontario. Her more recent assignments have been Acting Director, Human Resources during the 1992 reorganization, and Acting District Manager in Fort Frances.

R.P. (BOB) BAILEY Bob completed a Diploma in Forest Technology and a Bachelor's degree at Lakehead Univesityin 1971 and 1973 respectively. Prior to moving to the Northwest Territories in 1974 he was employed on fire crews at Thunder Bay and in woodland operations for Abitibi Paper. He has held progressively more responsible positions in the Forest Fire Management Program in the Northwest Territories in Inuvik and Fort Smith. He assumed his current role in 1987 when the program was transferred from the Government of Canada to the Government of the Northwest Territories.

CYNDI BAILOR Cyndi Bailor is a senior environment scientist and task manager with 5 years experience in risk assessment and environment impact analysis. She has conducted human health and ecological risk assessments on insecticides, herbicides, fungicides, and fire suppression chemicals for the Forest Service and the USDA Animal and Plant Health Inspection Service (APHIS). She has managed the preparation of a programmatic Biological Assessment on proposed APHIS activities, and has led Endangered Species Act Section 7 consultation with the U.S. Fish and Wildlife Service on pesticide issues. She has surveyed and analyzed biodiversity issues for the Department of Energy, and has served as a senior specialist on EPA's Wetlands Protection Hotline. Ms. Bailor is an M.A. candidate in Environmental Earth Sciences and Policy at Johns Hopkins University, and received a B.S. in Natural Resources Management from the University of Maryland.

JUDI BECK Education—B.Sc. in Forestry, April 1985, University of New Brunswick, Canada; M.Sc. in Forestry, April 1988, The Australian National University, Australia; Ph.D. Candidate, Curtin University, Perth, Western Australia

During my sojourn in Australia (7 1/2 years), I was fortunate to have had the opportunity to work with a number of forest and land management agencies including the Tasmanian Forestry Commission, the Department of Conservation and Land Management in Western Australia, the National Parks and Wildlife Service in New South Wales and the Bushfire Council in the Australian Capital Territory. I worked on fire behaviour and effects research in eucalypt forests and hummock grasslands, was involved in operational prescription planning and burn implementation, and developed GIS based decision support systems for fire management. I was a GIS, modelling and FORTRAN lecturer at Curtin University, and was involved in basic fire behaviour training for the Department of Conservation and Land Management in Western Australia. I am currently a Research Analyst with the Fire Management, Analysis and Development section of Protection Branch, and have been working for the British Columbia Ministry of Forests since May 1993.

RICHARD P. BIELEN Mr. Bielen is a Senior Fire Protection Engineer with the National Fire Protection Research Foundation. He has been with the Research Foundation for three years. Prior to working for the Research Foundation, Mr. Bielen was a Senior Fire Protection Engineer for the National Fire Protection Association and worked for several fire protection engineering firms.

Mr. Bielen has a Bachelors of Science in Electrical Engineering and a Masters of Science in Fire Protection Engineering, both from Worcester Polytechnic Institute. He is also a registered Fire Protection Engineer.

Mr. Bielen is presently the project manager for the National Class A Foam Fire Test Project, conducted by the Research Foundation at Underwriters Labor-atories Inc.

CHRISTINE BOIVIN Christine Boivin is a senior environmental scientist and project manager at LABAT-ANDERSON Incor-porated, where she directs the Risk Assessment/Environmental Analysis Group. She has led human health and ecological risk assessments of chemical, radiological, and biological substances for the U.S. Forest Service, Department of Defense, Department of Energy, State Department, Bureau of Land Management, and Animal and Plant Health Inspection Service. She has also developed briefings and reports on risk communication approaches for the Department of Defense and Department of Energy.

Ms. Boivin recently developed and presented a training course on the use of health-based risk assessment in the site restoration process at the U.S. Air Force School of Aerospace Medicine in San Antonio, Texas. She is currently managing a contract to provide technical support to the U.S. Forest Service for human health and ecological risk assessment, as well as overseeing LABAT-ANDERSON'S international environmental projects. Ms. Boivin has an M.S. in Environmental Science from George Washington University and a B.S. in Environmental Chemistry from the University of Michigan.

BILL CAREY Bill Carey is a Senior Staff Engineer in the Fire Suppression Section of the Engineering Services Division at Underwriters Laboratories Inc. (UL) main office and test station in Northbrook, Illinois. He started his career at UL in 1966 and has a bachelor of Science Degree in Fire Protection Engineering and a Masters Degree in Business Administration from Illinois Institute of Technology. Mr. Carey is a registered Professional Engineer and Past President of the Chicago Chapter of the Society of Fire Protection Engineers.

Bill is a member of numerous National Fire Protection Association (NFPA) technical committees including Foam, Halon, Carbon-Dioxide, Dry and Wet Chemicals, Water-Mist and Clean Agent Fire Extinguishing Systems. He is also a member of the U.S. Delegation to the International Standards Organization (ISO) committees of Fire Extinguishers, Foam and Sprinkler Systems.

Mr. Carey has served as Project Manager for several National Fire Protection Research Foundation (NFPRF) research projects including the National Class A Foam Research Project. Bill also managed a Class A Foam Research Project sponsored by the U.S. Army.

GEORGE CRAMPTON Mr. Crampton is a Senior Technical Officer with the National Fire Lab. He came to NRC in 1979 after completing the 3 year Physics Engineering Technology program at Algonquin College. He has worked for the NFL since 1980 designing and constructing instrumentation and performing full scale fire tests.

BOGAN DLUGOGORSKI Dr. Bogdan Dlugogorski is a Research Associate at the National Fire Laboratory. He joined the NFL in 1993 after completing a Ph. D. degree in Chemical Engineering at Ecole Polytechnique in Montreal. He also holds M. Eng. in Chemical Engineering from McGill University and undergraduate degrees in Geophysics and Chemical Engineering, both from the University of Calgary. He is a professional engineer with the Ordre des ingénieurs du Québec, a member of the American Institute of Physics, a member of the Canadian Society for Chemical Engineering, and an associate member of the Society of Fire Protection Engineers. In his research, he investigates suppression of fires, both experimentally and by a means of numerical modelling. His other interests include measurement of heat release rates, investigation of the interaction between water mist and unconfined fires, and the development of fixed foam systems.

LUC C. DUCHESNE Dr. Luc Duchesne obtained a Bachelor's degree in forestry from Laval University in 1983, a Master's degree from the University of Toronto in forest pathology in 1985, and a Ph.D. in botany from the University of Guelph in 1988. From there he conducted post-doctoral studies at Michigan State University in East Lansing, Erindale College in Toronto, University of Toronto, and Petawawa National Forestry Institute. He has been employed as a fire ecologist at the Petawawa National Forestry Institute since 1991, working on aspects of fire ecology including regeneration following fire, management of old-growth forests, bio-diversity, and ecological impact of fire protection.

SAMUEL DUNCAN Organization: Department of Army, Tank-Automotive Research, Development and Engineering Center (TARDEC), Mobility Technology Center - Belvoir, Fire Research and Development

Official Mailing Address: Tank-Automotive Research, Development and Engineering Center, Mobility Technology Center - Belvoir, AMSTA-RBWQ DUNCAN, 10115 Gridley Road, Suite 128, Ft. Belvoir, VA 22060-5843

Background: 22 years uniformed service with US Army; 3 years in Army research, development and engineering; Active member of Greater Springfield Volunteer Fire Department (Springfield, VA); Member of National Fire Protection Association

Education: Bachelor of Science, Business Management; Master of Arts, Procurement and Acquisition Management

C. BRUCE EDWARDS C. Bruce Edwards is Research Director of Firetech Engineering Inc. in Vancouver, which was incorporated for fire suppression research.

While living at Wabasca in northern Alberta, where he gained experience in wildland firefighting, his interest in better methods was awakened at 5:00 AM Nov 30, 1978 when called to fight an arson fire, with Mark 3 pumps, in a new hospital. Noticing that plain water didn't wet fuel, he developed Class A foam systems for urban interface fires and developed the concept of Critical Flow Rate (CFR), below which application of suppressant is ineffective.

On his return from six years of consulting in Zimbabwe, Pakistan, Philippines and Indonesia, he conducted exploratory burn tests in 1990 with Ronald R. Rochna, then of the National Interagency Fire Center. It seemed that combining the CFR concept with Class A foam/CAFS could produce dramatic results, but that scientifically credible quantitative evaluation was needed to compare and optimize suppression systems. Mr Rochna therefore asked him to initiate and coordinate this research. Bruce D. Lawson of Forestry Canada and Lt–Col. Gaétan Perron of the Canadian Forces secured initial funding, supplemented by funding from Task Force Tips, KK Products, Angus, Chemonics, Ansul and Robwen/Flameco.

He has established and headed departments of Nuclear Medicine and Computer Studies, co–founded a geophysics research group, lectured in electrical engineering, and served as advisor to governments on computer applications and technical education. He has a BASc in Electrical Engineering and a MASc in Biomedical Electronics from the University of Toronto, and is a graduate of the Institution of Fire Engineers in England.

SUSAN E. FINGER Susan E. Finger is an aquatic toxicologist with the National Biological Survey and serves as the Deputy for the Field Research Division at the National Fisheries Contaminant Research Center in Columbia, Missouri. Her research interests include effects of contaminants on survival of striped bass in the Chesapeake Bay ecosystem, effects of irrigation drainwaters on the aquatic ecosystems of the western United States, ecotoxicological effects of oil spills in freshwater systems, and effects of fire retardant and suppressant chemicals on terrestrial and aquatic ecosystems. She has authored or coauthored over 40 publications.

CHARLES W. (CHUCK) GEORGE Chuck's work experience with the Forest Service began in 1958 and consists of seven seasons on the Custer and Nez Perce National Forests in seasonal fire positions before joining the Fire Control Technology Unit of the Northern Forest Fire Laboratory. There he assisted in the conduct of prescribed fire and fire control systems research. He conducted graduate work at the Laboratory in prescribed fire research before joining the Fire Management Research Project in 1965 with respon-sibilities for fire retardant research studies. Besides conducting prescribed fire studies, he has conducted studies and programs related to fire retardants, aerial delivery systems, effectiveness, physical and chemical characteristics of wildland fire chemicals, and operational retardant applications. He was project leader for the operational retardant effectiveness (ORE) study and is now Program Leader for the National Wildfire Suppression Technology (NWST) Unit.

Chuck received a B.S. degree in Forest Engineering from the University of Montana in 1964, and a M.S. degree in Forestry (Fire Science) in 1969.

STEVEN J. HAMILTON Dr. Steven J. Hamilton is an aquatic toxicologist with the National Biological Survey. He is currently Leader of the National Fisheries Contaminant Research Center's Field Station in Yankton, SD. His research interests include development and evaluation of biological indicators of contaminant stress in fish, toxicological studies of inorganic contaminants associated with placer mining activities in Alaska on fish such as Arctic grayling, effects of inorganic contaminants associated with irrigation return flows on West Coast salmonids and endangered fish in the Colorado River basin, and fire retardant chemical effects on aquatic organisms. He has authored or coauthored over 30 publications.

DOUGLAS G. HIGGINS Following graduation in Mechanical Engineering Technology from Eastern Ontario Institute of Technology in 1968, Doug joined the Canadian Forest Service, Forest Fire Research Institute (FFRI) in Ottawa. In 1970 he joined Phillips Cable Limited in Brockville, Ontario as a Section Manager, returning to the Forest Fire Research Institute in 1971. In 1979 he transferred to PNFI as an equipment specilist where he continues to work on the development of national standards for fire suppression equipment and projects, along with studies related to equipment and product development and fire suppression methods and techniques.

Doug serves on various National Committees, acts as a technical advisor, and provides a technology transfer service to fire management agencies internationally on various aspects of firefighting technology.

ELWOOD F. HILL Dr. Elwood F. Hill is a research toxicologist for the National Biological Survey. He serves as Leader of the Wildlife Toxicology Group at the Patuxent Wildlife Research Center in Laurel, Maryland. He performs independent research on toxicity of pesticides and other contaminants to wildlife and leads multidisciplinary field and laboratory investigations of research scientists and graduate students. In addition to his work on the ecotoxicological effects of fire retardant chemicals, his current research focuses on agricultural pesticides, mosquito abatement practices, effects of microgold mining operations and cyanidation on wildlife, and toxicity and hazard of white phosphorus on Alaskan wildlife. He has authored or coauthored over 50 publications.

ROBERT L. (BOB) JOENS Bob started his career on the Mark Twain NF in Missouri. For the next 19 years he served as Asst. Ranger and District Ranger in Missouri, Minnesota, and Ohio. From 1982 to 1990 he was Fire, Aviation and Communication Staff Officer on the Superior NF in Minnesota. During this time he supervised the Northeast Fire Cache, the DHC Beaver program, started the Prescribed Natural Fire in the Boundary Waters Canoe Area Wilderness and was the chairperson of the Minnesota Incident Command System for the first four years. His fire experience started as firefighter and engine foreman to 12 years as Planning Section Chief and Incident Commander on the Regional Fire Team. He served on the Prescribed Fire Review Committee after the Yellowstone Fires, served as National Intelligence Officer and Military Liaison.

Present duties include responsibilities for the Forest Service fire equipment and fire chemicals program, liaison with Missoula and San Diams Technology and Development Centers, chair of NWCG's Fire Equipment Working Team, and FS representative to National Fire Working Team, and FS representative to National Fire Protective Association Forest Fire Protection committee.

Bob graduated from Iowa State in 1960 in Forest Management. He also served in the U.S. Army from 1961 to 1964 in Germany.

Cecilia W. (Ceci) Johnson

After receiving a bachelor's degree in chemistry and mathematics from Whitworth College, Ceci attended graduate school in chemistry at the University of Montana. While still a student, she joined the staff of the Forest Service's Intermountain Fire Sciences Laboratory in 1970.

Since then Ceci has worked in the National Wildfire Suppression Technology Program, formerly the Fire Suppression work unit, studying the effectiveness and safety of wildland fire chemicals. Studies have included combustion and pyrolysis, retardant-caused corrosion, rheology of long and short-term retardants. Recently efforts have been directed toward the fire chemicals qualification and evaluation, test methods and performance requirements, and quality assurance.

Since 1986 Ceci has also been working on the evaluation of the application and use of foam. She has participated in previous foam workshops in College Station (1987) and Denver (1988). Ceci was involved with the preparation of "Foam vs. Fire" and participated in the International Foam Specification Workshop in February 1992 and helped to draft the Proposed International Foam Specification. She is responsible for the coordination of the laboratory characterization of foam. Currently a major effort is to complete the first phase of the Foam Characterization study which will provide information on the performance of all of the approved wildland fire foams when tested in accordance with the International Class A Foam Specification.

Andrew Kim

Dr. Andrew Kim is a Senior Research Officer at the National Fire Laboratory of IRC/NRC. He has been with the National Fire Laboratory since 1985. His prior experience was in the energy conservation program, specializing in building air leakage and ventilation. He holds a B.A.Sc. from the University of Toronto, an M.A.Sc. and a Ph.D. from the University of Ottawa, all in Mechanical Engineering. His current research interest at the NFL is in fire suppression performance of halon alternative agents, compressed-air-foam and fine water mist systems. He also has interest in pre-flashover fires, foam test methods, and sprinkler protected glazing systems, and small-scale and full-scale fire testing. He is a member of Canadain General Standards Board and ASTM, and also a research advisor to the Standing Committee on Occupancy of the Canadian Commission on Building and Fire Codes.

R.R. Lafferty

Randy graduated from the University of Montana with a B.Sc. in Wildlife Technology and a M.Sc. in Forest Sciences.

He worked as a Fire Research Officer for the Canadian Forest Service for six years, spending most of his time on the Mission Tree Farm pioneering fire intensity ecological studies. He also developed the first safe helicopter rappell system, along with his partners in a private company, in the early 1970's.

In 1978, he brought the first gelled fuel helitorch into Canada and used it to backburn in the Northwest Territories.

After several years in private business in BC, Randy went to work for the forest industry. He has been working as a fire management officer and an environmental land use auditor since 1981 for MacMillan Bloedel Ltd. on the BC coast. During the 1985 Inver-mere fire bust, Randy was introduced to Class A fire foam and he says that this experience convinced him of a better way to fight fire. He was asked by the U.S. BLM to lead the subcommittee of NFPA that wrote the first international foam standard (#298) which deals with health, safety, and corrosion.

He was chairman of the Canadian Committee on Forest Fire Management for two years and the Northwest Fire Council for one term. He is also a member of the National Fire Protection Association Committee on Forest and Rural Fire Protection and a member of the Society of Professional Biologists of BC.

Randy will present a brief history of Class A foam in Canada up to 1986.

ROBERT LANGEVIN In charge of workers and environmental health and safety with fire extinguishing foams.

Work experience: 1992 - Ministère des Ressources naturelles du Québec. Evalaution of the impact of contaminants (herbicides, foams, fuel) used for forest management, on workers and the environment.

1992 - Hydro-Québec. Toxicity of mercury towards the avian, terrestrial and aquatic fauna.

1990-1992 - Environment Canada. Remediation of contaminated sediments in the Lachine canal (Montreal, Quebec.)

Selection of bioassays for the evaluation of the toxicity of the St. Lawrence river sediments. Ecotoxicological study of St. Lawrence river sediments elutriates. Survey of the existing bioassays for the toxicity evaluation of the aquatic environment.

DIANE L. LARSON Dr. Diane L. Larson is a research wildlife biologist with the National Biological Survey at Northern Prairie Wildlife Research Center. Dr. Larson's research interests center on the effects of disturbance and stress at different levels of biological organization. She is currently applying her expertise to studies involving global climate change and to investigations concerning the response of the vegetative community to fire retardant and suppressant chemical application. She has authored or coauthored over 10 publications.

FRANÇOIS LEFEBVRE François Lefebvre is a forestry engineer with the "Société de protection des forêts contre le feu", the organization mandated to ensure the protection against fire of all the forests in the province of Québec. Involved in forest fire protection since 1978, he is now in charge of development and special services. One of his responsibilities is to make sure that the use of wildland fire foam is worthwhile, that the techniques for applying it are conform to the legislation, that it respects the environment and doesn't pose any threat to the persons involved in using it.

DANIEL MADRZYKOWSKI Education: University of Maryland, B.S. Mechanical Engineering.

Mr. Madrzykowski has worked in fire suppresion and large fire research at the National Institute of Standards and Technology (NIST) since 1986. He began studies at NIST to measure the ignition inhibiting properties of compressed airfoam (CAF). Utilizing new measurement methods developed at NIST, the ignition delay time of "foamed" wood samples reltative to untreated wood samples was compared at different heat flux levels. The technique could be used to characterize CAF exposure protection capabilities.

Mr. Madrzykowski has conducted studies on gas and oil well fire suppression, fire sprinkler activation and effectiveness and large scale fire testing. He is a registered professional engineer and is a member of the National Fire Protection Association and the Society of Fire Protection Engineers.

J.R. MAWHINNEY J.R. (Jack) Mawhinney is a Senior Research Officer, at the National Fire Laboratory (NFL). He joined the NFL in 1990. From 1984 to 1989 he was technical advisor to the committees responsible for the National Fire Code of Canada. Prior to joining NRCC in 1984, Mr. Mawhinney worked in the sprinkler contracting industry. His current research involves the enhancement of water-based fire suppression systems as an alternative to halon, for application in machinery compartments on ships, and in electrical and electronic equipment in telecommunications facilities. Mr. Mawhinney is chairman of the National Fire Protection Association technical committee on Water Mist Fire Suppression Systems (NFPA 750). He has authored numerous papers on the subject of engineering design of water-mist fire suppression systems.

DAN W. MCKENZIE Dan received his formal engineering training at the University of Arizona, where he was graduated in 1958 with a Bachelor of Science degree in Mechanical Engineering. His first work experiences after graduation were with the U.S. Army as an Ordnance Officer and with Shell Oil Company, drilling oil wells. For the past thirty-three years he has been employed by the United States Department of Agriculture, Forest Service, at the Technology & Development Center, San Dimas California. During this time he has served as the supervisor of the Design Section of the Development and Testing Branch and as a Project Engineer.

At the Forest Service Technology & Development Center, he has been involved in the development of the Forestland Tree Planter, the Rangeland Drill, range vegetative equipment, range water pumping equipment, firefighting equipment, slash treatment equipment, and reforestation equipment.

Dan was recently awarded the Forest Service Chief's award for Excellence in Technology Transfer for his work in transferring firefighting foam technology. He was also selected to receive the Federal Laboratory Consortium Award for Excellence in Technology Transfer for 1994, for this same work.

Dan holds a Certificate of Proficiency as a Research and Development Manager from the U.S. Department of Army, which was earned through his activities in the U.S. Army Reserve.

SIG PALM Sig's Forest Service career began in 1961 with seasonal assignments (fire, recreation maintenance, timber and visitor information service) on the Roosevelt NF (R2). He was the first superintendent of the Wyoming Hotshots (Greybull, WY) from 1967-70. Sig held fire and multi-resource staff positions on the Bighorn NF (R2) from 1970-78, Staff Officer Prescott NF (R3) – Recreation, Lands, Minerals, Visitor Information and Law Enforcement. District Ranger on the Gila NF (R3) while concurrently administering the Gila Cliff Swellings National Monument (NPS) from 1980-82, District Ranger on the Tonto NF (R3) from 1982-85. Regional Office Timber Management (R3) in 1986. Northeastern Area, State and Private Forestry, Cooperative Fire Protection (Prevention, Training, Emergency Management planning for FEMA).

Sig has spent his entire career in various incident management positions from firefighter to operations section chief, logistics section chief, planning section chief and incident commander on type 1 and type 2 incident management teams in the Rocky Mountain, Southwestern, and Eastern Regions, and Multi-Agency Coordination Group coordinator for the Northern and Southwestern Regions, plus FEMA Regions V and VII. He completed the Advanced Fire Management Course (I-520) in 1982 and the Area Command Course (I-620) in 1990. Sig is currently the Program Leader for the Fire and Aviation Program at the USDA Forest Service Technology and Development Center, San Dimas, California.

Sig also spent a total of 28 years in the U.S. Army, Army National Guard and Reserve in various Battery staff and Command assignments up through Support Brigade Logistics Officer (S-4).

Sig completed a B.S. degree in Forestry and Range management at Utah State University in 1970.

BARRY C. POULTON Dr. Barry C. Poulton is an aquatic entomologist with the National Biological Survey. He is currently the Leader of the Aquatic Ecology Section for the Field Research Division at the National Fisheries Contami-nant Research Center in Columbia, Missouri. His current research involves community and ecosystem level effects of contaminants in small stream and river ecosystems influenced by such things as oil spills, mining-related activities, and exposure to fire retar-dant chemicals.

GORDON S. RAMSEY Gordon began his career in forestry with the Ontario Ministry of Natural Resources (Dept. L&F) in 1961. Between 1961 and 1965 he was employed in the Ministry's Forest Management, Forest Tree Nursery and Fish and Wildlife programs. In 1965 he joined the Canada Dept. of Forestry, Forest Fire Research Institute (FFRI) in Ottawa where he was Project Leader. He was responsible for studies focusing on forest fire suppression equipment performance and development. In 1979, following the closure of FFRI, he transferred to the Petawawa National Forestry Institute at Chalk River, Ontario, where he assumed the role of Project Leader, Equipment Development, Standard, and Technology Transfer.

In 1981 he became involved in the early development of Class A Foam and subsequently in the development of foam apparatus and standards. He is a member of the Underwriters Laboratories of Canada (ULC) Committee on Fire Fighting Apparatus and Equipment and serves as Chair of several related ULC subcommittees (i.e., hose, couplings, backpack pumps).

Gordon was a founding member of the Canadian Committee on Forest Fire Management (CCFFM), Forest Fire Equipment Working Group in 1982 and served as Chair for many years and has now assumed the role of permanent coordinator. In 1987 he was instrumental in the establishment of the permanent liaison between the National Wildfire Coordinating Group (NWCG), Fire Equipment Working Team (FEWT) and the FFEWG. He presently is Canadian advisor to FEWT and a member of FEWT's Task Group for International/Interagency Foams and Applications Systems. FEWT and FFEWG meet jointly every two years, alternating between the United States and Canada. This International Foam Symposium is an example of one of the US/CAN joint initiatives. Other include the Denver International Foam Workshop; Remote Sensing for Forest Fire Management International Workshop; and several foam workshop training sessions held throughout North America.

ROBERT J. SABOL Robert J. Sabol, CEO/President, STILLMEADOW, Inc., 12852 Park One Drive, Sugar Land, Texas, 77482. Bachelor of Science degree in Animal Husbandry from Delaware Valley College, Doylestown, PA. Sabol has worked in the field of toxicology since 1966. He became the founder and owner of STILLMEADOW, Inc. in 1975. Almost his entire work experience has been in the contract toxicology field. He has witnessed the development and sophistication, as well as the quality and regulation of toxicology testing. By managing and overseeing over 12,000 routine sample evaluations (mostly routine acute screening studies) over the years, he can attest to the change in attitude and respect for the necessity of acute toxicology testing.

PAUL SCHLOBOHM Paul received a bachelor's degree in Forestry from UC Berkeley in 1983. He began his career in fire management in 1984 working on prescribed fire and wildfire for the BLM in Salem, Oregon. In 1986, he started on a new project to develop Class A foam as a fire management tool and has been with this project until this year. For eight years Paul has used, evaluated, and documented foam products and equipment during prescribed fires and wildfires. Paul has been a part of international efforts to coordinate foam technology advancement, including: Developing and conducting foam training; producing user guides, videos and product specifications for the National Wildfire Coordinating Group; creating and revising a foam standard for the National Fire Protection Association; and writing and speaking about foam use.

Nimish B. Vyas

Dr. Nimish B. Vyas is a research toxicologist for the National Biological Survey. He works with the Wildlife Toxicology Group at the Patuxent Wildlife Research Center, Laurel, Maryland.

His current research focus is on effects of agricultural pesticides on migratory behavior in birds and the effects of fire retardants and foam suppressants on western wildlife populations.

International wildland fire foam

Symposium and Workshop

Keynote Address - May 3, 1994

Karan Aquino

Director, Aviation, Flood and Fire Management Branch, Ontario Ministry of Natural Resources

Good morning! On behalf of the Aviation, Flood and Fire Management Branch of the Ontario Ministry of Natural Resources, I would like to welcome you to The International Wildland Fire Foam Symposium and Workshop.

We are very pleased that the Symposium Steering Group chose Ontario for the location to bring together such an experienced group of foam practitioners from across Canada and the United States. Today and tomorrow we will hear papers prepared by these experts as well as several from France, Spain and Australia.

Although many speakers from outside of North America have not been able to attend the symposium due to travel constraints, their papers have been forwarded for presentation and will be included for publication in the proceedings.

As you will hear in presentations by Ministry of Natural Resources staff, Ontario has been using foam with our waterbomber fleet with impressive results since 1988. And this year, after several years of operational evaluation, Ontario will be implementing ground foam applications. Foam kits will be distributed for use by our fire crews on both wild and prescribed fire operations. Those of you who will be staying for the Foam Tactics and Applications Workshop after this symposium will see presentations and demonstrations of this kit.

But the work in Ontario has not been completed in isolation. On the contrary, our staff have been present at most of the meetings and workshops that have been organized and presented across North America. We have particularly benefitted from participating in the development of the Class A foam education and information plan. As you know, this plan was formulated the last time a group such as this gathered, at the first International Workshop held in Denver in 1988. Since that time, Ontario staff have been diligent, no - relentless - in stealing whatever information and technology that they could get their hands on!

Indeed, the group gathered here this week represents the large body of dedicated researchers and practitioners who must be recognized for developing the fire foam technology and application techniques. The use of fire foam has demonstrated the potential for improving forest fire suppression operations.

However, we also know that there are still many questions about the aspects of foam use that need to be addressed. In Ontario, we are confident we have the technical knowledge necessary to make foam and to use it effectively.

But as natural resource managers and resource stewards we still have a number of areas of concern.

First of all, we need to develop performance measures and indicators of cost-effectiveness for the use of foam. As public servants, particularly in the current fiscal environment, we must be concerned not only with the effectiveness of foam, but with it's cost effectiveness.

Related to that, we need to improve the operational guidelines that direct how foam should be used in order to maximize it's effectiveness and cost savings.

There is a need for improved understanding of the environmental impacts of foam use, both beneficial and detrimental. For example, how does the use of foam reduce the negative impacts on the environment resulting from traditional fire suppression operations, including blazing bulldozer lines and nozzle damage?

Last but not least, how can we best communicate the utility of foam to our staff, our stakeholders, and our public?

The symposium's first objective is to review the current wealth of knowledge. That knowledge has grown significantly since the Denver workshop six years ago. At that time, participants identified the immediate research, development and policy needs. Participants here are now challenged to carry the initiative forward by identifying future research needs and by setting the priorities for development over the next several years.

The agenda is a full one. The wide variety of topics should interest and engage us all.

In closing, I would like to wish you well in your deliberations. I am confident that we will continue to see the real benefits from your work as we move forward.

In order to know where we are going – It is helpful to know where we have been

A brief history of the International Foam Task Group

Hiram B. "Doc" Smith
Chairperson

The idea of a group to deal with issues of foam in an interagency/international context first surfaced with the NWCG Fire Equipment Working Team at a meeting in Grand Canyon National Park during Spring of 1987. FEWT appointed a Chairperson (Doc Smith, Fire Staff Officer for the Kaibab National Forest), suggested a number of people for possible membership, and gave the group the charge "CORRALL FOAM".

Foam Today is Pretty Much "In the Corral"

The first organizational meeting was held in Redding, California in the Fall of 1987. They formalized the Charter into four main functions:

- Improve communications and cooperation.
- Get agreement on questions and concerns.
- Guide establishment of performance requirements.
- Provide communications, training, direction and support to all users.

In Redding the Foam Task Group was more formally organized. It became:

- international
- interagency (at least in the U.S.)
- interdiciplinary including:

Wildlands	Aviation
Interface	Ground
Urban	Engine (trucks)

At Redding the International Foam Task Group set up an action plan to:

- Improve communications - The Foam Newsletter was born. (Three issues were published right away)
- Agreement on questions and concerns was addressed by starting the planning for a workshop to be in Denver during June of 1988.
- There was a beginning of training concepts starting with the Abbotsford international workshop in the Fall of 1987.

The Rochna/Schlobohm training sessions were developed into the interagency format that has served so well.

The Denver Workshop – June 6, 1988

The workshop was conceived, planned and carried out by the International Foam Task Group (with a lot of help from others).

The Proceedings were published by Petawawa National Forestry Institute of the Canadian Forest Service in the form of the "BLUE BOOK",

The BLUE BOOK provided guidance for a number of agencies, groups, and functional workers. The guidance included San Dimas, BIFC, Missoula Fire Lab, Petawawa National Forestry Institute, Foam Task Group, California Department of Forestry and Fire Protection, Florida Division of Forestry and many others.

The BLUE BOOK provided guidance applications, nozzles, proportioners, training, videos, aviation, concentrate and the tactics.

The Denver workshop provided guidance for several years and was thus a real success.

The Foam Newsletter

The Foam Newsletter now has 12 issues (this one makes number 13). The first five issues have had to be reprinted due to demand. There are 134 different articles in the first 12 issues and over 68,500 copies have been distributed in the U.S. and Canada.

Videos

The Fire Equipment Working Team through the Foam Task Group has produced a number of short videos that can be used in training, or other demonstrations. They include:

* Introduction to Class A Foam	produced in 1989
* Proportioners	produced in 1992
* Nozzles	produced in 1992

* Properties of Foam produced in 1993
* CAFS produced in 1993
* Tactics due out in 1994

These videos are a total of 103 minutes of very relative information.

Publications

The Fire Equipment Working Team through the Foam task Group has published two very informative publications.

The FOAM vs FIRE Primer

The FOAM vs FIRE Class A Foam

Another publication, FOAM vs FIRE Aerial Applications is due out in 1995

There have been a number of other items that have either been influenced by the Foam Task Group or have been sponsored by the Foam Task Group.

* Foam Kit part of the NFES cache. A kit containing a proportioner, nozzles, foam and a few other components.
* Foam Bibliography 1991. A scientific compilation of around a thousand articles about foam. This is on a diskette using the software "Procite". A copy can be obtained from the Fire Lab in Missoula.
* Input into NFPA 298. The NFPA foam standard.
* The Foam Task Group has developed the International Foam Specification 1992.
* The Foam Task Group assisted with the International Foam Symposium in Thunder Bay, Ontario.

Training

The Foam Task Group has provided coordination and direction for the BIFC training that Ron Rochna and Paul Schlobohm have developed.

They have conducted 3 International Workshops and some dozen workshops across the U.S. through the BLM and other agencies.

Ron Rochna and Paul Schlobohm developed a "Training Cadre" early on to help spread the word. They also developed training materials and rough lesson plans for the cadre to utilize.

Summary

The business of FOAM has come a long way since the Spring of 1987!

Today there are many users of foam in lots of places, in lots of ways

It is used in the WILDLANDS, the INTERFACE, the URBAN AREAS.

It is used AERIALLY, from the GROUND.

It is used in STRUCTURE protection.

They use it in the USA, CANADA, FRANCE, GERMANY, AUSTRALIA, SPAIN, ITALY and many other places.

There is INTERNATIONAL and INTERAGENCY COOPERATION.

We have good direction, excellent hardware, superior training aids, and a cost effective foam program.

Status

International wildland fire foam specification and NFPA 298 - Foam chemicals for fire control

Chuck George
National Wildfire Suppression Technology Program

Abstract

In 1986 when the USDA Forest Service began using foam in its wildfire control program, products were tested and procured under a set of Interim Requirements. The requirements were not specific to foams but were common to all of the wildland fire chemicals: health and safety, stability, and corrosion.

In 1992 an International Foam Specification Workshop was held in Missoula, Montana. A list of the characteristics of foam concentrate, foam solution, and foam that may be desirable or cause for concern to any of the user agencies was compiled. These characteristics were incorporated into a draft "International Wildland Fire Foam Specification." This document was reviewed by representatives of firefighting agencies and chemical suppliers from the United States, Canada, France, and Australia. Comments were incorporated into a revised specification.

Test methods and performance requirements were specified where they were readily available. In other cases a test method may be specified without performance requirements. In a few cases even the test method must be developed. That project is ongoing.

The National Fire Protection Association (NFPA) developed a standard (NFPA 298) to cover wildland fire foams during the same time period. The Forest Service and Bureau of Land Management worked on the original document and on the revision of NFPA 298 which is nearly complete. While not identical, NFPA 298 is very similar to the International Specification.

Résumé

En 1986, lorsque le Service des forêts américain (appartenant au ministère de l'Agriculture) a commencé à utiliser des mousses dans son programme de lutte contre les feux de végétation, ces produits ont été mis à l'essai et fournis aux termes d'exigences provisoires. Ces exigences ne s'appliquaient pas précisément aux mousses mais à l'ensemble des produits chimiques utilisés pour l'extinction des feux de végétation et portaient essentiellement sur l'innocuité, la stabilité et les propriétés corrosives des produits.

En 1992, on a organisé, à Missoula, dans le Montana, un atelier international en vue d'élaborer une spécification pour les mousses. On a établi, pour les concentrés, les solutions et les mousses, une liste des caractéristiques susceptibles d'intéresser ou d'inquiéter les organismes utilisateurs. Ces caractéristiques ont été consignées dans la version préliminaire d'un document intitulé «Spécification internationale des mousses utilisées dans la lutte contre les feux de végétation». Ce document a été revu par les représentants d'organismes de lutte contre l'incendie et par des fournisseurs de produits chimiques, venus des États-Unis, du Canada, de France et d'Australie. On a mis au point une version révisée à partir des commentaires formulés.

Des méthodes d'essai et des exigences de rendement ont été spécifiés lorsque celles-ci étaient déjà disponibles. Dans certains cas, on a précisé une méthode d'essai, mais non les exigences de rendement. Dans quelques cas, même la méthode d'essai n'a pas encore été mise au point. Les travaux se poursuivent.

Parallèlement, la National Fire Protection Association - NFPA (Association nationale de la protection contre les feux, aux États-Unis) a élaboré une norme (NFPA 298) sur les mousses utilisées dans la lutte contre les feux de végétation. Le Service des forêts américain et le Bureau of Land Management (Bureau d'aménagement des terres) ont travaillé à la rédaction du document de base et à la révision de la norme 298 de la NFPA, qui sera bientôt terminée. Bien que les deux documents ne soient pas identiques, la norme 298 est très semblable à la spécification internationale.

The USDA Forest Service requires that all firefighting chemicals be laboratory evaluated and approved prior to purchase and use by its field personnel. In 1985 when the Forest Service began investigating the possibility of using foam as a fire fighting tool, there were no performance requirements for Class A foams in wildland fire applications. There was little solid information about the performance of these materials.

The Interim Requirements were developed to fill the immediate need for a means of determining some minimum acceptable performance and allowing foams to be used in the field while additional information was developed. New products were submitted and evaluated against the listed requirements and performance characteristics common to all firefighting chemicals: health and safety (mammalian toxicity), long-term stability, uniform corrosion. There were no requirements specific to foam since the basic knowledge as to what makes a good foam was lacking. Products that met the minimal requirements contained in the Interim Requirements were listed on the Qualified/ Approved Products List of products that could be purchased and used for wildland fire fighting.

Over the next several years numerous studies in laboratories and in the field were undertaken to provide the missing basic knowledge. In 1992 a group of specialists met in Missoula, Montana, for an International Foam Specification Workshop. The goal was to share information about characteristics and performance that could be incorporated into a Forest Service specification. Ideally this specification, administered by the USDA Forest Service, would have international application and usefulness.

Time was spent developing a list of characteristics that might be desirable in a foam concentrate, foam solution, or foam. Test methods were suggested in some cases, while others remained unspecified when several options were available. In a few cases no known test method was considered applicable to the intended use.

In most cases, ranges or limits of performance were left undefined at that time. For some characteristics, the wide range of possible performance was seen as desirable for tailoring the product to the locale and intended use parameters. In other cases the information about what was "good" or "bad" was unknown or varied widely.

All of the information was gathered into a single document in specification format and a first draft Class A Foam Specification was prepared. This draft was reviewed by the entire group. Once their comments were incorporated, the resulting document was widely distributed for review and input. From these comments a "final" version of the specification has been prepared. There will continue to be revision as more is learned about foams but these will likely be minor.

Test methods were specified for the characteristics of interest; however, in some cases test methods were not readily available or were found to be inappropriate during the evaluation.

In general, no performance requirements were specified, as consensus regarding what was "good" foam was absent.

To provide the necessary technical information for implementing the specification, the National Wildfire Suppression Technology Program has an ongoing project, supported by FEWT and CCFFM. That project will be discussed in more detail in a later presentation.

During the same time period the National Fire Protection Association (NFPA) through its Technical Committee on Forests and Rural Fire Protection was developing its own standard for Class A Foam.

In 1989 the original document was approved, and the first revision was approved in 1994. Several of the same people worked on both documents (NFPA and FS) assuring that requirements were not mutually contradictory. In many cases the same requirements were used as development and revision of the two documents "leap frogged" each other with both incorporating the most recent knowledge and developments.

In 1994 the two documents are very similar. The Forest Service specification requires that the performance information for a number of tests and characteristics be determined to assist resource managers in determining which product best meets their needs. The NFPA document has narrowed the scope of their document somewhat to accommodate the narrower focus of their mission. This has been done by selecting some criteria found in the Forest Service specification and omitting others. They have also set limits in a few cases where the Forest Service has not.

Currently work by both the Forest Service and NFPA has broadened to include fire fighting effectiveness of Class A Foams. This work is likely to continue for some time.

References

Interim Requirements and Manufacturer Submission Procedures for Wildland Fire Foam; USDA Forest Service - San Dimas, CA; Special Report 8651 1803, August 1986.

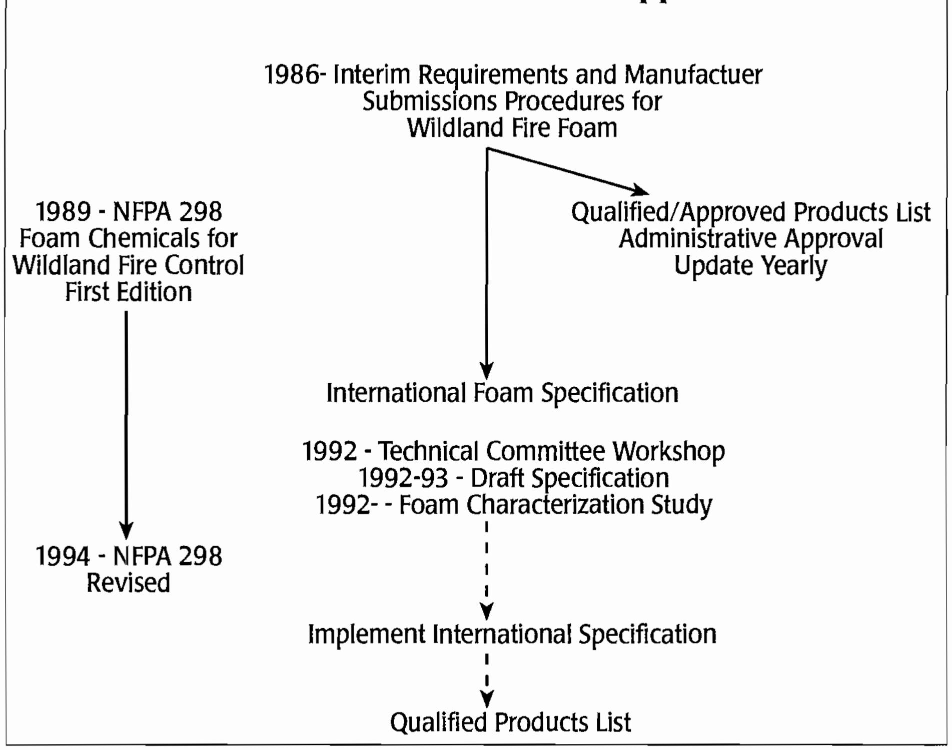
International Specification, Class "A" Foam for Wildland Fires, Aircraft or Ground Application, USDA Forest Service, August 1994.

Manufacturer Submission Procedures for Qualification Testing of Wildland Fire Chemicals; USDA Forest Service - Technology & Development Program; 5100-Fire, 8957 1803, December 1989.

Qualified/Approved Products List; prepared and updated each year by USDA Forest Service, Washington Office, Fire & Aviation Management, December 30, 1994.

Standard on Fire Fighting Foam Chemicals for Class A Fuels in Rural, Suburban and Vegetated Areas; NFPA 298, August 1994.

Foam for Wildland Fire Suppression



Characterization of Wildland Fire Foam

	Protocol selected	Performance information only	Required performance
Health, Safety, and Environment			
Mammalian Toxicity	Yes	No	yes
Fish Toxicity	Yes	No	Yes
Biodegradability	yes	No	Yes
Flash Point	Yes	No	Yes
Vapor Pressure	Yes	Yes	No
Stability			
Temperature Cycling	Yes	No	Yes
Temperature - Viscosity	Yes	Yes	No
Temperature - Proportioning	No	Yes	No
Physical Properties			
Density	Yes	Yes	No
pH	Yes	Yes	No
Viscosity	Yes	Yes	No
Pour Point	Yes	Yes	No
Effectiveness			
Miscibility	Yes	Yes	No
Foaming Ability	Yes	Yes	No
Wetting Ability	Yes	Yes	No
Expansion/Drain Time	Yes	Yes	No
Expansion/Drain Time			
Water Quality	Yes	Yes	No
Water Temperature	Yes	Yes	No
Concentration	Yes	Yes	No
Generator Type	Yes	Yes	No
Materials Effects			
Uniform Corrosion	Yes	No	Yes
Intergranular Corrosion	Yes	No	Yes
Protective Coatings	Yes	No	Yes
Non-metallic Materials	Yes	No	Yes
Concentration Effects			
Surface Tension	Yes	Yes	No
Conductivity	Yes	Yes	No
Refractive Index	Yes	Yes	No
Future Efforts			
Moisture Retention	No		
Fire Testing	No		
Compatability	No		

Characterization of Wildland Fire Foam

	Interim Req's	**NFPA 298 1989**	**Int'l Spec**	**NFPA 298 1994**
Health, Safety, and Environment				
Mammalian Toxicity	Req	Req	Req	Req
Fish Toxicity	No	Req	Req	Req
Biodegradability	No	Req	Req	Req
Flash Point	P.I.	Req	Req	No
Vapor Pressure	No	No	P.I.	
Stability				
Temperature Cycling	Req	Req	Req	Req
Temperature - Viscosity	No	No	P.I.	P.I.
Temperature - Proportioning	No	No	P.I.	No
Physical Properties				
Density	P.I.	No	P.I.	No
pH	P.I.	No	P.I.	No
Viscosity	No	No	P.I.	No
Pour Point	No	No	P.I.	No
Effectiveness				
Miscibility	No	No	P.I.	P.I.
Foaming Ability	No	No	P.I.	P.I.
Wetting Ability	No	No	P.I.	P.I.
Expansion/Drain Time	No	P.I.	P.I.	P.I.
Expansion/Drain Time				
Water Quality	No	P.I.	P.I.	P.I.
Water Temperature	No	No	P.I.	No
Concentration	No	No	P.I.	No
Generator Type	No	No	P.I.	No
Materials Effects				
Uniform Corrosion	Req	Req	Req	Req
Intergranular Corrosion	Req	Req	Req	Req
Protective Coatings	No	No	Req	No
Non-metallic Materials	No	No	Req	Req
Concentration Effects				
Surface Tension	No	No	P.I.	P.I.
Conductivity	No	No	P.I.	No
Refractive Index	No	No	P.I.	No
Future Efforts				
Moisture Retention				
Fire Testing				
Compatability				

P.I. indicates that the test is required to generate performance information.

Technical Session I:
Properties and Effectiveness

Efforts in characterizing wildland fire foams

Cecilia Johnson
National Wildfire Suppression Technology Program

Abstract

The International Specification for Wildland Fire Foam contains a number of characteristics of interest to users of fire fighting foam. A Foam Characterization Study was undertaken to provide the information necessary to transform the draft specification and characteristics list into a formal specification.The information to be developed for each characteristic includes a suitable test method, performance of foams currently in use, and a range of acceptable performance. The performance information will be available to the end user to aid in product selection. The characteristics fall into one of the following broad categories:

Health, Safety, and Environment
Corrosion and Materials Effects
Physical/Chemical Properties
Effectiveness
Stability

Where suitable test methods are available most of the work is between 75 and 100 percent complete. Several of the tests that have not been completed, have appropriate test methods available but the tests are costly to run. In other cases test methods had to be developed. That work is progressing.

Résumé

The International Specification for Wildland Fire Foam (la «Spécification internationale des mousses utilisées pour l'extinction des feux de végétation») renferme un certain nombre de caractéristiques susceptibles d'intéresser les utilisateurs de mousses carboniques. On a entrepris une étude de caractérisation des mousses afin de recueillir les renseignements dont on a besoin pour constituer une spécification officielle à partir des caractéristiques et des spécifications préliminaires. Parmi les renseignements à obtenir pour chaque caractéristique, mentionnons une méthode d'essai appropriée, le rendement des mousses actuellement utilisées ainsi qu'une plage des valeurs de rendement jugées acceptables. On mettra ces données de rendement à la disposition des utilisateurs afin de les aider dans le choix des produits. Les caractéristiques étudiées appartiennent à l'une ou l'autre des grandes catégories suivantes :

santé, sécurité et environnement;
corrosion et effets sur les matériaux;
propriétés physiques et chimiques;
efficacité;
stabilité.

Dans tous les cas où l'on disposait de méthodes d'essai appropriées, les travaux sont terminés ou achevés à 75 pour cent au moins.. Dans plusieurs des cas où les essais n'ont pas été complétés, on dispose des méthodes d'essai appropriées mais non des fonds nécessaires pour mener les travaux à bien. Dans d'autres cas, il fallait mettre au point des méthodes d'essai; ces travaux se poursuivent.

Background

In 1986 when the USDA Forest Service began using foam in its wildfire control program, products were tested and procured under a set of Interim Requirements. The requirements were not specific to foams for wildland fire fighting but were common to all of the wildland fire chemicals: health and safety, stability, and corrosion. In 1992 an International Foam Specification Workshop was held in Missoula, Montana. A list of the characteristics of foam concentrate, foam solution, and foam that may be desirable or that were of concern to any of the user agencies was compiled. These characteristics were incorporated into a draft version of an "International Wildland Fire Foam Specification." The draft was reviewed by representatives of fire fighting agencies and chemical suppliers from the United States, Canada, France, and Australia. Their comments were subsequently incorporated into a revised draft of the specification.

The proposed International Foam Specification contains requirements for the measurement of numerous aspects of the performance of foam concentrate, foam solution, and foam under a variety of conditions. Test methods and performance requirements were specified where they were readily available. In other cases a test method may be specified without performance requirements. In a few cases even the test method must be developed. The Foam Characterization Study was undertaken by the National Wildfire Suppression Technology Program, with support from FEWT and CCFFM, to provide the information needed to implement the specification. There are several steps in the process, which apply to each characteristics of interest.

- Select/adapt test method for each characteristic
- Determine performance of currently approved products
- Determine which characteristics should have limits
- Set appropriate limits
- Determine if each approved product meets the limits
- Compile information for end users.

In most cases several of the steps have already been accomplished. Regardless, the more that is already known about a characteristic the further down the path we were able to proceed.

For example, let's consider the mammalian toxicity tests. The test method selected was the same method used for other fire chemicals, the test has been performed on all of the approved products. The limits were set when the Interim Requirements were implemented and agency specialists agreed that those should continue. Each of the approved products meets the limits, indeed that was a condition of approval. That information is available, although indirectly, since approved products must meet the requirement to be approved.

A similar process has been undertaken for each of the characteristics found in the draft specification. It may take several tries to find a test method that is useful across the range of performance found with the current approved products. This may involve starting from scratch or it may be a simple modification of the method: weight or volume to be used, temperature during testing, duration of the test, etc.

As quickly as a reasonable test method is found, a base of data on the performance of currently approved products is prepared for use in determining the conditions and characteristics to be included in the final draft of the foam specification and to provide performance information to assist field personnel in their selection of foam products. Many of the tests are on the foam concentrate or foam solution, however some are performed on the foam itself. In order to test the foam it is first necessary to have a means of preparing reproducible foam in the quantity needed. NWST has been using a foam generator that is truly one-of-a-kind. It has been modified over the years as needs changed. While it has served the purpose and has a large data base associated with it, it is not likely to be replicated. To rectify this problem, a parallel study was undertaken in cooperation with the Bureau of Land Management to develop a new foam generator that retained the best characteristics of the original system but which incorporated some features that would be helpful in communicating with field fire people and which could be assembled by others working in the same area of interest.

A prototype has been developed and modified to correct problems found during initial testing. Additional testing is underway. The aim of this testing is to determine what settings, if any, can be used to produce the same types of foam with the same properties as those from the original generator.

While the generator evaluation is going on, the development of other test methods has also been moving forward. For simplicity, the characteristics of interest have been grouped into several categories. The remainder of the discussion will proceed in the same manner.

Health, Safety, and Environment

Product Review

The list of ingredients in each of the approved wildland fire foams has been compared against several lists of regulated chemicals appearing in the Code of Federal Regulations. The lists used were:

40 CFR 355.5	CERCLA Extremely Hazardous Substances
40 CFR 302.4	CERCLA Hazardous Substances
40 CFR 261.33	RCRA Acutely Hazardous and Toxic Wastes
40 CFR 372	SARA Title III sec 313

Annual Report of Carcinogens from the U. S. Dept. of Health and Human Services

Ingredients present in small amounts in various concentrates were found on the lists. The reportable quantities of these far exceed the likely use of the foam.

Mammalian Toxicity (Health and Safety)

All approved foam concentrates must meet the same requirements for mammalian toxicity as any other wildland fire chemical before they are approved for use. Included in this test series are acute oral and dermal toxicity and skin and eye irritation tests. All of the foam concentrates cause moderate to severe irritation to eyes. To prevent eye injury splash goggles should be worn when handling the concentrates. In addition, exposure can cause slight to moderate skin irritation and chapping. Wearing suitable impervious gloves will prevent exposure. All manufacturers have listed appropriate protective equipment on their Material Safety Date Sheets (MSDS) prepared for all of the foam concentrates.

Fish Toxicity

Fish toxicity (96-hour rainbow trout) tests have been proposed. Some testing has been done by the foam suppliers. Not all products have been evaluated using the specific test methods recommended.

The National Biological Survey, Yankton, SD has conducted a series of aquatic toxicity tests on representative wildland fire chemicals including two foams. Results will be discussed later this week. Tests are being performed on a variety of aquatic species. The results will assist in determining whether the rainbow trout is a good choice as an indicator species for evaluating the effects of foam on aquatic species.

Biodegradability

Aquatic aerobic biodegradability tests, as found in NFPA 298, have been proposed. Some testing has been done by the suppliers of the foam products, but not all products were evaluated using the same test method. Another test method, the closed bottle test, has been suggested with the comment that it is more commonly performed and more widely accepted. In this test, the bacteria are not acclimated to the test material prior to starting the measurement.

Studies of the biodegradability of all approved foams using both test methods are currently underway.

Flash Point

Two methods of determining flash point have applicability to the ways in which we use, handle, and store the foam concentrate operationally. The open cup method of determining flash point (and fire point) are a measure of the hazard in the workplace as when concentrate is being transferred into reservoir tanks, especially at high temperatures or near hot equipment.Closed cup methods are applicable in measuring the hazards involved in storing and transporting the concentrate. This is the method used by EPA and DOT to determine hazard under their regulations. Both open and closed cup flash points have been determined by an outside testing lab on all of the approved products. Only one of the approved products had a flash point by either open or closed cup method.
Vapor Pressure

The vapor pressure may provide a measure of how likely components are to be present in a form that may impact/impair the ability of flight crews to perform their jobs.The vapor pressure of each of the concentrates on the qualified/approved products list has been determined by an outside laboratory. Values for the foam concentrates range from 0.5 to 1.0 psi (26 to 52 mm Hg). For comparison,the vapor pressure of methanol is 97 mm Hg and of gasoline is 400 mm Hg.

Effectiveness

Miscibility

Many of the foam generating systems in use do not contain mixers to assure that foam concentrate and water are well mixed prior to application. Therefore the ease with which concentrate goes into water solution, miscibility, is of concern. If the product will not disperse easily, then it should not be used in dipping and scooping operations without good onboard mixing systems.

The foam concentrate and water (distilled, tap, and synthetic sea water) at several temperatures will be combined to determine ease of mixing. The first series of tests, using 70 F and 40 F tap water and foam concentrate, has been completed. The water, of proper temperature, was stirred slowly (about 60 rpm) as the concentrate was added. After each 10 revolutions, the stirrer was stopped and the contents of the beaker described. If the contents were not visually homogeneous, the process was repeated, with 10 revolution increments of stirring between observations.

With 70 F water and concentrate, most of the solutions were homogeneous after 10 revolutions of the stirrer, and all were homogeneous after 90 revolutions. When the water was at 70 F and the concentrate was at 40 F, 5 of the products were homogeneous after 10 revolutions, 2 products required 40-50 revolutions, and the last was homogeneous after 130 revolutions. When the water was cold and the concentrate was warm, 6 of the products were homogeneous after 10 revolutions, 1 product required 40 revolutions, and 1 product was not homogeneous after several hundred revolutions. When the water and the concentrate were cold, 3 products were homogeneous after 10 revolutions, 1 product required 30 revolutions, 3 products required 90-100 revolutions, and 1 never produced a homogeneous solution.

Foaming Ability

A simple test of foaming ability can be performed by mixing a small quantity of foam solution in a graduated cylinder, agitating the cylinder, and measuring the volume of foam produced. Tests on all of the approved products were performed. The visible foam structure remained intact through most of the test period, so that the more meaningful values are the total height of foam in the cylinder and the amount of solution drained out at 1 or 2 minutes. Wetting Ability

The detergent industry uses a skein test to measure the effectiveness of the wetting agents in their products. While not directly related to wetting of forest fuels, a skein test may be a reasonable measure for the comparison of the wetting abilities of foam solutions. It is a simple, inexpensive test that may lend itself to a quality control method.

A supply of cotton skeins was acquired. The only other equipment needed is a graduated cylinder, a stopwatch or watch with second hand, and a standard weight. Test measurements were made using ASTM D 2281, "Standard Method for Evaluation of Wetting Agents by the Skein Test."

Using the standard weight (3.0 grams), very fast, <5 seconds, sink times were obtained with all of the products. The very fast sink times made accurate time measurements difficult and did not allow for differentiation between products.

A modification was made to the procedure and a lighter, 0.8 gram, S-hook was used. This allowed for more accurate measurements and differences in performance for different products and for different concentrations of the same product. However, in some cases the skein did not sink at all, especially in low concentrations. Tests will be repeated using an intermediate weight hook, about 1.5 grams.

When the sink times and the surface tensions for the same product at the same concentrations are compared, it appears that the surface tension stabilizes at a lower product concentration than does the wetting ability. That is, surface tension is fairly constant across the concentration range, while the wetting ability requires somewhat more than 0.3 percent before the sink time levels out.

Expansion and Drain Time

Expansion and drain time are properties of the foam concentrate, concentration, generating system, water quality, and temperatures. The combination of all of these factors, and probably others, determines the quality of the foam produced. Work is underway to determine the relative performance of the approved foam concentrates under a variety of conditions. The basic matrix, shown below, looks simple, but results in several thousand tests.

Foam concentrate: All approved and candidate products
Water: Distilled, tap, artificial sea water
Temperature: 40, 70, and 100 F
Concentration: 0.3%, 0.6%, and 1.0%
Concentrate age: "fresh", frozen, aged (1 year)
Generator: 4 settings to simulate dry, fluid, and wet foam, and very wet (almost foam)

The tests with distilled and fresh water have been completed. The tests with artificial sea water are in progress.Expansions from 1.5:1 to nearly 25:1 have been produced. Combinations of some foam brands and generator settings yield distinctly different foams, especially with the high and low water temperatures. Comparing the results of distilled water foam and tap water foam suggests that some products are much more sensitive to water quality especially presence of some mineral salts than others. Similarly, some products perform equally well in cold or warm water, while others show significant differences in performance.

Physical Properties

Viscosity, Density, and pH

Baseline measurements on the viscosity, density, and pH of the approved concentrates at room temperature (approximately 70 F) have been made. Viscosities range from 30 to 145 centipoise; densities from 1.010 to 1.042 grams per milliliter; and pH from 6.6 to 8.9.

Pour Point

The pour point of a concentrate is a measure of how low a temperature the concentrate can attain and remain fluid. It is a very simple test that could be easily run in the field or the lab. All of the concentrates are sufficiently fluid to pour at temperatures between 20 and 30 F. The ease of pouring is not measurable by this test.

Concentration Effects

Surface Tension

Surface tension is related to wetting ability. While it is indirect, it lends itself to reproducible, quantifiable results in the laboratory. All products were tested using 0.01%, 0.05%, 0.1%, 0.3%, 0.6%, and 1.0% foam concentrate in water. Values for all products were comparable, with surface tensions ranging from 23.1 to 33.4 dynes/cm. For comparison, water has a surface tension of approximately 73 dynes/cm. A Forest Service approved wetting agent had values from 28.5 to 48.3 dynes/cm over the same range of dilutions.

Conductivity

Measuring the conductivity of a foam solution has been suggested as a simple, inexpensive means of determining concentration. The conductivity of foam solutions of known concentration have been determined at several predetermined temperatures. There is good correlation between the concentration of the foam solution and the conductivity. The conductivity increases with increasing concentration and also with temperature. A 0.3% solution at 90 F has about the same conductivity as a 0.6% solution at 70 F. The combined effects of temperature and concentration may be large enough to make the use of conductivity as a field quality control measure difficult. Preliminary studies suggest that a temperature compensated, conductivity pen could be suitable for a field quality control device for measuring the concentration of the foam solutions. Tests to determine the ability of the pen to compensate for temperature in the range of interest for foam concentrates and to provide reproducible conductivity readings are planned.

Refractive Index

Refractive index, measured by a simple hand-held refractometer has been used for some time as a quality control measure for long-term retardants. It is also used in several NFPA documents for Class B and AFFF foams. However, the handheld refractometers do not measure with sufficient precision in the range of interest for Class A foams.

Materials Effects

Uniform Corrosion

All of the approved products were tested to determine the corrosivity of the foam concentrate and foam solutions (one percent and one-tenth percent) to 2024-T3 aluminum, 4130 steel, yellow brass, and Az31B magnesium at two temperatures (70 F and 120 F) and two immersion conditions (total and partial immersion). All results were within the required limits (set for all wildland fire chemicals) for use from fixed-wing airtankers, helicopter buckets, and ground engines. Agencies may restrict use based on other policies and considerations.Two products were granted administrative approval for use from fixed-tank helicopters, based on corrosion test results that are least corrosive to magnesium (but exceed the required limit). Recently, one of the newly approved products fully met the corrosion requirements for use from fixed-tank helicopters. Until it is available for purchase by natural resource agencies, through General Service Administration (GSA), the temporary approvals remain in place.

Intergranular Corrosion

All of the approved foam concentrates produce foam solutions which do not cause intergranular corrosion to 2024-T3 aluminum during the uniform corrosion tests. In addition those products approved for use from fixed-tank helicopters do not cause intergranular corrosion to magnesium.

Effects on Protective Coatings

Much of the concern that Canadair has expressed in regard to foams centers around the effects of exposure to the foam concentrate, solutions, and foam to the integrity of the coatings that they use to protect their aircraft from corrosion. Canadair has recently of updated their foam specification to include materials used on the CL-415.

Canadair has supplied small samples of production coated metal pieces to be tested in accordance with their specification and their in-house test procedures. The test samples have been exposed to the foam concentrations and solutions. All samples are being examined for blistering, peeling, or other evidence of poor performance. The results will be compared to those obtained by Canadair on the same materials.

Effects on Non-metallic Materials of Construction

Exposure to foam may degrade the materials used on aircraft, such as fiberglass, neoprene, gaskets, foams. To minimize this problem, Canadair has developed their own specification containing test methods, materials, and required results to protect these materials. Applicability of these results go beyond Canadair concerns as most of these materials are used in other foam systems.Canadair has supplied a small quantity of each of the non-metallic materials to be tested and the procedures used for their in-house testing. The volume and hardness of all materials were measured prior to exposure to the foams. Samples were exposed to the foam solution. At the end of the exposure, hardness and volume measurements were repeated for comparison to the original values.

Stability

Viscosity as a Function of Temperature

The viscosity of the concentrate is related to the ability of the concentrate to flow and the ease, accuracy and reproducibility of proportioning. The viscosity of the concentrates were measured at 35 F, and at 10 degree intervals from 40 to 100 F. Maximum viscosities for the various products ranged from 65 to 1120 centipoise at the lowest temperatures and from 18 to 40 centipoise at the high temperature. Representatives of several Canadian forestry agencies have requested that the low temperature measurements be performed at 32 F or lower. Members of the NFPA Committee on Forest and Rural Fire Protection have requested that the high temperature limit be increased to 120 F. This work, when completed, will more accurately reflect the environmental extremes to be found in North America.

Marsh Funnel Flow Time as a Function of Temperature

Work using the Marsh Funnel with a small tip insert has been conducted. This method shows some promise for a simple laboratory test of proportionability. All of the currently approved foam concentrates have been tested using the Marsh Funnel. Results indicate some differences at 70 and 100 F, with some overlap of values. The flow-through times at 70 F range from 49 seconds to 1 minute:17 seconds. The values at 100 F range from 41 seconds to 58 seconds. There are large differences in flow-through times at 40 F, with different concentrates taking from 1 minute: 16 seconds to 3 minutes: 54 seconds for 1 quart of concentrate.

Future Efforts

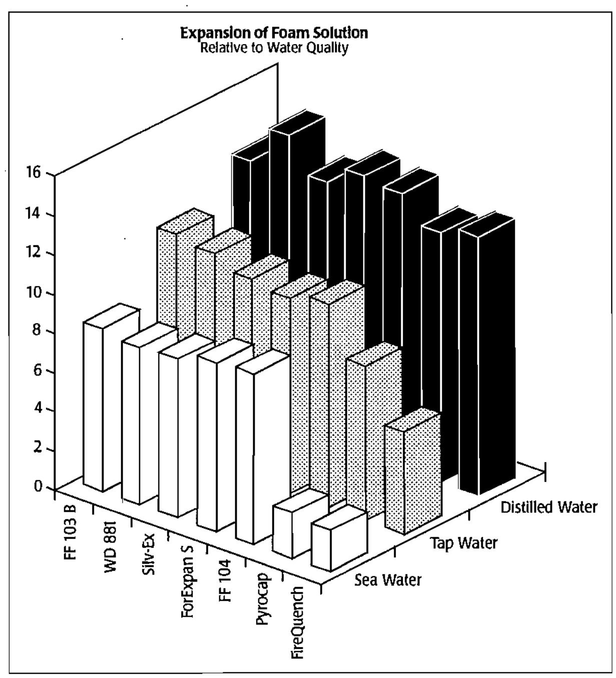
There is still much work to be done, especially in regard to several aspects of effectiveness:

Moisture Retention
Fire Testing
Compatibility

Several tests have been tried with varying levels of success. In most cases the results are negative, that is they show that the particular test does not differentiate between products or have applicability. Effects will continue. There has been much information developed that will be shared this week. Some may be of help.

International Standards and Standards Updates

The International Organization for Standardization (ISO) functions much like ASTM or NFPA on an international scale. They provide a framework of test methods and procedures for use worldwide. As they become available, they will be included as citations for ISO standard methods into the International Class A Foam Specification.Several of the specifications, standards, and regulations cited in drafts of the foam specification have been revised, updated, or eliminated since copies were obtained. Review of each situation is ongoing, on a case by case basis, to determine whether the revised information should be used and the impact, if any, on the foam characterization program.



NFPA recent and future studies

Rich Bielen, P.E.
NFPA Research Foundation, Batterymarch Park, Quincy, MA USA

Abstract

Class A foam has been used very effectively to fight wildland fires. This success has raised many questions as to the effectiveness of Class A Foam on structural fires. The Research Foundation was approached to start a project which would quantify the effectiveness of Class A foam vs. water on Class A materials.

The Research Foundation has completed one phase of the project which examined and measured the effectiveness of Class A foam and CAF vs. water on the extinguishment and rekindle of wood crib fires, exposure protection of wood cribs, and retention properties on wood cribs.

Presently, the Research Foundation is conducting the next phase of the project which is to examine and measure the effectiveness of Class A foam and CAF vs. water in full scale room fire tests, with a UL 1626 residential fuel package and upholstered furniture.

Résumé

Les mousses de classe A se sont révélées très efficaces pour combattre les feux de végétation. Ces résultats ont soulevé de nombreuses questions quant à l'efficacité de ces produits dans la lutte contre les incendies dans les bâtiments. On a demandé à la Research Foundation de mettre sur pied un projet qui aurait pour but de quantifier l'efficacité relative des mousses de classe A et de l'eau ordinaire sur des matériaux de classe A.

La Research Foundation a terminé la première phase de ce projet qui consistait à examiner et à mesurer l'action des mousses de classe A et des mousses entraînées par air comprimée, d'une part, et celle de l'eau ordinaire, d'autre part, sur l'extinction et la reprise des flammes, la protection et les propriétés de rétention, dans des essais menés sur des bûchers en bois.

À l'heure actuelle, la Research Foundation travaille à la deuxième phase du projet; elle examine et mesure l'efficacité relative des mousses de classe A, des mousses entraînées par air comprimé et de l'eau ordinaire par des essais réalisés dans des compartiments en vraie grandeur sur des matériaux résidentiels combustibles et des meubles rembourrés, conformes à la norme 1626 des UL.

A brief overview of the National Class A Foam Fire Test Project will be presented here. For those of you who are not familiar with the NFPA Research Foundation, an overview of the Foundation will be given along with the history and background for the Class A foam project.

Mr. Bill Carey of Underwriters Laboratories Inc. of Northbrook, IL, USA was the contractor for the fire tests and he will go into more detail of the test results in his presentation.

The NFPA Research Foundation

The Research Foundation is an independent, public, non-profit Foundation, whose mission is to provide practical, usable data on fire risk, new technologies and strategies, and state-of-the-art firesafety methods.

How does the Research Foundation Operate?

First of all the Research Foundation identifies a need to conduct research. The need sometimes is identified by a NFPA technical committee and sometimes from an outside source such as industry members. The class A foam project need was identified by manufactures who saw a new market for class A foam, structural fire fighting.

Once the need has been identified and it appears this could be a viable, fundable project, a core planning meeting is held. A core planning meeting consists of about 10 members who help identify the goals and objectives of the project, the scope, the tasks, the schedule, the budget and sources of funding for the project.

As a result of the core planning meeting, the Foundation then decides if the project should go forward and is fundable. The Research Foundation does not have a pot of money for research. All projects must be funded by conducting a fundraising campaign. A proposal is then developed and is used in a solicitation package for fundraising.

A Technical Advisor Committee (TAC) is formed, consisting of the principal sponsors of the project and building code-and-standards writers. The TAC is the body that directs the project, reviews the test results, and makes recommendations on future test parameters. They are invited to witness all fire tests and also review and comment on the draft and final report.

In summary the Foundation facilitates research, provides a mechanism, an independent process, gets research data to people who need it, facilitates decision-making and raises funds.

National Class A Foam Fire Test Project

There are two phases of the project:

- Testing and Analysis Phase
- Full Scale Room Fire Testing & Analysis Phase

Testing and Analysis Phase History and Background

The Research Foundation was approached by the industry representatives in 1991 to conduct a test program for class A foam in structural fire fighting. Class A foam was being used very successfully in wildland fires and they could see an advantage to using class A foam to enhance structural fire fighting.

The Research Foundation completed a request for proposal and in February 1993 selected Underwriters Laboratories to conduct the testing. Fire tests were conducted in August 1993 with the draft report completed in the fall of 1993. The Report for this phase was issued in January of 1994.

Testing & Analysis Phase Testing Program

There were three major areas investigated in this phase:

- 20A Wood Crib-Knockdown, Rekindle
- Exposure Protection
- Retention Tests

The 20A wood cribs were used to investigate the comparison of water, air aspirated class A foam and compressed air foam (CAF). This crib fire is normally extinguished with 33 gpm of water applied for one minute on the crib. In these tests only 15 gpm of agent was used for one minute, applied to three sides. A comparison of knockdown, rekindle and crib weight loss was recorded for various mix and expansion ratios.

For the exposure protection tests, a smaller 1A wood crib was used. The ignition times of the wood cribs were recorded as the crib was exposed to several heat fluxes. The cribs were untreated, treated with water and treated with air aspirated foam and CAF at various mix and expansion ratios.

In the retention tests, a 1A wood crib was used as a base sample. Again water, air aspirated foam and CAF were used for comparison. The agents were applied to the cribs for a designated amount of time. The weight of the crib before agent was applied as well as the weight of the crib after the agent was applied was recorded. The agent application time and measurement times were varied as well as the mix and expansion ratios.

Testing and Analysis Phase Technical Advisory Committee

The following is a list of the TAC which directed the project and reviewed test data and made recommendations:

Ansul Fire Protection
California State Fire Marshal
Canadian Forces Fire Marshal Staff
Elkhart Brass Manufacturing
Fire Apparatus Manufacturers Association
Fort Worth Fire Department
Hale Products/Foam Pro
Nashville Fire Department
National Foam
Pierce Manufacturing
Plano Fire Department
J. Gordon Routley
State Farm Fire & Casualty Company
U. S. Air Force
U. S. Forest Service
Underwriters Laboratories Inc.

Full Scale Room Fire Testing & Analysis Phase History and Background

This phase of the project is an extension of the testing and analysis phase. The Research Foundation held a project briefing in December 1993 in the Washington, D.C. area. The fundraising was initiated in January 1994 and the TAC for this phase, first met in March 1994.

Fire tests were initiated in April 1994. The testing for this phase is approximately one half way completed. Further testing is to be conducted in May/

June. It is anticipated that this phase of the project will be completed in July 1994.

Full Scale Room Fire Testing & Analysis Phase

This phase of the project will examine the effectiveness of water, air aspirating class A foam and CAF to extinguish a room fire. The room is 8'x12'x8' high with a 60" opening in one side. The walls are lined with combustible paneling and the ceiling is combustible ceiling tiles. The fuel package consists of two wood framed, poly ether foam covered simulated pieces of furniture. The two pieces of simulated furniture are turned into the corner. Also in the corner is a small pan of heptane and a small wood crib.

The heptane and wood crib is ignited and the room is allowed to free burn until flashover. Five seconds after flashover, the agent is applied to fire until extinguishment. The heat release rate, oxygen content, carbon monoxide, carbon dioxide, optical density, smoke release rate and temperatures are all recorded.

Full Scale Room Fire Testing & Analysis Phase Technical Advisory Committee

The following is a list of the TAC which directed the project and reviewed test data and made recommendations:

California State Fire Marshal
Canadian Forces Fire Marshal Staff
Elkhart Brass Manufacturing
Fort Worth Fire Department
Hale Products
Insurance Service Organization
Nashville Fire Department
Plano Fire Department
Pyrocap Inc.
J. Gordon Routley
State of Texas
U. S. Air Force
U. S. Forest Service
Underwriters Laboratories Inc.
Waterous Co.

Where Do We Go From Here?

There has been considerable interest from sprinkler manufacturers to examine the effectiveness of class a foam in sprinkler systems. This possibility will be examined in the near future.

Army fire research and development Class A foam evaluation

Samuel Duncan

Department of Army, Tank-Automotive Research, Development & Engineering Center
Fire Research and Development, Fort Belvoir, Virginia

Abstract

The Army Materiel Command (AMC), responding to procurement inquiries, requested information from the Army research community at Fort Belvoir about the performance of Class A firefighting foam.

In compliance with current Department of Defense policy, we sought non-government standards as guidance for our response to AMC and found that there were no performance standards for Class A firefighting foams. We determined that an appropriate response might include a program of performance evaluations of foams regarded as having met a level of environmental acceptance, such as the U.S. Department of Agriculture's Qualified Products List.

The evaluation was conducted using test procedures found in the NFPA project. The program received limited funding and the data is not considered conclusive. It clearly shows, however, the Class A firefighting foams improve the performance of water alone and that much more research is needed.

Résumé

En réponse à des demandes de renseignements au sujet de l'approvisionnement, les Services du matériel des forces terrestres des É.-U. se sont adressés aux chercheurs de Fort Belvoir pour obtenir des détails sur le rendement des mousses carboniques de classe A.

Conformément à la politique actuelle du Department of Defense, nous avons cherché des normes non gouvernementales qui nous auraient permis de répondre aux demandes de renseignements des Services du matériel et constaté qu'il n'existait aucune norme de rendement sur les mousses carboniques de classe A. Pour fournir une réponse satisfaisante, nous avons dû mettre sur pied un programme d'évaluation des mousses réputées présenter un degré acceptable d'innocuité pour l'environnement, notamment celles qui figurent sur la liste des produits homologués par le ministère américain de l'agriculture.

Nous avons évalués ces produits à l'aide des méthodes d'essai recommandées par la NFPA. Notre programme a bénéficié d'un financement limité, et nous estimons que les données obtenues sont peu concluantes. Toutefois, les essais ont clairement démontré que les mousses carboniques de classe A amélioraient sensiblement le rendement de l'eau ordinaire et que seules des recherches beaucoup plus approfondies permettront d'obtenir des résultats tangibles.

Good morning, Ladies and Gentlemen, I am honored to be here representing the United States Army and the Tank-Automotive Research, Development and Engineering Center's fire research and development. I want to thank Chuck George and Bob Joens for inviting me and our Canadian hosts for putting the symposium together. I would also like to thank firefighters everywhere for their magnificent and brave performance.

Department of Army recently began reestablishing research and development activities for Army fire service. That rebirth includes, but is not limited to, the development and procurement of a new Halon recharging machine, tactical liquid fuel firefighting for soldier firefighters and Class A firefighting foam evaluation. We want a measurable standard that will allow the scientific endorsement of the highest level of performance of Class A foam for extinguishment, prevention of reignition and exposure protection available on the market.

Before June 1992 the Army procured fire trucks and other firefighting equipment through a process both painful and protracted. The process required the R&D Center to write a military specification, or MIL-SPEC, for the equipment. A procurement authority, using the federal acquisition regulations and procedures, would solicit bids and ultimately award a contract. Although the MILSPEC was reviewed by selected

Army fire chiefs before being finalized and forwarded to procurement, fire personnel were not contacted or consulted through the process of award, manufacturing and delivery. Operational life expectancy for apparatus was 15 years but replacement of overaged equipment was funded only when dollars became available at the end of the fiscal year. No plan, no budget, no program and no research designed to address Army requirements existed.

In June of 1992 the GSA began offering fire trucks under a process that is easy to use and cost effective; their program has been successful in many ways. The Army fire research, development and procurement community can now focus on specific requirements not currently being met that are singular to Army fire service rather than developing MILSPECS for fire trucks.

While many operational similarities between the DoD fire services abound there are differences. Because of those differences and because no single agency should have to fund or conduct the research and development required, the Army is moving toward the development of a structured program that will serve Army firefighters, including soldier firefighters in the Engineers, four ways: increase firefighter safety, increase firefighting effectiveness, reduce or simplify equipment and rapidly exploit new and emerging technologies.

Nothing is new in that agenda, any agency responsible for firefighters is striving for each item. What is new is the manner in which Army will pursue safety, effectiveness, equipment and exploitation of new technology. We believe fighting fires is very much like warfare. Army doctrine requires a highly mobile force take the battle to the enemy, deliver devastating blows with pinpoint accuracy against the targets most likely to cause total capitulation thus achieving the quickest end to the conflict. We will take the battle to the fire in ways more vigorous than before.

Firefighters learn quickly on the fire ground. They must learn quickly or their repeated mistakes will earn them failure, injury or death. Researchers' mistakes cause repetitious, and sometimes painful, explanations about data obtained, test protocols redefined and the incessant petitioning for additional funds to conduct tests that will answer questions very often posed by the funding authority.

We will be accountable to the firefighter and no other. We will be driven by the firefighters requirements and fire ground inabilities; we will coordinate research and equipment development with the trainer and the user and we will compete successfully for research funds on several fronts, through the budget process, through aggressive partnering, with other government agencies at any level, academia and corporate interests and by seeking to convert funds for inactive or terminal programs.

Department of Army has for many years fomented its own specification and standards largely ignoring non-military groups such as the National Fire Protection Association and American National Standards Institution. We intend to use, to contribute to and promulgate the standards set by the appropriate bodies recognized in that field. In the interest of national security and readiness of our military forces, however, we must reserve the right to suspend them or to apply stricter standards and more narrowly defined specifications, where required. We are members of the community and we have a duty to be a part of it, to play the role that will be most beneficial according to our ability.

The data from the Class A foam tests performed for Army are, in our opinion, inconclusive. But the report is public domain, with unrestricted release and we believe it is the most comprehensive report available regarding the firefighting performance of Class A foams with quantifiable environmental acceptance and market availability. We offer it to the community as responsible scientific information without product endorsement. It is apparent by the data in this report that market availability of Class A foam exhibiting firefighting performance substantially above water alone has been achieved. The minimum level of performance acceptable for a tool used to save lives and protect the further erosion of our environment should be the highest level possible. Do we expect less than that of firefighters? We do not. Do they expect less of researchers? If they do, we have treated them badly, tainted our profession with indifference and arrogance and we must regain their confidence. Our direction of investigation should be guided by what firefighters need and it should never be "good enough"; it must be, like the firefighter, the best there is.

Class A foam research projects

William M. Carey
Senior Staff Engineer, Engineering Services, Dept. 411, 333 Pfingsten Road, Northbrook, ILL 60062-2096, USA

Abstract

Underwriters Laboratories Inc. (UL) has recently conducted research projects involving a comparison of the effectiveness of Class A foam solutions to plain water for the National Fire Protection Research Foundation (NFPRF) and the U.S. Army. Both series of tests were conducted at UL's main office and test station in Northbrook, IL.

The NFPRF project involved the conduct of a series of performance tests using plain water and a single Class A foam concentrate. The Class A foam concentrate was a mixture of three batches of the same foam and was supplied by the United States Forest Service. It was approved as a Wildland Firefighting Foam and neither the brand nor the manufacturer of the foam was known to UL or to the project participants.

By using a single Class A foam concentrate for all of the testing, variables such as solution concentration, foam generation method and expansion ratio could be compared to determine which variable or combination of variables had the greatest impact on the test results. In addition, a series of viscosity, specific gravity, surface tension and density tests were conducted on the Class A foam concentrate and foam solutions.

The performance tests consisted of conducting Class 20A wood crib fire, exposure protection and retention tests. For the Class 20A fire tests, Class A foam solution concentrations of 0.1, 0.3, and 0.5 percent were used. Foam was generated at a nominal expansion ratio of 5 using a standard, adjustable spray nozzle set to a straight stream position and at a nominal expansion ratio of 7.5 using an air-aspirated nozzle and compressed air foam (CAF). For the exposure protection and retention tests, solution concentrations of 0.3, 0.6, and 0.9 were used. Foam was generated at nominal expansion ratios of 7.5 and 15 using CAF equipment. Foam quality tests were conducted on each solution concentration and foam generation method as described in the Standard for Foam Chemicals For Wildland Fire Control, NFPA 298.

The results of this research project are described in a test report titled, "National Class A Foam Research Project Technical Report - Knockdown, Exposure and Retention Tests" dated December 1993. Copies of this report are available from NFPRF.

The United States Army Class A foam research project involved the conduct of performance tests using six Class A foams which had been approved by the U.S. Forest Service as Wildland Firefighting Foams. In addition, a UL Listed aqueous film forming foam (AFFF) was also investigated. All of the Class A foams were on the Army's Qualified Products List (QPL), yet no fire performance tests are required for a Class A foam to be included on the QPL. Therefore, it was desired to conduct a series of performance tests to determine the fire suppression performance characteristics of currently available Class A foams as compared to plain water.

The performance tests consisted of conducting Class 20A wood crib fire and exposure protection tests. For the Class 20A fire tests, plain water or Class A foam solution concentrations of 0.5 and 1.0 percent were used. Foam was generated at a nominal expansion ratio of 7.5 using a standard adjustable spray nozzle fitted with an air-aspirating adapter. For the exposure protection tests, a Class A foam solution of 0.5 percent was used and foam was generated using an air-aspirating nozzle. Foam quality tests were conducted on each Class A foam solution concentration and nozzle combination as described in the NFPA 298.

The results of these tests are contained in a report titled, "Report of Class A Foam Tests" dated February 1994, which was conducted for the Department of the Army, Belvoir Research, Development and Engineering Center, Fort Belvoir, VA.

Résumé

Les Underwriters Laboratories Inc. (UL) ont récemment entrepris des projets de recherche afin de comparer l'efficacité relative des mousses de classe A et de l'eau ordinaire, à la demande de la National Fire Protection Research Foundation (NFPRF) et de l'armée américaine. Les deux séries d'essais ont été menées au bureau central des UL et à la station d'essai de Northbrook, en Illinois.

Dans le cadre du projet de la NFPRF, on a mené une série d'essais de rendement à l'aide de l'eau ordinaire et d'un seul concentré de mousse de classe A. Le concentré de mousse de classe «A» consistait en un mélange de trois lots d'une même mousse fourni par le Service forestier des États-Unis. Cette mousse a été approuvée pour la lutte contre les feux de végétation; les UL et les personnes qui participaient au projet ont procédé aux essais en aveugle, c'est-à-dire, sans connaître la marque ou le fabricant du produit.

En utilisant un seul concentré de mousse de classe A pour tous les essais, on a pu comparer certaines variables, notamment la concentration de la solution ainsi que le mode de production et le taux de foisonnement de la mousse, pour déterminer quelle variable ou combinaison de variables avaient l'incidence la plus marquée sur les résultats d'essai. Par ailleurs, on a mené une série d'essais pour mesurer la viscosité, le poids volumique, la tension superficielle et la masse volumique du concentré de mousse de classe A et des solutions de mousse.

Les essais de rendement consistaient en des essais de combustion de classe 20A sur des bûchers de bois ainsi qu'en des essais de protection et de rétention. Dans les essais de combustion de classe 20A, on a utilisé des solutions de mousse de classe A dans des concentrations de 0,1 et de 0,3 ainsi que de 0,5 pour cent. La mousse était produite à un taux nominal de foisonnement de 5, au moyen d'une buse de pulvérisation réglable de type courant réglée pour fournir un jet linéaire, et à un taux nominal de foisonnement de 7,5, à l'aide d'une buse à aspiration d'air et une mousse entraînée par air comprimé. Dans les essais de protection et de rétention, on a utilisé des concentrations de 0,3, de 0,6 et de 0,9 pour cent. La mousse était produite à un taux nominal de foisonnement de 7,5 et de 15, par un appareil de distribution à air comprimé. Des essais visant à déterminer la qualité de la mousse ont été menés pour chaque concentration de solution et chaque méthode de production, tels qu'ils sont décrits dans la norme 298 de la NFPA (loi américaine sur la Protection de la nature et des forêts) sur les mousses chimiques utilisés dans la lutte contre les feux de végétation.

Les résultats de cette recherche sont présentés dans un rapport d'essai intitulé «National Class A Foam Research Project Technical Report - Knockdown, Exposure and Retention Tests», daté de décembre 1993. Un peut obtenir des exemplaires de ce rapport auprès de la NFPRF.

Le projet de recherche mis sur pied par l'armée américaine consistait à mener des essais de rendement sur six mousses de classe A approuvées par le Service des forêts américain pour la lutte contre les feux de végétation. En outre, on a éprouvé une mousse aqueuse filmogène homologuée par les UL. Toutes les mousses de classe A figuraient sur la liste des produits homologués par l'armée, encore qu'aucun essai de rendement ne soit exigé préalablement à l'inscription des produits sur cette liste. On a donc jugé utile de soumettre les mousses de classe A que l'on trouve actuellement dans le commerce à une série d'essais de rendement afin d'en comparer les propriétés d'extinction à celles de l'eau ordinaire.

Les essais de rendement consistaient en des essais de combustion de classe 20A sur des bûchers en bois et en des essais de protection. Dans les essais de combustion de classe 20A, on a utilisé de l'eau ordinaire ou des solutions de mousse de classe A dans des concentrations de 0,5 et de 1,0 pour cent. La mousse était produite à un taux nominal de foisonnement de 7,5 au moyen d'une buse de pulvérisation réglable de type courant munie d'un adaptateur à aspiration d'air. Dans les essais de protection, on a utilisé une solution de mousse de classe A dans une concentration de 0,5 pour cent; la mousse était produite par une buse à aspiration d'air. Des essais visant à évaluer la qualité de la mousse ont été menés pour chaque combinaison de concentration de solution de mousse de classe A et de buse, de la manière recommandée dans la norme 298 de la NFPA.

Les résultats de ces essais sont présentés dans un rapport intitulé «Report of Class A Foam Tests», daté de février 1994, qui a été établi à la demande du Département de l'Armé américain, pour le Belvoir Research, Developement and Engineering Center, à Fort Belvoir, en Virginie.

Introduction

UL has completed the National Class A Foam Research Project for the National Fire Protection Research Foundation. A copy of the Report, dated December, 1993, is available from the Research Foundation.

As can be seen from the attached Executive Summary, the objective of this Research Project was to document the effectiveness of Class A foam hose streams as compared to plain water. A series of wood crib fire, exposure protection and retention tests were conducted. All of these tests were conducted using a single Class A foam concentrate. Class A foam solution concentrations of 0.1, 0.3, 0.5, 0.6 and 0.9 percent were used as well as standard adjustable spray nozzles, air aspirated nozzles and compressed air foam (CAF) equipment. Foam expansion ratio and 25 percent drainage times were recorded for each foam solution/nozzle combination.

We have also recently completed a Class A foam Research Project for the US Army. A copy of the Executive Summary from this Report is also attached. This project involved the conduct of wood crib fire and exposure protection tests using six Class A foams which have been approved by the US Department of Agriculture, Forest Service Division, as Wildland Class A fire fighting foam liquid concentrates.

The results of these tests demonstrated that there are fire performance differences between these approved Class A foams and that there is a need to establish a performance based Standard and possible rating system for these products. We hope to continue working with the U.S. Army to develop appropriate test criteria for these products.

A copy of this Report can be obtained by contacting Mr. Samuel Duncan, USA Tank Automotive Command, Mobility Technical Center Belvoir, AMSTA-RBW, 10101 Gridley Road, Suite 104, Fort Belvoir, VA 22060-6818.

UL National Class A Foam Research Project
for the
National Fire Protection Research Foundation

Executive Summary

Class A foams have been used to fight forest and brush fires for many years. The United States Department of Agriculture (USDA) investigates Class A foams with respect to their toxicity and environmental characteristics. There are no test methods or requirements specified in the National Fire Protection Association (NFPA) Standard for Foam Chemicals For Wildland Fire Control, NFPA 298, to evaluate the fire fighting effectiveness of these foams.

Under this research project, wood crib fire and exposure protection tests were conducted to evaluate the fire fighting effectiveness of Class A foam hand hoselines as compared to water only. Foam quality tests were also conducted as a part of the research project. These tests were conducted using six Class A foams on the Qualified Products List (QPL) published by the USDA, a UL Listed one percent aqueous film forming foam (AFFF) and water only. Due to the limited number of tests conducted under this investigation, the results were considered inconclusive with respect to quantifying the fire fighting effectiveness of Class A foams.

The wood crib fire tests were conducted using Class 20-A wood cribs described in the Standard for the Rating and Fire Testing of Fire Extinguishers ANSI/UL 711. These cribs were designed to be extinguished by a 33 gpm straight stream hoseline applying water only for one minute. For this series of tests, a hand held nozzle set to a straight stream position and fitted with an air aspirating attachment was used at a flow rate of 15 gpm. Class A foam solution concentrations of 0.5 or 1.0 percent were used for all of the tests except those with water only. Except for one of the Class A foam solutions, the results of the wood crib fire tests demonstrated the ability of the Class A foam solutions to extinguish the Class 20-A wood crib. During baseline tests conducted with water only at 15 gpm, the Class 20-A wood crib was not extinguished at the end of the 60 second discharge.

Exposure protection tests were conducted using water only and a Class A foam solution concentration of 0.5 percent. All of the tests were conducted using a hand held air-aspirated nozzle at a flowrate of 1 gpm.

The exposure protection tests involved the application of water only or Class A foam solution to wood cribs and then exposing them to heat fluxes of 25 and 50 kW/m^2 until they ignited. The results of these tests demonstrated the ability of the Class A foams to retard the ignition of the wood crib as compared to cribs exposed to water at the 50 kW/m^2 heat flux.

It is recommended that additional research be conducted to develop appropriate fire test procedures and requirements to establish an acceptable level of fire fighting performance for Class A foams.

UL National Class A Foam Research Project
for the
US Army

Executive Summary

Class A foams have been used to fight forest and brush fires for many years. Recently, municipal fire departments have been using Class A foams to improve the operating efficiency of manual fire streams for structural fire fighting purposes.

To help quantify the improved fire fighting efficiency of Class A foam manual fire streams as compared to plain water, a series of wood crib fire, exposure protection and retention tests were conducted. Laboratory analyses and foam quality tests were also conducted under this project. All of the Class A fire tests were conducted using a single Class A foam concentrate which was approved by the United States Forest Service as a Wildland Fire Fighting Foam at concentrations between 0.1 and 1.0 percent.

The wood crib fire tests were conducted using Class 20-A wood cribs as referenced in the Standard for Rating and Fire Testing of Fire Extinguishers, ANDI/UL 711. These cribs were designed to be extinguished by a 33 gpm straight stream hoseline applying water only for one minute. For this series of tests, an adjustable nozzle set to a straight stream position and a flow rate of 15 gpm was used. Class A foam solutions of 0.1, 0.3 and 0.5 percent were used with a (1) standard, adjustable pattern nozzle (2) an air-aspirated nozzle and (3) by mixing the solution with compressed air to produce compressed air foam (CAF). The results of the wood crib fire tests demonstrated improved fire fighting effectiveness of using a Class A foam as compared to water. During baseline tests conducted with water only at 15 gpm, the crib was not extinguished at the end of discharge, even with the discharge duration increased from 60 to 90 seconds.

The exposure protection tests involved the application of water or Class A foam to wood cribs and then exposing them to heat fluxes of 25 and 50 Kw/m^2 until they ignited. The results of these tests demonstrated the enhanced ability of the Class A foam to retard the ignition of the wood test crib as compared to water at the 50 Kw/m^2 heat flux.

The retention tests measured the gain in weight of Class A foam applied to Class 1-A wood cribs for durations of 15 and 60 seconds. The results demonstrated that cribs exposed to a Class A foam had a 33 to 100 percent increase in retained weight as compared to cribs exposed to water.

It is recommended that additional research be conducted to measure the effectiveness of Class A foam as compared to water only using full scale room configurations. These tests should be conducted under a colorimeter so the rate of heat release, products of combustion, smoke obscuration and smoke density can be continuously monitored during each test.

Preliminary investigation of the fire extinguishment effectiveness of compressed air foam

Daniel Madrzykowski

Building and Fire Research Laboratory, National Institute of Standards and Technology, Technology Administration, U.S. Department of Commerce, Gaithersburg, Maryland

Abstract

A study was conducted to investigate the extinguishment effectiveness of compressed air foam (CAF) on Class A fires as a means to assess the feasibility of a self-contained, CAF sprinkler system for residential fire protection. Two types of fire tests were conducted: (1) fire extinguishment effectiveness tests and, (2) sprinklered compart-ment fire suppression tests.

The fire extinguishment effectiveness tests utilized wall configuration wood cribs, with overall dimensions of 0.61 m x 1.22 m in height. This crib configuration exhibited a steady-state heat release rate of approximately 250 kW. After the crib was ignited and allowed to reach full involvement, manual extinguishment was initiated by applying the extinguishing agent in a predetermined pattern over the burning fuel. When the flames were suppressed, the operator would look for smoldering combustion (hot spots) and apply more agent only to those areas. This technique was used to minimize the amount of agent used to extinguish the fire. The CAF and plain water were applied to the fuels at the same mass flow rate for each comparative case. Based on time to extin-guishment, CAF exhibited an effectiveness similar to water when suppressing the wood crib fires. The sprinklered compartment fire suppression tests required the agent, delivered from a sprinkler, to suppress a wood crib fire in a 2.4 m x 2.4 m x 2.4 m compartment. The wood cribs had external dimensions of 0.25 m x 0.25 m x 0.30 m in height and a calculated peak heat release rate of approximately 50 kW. The crib was allowed to become fully involved prior to manual activation of the sprinkler system.

At a spray application rate of 2.9 mm/min. (0.07 gpm/ft^2), CAF was found to be no more effective than water in suppressing the fire. A discussion of the limitations of the results from this study and needs for future research are included.

Résumé

Nous avons mené une étude visant à établir l'efficacité d'une mousse à air comprimé dans l'extinction d'incendie de classe A en vue d'évaluer la possibilité d'utiliser un système de têtes d'extincteur à mousse à air comprimé pour la protection résidentielle contre les incendies. Deux types de tests ont été effectués : (1) des tests d'efficacité d'extinction et (2) des tests d'extinction en compartiments dotés d'une tête d'extincteur.

Pour les tests d'efficacité d'extinction, nous avons utilisé des murets de bois, dont les dimensions étaient de 0,01 m x 1,22 m de hauteur. Ces arrangements montraient un taux stabilisé de dégagement calorifique de 250 KW. Après que le muret ait été allumé et pleinement embrasé, nous avons commencé l'extinction de façon manuelle en appliquant, suivant des modalités prédéterminées, l'agent extincteur sur le combustible en feu. Une fois les flammes éteintes, l'opérateur recherchaient les zones de feu couvant (points chauds) et appliquaient plus d'agent sur ces zones seulement. Cette technique a été adoptée pour minimiser la quantité d'agent utilisée pour éteindre le feu. La mousse à air comprimé et l'eau ordinaire ont été appliquées aux combustibles à des débits massiques identiques pour chaque cas comparatif. Sur la base du temps qu'il a fallu pour éteindre les feux, la mousse à air comprimé a montré une efficacité similaire à celle de l'eau. Les tests en compartiments munis d'une tête d'extincteur consistaient en l'extinction de feux de structures de bois avec l'agent appliqué au moyen d'une tête d'extincteur dans un compartiment de 2,4 m x 2,4 m x 2,4 m. Les structures de bois avaient des dimensions extérieures de 0,25 m x 0,25 m x 0,30 m de hauteur et un taux calculé de dégagement calorifique maximal d'environ 50 KW. On laissait la structure prendre en feu complètement avant que la tête d'extincteur soit activée manuellement. À un taux d'application de 2,9 mm/min (0,07 gpm/pi^2), la mousse à air comprimé ne s'est montré pas plus efficace que l'eau pour éteindre le feu. Nous présentons aussi dans cet article une analyse des limites des résultats de cette étude et les besoins futures dans ce domaine de recherche.

Performance of Class A compressed-air-foam from a fixed system

Andrew K. Kim, Bogdan Z. Dlugogorski, George P. Crampton, and Jack R. Mawhinney
National Fire Laboratory, Institute for Research in Construction,
National Research Council Canada, Ottawa, Ontario, CANADA, K1A 0R6

Abstract

A series of experiments in open-space and in a compartment was conducted to explore the suppression efficiency of a newly-developed compressed-air-foam (CAF) using a fixed piping system. The tests conducted at the National Fire Laboratory confirmed that the CAF system was effective in suppressing Class A (cellulosic materials) and Class B (flammable liquid) fires. The CAF had sufficient momentum to penetrate the fire plume and reach the fuel surface. In Class B fires, it formed a foam blanket on the fuel surface, which blocked the radiation to the fuel and reduced the evolution of flammable gases. The paper provides an overview of the test set-up and presents the test results.

Résumé

On a mené une série d'expériences à ciel ouvert de même que dans un compartiment résistant pour évaluer les propriétés d'extinction d'une nouvelle mousse entraînée par air comprimé distribuée à l'aide de tuyaux fixes. Les essais menés au Laboratoire national de l'incendie ont confirmé que ce système était efficace lors de l'extinction d'incendies de classe A (matériaux cellulosiques) et de classe B (liquides inflammables). Le système fournissait une force d'entraînement suffisante pour permettre au produit de pénétrer la colonne de flammes et atteindre la surface combustible. Dans les incendies de classe B, le produit formait une couverture de mousse sur la surface combustible, protégeant celle-ci contre la chaleur rayonnante et ralentissant la production de gaz inflammables. Le rapport donne un aperçu des conditions d'essai et présente les résultats obtenus.

Introduction

Forestry personnel have been using foams for many years to suppress forest and wildland fires. Recently, a new technique has been developed in which compressed air is injected into the water line containing the foam solution. The injection of the compressed air at the nozzle produces a well-entrained foam that can be projected quite far from the nozzle. It has been shown that a Compressed-Air-Foam (CAF) system can provide rapid cooling and fire extinction using less water than would be required for traditional hose-stream techniques[1].

Technical difficulties related to the degradation of the foam in fixed piping and the lack of an appropriate nozzle has, to date, prevented the use of CAF technology in fixed systems. For the program outlined in this paper, the National Fire Laboratory (NFL) of the Institute for Research in Construction, National Research Council of Canada successfully developed a means of producing CAF using a fixed piping system. In addition, an innovative foam nozzle was developed to distribute the foam to cover a wide area without loosing its high momentum.

This paper describes the experimental test set-up and procedures. In the study, the suppression efficiency of the foam was evaluated using the heat release rate of the fire during suppression. The paper discusses the effects of different foam expansion ratios and different fuels, as well as enclosure effects on CAF extinguishing efficiency.

Experimental Set-up and Procedure

All tests were conducted using the NFL's calorimeter facility. The calorimeter facility includes a 3 m by 3 m canopy hood which is connected to a 15 m long, 0.56 m diameter exhaust duct. As shown in Figure 1, the exhaust duct contains a pitot-static probe, thermocouples and gas sampling ports as well as a smoke meter, to measure the gas flow rate, temperatures, CO, CO_2 and O_2 concentrations, and the smoke production rate. The heat release rates of the fire during the test were determined using the oxygen consumption method[2]. The concentration of unburned hydro-carbons and the amount of water vapour present in the exhaust gases were also measured.

Two series of tests were conducted; one in a mobile test unit, which represented an open space fire with unlimited ventilation, and the other in a compartment with natural ventilation through a window opening, representing an enclosed fire scenario. The

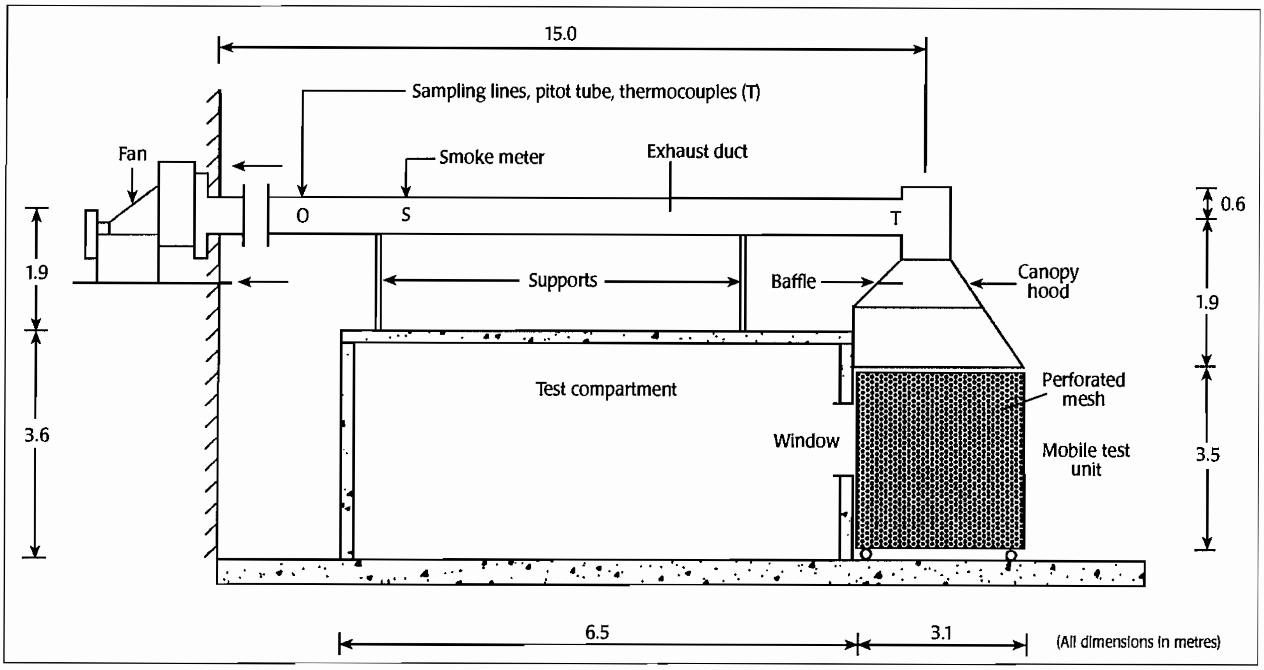


Figure 1. General experimental set-up, profile view.

mobile unit was 3.5 m by 3.1 m and 3.3 m high, and its walls were constructed of perforated sheet steel to break up the convective air currents without limiting the ventilation rate. The unit was instrumented with thermocouples and heat flux meters. As shown in Figure 1, the mobile test unit was placed under the canopy hood of the calorimeter so that all combustion gases would be collected by the calorimeter.

Tests were conducted with either one or two nozzles. In the single nozzle tests, the nozzle was mounted directly above the fuel at the ceiling. When two nozzles were used, the nozzles were mounted at the ceiling of the enclosure, 2 m apart and at equal distances from the fuel.

In the compartment fire tests, the canopy hood of the calorimeter was located such that one side of the hood was touching the wall above the window of the test compartment to collect combustion gases coming out through the window (see Figure 1). The fire test compartment inside dimensions were 6.1 m by 6.1 m by 3.2 m high. There were two 1.5 m by 1.2 m windows, side by side, in one wall and a 1.9 m by 0.8 m access door opening in the other wall. The fuel was placed in the centre of the room and two foam nozzles were mounted at the ceiling.

The suppression efficiency of a fixed Class A compressed-air foam system was evaluated on wood crib (Class A combustible) and heptane and diesel (Class B combustibles) pool fires. The wood cribs were constructed from 5 or 10 layers of white pine sticks. Each layer contained 10 sticks 19 mm by 38 mm by 610 mm. The tests in open space were carried out with 5 layer cribs, and those in the compartment with 10 layer cribs. Heptane and diesel pool fires were conducted with a 0.9 m diameter steel pan, with a 0.1 m lip height.

For the crib and the diesel pool fire tests, the fires were permitted to burn for approximately 2 min before activation of the suppression system, to allow the fire to reach a fully developed stage. For the heptane pool fire, a 1 min pre-burn was allowed since the heptane pool fire reached steady burning conditions in a shorter time than the other fuels.

Generation of Compressed-Air-Foam

Figure 2 shows the schematic diagram of the CAF system. Pre-mixed water and foam concentrate were mixed in the tank, which was then pressurized to 690 kPa (100 psi) with air. The container was weighed before and after the tests to record the total quantity of foam solution used. Compressed air was also injected into the flowing foam solution, and the mixture turned into foam as it flowed through the pipe system before it reaching the nozzles. For all tests discussed in this paper, a solution with 0.3% Class A foam was used.

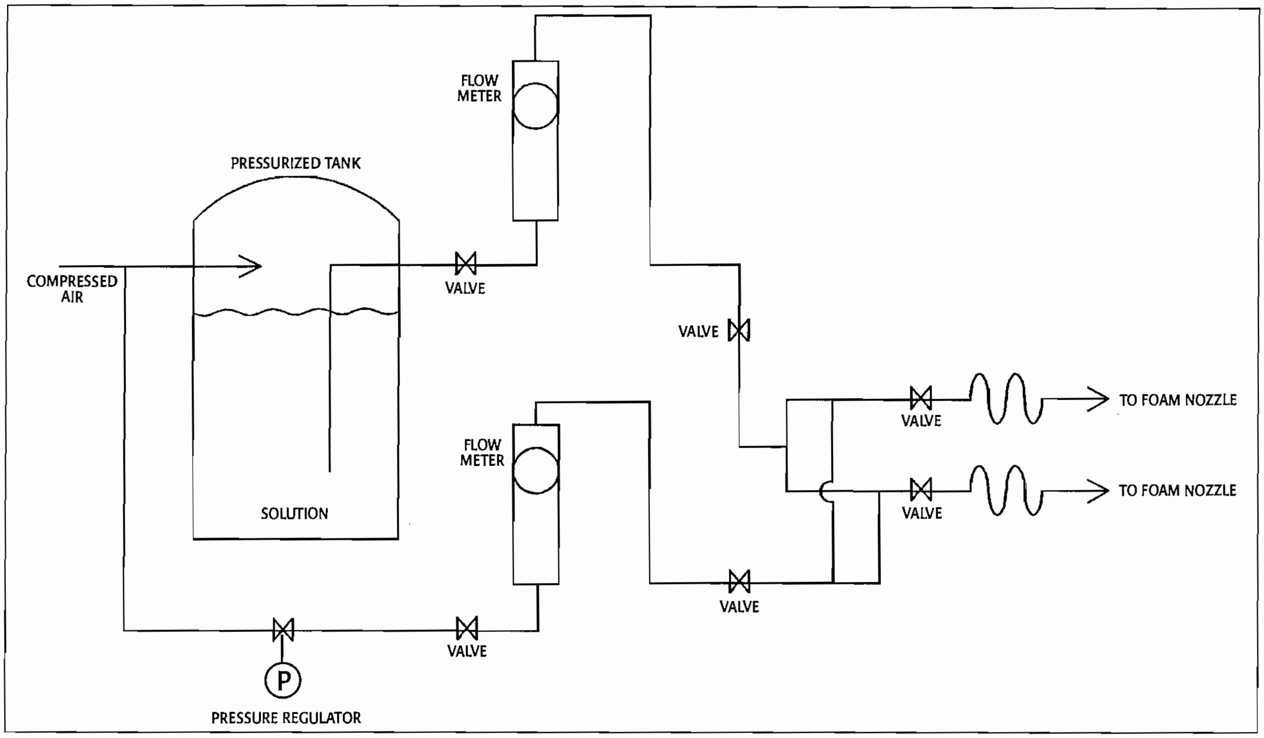


Figure 2. Schematic of foam generation equipment.

Extensive exploratory tests were conducted to develop a means to produce reliable CAF. Injecting foam solution and air into steel piping did not produce foam. It caused instability in the discharge pressure, resulting in the generation of a pulsating soapy water stream. A series of tests was conducted to understand the different parameters which affect the development and breakdown of the foam. The air injection and mixing process, length of mixing zone, number of bends in the piping, type of nozzle, all played a role in the quantity and quality of foam produced. After a considerable number of trials, the NFL developed a method to produce good quality CAF in a fixed piping system. The National Research Council has applied for a patent on this CAF generation concept, therefore, the details of the foam generation equipment cannot be described here.

Results

Heptane Fires in Open Space

The test results with a single foam nozzle, located directly above the fuel, showed that the compressed-air-foam (CAF) system using 0.3% Class A foam solution suppressed a 0.9 m diameter heptane pool fire within 45 s of activation. A foam with a 1:4 expansion ratio extinguished the fire in 38 s compared to 44 s for a foam with an expansion ratio of 1:10. In both cases, the foams were applied from the same nozzle with the same pressure, and the expanded foam volumetric flow rate was approximately the same. This does not necessarily mean that the lower expansion ratio foam was more efficient than the higher expansion ratio foam. One should consider that the 1:4 expansion ratio foam used 2.5 times more foam solution than required in the 1:10 expansion ratio foam. In fact, considering the volume of foam solution required for extinguishments, a higher expansion ratio foam may be more efficient in extinguishing a liquid fuel pool fire. If the expansion ratio is too high (above 1:10), however, the foam may be too dry and too light to penetrate the fire plume and reach the fuel surface to suppress the fire.

For the cases with two foam nozzles spaced 2 m apart, a higher foam application density was obtained at the fuel location, compared to the single nozzle case (6 kg/min/m^2 versus 5 kg/min/m^2)[3]. The CAF, with a 1:4 expansion ratio, extinguished the fire at 25 s and with the 1:10 expansion ratio foam extinguished the fire at 30 s. These extinguishment times are slightly shorter than the ones from the single nozzle case, indicating the improved fire suppression performance of the CAF with increased foam application density.

Diesel Fires in Open Space

The test results with two foam nozzles showed that Class A CAF with an expansion ratio of 1:10 extinguished a 0.9 m diameter diesel pool fire at 35 s. Foam with an expansion ratio of 1:4 extinguished the fire at 28 s. The CAF extinguished, with equal effectiveness, the pool fires with diesel (flash point of 60°(C) and heptane (flash point of -4°(C). The CAF system extinguished the pool fires by providing a foam blanket on the fuel surface to reduce the thermal feedback and the evolution of volatile fuel vapours, therefore, the flash point temperature of the fuel was not a factor in the performance of the foam system.

Wood Crib Fires in Open Space

Two foam nozzles, located 3 m above the crib and 2 m apart, provided sufficient foam to blanket the top and sides of the wood crib, and extinguished the fire. Figure 3 shows the heat release rates for the fires during suppression with two different expansion ratio foams. The low expansion ratio foam (1:4) (with an application density of 15 kg/min/m^2) suppressed the fire quickly, extinguishing it in 37 s, whereas the 1:10 foam (with an application density of 6 kg/min/m^2) extinguished the fire in 1 min 42 s. For comparison, two standard sprinklers (with an application density of 20 L/min/m^2) required 4 min 35 s to extinguish the same fire. The CAF not only extinguished the wood crib fire much sooner than the sprinkler system, but it required much less water than the sprinkler system. The test results showed that the CAF was a very efficient fire suppression system in extinguishing wood crib fires.

Compartment (enclosed) Fire Tests

There was little difference in the performance of the CAF system in extinguishing open space and enclosed fires. Class A CAF (with an expansion ratio of 1:10) immediately controlled the heptane pool fire in the compartment and extinguished it in 25 s. The same foam system extinguished the same heptane fire in open space at 30 s.

The CAF (1:10 expansion ratio) extinguished the diesel pool fires, both in the compartment and in open space, at 35 s.

The primary extinguishing mechanism was the same in the compartment as in the open space; a foam blanket formed on the fuel surface and blocked the thermal feedback to the fuel surface reducing the evolution of volatile gases. There does not seem to be any enclosure effect in fire suppression using the CAF system, and thus it was equally effective in suppressing fires in open spaces as in compartments.

Discussion

Foam achieves suppression by forming a blanket on the fuel surface. This foam blanket acts as a physical barrier blocking the radiation from the flame to the fuel, and reducing the evolution of the gaseous fuel. The blanket of foam also constitutes a slowly-draining reservoir of water, confined in the foam bubbles, which cools the fuel.

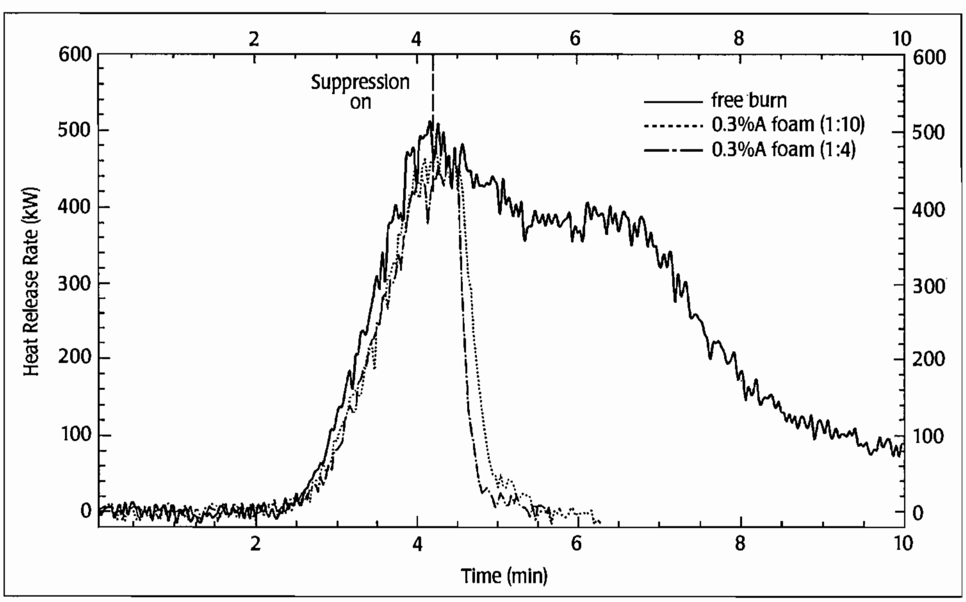


Figure 3. Head release rates of wood crib fires in open space (two foam nozzles).

With the fixed pipe CAF system, it was possible to produce foams with expansion ratios ranging from 1:3 to 1:20 by controlling the foam solution and air flow rates. Although in wildland and structural fire fighting, foams with expansion ratios ranging between 1:2 to 1:100 may be used, (as dictated by a specific application), the optimum fire suppression efficiency in the current test set-up, was obtained by foams with expansion ratios between 1:4 and 1:10. Foams with expansion ratios higher than 1:10 were too dry to penetrate the flame and reach the fuel surface. Foams with lower expansion ratio than 1:4 drained too quickly to maintain a foam blanket on the fuel surface. Also, the amount of water required for the lower expansion foam was considered to be too great.

Conclusions

The National Fire Laboratory has developed a means of producing Class A compressed-air-foam (CAF) in a fixed pipe system, incorporating a new and innovative foam distribution nozzle. The system delivers high momentum CAF at the optimum foam expansion ratio of 1:4 to 1:10. Foam break-up, which prevented the development of this technology in the past, was avoided by the careful engineering design of the nozzle and the piping system. The system extinguished heptane and diesel pool fires and wood crib fires quickly, with a small amount of water. This makes it an ideal candidate for applications in areas where water supply is limited.

Acknowledgments

The authors gratefully acknowledge the financial support from Canadian Forces Fire Marshal's Office, National Defence Canada, and the technical contributions from Robert Onno in the course of this project.

References

[1] Liebson, J., "Introduction to Class A Foams and Compressed Air Foam Systems for the Structural Fire Service", International Society of Fire Service Instructors, Ashland MA, 1991.

[2] Dlugogorski B. Z., Mawhinney, J. R., and Vo Huu Duc, "The Measurement of Heat Release Rates of Oxygen Consumption Calorimetry in Fires under Suppression", presented at the 2nd International Symposium of Fire Safety Science, Ottawa, Ontario, June, 1994 (In Press).

[3] Kim, A. K., Dlugogorski, B. Z., and Mawhinney, J. R., "The Effect of Foam Additives on the Fire Suppression Efficiency of Water Mist", Proceedings of the Halon Options Technical Working Conference, Albuquerque, NM, May, 1994.

Evaluation of enhanced water fire suppression
Class "A" foam crib burns

C. Bruce Edwards
Firetech Engineering Inc., 1373 East 15th Street, North Vancouver, BC Canada V7J 1K9

Abstract

To use scarce water resources most effectively, firefighters must maximize the number of metres of wildfire that can be suppressed per litre of water, for a given fuel type, topography and weather. This is done by optimizing the delivery system, method of application, and flow rate. As a step to achieving this, reproducible wood crib fires are being studied to quantify the effect of factors involved in suppression. Large cribs, extrapolated from the UL 711 standard design (up to 40–A cribs), are being used so results will be relevant to field personnel.

Preliminary burns of eight "100–AB" (3300 lb) fuel cribs in 1992 confirmed the value of testing large fires and the feasibility of quantitative studies. These burns led to estimates of CFR (Critical Flow Rate) for straight streams of ALEF–A (Aspirated Low Expansion class A Foam) of 67 gpm compared to 127 gpm for plain water. Foam solution was tested and appeared to be highly effective. Also, low pressure (50 psi) water spray appeared to be much more effective than standard 100 psi spray.

Video clips of test burns, form part of this presentation. Rationale for the experimental design is discussed.

Crib fires in 1994 will indicate fire scaling in fuel cribs, which information will be used to size sixty "60–AB" fuel cribs and, given additional funding, twenty "100–AB" cribs. These will be attacked with plain water and several class A foam delivery systems, including Compressed Air Foam Systems (CAFS), using various application methods. This procedure will quantitatively identify the most promising combinations. It is intended, if resources permit, to evaluate these combinations with fires in natural fuels.

Résumé

Pour utiliser plus efficacement les réserves limitées d'eau lors d'un feu de végétation, les pompiers doivent s'assurer que chaque litre d'eau couvre la plus grande superficie possible, pour un combustible, une topographie et des conditions météorologiques donnés. À cette fin, on doit optimiser le système de distribution, la méthode d'application et le débit. On tente actuellement de quantifier l'effet des facteurs de suppression à partir des essais reproductibles menés sur des bûchers en bois. On utilise des bûchers de grandes dimensions, dont les caractéristiques sont dérivées de la norme de calcul UL 711 (jusqu'à 40-A), de sorte que les résultats obtenus seront significatifs pour le personnel travaillant sur le terrain.

La combustion préliminaire de huit bûchers du type «100-AB» (3300 lb) en 1992 a confirmé le bien-fondé des essais qui reposent sur des incendies d'envergure et la faisabilité des études quantitatives. Ces essais ont permis d'estimer à 67 gallons par minute le débit critique pour un jet linéaire d'ALEF-A (mousse de classe A à faible foisonnement pulvérisée par aspiration d'air), débit qui passe à 127 gallons par minute dans le cas d'eau ordinaire. La solution de mousse a été mise à l'essai et on l'a très efficace. Une pulvérisation d'eau à basse pression (50 lb/po) semble par ailleurs beaucoup plus efficace qu'une pulvérisation type à 100 lb/po.

Des vidéos seront aussi présentés dans le cadre de cet exposé. On y discutera des raisons qui ont déterminé le modèle expérimental.

Les essais de combustion menés en 1994 permettront d'évaluer les caractéristiques de combustion des bûchers, information qui sera appliquée à soixante bûchers du type «60-AB» et, advenant l'apport de fonds supplémentaires, à vingt bûchers du type «100-AB». On tentera d'éteindre l'incendie au moyen d'eau ordinaire et de plusieurs systèmes de distribution de mousses de classe A, dont des systèmes de pulvérisation à air comprimé, à l'aide de diverses méthodes d'application. Ce procédé permettra de déterminer quantitativement les combinaisons les plus prometteuses. Si les ressources le permettent, on entend évaluer ces combinaisons en soumettant des combustibles naturels à des essais de combustion.

Introduction

Class A foam has been in use for ground–based fire suppression since the 1970s. Those of us who use it routinely are convinced of its efficacy. Unfortunately, although there have been anecdotal reports of dramatic results, negligible full–scale scientifically credible research, quantitatively evaluating and optimizing Class A foam systems, has been published.

Fundamental questions have been unanswered, namely;

1. Which Class A foam system is best for each use? – foam solution? (straight stream or spray?), compressed air foam?, aspirated foam?, should it be low or medium expansion foam?, which is the best formulation? how dry should it be?, and what is the optimum drain time?
2. What is the best method of application of the preferred suppressant?
3. How much better is Class A foam than plain water? In wildland firefighting, the question is "How many metres of fire can 1000 litres of water darken (or mop up) with foam "X", compared to plain water?

This study, Quantitative Evaluation of Enhanced Water Fire Suppression, seeks to answer the above questions.

Preliminary Burns

A crib ignition test and eight preliminary burn trials were conducted at the Vernon Military Camp at Vernon B.C., Canada in 1992 October 2 to 17. The concrete floor slab of a large military building previously destroyed by fire, was used for the tests.

The preliminary burns were conducted to;

1. Find numerical values if possible for:

   Energy release,
   Heptane accelerant required for ignition,
   Ignition uniformity,
   Effect of wind and other factors,
   Gpm required for testing both straight streams and fog patterns,

2. Identify and solve problems in experimental method,
3. Determine whether Critical Flow Rate analysis is an appropriate method of comparing suppression systems,
4. Estimate resources needed for project completion, and
5. Provide the fire service with preliminary answers to the question "How does aspirated low expansion foam compare with plain water in a straight stream?"

This preliminary research answers the first 4 questions and suggests a preliminary answer to the last question above.

Since details of the tests have been given in the interim technical report to Forestry Canada (Edwards 1992a) and to the North West Fire Council (Edwards 1992b), this presentation features video clips of the preliminary burn tests.

Experimental Design

Underwriters standard UL–711 for lumber fuel cribs was used in crib design so results could be compared with extinguishment of known fires and for easy reproducibility. Large cribs were built to simulate large fires beyond the knockdown capability of a conventional plain water attack.

Since the UL–711 standard only goes up to a 40–A crib, the UL crib specifications were extrapolated to a larger crib called "100–AB".

Each crib consisted of 261 pieces of 2 by 4 SPF (Spruce, Pine or Fir) lumber, 9'– 5" long forming a filled square crib 9' – 5" square, weighing about 3300 lb. The total height of a crib was about 36".

The first video clip shows the burn site and crib in place on the weighing frame.

The second video clip shows a heptane ignition fire (111 lb heptane). By about 3 minutes after ignition, all the heptane had burned out. The fire was then allowed to preburn and attacked 4 minutes after ignition. Load cell data showing a steady decline of weight confirmed a uniform fire intensity.

These fires are extremely hot and difficult to darken. The solid flame height, even after the heptane had burned out, was estimated from a level video camera to be about 30 feet. The maximum fireball height was about 45' above the crib. A face shield was needed to approach closer than about 60' from the crib.

Attack Method

Four possible attack geometries were considered:

1. The UL 711 standard method of attack for fire extinguishers, is to attack from the sides and front, the top and bottom, but not from the back of the crib. For comparison purposes, this method is less

than ideal because of the effect of stream geometry. As shown in figure 1, stream diameters are about the same size as the spacing between 2 by 4s.

The stream diameter of a straight stream of plain water and solution and of a CAFS stream are much smaller than the 3.8" spacing between 2 by 4s so much of the stream will shoot straight through without wetting the fuel. It will be wasted except for some cooling of the flame volume, as shown in video clip 3.

The diameter of an Aspirated Low Expansion Foam (ALEF) stream, in contrast, is about twice the spacing, so foam tends to pile up on the upstream side of the crib, with relatively less shooting straight through as shown in video clip 4. Because of this error, another method was needed.

2. Another approach is to use a fixed nozzle, which suggests a sprinkler test.

This approach was tried for the first two fires, using standard spray (100 psi) then low pressure fog (50 psi) from a tower on the crib diagonal as shown in figure 2 to cover the entire crib. One problem is that the advantage of class A foam in reducing rekindles, is not emphasized. Also, this does not simulate a feasible method of attacking wildland fires. Video clip 5 shows a test fire attacked with this method.

3. The third approach is to attack from a fixed position along the crib diagonal as in figure 2, so that the stream can hit two sides as well as the top. Because the stream is never directed parallel to the 2 by 4s, the above geometrical effect is reduced.

An advantage of this configuration is that one camera position along the other diagonal can see both a front side and a rear side. A disadvantage is that this does not simulate attack of a line fire.

This method was used for the preliminary burns.

For straight stream attack, the stream was moved from left to right starting at the bottom left of the crib and ending at the top right corner.

4. For burn tests in 1994, to better simulate attack of a line fire, the nozzle will be placed at right angles to the front of the crib, as shown in figure 3.

The fire can be attacked either by sweeping the nozzle left to right as it is more slowly moved from the bottom edge of the crib to the top, or by sweeping the nozzle up and down as it is more slowly moved from left to right, the advantage of class A foam in reducing immediate rekindles should be shown by this method.

Nozzles

Because a wide range of quickly adjustable flow rates was needed with the same nozzle geometry and because exit velocity should be constant with variations in flow rate, an automatic nozzle was needed for attack. It was also preferable for comparison purposes to use the same nozzle for aspirated low expansion foam as for plain water. For these reasons Task Force Tips (TFT) Dual Force (50 and 100 psi) and Handline nozzles with FoamJet foam attachments were selected.

Nozzle Mounting and Fire Pump

Fires were attacked from a skid–mounted wooden tower. The attack nozzle was attached to a modified FirePro FPTM–750 2_" deck gun with truck mount base bolted to the tower. The nozzle height above ground was about 11'.

For flow rates under 135 gpm, a Wajax Defender 350 pump was used. For higher flow rates, municipal fire engines from the Lumby, Okanagan Landing and Vernon Fire Departments were used, all drafting from a portable tank in which foam concentrate was batch mixed.

Foam Concentrate and Concentration

Ansul Silv–ex, Chemonics FireTrol 103 and 3M FB–100 concentrates were donated by the manufacturers. A 0.5% concentrate was chosen for the tests because that concentration seems to be most commonly used. FireTrol 103 was selected for the tests by the toss of a coin.

Results

There were nine test fires in 1992. In the first, the heptane ignition–fire duration was measured without a crib in place to determined the amount of heptane needed. Three suppressants were tried as follows:

- 4 cribs with plain water (2 with fog and 2 straight stream),
- 1 crib with foam solution applied in a straight stream, and
- 3 cribs with ALEF applied in a straight stream.

A summary of 1992 results obtained from the 8 crib fires is given in Table 1.

Table 1. Data from 8 crib fires in 1992 using three suppression methods: Plain Water, Foam Solution (Sol'n) and Aspirated Low Expansion Foam (ALEF)

Suppressant	**Plain water**			**Sol'n**			**ALEF**	
Pattern	**Fog**		**Straight stream**					
Crib number	1	2	4	5	3	6	8	7
Nozzle	DF	HTFT	DF	DF	DF	DF	DF	DF
Nozzle psi	50	100	50	50	50	100	100	100
Ignition								
Heptane lbs	137	111	111	111	111	111	111	111
Heptane burned out in (secs)	228	169	168	161	190	165	184	174
Attack								
GPM	84/196	324	132	202	127	72	138	228
Duration sec	24/4	22	189	55	14	273	56	41
Gallons	34/13	41	416	185	30	328	129	156
~Visibility	Good	Good	Fair	Poor	Poor	Poor	Good	Good
Exceeds CFR	No	No	Close	+Yes	+Yes	Just	Yes	Yes
Stream effect	Fair	Fair	Good	Poor	Poor	Poor	Good	Excel
Knockdown								
Degree	95%	90%	@Full	60%	70%	Full	95%	Full
Seconds	#	#	189	*55	*20	*149	*^34	14
Gallons	#	#	416	*185	*42	*179	*^78	53

~ Poor visibility precluded aiming the stream effectively.
+ If stream had been aimed better, fire could have been darkened.
@ Knocked down when fuel decreased so that CFR was exceeded.
# Steady state shown clearly.
• Guesstimate of knockdown requirements.
^ Rear face of right hand corner not knocked down. Shows steady state fire inside crib, with no flame showing above it.

Discussion

Visibility during straight stream attacks was usually adequate until the main body of fire was darkened, then white smoke from suppression, and black smoke from rekindling immediately after the stream passed, obscured both the stream and the crib. A lot of suppressant was therefore wasted. To estimate knockdown times under these conditions, the video recordings were analyzed. The time when the main body of fire was darkened was noted, then an additional time to darken the rest with a fully effective stream was guesstimated.

After the main body of flame was darkened for fire 8, an internal fire persisted, with no flame showing above the crib. It could not be darkened, probably because poor visibility precluded aiming the stream accurately and seeing its effect.

Unlike a straight stream attack, where stream effectiveness can be seen and the additional application time to darken a fire can be guesstimated, a fog pattern covering the entire fire behaves differently. After a few seconds, a state of equilibrium is reached between the heat of the fire and the cooling effect of the stream. By definition, additional suppression time will not darken the fire until it runs out of fuel. There is no way to guess the additional flow rate required for knockdown.

Even slight gusts of wind under 0.5 Km/hr will change these fires considerable, so they could not be considered reproducible fires.

Also, inconsistency of application arises from a human nozzle operator.

Finally, knockdown and rekindle cannot be defined objectively by a human, even given good visibility. This precludes true quantitative comparisons. For these reasons the above results must be considered preliminary.

The problem of wind has been addressed by building a new burn facility at Chaput Logging's gravel pit near Lumby B.C. where there is a high probability of calm wind.

To eliminate the human factor in fire attack, a programmable robot nozzle has been built.

To objectively define knockdown and rekindle, a fast response thermocouple array is being designed and built.

Method of Quantitatively Comparing Suppression Systems

Previous attempts at evaluating suppression systems have been plagued by the problem of how to validly compare them, since different flow rates and knockdown times are involved. Also, because water is usually in short supply, any comparison should include gallons of water used.

A promising way to compare suppression systems is therefore to plot gallons to suppress the fire vs gpm showing Critical Flow Rate (CFR) (Edwards 1992b) as in figure 4. This type of graph is called a knockdown curve.

The CFR method was used for analysis in this experiment.

Foam vs Plain Water Applied in a Straight Stream

Video clip 5 compares fires 5 and 7, attacked with roughly the same flow rate. The superiority of Class A aspirated low expansion foam (ALEF) is apparent.

Fourteen seconds into the attack, plain water had only partially darkened fire 5, but Class A ALEF had knocked down Fire 7, as indicated by a billow of white smoke and lack of flame showing above the crib. Only two 4" flames are visible on the South–East side, which the foam couldn't reach directly.

The plain water attack of fire 5 was stopped after one minute as it was apparent that the fire, with an 8′ flame height, would not be darkened until it ran out of fuel. It rekindled to half the crib diagonal 70 seconds after the attack ended.

Fire 7 was completely darkened after a 42 second ALEF attack. It took 220 seconds to rekindle to half the crib's diagonal width.

Visibility seemed to be much better after an ALEF attack than after attack with plain water.

The 10% higher average flow rate for ALEF seemed to be more than compensated by wind gusting to about 5 km/hr blowing Fire 5 so that only about 3/4 of the crib ignited and the part ignited was closest to the nozzle. This gave plain water a considerable advantage over ALEF, so that in comparison, ALEF is probably even more effective than the numbers indicate.

Results are plotted in figure 4, which shows the Critical Flow Rates, below which the fire cannot be fully darkened. The vertical CFR lines are asymptotic to the curves. The CFR of water (127 gpm) is roughly twice that of ALEF (67 gpm), indicating that twice the flow rate is needed for plain water to have the same effect as ALEF.

It takes a long time and a lot of suppressant to attack at the CFR. Attacking at many times the CFR, while taking little suppressant, requires large pumping capability. In practice, attacking at 50% above the CFR seems to be an appropriate compromise. In this case, figure 4 shows that this requires 190 gallons of plain water applied at 190 gpm, or 95 gallons of water applied as ALEF at 100 gpm.

Low Pressure Spray Results

The first two fires were attacked with a fog pattern covering the entire crib. To cover the entire crib with standard pressure 100 psi fog (Fire 2), the nozzle tower had to be moved up to 13′ from the crib. With low pressure spray, the crib could be covered with the nozzle moved back to 16′ from the crib corner. These fires are shown in video clip 6.

Even 324 gpm failed to darken fire 2 after 22 seconds. It appeared that a steady state was quickly reached in which the heat of the fire balanced the cooling effect of boiling the fine water droplets of the spray. The fireball flame height was reduced from about 45′ to 15′ above the crib, but there was no sign that the fire could be darkened. This video clip is an excellent illustration of the effect of attacking a fire below the Critical Flow Rate.

Most water applied seemed to be evaporated by the flame in the plume without having appreciable effect on the fire. It is expected that the major effect of cooling the plume is to slightly reduce convection currents bringing oxygen to the fuel crib.

Low pressure fog (50 psi) was used for fire 1. Adequate coverage of the crib could be achieved with the nozzle tower moved back to 16′ from the crib. Initially, 84 gpm was applied for 24 seconds, and seen to be inadequate to darken the fire. It was then raised to 196 gpm for a few seconds. This darkened the fire to roughly the same degree as did the standard fog (100 psi) at 324 gpm.

The advantage of low pressure fog may be that the larger droplets seem to penetrate the plume and reach the fuel crib surface without evaporating fully. The fine fog of a standard fog nozzle seems to be fully evaporated by the plume, so it doesn't penetrate to the fuel.

Low pressure fog appears to be about twice as effective as standard fog (100 psi). Since the nozzle reaction for low pressure fog (50 psi) is 30% less than that of standard fog (100 psi) for the same flow rate, it is apparent that research into the benefits of low pressure fog is warranted.

Because neither fire was darkened with fog, meaningful rekindle times could not be measured. Since the degree of darkening was similar though, the similar times suggest that rekindling may be similar with both standard fog and low pressure fog.

Since there was only one fire with each, statistical spread and significance can't be estimated.

Low Pressure Solution Fog

A potentially useful combination suggested by the above results is a narrow spray of foam solution since the slower–moving heated droplets containing surfactants are likely to wet the fuel without running off better than the higher–velocity cold water of a straight stream.

Conclusion

Although the 1992 results reported above are strictly preliminary and do not purport to be scientifically credible, this study has demonstrated that it is feasible to quantitatively compare fire suppression systems.

Solutions have been found for problems identified in the experimental method. In 1994/95, A series of 10 fire scaling burns – five pairs of successively deeper cribs – will indicate the optimum depth for comparison. This should lead to effective and economical experimental design for a full–scale series of 60 8–foot square crib burns to begin in 1995. The series will be designed to produce statistically significant results. The proposed sequence of burn tests is as follows:

1. Fire scaling tests 64 sq feet; 5 pairs of 64 sq. foot cribs: 3, 5, 7, 9 and 11 layers.

These will also be used to test the instrumentation and nozzle robot, and to explore the use a narrow spray of foam solution applied at medium and low pressures.

2. Suppression comparison tests; 60 cribs, each 64 sq ft, to compare Straight streams of

   Plain water
   Foam solution
   ALEF
   CAFS
   Narrow sprays of
   Plain water
   Foam solution

3. Large scale suppression tests of 100 sq ft cribs.
4. Burn tests in natural fuels

Preliminary results of the fire scaling burn tests follow this report.

Characterization of foam concentrates, up to now, has considered many properties, but not whether the formulation is effective in fire suppression. It is anticipated that the method being developed as part of this study can, after refinement, be used to quantitatively determine the effectiveness of foam formulations in fire suppression.

Acknowledgment

The author gratefully acknowledges the support of the many organizations who have contributed financially and in–kind.

This study was partially funded by Forestry Canada (now the Department of Natural Resources) and the Ministry of Forests under the Canada–British Columbia Partnership Agreement on Forest Resource Development: FRDA II (1991–1995).

This report has been reviewed by the Canadian Forest Service and approved for distribution.

This approval does not necessarily signify that the contents reflect the views or policies of the Department of Natural Resources or the Ministry of Forests.

The use of trade or manufacturer names in this paper is for reader information only and does not imply endorsement.

References

Edwards, C.B. 1992a. Quantitative Evaluation of Enhanced Water Fire Suppression. Interim Technical Report, Forestry Canada, Pacific Forestry Centre FRDA II.

Edwards, C.B. 1992b. Proc. North West Fire Council.

Edwards, C.B. 1992c. Critical Flow Rate. Fire Engineering. Sept.

APPENDIX

1994 UPDATE: THE CHAPUT FIRE SCALING BURNS & EXPLORATION OF A LOW-PRESSURE SPRAY OF FOAM SOLUTION

Introduction

This update reports results of the first fire scaling test burns, introduced above.

The Camp Vernon burns (Edwards 1992a) suggested that a narrow spray of low-pressure foam solution might provide more efficient suppression than a straight stream. For economy, therefore, the scaling fires were also used to explore class A foam solution applied in a spray pattern, compared with straight streams of water and foam solution.

In October 1994, at the new Chaput Logging burn site near Lumby, B.C., five cribs were burned to test instrumentation and the robot nozzle which was developed to assure reproducible fire attack, to decide the best height for sixty 8 foot square Spruce- Pine-Fir fuel cribs to be burn tested in 1995, and to estimate the Critical Flow Rate for experimental design.

Method

The setup and ignition was similar to that described for the 1992 burns (Edwards 1992b), except that a computer Data Acquisition System was used, high-temperature viewing window was installed and four 500 lb load cells were used to measure heat output by weighing the crib dynamically during the burn. The weight difference for the sixty seconds preceding attack was multiplied by 19 MJ/Kg.

Minimum acceptable flame heights for the 60 crib series were arbitrarily chosen as 20 and 12 feet for the average height and peak fireball height respectively. Cribs of various depths, from 3 layers to 9 layers were burned, and flame heights recorded with a Panasonic 4-camera colour video system with a quadswitcher to permit all four views to be recorded on one Super VHS cassette for simultaneous viewing and analysis.

The experimental method for estimating the effect of foam solution was to attack cribs of all depths with the same flow rate of roughly 40 gpm using different pressures and application techniques as shown in the table. As experience with these cribs and the new robot nozzle increased, the method of application was improved.

Two three-layer cribs were burned first. The first crib was attacked with a straight stream of plain water for reference, and the second with foam solution. The nozzle was swept up and down.

The rest of the cribs were attacked with foam solution applied in a narrow spray pattern. A taller 5-layer crib, was attacked with a medium-pressure narrow spray. Then a 7-layer crib was attacked with a low-pressure narrow spray. Finally, a one-ton 9 layer crib was attacked with a low pressure narrow spray using a slower horizontal nozzle sweep.

Results

Results are given in appendix table 1, which shows that to meet the flame height criteria, cribs should have either seven or nine layers.

Analysis of suppression effectiveness is not so straightforward. The first two cribs (3-layer) were attacked with a straight stream, which had a diameter of roughly three inches when it hit the crib. The left-to-right sweep which took 8 seconds, swept one foot during a complete up-and-down cycle of the stream, with an arbitrary period of one second. This meant that the stream hit 50% of the crib surface directly. The first 3-layer crib was fully darkened by a straight stream of plain water. The second, attacked with foam solution was darkened as well, except that the stream missed the left hand rear corner, so it could not be darkened.

Both attacks appeared to be at least double the Critical Flow Rate (Edwards 1992c), placing it on the flat part of the knockdown curve, making comparison of effectiveness difficult.

The third crib (5 layers) was attacked with a narrow spray of about 15" when it hit the crib, using the twice the sweep speed as for the previous two cribs to try to reduce the effect of immediate rekindle. This gave slightly overlapping coverage over the crib surface.

Even though the heat release was four times that of the previous two cribs, the fire was darkened in just twice the time. The flow rate seemed to be just above the CFR. The fast sweep speed seemed to cause a "standing wave" pattern, so that coverage was not uniform over the crib.

Because the larger droplet size from low pressure spray (50 psi) seemed in the 1992 tests to penetrate the plume better than the smaller droplets from a standard pressure spray (100 psi), low pressure spray was used to attack the fourth crib. The sweep speed was returned to the original 8 seconds.

Even though this fire was very much more intense than the previous ones, the low pressure solution spray darkened it readily, except for the far rear of the crib. The stream seemed to significantly exceed the CFR, suggesting that low pressure spray is indeed effective.

The fifth crib, with eight times the energy release of the first, was attacked by sweeping the stream from left to right, rather than up and down, as the stream was elevated from the front of the crib to the back. The crib was covered in 8 seconds as before. Although this test was somewhat spoiled because the sweep started after the nozzle valve was opened, the stream darkened all but the rear edge of the fire in the first sweep. The flow rate of the stream appeared to exceed the CFR by a large margin.

Improving the experimental method

Several deficiencies in the method were pinpointed by these test burns. The inability of the stream to reach the rear of the crib, found in cribs 3, 4 and 5 despite increasing overshoot in wet– tests with a dummy crib, can be solved by narrowing the spray diameter to about 8" at the crib.

To ensure that the sweep and nozzle valve opening occur at the correct time, a digital IO (Input/Output) control system is being built. This will begin the sweep and the fireflow at a fixed time, probably four minutes, after ignition.

For accurate analysis of data, the video recording should be precisely synchronized with the data acquisition system to within one video frame. This problem, which was apparent during these tests, will be addressed by having the DAS/IO fire a photographic flash unit, placed within a camera's field of view, at known intervals.

To objectively determine knockdown and rekindle, a fast response– time thermocouple array, to be placed above the cribs, has been designed and is being tested.

Conclusion

It was concluded that the method is feasible and that the 60 existing 4–layer cribs should be built up to seven or nine layers for the next phase of the study.

Because the purpose of these tests was to glean information to be used for setting the experiment for subsequent burns, results are not truly quantitative. Nevertheless, since a 19 KW fire attacked with a narrow spray of foam solution was darkened to roughly the same degree as a 2.3 KW fire attacked with a straight stream of water, the preliminary indication is that the latter could be eight times as effective as a straight stream of plain water.

This seems too optimistic, but the results lend credence to the suspicion that by optimizing the suppressant, flow rate, and method of application, fire knockdown effectiveness can be at least tripled compared to conventional means. Continued research is therefore warranted.

The facility, with robot nozzle, video quadswitcher, fast thermocouple array and closeup viewing window offers many possibilities, including quantitatively comparing the effectiveness of fire suppression products so that a fire suppression performance specification can be included in new foam standards.

The Department of National Defense provided $40,000 for 1994. Over $200,000 in kind has been donated. It is estimated that $40,000 is required to complete the proposed 60 crib series in 1995.

Appendix References

Edwards, C.B. 1992a. Proc. North West Fire Council.

Edwards, C.B. 1992b. Quantitative Evaluation of Enhanced Water Fire Suppression. Interim Technical Report, Forestry Canada, Pacific Forestry Centre FRDA II.

Edwards, C.B. 1992c. Critical Flow Rate. Fire Engineering. Sept.

Evaluating the effectiveness of retardant and foam composites

Judi Beck, Jeff Berry and Kevin Wallinger
British Columbia Ministry of Forests, Protection Branch, 2nd Floor, 31 Bastion Square, Victoria, BC

Abstract

From 1988 to 1992, several operational trials were conducted by the British Columbia Forest Service to evaluate the suppression effectiveness of retardant and foam composites. These preliminary air tanker trials indicated that retardant and foam composites may offer a number of advantages over conventional unthickened retardant. More rigorous study is required to substantiate these preliminary findings, and to address other issues related to the use of retardant and foam composites.

The current study has been initiated to determine if the effectiveness of long term retardant at various dilution rates (5 parts water to 1 part liquid concentrate by volume, 8:1, 11:1 and 15:1) is improved when 0.3% Class A foam is added. To compare the effectiveness of retardants and composites, eight plots (approximately 30 m in diameter) will be established for each of several burn trials, which will be conducted in a variety of fuel types. Rate of spread and intensity will be monitored to determine if product effectiveness, using a ground application system, varies with fire behaviour characteristics. Burnt and unburnt vegetation responses will be measured to determine if composites or retardants have an adverse effect on growth. This report details the methodology of the field trials, presents preliminary results of the first experiment and makes recommendations for future trials.

Résumé

De 1988 à 1992, le Service des forêts de la Colombie-Britannique a mené plusieurs essais opérationnels afin d'évaluer les propriétés d'extinction de produits à base de préparations ignifuges et de mousses. Ces essais préliminaires menés au moyen d'avions-citernes ont révélé que ces produits composites pourraient être beaucoup plus avantageux que les préparations ignifuges liquides classiques. Il faudra procéder à des études plus rigoureuses pour confirmer ces résultats préliminaires et recueillir des données sur d'autres aspects de l'utilisation des produits composites.

On a entrepris la présente étude pour déterminer si, à différentes concentrations (à raison de 5 parties d'eau à 1 partie concentré liquide, de même que dans les proportions de 8:1, 11:1 et 15:1, par volume), les produits ignifuges de longue durée sont plus efficaces lorsqu'on y ajoute une mousse de classe A à 3,0 pour cent. Pour comparer l'efficacité des produits ignifuges et des préparations composites, nous définirons huit parcelles d'environ 30 mètres de diamètre pour chacun des essais de combustion menés sur différents combustibles. Nous surveillerons le taux de propagation et l'intensité des flammes pour déterminer si l'efficacité des produits, appliqués par voie terrestre, varie en fonction des caractéristiques du comportement du feu. Nous mesurerons la réponse des espèces végétales brûlées et non brûlées pour déterminer si les préparations composites ou les produits ignifuges ont un effet nocif sur la croissance. Ce rapport contient une description de la méthodologie employée pour la conduite des essais sur le terrain, les résultats préliminaires des premiers travaux expérimentaux et des recommandations pour les essais futurs.

Introduction

Due to escalating costs, decreasing budgets and the need to increase operational efficiencies, the cost and effectiveness of aerial retardant programs have been under scrutiny in recent years. From 1988 to 1992, several operational trials were conducted by the British Columbia Forest Service (Wallinger and Berry 1992) to evaluate the effectiveness of retardant and foam composites. Two aircraft were modified to allow for the delivery of retardant and foam composites. An onboard foam injection system, which was capable of airborne injection at selected concentrations, was installed in one of the aircraft. The second aircraft was fitted to allow for the induction of foam into the loading manifold, which produced foam capabilities without the aircraft weight and balance problems that occur as a result of an onboard mixing system.

Operational trials were carried out over five fire seasons to evaluate the effectiveness of retardant (Fire-Trol 9311*, Canadian formulation) and foam

*The use of trade, firm or corporate names in this report is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the British Columbia Forest Service of any product or service to the exclusion of others which may be suitable.

(FireFoam 103) composites. Unthickened retardant at 5.5:1 was mixed with 0.3% to 1.0% foam. The results of the air tanker trials that were conducted by Wallinger and Berry (1992) suggest that retardant and foam composites offer a number of advantages over straight retardant:

- canopy penetration, drip and fuel wrap around is superior;
- drop perimeters are sharper and well defined in comparison to the dispersed edge of a conventional retardant drop; and,
- the visibility of the composite is enhanced significantly.

It should be noted that the enhanced visibility of retardant and foam composites may also have a negative visual impact after fire control, depending on the longevity of the effect.

Drop patterns were evaluated using cups and a sampling grid similar to that discussed by Noste (1973). These tests also indicated that composites offer advantages over conventional retardant:

- drop coverage levels are more uniform with less puddling and pooling; and,
- reduced retardant losses due to wind drift are incurred.

In studies that were reported by Bradley (1990), expansion ratios for retardant (5.0:1) mixed with 0.5% foam were less than those obtained for foam alone, and drainage rates were faster for composites than foam alone.

Several additional questions have arisen as a results of these preliminary trials. Although drop patterns and product visibility are improved for retardant and foam composites over conventional retardant, the impact of composites on suppression effectiveness has not been quantified. If drop patterns are more contiguous for retardant and foam composites, perhaps the dilution rate of retardant can be reduced without risking guard breach. Furthermore, environmental studies of the component products may not be applicable to composites, and some work may be required to determine if retardant and foam composites have an adverse effect on species composition or vegetation growth.

At present, the British Columbia Forest Service uses a single mixing ratio, 5.5 parts water to one part retardant, regardless of fuel characteristics or fire behaviour. According to George et al. (1977), the USA also uses a standard dilution rate, although a higher salt concentration (4:1) is used in the USA. Burn trials carried out by Stechishen (1976) and Rothermel and Philpot (1974) suggest that variations in the structure of available fine fuels, and the moisture content thereof, have an impact on the level of retardant coverage that is required to suppress a fire. If product effectiveness varies with fuel type and fire behaviour, it may also be possible to optimize retardant dilution rates for a given situation, which could result in significant cost savings.

Performance studies have been carried out to quantify the drop patterns and coverage levels produced with a variety of aerial delivery systems and chemical treatments, towards improving these systems or identifying those technologies that are appropriate for a given situation (Grigel and Lieskovsky 1972; George and Blakely 1973; Grigel et al. 1974; Grigel et al. 1975; George 1982, 1985 and 1992). Rather than focus on the technology that is available at present, the current study has been designed to provide quantitative data on the effectiveness of retardants and composites.

The primary objectives of this study are to:

- determine if the effectiveness of long term retardant at various dilution rates is improved when Class A foam is added;
- to determine if the effectiveness of retardants or composites varies with fuel type and fire behaviour;
- to determine if retardant and foam composites have an adverse effect on species composition or vegetation growth; and,
- to develop a method by which field trials can be repeated and compared.

Preliminary Study Area

The first study site (50° 07.3′ latitude, 120° 23.2′ longitude) was located 25 kilometers east of Merritt, British Columbia, at an elevation of about 1200 m. Native pasture occupied this site, which contained mainly rough fescue (*Festuca scabrella* Torr.) and a marginal component of bluebunch wheatgrass (*Agropyron spicatum* (Pursh) Scribn. & Smith). Other species present were *Koeleria macrantha* (Ledeb.) Schultes, *Stipa comata* Trin. and Rupr., *Ranunculus* spp., *Rosa acicularis* Lindl., *Fritillaria pudica* (Pursh) Spreng., *Achillea millefolium* L., *Arabis drummondii* Gray, *Viola* spp., *Geum triflorum* Pursh, *Artemisia frigida* Willd., *Zigadenus venenosus* Wats. and *Verbascum thapsus* L.

Accurate measurements of fire behaviour characteristics in native pasture will also provide validation data for the grassland rate of spread models that are used in Canada (Forestry Canada Fire Danger Group 1992). These models have been adapted from fire behaviour studies that were carried out in tropical grasslands in Australia, and they have not been validated for use in Canada.

Methodology

About three weeks prior to the burn, an automatic weather station was established at a nearby site. Eight sample plots were established within the area to be burnt. Four retardant (Fire-Trol 931) dilution rates (5:1, 8:1, 11:1 and 15:1) were applied with and without foam (0.3% FireFoam). The sample plots were located along a topographic bench at the top of a uniform slope (25%) with a westerly aspect.

Portable tanks, one for each of the eight treatments, were used to mix retardants and composites manually at the bottom of the hill. To provide more detailed coverage information for two of the sample plots, catch cups were placed at one meter intervals along two transect lines (one across slope and one down slope), which radiated out from the sprinkler head. Chemical treatments were pumped to the top of the hill and applied to each plot using a Nelson F33 series sprinkler with a 10 gpm constant flow nozzle. A plot radius of approximately 10 to 15 meters, with an application rate of approximately 1 liter per square meter, was sought. The required coverage was achieved after an application period of about ten minutes.

Duff pins were used to mark the visual extent of retardant and composite mixtures for each sample plot. After the burn, the bearing and distance from the sprinkler head to each duff pin was recorded, along with the distance to which the burn penetrated the treatment.

The fuel load was established by sampling four plots (30 cm by 30 cm) destructively, and oven drying (100°C for 24 hours) and weighing the samples. Fuel samples were also collected to establish post fire fuel loads. Ten grab samples were collected and weighed immediately before the fire was lit, so they could be oven dried and re-weighed for the determination of moisture content.

Metal posts were erected at 10 meter intervals up the slope to within 20 m of one of the central sprinkler heads, and the distance between the line of ignition and the first metal post was about 30 m. The arrival time of the fire front was recorded for each post, so that rates of spread could be determined from distance/time information.

Preliminary Results

The first fire was conducted in the spring (April 20, 1994), and new growth was barely beginning to emerge. The pasture had over wintered fully cured but had not been compacted by snow. It had been 10 days since the area last had rain (2 mm), and the pasture was about 90% cured. At the time of ignition (14:00 hr), the temperature was 18 °C, the relative humidity was 35%, the moisture content of the fuel was 24% and the wind was from the southwest at 6.3 km/hr. Live and dead fuels were 0.57 t/ha and 3.74 t/ha respectively.

Only four pumps were available on the day of the burn, and the first four treatments (5:1, 8:1, 11:1 and 15:1 without foam) were applied simultaneously. Pump problems meant that the second set of treatments (5:1, 8:1, 11:1 and 15:1 with 0.3% foam) were not applied until 1/2 hour after the first set, hence a longer drying time was incurred on the first four treatments.

Winds on the day of the burn resulted in coverage areas that were roughly elliptical in shape. Typical fluid distribution profiles are illustrated in Figure 1.

The fire was lit at the bottom of the slope, *via* drip torch, using a single line of ignition. In general, the fire traveled upslope with the wind, although some cross-slope winds occurred. To allow the fire to accelerate towards a steady state rate of spread, the fire burnt for 30 meters before any fire behaviour measurements were made. The headfire rate of spread was 11.25 m/min, flame heights varied between 0.6 and 1.2 m, 58.93% of all fuel was consumed and the frontal fire intensity was 857 kW/m.

In general, an elliptical area within each treatment area was left unburnt (Figure 2). Most of the treatments effectively stopped the progress of the fire, however, part of the fire burnt through the center of one of the plots, namely that treated with retardant at a dilution rate of 15:1 (no foam). Full treatment breach was considered to have taken place in this case, despite the fact that a small sickle shaped area was left unburnt.

One of the plots, 8:1 without foam, was not exposed to the headfire in the same manner as the others, because it was sheltered on the lee side of an adjacent plot. Hence, the study results are apt to overestimate the effectiveness of this treatment.

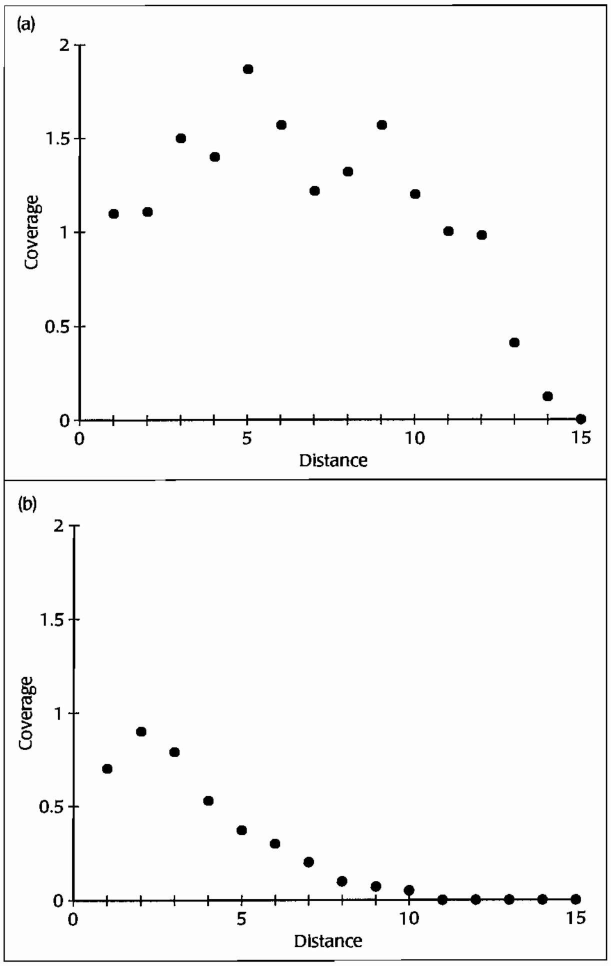


Figure 1. Typical fluid distribution profiles for one of the treatment plots, where coverage is in liters per square meter and the distance from the sprinkler head is given in meters. Fluid distribution profiles were measured across (a) and down slope (b), and were roughly aligned with and against the wind, respectively.

The area burnt as a percentage of the area treated was calculated for each treatment. However, duff pins were only used to mark the extent of about half of the treated and burnt areas (Figure 2), hence treatment and burnt areas were calculated for exactly the same 180 degree portion of each plot. The percentage area burnt increased markedly with retardant dilution rate (Figure 3), regardless of whether or not foam was added to the mixture. A paired difference test indicated that there was no significant difference in the percentage area burnt for those plots treated with foam *versus* those without foam, with a mean difference (foam - no foam) of -4.92% ($T = -0.5399$, $PROB > |T| = 0.6268$). There is no doubt, however, that the overestimated effectiveness of the sheltered plot (8:1 without foam) had a significant impact on the

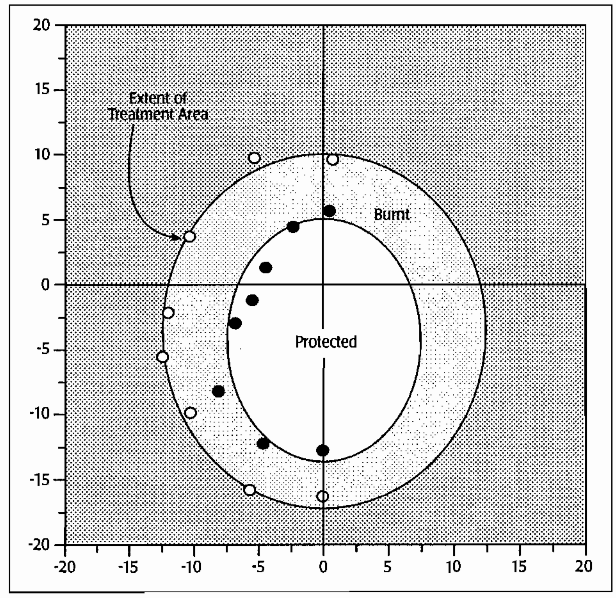


Figure 2. Hollow circles indicate the visual extent of the treatment area, and the solid circles indicate the point to which the fire burnt. The origin of the system indicates the location of the sprinkler head that was used to apply the treatment, and axes distances are given in meters.

results of this preliminary trial. For the weather and fuel conditions experienced, the results of this first burn trial would suggest that the addition of 0.3% foam does not increase the suppression effectiveness of retardant significantly at the dilution rates tested. In fact, for all retardant dilution rates except one, the percentage of the treatment area that burnt was greater with foam than without foam. However, the difference in treatment drying times may have had an impact on these results.

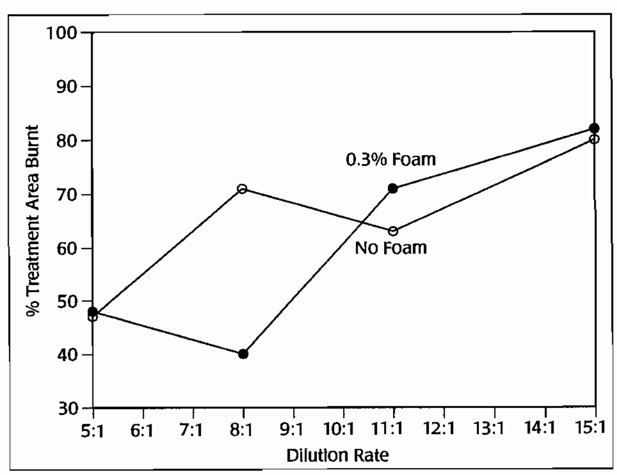


Figure 3. Area burnt as a percentage of the area treated versus retardant dilution rate with (dots) and without (hollow circles) 0.3% foam.

Recommendations

Several difficulties were encountered during this first field experiment, although these problems are largely overcome by way of a few simple modifications to the methodology of the study. Duff pins were used to demarcate about half of the visual extent of each treatment area. In future studies, the entire extent of the treatment area should be surveyed, and treatment and burn penetration distances should be measured at identical bearings for each treatment plot.

In future studies, eight pumps should be used to ensure that drying times are similar for all treatments. Moreover, if treatments with and without foam at similar retardant dilution rates were applied simultaneously, it would be easier to manage pump problems or delays so that drying times were similar for at least these treatments.

These preliminary study results indicate that no gains in suppression efficiency are experienced using retardant and foam composites over conventional retardants. It should be noted, however, that all treatments at a retardant dilution rate of 11:1 or less effectively stopped the fire. Under similar conditions of fuel, weather and fire behaviour, it may be possible to relax British Columbia's standard retardant dilution rate of 5.5:1, which could yield considerable cost savings, provided that similar coverage levels and extents can be achieved in air tanker operations.

Acknowledgments

This work could not have carried out without the assistance of the staff of the Merritt Forest District, who established the weather station, prepared equipment, identified plant species and assisted us with all aspects of the burn. We are grateful to the Fire Research Group at the Pacific Forestry Centre, Canadian Forest Service, for providing access to their oven drying facilities. We thank Dave Langridge, Tom Lacey, Phil Symington, Peter Fuglem and Duane Wall for their helpful suggestions and support of this work.

Literature Cited

Bradley, R.W. (1990) An overview of R&D involving foam/long term retardant mixtures. A paper presented to ACAFA Symposium. Cemonics Industries (Canada) Ltd. 24 p.

Forestry Canada Fire Danger Group (1992) Development and structure of the Canadian Forest Fire Behavior Prediction System. Forestry Canada, Science and Sustainable Development Directorate, Ottawa. Inf. Rep. ST-X-3. 63 p.

George, C.W. (1982) Measurement of airtanker drop conditions during firefighting operations. USDA For. Serv., Intermt. For. Range Exp. Stn., Ogden, Utah. Res. Pap. INT-299. 10 p.

George, C.W. (1985) An operational retardant effectiveness study. Fire Management Notes, 46(2): 18-22.

George, C.W. (1992) Improving the performance of fire retardant delivery systems on fixed-wing aircraft. USDA For. Serv., Intermt. For. Range Exp. Stn., Ogden, Utah. Res. Note INT-400. 12 p.

George, C.W. and A.D. Blakely (1973) An evaluation of the drop characteristics and ground distribution patterns of forest fire retardants. USDA For. Serv., Intermt. For. Range Exp. Stn., Ogden, Utah. Res. Note INT-134. 60 p.

Grigel, J.E. and R.J. Lieskovsky (1972) A comparison of the B-26 and Thrush Commander airtankers. Can. For. Serv., Inf. Rep. NOR-X-17. 42 p.

Grigel, J.E., R.J. Lieskovsky and R.G. Newstead (1974) Air drop tests with helitankers. Can. For. Serv., Inf. Rep. NOR-X-77. 77 p.

Grigel, J.E., R.G. Newstead and R.J. Lieskovsky (1975) A review of retardant delivery systems used in fixed-wing airtankers. Can. For. Serv., Inf. Rep. NOR-X-134. 66 p.

Noste, N.V. (1973) A field method for measuring patterns of water dropped from helicopters. USDA For. Serv., Pacific North West For. Range Exp. Stn., Portland, Oregon. Res. Note PNW-202. 11 p.

Rothermel, R.C. and C.W. Philpot (1975) Reducing fire spread in wildland fuels. *In* Experimental Methods in Fire Research. Proceedings of the meeting to honor Clay Preston Butler, Stanford Research Institute, May 9-10, 1974. 369-403.

Stechishen, E. (1976) Cascading Fire-Trol 931 fire retardant into a jack pine stand. Can. For. Serv., Inf. Rep. FF-X-58. 18 p.

Wallinger, K. and J. Berry (1992) An operational trial of foam enhanced LC 931. Unpublished Report. British Columbia Ministry of Forests, Protection Branch, Victoria.

Technical Session II:
Application and Use

A brief history of Class A fire control foam in Canada

R.R. Lafferty
Fire Management Officer, MacMillan Bloedel Ltd.

Abstract

Class A foams were used in Europe in the 1930's, but those products that we use today evolved from some special work done in eastern Canada in the early 1980's and northwestern Canada in the mid 1980's. Of course, considerable development work has been done on product and equipment since then.

Many industry and government people, in the United States and Canada, deserve credit for the high level of expertise that exists in the world today. Five years from now there will be more development to report due to the dedicated people in the business.

The new generation Class A fire control foam is unique because of its ability to perform well at 1.0% and 0.1% solution mix. Because of the low concentrations, it is used in fire bombing fixed wing and rotor wing aircraft. Class A foams are not bulky and some say they are inexpensive. They do suppress fires that plain water has little impact on. There is no doubt that Class A foam is an efficient fire suppressant.

In 1981, 1982, and 1983, Class A foams were 3% to 6%. In 1983, George Cowan and Eddie Cundasamy of Wormald International invented Silv-Ex Class A Foam. This new generation foam was concentrated and intended to be mixed at 1.0% to 0.1% solution.

Since 1984, several other companies have developed concentrated Class A foam and many millions of litres have been used. My talk gives a brief description of some of the activities that have led to the use of foam today.

Résumé

Dans les années 1930, on utilisait déjà les mousses de classe A en Europe, mais les produits que nous employons aujourd'hui sont nés des travaux spéciaux menés dans l'est du Canada au début des années 80 et dans le nord-ouest du pays, au milieu des années 80. Bien entendu, les produits et l'équipement ont fait l'objet de nombreux perfectionnements depuis cette époque.

De nombreux représentants de l'industrie et du gouvernement, aux États-Unis et au Canada, ont largement contribué à la formation des vastes connaissances techniques que nous avons dans le monde en matière de la lutte contre les incendies. Dans cinq ans, de nouveaux progrès seront enregistrés en raison du travail et à l'engagement des gens qui œuvrent dans le secteur.

La nouvelle génération de mousses carboniques de classe A est unique en ce que ces produits se révèlent très efficaces même lorsqu'ils sont utilisés en solution dans des concentrations de 1,0 ou de 0,1 pour cent. Étant donné les faibles concentrations, on utilise les produits lorsqu'on charge les aéronefs anti-incendie à ailes rotatoires et à voilure fixe pour bombarder les incendies. Les mousses de classe A sont peu volumineuses et, selon certains, peu coûteuses. Elles éteignent des incendies sur lesquels l'eau ordinaire demeure sans effet. Il ne fait aucun doute que les mousses de classe A sont des produits d'extinction efficaces.

En 1981, de même qu'en 1982 et en 1983, les mousses de classe A étaient utilisées dans des concentrations de 3 à 6 pour cent. En 1983, George Cowan et Eddie Cundasamy de Wormald International on inventé la mousse Silv-Ex. Cette nouvelle génération de mousse plus concentrée était conçue pour être utilisée en solution dans des concentrations de 0,1 à 1,0 pour cent.

Depuis 1984, plusieurs autres sociétés ont mis au point des mousses de classe A concentrées dont on a vendu des millions et des millions de litres. Dans notre exposé, nous décrivons brièvement certaines des activités qui ont mené à l'utilisation des mousses.

Introduction

On behalf of MacMillan Bloedel, I want to thank all the people that have made foam what it is today.

Class A foam was used in Europe in the 1930s on heather fires and were generally protein based products. Products used today evolved from special work done in eastern Canada in the early 1980s and in western Canada in the mid 80s. Of course, considerable developmental work has been done on products and equipment since the mid 1980s. Industry and government people, both in the USA and Canada, deserve credit for where we are today. On behalf of MacMillan Bloedel Ltd. and myself, I want to thank those people that contributed so much towards making foam a success today. In my opinion, Class A foam is still the darling of the future.

An interview with George Cowan and Gord Ramsey provided most of the information in my talk. Both gave credit where credit was due, unfortunately there is not time to mention everyone that has been involved in developing Class A foam. For more history, read Rockna's brief history report; or contact the Texas Forest Service who invented the Water Expansion Pumping System (WEPS) in the 1970s; talk to Gord, Doug Higgins or Paul Schlobohm.

The new generation Class A fire control foam is unique because of its ability to perform well between 0.1% and 1.0% solution mix. This allows more efficient use of aircraft and water tender because of reduced weight and bulk of the concentrate.

Because Wormald International and their foam product called Silv-ex played a highly significant role in development and marketing (demonstrations) of concentrated Class A foam, I mention them. I am not promoting nor condoning the use of any particular product. However, I believe it is useful to record some of the people that took the initiative, and as a group, were responsible for Class A foam as we know it today. For the record, Bob Schaffer of 3M Inc. sold and promoted a concentrated foam product in the early 1980s also.

1982

In 1982, Wormald International Ltd. (WI) purchased Lorcan Fire Foam Division. George Cowan was made General Manager to develop a product and to develop a market for Class A forest fire fighting foams. Mid-ex, a synthetic based chemical, was the Class A product of Lorcan at that time.

Petawawa National Forest Institute (PNFI) was working on developing a use for Class A foam under the direction of Gord Ramsey, Doug Higgins and Ed Stechishen. They were testing/developing inductors and nozzles to improve foam. PNFI demonstrations using 3M and Mid-ex showed promise in 1882, but because of snow and cool temperatures, some of the tests were inconclusive. Gord, Doug and Ed also recognized the potential of foam.

1983

The Petawawa foam research group decided that more tests should be done. At Dunphy Airfield a cooperative test between PNFI, New Brunswick Forest Service and WI was carried out. Klaus Barth was in charge of the project and represented New Brunswick. Aerial tests using a Dromadaire Aircraft with a pay load of 300 gallons of solution was used. A comparison test of 3% Aqueous Film Forming Foam and Mid-ex showed that Mid-ex (3%) worked and that the concept had promise. More testing was needed.

The Ontario Ministry of Natural Resources were experimenting with foam also. There Timmins initial attack crews used it for backburning and direct attack with success.

Jim Dunlop, of the British Columbia Forest Service, in 1983, organized a helicopter drop of a 3% premix solution of Mid-ex through Conair's Frontier Helicopters. Three drops were carried out with positive results except that the helicopter crew reported that the mix ratio of 3% was too high. To carry a resupply of the concentrate meant cutting down on fuel supply or water load. Neither alternative was acceptable. More testing was needed.

The B.C. tests confirmed some of G. Cowan's thoughts about the need to reduce the weight or volume of concentrate, so he took this information back to the WI plant in Thurso, Quebec where Dr. Eddie Cundasamy was responsible for research. They decided to formulate a new product as concentrated as possible but still maintaining stability and foaming in fresh and salt water. The new generation foam product Dr. Cundasamy developed was called Silv-ex. The uniqueness of Class A forest fire fighting foam was initiated. This was a significant day in the history of forest fire suppression.

Earlier research done with Mid-ex showed the possibilities of using Class A foam on forest fires. New generation foam made possible and practical sustained attack using Class A foam in helicopter and some fixed-wing aircraft. This proved to be economical, practical and effective. Silv-ex was the first practical concentrated foam product made available by aggressive marketing to both forest and rural fire fighters. Previous development work on inductors, nozzles, test apparatus, compressed air-foam systems and the like, showed the benefits of applying and using Class A foam also.

1984

Tom Blom, of the BCFS, asked Glen Stare of Fleck Brothers and G. Cowan to do a field trial using Silv-ex. Twenty pails of foam were used operationally that summer by the BCFS with exceptional success. Ground crews reported that less manpower and water was needed when foam was used.

During 1984, and again in 1985, Glen Stare gave Forest Industries Flying Tankers Ltd. many pails of Silv-ex which were used operationally.

1985

This year (1985) was the turning point for the new generation Class A foam in Canada, and the world.

In some provinces, there was a problem that restricted the use of foam. Fire retardant could not be used by government agencies without that product first passing USDA Forest Service specifications. There were no protocols for testing Class A foam at that time. There was no quantitative data to give governments comfort. This problem was partially overcome by aggressive marketing and demonstration. It seemed to be a matter of risk and reward who would use foam.

In August, B.C. started to burn. The Invermere/ Canal Flats country took all, and more, of the Province's fire control resources. Fire fighters were brought in from across Canada and all available local help was deployed.

Fleck's, Glen Stare and WI's, George Cowan, took the initiative and moved 100 five-gallon pails of Silv-ex to Invermere with the intent of demonstrating some new nozzles and the foam concentrate. After four days of demonstration, the BCFS purchased the first 100 pails and ordered another 1000 pails per day until WI was told to quit shipping. About 6000 five-gal pails were bought. All fire fighters who used foam described positive results, i.e., less water used, less effort to put out the fire, no rekindles and fewer reburns. Two medium helicopters stopped an advancing fire that several DC-6 aircraft with long-term retardant could not stop. These were common stories heard at lunch breaks and after the battle was over.

The positive experiences at Invermere convinced MacMillan Bloedel Ltd. (MB), a major forest company, to request FIFT, one of their subsidiaries, to accelerate their foam development program for both the Martin Mars and helicopter aircraft. FIFT prepared a Martin Mars aircraft so that 12 pails of foam concentrate could be put into the 26,000 litre tank. Ted Schaffer of 3M provided the foam concentrate for experimental use. Many test drops were done the next year with 3M.

Other chemical companies were now impressed with the future of foam and started to develop and market their products.

1986

MacMillan Bloedel Ltd. wrote a standard that said, "all water applied either from the ground or air shall have chemicals added". The preferred and insinuated chemical was Class A foam. Some long-term fire retardants and some wetting agents were acceptable also. This policy helped ensure that fire control people would use and learn about the benefits of foam. From this time on, MB has increased the use of Class A foam and at the same time reduced the severity of wildfire and prescribed fire. Fire bosses say "foam puts fire out", and pilots say that "they have never had a product that controls fire so well". The policy to use foam has proven cost effective.

MB have about 150 fire trucks which have foam on board. We have been responsible for helping volunteer fire departments get Compressed Air-Foam Systems and have helped promote foam products that meet NFPA Standard #298, a standard that they helped develop.

Forest Industries Flying Tankers fight both industry and Provincial fires. The work that FIFT does is described as exceptional and unique by both industry and government. Tom Irving, General Manager FIFT, reports the following volumes of foam solution dropped between 1986 and 1993:

FIFT Foam Solution Dropped (8 years)

	Imperial Gallons	Litres	U.S. Gallons
Helicopter	1,462,420	6,648,161	1,756,263
Mars	8,320,500	37,824,993	9,992,337 avg. 1.3 million/yr
Total	**9,782,920**	**45,835,135**	**11,748,600** avg. 1.5 million/yr

Coincidental

Another impact Canada has had on the international scene was the marketing work that WI, and other companies did with Canadair and the French and Spanish governments. That work helped accelerate the use of Class A foam in foreign countries. A benefit to Canada, I believe.

People in Canada, both in government and industry, have shown exceptional inventiveness and enthusiasm towards the development of new generation Class A foam during the 1980s. Throughout the development of Class A foam all North Americans, USA and Canadian, have worked together to ensure safe and effective foam products.

The future of Class A foam looks good and I expect some innovations will occur to improve its effectiveness. Those who want to reduce forest and rural fire losses and suppression costs will be wise to learn about the use of Class A foam.

National survey of use of Class "A" foam for wildland fire management

R.P. Bailey and Wm. Mawdsley
Department of Renewable Resources, Northwest Territories

Summary of Responses to Survey Questionnaire

Agencies Completing Questionnaire

Alberta Forest Service
British Columbia Ministry of Forests
Canadian Forestry Association
E.B.Eddy Forest Products
Forestry Canada - Newfoundland and Labrador
MacMillan Bloedel
Manitoba Natural Resources
Newfoundland Forest Service
New Brunswick Natural Resources
Nova Scotia Department of Natural Resources
GNWT - Dept. of Renewable Resources
Ontario Ministry of Natural Resources
PEI Dept. of Energy and Forestry
Québec Service de la Protection Contre le Feu
Saskatchewan Natural Resources
DIAND - Yukon Forest Service
DOE - Parks Canada (Riding Mountain)

Summary of Answers:

3. What was your agencies volume of concentrate use in the past five years? (Litres of Concentrate)

Agency	1988	1989	1990	1991	1992	Total
Alberta Forest Service	27730	18650	60189	73550	23298	203417
BC Ministry of Forests	100785	18645	11300	6350	14175	151255
E.B. Eddy				182		182
Flying Tankers	9274	40944	20831	5344	20220	96613
MacMillan Bloedel	2200	2200	2200	2500	3000	12100
Manitoba NR	9080	136200	4540	45400	18160	213380
Nfld. Forest Service		2460	4715	3810	7189	18174
NB Natural Resources	4600	5869	11328	16803	15465	54065
NS Natural Resources			500	3300	3200	7000
NWT Renewable Res.	10660	24545	58353	22343	43050	158951
Ontario MNR	20000	25000	30950	60750	40650	177350
PEI Energy & Forestry					100	100
Québec SPCF	1900	12700	20100	55100	39400	129200
Sask. Natural Res.	68300	57700	44700	52850	62100	285650
DIAND - Yukon L&F	8500	8500	8500	2000	2000	29500
DOE - Parks Canada		5	20	100	200	325
National Totals	263029	353418	278226	350382	292207	1537262

** Notes **
BC Ministry of Forests - Litres Purchased
E.B. Eddy - Numbers converted from gallons
Manitoba - Numbers converted from gallons
New Brunswick - foam and firetrol/foam

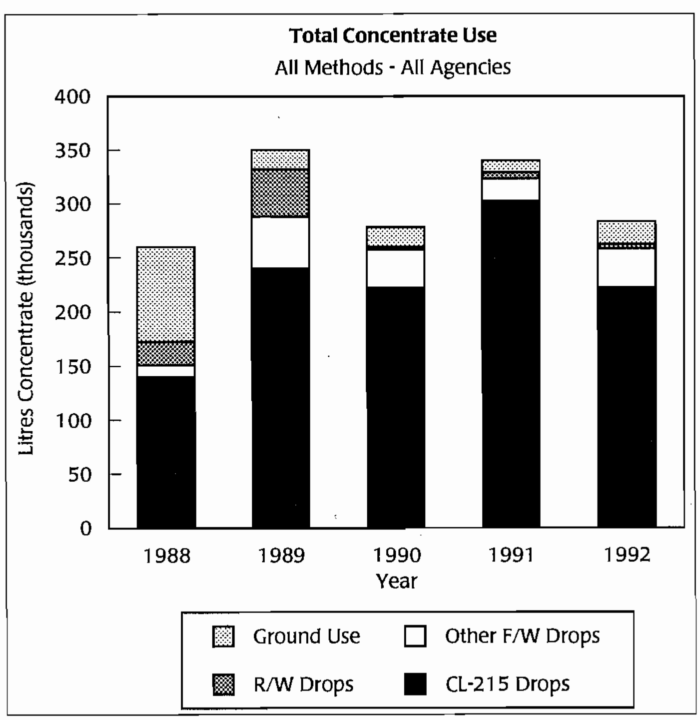


Figure 1. Total Foam Concentrate Use — Nationally.

4. How has your agency been applying Class "A" foam over the past five years?
   A. Aerial Delivery:
   CL-215 Use - Litres of Concentrate (Converted from Gallons or Drop Totals)

Agency	1988	1989	1990	1991	1992	Total
Alberta Forest Service	27730	18650	60189	73550	23298	203417
BC Ministry of Forests						
E.B. Eddy						
Flying Tankers						
MacMillan Bloedel						
Manitoba NR	2270	90800	4540	45400	18160	161170
Nfld. Forest Service		2460	4715	3730	6965	17870
NB Natural Resources	700		900		1600	3200
NS Natural Resources				2200	2000	4200
NWT Renewable Res.	10660	25545	58353	22243	43050	159851
Ontario MNR	20000	25000	28000	58000	38500	169500
PEI Energy & Forestry						
Québec SPCF	1900	12700	20100	54100	38400	127200
Sask. Natural Res.	68300	57700	35500	42600	50100	254200
DIAND - Yukon L&F	8500	8500	8500			25500
DOE - Parks Canada						
National Totals	140060	241535	220797	301823	222073	1126108

** Notes **
Alberta Forest Service – Converted at 0.4% concentration levels
BCFS, E.B. Eddy, Flying Tankers, PEI E&F, Parks – No CL-215's
Manitoba – converted from gallons

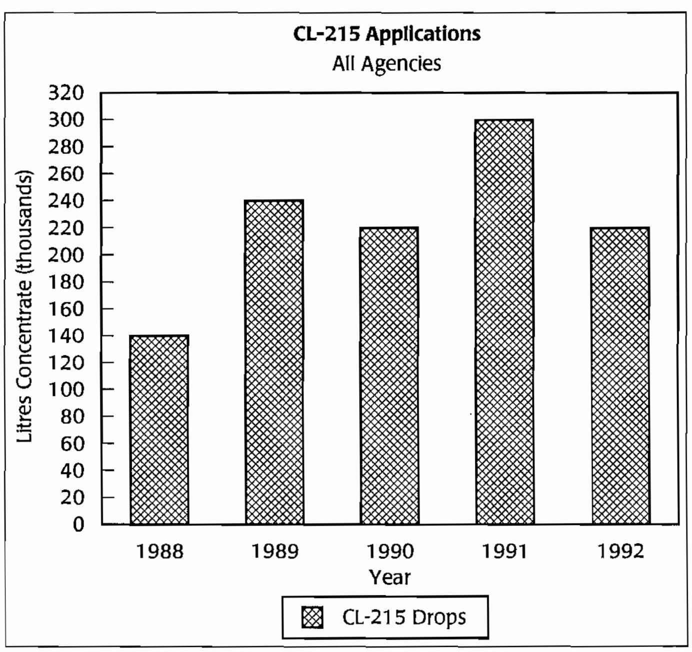


Figure 2. Total Foam Concentrate Use – Nationally Aircraft Applications – CL-215.

4. How has your agency been applying Class "A" foam over the past five years?
A. Aerial Delivery: (Continued)
Other Fixed Wing Concentrate Use

Agency	1988	1989	1990	1991	1992	Total
Alberta Forest Service						
BC Ministry of Forests						
E.B. Eddy						
Flying Tankers	9274	38678	20749	4446	17173	90320
MacMillan Bloedel						
Manitoba NR						
Nfld. Forest Service						
NB Natural Resources	2500	1300	3000	4700	1500	13000
NS Natural Resources						
NWT Renewable Res.						
Ontario MNR						
PEI Energy & Forestry						
Québec SPCF						
Sask. Natural Res.			9200	10250	12000	31450
DIAND - Yukon L&F						
DOE - Parks Canada						
National Totals	11774	39978	32949	19396	30673	134770

** Notes **
Flying Tankers – Martin Mars - also provide service to Macmillan-Bloedel
New Brunswick – Grumman TBM
Saskatchewan – PBY Canso

4. How has your agency been applying Class "A" foam over the past five years?
A. Aerial Delivery: (Continued)
Rotor-Wing Concentrate Use

Agency	1988	1989	1990	1991	1992	Total
Alberta Forest Service						
BC Ministry of Forests	20000	4000	2000	1200	3000	30200
E.B. Eddy						
Flying Tankers		2266	82	1198	3047	6593
MacMillan Bloedel						
Manitoba NR	2270	45400				47670
Nfld. Forest Service						
NB Natural Resources				512	307	819
NS Natural Resources				100	200	300
NWT Renewable Res.						
Ontario MNR			2000	2000	1500	5500
PEI Energy & Forestry						
Québec SPCF				1000	1000	2000
Sask. Natural Res.						
DIAND - Yukon L&F						
DOE - Parks Canada						
National Totals	22270	51666	4082	6010	9054	93082

** Notes ** Flying Tankers service Macmillan-Bloedel

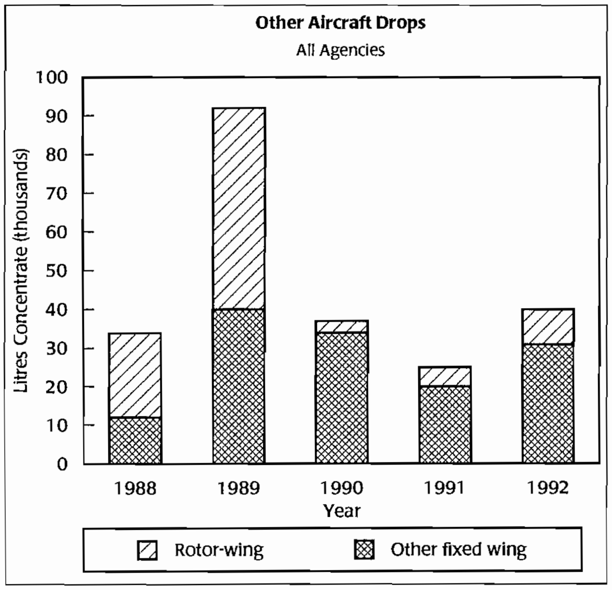


Figure 3. Total Foam Concentrate Use – Nationally
Other Aircraft Application
(Martin mars, Canso, TBM, Rotary-Wing)

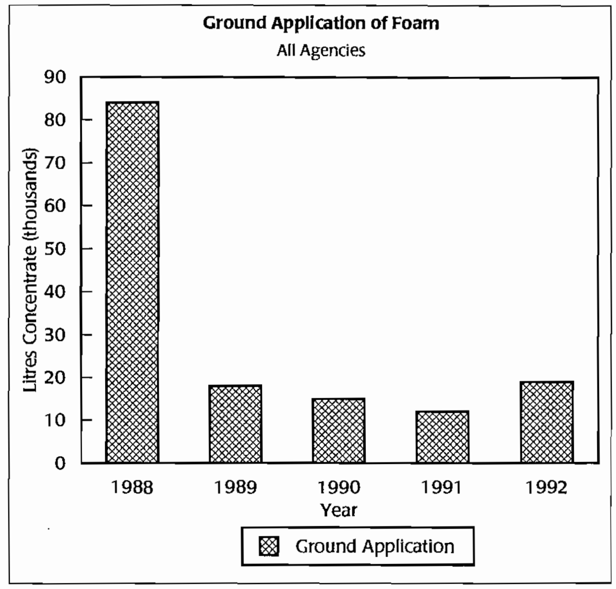


Figure 4. Total Foam Concentrate Use – Nationally
Ground Application of Foam

4. How has your agency been applying Class "A" foam over the past five years?
B. Ground Application:
Ground Application Concentrate Use

Agency	1988	1989	1990	1991	1992	Total
Alberta Forest Service				unknown	unknown	
BC Ministry of Forests	80785	14645	9300	5150	11175	121055
E.B. Eddy				180		180
Flying Tankers						
MacMillan Bloedel	2200	2200	2200	2500	3000	12100
Manitoba NR						
Nfld. Forest Service				8	224	232
NB Natural Resources	200	200	400	450	500	1750
NS Natural Resources			500	1000	1000	2500
NWT Renewable Res.		1050	475	45	50	1620
Ontario MNR			950	750	650	2350
PEI Energy & Forestry				100		100
Québec SPCF			some	some	some	
Sask. Natural Res.						
DIAND - Yukon L&F			1000	2000	2000	5000
DOE - Parks Canada		5	20	100	200	325
National Totals	83185	18100	14845	12283	18799	147212

** Notes **
BC Ministry of Forests - Foam Purchases (Actual use may be considerably less)
NS Natural Resources - Ground Tankers

5. (a) What Concentrations (e.g. .1%) of Class "A" Foam are being used by your agency
i. by application method; ii. by fire danger class; iii. by fuel type

Alberta Forest Service	0.2-0.7	CL-215	following Forestry Canada Tech transfer note - April 1989
BC Ministry of Forests	0.1-0.5	Ground Application, All Classes & Fuels	
E.B. Eddy	0.1-0.2	Ground App.	High S-1
Flying Tankers	0.4	All Aircraft	
MacMillan Bloedel	0.1-0.4	High	Air 0.4
	0.1	Low	Ground 0.1-0.4
	0.3	Med-High	Concentration increased as drier it is. All fuels.
Manitoba NR	0.3-0.5	All classes and fuels	
Nfld. Forest Service	0.5	CL-215's	
	0.2-0.6	Ground	
NB Natural Resources	0.2-0.4	Low Light Fuels Ground	
	0.4-0.8	Heavy Fuels	
	0.3-0.5	All Low Air	
	0.5-0.7	All M-H Air	
NS Natural Resources	0.5	All CL-215 H-E	
	0.5-0.7	All R/W H-E	
	0.3-1.0	All Ground H-E	
NWT Renewable Res.	0.3-0.7	Not Higher than 1.0 -Air	
	0.1	Ground	
Ontario MNR	0.5-0.7	M-E, All Fuels Air	
	0.3-0.7	All Ground	
PEI Energy & Forestry	Unknown		
Québec SPCF	0.4	All	
Sask. Natural Res.	0.2-0.5	All types, ground	
	0.2-0.3	L-M All SPF Types Air	
	0.3-0.5	H-E All SPF	Types Air
DIAND-Yukon L&F	0.5-0.7	All Air	
DOE - Parks Canada	0.7	Ground S-2	

5. (b) How does your agency determine the correct type of foam that is required for a fire?

Alberta Forest Service	Experience Training, using Foam Manual as Guide
BC Ministry of Forests	By use or fuel type, dictated by equipment
E.B. Eddy	Training and Experience
Flying Tankers	0.4% on the first load, fireboss advice after
MacMillan Bloedel	Subjective site evaluation
Manitoba NR	Experience, training, literature on subject
Nfld. Forest Service	Fire Conditions, Values at Risk, Visual assessments
	Structural - dry foam
NB Natural Resources	Fire Behaviour, Buildup Index, Fuels
NS Natural Resources	Use a wet foam for all applications
NWT Renewable Res.	Training, Experience, Fuel Types, FB, Followup
	Assessment by the fireboss, air attack officer, other line staff
Ontario MNR	Wet Dripping Foam
PEI Energy & Forestry	Not There Yet
Québec SPCF	Subjective Eval, Manufacturer advice, Training
Sask. Natural Res.	Subj. Evaluation, Experience, Literature
DIAND - Yukon L&F	Trial, Error, Experience, Literature
DOE - Parks Canada	No set guides developed yet

6. (a) What % of fires by response category is foam used on?
Are these percentages increasing or decreasing?

	IA		SA		Mopup		PB	
Agency	% Fires	≥ or ≤	% Fires	≥ or ≤	% Fires	≥ or ≤	% Fires	≥ or ≤
Alberta Forest Service		inc		inc				
BC Ministry of Forests	unknown	inc			unknown	inc		
E.B. Eddy			90	inc			10	inc
Flying Tankers	98	inc			98	inc		
MacMillan Bloedel	50-100	inc						
Manitoba NR	12	inc						
Nfld. Forest Service	60	inc			5	inc		
NB Natural Resources		inc		inc		inc		
NS Natural Resources	25	inc	5	inc	5	inc		
NWT Renewable Res.	90	inc	10-50	inc-dec	25-50	inc		
Ontario MNR	40	inc	_ 10	inc				
PEI Energy & Forestry	4	inc						
Québec SPCF	40	inc	_ 0	inc		inc		inc
Sask. Natural Res.	_5-90	inc-dec						
DIAND - Yukon L&F	5	inc	10	inc				
DOE - Parks Canada							100	inc

** Note ** Macmillan-Bloedel: Policy to use foam on all fires
New Brunswick: Use dependent on availability of dispensing systems

6. (b) What duration (time) of foam effectiveness are you experiencing at concentration levels?
e.g. 8 minutes at 0.1% concentration

	Concentration Levels (%)							
Agency	.1	.2	.3	.4	.5	.6	.7	.8
Alberta Forest Service				0.5 hours ±				
BC Ministry of Forests					nil records			
E.B. Eddy					no information			
Flying Tankers				2-3 hours				
MacMillan Bloedel	Estimate 0.5 hours							
Manitoba NR			6 min		8 min			
Nfld. Forest Service					2-10 h			
NB Natural Resources				inc with concentration				
NS Natural Resources					no information provided			
NWT Renewable Res.	20-24h		10 m		20 m		30 m	
Ontario MNR				.25-1.2h				
PEI Energy & Forestry								
Québec SPCF						30 m		
Sask. Natural Res.		10 m	30 m		45 m			
DIAND - Yukon L&F							30 m	
DOE - Parks Canada							45-60	

** Notes **
NWT - temperature of water and concentrate affects quality of foam

7. (a) Does your agency have a method of measuring or evaluating the effectiveness of air or ground applied foam?
Please describe.

Alberta Forest Service	Yes	Forms Developed and used for field reports
BC Ministry of Forests	No	
E.B. Eddy	No	
Flying Tankers	Yes	Informal responses from field users
MacMillan Bloedel	Yes	Informal responses from field users
Manitoba NR	Yes	Informal responses from field users
Nfld. Forest Service	No	Low fire incidence past few years
NB Natural Resources	Yes	Informal responses from field users
NS Natural Resources	No	
NWT Renewable Res.	Yes	Informal responses from field users
Ontario MNR	No	PEI Energy & Forestry No
Québec SPCF	No	But interested in a format
Sask. Natural Res. study for	Yes	Subjective Evaluation responses from field, and results from 1989 foam comparison
DIAND - Yukon L&F	No	But informal field responses
DOE - Parks Canada	No	

7. (b) Please provide your subjective evaluation of the effectiveness of foam products applied
A. Aerial Application:

Alberta Forest Service	50 - 100 % depending on technique and fire
BC Ministry of Forests	No Record
E.B. Eddy	2-3 times on most fires aerial application using OMNR aircraft. Ground use not evaluated.
Flying Tankers	3-4 times extreme conditions 2-3 times moderate to high conditions 3-4 times all rotor wing
MacMillan Bloedel	significant improvement on aerial application, takes less men and equipment to suppress fires
Manitoba NR	Quite useful on aerial application for high an extreme danger class fires (C-2, C-3 fuels)
Nfld. Forest Service	Very effective on C-1 fuel type, aerial application
NB Natural Resources	Greatly improved mopup aerial application, hotspotting easier because of burn-through
NS Natural Resources	Use primarily in high to extreme hazard; feel foam extremely effective in applications over water alone
NWT Renewable Res.	Foam longer lasting, more visible Effect improved substantially Pump spray distance and pressure reduced
Ontario MNR	
PEI Energy & Forestry	Not enough experience with foams yet
Québec SPCF	2-4 times all C class fuels on aerial application
Sask. Natural Res.	50-100% conifer fuel types, aerial application, depending on hazard rating
DIAND - Yukon L&F	3-10 times C-fuels aerial application
DOE - Parks Canada	No Aerial applications

B. Ground Application:

Alberta Forest Service	40-50% improvement
BC Ministry of Forests	Much more effective, but nor formal evaluation done on increase in effectiveness
E.B. Eddy	No Estimate
Flying Tankers	
MacMillan Bloedel	50% improvement
Manitoba NR	
Nfld. Forest Service	Most applications on waste sites, property, stacked wood - no estimates
NB Natural Resources	50-200% improvement
NS natural Resources	See Aerial Application (above)
NWT Renewable Res.	
Ontario MNR	
PEI Energy & Forestry	
Québec SPCF	50-60% improvement on mopup
Sask. Natural Res.	100 % improvement
DIAND - Yukon L&F	5-10 times improvement over water
DOE - Parks Canada	Applied foam as a fireguard

8. (a) Has your agency used or tested foam mixed with retardants in aerial or ground applications? Please describe.

Alberta Forest Service	Drop tests on the A-26, concern about duration
BC Ministry of Forests	Operational trial of Foam Enhanced LC 931
E.B. Eddy	Not Tested
Flying Tankers	Not Tested
MacMillan Bloedel	Not Tested
Manitoba NR	Not Tested
Nfld. Forest Service	Not Tested
NB Natural Resources	Using Foamed Retardants - concerned about storage problems - 80% use in aerial applications in 1992
NS Natural Resources	Not Tested
NWT Renewable Res.	Drop tested from DC-6 - concerns about environmental impact
Ontario MNR	Not Tested
PEI Energy & Forestry	Not Tested
Québec SPCF	Not Tested
Sask. Natural Res.	Drop tested with Tracker - No results available - No further plans to test
DIAND - Yukon L&F	Drop tested with A-26 - no further information
DOE - Parks Canada	Not Tested

8. (b) Does your agency have a method of measuring or evaluating the effectiveness of air or ground foam mixed with retardants?
Please describe.

Alberta Forest Service	A formal evaluation system is being set up, with Forestry Canada; but no use of foamed retardants in Alberta
BC Ministry of Forests	Project evaluating foam mixed with unthickened retardants in two airtankers operating in BC
NB Natural Resources	No Method in place
NWT Renewable Res.	No Method in place
Sask. Natural Res.	No method in place
DIAND - Yukon L&F	No method in place

8. (c) State your subjective evaluation results of the effectiveness of foam mixed with retardants products applied

BC Ministry of Forests -Report: An Operational Trial Foam
Enhanced LC 931

9. Has the use of foam products reduced the mop up time on fires?
If so, by what percentage decrease in time?
(Mop up - the Act of extinguishing a fire after it has been brought under control).

Alberta Forest Service	50 % reduction
BC Ministry of Forests	Not studied, but feel it is much more effective
E.B. Eddy	No estimate, but believe it has
Flying Tankers	50 % reduction estimate
MacMillan Bloedel	25-30 % reduction
Manitoba NR	25-30 % reduction
Nfld. Forest Service	30-50 % reduction on small fires
NB Natural Resources	0-100% reduction
NS Natural Resources	Time reduced but unable to estimate percentage
NWT Renewable Res.	20-50% reduction
Ontario MNR	20-80% reduction
PEI Energy & Forestry	Not enough use to estimate yet
Québec SPCF	30 % reduction
Sask. Natural Res.	No estimate
DIAND - Yukon L&F	Foam use not promoted for mopup
DOE - Parks Canada	Not used for mopup

10. List fire fighter (or other such as air crew) health and safety issues your agency has encountered since the introduction of foam.
A brief explanation of each is requested.

Alberta Forest Service	Eye irritation from concentrate Skin irritation from concentrate Diarrhoea from drinking solution
BC Ministry of Forests	Some workers concerned with exposure to skin and eyes, short term effects.
E.B. Eddy	None noted
Flying Tankers	None noted
MacMillan Bloedel	Eye and Skin irritation -resolved when MSDS followed. Inhalation danger questioned
Manitoba NR	Skin Irritation Slippery footing on fires Leather boots deteriorate from foam exposure
Nfld. Forest Service	Fumes and odours a concern
NB Natural Resources	None noted
NS Natural Resources	Odour in helicopter from transportation of helicopter bucket and concentrate Drying of skin while handling concentrate
NWT Renewable Res.	Cumulative long-term exposure a concern Allergic skin reactions Boots rot from extended exposure Safety of crews working in airdropped foam Concerns about foam in helicopters
Ontario MNR	Aircrew concerned about fumes in aircraft Firefighters have general health concerns
PEI Energy & Forestry	Concerns about inhalation of fumes

10. (cont'd)

Québec SPCF	None noted
Sask. Natural Res.	Eye irritation from exposure during drops Eye irritation during offloading of concentrate
DIAND - Yukon L&F	Drying of skin Impact on leather boots Slippery footing on fires
DOE - Parks Canada	None encountered

11. List public or environmental agency concerns your agency has encountered. A brief explanation of each is requested.

DOE - Parks Canada	None encountered
Alberta Forest Service	Contamination of water sources from air drops
BC Ministry of Forests	None noted
E.B. Eddy	None noted
Flying Tankers	Concerns about contamination of water sources. BC Environment did not feel there was a problem.
MacMillan Bloedel	Visual impact of foam on water, fish stream contamination
Manitoba NR	None noted
Nfld. Forest Service	Concern about contamination of ground water supplies (public), environmental guidelines being prepared
NB Natural Resources	Domestic Water contamination concerns Contamination of water in muskeg/bogs/sloughs Effects on ground water a concern
NS Natural Resources	Ornamental trees and shrubs damaged around houses Concern expressed by Environment Department over concentrate in water course
NWT Renewable Res.	Concern about contamination of waterbodies, long-term effects on fire crews
Ontario MNR	Concern about contamination of waterbodies during pickups - splash
PEI Energy & Forestry	Impact on plantations a concern Pollution of water sources
Québec SPCF	Québec Environment restrictions had to be followed - avoiding contamination of waterbodies
Sask. Natural Res.	None noted
DIAND - Yukon L&F	Contamination of waterbodies Crew Health and Safety
DOE - Parks Canada	Effects on waterbodies

12. Give a brief outline explaining how the standard operating procedures or guidelines practised by your agency were developed for the air and ground application of foam.

Alberta Forest Service	A foam use manual was developed to deal with foam application issues
BC Ministry of Forests	No manual of standard operating procedures. Worked with the Foam Task Group developing foam videos Developed a pocket foam guide, training material in the S-232 course given to firefighters
E.B. Eddy	Staff attend OMNR seminars and Wajax demonstrations
Flying Tankers	SOP's developed through trial and error
MacMillan Bloedel	Developed through common sense,experience, following Manufacturers' recommendations, and NFPA 298 circular
Manitoba NR	Reviewed and revised material from other agencies
Nfld. Forest Service	Guidelines (air) developed internally to deal with observed problems. Ground guidelines due in 1993

12. (cont'd)

NB Natural Resources	Developed through experience
NS Natural Resources	Combination of standards and guidelines from other provinces and additional materials necessary to ensure safe use and handling by staff
NWT Renewable Res.	Developed through experience, with safety training from outside agencies, experience
Ontario MNR	Developed with input from other agencies, and input from manufacturers
PEI Energy & Forestry	No comment provided
Québec SPCF	Comprehensive SOP's not completed yet; Foam Utilization guide provided to employees
Sask. Natural Res.	Developed through experience and information from other agencies
DIAND - Yukon L&F	Developed internally in response to identified needs
DOE - Parks Canada	Procedures developed based on Alberta Forest Service program

13. What special equipment, employee training, environmental concerns or storage and handling facilities were required?

Alberta Forest Service	Wildfire Foam Manual (1992) deals with foam training and safety issues
BC Ministry of Forests	All employees using foam provided with protective equipment
E.B. Eddy	No comment offered
Flying Tankers	Foam stored in containment dykes, all employees trained in safety and health issues
MacMillan Bloedel	Foam Unit Carried on a 5-ton Truck, developed non-leaking storage systems, employee training for safety
Manitoba NR	Safety gear provided to employees Employees trained by government and industry Non-corrosive containers and equipment
Nfld. Forest Service	Listed specialized equipment needed to handle foam - heated storage facility, forklift, specialized transfer units Additional foam use training is required
NB Natural Resources	DSP systems only Cold weather storage a problem
NS Natural Resources	New storage facilities for foam and other chemicals New foam kits including rubber gloves, goggles, moisturizing cream New handling procedures for air and ground use of foam
NWT Renewable Res.	Overwinter storage a concern Training provided in safe handling of concentrate safe application on the ground for crews handling foam Protective clothing provided to staff Specialized application and handling equipment
Ontario MNR	Protective clothing provided Brief training on safety given to staff
PEI Energy & Forestry	Foam workshop training Foam use still in the introductory stage
Québec SPCF	Protective clothing provided for handlers Employee training given following the agency foam utilization guide published by Québec Specialized foam transfer units installed at tanker bases
Sask. Natural Res.	Protective clothing provided, eyewash stations installed at handling sites Annual employee training in safety and health
DIAND - Yukon L&F	Protective clothing provided for staff
DOE - Parks Canada	Protective clothing for staff, annual employee training, no special storage or handling facilities

14. What worker comments/concerns has your agency received since introducing foam.

Alberta Forest Service	Effective product in fire work Need more equipment development Crews concerned about wage losses Prior to training - concerns about health and safety
BC Ministry of Forests	Concern with skin and eye exposure and short term effects
E.B. Eddy	No comment offered
Flying Tankers	No WHMIS data at start of use of foam
MacMillan Bloedel	Good product, concerns about short-term and long-term health effects.
Manitoba NR	Slippery working conditions with foam Skin irritation when no safety gear used
Alberta Forest Service	Effective product in fire work
Nfld. Forest Service	Concerns with the handling of the concentrate, ingestion of fumes and odours Slippery footing on fires Comments that foam very effective, but training needed
NB Natural Resources	Foam tough on overtime Foam fumes attracted wasps Foam hard on footwear Skin problems, but overcome by specific treatments
NS Natural Resources	Pilot concerns over odour, toxicity, corrosive potential Worker concerns over use of concentrate Concerns over degreasing of pump seals
NWT Renewable Res.	Concern about carrying foam in aircraft (R/W) Allergic reactions to exposure Foam - seen as a labour and timesaver
Ontario MNR	Aircrew - concern about headaches from fumes Firecrews - concern about general health effects Crews generally impressed with the product
PEI Energy & Forestry	Not enough use to comment
Québec SPCF	Foam irritation of skin and eyes from exposure Concern about foam being worse than not using foam in fire suppression activities
Sask. Natural Res.	Concerns about fumes in aircraft
DIAND - Yukon L&F	Good effectiveness of foam
DOE - Parks Canada	None provided

15. Fire History by Agency - Number of Fought Fires (CIFFC Database)
Data is taken from the government agencies only. No research was made into fire activity of the corporate respondents.

	1988	1989	1990	1991	1992	Totals	Mean
Alberta Forest Service	865	795	1295	921	1005	4881	976
BC Ministry of Forests	1951	3537	3257	2037	3669	14451	2890
Manitoba NR	982	1143	537	611	257	3530	706
Nfld. Forest Service	115	192	196	135	108	746	149
NB Natural Resources	438	392	377	656	561	2424	485
NS Natural Resources	328	425	496	733	285	2267	453
NWT Renewable Res.	105	298	206	240	244	1093	219
Ontario MNR	3081	2140	1472	2441	903	10037	2007
PEI Energy & Forestry	21	29	38	48	20	156	31
Québec SPCF	1267	1065	799	1150	707	4988	998
Sask. Natural Res.	988	813	786	672	563	3822	764
DIAND - Yukon L&F	89	174	122	140	94	619	124
DOE - Parks Canada	73	130	128	53	55	439	88
	10303	11133	9709	9837	8471	49453	9891

16. Fire History by Agency - Annual Area Burned (CIFFC Database)
Data is taken from the government agencies only. No research was made into fire activity of the corporate respondents.

Agency	1988	1989	1990	1991	1992	Totals	Mean
Alberta Forest Service	14051	6754	31097	6130	3256	61288	12258
BC Ministry of Forests	11462	22386	72504	29396	27082	162830	32566
Manitoba NR	470406	3281300	19784	21698	113056	3906244	781249
Nfld. Forest Service	86	68156	46817	38853	1437	155349	31070
NB Natural Resources	1975	343	6114	3335	5055	16822	3364
NS Natural Resources	335	462	1068	1775	1163	4803	961
NWT Renewable Res.	1890	137283	33895	3580	10214	186862	37372
Ontario MNR	74217	11139	9250	20408	15937	130951	26190
PEI Energy & Forestry	17	216	102	120	41	496	99
Québec SPCF	7041	6498	16067	379861	9431	418898	83780
Sask. Natural Res.	52817	166645	68785	57308	14175	359730	71946
DIAND - Yukon L&F	537	107674	109062	79426	15372	312071	62414
DOE - Parks Canada	331	830	25041	791	360	27353	5471
	635165	3809686	439586	642681	216579	5743697	1148739

Hypotheses on The Status of Use Class "A" Foams in Canada

Hypotheses on the Use of Class "A" Foams for Wildland Fire Management in Canada

Hypothesis No. 1

Class "A" foam for wildland fire applications is in widespread use across Canada. Volumes of concentrate used are high and on the increase.

True and False:

Volumes of concentrate used in Canada have not increased significantly over the past five years, generally across agencies, and, generally within agencies. The response tables for questions 3 and 4 (and subquestions) provide the details.

The following graph provides an overall picture. The Ground use amounts for 1988 are skewed by BCFS figures, which are purchases. Their actual application use may be considerably less.

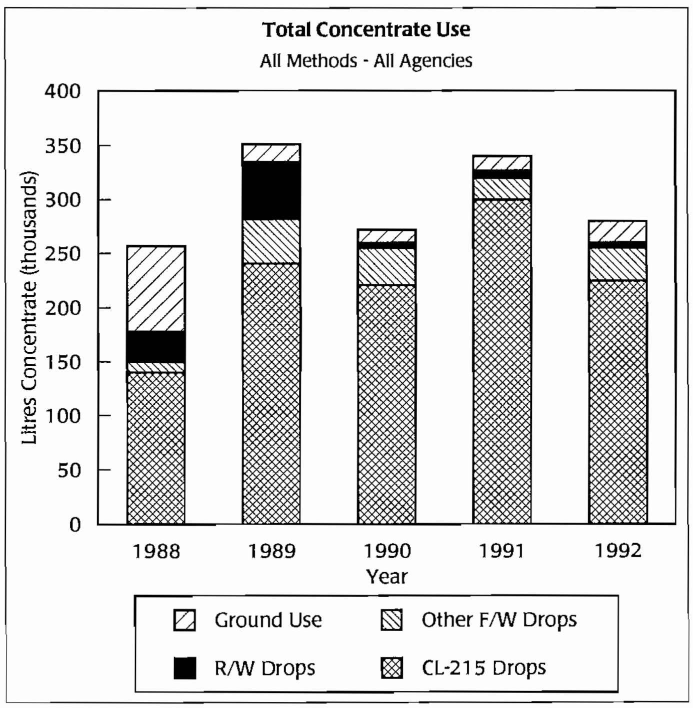


Figure 5. Total Foam Concentrate Use - Nationally.

Hypothesis No. 2

Agencies are generally aware of required concentration levels for given fuel types and fire behaviour conditions.

False:

Based on the variation in response across agencies, and within agencies in some cases, effective concentration levels are not clearly defined.

Response results supporting this claim are contained in question 5(a). Tabular results are as follows.

Table of Ranges of Concentrations by Agency

	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Alberta Forest Service		—	—	—	—	—	—	—	—	—
BC Ministry of Forests	—	—	—	—	—					
E. B. Eddy	—	—								
Flying Tankers				—						
MacMillan - Bloedel	—	—	—	—						
Manitoba NR			—	—	—					
Nfld. Forest Service		—	—	—	—	—				
NB Natural Resources		—	—	—	—	—	—	—		
NS Natural Resources	—	—	—	—	—	—	—	—	—	—
NWT Renewable Res.	—		—	—	—	—	—			
Ontario MNR			—	—	—	—	—			
PEI Energy and Forestry										
Québec SPCF				—						
Sask. Natural Res.		—	—	—	—					
DIAND - Yukon L&F					—	—	—			
DOE - Parks Canada							—			

Hypothesis No. 3

Agencies have a method of measuring or evaluating the effectiveness of air or ground applied foam.

Generally False:

Based on the information provided, only one agency (Alberta) has developed a system for evaluating the use of ground or air applied foam.

Question 7(a) (results below) does not support this hypothesis, with the exception of Alberta.

Alberta Forest Service	Yes	Forms Developed and used for field reports
BC Ministry of Forests	No	
E.B. Eddy	No	
Flying Tankers	Yes	Informal responses from field users
MacMillan Bloedel	Yes	Informal responses from field users
Manitoba NR	Yes	Informal responses from field users
Nfld. Forest Service	No	Low fire incidence past few years
NB Natural Resources	Yes	Informal responses from field users
NS Natural Resources	No	
NWT Renewable Res.	Yes	Informal responses from field users
Ontario MNR	No	
PEI Energy & Forestry	No	
Québec SPCF	No	But interested in a format
Sask. Natural Res.	Yes	Subjective Evaluation responses from field, and results from 1989 foam study for comparison
DIAND - Yukon L&F	No	But informal field responses
DOE - Parks Canada	No	

Hypothesis No. 4

Class "A" foams reduce mopup time, and the amount of reduction is known.

Cannot be Validated:

Nine agencies indicated that foams reduce mopup time, three could not or did not provide a response, and two did not use foams in mopup.

The agencies supporting the hypothesis considered that foams reduced mopup time by as much as 100% and as low as 0%, with an average of 25-50%. The range of results are

Alberta Forest Service	50 % reduction
BC Ministry of Forests	Not studied, but feel it is much more effective
E.B. Eddy	No estimate, but believe it has
Flying Tankers	50 % reduction estimate
MacMillan Bloedel	25-30 % reduction
Manitoba NR	25-30 % reduction
Nfld. Forest Service	30-50 % reduction on small fires
NB Natural Resources	0-100% reduction
NS Natural Resources	Time reduced but unable to estimate percentage
NWT Renewable Res.	20-50% reduction
Ontario MNR	20-80% reduction
PEI Energy & Forestry	Not enough use to estimate yet
Québec SPCF	30 % reduction
Sask. Natural Res.	No estimate
DIAND - Yukon L&F	Foam use not promoted for mopup
DOE - Parks Canada	Not used for mopup

Hypothesis No. 5

The application of Class "A" fire foams in solutions is more effective than water, and the factor of improvement is known or can be accurately estimated.

Cannot be Validated:

The estimated effectiveness of foam over water ranges from 50-100% improvement to 5 - 10 times (300-10000%) improvement.

Hypothesis No. 6

Agencies have been experimenting with foam mixed with retardants, with results available.

False:

Four agencies (Alberta, NWT, Saskatchewan, Yukon) have drop tested foamed retardants, and one agency is using the process (New Brunswick). The former four do not indicate plans to continue tests. The BC Ministry of Forests has produced a report titled

An Operational Trial
Foam Enhanced LC 931
Wallinger K., and, Berry J.
BC Ministry of Forests
Caribou Region, Kamloops Region

Hypothesis No. 7

Fire foams are safe on the environment.

Cannot be Validated:

Public concerns have been expressed about potential for contamination of water bodies. No information was found or provided to refute or support the concerns. Refer also to the next hypothesis.

Hypothesis No. 8

Public concerns over environmental impacts have been addressed.

Cannot be Validated:

Although most responding agencies noted public concerns, only one agency (Forest Industries Flying Tankers) indicated having addressed the issues, and in that case only the short-term impact.

Based on the information provided, it is speculated that the assessment of impacts has not been done in Canada.

Hypothesis No. 9

Handling and use of fire foams requires special personal protective equipment.

True:

Based on the responses to questions 13 (special equipment) and 14 (worker concerns), special equipment is necessary for handling and use of fire foams. Further, WHMIS guidelines, Transport of Dangerous Goods Regulations, and Manufacturer recommendations support this hypothesis.

Hypothesis No. 10

Worker concerns over the use of foam are mainly the result of the introduction of something new.

False:

The responses indicate that worker concerns are predominantly the health effects of continued or intermittent exposure, and the effect of foams on safe working conditions on fires (slippery footing).

Hypothesis No. 11

There are comprehensive guidelines for the storage, handling, and application of Class "A" fire foams.

True and False:

WHMIS and Dangerous Goods Regulations apply to the storage and handling of Class "A" fire foams.

Other guidelines for the storage, handling, and application of Class "A" fire foams are generally sketchy or nonexistent. Québec and Alberta have developed some guidelines.

Hypothesis No. 12

Agencies can quantify cost savings generated by the use of fire foams.

Cannot be Validated:

Questions 5,6 and 7 (and sub-questions) provide the variation in estimates of the amount of foam required, the benefit of foams, and estimated improvement. The responses do not provide a basis for an assessment of the cost savings.

The total cost of foam concentrate exceeds $1 000,000 annually, exclusive of the cost of application. No estimate can be made from the information provided on the savings/expense of application.

The following graph illustrates the annual costs (estimated)

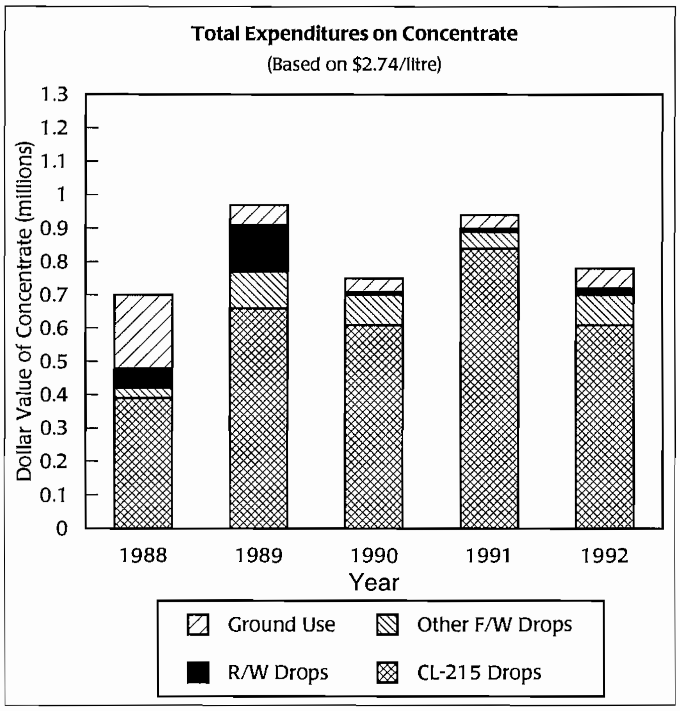


Figure 6. Annual Cost of Foam Concentrate Use - Nationally (Calculated at $2.74/litre FOB Agency Base)

Hypothesis No. 13

There is a correlation between the reported foam concentrate use, and the number of fought fires or the area burned of fought fires.

False:

A correlation analysis was done on the reported figures for foam use, number of fought fires (CIFFC database) and area burned in fought fires (CIFFC database).

Correlation values by agency were calculated comparing foam concentrate use to both number of fires and area burned. The table of r-values is shown below. There are no good fits ($r \sim \pm 1$) although Manitoba and New Brunswick show some correlation, albeit weak.

A correlation of foam concentrate use to the number of fires, nationally, was also calculated. Again, there is a weak correlation (r^2=.45). A speculative graphic display of the relationship is provided.

Any correlation results would be doubtful, given the number of years of data (five), the number of years of full use (variable), and the inherent variability of fire occurrence and fire behaviour.

Correlation Analysis of Total Foam Use, Fought Fires, Area Burned

Correlation Analysis	r-value Number of Fires	r-value Area Burned
Alberta Forest Service	0.49	0.38
BC Ministry of Forests	-0.29	-0.67
Manitoba NR	0.63	0.93
Nfld. Forest Service	-0.05	-0.06
NB Natural Resources	0.79	0.64
NS Natural Resources	0.34	0.86
NWT Renewable Res.	0.29	-0.01
Ontario MNR	-0.19	-0.40
PEI Energy & Forestry	-0.53	-0.42
Québec SPCF	-0.28	0.77
Sask. Natural Res.	0.29	-0.17
DIAND - Yukon L&F	0.18	0.27
DOE - Parks Canada	-0.69	-0.30

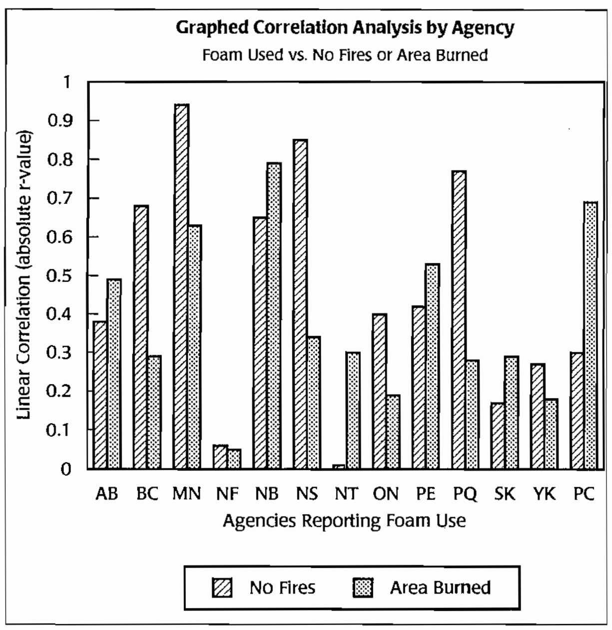


Figure 7. Correlation Analysis
Foam Use to Fought Fires and Area Burned by Agency.

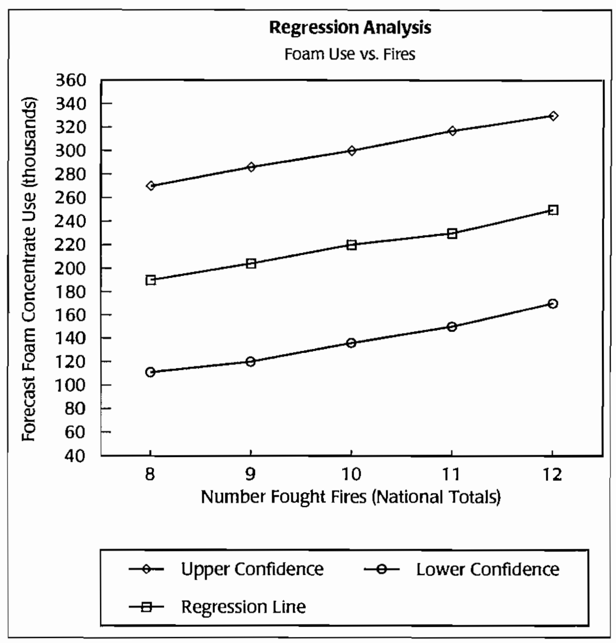


Figure 8. Regresson Graph
Foam Concentrate Use vs. Number of Fought Fires
Intercept = 54500; $r^2 = 0.45$, Standard Error = 81421.

Appendix I: Selected Bibliography of Reference Documents

1. Alberta Forest Service. March 1992.
   Alberta Forest Service Wildfire Foam Manual
   Alberta Forest Service, Forest Protection Branch
   71 pp.

2. Canadian Committee on Forest Fire Management. January 1987.
   Proposed Standard for Fire Foam Liquid Concentrate.
   Canadian Committee on Forest Fire Management. Forest Fire Equipment Subcommittee. Forestry Fire Foam Specification Working Group. 14 pp.

3. Chemonics Industries. May 1989.
   Material Safety Data Sheet. Fire-Trol Firefoam (R) 103.
   Chemonics Industries, Kamloops BC. 7 pp.

4. Chemonics Industries. March 1991.
   Material Safety Data Sheet. Fire-Trol Firefoam (R) 104
   Chemonics Industries. Kamloops BC. 6 pp.

5. Foam Task Group. Fire Equipment Working Team. NWCG., and, Canadian Committee on Forest Fire Management, Forest Fire Equipment Working Group. June 1992.
   Foam vs Fire. Class A Foam for Wildland Fires
   Boise Interagency Fire Center. NFES #2246.
   28 pp.2.

6. Gouvernement de Québec. Ministère des Forêts. 1991
   Guide d'Utilisation de la Mousse Extintrice dans la Lutte Aérienne Contre les Feux de Forêt au Québec.
   Bibliothèque Nationale du Québec. 19pp.
   ISBN 2-550-21747-0

7. Haessler, Walter M.
   The Extinguishment of Fire.
   Bureau of State Fire College, Ocala Florida.
   National Fire Protection Association. 44 pp.

8. H.I.S. Ventures Ltd. 1989.
   Operation Manual Ground and Helicopter Application of Foam. Prepared for Government of the Northwest Territories, Department of Renewable Resources.
   37 pp.

9. Lee, Ernie, and, Timmenga Hubert. June 1990.
   Biodegradability of Foam Chemicals for Wildland Fire Control
   Applied Biology Division, British Columbia Research Corporation.
   Prepared for Chemonics Industries. 39 pp.

10. Norecol Environmental Consultants, and, Wheeler, Ian P.
    April 1989.
    Toxicological Review of Fire Fighting Foams.
    Norecol Environmental Consultants Ltd. Prepared for Forest protection Branch. British Columbia Ministry of Forests. 84 pp.

11. Ogilvie, C.J., Alexander, M. E., Lieskovsky, R.J., Bird, J. 1989
    Interim Guidelines for Aerial Application of Foam on Forest Fires.
    Forestry Canada, Government of Canada
    Technology Transfer Note A-010

12. Parminter, John. July 1989.
A Primer on Wildland Fire-fighting Foams With a Summary of Experience to Date and Recommendations for Operational Use.
Forest Protection Branch. British Columbia Ministry of Forests. 61 pp.

13. Rochna, Ron., and Schlobohm, Paul. June 1988.
Foam Project Issue Paper.
Boise Interagency Fire Center. 15 pp.

14. Wallinger, Kevin. and Berry, Jeff. 1992.
An Operational Trial: Foam Enhanced LC 931;
British Columbia Ministry of Forests
Forest Protection Branch, Kamloops and Caribou Regions.
80 pp.

15. Wotton, Brian. June 1990.
Foam Use in Manitoba
Province of Manitoba, Department of Natural Resources
8 pp.

16. U.S. Department of Agriculture, Forest Service. April 1992.
Specification for Foam, Class A, for Wildland Fires
Aircraft or Ground Application
Draft International Specification 5100-00307
20 pp.

17. U.S. Department of the Interior
An Operational and Tactical Guide to Ground-Applied Foam applications.
US Department of Interior. 32 pp.

18. Verbruggen, M. Kim, 1990.
An Examination of the Role of Foam in Forest Fire Management
An Undergraduate Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science in Forestry. School of Forestry. Lakehead University. 163 pp.

19. Class "A" Foam for Wildland Fire Management Research
Questionnaire

Appendix II. Class "A" Foam for Wildland Fire Management Research Questionnaire

In order to determine the requirements for future research and development in Class "A" foam, the CCFFM needs information on the present and historical use of foam in Canada.

Would you please take a few minutes of your time to complete the following questionnaire and/or offer your thoughts on Class "A" foams.

Please add additional pages of remarks as you feel appropriate.

Thank you for your time.

R. P. Bailey
Forest Fire Foam Research
Task Group

Agency:		
Address:		
Representative:	Telephone:	Date:

1. Does your agency use Class A Foam for fire management purposes?

   Yes ❑ No ❑

2. If no, please indicate why

   - ❑ Costs:
   - ❑ Application Methods:
   - ❑ Environmental Concerns:
   - ❑ Other

Remarks:

If You answered No to question 1, it is not necessary to complete the rest of this questionnaire.

3. What was your agencies volume of concentrate use in the past five years? Please indicate units of measurement.

Year	1988	1989	1990	1991	1992
Volume					

4. How has your agency been applying Class "A" foam over the past five years?
   A. Aerial Delivery:
   Please indicate amounts and methods.

	Year				
Method (Type)	1988	1989	1990	1991	1992
e.g. Rotary-wing				1000 l.	

B. Ground Application:
Please indicate amounts and methods.

Method (Type)	Year 1988	1989	1990	1991	1992
e.g. Ground Tanker				100 l.	

5. (a) What Concentrations (e.g. .1%) of Class "A" Foam are being used by your agency
   i. by application method;
   ii. by fire danger class;
   iii. by fuel type

Method of Application	Danger Class	Fuel Type	Concentration(s)
e.g. CL-215	Low	C-1	0.1%

5. (b) How does your agency determine the correct type of foam that is required for fire?

6. (a) What % of fires by response category is foam used on? Are these percentages increasing or decreasing?

Response Category	% Fires	Increase/Decrease
e.g. Initial Action	10	Inc.

Do you have any additional comments on this subject?

6. (b) What duration (time) of foam effectiveness are you experiencing at concentration levels? e.g. 8 minutes at 0.1% concentration

Concentration	Duration	Concentration	Duration

7. (a) Does your agency have a method of measuring or evaluating the effectiveness of air or ground applied foam?
Please describe.

7. (b) Please provide your subjective evaluation of the effectiveness of foam products applied.

A. Aerial Application:
(by type, fire danger class, and fuel type)
e.g. - CL-215 application, extreme danger class, C-2 Fuel Type: foam increased effectiveness over water only on initial attack by 50%.

B. Ground Application:
(by type, fire danger class, and fuel type)
e.g. - ground tanker application, moderate danger class, S-1 fuel type: foam increased effectiveness over water only by 60%.

8. (a) Has your agency used or tested foam mixed with retardants in aerial or ground applications?
Please describe.

8. (b) Does your agency have a method of meauring or evaluating the effectiveness of air or ground foam mixed with retardants?
Please describe.

8. (c) State your subjective evaluation results of the effectiveness of foam mixed with retardants products applied

A. Aerial Application:
(by type, fire danger class, and fuel type)
e.g. - CL-215 application, extreme danger class, C-2 Fuel Type: foam mixed with retardants increased effectiveness over water only by 50%.

B. Ground Application:
(by type, fire danger class, and fuel type)
e.g. - ground tanker application, moderate danger class, S-1 fuel type: foams mixed with retardants increased effectiveness over water only by 60%.

9. Has the use of foam products reduced the mop up time on fires? If so, by what percentage decrease in time?
(Mop up - the Act of extinguishing a fire after it has been brought under control).

10. List fire fighter (or other such as air crew) health and safety issues your agency has encountered since the introduction of foam.
A brief explanation of each is requested.

11. List public or environmental agency concerns your agency has encountered.
A brief explanation of each is requested.

12. Give a brief outline explaining how the standard operating procedures or guidelines practised by your agency were developed for the air and ground application of foam.

13. What special equipment, employee training, environmental concerns or storage and handling facilities were required?

14. What worker comments/concerns has your agency received since introducing foam.

The use of foaming agents in forest firefighting in Spain

Ricardo Velez
Chief, Forest Fire Service, Ministry of Agriculture, Gran Via San Francisco 4, 28005 Madrid, Spain

Abstract

A historical overview on the aerial means used for foam application is made. It is specially described the technical requirements for the concentrate. It is also described which is the current "state-of-the-art" regarding foam application for the "when and how" questions. Finally future developments in that field are discussed.

Included is a historical overview, characteristics of the concentrate, current situation, future developments, and aerial means operating in Spain for Forest Firefighting in 1994.

It was in 1987 when foaming agents appeared in the forest fires scenario to improve water drops efficiency. At that time, only 3 of a fleet of 12 Canadair CL-215 aircraft were equipped with foam injection systems. Later, taking advantage of revamping to turbo-engines in Canada, they were progressively equipped with the above mentioned system up to a total of nine in 1994 operative with foam.

In a similar way, helicopters began to be used in extinction jobs, not only those exclusively prepared for that purpose with fixed tanks, but also those for which the main commitment is to transport firefighters at the operation scenario. Once there, the pilot attaches the bucket and starts its fight against the wildfire.

In 1993, approximately 50 percent of the heli-copter fleet involved in forest firefighting used foam. Foam was also used by a DC-6 that operated from Almeria (South of Spain) with very satisfactory results.

The average use of foam concentrates for the last four years has been approximately 50,000 litres per year.

The essential requirements that a foam concentrate must have for use in Spain are:

1. *They must be highly concentrated so they can be used with successful results at a lower concentration than 1 percent.*
2. *Foaming agents must be corrosion inhibited for their use in aerial means—specially in helicopters with fixed tanks where the tail rotor can be corroded when wetted in the drop.*
3. *Acceptance from recognized bodies, like Canadair, Inc., that foam concentrate can be loaded, transported, and handled safely by aerial means (a very high ignition point, etc.).*
4. *Studies from well known laboratories about the effects of foam use on the ground on aquatic flora and fauna.*

All these points are included in the technical requirements described in our respective specification.

Guidelines for foam use include foam concentra-tions, foam percentages, and logistics.

Our operational percentages of foaming agent on ground use in either direct or indirect attack are 1 percent concentrations. For mop-up opera-tions, where foam is not required but a good wetting effect is needed, the percent is 0.1.

The trend is toward the design of equipment that allow a variable injection of foam concentrate according to the water flow. This compact equipment should be placed in a truck and essentially would include:

1. Flow-meter
2. *Microprocessor*
3. High-pressure volumetric pump (variable flow rate)
4. *Accessories (check valve, etc.)*

We expect to test some equipment this year, during the summer, in a real fire situation.

Fixed-wing aircraft used by ICONA in1993 included 21 Canadair CL 215, 5 CANSO PBY, and 1 DC-6. Twenty helicopters were equipped with buckets, 5 used fixed tanks, and 4 were used for surveillance.

Résumé

Le rapport donne un aperçu des moyens aériens utilisés pour l'application des mousses. On y décrit tout particulièrement les exigences techniques applicables au concentré et les dernières techniques d'application employées dans différentes situations. On expose enfin les progrès qui devraient être réalisés dans ce domaine.

On trouvera par ailleurs un bref historique ainsi qu'une description des caractéristiques des concentrés, de la situation actuelle, des perfectionnements prévus et des moyens aériens utilisés en Espagne pour l'extinction des incendies de forêt en 1994.

En 1987, on a commencé à employer des agents moussants pour améliorer les propriétés d'extinction des gouttelettes d'eau. À cette époque, seuls trois des 12 aéronefs CL-215 de Canadair étaient équipés de systèmes d'injection de mousse. Par la suite, on a profité des opérations de modernisation des turbomoteurs au Canada pour doter les appareils de ce système d'injection de mousse. Neuf de ces appareils étaient en service en 1994.

De même, on a commencé à employer des hélicoptères dans les opérations d'extinction, non seulement ceux qui étaient dotés de réservoirs fixes et conçus spécialement pour ces interventions mais aussi ceux qui servaient essentiellement au transport des équipes sur les lieux de l'incendie. Une fois sur place, le pilote fixe le seau pompe et commence l'arrosage aérien.

En 1993, environ 50 pour cent de la flotte d'hélicoptères anti-incendie utilisaient des mousses. Un DC-6, basé à Almeria (dans le sud de l'Espagne), a aussi obtenu des résultats très satisfaisants avec ces produits.

Au cours des quatre dernières années, on a utilisé en moyenne 50 000 litres de concentré de mousse par an.

Voici les principaux critères auxquels les concentrés de mousse doivent répondre en Espagne :

1. *Ces produits doivent être fortement concentrés, de sorte qu'une concentration de moins de 1 pour cent donne des résultats satisfaisants.*
2. *Les agents moussants utilisés dans des véhicules aériens doivent être non corrosifs, surtout lorsqu'il s'agit des hélicoptères à réservoir fixe dont le rotor anticouple peut être corrodé s'il est mouillé au moment du largage.*
3. *Des organismes reconnus, comme Canadair, doivent certifier que le concentré de mousse peut être chargé, transporté et utilisé en toute sécurité par voie aérienne (le concentré doit présenter un point d'inflammation très élevé, etc.).*
4. *Des études doivent avoir été menées par des laboratoires réputés sur les effets de la mousse appliquée au sol sur la flore et la faune aquatique.*

Tous ces aspects sont abordés dans les exigences techniques énoncés dans notre spécification.

Les lignes directrices pour l'utilisation des mousses régissent les concentrations, les pourcentages de mousse et les aspects logistiques.

Dans les interventions directes ou indirectes, nous utilisons une concentration d'agent moussant de 1 pour cent. Lorsque les propriétés particulières des mousses ne sont pas essentielles mais que l'on recherche un bon mouillage, par exemple, dans les opérations de nettoiement des zones incendiées, on utilise une concentration de 0,1 pour cent.

On tend actuellement à concevoir des équipements qui permettent de régler l'injection du concentré de mousse en fonction du débit d'eau. Le matériel compact suivant devrait être placé dans un camion :

1. *Débitmètre;*
2. Microprocesseur;
3. *Pompe volumétrique haute pression (à débit variable);*
4. *Accessoires (clapet de retenue, etc.);*

Au cours de l'été, nous prévoyons faire l'essai de certains équipements dans des conditions réelles d'incendie.

Les aéronefs à voilure fixe utilisés par ICONA en 1993 comprenaient vingt-et-un CL-215 de Canadair, cinq CANSO PBY et un DC-6. Vingt hélicoptères étaient équipés de seaux pompes; cinq étaient munis de réservoirs fixes et quatre étaient utilisés pour la surveillance.

The use of wildland fire foam in the Province of Québec

François Lefebvre
Société de protection des forêts contre le feu, Sainte-Foy, Québec

Abstract

The objective to minimize the costs and losses due to forest fires has pushed the Québec organization, like every other agency involved in forest fire protection, to look for new tools to fulfill its mandate. The province of Québec has been involved in the use of wildland fire foam since 1985. The high expectations from the beginning have been replaced by a major concern: is the use of wildland fire foam worthwhile? We have three major questions: is the use of wildland fire foam economically viable; does our knowledge about these products allow us to use them the proper way; what are the consequences on the environment when these products are used. When we tried to find some answers in existing literature, we discovered that very few quantitative results exist. In 1993 we initiated a small experiment. Two objectives were established, find out: 1) what effect does wildland fire foam have on the fuel moisture compared to the simple use of water; 2) what effect does wildland fire foam have on extremely hot fuel.

Résumé

La nécessité de réduire au minimum les coûts et les pertes associés aux incendies de forêt a incité l'organisation québécoise, comme tous les autres organismes chargés de protéger les forêts contre l'incendie, à chercher de nouveaux outils pour remplir son mandat. La province du Québec utilise les mousses carboniques depuis 1985 pour lutter contre les feux de végétation. Les attentes élevées que suscitaient ces produits à l'origine ont rapidement fait place à une grande préoccupation : ces mousses s'avèrent-elles utiles? Il y a trois questions qui se posent : ces produits sont-ils économiquement viables? Connaissons-nous assez bien ces produits pour pouvoir les utiliser correctement? Quelles incidences ces produits ont-ils sur l'environnement? Lorsque nous avons cherché des réponses à ces questions dans les documents existants, nous avons constaté que l'on disposait de bien peu de données quantitatives. En 1993, nous avons décidé de faire une petite expérience. Nous nous sommes fixés deux objectifs. Il s'agissait d'abord de découvrir les effets que pouvaient avoir les mousses carboniques sur la teneur en humidité des combustibles et, ensuite, de déterminer les effets de ces mousses sur les combustibles extrêmement chauds.

History of the Use of Wildland Fire Foam in Québec

In the early 60's, Québec acquired 6 CANSO water bombers. In the early 70's, Québec acquired 15 more water bombers, this time they were CL-215's. The goal was to provide a fast and strong initial attack and take advantage of the numerous lakes that we have in Québec.

During the 70's, field tests were carried out with the long term retardant. The need for mixing equipment and the need to return to the base for refilling were incompatible with the way the CL-215 is used in the Quebec organization. In fact, the mobility of the water bombers was very limited compared to when they scooped up water from lakes.

In 1985, the first discussions about the "WILDLAND FIRE FOAM" were held with the manufacturers. The product was supposed to be the miracle solution:

- environmentally clean;
- 3 to 10 times more effective than just water;
- only small amount of foam concentrate needed for 20 drops
- no need for mixing equipment at home bases.

With the collaboration of the Petawawa National Forestry Institute (PNFI), the first field test was done with the expectation of solving a problem for some regions in Quebec: the shortage of lakes suitable for scooping water.

The second test took place in 1987 with a ground application. We concluded that the use of foam in an indirect attack was beneficial. We also used foam on a prescribed fire and we concluded once again that water plus foam is superior to using only water in reducing flames and smoke.

In 1988 we obtained the authorization from the "ministère de l'Environnement du Québec" (MENVIQ) for an experimental use of foam with the CL-215 on wild forest fires. The authorization was restricted to the use of Monsanto Phoschek WD 881. We had to minimize the contact of the foam solution with any body of water. For that test, two CL-215's were equipped with Canadair injectors.

That year, 58 drops with the water and foam were made on 14 forest fires. Concentration levels averaged 0.6% (chart 1). All the comments expressed were in favor of using the foam because of its effectiveness, the visibility of the drops, the longer delay before reignition.

In 1989 we obtained once again the authorization from the MENVIQ for an experimental application (it is an annual authorization). On 24 forest fires we did a total of 469 drops with foam that averaged a concentration level of 0.5%.

In 1990 we again obtained the authorization for an experimental application. With the purchase of an Airspray injector system, we were able to use three CL-215's. A total of 930 drops with foam were made on 53 forest fires, and the average concentration of the foam was 0.4%. It was agreed upon that the bird-dog officer was the one to decide if the foam was to be used or not.

In 1991, a user guide was produced. It contained the rules and regulations regarding the environment and the safety of the personnel. That year we obtained the authorization from the MENVIQ to use three other kinds of foam: the Silv-ex, the Firefoam 103, and the Forexpan. The fire season was very intense in the Baie Comeau region so we borrowed 12 CL-215's with foam injectors. On 101 forest fires, a total of 2,506 drops were made with foam averaging concentration levels of 0.4%.

In 1992 we obtained permanent authorization from the MENVIQ to apply foam with the CL-215. We had to respect the application rules stated in the user guide and write an annual report on use of the foam for the MENVIQ. That same year, the remaining Québec CL-215's were equipped with a new foam injector system developed by the the Quebec government's aerial service. With that organization, 1,777 drops of foam were made on 56 forest fires with the foam having an average concentration of 0.4%. This new foam injector system is now the property of Canadair.

In 1993, 1,253 drops with foam were made on 36 forest fires with the foam having an average concentration of 0.4%.

Need for Further Field Tests

Many questions are raised with the use of foam. The major concern is: is the use of wildland fire foam worthwhile?

We have invested a lot of money in equipment and the foam is not cheap. So is the use of wildland fire foam economically viable?

Past experience with foam has shown us results that indicate that the foam may be less effective than expected. Is our knowledge about these products sufficient?

We have strict legislation regarding the protection of the environment. The safety and security of the personnel must also be respected. The use of foam increases the maintenance needs (corrosion, lubricating more often some of the parts on the CL-215). What are the effects on the environment, the personnel, and the equipment when these products are used?

The many questions prompted us to look for some answers. When we consulted the existing literature, we discovered that very few quantitative results were available. You have to keep in mind we are looking at aerial application. This led us to do more field tests in 1993. Two objectives were established: 1) what effect does wildland fire foam have on fuel moisture compared to the simple use of water; 2) what

Chart 1. Use of foam with CL-215 on forest wildfires

Year	Foam drops on fires	Average concen-tration	Number of fires involved	CL-215 with injector systems	Total number of foam drops
1988	58	0.6%	14	2	2.6%
1989	469	0.5%	24	2	4.4%
1990	930	0.4%	53	3	10.0%
1991	2,506	0.4%	101	3	16.0%
1992	1,777	0.4%	56	18	40.0%
1993	1,253	0.4%	36	18	57.0%

effect does wildland fire foam have on extremely hot fuel?

Effect on the Fuel Moisture Content

Following an experimental protocol recommended by the Petawawa National Forestry Institute, we carried out two tests, each consisting of three drops: one with water, one with a 0.3% foam solution, and one with a 0.6% foam solution. The drops were made on harvested areas (4 years). Samples (at least 3) of fine fuel (for the fine fuel moisture code FFMC) and of humus (for the duff moisture code DMC) were taken in the middle of the drop areas. Samples were taken:

- 30 minutes before the drop;
- immediately before the drop;
- 30 minutes after the drop;
- 1 hour after the drop;
- etc.

The few results that we obtained indicated that in the drying conditions that we had, the foam solution could multiply by 2 or 3 the time required to dry the fine fuel compared to the effect of just water (figure 1). We must keep in mind that those preliminary results were based on only two tests.

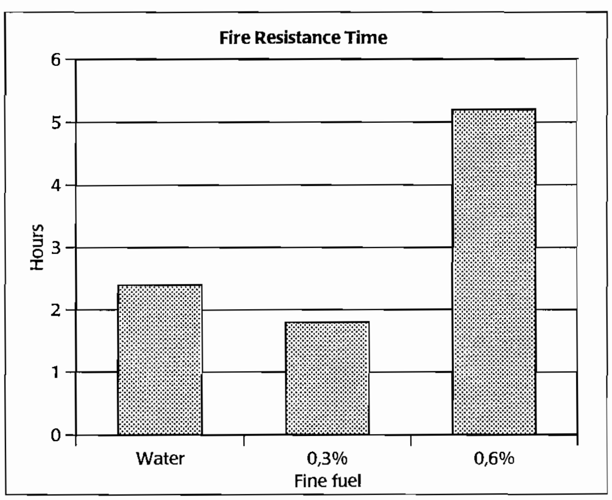


Figure 1. Fine fuel drying time, Water vs. Foam.

During those two tests we found that the area covered by the drops with foam was much larger: 2,500 square feet for water; 4,000 square feet for the 0.3% foam solution and 6,100 square feet for the 0.6% foam solution. The uniformity of the drops with the foam was also better than with just water. On the other hand, the wind had a stronger effect on drops with the foam solution.

Effect on Hot Fuel

To find out what impact the foam solution had on an active fire, we carried out four tests. The water and the foam solution were applied from the ground. Slash piles were ignited and after waiting a period of time the water and the foam solution were applied on two similar areas until no smoke was visible. The time required for the operation and the quantity of water and foam solution used were measured. Once again, we have to keep in mind that the results are based on only four tests.

The results obtained let us believe that the use of foam on hot fuel was not advantageous compared to water. The foam solution seemed to evaporate faster than water on an active burning area. It seemed more profitable to cool the hot fuel with water first and then cover it with the foam solution.

Need for More Tests

It is certain that the wildland fire foam has a positive impact on the fine fuel moisture content. But there is a need to evaluate the effect of different foam solution concentration on different fuel types with different weather and index conditions.

Other benefits of using foam are: the ease which previous drops are located, the better uniformity in the distribution, a larger area covered with a drop. But there is a need to develop a guide on how and when a foam solution should be used. Are we using the foam properly? Is it really as effective as we think it is?

Evaluating foam: A systems level perspective

David L. Martell
Faculty of Forestry, University of Toronto, 33 Willcocks Street, Toronto, Ontario M5S 3B3, Canada

Abstract

The author begins with a very brief discussion of classical fire economics and describes some of its limitations. He then shows how "single fire" evaluations of foam and other technological innovations can produce misleading results. He describes how forest management planning models can be used to assess the economic impact of fire from a forest level perspective, and illustrates how such approaches can be used to assess the cost effectiveness of fire management activities. He then demonstrates how the LANIK level of protection decision support system can be used to evaluate the cost effectiveness of foam used by fire crews, and concludes with a short list of requests addressed to foam researchers and fire managers involved with evaluations of the cost effectiveness of foam.

Résumé

L'auteur commence par exposer très brièvement les principes économiques classiques relatifs aux incendies et indique certaines de leurs limites. Il montre ensuite que les évaluations des nouvelles techniques ou des nouveaux produits (comme les mousses) fondées sur un seul incendie peuvent donner des résultats trompeurs. Il explique comment les modèles de planification de l'aménagement des forêts peuvent servir à évaluer l'impact économique des incendies à l'échelle de la forêt et il montre comment utiliser de telles approches pour évaluer la rentabilité des activités de lutte contre les incendies. Il fait voir l'utilité du niveau LANIK du système d'aide aux décisions de protection pour les évaluations de la rentabilité des mousses employées par les équipes de suppression. Enfin, il présente une courte liste de demandes adressées aux chercheurs sur les mousses et aux gestionnaires des incendies qui participent à ces évaluations.

Introduction

North American forest fire managers are increasing their use of foam to enhance the effectiveness of both airtankers and ground crews. That increased use is based in part, on a belief that foam is cost effective. In this paper I address the cost effectiveness aspects of foam and discuss how foam and other technological innovations might be evaluated. I begin with a very brief review of classical fire economics and describe how foam and other technological innovations can be evaluated from a systems level perspective. I then describe how LANIK, a new decision support system, was used to produce a preliminary assessment of the cost effectiveness of foam. I conclude with a short list of requests addressed to foam researchers and fire managers who wish to evaluate foam.

Classical Fire Economics

The implicit objective of most forest fire management agencies is to minimize the net destructive impact of fire subject to constraints on resource availability and use. Funds are allocated to fire management on the assumption that the ensuing benefits will exceed the value of the money spent. Fire management costs can easily be expressed in monetary terms. The benefits of fire management activities include the reduced losses that result from limiting the number and size of destructive wildfires, the increased productivity that results from the proper use of prescribed fire, and the enhanced environment that results from successfully monitoring and modifying the suppression of beneficial wildfires.

One of the most basic principles of fire economics is what is referred to as the deterministic Least Cost Plus Damage or deterministic LCD model. The term "deterministic" indicates we ignore the uncertainty or variability that arises from fluctuations in weather and other random processes. Although the simple LCD model cannot be used to specify how much money should be spent on forest fire management, it provides valuable insight into the problem.

The simple deterministic LCD model does of course have many limitations. In order to use the LCD model one must relate fire loss to presuppression expenditures. That calls for a production function that relates area burned to presuppression expenditures and makes it necessary to estimate economic loss as a function of area burned. The development of such relationships is complicated by the fact that historical data is not always relevant due to changes in land use patterns, the fire environment, and technological innovation. Furthermore, the simple LCD model does not account for the fact that there is more than one type of fire suppression resource, nor does it reflect the inherent stochastic nature of the problem (i.e., the uncertainty and random processes that complicate forest fire management).

The Validity of "Single Fire" Evaluations of Foam

Fire managers often evaluate proposed technological innovations by assessing how well they perform on a sample of representative fires, and extrapolating the apparent savings to the entire fire organization. That approach is not valid as it ignores the fact that fires are not independent of each other; they interact via fire suppression resources. One cannot assess savings by simply multiplying the area saved (i.e., not burned as a result of using foam) by a fixed dollar value per hectare.

The following hypothetical cases illustrate some of the ways in which fires can interact with each other.

Case 1

A crew equipped with foam carries out initial attack action on one fire and then fights a second fire without using foam. The effectiveness of foam is such that the first fire is declared being held (BHE) earlier than it would have been declared BHE if the crew had not used foam. The crew's response time to the second fire is less than it would have been had they not used foam on the first fire. The use of foam on the first fire therefore enhances the productivity of the initial attack crew on the second fire as well as the first fire. Single fire evaluations ignore such interactions.

Case 2

A crew equipped with foam and airtankers attack a fire and a second crew and the same airtankers attack a second fire. The effectiveness of foam is such that the first fire is declared BHE earlier than it would have been so declared if the crew had not used foam. The airtanker response time to the second fire is therefore less than it would have been had the crew not used foam on the first fire. The use of foam on the first fire therefore enhances the productivity of the initial attack force (another crew and the same airtankers) on the second fire as well as the first fire. Single fire evaluations ignore such interactions.

Case 3

A crew with foam attacks a potential "project" fire the first day, and crews without foam but with airtankers attack several fires during subsequent days. Suppose the use of foam by the crew on the first fire enables it to contain at 0.1 ha, a fire that would otherwise have escaped to become a very large project fire. The existence of a large project fire may have drawn down the initial attack strength of the fire organization for several days. Thus the effective use of foam on the first fire has a very important secondary beneficial impact that ripples throughout all the fires fought during the following few days. Single fire evaluations ignore such interactions.

The impact of a specific fire should be assessed from a forest level perspective that indicates how that particular fire will effect the flow of timber from the entire forest or management unit. We can use a forest level timber supply model of a hypothetical forest to illustrate the principle[3]. Consider a hypothetical 500,000 hectare forest that is used primarily for timber production. Ignore the small area occupied by town, lakes, roads, and cottages and assume our forest is completely covered with 75 year old stands of Site Class II jack pine at the start of the planning horizon. The forest is fully accessed by roads and we assume both harvested and burned areas regenerate naturally at no cost with a five year delay. We will use a 300 year planning horizon that is partitioned into thirty 10-year periods. Timber harvest flow is constrained to be constant, and we constrain the merchantable volume of the growing stock in the forest to average at least 40.2 cubic metres per hectare at the end of the planning horizon. Wood is sold at a stumpage rate of $30.00 per cubic metre and future revenues are discounted at a rate of 3.0% per annum. We ignore salvage, harvest, regeneration, and transportation costs.

In order to assess the impact of fire and fire management we require a model that can be used to predict how the hypothetical forest will respond to fire and harvesting. We assume fire losses occur at some average rate with no variance (i.e., some constant average fraction of the forest burns each year), but that fraction is determined in part by the amount of money spent on forest fire management. Assume the fraction of the forest burned each year decreases as the amount of money spent on fire management increases.

[3]The model is similar to the one described in Martell (1994).

Assessing the Impact of Fire Regimes on Timber Supply

Each possible fire regime can be represented by its corresponding fraction of the forest burned each year. We varied the portion of the forest burned each year from 0% to 4.0% and related the volume harvested each year or the annual allowable cut to the fraction burned. We arbitrarily set the fraction of each age class burned within the forest equal to the fraction of the forest burned. The results are presented in Figure 1. The volume harvested each year is slightly convex upwards for roughly one half of its range after which there is a point of inflection and it becomes convex downwards, a consequence of the terminal volume constraint. A 1.5% annual burn rate reduces the allowable cut by 36%, what superficially appears to be a disproportionate reduction in the harvest. An annual burn rate of 1.5% means the probability that any small stand will burn is 0.015 during any year. If a stand is established and scheduled to be harvested when it is 50 years old, the probability that it will survive until then is 0.47.

Assessing the Impact of Individual Fires

The mean value timber harvest scheduling model can also be used to assess the impact of a fire that has burned some portion of the forest. In the past, people often focussed on the burn itself and assessed fire damage in terms of the apparent value of the timber destroyed by the fire. That approach neglects the fact that a forest is a complex dynamic system that often provides managers with flexibility that can be used to buffer fire losses.

Consider for example, a 150,000 ha fire in our hypothetical forest, all of which was covered by 75 year old Site Class II jack pine at the start of the planning horizon. A superficial fire loss assessment obtained by multiplying the area burned by the volume of wood per unit area (190 m^3/ha) and the price (\$30/m^3) at which the burned wood was to have been sold would produce an estimated fire loss of 855 million dollars.

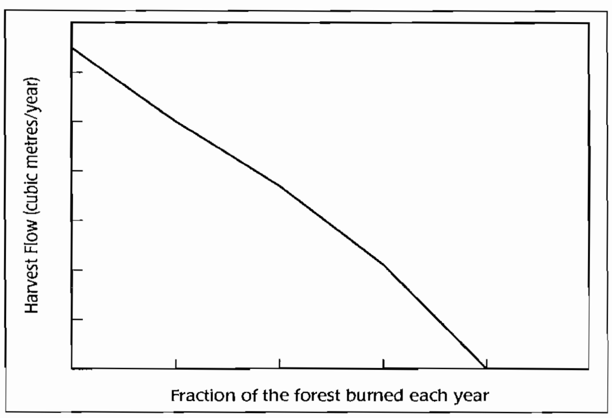


Figure 1. Relationship between the allowable cut and the fraction of the hypothetical jack pine forest that burns each year.

We can use the forest level mean value model to assess the impact of such a fire from a forest level perspective. The timber loss attributed to the 150,000 ha fire is the expected return from the forest given the best planned harvest schedule before the fire (which is obtained by running the timber supply model with a 500,000 hectare 75 year old flammable forest and a specified average annual fraction burned associated with the appropriate fire regime), less the expected return given the best revised harvest schedule produced after the fire (which is obtained by running the timber supply model with the same forest, 150,000 ha of which has been burned). A 150,000 ha fire that burned 30% of the area of the forest would reduce the present net worth of our hypothetical forest by about 2 million dollars or 0.24%, very much less than the superficial site-specific estimate described above. Harvest schedule flexibility and the ability of forests to regenerate after fire help reduce the economic impact of fires in forests that are not being taxed to their limits.

Note that these results are specific to our particular hypothetical forest. The cost of a fire will increase for example, if the forest is not fully accessed, the burned area is near established roads, or there are monetary penalties other than stumpage losses associated with significant reductions in harvest volumes.

LANIK Level of Protection Decision Support System

The Ontario Ministry of Natural Resources (OMNR) forest fire management program is designed to meet the needs of other branches and government agencies (e.g., timber and wild life management) and many external clients including the forest industry and residents of communities that are surrounded by flammable forests. It is very difficult for fire managers and governments to evaluate fire management programs as the interests of the many internal and external clients are very diverse and a wide range of benefits that flow from Ontario's forests. There is also a high degree of uncertainty that makes it impossible to transform fire management plans into precise deterministic predictions concerning the social, biological, and economic impacts of fire management programs.

LANIK (Martell et al. 1995) is a computer based decision support system that is designed to enable fire managers and fire management planners to quickly and inexpensively explore the broad implications of fire management program alternatives. We used LANIK to conduct a very "quick and dirty" assessment of the potential cost effectiveness of foam. One of the most attractive features of LANIK is its "user friendly" interface and the relative ease with which fire management planners can describe and evaluate fire management alternatives. We required less than two hours to produce the graphical results presented in Figure 2 which constitute a very rough but revealing preliminary assessment of the cost effectiveness of ground-applied foam in Ontario.

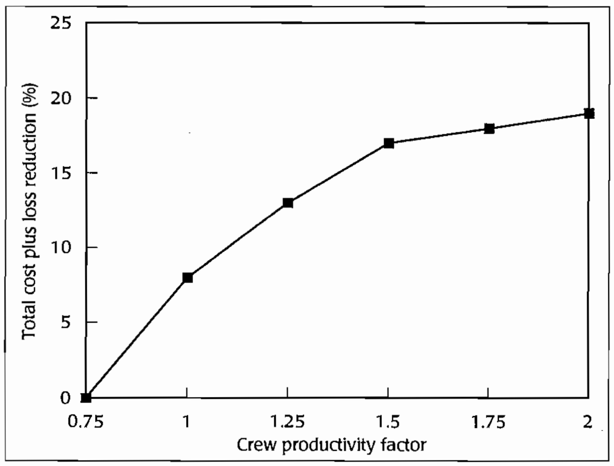


Figure 2. Preliminary assessment of the potential impact of enhanced crew productivity that may result if fire crews use ground applied foam on initial attack in the province of Ontario.

The initial attack model in LANIK has a fire line construction subsystem that is designed such that crew productivity can be calibrated to ensure model predictions are consistent with historical fire data. When we calibrated the model for Ontario we found that the crew productivity factor should be set equal to 0.75 to bring model predictions into line with historical fire data. The results presented in Figure 2 suggest that if the crew productivity can be increased by 66% from 0.75 to 1.25, fire cost plus loss would be reduced by approximately 13%. Fire managers can use such results as a preliminary screening mechanism by comparing the cost of potential improvements with their associated cost reductions. If they find such improvements are potentially cost effective they may decide to invest in further studies that would produce improved estimates of the cost and productivity of crews using foam, and then use LANIK to generate more accurate cost effectiveness assessments.

Discussion

LANIK is a decision support system that can be used to help evaluate foam and other technological innovations. However fire managers, fire management planners, and researchers must work together to enhance LANIK and its ability to model initial attack system performance. We must develop mathematical models that will predict how well foam equipped crews will perform on representative fires. We can begin by revising the parameters of existing models like those currently imbedded in LANIK, but fire researchers and equipment specialists should be encouraged to develop better models that can be imbedded in LANIK and other decision support systems.

We also require good estimates of the costs of acquiring and using foam technology. And finally, dispatch guidelines in LANIK were developed before foam was used for forest fire suppression purposes. We need new dispatch guidelines that should be developed as part of the foam cost effectiveness assessment process.

Literature Cited

Martell, D.L. 1994. The impact of fire on timber supply in Ontario. For. Chron. 70(2):164-173.

Martell, D.L., D. Boychuk, J. I. MacLellan, B. M. Sakowicz, and R. Saporta. 1995. Decision analysis of the level of forest fire protection in Ontario. Sixth Symposium on Systems Analysis and Management Decisions in Forestry, Pacific Grove, California, September 6-9, 1994. To appear in the Proceedings.

Indirect applications with foam

Paul Schlobohm
Fire Management Specialist, Bureau of Land Management, National Interagency Fire Center

Abstract

Class A foam is a short-lived foam relative to other types of foam. Rapid drainage and unstable structure are ideal for direct suppression activities such as flame knockdown and mop-up. Why then, is foam so successful for indirect applications such as fireline construction and resource protection?

The answer is foam's active ingredient–water. Water is a powerful medium for slowing the spread of fire, but, unaltered, water is not efficient. Foam is a way of restructuring water to a form that best fits the task. A variety of foam generating equipment has provided an array of options for effectively placing water on exposures. The use of foam has enabled us to put water in place as a barrier like we have never done before. Successful applications depend on the appropriate foam type, complete coverage, and wetting of the exposure timed to match the time of flame impingement.

Résumé

Les mousses de classe A ont une durée de vie plus courte que les autres mousses. Puisqu'elles sont rapidement drainées et possèdent une structure instable, elles sont particulièrement efficaces dans les opérations directes, comme les interventions de choc et le nettoiement des zones incendiées. Comment se fait-il, dans ce cas, que les mousses soient si efficace dans les applications indirectes, comme les systèmes de tranchées garde-feu et la protection des ressources?

Tout simplement parce que l'eau est l'ingrédient actif des mousses. L'eau a le pouvoir de ralentir la propagation des flammes, mais l'eau seule n'est pas efficace. L'ajout de mousse permet de restructurer l'eau et lui confère une forme qui donne de meilleurs résultats. Une vaste gamme de générateurs de mousse offrent plusieurs méthodes pour fixer l'eau sur les éléments exposés. L'ajout de mousses nous a permis de construire des barrières extrêmement efficaces. Pour obtenir de meilleurs résultats, il faut choisir le type de mousse approprié, assurer une bonne couverture des éléments et mouiller les éléments exposés de même que synchroniser les opérations en fonction de l'avance des flammes.

Water and Foam

Class A or "wildland" foam products in use today are well suited for extinguishment, mop-up, and other direct attack activities because they make structurally weak foams. These foams are designed for rapid drainage. The foam structure of Class A products persists for, at most, a couple of hours under favorable conditions. However, rapid drainage means water is released from the bubbles and available for heat absorption. Increased production is evident to anyone who uses foam for extinguishment or mop-up.

Why, then, is the fire community so interested in using these short-lived products indirectly as a barrier to fire? Based on my experience using foam on wildland fires, the answer is in the water. Foam has not taken the place of water as a firefighting tool. Foam is a restructured improvement; water is still the active ingredient. Use of foam as a barrier takes full advantage of the abilities of water to wet fuels and absorb heat. At the same time, foam use reduces the tendency of water to fall off exposures before it can wet or insulate.

Foam holds water in place longer by expanding it into a self-adhesive mass of bubbles, which are less influenced by gravity than water drops. This expansion spreads foamed water over a ~ .. is possible with untreated water. The longer useful lifetime of water as foam provides a wider ignition window and an alternative to soil-disturbing methods of fireline construction.

While it is difficult to specify how much plain water to apply to a given area, an application of foam can be quantified: "Construct a continuous foam line 6 inches deep and 3 feet wide around the area to be burned." The amount and location of the application is visible to the nozzle operator, the ignition specialist, and the incident commander.

Foam is also being used to build fire control lines and to protect significant resources because it is now practical to do so. The advantages of using water as a foam have been demonstrated since the 1930's (Godwin). But, until recently, foam production has been too cumbersome. A significant technological breakthrough was the development in the early 1980's of foam concentrates that could be used at mix ratios below one percent as compared to the conventional three or six percent. These low mix ratios allow fire engines and aircraft carry small amounts of concentrate that last for several loads water. Also, the same product can be used to make a foam for direct or indirect applications.

Indirect Applications

Class A foam applications that support indirect tactics are fireline construction and resource and property protection. The objective of each is to create a heat sink of wet fuels under a protective foam blanket. To burn through the treated fuels, fire must first dry out the bubbles of the foam blanket. Bubbles are efficient at absorbing heat, due to their high ratio of surface area to mass. Then fire has to dry out the wet fuels before they will burn.

Control lines and barriers are constructed from pump-and-roll applications, downhill flows from stationary nozzles, and progressive hoselay applications.

Pump-and-roll applications include foam made with aspirating nozzles or compressed air foam systems (CAFS). Following close behind a pump-and-roll foam line with a drip torch or fusee is an effective way or firing out. A long-term, low impact control line can be made by burning out between two foam lines.

A downhill flow application is made by setting a high or medium expansion aspirating nozzle at the top of a slope and directing its discharge to produce a certain width of foam line on the slope. The foam covers the fuels in its path, creating a slick chute for the foam flowing down behind.

Progressive hoselay applications are necessary in terrain and fuels that are not suited for pump-and-roll or downhill flow.

Resource or property protection is the treatment of surface or aerial exposures with the objective of preventing ignition. Surface exposures protected by foam may be endangered plants, headwalls, seedlings, or critical habitat. Aerial exposure protection applications include snags, wildlife trees, saplings,stream protection zones, special resources such as giant sequoias, whole stand canopies. Property that foam is often used to protect includes homes, sheds, wood piles, barns, archeological or historical sites, pump houses, fence posts, and telephone poles.

Rules of Thumb

Foam lines and protective barriers can be designed either for ignition next to the foam, allowing fire to back away from the barrier, or for ignition away from the foam, allowing fire to run into the foam. A successful application depends on three conditions:

1) The application is made with completely continuous coverage; there are no untreated gaps where fire can burn through or get a start. The application must also be wide enough to contain the expected flame length.
2) Enough time is allowed for fuels to be adequately wetted. A blanket of foam covering dry fuels is not enough. Ten-hour branches will need more time to get wet than 1-hour grasses.
3) An ignition strategy is chosen which places flames and heat against the barrier while the fuels are still wet and covered in foam. There is nothing in the foam besides water to absorb heat, inhibit combustion, or otherwise slow the spread of fire.

A snag that is treated on the bole and around the base is more likely to be saved during prescribed fire if adjacent fuels are ignited first. To treat the snag and then ignite the unit as if the snag were not there will likely preheat the snag, drying out the foam before flame impingement.

Equipment

To be efficient at making these types of applications, a variety of foam-generating equipment is necessary. Low-expansion foam generators, especially the compressed air foam system, are designed to throw foam long distances from the nozzle. This makes them ideal for treating canopies, wildlife trees, roofs and eaves, and other exposures off the ground.

Medium- and high-expansion foam generators are designed to make lots of bubbles. With most of the pump energy going into bubble production, the foam drops out the nozzle at your feet. Large foam production and low discharge distance make these nozzles ideal for creating barriers and foam lines on ground fuels, including grass, brush, slash, and litter at the base of a seed tree.

Many applications may best be accomplished with more than one foam generator. A snag cannot be protected with only medium expansion foam. But to cover the litter and ground fuels around it with low expansion foam would take more time to achieve complete coverage. The combination of low expansion foam to treat the aerial exposures and medium or high expansion foam to cover the ground exposures optimizes foam production.

Cost

Product cost estimates for specific applications of foam should be compared to the alternatives of retardant, untreated water, and no treatment. Protection of snags averaging 50 feet in height and 30 inches dbh requires about $4 of foam concentrate per snag (USDI). Complete coverage with retardant is not practical. Protection with water alone would also not be practical because a constant flow of water on the exposure would be necessary. The no-treatment alternative fails to meet the objective of preserving the snag.

The product used to construct foamline in mixed sage/grass fuels costs about 5-50 cents per 100 ft^2 depending on the method of application (USDI). The product used in line construction with dry powder retardant costs about $1 per 100 ft^2 (Payne). The use of water alone as a barrier to burn from is often not practical, because of the volume required, or not effective, because it disappears so quickly. The no-treatment choice is not usually a practical option.

Conclusion

Class A foam has value to prescribed fire and wildfire tactics beyond direct suppression and mop-up. Foam is not a replacement for water. It is water that has been shaped into a form that better meets the tactical objective. The variety of equipment available allows for shaping water into foam of almost any size and stability. However, foam is not retardant. Applications are successful when the useful lifetime of foam has been addressed. Once we view foam as an alteration of water rather than some magic potion, our use of foam as a barrier to fire will be limited only by our imagination.

References

Godwin, D.P. 1936. Aerial and chemical aids. Fire Control Notes. 1(1). Washington, D.C.: U.S. Department of Agriculture. p. 5-10.

Payne, Andy. Fire Management Officer, U.S. Department of Interior, Bureau of Land Management, Shoshone District. Personal communication with Paul Schlobohm. May 12, 1994.

U.S. Department of Interior, Bureau of Land Management, National Interagency Fire Center. Data on file. Boise, ID.

CAFS power systems and proportioning equipment performance

Dan W. McKenzie
Mechanical Engineer, Forest Service–USDA, Technology and Development Center, San Dimas, California, USA

Abstract

In the design and fabrication of Compressed Air Foam Systems (CAFS) good practice and guidelines should be followed. Centrifugal water pumps should be used with water pressure controlling air pressure and they should have automatic regulating foam proportioning systems injecting foam concentrate into the discharge side of the pump. Foam proportioning systems are of two general types, (1) manually regulated proportioning systems and (2) automatic regulating proportioning systems. Automatic proportioning systems should be used and manually regulated proportioning systems should be avoided. There is equipment available to test foam proportioners and pump flows with digital read outs. The use of this equipment should be encouraged.

Résumé

Lors de la conception et de la fabrication des systèmes de mousses entraînées par air comprimé, on doit se conformer aux règles de l'art et suivre certaines lignes directrices. Il faut utiliser des pompes à eau centrifuges, qui permettent de régler la pression de l'air sur celle de l'eau. Ces pompes doivent être équipées d'un système de dosage qui injecte le concentré de mousse automatiquement dans le côté refoulement de la pompe. Il existe deux types de système de dosage : 1) les systèmes de dosage à réglage manuel et 2) les systèmes de dosage automatique. Il faut utiliser les systèmes de dosage automatique, tandis que les systèmes manuels sont fortement déconseillés. On trouve dans le commerce du matériel d'essai doté d'indicateurs numériques qui permettent d'évaluer les systèmes de dosage et le débit des pompes. On recommande vivement l'utilisation de ce matériel.

CAFS Power Systems

In designing and fabricating power systems for Compressed Air Foam Systems (CAFS) the following guidelines should be followed:

* With the CAFS in place, there should be no deterioration of the water handling capability or reliability of the fire engine.
* With the CAFS in operation the fire engine should be able to make a running attack.
* Operation of the fire engine equipped with CAFS should be easy and simple (user friendly).

There are five general arrangements now in use to power CAFS. They are:

1. Two auxiliary engines, one driving the centrifugal water pump and the other driving the air compressor.
2. Single auxiliary engine mechanically driving both the centrifugal water pump and the air compressor.
3. Fire truck engine driving the centrifugal water pump and the air compressor by direct mechanical drives.
4. Fire truck engine driving the centrifugal water pump and the air compressor through a load sense hydraulic drive system.
5. Fire truck engine driving the centrifugal water pump and the air compressor by a direct mechanical drive and driving the fire truck by a constant engine speed automatic transmission.

Drive systems 1, 2, 4, and 5 will allow the fire truck to make a running attack. When using drive arrangement 3 the CAFS fire truck cannot make a running attack. If running attack is not required or not important, directly mechanically driving of the water pump and the air compressor by the fire truck engine is a good way to drive the CAFS equipment and is mechanically equivalent to a single auxiliary engine CAFS drive system.

Each of the components of a CAFS (centrifugal water pump, air compressor, foam concentrate proportioning system, and control and instrument system) must be sized, driven, and controlled to produce a well operating and reliable CAFS unit. In recent years as the use of CAFS has increased, several good "rules of thumb" have been identified. They are:

1. A centrifugal water pump should be used in a CAFS unit with water pressure controlled by pump rpm and, if possible, stand alone in operation.
2. The air compressor used in a CAFS should be a modulating-type with pressure adjustment at the

panel and, if possible, stand alone in operation. When in CAFS operation the air pressure should be capable of being controlled by water pressure.

3. As a general rule the centrifugal water pump selected should have a rating in gpm of at least twice the air compressor rating in cfm.
4. In the operation of a CAFS unit, static water pressure and static air pressure should be equal and air pressure should be automatically controlled by water pressure.
5. Water flow and air flow should be adjustable and controlled by variable orifices (ball valves) or other equal controls.
6. At a minimum; water, air, and mix point pressures gauges, plus water and air flowmeters should be available to the operator. Also desirable is an indication that foam concentrate is flowing.
7. An automatic regulating proportioning system injecting foam concentrate into the discharge side of the pump should be used.
8. Open CAFS nozzles very slowly. If they are opened quickly, the nozzle reaction can be quite intense for a short time.

By following the above "rules-of-thumb" satisfactory results are currently being obtained in the design, manufacture, and operation of CAFS units. When procuring CAFS equipment, a person knowledgeable in CAFS equipment should be used in the development of the specifications and should assist in the contract administration, inspection, and test. Crew leaders and crew members should also receive special training in CAFS operation.

Foam Proportioning Equipment

There are two basic types of foam concentrate proportioning systems:

1. Manually regulated proportioning systems
2. Automatic regulating proportioning systems

Manually regulated proportioning systems include:

Batch mixing
Suction-side proportioner
In-line eductor
Variable flow, bypass eductor
Around-the-pump proportioner
Direct injection, manually regulated

Automatic regulating proportioning systems include:

Balanced pressure venturi systems
a. Pump systems
b. Bladder tank systems

Water-motor meter proportioner
Direct injection, automatic regulating proportioner

All manually regulated proportioning systems have significant disadvantages when used in wildland fire applications. In general, manually regulated proportioning systems do have one desirable advantage—low initial cost. However, manually regulated proportioning systems (other than batch mixing) have the potential of using more foam concentrate than necessary, negating their initial low cost advantage and, in reality, becoming the most costly proportioning system. Thus, manually regulated proportioning systems should be avoided, or, when used, used with caution in wildfire suppression operations.

Due to the many shortcomings of the manually proportioning systems, automatic regulating proportioning systems have been designed to reduce these limitations. Specifically, the automatic regulating proportioning systems are designed to remain proportional over a wide range of flows. They are not affected by changes in engine pressure, changes in hose length and size, or changes in nozzle adjustments, size, or elevation and generally inject the foam concentrate into the discharge side of the pump. The use of automatic regulating proportioning systems injection into the discharge side of the pump should be encouraged.

To encourage the use of automatic regulating proportioning systems injecting into the discharge side of the pump, automatic regulating proportioning systems should be formally tested and test results appropriately disseminated. Proportioning systems installed on engines should also be tested to insure that they are operating properly as installed.

Foam Proportioner and Pump Testing Equipment

To test a proportioner, engine pump flow, and pressure the following equipment can be used:

Flowmeters

Portable digital flowmeter, Fire Research Corp. model MFPD-1 1/2 (flow from 20 gpm to 350 gpm) with

(1) an internal rechargable battery
(2) an external charger for the battery
(3) a paddlewheel flow sensor in a 1 1/2" flow tube with 8 feet of connecting cable to;

(4) a digital display unit (to display in gallons per minute) with low battery indicator.

Flowmeter, Lake flowmeter B4B6W25D (flow 2 to 25 gpm)

Foam Percent Meter

Foam percent meter, 9 volt battery (internal), portable, with 1/2 BSP mount, (available from New Zealand Institute of Geological and Nuclear Sciences, Ltd or W. S. Darley & Co.)

Note: An improved model of this foam percent meter, which will be temperature compensated, is under development. This improved meter should be available at the time of publication of this article.

Pressure Gauge, Test, Correct Range

Sources of equipment:

Digital flowmeter

Fire Research Corp
26 Southern Blvd.
Nesconset, NY 11767
(516) 724-8888
(800) 645-0074

Lake flowmeter

Lake Monitors Inc.
1405 16th Street
Racine, WI 53403
(414) 637-6789

Foam percent meter

Institute of Geological and Nuclear Sciences, Ltd.
Attn: Dr. Gavin Wallace
30 Gracefield Rd
P. O. Box 31212
Lower Hutt, New Zealand
64-4-569-0637
FAX 64-4-569-0657

W. S. Darley & Co.
2000 Anson Drive
Melrose Park, IL 60160-1087
(708) 345-8050

With the above equipment the percent of foam the proportioner is dispensing can be tested along with the pump pressure and flow. There are two flowmeter, one a high flow meter (20 to 350 gpm) and one a low flowmeter (2 to 25 gpm).

To test the foam proportioner, hook up pressure gauge, flowmeter(s), and foam percent meter. Follow instructions for using the foam percent meter (zero meter with plain water flowing, then turn on the proportioner). Flow the pump at the pressures and flow desired and record the percent foam from the foam percent meter. To gain an understanding on the performance of the proportioner, plot the percent foam against pump flow. Percent foam should be plotted on the vertical axis and the pump flow on the horizontal axis. Ideally this plot should be a straight level line.

The utilization of foam with water scooping aircraft in Ontario

Gordon Luke
Ontario Ministry of Natural Resources, Thunder Bay, Ontario

Abstract

The operational use of the CL-215 Water Bomber, equipped to deliver fire fighting foam, has had a pronounced effect on Forest Fire Management in Ontario. This paper presents the history of aerial foam use in Ontario CL-215s, describes operational considerations and provides specific examples of aerial foam use on fires.

Résumé

L'utilisation d'un bombardier à eau CL-215 équipé pour larguer de la mousse carbonique a eu un effet marqué sur la gestion des incendies de forêt en Ontario. Le présent rapporte relate les méthodes employées jusqu'à ce jour en Ontario pour appliquer des mousses carboniques au moyen de CL-215, décrit les aspects opérationnels de ce procédé et fournit des exemples spécifiques où ce système a été utilisé pour combattre des incendies.

Introduction

The operational use of the CL215 Water Bomber, equipped to deliver fire fighting foam, has had a pronounced effect on Forest Fire Management in Ontario.

Within the intensively managed areas of the province there have been fewer escaped fires, which has resulted in reduced acreage lost. The use of foam has also allowed the formation of smaller, more efficient initial attack crews and reduced the overall time spent on individual fires by both aircraft and ground crews.

The bottom line is that the province can handle larger numbers of more intense fires with reduced levels of manpower and equipment.

History

After hearing about the experiences of other provinces that had been using foam with CL215's since 1985, Ontario began looking more closely at it in 1987. An attempt was made to evaluate fire fighting foam during July and August of that year when one Ontario CL215 was equipped with a Conair foam injection system. Unfortunately, these months had a very low fire load and the results were inconclusive.

The following year, 1988, a second evaluation was conducted with the objective of evaluating 1) available onboard injection systems; 2) the foam concentrates; and 3) the end product (the foam's effect on fire compared to straight water). Fortunately, 1988 turned out to be a very active fire year and was a good opportunity for Fire and Aviation staff to gain exposure to the fire fighting capability of foam.

Two MNR aircraft were equipped with injection systems, and foam equipped aircraft from other provinces were acquired through the MARS agreement. When fires occurred that required more than one tanker, there would usually be a mix of equipped and unequipped CL215's, providing an excellent opportunity to compare foam and water drops on fires of similar intensity and conditions (fuel, topography, canopy, closure, etc.).

The comparison of the fire fighting qualities of the foam versus straight water concluded that foam out performs water. This was evident very early in the evaluation. The test started in mid-May and by the end of May or early June, fire managers would ask specifically for foam equipped CL215's to be sent to their fires.

Evaluation forms returned by Air Attack leaders and Initial Attack Crews reported enhanced flame knock down and flame extinguishment. Ground crews also reported that total fire extinguishment was easier on fires that had been treated with foam.

One report read, "on an intense fire in spruce slash and standing timber a load of 0.7% foam appeared to be equivalent to three loads of water". This was typical of many of the forms returned.

Another concern that was addressed during this evaluation was the cost of foam. People asked, "Why pay for foam when we can get the water free?" The evaluation found that foam costs are well offset by the efficiencies provided through its use. This was demonstrated by the fact that in one region of Ontario alone, at least three intense fires were held by foam equipped CL215's. Fire staff involved credited these successes largely to the superior fire fighting qualities of foam. Had these fires escaped control, the cost of containing them would have very quickly exceeded the cost of any foam used during the initial attack.

Of the various injection systems evaluated, the Canadair system was chosen. The intent was to evaluate four different foam concentrates. Two did not pass due to poor cold water performance, the remaining two provided excellent results. No discernable difference could be seen in the generated foam produced by the various foam injection systems and the two foam concentrate products.

Following the evaluation, the final report recommended that the MNR endorse the use of foam for fire suppression purposes through the purchase and installation of foam injection systems for each aircraft. Over the following years this was done and, as of 1989, all nine of Ontario's CL215's were foam equipped.

Operational Considerations

As of April 1993, a five year average of approximately 2300 fires burn in Ontario each fire season. Of these 2300, 1600 are actioned by the MNR – the rest were actioned by Municipal fire departments, woods industry operators and the general public.

Of these 1600 fires, 500 received attack by CL215's (this does not include the fires attacked by our five Twin Otters or the helicopter fleet). Of these 500 fires, approximately 70% received foam, varying from 60%-80% depending on which areas of the province you are considering.

CL215 water bombers make approximately 725 foam drops/year for a total of 4,000,000 litres of foam solution dropped.

When is foam not used?

- Low intensity fires or fires in light fuel type; for example, foam would probably not be used on a grass fire.
- We do not use foam when it will enter a water course, including small streams.
- In most situations, we would not drop foam on a travelled highway.
- We do not drop foam around wells or livestock.
- We do not drop foam in designated wilderness parks (ie: Quetico Provincial Park) without first receiving authorization to do so.
- We do not use foam when the skimmers pick up in designated lakes.

However, if foam were required to stop the advance of a fire in a critical area; for example, to save human lives or private property, authorization to use it could be given for a specific instance.

When you look at the ratio of foam drops to water drops for last year (1993), it works out to about seven water to three foam. There are several reasons for this. First, we tend to use less foam in the southern and eastern areas of the province since they have more built up areas and sensitive areas than there are in the north and west regions. This means there are more areas where foam use is not wanted, and more lakes that aircraft are not authorized to pick up in if they use foam.

As well, a fully charged foam injection system is good for approximately 17-24 loads of foam depending upon the foam/water mix ratio, so during a sustained or support attack, the foam is depleted early and much of the mission is flown dropping straight water.

Conversely, a successful Initial Attack would be accomplished with only a few drops of foam.

Under normal circumstances the decision to use or not to use foam is made over the fire by the Air Attack Officer or the Fire Boss. In most instances, when foam is used, it is applied directly to the flame front to achieve rapid flame knockdown and halt the spread of the fire. Occasionally it is dropped in advance of the fire, usually to protect specific values (structures) in front of the fire by laying a heavy foam blanket around or on the value itself. It can also be used to completely envelop piles of cut wood or heavy equipment in front of the fire. However, when using this tactic, caution must be used to ensure that structures being covered with foam are not damaged by the drop cloud striking the building.

Foam is also used for smoke abatement by dropping loads of dry foam within the burned area. This is done to improve the work environment for ground crews and increase visibility over the head of the fire for target identification and to maintain safe flying conditions.

The foam concentrations required for each drop are determined by the fire behaviour and canopy closure, and is identified by the Air Attack Officer and controlled from within the water bomber by the First Officer.

The Interim Guidelines produced in Forestry Canada's "Recommended Foam Consistencies for Aerial Attack" are used as a guide when determining what a particular mix ratio should be. These interim guidelines classify and describe three broad classifications of foam:

1) Dry - Foam type 1 & 2 - 0.8% - intercepted by the tree canopy, coats and insulates well, releases water slowly, visible from the air for 30+ minutes.
2) Dripping - Foam type 3 - 0.5% visible from air for 20 minutes.
3) Wet - Foam type 4 - 0.3% penetrates canopy well and drains onto forest floor quickly, its presence is short lived, visible from the air for 5 minutes.

These guidelines also contained a chart showing what category or combination of categories should be used by fuel types, canopy closure, forest floor duff depth and time delay before the arrival of ground crews.

As an example of how we use foam, and to illustrate foam's effectiveness on critical fires, I would like to talk about a fire I dealt with in 1989. This fire was Geraldton No. 16 and occurred within the village of Webequie, a very remote village about 220 miles north of Geraldton. This fire started as a result of a garbage dump fire that was ignited in high winds and escaped the trench.

The forest fuel the fire occurred in consisted of standing black spruce with a heavy layer of forest litter and slash covering areas of the ground from log cutting and pruning activity by people in the village.

The fire occurred on June 20, and that far north the trees had not yet completely flushed out so we were still dealing with a spring fire hazard.

The 1300 weather that day was:

TEMP:	30°C
R.H.:	35
WD:	180
WS:	50 kph

This produced the following indices:

FFMC	92
DMC	43
DC	143
BUI	49
ISI	67
FWI	73

The village itself is comprised of log and frame buildings, most having asphalt shingle roofs. There were numerous firewood piles throughout the village and, at this time of year, all the grass in the village was cured. Several spot fires were already burning in the village and a number of buildings had already been destroyed. The only reason the village had not been completely destroyed was that the residents had held the fire briefly several times before losing it due to wind velocity.

The bird dog aircraft and one tanker arrived over the fire at 19:10 and immediately began working the fire – the water source was very close. The first loads dropped were dry foam (0.8%) placed on values and spot fires ahead of the fire. Next, dry foam was used again on the flanks to knock down some smoke and improve visibility on the head of the fire. At this point we had used up approximately half our available foam so Dripping Foam (0.5%) was used on the head and to re-treat any values or spot fires within the village. After we ran out of foam, straight water was used for hotspotting the fire and to treat the rear of the fire until ground crews arrived to take over.

Twenty foam loads and 20 water loads were dropped on the fire in 1 and 1/2 hours. This was the first critical fire I had worked with foam and, despite the short turn around time and pilot skill displayed, I was surprised by the outcome. When I initially arrived over the fire I anticipated our loses would be much greater. I attribute our success on Geraldton 16 to the superiority of foam over water for values protection, smoke abatement and flame knockdown.

Although this was by no means a typical fire in Ontario, I think it is a good example of how we utilize foam delivered by aircraft.

The way we normally operate is to have the foam mix concentration set around 0.5% of 0.6% at the start of a mission. The Air Attack Officer then adjusts the concentration up or down as the fire behaviour or canopy conditions dictate, and as he observes the foam's effect on the fire's behaviour.

Conclusions

We can definitely say foam has greatly enhanced our air attack program and that we can control more intense fires by applying it and thereby have fewer escaped fires thus saving money. It is impossible to come up with a concrete figure on exactly how much money we are saving. We will have to come up with a means of measuring these savings.

It would also help to have more information on the environmental impacts of foam. This could go a long way towards alleviating some perceptions held by fire managers and the public about the environmental impacts of foam and could allow foam to be used in areas it is presently unwanted if it is proven to be harmless.

Over the years in Ontario we have found that the best remedy for wildfires within our intensive zones is an aggressive, coordinated attack from the ground and the air. The ability of our air tanker fleet to deliver foam has greatly enhanced the Initial Attack. With the use of ground foam, now considered operational in Ontario, we look forward to continued successes.

Thank you for giving me the opportunity to talk to you today.

Technical Session III:

Environmental

The ecological impact of fire protection and its role in forest ecosystem management

Luc C. Duchesne and T. Hinrichs
Canadian Forest Service, Petawawa National Forestry Institute, P.O. Box 2000, Chalk River, Ontario, Canada KOJ 1JO

Abstract

An important emerging challenge facing forest managers is the development of forest management plans that will preserve biodiversity, favour multiple use of forest lands, and promote sustainable use. The successful implementation of forest fire suppression policies within this century served to protect the life and the homes of people as well as valuable timber but, at the same time, it also has had negative impacts on ecosystems at the microsite, stand, landscape, and genetic levels. Without consideration for the ecological role of fire in forest ecosystem management, the ecological integrity and productivity of forests may be compromised. Vegetation changes due to fire suppression can lead to loss of fire-adapted species, reduced biological niches, decreased productivity, and increased susceptibility to breakdown. The recognition of these impacts, along with the development of means to counteract them, may become an important part of forest ecosystem management schemes that address fire-driven ecosystems.

Résumé

L'un des plus importants défis que doivent aujourd'hui relever les gestionnaires forestiers est la mise au point de plans de gestion forestière qui permettront de préserver la biodiversité, de favoriser la foresterie à objectifs intégrés et d'encourager l'exploitation durable des ressources. La mise en œuvre efficace des politiques de lutte contre les incendies de forêt au cours des dernières décennies rendu possible de protéger la vie des personnes et leurs habitations ainsi que les précieuses ressources que constitue le bois d'œuvre, néanmoins ces interventions ont aussi eu des effets indésirables sur les écosystèmes aux niveaux des niches écologiques, des peuplements et du paysage et du point de vue génétique. Si l'on ne tient pas compte du rôle écologique que jouent les incendies dans la gestion des écosystèmes forestiers, on risque de compromettre l'intégrité écologique et la productivité des forêts. Les modifications que subit la végétation par la suite des interventions contre l'incendie peuvent entraîner une perte d'espèces qui vivent bien sur les brûlis, une réduction des niches biologiques, une plus faible productivité de même qu'une plus grande susceptibilité à la détérioration. La reconnaissance de ces incidences, ainsi que la mise au point de méthodes qui permettront de surmonter ces problèmes, peuvent devenir un aspect important des plans de gestion axés sur les écosystèmes produits par les brûlis.

Introduction

The objective of this paper is to discuss the role of fire suppression in forest ecosystem management. A careful analysis of the relationship between forest management policies and the use of Canada's forest resources illustrates a number of trends that clearly suggest possible future changes in the role of fire protection.

Before the arrival of Europeans in North America, wildfire was one of the most important natural forces that shaped Canada's forests. Wildfire established and maintained forest diversity by its recurrent passage through the landscape. Forest fires were ignited mainly by lightning, and to a smaller extent by native peoples who made use of fire to encourage berry production, create desirable habitats for game, enhance productivity of agricultural systems, and corral game during hunting parties (Pyne 1982).

In the early days of European colonization, settlers also used fire extensively to convert forested areas into farmland (Stocks and Simard 1993). However, extensive logging in the 1800s in eastern Canada led to large amounts of slash, which combined with careless range burning, favoured the widespread occurrence of large conflagrations that endangered human life and the livelihood of farmers, loggers, and trappers. For example, the Miramichi fire of 1825 burned nearly one million hectares in New Brunswick and another 800 000 acres in Piscataquis County, Maine (Pyne 1982). Hundreds of settlers perished in that fire, and contemporary documents claimed that more game perished in the Miramichi fire than had been hunted since the coming of Europeans (Pyne 1982). However, based on our current knowledge of the effect of fire on wildlife (Alexander and Euler 1981, Naylor 1993), the actual impact of the Miramichi fire on wildlife was certainly exaggerated. However, this claim illustrates clearly the settlers' perception of wildfire. Whereas forest fires were relatively rare and unimportant in the wetter climate of Central Europe (Pyne 1982), they were more frequent and ecologically more important in North America. Moreover, their destructive power reinforced the Old World concept in the mind of the European settlers that fire is merely a destructive agent. Thus, pressured on the one hand by a need to protect human lives, property, and valuable timber and, on the other, by traditional European attitudes toward wildfire, a country-wide fire exclusion policy was enacted by the early 1900s (Pyne 1982, Stocks and Simard 1993, Van Wagner 1990).

Original fire suppression policies were only partly successful, especially during periods of extreme fire weather (Stocks and Simard 1993). However, concerted research by foresters and scientists led to development of new methods for the prevention, detection, and suppression of forest fires. The success brought by several decades of research and technological application led to a basic transformation of the fire regime of Canada's forest ecosystems, changing fire frequency (Table 1) and size for most ecosystem types. For example, a recent study shows that, under modern fire protection systems, fire has no significant impact in most Ontario districts (Martel 1994), a dramatic change from pre-settlement conditions where 1 to 3 percent of the province's forests were likely burned during the average fire year.

Whereas a reduction in fire frequency and size is a desirable achievement from a timber protection perspective, it is not necessarily sound from an ecological viewpoint. This is particularly evident in national and provincial ecological parks and reserves where the complete eradication of fire is often not compatible with conservation objectives because most of Canada's natural ecosystems are fire-driven (Day et al. 1990). Consequently, debate took place between fire fighters and ecologists as to whether or not some wildfires should be allowed in large parks (Van Wagner 1973). In 1979, however, fire was acknowledged as an important natural process for the management of national parks (Lopoukhine and White 1985). A similar stand was taken in the United States where, after 1968, fire was viewed as a natural process rather than a menace (van Wagtindonk 1991).

Consequent to extensive discussion, a novel fire management strategy was put forward in Canada during the 1970s, in which not only the economics of fire suppression but also the ecological role of fire were taken into account (Stocks and Simard 1993). Following this strategy, there are Intensive Protection Zones (high-value forest sites or wildland-urban interface areas where more fires are suppressed) and Extensive Protection Zones (areas such as wilderness parks or remote forested lands of limited economic value where fire is often allowed to develop naturally). Wildfire occurrence in Canada increased from 6000 fires/year in 1960 to 10 000 fires/year in the late 1980s, in part because of this new policy and possibly because of an increase in the Fire Weather Index (Kiil 1991). This modified suppression policy is currently in effect in parts of the Northwest and Yukon Territories, as well as in the northern regions of the provinces of Québec, Ontario, Manitoba, and Saskatchewan (Stocks and Simard 1993). Although this new perspective on fire protection applied well to the economic and ecological constraints of the 1970s, the forthcoming emergence of ecosystem-based management requires a reexamination of Canadian fire protection policies.

Based on the principle that forest ecosystems comprise a variety of important resources, of which timber is only one, forest ecosystem management is perceived as a promising approach guiding forest users in North America (Slocombe 1993, Thompson and Welsh 1993). One of its basic tenets is that timber

Table 1. Fire frequencies of Canadian Northern ecosystems before and after European settlement

	Fire frequencies	
Ecosystem type	**Pre-columbian**	**Modern**
Aspen parklands	3–15 years	50 years
White and red pine	20–300 years	1000–2000 years
Jack pine	15–100 years	100–500 years
Black spruce	50–500 years	500–1000 years
White spruce	150–300 years	+
Balsam fir	150–300 years	+
Red spruce	150–300 years	>230 years
Lodgepole pine	25–100 years	>1000 years
Tundra	1000–10000 years	1000–10000 years

+: data not available

harvesting or any other resource ought not to degrade or diminish other equally important values such as wildlife (including all life forms), water, and ecological integrity (Rowe 1992). Furthermore, ecosystem management proposes an holistic view of nature and encourages collaboration among all those whose activities affect ecosystems (Anonymous 1991). Despite popular acceptance of the basic tenets of forest ecosystem management, there is an urgent need to develop specific objectives and methodologies before this concept can be applied in practice.

Historically, the concept of forest ecosystem management arose from three important needs:

1) *The need to preserve biodiversity*: Biodiversity can be defined as the variety of life forms. Broadly taken, it refers to the number and frequency of genes, species, interactions, and ecosystems. The value of biodiversity lies within many ecological, ethical, and economic reasons (see Burton et al. 1992, Boyle 1992) of which one of the most important aspect may be adaptability to disturbance or the ability of nature to maintain itself in an ever changing environment. In addition, maintaining biological diversity is becoming increasingly important in managed forests because of the inability of parks and natural reserves to safeguard biodiversity (Hansen et al. 1991).
2) *The need to develop satisfactory rules for multiple use of forest lands*: Even in a country as large as Canada, and with a population as small and scattered, multiple forest use is becoming an important issue because of a growing variety of needs and expectations of the forests. In future, Canada's population is expected to grow steadily and so the use of the forest for recreational purposes will increase (Stocks and Simard 1993). Furthermore, preservation of endangered species or primeval ecosystems such as the coastal rainforest in British Columbia is an important task entrusted to foresters by the public in Canada and abroad. In other, older, more populated countries, the integration of all forest uses has long since taken place. For example, in Germany three functions of the forest are seen as equally important: timber use, protection (of species, ecosystems, water quality, and air), and recreation.
3) *The need to develop feasible sustainable forestry programs*: Sustainability implies forest management that ensures the long-term renewability and maintenance of natural resources. Nevertheless, a forest management perspective that includes sustainability must emphasize ecosystem health rather than timber production (Griss 1993). However, in the past there have been some misconceptions about the meaning of sustainability, mostly because of overly narrow definitions (Webster 1993). For example, as Webster (1993) points out, it is distinctly unhelpful to expect that all ecological features should remain undisturbed except by natural processes. This is simply total protection, which we recognize to be an exception rather than the rule.

One important consideration for ecosystem management is that fire was a natural disturbance in most of Canada's forest ecosystems. Consequently, we speculate that fire protection, like other human activities, creates an unique type of disturbance in forests. This raises important questions regarding the role of fire and fire suppression in maintaining forest health which, in turn, affects productivity and ecological integrity. Unfortunately, very little attention has been devoted to this problem, presumably because of the novelty of forest ecosystem management.

Fire Protection Has Different Impacts on Different Forest Regions

Possible consequences of fire suppression at the microsite, ecosystem, and landscape levels include: 1) blocking of nutrient turnover; 2) accumulation of fuel; 3) soil isolation from heat and sun exposure; 3) hindering the regeneration of plant species which need mineral soil; 4) reduced regeneration of serotinous and other fire-dependent species; 5) increased inter- and intraspecific competition for moisture, nutrients, and light; 6) denser stand structure; 7) possible decrease of genetic diversity; and, 8) changing the overall landscape mosaic.

However, it is important to acknowledge that the effect of protection varies according to each forest region, ecosystem type, and intensity of fire protection. This is based on the observation that each forest region is characterized by its own fire regime, with variations at the ecosystem level, resulting from the interaction of climate, topography, and fuel type.

Fire frequencies varied between approximately 10 and 10 000 years among forest regions of Canada (Duchesne et al. 1994). Short fire frequencies were typical of the Canadian prairies, the montane forest region, and parts of the Great-Lakes St. Lawrence forest region whereas long fire frequencies were found in the coastal forests of British Columbia, the Arctic tundra, and in the Atlantic provinces (Table 1). However, the role of fire varied greatly from one region to the next. For instance, there are even some

Human health and ecological risk assessments: Wildland fire suppression chemicals

Christine Boivin and Cyndi Bailor
Labat-Anderson Inc., Arlington, Virginia

Abstract

This report summarizes a quantitative assessment of the risks to human health as a result of exposure to four types of chemicals approved by the U.S. Forest Service for wildland fire suppression: Long-term retardants, foams, short-term retardants, and wetting agents. A hazard analysis was conducted for each chemical to determine an acceptable dose level, and this level was compared to the estimated doses to both workers and members of the public from both average and upper end scenarios. The results show a potential for risk to certain categories of workers from some, but not all, of the retardant and foam formulations currently approved. No risks were identified for members of the public from foams, but some retardant formulations were associated with potential risks. However, there is significant uncertainty in this analysis, primarily due to the limited toxicity database. The use history of these chemicals reveals only incidents of skin and eye irritation, and no reported cases of systemic toxicity.

Résumé

Le présent rapport résume l'évaluation quantitative des risques pour la vie humaine d'une exposition à quatre types de produits chimiques approuvés par le Service des forêts des États-Unis pour la lutte contre les feux de végétation, soit les produits d'ignifugation de longue durée, les mousses, les produits d'ignifugation de courte durée et les agents mouillants. On a mené une analyse des dangers pour chaque produit chimique afin de déterminer la dose admissible, dose qui a été comparée aux doses auxquelles on estime que les travailleurs et la population sont exposés, au niveau d'absorption moyen ou extrème. Selon les résultats, il y a des mousses et des produits d'ignifugation approuvés qui présentent des risques pour certaines catégories de travailleurs. Les mousses ne comportent aucun risque pour la population, mais certains types de produits d'ignifugation pourraient se révéler nocifs. Il faut toutefois souligner que le degré d'incertitude associé à cette analyse est très élevé, principalement en raison du peu de données toxicologiques disponibles. Depuis qu'ils sont utilisés, ces produits ne semblent avoir provoqué que des irritations de la peau et des yeux, et aucun cas d'intoxication générale n'a été signalé à ce jour.

Introduction

The U.S. Forest Service uses a variety of chemicals to aid in the protection of forest resources from wildland fires, including long-term fire retardants, short-term retardants, foams, and wetting agents. These chemicals have been in use since the 1930s, but their potential human health and ecological impacts have not been thoroughly assessed from a programmatic perspective. This discussion provides an assessment of the risk to human health and ecological resources from using chemicals for wildland fire suppression. The assessment looked at long-term retardants, short-term retardants, and foams. No toxicity data were available on wetting agents, so they were excluded from this analysis.

The human health risk assessment employs the three principal analytical elements that the National Research Council considers necessary for characterizing the potential adverse health effects of human exposures to existing or introduced hazards in the environment: hazard analysis, exposure analysis, and risk characterization. The ecological risk assessment follows EPA's recent Framework for Ecological Risk Assessment, which recommends three parts: problem formulation, analysis, and risk characterization. Both assessments also identify uncertainties that are associated with the conclusions of the risk characterization.

Human Health Risk Assessment

Hazard Analysis

Hazard analysis determines whether the likelihood of adverse health effects may be increased by a particular chemical exposure, and identifies a dose-response relationship. Information on effects in non-human test systems usually provides the basis for an informed judgment as to whether an adverse impact is correlated with a particular exposure. There are two types of toxicity endpoints: noncarcinogenic forest regions, such as the wetter parts of the west coast or parts of Cape Breton Island or western Newfoundland, where fire occurs so rarely that it is ecologically less important (Van Wagner 1990). Natural fire size also differs among forest regions. Flat, monotonous landscapes display larger fires than landscapes which limit the spread of fire by streams, lakes, and slopes (Wright and Bailey 1982).

Conclusions

Over the last three and half centuries of Canadian history, changing needs and perceptions have led to various forms of forest fire policies. Particularly, the advent of organized fire protection at the turn of the nineteenth century led Canadians on a path that dramatically changed the dynamics of Canadian forests. Because fire was the most widespread disturbance agent controlling diversity in primeval times, efficient fire protection introduced new forest dynamics.

In future, fire ecologists should participate more actively in ecosystem-based forest management in those areas of Canada where fire was a dominant feature of the landscape in pre-settlement times. Increasingly, fire ecologists, along with forest managers, will examine past impact of fire management, predict their future effects, and help devise new policies and/or silvicultural methods that accommodate the evolving needs Canadians have for their forest lands.

References

Alexander, M.E; Euler, D.L. 1981. Ecological role of fire in the uncut boreal mixedwood forest. Pages 42-64 *in* Proc. Boreal Mixedwood Symp., Sept 16-18, 1980, Thunder Bay, Ont. Dep. Environ., Can. For. Serv., Great Lakes For. Res. Cent., Sault Ste-Marie, Ont. COJFRC Symp. Proc. O-P-9

Anonymous. 1991. Looking ahead: A wildlife strategy for Ontario. Ontario Wildlife Working Group. Ont. Min. Nat. Res.,Toronto, Ont.

Boyle, T.J.B. 1991. Biodiversity of Canadian forests: current status and future challenges. For. Chron. 68: 444-453.

Burton, P.J.; Balisky, A.C.; Coward, L.P.; Cumming, S.G.; Kneeshaw, D.D. 1992. The value of managing for biodiversity. For. Chron. 68: 225-237.

Day, D.L.; White, C.A.; Lopoukhine, N. 1990. Keeping the flame: fire management in the Canadian Parks Service. Pages 35-48 *in* Alexander, M.E; Bisgrove, G.F., ed. The art and science of fire management. For. Can., Northern For. Res. Centre, Edmonton, Alberta. Inf. Rep. NOR-X-309.

Duchesne, L.C; Applejohn, A.; Clark, L.M.; Mueller, C. 1994. Fire in northern ecosystems. *In* Brown, J; Mutch, R., ed. Fire effects on fauna. USDA Forest Service (in press).

Griss, P. 1993. Implementing sustainable forests: A Canadian commitment. For. Chron. 69: 535-538.

Hansen, A.J.; Spies, T.A.; Swanson, F.J.; Ohmann, J.L. 1991. Conserving biodiversity in managed forests - Lessons from natural forests. BioScience 4: 382-392.

Kiil, A.D. 1991. Fire research and management issues in Canada. Pages 131-140 *in* Proc. Soc. Amer. For. National Convention. San Francisco, CA, Aug. 4-7, 1991.

Loupoukhine, N.; White, C. 1985. Fire management options in Canada's National Parks. Pages 59-69 *in* Proc. Intermountain Fire Council 1983 Fire Management Workshop. Dube, D.E., ed. For. Can, Northern For. Res. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-271.

Naylor, B. 1993. The impact of natural and prescribed fire on wildlife. *In*: Prescribed burning workshop. September 22-23, 1993. Petawawa National For. Inst., Chalk River, Ont.

Martel, D. L. 1994. The impact of fire on timber supply in Ontario. For. Chron. 70: 164-173.

Pyne, St.J. 1982. Fire in America. A cultural history of wildland and rural fire. Princeton Univ. Press. Princeton, New Jersey.

Rowe, J.S. 1992. The ecosystem approach to forest land management. For. Chron. 68: 222-224.

Slocombe, D.S. 1993. Implementing ecosystem-based management. BioSci. 43: 612-622.

Stocks, B.J.; Simard, A.J. 1993. Forest fire management in Canada. Disaster Mgmt. 5: 1993.

Thompson, J.D.; Welsh, D.A. 1993. Integrated resource management in boreal forest ecosystems - impediments and solutions. For. Chron. 69: 32-39.

Van Wagner, C.E. 1973. Forest fire in the parks. Park News. June 1973, Pages 25-31.

Van Wagner, C.E. 1990. Six decades of forest fire science in Canada. For. Chron. 66: 133-137.

van Wagtindonk, J.W. 1991. The evolution of national park fire policy.USDA For. Serv. 52: 10-15.

Wright, H.A.; Bailey, A.W. 1982. Fire Ecology - United States and Southern Canada. John Wiley and Sons, New York, NY.

effects and carcinogenic effects. For noncarcinogenic effects, it is generally assumed that there is a threshold level, and that doses lower than this threshold can be tolerated with little potential for adverse health effects. The U.S. Environmental Protection Agency (EPA) refers to these threshold doses as reference doses (RfDs). These thresholds have been historically described as acceptable daily intakes (ADIs) by such groups as the World Health Organization. In this risk assessment, these levels are termed ADIs; however, when EPA has set an RfD for a chemical, this RfD is used as the ADI in this risk assessment. For carcinogenicity, a chemical's cancer slope factor is used to relate its carcinogenic potency to the estimated risk from a particular level of exposure, no matter how small the exposure is. The goal of the hazard analysis is to determine ADIs and cancer slope factors (where appropriate) for the chemicals of interest.

Because no long-term studies have been conducted on any of the fire suppression chemical formulations, there are no data with which to evaluate carcinogenic potential for the formulations as a whole. The carcinogenic potential of individual ingredients in the formulations was evaluated as a separate activity in the human health risk assessment, which we'll discuss later.

For noncarcinogenic endpoints, an ADI may be derived from the results of laboratory studies. Ideally, the results of a lifetime study are available that provide an unequivocal no-observed-effect level (NOEL). However, for many chemicals, including the majority of those found in the fire suppression chemical mixtures and the mixtures themselves, long-term study data are not available. Layton et al. developed a methodology for deriving ADIs for noncarcinogenic compounds for which chronic toxicity data are unavailable; this method uses acute toxicity data, specifically, LD_{50}s (median lethal doses). Acute and chronic toxicity values for many chemicals were correlated to identify a factor that allowed a reasonable estimate of a chronic NOEL based on an LD_{50}; this factor was 1×10^{-5}. An additional factor of 5 was found to correlate subchronic with chronic NOELs. The resulting estimated subchronic NOEL was then multiplied by 0.1 to account for the uncertainty associated with interspecies extrapolation from laboratory animals to humans, and then multiplied by 0.1 again to allow for intraspecies variation among humans. To summarize, the estimated ADI was determined as follows:

$$\text{ADI (mg/kg/day} = \frac{LD_{50}\,(\text{mg/kg}) \times 1 \times 10^{-3} \times 5}{100}$$

This calculation was applied to each of the chemicals and mixtures assessed, to provide an estimate of an acceptable exposure level.

Doses and ADIs are usually expressed in units of milligrams of chemical per kilogram of body weight per day, or mg/kg/day.

The LD_{50}s for the concentrated and mixed fire suppression chemicals were obtained from Material Safety Data Sheets (MSDSs) prepared by the manufacturers, and from toxicity data submitted to the U.S. Forest Service by the manufacturers. In general, the types of data that were available included oral and dermal LD_{50}s, and inhalation LC_{50}s presented in units of mg/m^3 in the air. The toxicity data were often in the form of "> X mg/kg," requiring the use of "X" as the LD_{50}, even though the true value may be much higher. (The higher the LD_{50}, the lower the toxicity.)

ADIs were calculated for each of the wildland fire suppression chemicals. The ADIs range from 0.025 to 0.25 mg/kg/day. For two chemicals for which the LD_{50} is listed as ">505 mg/kg" (Fire-Trol LCA-R) or ">500 mg/kg" (Fire-Trol STH-F), the ADIs were estimated to be 0.025 mg/kg/day. For the other chemicals, the LD_{50}s were listed as ">5,050 mg/kg" or were given as an exact figure, which ranged from 3,100 mg/kg and higher. For Fire-Trol LCA-R and STH-F, the LD_{50}s are likely to be significantly higher than the 500 or 505 mg/kg value used in this risk assessment.

Exposure Analysis

Exposure analysis is the process of measuring or estimating the intensity, frequency, and duration of human exposures to an agent, for the purpose of estimating a dose, in mg/kg/day. Two human populations may potentially be exposed to wildland fire suppression chemicals. The first group at risk consists of the wildland fire suppression workers. The second group at risk includes members of the public. It is important to note that the exposure scenarios estimate risks from clearly-defined types of exposures. If all the assumptions in the exposure scenarios are not met, the dose will differ from that estimated here, or may not occur at all.

For both workers and members of the public, exposure scenarios included average and upper end exposures. **Average exposure** assumptions attempt to target the average dose an individual may receive. **Upper end exposure** assumptions attempt to define the upper bound of credible doses that an individual may receive.

Worker Exposure Analysis

Potentially exposed workers include mixmasters, loaders, helitack crews, smokejumpers, hotshot crews, firefighters and overhead workers, and engine crews. The average scenarios were based on the average amount of time that the workers spend in contact with fire suppression chemicals during a typical fire season. The upper end scenarios were based on exposures that were observed during a fire season with many large fires that required heavier usage of fire suppression chemicals. Exposure types and duration were derived from information provided by multiple wildland agencies throughout the U.S.

The standard assumption was made that each worker weighs 70 kg. The activity profile for each type of worker identified details of activities, formulations to which exposure is possible, clothing, personal protective equipment, and duration of exposure on a daily, yearly, and career basis.

Mixmasters were evaluated for dermal exposure to concentrated powdered and liquid retardants, and inhalation exposure to powdered retardants, during the course of their duties. Their inhalation rate was assumed to be 2.5 m^3/hour, which indicates a moderate level of physical activity. Loaders were assumed to receive a dermal dose during loading of a diluted solution on an airtanker. For helitack crews, smokejumpers, hotshot crews, and firefighters and overhead workers, dermal doses from contact with treated vegetation were estimated. For engine crews, the dermal dose from mixing foams or wetting agents was added to the estimated dose from applying the chemicals while moving through treated vegetation.

For helitack crews, smokejumpers, hotshot crews, and firefighters and overhead workers, the potential dose from being in the path of an aerial drop of fire suppression chemicals was calculated. In each of these cases, it was assumed that the worker receives the full application rate over 30 percent of the body surface area.

Public Exposure Analysis

Members of the public may be exposed to the fire suppression chemicals only on a rare occasion or accidentally. However, two scenarios were evaluated: an accidental drop of a chemical onto an adult or child spectator at a fire-fighting activity, and exposure of an adult or child member of the public while cleaning structures or handling objects following application of fire suppression chemicals to the premises.

The first scenario is based on a member of the public cleaning a structure (for example, a house) after it has been treated with fire suppression chemicals, resulting in dermal exposure to the hands and forearms. This scenario was evaluated for an adult and a 6-year-old child. The total surface area of the adult and child is assumed to be 1.94 and 0.87 m^2, respectively. The average body weight is assumed to be 50 and 20 kg for an adult and child, respectively. The exposure duration is assumed to be 4 hours per day to a solution of aqueous cleaning rinsate (resulting from hosing and scrubbing the property with water), at a strength not greater than that of the applied mixture.

The second scenario is based on a member of the public getting drenched with aerially applied chemicals, and is examined for both an adult and a 6-year-old child. Thirty percent of the body surface area is assumed to be exposed, and the chemical is washed off within two hours.

Risk Characterization

Risk characterization combines the hazard information with the dose estimates to predict the potential for health effects to exposed individuals. Separate risks are estimated for noncarcinogenic and carcinogenic effects. The likelihood of noncarcinogenic health effects may be assessed by using a simple ratio, obtained by dividing the estimated dose by the acceptable daily intake to obtain a hazard quotient, as follows:

$$\text{Hazard Quotient} = \frac{\text{Dose (mg/kg/day)}}{\text{ADI (mg/kg/day)}}$$

There is a potential risk of noncarcinogenic health effects if the hazard quotient exceeds 1, that is, if the estimated dose exceeds the acceptable level of exposure.

Carcinogenic risks are expressed in terms of the increase in an individual's lifetime probability of developing cancer that can be attributed to a specified exposure. This is a function of the dose, averaged over a lifetime, and the carcinogenic potency of the chemical, as indicated by its cancer slope factor, as follows:

$$\text{Cancer Risk} = \text{Average Lifetime Dose (mg/kg/day)} \times \text{CSF [(mg/kg/day)-1]}$$

In general, cancer risks less than 1 x 10^{-6} (1 in 1 million) are considered to pose a negligible addition to the background cancer risk in the U.S. of approximately 0.25 (1 in 4).

Average exposures resulted in hazard quotients of 1.0 or less for all workers and members of the public cleaning their property, indicating little potential for health risks.

Under upper end assumptions, mixmasters were calculated to have potential health risks from some formulations of long-term retardants (Fire-Trol LCA-R, LCG-R, and LCG-F). The hazard quotients were 1.3, 1.1, and 1.2, respectively.

Loaders in upper end scenarios may be at risk from all long-term retardants except Phos-Chek D75-R and D75-F. These hazard quotients ranged from 1.1 to 2.0. No risks from upper end exposures were predicted for helitack crews, smokejumpers, hotshot crews, and firefighters and overhead workers.

Upper end scenarios evaluating all fire-fighting foams resulted in a prediction of potential risk for engine crews. Hazard quotients were 1.1 for all foams.

Upper end exposures to members of the public cleaning their property are not expected to pose risks.

For an adult drenched from being in the path of an aerial drop, the hazard quotients range from no risk (<1) to 3.4. For a child drenched, the hazard quotients range from no risk (<1) to 3.8. For workers, the hazard quotients from being drenched range from no risk (<1) to 3.7.

An individual ingredient in a formulation was targeted for additional analysis if (1) it is a suspected or known carcinogen; (2) the oral LD_{50} is ≤500 mg/kg, or (3) the MSDS lists it as a toxic chemical reportable under SARA Section 313 or a hazardous chemical reportable under OSHA's Hazard Communication Standard. Nine individual ingredients were evaluated due to low LD_{50}s or reportability to EPA/OSHA.

For average exposures to workers, all targeted ingredients are predicted to have hazard quotients less than 1, and therefore are predicted to pose no risks. For workers, some of the upper end hazard quotients derived from analysis of individual ingredients exceeded 1.0, ranging up to 1.9. The estimated risks are similar to those predicted to result from upper end exposure to the formulated products.

Average and upper end exposures to adults or children cleaning their property resulted in predictions of no risk from individual ingredients in the formulations.

Similar to the risks predicted for the entire product, drench doses resulted in hazard quotients as high as 3.6 for exposure to individual ingredients.

The formulations currently in use include nine compounds for which any indication of carcinogenicity was found in the literature, including seven that have not been generally considered to be carcinogens. The reliability of the sources for the reports on these seven chemicals is unknown, and no quantitative data were provided to support these claims. The two additional chemicals include one probable human carcinogen and a petroleum-derived mixture that often contains carcinogens. In addition, thiourea, which was previously an ingredient in one long-term retardant formulation, was evaluated for carcinogenic risk.

The probable human carcinogen is only considered to be carcinogenic when inhaled. Since it is not present in the powder retardant formulations for which inhalation was deemed to be significant, it is not expected to pose any appreciable cancer risk.

The presence of the petroleum derivative was predicted to result in lifetime cancer risks less than 1 in 1 million for all workers and members of the public.

As previously used in one long-term retardant formulation, thiourea's predicted cancer risks are less than 1 in 1 million for members of the public; less than 1 in 1 million for all workers except loaders; 9.4 in 1 million for average exposures to loaders; and 3.0 in 100,000 for upper end exposures to loaders.

Uncertainties in the Analysis

There is considerable uncertainty in some of the exposure and toxicity parameters used in this analysis. Confidence can be placed in the assumptions regarding exposure time, frequency, and duration, because average and upper end estimates were obtained through a consensus of individuals with long experience in wildland fire suppression.

The risks predicted by this assessment are not probabilistic estimates of risk, but are conditional estimates. That is, these risks are likely only if (1) all exposure scenario assumptions that were described are met, and (2) subchronic acceptable daily intake levels can be reasonably predicted using LD_{50} data.

The primary areas of uncertainty include the ADI for each chemical, the dermal penetration rates of the mixtures, and the quantity of chemical to which each individual is exposed. The first two areas could be addressed by conducting toxicity and absorption testing in laboratory animals, and the third could be addressed by an extensive monitoring program of fire-fighting operations. However, during the many years of these chemicals' use, there have been no links established between exposure and human toxicity. Incident reports have been limited to cases of skin and eye irritation. In addition, many of the primary ingredients are found in household items such as fertilizer, soaps, and detergents. Therefore, extensive testing does not appear to be warranted, given the emergency nature of the use of these formulations.

Ecological Risk Assessment

Ecological risk assessments consist of three parts:

- **Problem formulation**, which identifies the characteristics of the stressor, discusses possible types of adverse effects, identifies potentially affected ecosystems, defines assessment and measurement endpoints for adverse effects, and creates a conceptual model from a series of hypotheses describing how the stressor may come into contact with the ecosystem.
- **Analysis** characterizes exposures and further investigates the types of ecological effects associated with particular types of exposures.
- **Risk characterization** consists of an evaluation of the likelihood of adverse ecological effects as a result of exposure to stressors.

Problem Formulation

In this analysis, the stressors are long-term retardants and fire-fighting foams. No data were available on which to base an analysis of ecological risk from short-term retardants or wetting agents. Stressor characteristics include the following:

- **Type**: Aerially and ground applied fire suppression chemicals.
- **Intensity**: Applied at variable rates according to magnitude of fire and type of fuel.
- **Duration**: Soil, water, and foliar half-lives are unknown for formulations as a whole.
- **Frequency**: Varies, but typically no more than once every few years on a site.
- **Timing**: Mostly late summer, early fall.
- **Scale**: Varies, but assumed to be applied to relatively small areas in a long, narrow strip.

A review of existing studies revealed that the ecological toxicity characteristics of long-term retardants include

- low direct toxicity to mammals, birds, and terrestrial invertebrates
- possible indirect toxicity from nitrate in plants
- possible phytotoxicity
- low toxicity to fish, and slight toxicity to aquatic invertebrates

For fire-fighting foams, studies have shown that they are associated with:

- low toxicity to mammals, birds, and terrestrial invertebrates,
- slight toxicity to fish, and
- moderate toxicity to aquatic invertebrates.

Little data on phytotoxicity of foams were available.

Seven types of potentially affected ecosystems were defined, according to the long-term retardant coverage level recommendations:

- short grass prairie
- Appalachian oak forest
- Ponderosa pine woodland
- pinyon-juniper woodland
- Douglas fir forest
- Alaska black spruce forest
- California chaparral

A profile of the terrestrial and aquatic systems in each ecoregion was compiled, including topography, soils, climate, vegetation, wildlife, streams, and aquatic species.

The next step in the ecological risk assessment was to determine the endpoints that would be evaluated. **Assessment endpoints** reflect the actual environmental values to be protected. Assessment endpoints for terrestrial species were injury from an aerial application, adverse effects from ingesting treated food, adverse effects to vegetation, and indirect effects on all species. Assessment endpoints for aquatic species were a decline in sport fishery species, effects on stream community and diversity, effects of components/degradation products on aquatic species, and eutrophication of water bodies.

To obtain an indication of whether there may be an effect on a particular assessment endpoint, the endpoint must be related to something that can be quantitatively or qualitatively evaluated. **Measurement endpoints** are measurable responses that relate to assessment endpoints. The measurement endpoints for terrestrial species were the likelihood of animals remaining in drop area, toxic dietary levels and phytotoxicity, and potential for damage to trophic levels. For aquatic species, measurement endpoints were a comparison of acute toxicity to estimated concentrations, and nutrient status and trophic level effects in aquatic ecosystems.

The conceptual model details the scenarios developed to describe how the fire suppression chemicals may interact with the ecosystems involved. This model attempts to identify the hypotheses that are considered likely to create some risk to the ecosystems involved. Separate scenarios were developed for terrestrial and aquatic species. Each scenario includes measurement and assessment endpoints, which are used to assess the relationship between the chemicals and the ecosystem.

The scenarios in the conceptual model for terrestrial species analysis were:

- direct contact by plants or animals in the drop area of an application
- ingesting food contaminated with the chemicals
- indirect effects, such as if the chemical affects a food source or habitat requirement

The scenarios in the conceptual model for aquatic species analysis were:

- direct exposure to runoff from treated areas or accidental applications to streams (formulations, components, and degradation products)
- indirect effects, such as reduction in a species' food source
- effects of nitrogen and phosphorus loading on stream's nutrient status (long-term retardants only)

Analysis

In the analysis phase of the ecological risk assessment, the parameters of the model were defined. An examples is the application rates of the chemicals. Retardant application rates ranged from 1 to 7 gal/100 ft^2, depending on the ecoregion. The foam application rate was conservatively assumed to be 10 gal/100 ft^2, regardless of ecoregion.

Doses were estimated for terrestrial species as a result of dietary exposures to retardants and foams. Chemical residues on various food items were calculated using a model developed for estimating pesticide residues as a result of aerial applications. The dietary doses to representative species were estimated, based on the assumption that 25 percent of their food items were contaminated. The estimated doses from long-term retardants ranged from 10 mg/kg/day for a squirrel in an area treated at 1 gal/100 ft^2, to 1,673 mg/kg/day for a blue jay in an area treated at 7 gal/100 ft^2. The estimated doses for fire-fighting foams ranged from 0.8 mg/kg/day for squirrels and woodpeckers, to 18 mg/kg/day for blue jays.

To evaluate risks to aquatic systems, the Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) computer model was used to predict the amount of fire suppression chemical entering a stream after application in a watershed. This model, originally designed to assess agricultural management practices, was adapted over the years to encompass forested areas. It is able to simulate infiltration, surface runoff, sediment transport, nutrient cycling, adsorption, and degradation. It also has a nutrient cycling subroutine, which was used to model nutrient cycling of nitrogen and phosphorus in receiving waters after applications of long-term retardants to an area. Accident scenarios in which a stream was in the path of an aerial drop were also evaluated, based on the direct application rate.

Following applications of long-term retardants, the GLEAMS analysis predicted ammonia concentrations in streams ranging from negligible to 0.8 mg/L from runoff, and from 0.4 to 50 mg/L following an accidental drop. Following applications of foams, GLEAMS estimated stream concentrations ranging from 0.03 to 6 mg/L from runoff, and from 6 to 400 mg/L following an accidental drop.

The analysis also included a review of existing qualitative and quantitative information on hazards to terrestrial species', including their behavior in an area where fire suppression chemicals are applied; acute toxicity data from laboratory studies; toxicity to plants (only limited information was available) and their uptake of components and degradation products, such as nitrates; and toxicity to individuals at different trophic levels.

For aquatic species, potential effects data included acute toxicity values for sport fish species, acute toxicity values for species throughout the stream community, information on the toxicity of individual component chemicals, and phosphorus and nitrogen loading tolerances.

Risk Characterization

Risk characterization is the final phase of the ecological risk assessment process. The exposure profile is compared to the response profile and the likelihood of adverse effects is estimated.

Risk estimates are made by the Quotient Method. Using this method, the ratio of the estimated exposure to the exposure level expected to have an adverse effect provides the risk estimate. Because of the uncertainties involved, the quotient (Q) is assessed as follows:

$Q < 0.1$ = No adverse effects
$0.1 < Q < 10$ = Possible adverse effects
$Q > 10$ = Probable adverse effects

Terrestrial Species Risk Estimation

The likelihood of physical injury to terrestrial species from applications of fire suppression chemicals is remote. Large animals leave the area of a fire, and small mammals seek shelter in burrows. Any physical impacts to wildlife would be to individuals and would not affect the population as a whole.

For risks to individual animals, the assessment indicated possible risks to the blue jay and the wild turkey at from application of long-term retardants at 2 gal/100 ft^2 and higher. At coverage levels of 6 gal/100 ft^2 and greater, adverse effects to rabbits are also possible. No adverse effects to individual animals were predicted to result from fire-fighting foams.

Although the literature review did not reveal much information about phytotoxicity, fire retardants containing ammonium sulfate may be expected to cause damage to foliage or even death to some exposed plants. In evaluating the importance of this phenomenon, one must weigh the damage caused by fire retardants against the damage caused by fire, realizing that, in some instances, leaf damage and even death of some trees or plants may be preferable to fire damage.

Potential indirect effects from fire suppression chemicals may include increased productivity due to the fertilizer effects of the long-term retardants, or indirect nitrate toxicity to herbivorous mammals. Many of the effects of increased productivity will be similar to the indirect effects of the fire itself, as fires can create increased foraging opportunities. Increased nitrate uptake by plants is only likely to occur in unusual circumstances of drought, low light conditions, or certain mineral deficiencies. Even under these conditions, the total effect is likely to be small; the areas covered by a retardant drop are narrow, and the nitrate-contaminated forage is likely to be only a small part of the diet of the large ruminant mammals most affected.

Aquatic Species Risk Estimation

All accidents involving direct application of a retardant or foam to a stream were predicted to have a potential for adverse effects on the aquatic ecosystem.

Under normal operations, possible risks to sport fishery species were indicated from long-term retardant use in the eastern deciduous forest and Alaska black spruce forest ecoregions. Fire-fighting foams were associated with possible adverse effects to sport fishery species in the short grass prairie and ponderosa pine woodland ecoregions.

For the eastern deciduous forest and Alaska black spruce forest ecoregions, possible risks from long-term retardants to the entire stream community are predicted, with probable risks to aquatic invertebrates (as represented by daphnia) in the Alaska black spruce ecoregion. For foams, risk estimates for the stream community indicate possible adverse effects for the short grass prairie and ponderosa pine woodland ecoregions. Possible risks to aquatic invertebrates (as represented by daphnia) and algae are indicated for all ecoregions except for the pinyon-juniper woodland and chaparral.

Similar to the approach taken in the human health risk assessment, some individual chemicals were also analyzed in the ecological risk assessment. An ingredient in a formulation was targeted for this additional analysis if the LD_{50} is less than or equal to 500 mg/kg, or if the LC_{50} is less than or equal to 10 mg/L. Four individual ingredients in the formulations were evaluated. All estimated risks were no greater than those predicted to result from the parent compound in the risk assessment.

The assessment also examined the effects of nitrogen and phosphorus loading on water bodies. The nutrient level in many streams, especially in the Western United States, is naturally low. In fresh waters, the limiting nutrient is assumed to be phosphorus. However, nitrogen may be the limiting factor in some cases, such as in summer when dissolved nitrogen is low. In water in which phosphorus is the limiting factor, the addition of phosphorus may create a temporary increase in biomass. The impact of added phosphorus is highly dependent on the nutrient status of the receiving body of water. The phosphorus contained in the long-term retardants is not likely to present a hazard to aquatic systems, as the phosphorus is retained by the soil in a nonleachable form. Therefore, if the limiting factor is phosphorus, the risk of eutrophication is very small. The impact of nitrogen loading is more difficult to determine; site-specific nutrient analysis would be required.

In all scenarios, it was found that soil type, slope, stream size, temperature, and pH have a greater impact on the potential for adverse effects than does the total quantity of a long-term retardant applied to a watershed.

In general, the following are some specific factors that increase the potential for adverse impacts to streams:

- high clay content
- low organic matter content
- steep slopes
- shallow soil
- low permeability of soil
- high pH in receiving body of water
- small stream or low flow
- sensitive fish species

Uncertainties in the Analysis

Major areas of uncertainty in the ecological risk assessment include the following:

- The assumption that 25 percent of an animal's diet is unburned vegetation, seeds, berries, or insects that are contaminated with fire suppression chemicals with no degradation.
- Model ecosystems were created and assessed, with standard assumptions for all characteristics, including species present, topography, soils, climate, and hydrology

A sensitivity analysis was conducted to evaluate the influence of some of the assumed parameters on the model output. This evaluation showed that:

- The runoff analysis was highly sensitive to changes in the estimated K_{oc} for the formulations,
- The SCS runoff curve number had a great influence on surface runoff and erosion, and
- Assumptions about porosity, field capacity, and wilting point were also important parameters in the analysis.

Toxicity, health, and safety of wildland foams

Robert J. Sabol
STILLMEADOW, Inc., 12852 Park One Drive, Sugar Land, Texas 77478

Abstract

The paper includes an overview of the history of mammalian testing and specifically how this type of testing was adapted to the needs of the U.S. Forest Service. Current testing requirements are reviewed and the estimated cost of the evaluation of a sample in the primary areas of acute toxicology testing are presented. A consideration of possible future testing requirements in the areas of inhalation, skin sensitization, and in vitro *options are also explored.*

Résumé

Le rapport fournit un exposé chronologique des essais menés sur les mammifères et précise en quoi ces essais sont adaptés aux besoins du Service des forêts américain. On passe en revue les exigences actuelles d'essai et l'on fournit une estimation des coûts associés à l'évaluation d'un échantillon dans le cadre d'essais de toxicité aiguë. On y explore par ailleurs les exigences qui pourraient être adoptées dans l'avenir pour les essais d'inhalation et de sensibilisation cutanée ainsi que pour les expériences menées en milieu artificiel.

The objective of this presentation is to give an overview of the toxicity testing of wildland fire-fighting foams. This will include the history of toxicity screening, and in particular, that of the US Forest Service, the present testing requirements and study design. We will look into future considerations in the area of toxicity screening.

Brief History of Toxicity Testing

1. 1940's: During this period of time, a great variety of materials were being put on the market, and there was no mechanism for effective evaluation of materials to which humans were being exposed. It was during this time that more formal screening was developed.

   During the 1940's Draize, et al., (Draize, J.H., Woodard, G. and Calvary, H.O.: Methods for the study of irritation and toxicity of substances applied topically to the skin and mucous membranes. J. Phar, Exp. Ther., 82: 377, 1944.) formulated a scoring system for the classification of the potential effect of a test substance on both eye and skin irritation. This system was designed as a comparison of one material to another. His scoring system is used in both eye and skin irritation studies. The term "Draize test" is a commonly used term for both the eye and skin irritation screening studies. They are the accepted studies for the USEPA.

2. 1950's: More companies got on the bandwagon and began to screen their products for efficacy and safety. Independent laboratories began operating to perform these tests. The Environmental Protection Agency of the government began drafting guidelines for testing. Today there are sets of guidelines for pesticides and for chemicals other than pesticides, although the tests themselves are very similar.

3. 1960's: Mass product screening with little adherence to any standard tests and little federal guidance or guidelines. Many procedures and protocols were being developed. Testing became much more commonplace. Groups in different disciplines began to set goals and objectives and share information.

4. 1970's: The federal government began to get more involved with all aspects of product registration and started inspecting facilities to evaluate both services and integrity. They found a lot of questionable data and were not able to document a lot of the scientific data submitted to them for review. As a result of the early 1970's lack of organization, the USEPA began issuing revised guidelines for study design and requirements for product registration under their control. In 1978 major guidelines for the conduct of non-human studies were issued by the USEPA. These are known as the Good Laboratory Practices (GLP's). The GLP's have had a major impact on protocols, study conduct, reporting, and a detailed data trail for information pertaining to the conduct of product safety studies.

5. 1980's: The study screening and registration process remained primarily the same, but the full impact and interpretation of the GLP's began to take more control of laboratory work. The position and responsibilities of management and scientific personnel were better defined, and the role of Quality Assurance was enhanced.

6. 1982: Prior to 1982, the Forest Service had no formal toxicity screening regulations for the control of the chemicals used by the wildland firefighting personnel. The US EPA control did not affect the Forest Service products since the Forest Service was a separate branch of the government and therefore controlled heir own operations. In 1982 the US EPA required the following acute (one time administration) testing of most of the formulations they review.

   The six studies were based on the predicted routes of human exposure. With an acute screening process, one was able to relate the safety of products relative to one another. The test animals selected for the different tests was thought to be more sensitive than the human, thereby adding another safety factor to dose selection.

   In 1982 the US Forest Service determined that it was appropriate that the toxicity testing required should follow EPA Guidelines because they were the most stringent agency tests generally approved. Other agencies (such as DOT, CPSC, and FDA) had requirements that did not fit the needs of the US Forest Service.

   The US Forest Service selected the acute rat oral toxicity, acute rabbit dermal toxicity, acute rabbit eye irritation, and acute rabbit skin irritation as a necessary screening package for all products that they might eventually approve. The acute rat inhalation toxicity and guinea pig skin sensitization study were not included in the screening battery at that time because their relevance to Forest Service product usage was yet to be determined. The cost of these additional studies was significantly higher than the four tests selected and the US Forest Service wanted to encourage the introduction of new products with minimal financial impact on their producers.

7. 1990's: Toxicity testing in the 90's continues on. The major changes in current studies have to do with detailed record keeping, protocol design, manufacturing processing, as interpreted by the EPA. Accurate training records of personnel are very important and should be continually updated.

Present Testing Requirements of the US Forest Service

The US National Forest Service has selected four studies to be used as a screen for testing compounds which they are considering for purchasing and use:

Types of Studies:

1. Acute Oral Toxicity Study in Rats
2. Acute Dermal Toxicity Study in Rabbits
3. Acute Eye Irritation Study in Rabbits
4. Acute Skin Irritation Study in Rabbits

Prior to toxicity testing, samples submitted to the US Forest Service from manufacturers go through internal agency analyses including metal corrosion tests. Once their internal tests are completed and a product passes their requirements, the product is then submitted for toxicity evaluation as a means to test their effect on mammalian systems. The test are acute (single treatment; usually at a high level) and last for a few days or a couple of weeks.

Testing of US National Forest Service Material

1. All testing is done "blind". Materials received by STILLMEADOW, Inc. are labeled with no identification. Samples are labeled, for example:
   a. 94-HS-1
   b. 94-HS-2
   c. 94-HS-3
2. Studies are conducted with the four standard generic protocols approved by the National Forest Service. These protocols are similar to USEPA accepted standards.
3. Results of the four studies conducted on each material are submitted along with a summary sheet to the National Forest Service.
4. Study costs are invoiced directly to the manufacturer.
5. The unused test material is returned to the US Forest Service.
6. We usually test a concentrate and a diluted (projected use sample) of each test material.

Protocol Design

1. All studies are performed using approved protocols (too lengthy to be included in this report and varying from 8 to 13 or more pages). The previous table summarizes each of the tests and gives a rough idea of the cost of each test.
2. The species selected for each study is based on the selection of an animal that is generally considered more sensitive than the human for this particular test and/or there is a great deal of historic data for comparison of results.
3. The number of animals allows for biological variations and minimal numbers for any statistical analysis which may be required.
4. The limit dose for the rat oral and rabbit dermal is considered the `safe' and generally accepted treatment (with safety factors built in) where it is considered acceptable for human exposure. If significant mortality occurs at the limit test in the rat oral or rabbit dermal toxicity tests, then additional levels will be treated to assess the toxicity potential within different ranges of safety. Product labels should ultimately reflect these results.
5. The eye irritation and skin irritation tests look for the irritation of the product in their particular areas of exposure and are evaluated accordingly. The length of the study is based upon the degree of the reaction and the reversibility of symptoms that may occur after treatment.
6. The cost for these tests vary widely between contract laboratories, but these costs reflect STILLMEADOW, Inc.'s present charges for these tests.

Results - Classification of Test Materials

The summary tables below give the guideline for the determining of the labeling for products. When one reads a product label, one should be able to correlate the signal words (Caution, Warning, and Danger) to the results of the product testing. The label reflects the most severe rating of all of the tests performed.

To date all test material tested for the US Forest Service have had an oral LD50 in rats of >500 mg/kg (Classification III) and a rabbit dermal LD50 of >2000 mg/kg. The individual results of each product are not known since each product is tested "blind".

Future Considerations

The inhalation and guinea pig skin sensitization studies have not been routinely a part of he Forest Service screening process. The table below summarizes these types of studies. If these studies were added the screening process, one would need to determine the human risk which might occur after repeated exposure (Guinea Pig Sensitization) or the effect of burning foams as to whether they, in combination with the smoke, become more toxic than the forest smoke alone. I think that the most critical of these two studies would be that of inhalation exposure and should be considered as a required test in the future.

"*In vitro*" is still under review. Latest word is that the USEPA may take 4 - 6 years to make a firm decision. STILLMEADOW, Inc. is certified to run *in vitro* studies by two prominent firms in the business.

In recent years, a great deal of discussion has concerned the use of *in vitro* testing rather than the use of laboratory animals in some instances. *In vitro* roughly means "in glass". These are tests performed in analytical or microbiological laboratories where cell tissues rather than animals are used. The major problem at this time is that there isn't sufficient background or historical data to correlate with these tests to the traditional animal tests. The area where *in vitro* testing might make some inroads as a screening tool would be in the area of irritation (both skin and eye). The best estimate is that the USEPA may be 5 or 6 years away from accepting this data as reliable and useful. Will *in vitro* testing replace animal testing? The vast majority of researchers do not believe it will, but may use it along with animal testing as a screening tool or to complement animal testing. I feel strongly that animal (mammalian) testing will never be replaced by *in vitro* testing. When we the humans become exposed to all types of products, I feel we should use all types of product safety evaluation before we become exposed to it in field application.

Summary and Conclusions

A brief overview of human, health, and safety has been presented. I believe that it is imperative that we continue to evaluate all new and reformulated products so that we may be able to use them and be aware of the precautions we must take with their use.

Study Title	Animal Species	No. of Animals	Limit Dose	Study Length	Additional Testing	Approx. Cost**
Oral Toxicity	Rat	10	~5000 mg/kg*	≥14 days	~500 mg/kg	$ 550/level
Dermal Toxicity	Rabbit	10	~2000 mg/kg	≥14 days	~200 mg/kg	$1075/level
Eye Irritation	Rabbit	9	Liquid: 0.1 ml/eye Solid: 100 mg/eye or 0.1 ml by vol/eye	≥72 hours ≤21 days	NA	$ 875 +
Skin Irritation	Rabbit	6	Liquid: 0.5 ml Solid: 500 mg	≥72 hours ≤21 days	NA	$725 +

All studies are performed under USEPA GLP Guidelines
* - Equivalent 200 lb human exposure is 1 lb or 454 grams (16 oz or 2 cups).
** - STILLMEADOW, Inc. cost (1994).

EPA Toxicity Classification	Signal Word	Rat Oral Toxicity	Rabbit Dermal Toxicity	Rabbit Eye Irritation
I	Danger	LD_{50} ≤50 mg/kg	LD_{50} ≤200 mg/kg	Corrosive or corneal involvement or irritation for ≥21 days
II	Warning	LD_{50} >50 -≤500 mg/kg	LD_{50} >200 -≤2000 mg/kg	Corneal involvement or irritation clearing in 8 -21 days
III	Caution	LD_{50} >500 -≤5000 mg/kg	LD_{50} >2000 -≤5000 mg/kg	Corneal involvement or irritation clearing in 7 days or less
IV	Caution	LD_{50} >500 -≤5000 mg/kg	LD_{50} >5000 mg/kg	Minimal effects clearing in less than 24 hours

EPA Toxicity Classification	Signal Word	Rabbit Derman Irritation - Toxicity Categories	Rabbit Derman Irritation - Primary Irritation Index (PII)*	Rabbit Derman Irritation - Maximum Average Irritation Score**
I	Danger	Corrosive	5.1 - 8.0	Corrosive = 7.1-8.0 Severe Irritant = 5.1 - 7.0
II	Warning	Severe irritation at 72 hours (erythema or edema)	2.0 - 5.0	Moderate Irritant = 3.1 -5.0
III	Caution	Moderate irritation at 72 hours (moderate erythema)	0.0 - 1.9	Slight Irritant = 0.5 - 3.0
IV	Caution	Mild or slight irritation at 72 hours (no irritation or slight erythema)	0.0	Practically not an Irritant = 0.0 - 0.4

* - Primary Irritation Index is calculated using only the 1, 24, 48, and 72 hour observations. Mean erythema and edema for each animal are used to calculate PII (Current EPA scoring system).
** - Rabbit Dermal Irritation - Maximum Average Irritation Score derived from the time period with the highest average irritation score.

Study Title	Species of Animal	Number of Animals	Limit Dose	Length of Study	Addi-tional Testing	Approximate Cost	Other*
Inhalation Toxicity	Rat	10	~2.0 g/L	≥14 days	~500 mg/L	$ 3900/ level	Nose-only or Full body
Skin Sensitization	Guinea Pig	10	Pretest Screen to determine: 1. Maximum dose that is not excessively irritating - to be used for 3 induction treatments 2. Maximum non-irritating dose - to be used for challenge treatment	≥35 days	lower dose	$ 3600/ sample	

*Other considerations: what form of material would be tested; simulate smoke, heat and vaporization of material.

Environmental implications of fire-fighting chemicals: A summary of current research by the National Biological Survey

Susan E. Finger
Midwest Science Center, 4200 New Haven Road, Columbia, MO 65201

Abstract

Fire retardants and suppressants are used extensively for suppression and control of range and forest fires. Each year, fire control agencies utilize millions of gallons of these mixtures on a wide array of ecosystems. These chemicals are commonly applied to environmentally sensitive areas that may contain endangered, threatened, or economically significant plant and animal species. Relatively little information is available on the toxicity of these chemicals to aquatic and terrestrial life. Even less information is available on the community and ecosystem level effects. The National Biological Survey, a newly formed research agency within the Department of Interior, is conducting studies to provide sound scientific and legally defensible information on the potential effects of these chemicals to aquatic and terrestrial resources. Specific objectives of these studies include (1) to evaluate the acute toxicity of a group of these chemicals to aquatic organisms under laboratory conditions, (2) to evaluate the toxicity of a group of these chemicals to terrestrial organisms under controlled conditions, and (3) to determine the ecological significance of application of these chemicals. Results from these studies will be summarized in presentations by scientists from the National Biological Survey.

Résumé

Les produits d'ignifugation et d'extinction sont largement utilisés pour éteindre ou maîtriser les feux de prairies et de forêts. Chaque année, les organismes de lutte contre l'incendie déversent des millions de gallons de ces préparations sur une grande variété d'écosystèmes. Ces produits chimiques sont utilisés couramment sur des milieux sensibles qui peuvent abriter des espèces animales et végétales menacées ou en voie de disparition ou qui constituent des ressources importantes sur le plan économique. On dispose de peu d'information sur les effets toxiques de ces produits chimiques sur les formes de vie aquatique et terrestre. On possède encore moins de données sur les effets qu'ils peuvent avoir sur les populations et les écosystèmes. Le National Biological Survey, un organisme de recherche récemment mis sur pied au sein du Department of Interior (ministère de l'Intérieur), a entrepris des études afin de recueillir des données scientifiques solides et légalement défendables sur les effets potentiels de ces produits chimiques sur les ressources aquatiques et terrestres. Plus précisément, ces études visent à 1) évaluer les effets toxiques aigus d'un groupe de ces produits sur les organismes aquatiques dans des conditions expérimentales; 2) évaluer les effets toxiques d'un groupe de ces produits sur les organismes terrestres dans des conditions contrôlées; et 3) déterminer les incidences écologiques que peut avoir l'épandage de ces produits chimiques. Les chercheurs du National Biological Survey présenteront brièvement les résultats de ces études dans le cadre d'une série d'exposés.

Introduction

Fire retardants and suppressants are used extensively in the United States for suppression and control of range and forest fires. Each year, fire control agencies utilize millions of gallons of these mixtures on a wide array of ecosystems. These chemicals are often applied in environmentally sensitive areas which may contain endangered, threatened, or economically significant plant and animal species. Relatively little information is available on the toxicity of these chemicals to aquatic and terrestrial life; less information is available concerning impacts at the community and ecosystem level.

The extensively used ammonium compounds - essentially dry or liquid fertilizer formulations - have long been considered to have minimal toxicological or ecological impact. Research is mostly confined to effects on aquatic organisms. Several authors have reported on the toxicity of the active ammonium salts found in most fire retardants (Pramanik and Sarkar 1987, Sheehan and Lewis 1987, Ram and Sathyanesan 1986, Singh et. al. 1985). Limited studies concerning nitrate poisoning to aquatic animals (Johnson and Sanders 1977) from fire retardant formulations have been conducted. Even less information is available on foam products. Although the risk associated with fire fighting chemicals has generally been accepted as minimal, extensive fish kills have been documented after accidental drops of chemicals directly in a stream. For example, many trout were killed in the Little Firehole River during the major 1988 fire in Yellowstone National Park (Minshall and Brock 1991). Specific concerns over potential fire chemical effects on endangered and threatened fish has underscored the need to define "safe" distances for chemical application in areas supporting aquatic resources.

Based upon the few reported studies concerning fire retardant chemicals and formulations, it was impossible to ascertain their impact without additional research. Moreover, the effects of repeated applications on aquatic and terrestrial ecosystems was unknown. Therefore, researchers from the National Biological Survey in cooperation with individuals from the Interior Fire Coordinating Committee (Interagency Fire Center-Boise, ID) formulated studies to address the toxicity of these chemicals to aquatic and terrestrial organisms in a comprehensive manner. Research was to include standard laboratory testing of select chemicals followed by two years of field studies to evaluate ecological effects resulting from fire chemical application. It was agreed that these studies would be conducted in a prairie wetland habitat in North Dakota and in an area in the Great Basin region of northern Nevada. Terrestrial and aquatic laboratory studies were initiated in 1992 with field studies to be conducted in 1993 (North Dakota) and 1994 (Nevada).

Research in these areas will provide valuable information to fire managers and policy developers to insure that sound decisions are made concerning fire-fighting activities on private, state, and federal lands.

Current Research Summary

In 1992, laboratory studies were initiated at the Midwest Science Center (S.Hamilton, this symposium) and the Patuxent Ecological Science Center (N.Vyas and E.Hill, this symposium) to determine the toxicity of five commonly used fire-fighting chemicals (Fire-Trol GTS-R, Phos-Chek D75-F, Fire-Trol LCG-R, Silv-Ex, and Phos-Chek WD-881) to two fish, two aquatic invertebrates, an algae, three birds, a mammal, and a terrestrial invertebrate. In general, all chemicals were of comparatively low order of toxicity to terrestrial species. For all test species, the LD50 exceeded the limit criteria for significant acute toxicity. In contrast, tests with aquatic organisms indicated the two foam suppressants (Silv-Ex and Phos-Chek WD-881) were similar in toxicity and were significantly more toxic than were the three non-foam chemicals. Water quality did not modify toxicity in a consistent manner for all species. In general, the egg life stage of both fish species was more tolerant of chemical exposure than other life stages; swim-up stage was most sensitive for all chemicals. Such results imply that accidental introduction of these chemicals into an aquatic system during the salmonid swim-up period could cause significant mortality and be catastrophic to a local population, especially if that population were threatened or endangered.

Based on information from laboratory toxicity tests, field studies were initiated to evaluate the response of the aquatic, terrestrial, and vegetative communities associated with a prairie wetland habitat to several fire-fighting chemicals in May 1993. The vegetative and terrestrial components were exposed to the retardant, Phos-Chek G75-F, and a foam suppressant, Silv-Ex. In the aquatic ecosystem, two foam suppressants, Silv-Ex and Phos-Chek WD-881, were compared. The purpose of this phase of the study was not only to provide information on aquatic, terrestrial, and vegetative responses to fire-fighting chemicals in a prairie wetland environment, but also to develop field assessment methods that could be used to determine the effects of these chemicals in a more complex ecological system such as the Great Basin area of Nevada, a study planned and implemented during the summer of 1994.

Results from the vegetative study on a mixed-grass prairie site in North Dakota suggested that fire chemical application may cause changes in growth, including biomass accumulation, and changes in species diversity (D.Larson, this symposium). Fire retardants such as Phos-Chek are primarily fertilizers, and as such stimulate growth. Although the fertilization effect from Phos-Chek produced a pronounced increase in herbaceous biomass, species diversity was depressed. This likely resulted from the strong response of the exotic grass, Poa pratensis, to fertilization, thus allowing it to outcompete other species. Foams such as Silv-Ex did not effect growth, but did depress species diversity.

Implications of this research depend on the objectives of the manager. If the objective is to halt an uncontrolled fire, subtle changes caused by Silv-Ex and Phos-Chek may be of little importance. On the other hand, if the objective is to aid in the control of prescribed burns, the potential effect on species diversity should be considered. In particular, if the control of exotic, robust grasses such as *Poa pratensis* is important, these results suggest that use of these chemicals should be minimized or avoided.

Terrestrial field studies indicated no measurable effects on small mammal populations (N.Vyas and E.Hill, this symposium). Although this is supported by laboratory information, which suggests a relatively low level of acute toxicity for these chemicals, field results are confounded by the extremely low population densities that likely resulted from the unusually cold and wet weather in North Dakota during summer 1993. Analysis of ant population data also revealed no dose-related effect.

Overall, interpretation of this information for management purposes must be guarded due to the unseasonal events of the 1993 summer. However, development of methods during this study greatly benefitted the experimental design and method selection for the 1994 field season in the Great Basin.

Of the two foams tested in the aquatic environment, Silv-Ex was more toxic than was Phos-Chek WD-881 (B.Poulton and S.Finger, this symposium). Survival of water boatmen (*Cenocorixa* sp.) was reduced dramatically by exposure to 6 mg/L Silv-Ex, the exposure representing the lowest observable effect concentration for daphnids under laboratory conditions. These invertebrates are dependent on surface tension for mobility. It is likely that the effect of the surfactant associated with Silv-Ex reduced the surface tension and resulted in the observed mortality. The slightly lower concentration of Phos-Chek WD-881 (4.7 mg/L) resulted in no mortality to the water boatmen. However, organisms showed impaired movement that suggested a sublethal response related to chemical exposure. Sensitivity of fathead minnows to Silv-Ex was similar between field and laboratory exposures. The most dramatic decrease in survival occurred during the first 24 hours. No dose-related fluctuations in pH, conductivity, oxygen, phosphates, sulfates, chlorides, or chlorophyll *a* were measured during the study. Ammonia never exceeded concentrations known to be acutely toxic to fish and aquatic invertebrates. In addition, no effects on the macroinvertebrate community resulting from either the Silv-Ex or Phos-Chek foams were evident after 96 hours.

A safety factor of 100 is commonly applied to toxicity data to estimate a maximum acceptable toxicant concentration for the protection of aquatic organisms (Rand and Petrocelli 1985). Based on information derived from this field exposure with fathead minnows, a spill of 1% Silv-Ex into a closed aquatic system such as a pond or terminal wetland would require a 41,600-fold dilution. Thus, in a one acre pond with an average depth of 10 feet, use of a safety factor of 100 would estimate that about 78 gallons of 1% Silv-Ex spilled directly into the pond would represent no threat to aquatic organisms. Inclusion of a safety factor is essential to provide protection for all trophic levels in an ecosystem. Although aquatic invertebrates do not represent an economical or recreational resource, they represent an essential food source for most fish and are thus, essential to the integrity of the ecosystem. Caution should be exercised when applying foam suppressant chemicals near aquatic ecosystems to reduce the potential for accidental spillage or incidental overspray of the chemicals during application.

Most recently, field studies have been completed in the Great Basin area of northern Nevada (summer 1994). Effects of Phos-Chek D-75F and Silv-Ex were studied. Analysis of these data is underway. Preliminary information suggests that the chemicals may have minimal effects on the terrestrial community. However, in-stream exposures with Lahontan cutthroat and rainbow trout confirm that, similar to laboratory testing, Silv-Ex is more toxic than is Phos-Chek D-75F. Research to evaluate the rate of degradation and potential risks associated with mobilization of these chemicals from the terrestrial environment into the aquatic environment is also in progress.

Preliminary results from this extensive research effort confirm that the current policy of exercising caution when applying fire chemicals near streams with threatened or endangered species is appropriate. For protection of fish populations, the time of application as it coincides with fish development will be a decisive factor in estimating potential effects. For desired vegetation responses, objectives of the land manager may be most important. Overall, these combined field and laboratory studies will result in information that will clearly define effects expected from chemical application. In addition, this research should provide the capability to delineate, for aquatic systems, the "safe" zones required to protect fish and wildlife resources from chemical-induced mortality. Most importantly, toxicity information from these studies must be combined with existing knowledge of ecological effects of fire on terrestrial and aquatic systems to insure that the best possible management alternative is exercised.

Literature Cited

Johnson, W.W., and H.O. Sanders. 1977. Chemical forest fire retardants: Acute toxicity to five freshwater fishes and a scud. Technical U.S. Department of Interior, Fish and Wildlife Service, Number 91.

Minshall, G.W. and J.T.Brock. 1991. Observed and anticipated effects of forest fire on Yellowstone stream ecosystems. *In* R.B. Keiter and M.S. Boyce (eds.), Greater Yellowstone Ecosystem: Redefining America's Wilderness Heritage. Yale University Press, New Haven, CT.

Pramanik, A., and S.K. Sarkar. 1987. Comparative study of the sensitivity of egg spawn and fry of cyprinus - carpio exposed to ammonium sulfate at different temperature. Geobios 14:229-230.

Ram, R.N., and A.G. Sathyanesan. 1986. Inclusion bodies formation and degeneration of the oocytes in the fish channel-punctatus in response to ammonium sulfate treatment. Ecotoxicology and Environmental Safety 11:272-276.

Rand, G.M., and S.R. Petrocelli. 1985. Fundamentals of Aquatic Toxicology. Hemisphere Publishing, Washington, D.C. 666 pages.

Sheehan, R.J., and W.M. Lewis. 1987. Influence of pH and ammonia salts on ammonia toxicity and water balance in young channel catfish. Transactions of the American Fisheries Society 115:891-899.

Singh, H.R., Dobriyal, A.K., and R.C. Pokhriyal. 1985. Toxicity of diammonium phosphate of the hill stream minor carp barilius benedelisis. Uhar Pradesh Journal of Zoology 5:89-92.

Effects of fire suppressant foam on vegetation in North Dakota Prairie

Diane L. Larson and Wesley E. Newton
Northern Prairie Science Center, Jamestown, ND

Abstract

During spring 1993, studies were conducted to evaluate the effects of a fire retardant foam, Silv-Ex, on the terrestrial vegetation bordering a wetland ecosystem. A grid, of 30 blocks of 0.4 hectare each, was delineated in a quarter section of unbroken prairie sod at Woodworth Field Station, Stutsman County, North Dakota. Each of four treatments was assigned randomly to six 10 m x 10 m blocks (one centered within each 0.4 hectare block) within the grid. Treatments included (1) Silv-Ex application, (2) burn plus Silv-Ex, (3) burn only, and (4) no manipulation. A 0.5% Silv-Ex solution was applied at the rate of 50 gallons per 10 m x 10 m plot, resulting in approximately 0.25 gallons of Silv-Ex on each plot. Expansion was estimated to be 1:10. We examined variation among treatments in growth rate, biomass accumulation, herbivory and number of plant species per plot.

Silv-Ex application had no effect on biomass accumulation, whether or not the plot had been burned. The foam did depress the number of species per plot; this effect was enhanced by burning. Bluegrass growth rate was not affected by Silv-Ex. Herbivory, although slight, varied among treatments. In the absence of fire, both broad-leaved and graminoid species experienced considerable browning after foam application.

Résumé

Au printemps 1993, des études ont été entreprise pour évaluer les effets d'une mousse ignifuge, Silv-Ex, sur la végétation terrestre qui borde un écosystème de terres humides. On a tracé un quadrillage, formé de trente parcelles de 0,4 hectare, dans une zone gazonnée ininterrompue à la Woodworth Field Station, dans le comté de Strutsman, dans le Dakota-Nord. Pour chacun des quatre traitements, on a attribué au hasard six zones de 10 sur 10 mètres (dont l'une est située au centre de chaque parcelle de 0,4 hectare). Les traitements consistaient en 1) application de Silv-Ex, 2) application de Silv-Ex et brûlage de la végétation, 3) brûlage seulement et 4) aucune manipulation. Une solution de Silv-Ex à 0,5 pour cent à été appliquée à raison de 50 gallons par 10 mètres carrés, ce qui représentait environ 0,25 gallon par parcelle. Le taux de foisonnement a été estimé à 1:10. Nous avons ensuite examiné l'effet de chaque traitement sur le taux de croissance, l'accumulation de la biomasse, ainsi que sur les herbes et le nombre d'espèces végétales dans chaque parcelle.

L'application de Silv-Ex n'a eu aucun effet sur l'accumulation de la biomasse, que la parcelle ait été brûlée ou non. La mousse a causé une réduction du nombre d'espèces par parcelle, effet qui a été accentué par le brûlage. Le taux de croissance du pâturin n'a pas été ralenti par le produit. Bien que les différences observées étaient peu marquées, les herbes n'ont pas réagi de la même façon aux différents traitements. En l'absence de brûlage, la mousse a provoqué un brunissement important tant chez les herbes à feuilles larges que chez les graminées.

Introduction

Fire suppressant foams are used in wildland fire suppression and in prescribed burns for habitat management. Despite their relatively widespread use, little is known about potential effects of foams on terrestrial and aquatic ecosystems. The purpose of this study was to examine experimentally the effect of foam application on vegetation. We studied the effects alone and in combination with fire. In addition, we examined the effects of foam and fire on insect herbivory, which provides a link to higher levels in the food chain. A simple ecosystem, represented by a mixed-grass prairie, was chosen for the first year's work, so that general patterns could be identified. Subsequent studies will be done in more complex habitat, where fire suppressant foams are more often applied.

Our objectives were (1) to estimate effects of fire suppressant foam application on growth and species diversity of burned and unburned prairie vegetation, and (2) to assess the response of herbivorous insects, in terms of number of insects and their effects on plants, to burning and application of fire suppressant foam to their host plants.

Description of study site

The 1993 study was conducted at the Woodworth Station, a research facility of the Northern Prairie Science Center, Jamestown, N.D. The station is located in T142N, R68W, on the Missouri Coteau physiographic region of central North Dakota. The region is characterized by thick deposits of glacial till with knob-and-kettle topography. The station was established in 1963 for the study of effects of land use practices on wildlife. Records of land use practices throughout the station have been maintained since its establishment. Prior to 1960, our study area was sporadically grazed and hayed. The 65-ha field containing the study site has never been plowed. Biologists burned the field in 1969, 1970, 1971, 1972, 1976, 1979, 1981, and 1990; it has not been grazed since 1974. Currently, vegetation in the study area is dominated by *Poa pratensis*, an exotic cool-season grass. Other grass species found during previous studies on the site include *Stipa viridula, S. comata, Agropyron repens, Muhlenbergia cuspidata*, and *Bromus inermis. Rosa arkansana, Elaeagnus commutata*, and *Symphoricarpos occidentalis* are common woody plants.

Methods

We delineated a grid of 30 0.4-ha blocks in the study field (Figure 1). Each block was separated from adjacent blocks by a mowed, 5-m-wide fire break. Four treatments [burning (B), foam application (F), burning and foam application (BF), and no manipulation (C)] were each assigned at random to six blocks. We established a 10 m x 10 m plot in the center of each of the 24 blocks (Figure 1) for vegetation sampling. The remaining six blocks were used for a separate study.

Inside each 10 m x 10 m vegetation plot we randomly selected five 1-m^2 permanent vegetation subplots and four 0.25-m^2 biomass subplots (Figure 1). Prior to treatment, we counted stems of the woody species, *Symphoricarpos occidentalis* and *Rosa arkansana*, counted the total number of plant species, and measured litter depth in each permanent vegetation subplot. We made all pretreatment measurements during 17-28 May 1993.

On 1 June B and BF blocks were burned with a drip torch to ignite the down-wind side. As the back fire progressed across the block, the flanks were ignited. As soon as these fires had blackened enough of the block to form a safe fire break, a head fire was started to complete the burn. All fires were allowed to burn to completion.

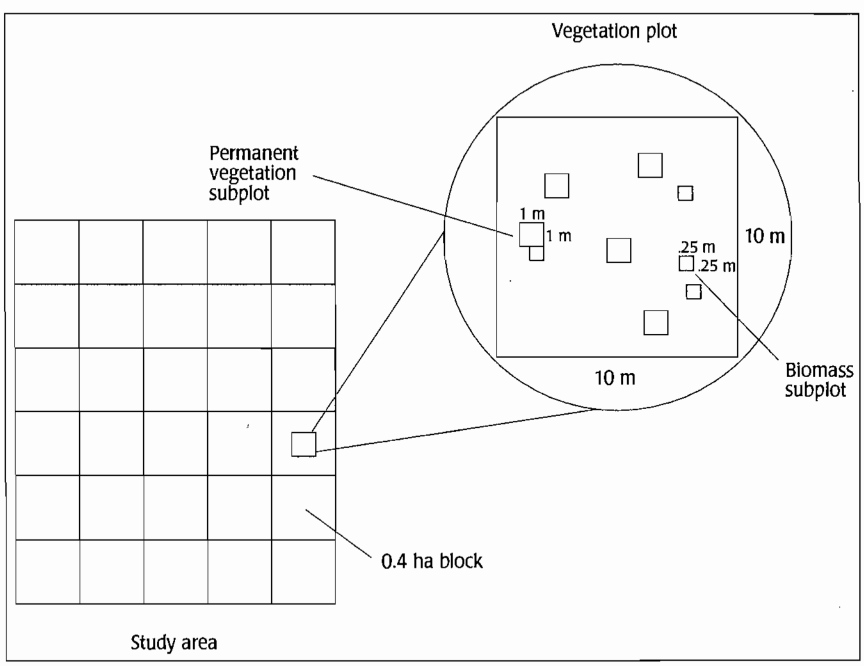


Figure 1. Study area, showing 0.4-ha blocks, 10 m x 10 m vegetation plots, and randomly located 1-m2 permanent vegetation subplots and 0.25 m x 0.25 m biomass plots. Treatments were assigned at random, six blocks per treatment.

On 10 June we applied Silv-Ex in 0.5%-solution maintained by a proportioner to F and BF blocks. The rate of application was approximately 189 liters per 10 m x 10 m plot, resulting in approximately 1 liter of Silv-Ex on each vegetation plot. Only the vegetation plots were treated on BF blocks. Although the entire 0.4-ha F blocks were treated, the smaller vegetation plots were treated first and at a higher rate than the remaining areas because a more even coverage was desired. The foam was applied with a 3.66-m boom mounted on bicycle tires. Nozzles mounted on the boom every 30 cm each produced approximately a 1:10 expansion. The boom was pushed by two people while other personnel handled the hose between the boom and a 3785-liter pumper parked at the edge of the 0.4-ha block.

We conducted post-treatment vegetation sampling at 2-week intervals, beginning June 30 and ending August 13. Post-treatment vegetation sampling concentrated on four species: *Poa pratensis*, *Symphoricarpos occidentalis*, *Rosa arkansana*, and *Solidago rigida*. Height of *Poa pratensis* was measured at four locations on each subplot at each sampling period. For the other three species, we marked individual plants in each permanent vegetation subplot as follows: two *Symphoricarpos occidentalis*, two *Rosa arkansana*, and ten *Solidago rigida*. If fewer individuals were found in a subplot, we marked all found individuals. Plants were marked near the base with either blue or red flagging (*Rosa arkansana* and *Symphoricarpos occidentalis*), or numbered metal tags (*Solidago rigida*). In addition, five shoots, defined as current year's growth, were marked and followed through the three sampling periods on each *Symphoricarpos occidentalis* and *Rosa arkansana* plant.

On each of the three non-grass plants, we measured the length of two fully expanded leaves. We measured the total length and counted the number of galls, leaf miners, aphids, chewed leaves, and flowers on each of the five shoots. Galls, leaf miners, aphids, and chewed leaves were recorded on a per-leaf basis. In each permanent subplot, we counted the total number of plant species and measured litter depth at four locations. Total stems of *Symphoricarpos occidentalis*, *Rosa arkansana*, and *Solidago rigida* were also recorded in each plot at each sample period.

Two of the 0.25 m x 0.25 m biomass subplots were clipped to ground level on July 7-8 and two on September 7-10. Dead and woody vegetation was removed and discarded. Live non-woody vegetation was oven dried to constant weight and weighed.

Statistical Methods

We used analysis of variance (ANOVA) techniques in a repeated-measures type design with subsampling to assess the effects of the burn-foam treatments, time since treatment, and their interaction on all measured variables. Mean separations of significant effects in the ANOVAs were done with Fisher's protected least significant difference value (Milliken and Johnson 1984). Analyses were made in the original scale of measurement and with a log(y+1) transformation (Steel and Torrie 1980), but only results in the original scale of measurements are reported because only slight differences were observed in ANOVA results. ANOVAs were done using the General Linear Models procedure of SAS (SAS Inst. Inc. 1989). Significance was accepted at the 0.05 level.

Because vegetation plots differed significantly in number of plant species at pre-treatment, this difference was taken into account in subsequent analysis by using the change in number of species between pre- and post-treatment as the response variable. Plots were similar in all other pre-treatment measurements.

Results

Change in number of species, ratio of chewed to unchewed leaves in *Symphoricarpos occidentalis* and *Rosa arkansana*, and mean shoot length and leaf length in *Symphoricarpos occidentalis* were affected by treatment (ANOVA, $p < 0.05$). The number of plant species increased between pre- and post- treatment in all plots, but the increase was smaller in plots treated with Silv-Ex than in untreated plots (Figure 2). Burning did not influence this difference.

Because the summer of 1993 was exceptionally cool and wet, insect abundances were uniformly low at our study site (D. Larson, personal observation). However, we found evidence of an effect of Silv-Ex application on the ratio of chewed to unchewed leaves on *Symphoricarpos occidentalis* (Figure 3) and *Rosa arkansana* (Figure 4). Silv-Ex treated plants of both species experienced greater herbivory late in the season. More untreated *Rosa arkansana* leaves were chewed early in the season; herbivory on burned plants was not affected by Silv-Ex. Treated *Symphoricarpos occidentalis* experienced greater herbivory throughout the season; this effect persisted on burned plants after leaves had begun to emerge.

Silv-Ex application had little effect on overall plant growth, as evidenced by the lack of difference in biomass accumulation between treated and untreated plots, irrespective of burning (Figure 5, four weeks post-treatment; Figure 6, end of growing season). Nonetheless, growth characteristics between Silv-Ex treated and untreated *Symphoricarpos occidentalis* differed. Leaf length was greater on plants treated with Silv-Ex than on untreated plants (Figure 7), an effect that persisted through the season. However, *Symphoricarpos occidentalis* shoots did not lengthen as much on Silv-Ex treated plants as on untreated plants (Figure 8). Burning significantly enhanced shoot growth compared with all other treatments.

Discussion and management implications

Overall, Silv-Ex application had little effect on the vegetation characteristics we measured, and affected only five of 33 possible characteristics. Effects were subtle. Silv-Ex application encouraged

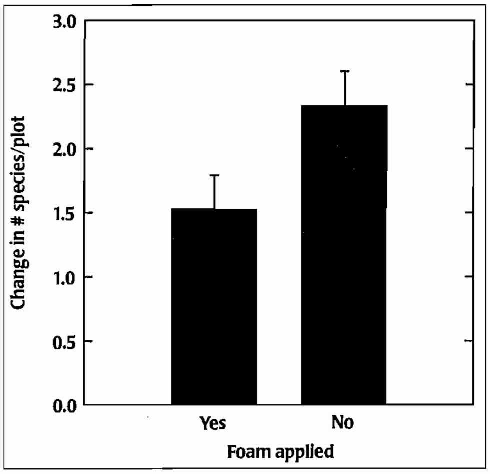


Figure 2. Change in mean number of species per plot between pre-and post-treatment, with and without Silv-Ex application. Error bar indicates one standard error of the mean.

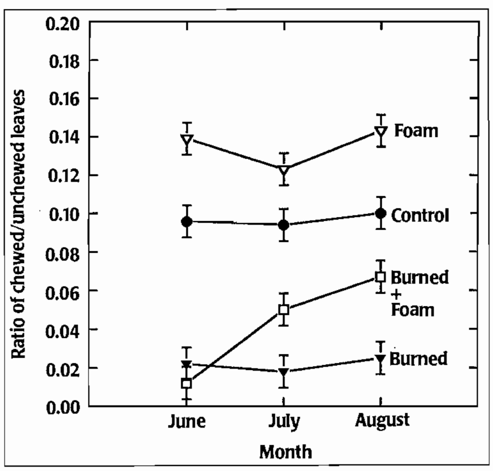


Figure 3. Ratio of chewed to unchewed leaves on *Symphoricarpos occidentalis.* Shown is the mean + one standard error of the mean.

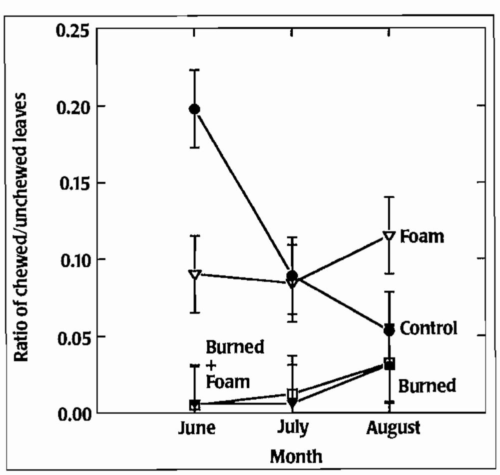


Figure 4. Ratio of chewed to unchewed leaves on Rosa arkansana. Shown is the mean + one standard error of the mean.

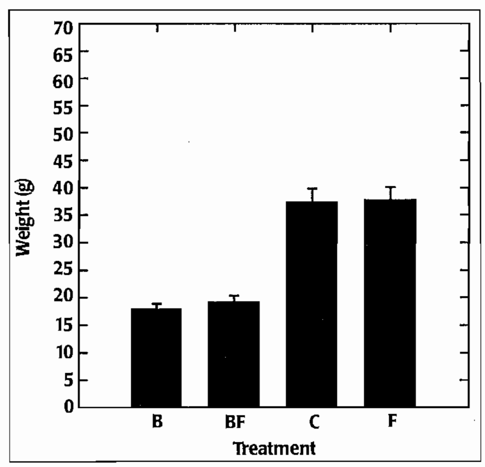


Figure 5. Mean (+ one standard error of the mean) herbaceous biomass accumulation, four weeks post-treatment.

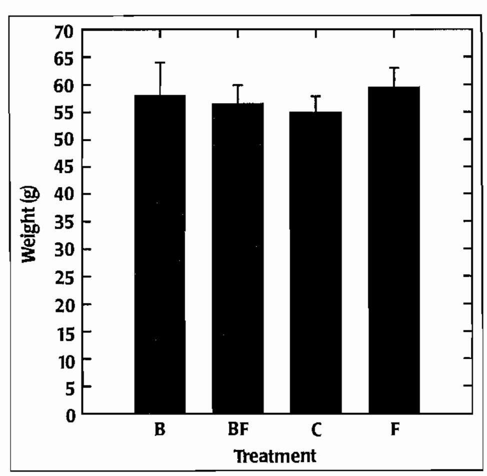


Figure 6. Mean (+ one standard error of the mean) herbaceous biomass accumulation at the end of the growing season.

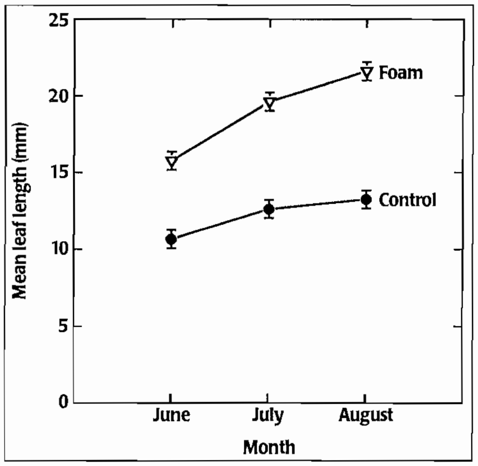


Figure 7. Mean (+ one standard error of the mean) leaf length on *Symphoricarpos occidentalis* plants treated or not treated with Silv-Ex.

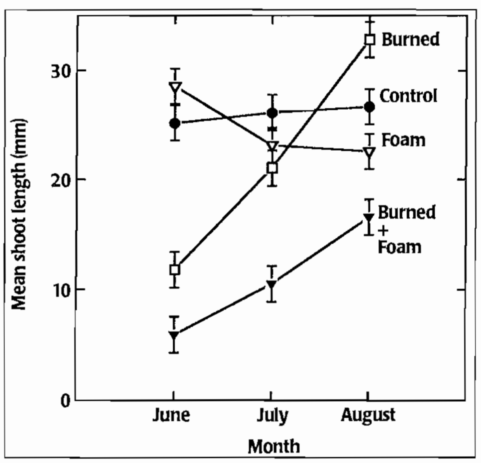


Figure 8. Mean (+ one standard error of the mean) shoot length on *Symphoricarpos occidentalis* plants treated or not treated with Silv-Ex.

herbivory, as evidenced by the proportion of chewed leaves on *Symphoricarpos occidentalis* and *Rosa arkansana* (Figures 3 and 4). It also influenced growth of leaves and shoots of *Symphoricarpos occidentalis*, resulting in longer leaves but shorter shoots (Figures 7 and 8). The significant decline of shoot length between June and July for Silv-Ex treated plants suggests either shoot damage and subsequent breakage or vertebrate herbivory. Nonetheless, herbaceous biomass accumulation was not affected by Silv-Ex (Figures 5 and 6), suggesting little effect on average plant vigor.

Of concern to land managers is the potential depression in species diversity associated with Silv-Ex application. The change in number of species per plot was significantly lower after Silv-Ex application, regardless of whether or not the plot was burned (Figure 2). The plots were dominated by *Poa pratensis*, which may have increased in response to the disturbance and crowded out other species. Further work in areas not dominated by *Poa pratensis* will help define this relation.

Implications of this research depend on the objectives of the manager. If the objective is to halt an uncontrolled fire, subtle changes caused by Silv-Ex may be of little importance. On the other hand, if the objective is to aid in the control of prescribed burns, the potential effect on species diversity should be considered.

Literature Cited

Milliken, G.A. and D.E. Johnson, 1984. Analysis of messy data, volume I: designed experiments. New York, NY: Van Nostrand Reinhold Co. 473 pp.

SAS Institute Inc., 1989. SAS/STAT user's guide. Version 6, fourth edition, volume 2. Cary, NC: SAS Institute Inc. 846 pp.

Steel, R.G.D. and J.H. Torrie, 1980. Principles and procedures of statistics, a biometrical approach, 2nd edition. New York, NY: McGraw-Hill Inc. 633 pp.

Toxicity of fire retardant chemicals and fire suppressant foams to vertebrate and invertebrate wildlife species

Nimish B. Vyas and Elwood F. Hill

Patuxent Environmental Science Center, Wildlife Toxicology Group, 1510 American Holly Drive, Laurel, Maryland 20807-4017

Abstract

Under laboratory conditions, acute single-dose oral toxicity tests (LD50) were conducted with three fire retardant chemicals (Fire-Trol GTS-R, Phos-Chek D75-F, and Fire-Trol LCG-R) and two fire suppressant foams (Silv-Ex and Phos-Chek WD-881) to determine effects on adult northern bobwhite, American kestrel, red-winged blackbird, and white-footed mouse. In addition, earthworms were exposed (LC50) for 14 days in treated soil.

In general, no toxic responses were evident. For northern bobwhite, the LD50 for all five chemicals was >2000 mg a.I./kg of body mass. American kestrels regurgitated all chemicals except Silv-ex; LD50s all exceeded 2000 mg/kg. The LD50 for red-winged blackbird was also >2000 mg/kg for all chemicals except Fire-Trol GTS-R which is currently undergoing further testing. In addition, the LD50 for white-footed mouse was >2000 mg/kg for Phos-Chek D75-F. The 14-day LC50 for earthworms was >1000 ppm for all chemicals. Therefore, we concluded that these retardants and foams do not pose an acute hazard to adult birds, mammals, or earthworms. However, ecological studies to evaluate the potential effects of these formulations on vertebrate behavior and population dynamics are in progress.

Résumé

On a mené des essais en laboratoire pour déterminer les effets toxiques aigus d'une seule dose orale (DL50) de trois produits chimiques ignifuges (Fire-Trol GTS-R, Phos-Chek D75-F et Fire-Trol LCG-R) et de deux mousses d'extinction (Silv-Ex et Phos-Chek WD-881) sur des spécimens adultes, soit des colins de Virginie, des crécerelles d'Amérique, des carouges à épaulettes et des souris à pattes blanches. On a également exposé des vers de terre (CL50) au sol traité pendant 14 jours.

En général, on n'a enregistré aucun effet toxique. Dans le cas du colin de Virginie, la DL50 pour les cinq produits était inférieure à 2000 milligrammes d'ingrédient actif par kilogramme de masse corporelle. Les crécerelles d'Amériques ont régurgité tous les produits chimiques sauf Silv-Ex, et la DL50 dépassait 2000 mg/kg dans tous les cas. Dans le cas des carouges à épaulettes, la DL50 était également supérieure à 2000 mg/kg pour tous les produits chimiques, à l'exception du Fire-Trol GTS-R qu'on soumet actuellement à des essais complémentaires. Par ailleurs, chez les souris à pattes blanches, la DL50 était de plus de 2000 mg/kg pour le Phos-Chek D75-F. Dans le cas des vers de terre exposés pendant 14 jours, la DL50 était de plus de 1000 ppm pour tous les produits. Nous pouvons donc conclure que ces produits d'ignifugation et d'extinction ne constituent pas un risque d'intoxication aiguë pour les oiseaux, les mammifères et les vers de terre adultes. On mène toutefois des études écologiques pour évaluer les effets potentiels de ces préparations sur le comportement et la dynamique des populations des vertébrés.

Introduction

Fire-fighting chemicals are frequently used to suppress or extinguish wildland fires. These chemicals are often applied in environmentally sensitive areas that may contain endangered, threatened, or economically significant plant and animal species. Relatively little is known about the toxicity of these chemicals to terrestrial organisms; less information is available concerning impacts at the community and ecosystem level. This study evaluated the toxicity of five commonly used fire-fighting chemicals to terrestrial species under laboratory conditions and then investigated the effects of these chemicals on terrestrial species in a mixed-grass prairie ecosystem. Specific objectives of this research were:

(1) to determine the toxicity of five commercially available and commonly used wildland fire retardant and foam products to specific vertebrate and invertebrate species
(2) to evaluate potential effects of fire fighting chemicals on small mammal and insect populations in a mixed-grass prairie ecosystem

(3) to develop and validate methods for the evaluation of ecological effects of fire fighting chemicals on terrestrial organisms in a more complex ecosystem during 1994 (Great Basin-Nevada)

Methods

Laboratory Studies

Acute oral, and subacute and subchronic (as indicated from results of subacute tests) dietary toxicity tests on selected representative terrestrial vertebrates and earthworms were conducted with three commonly used fire retardants (Fire-Trol GTS-R, Phos-Chek D75-F, and Fire-Trol LCG-R) and two fire suppressant foams (Silv-Ex and Phos-Chek WD-881) that were also tested for aquatic toxicity. Chemical selection was based on consultation with the Bureau of Land Management, the Interior Fire Coordination Committee and results of aquatic toxicity tests conducted by the Yankton Field Research Station. Northern bobwhite (*Colinus virginianus*), American kestrel (*Falco sparverius*), red-winged blackbird (*Agelaius phoeniceus*) and white-footed mouse (*Peromyscus leucopus*) were selected as primary vertebrate models and the earthworm (*Eisenia foetida*) as the invertebrate model.

The standardized acute oral toxicity testing was designed to determine the single-dose 24-h median lethal dosage (LD_{50}). Acute toxicity tests with Fire-Trol GTS-R, Phos-Chek D75-F, Fire-Trol LCG-R, Silv-Ex and Phos-Chek WD-881 were conducted with northern bobwhite, American kestrel, red-winged blackbird, and white-footed mouse. The chemicals were administered orally by gavage. Procedures for administering test compounds in basic acute tests followed previously described protocols (northern bobwhite: Hill and Camardese, 1984; white-footed mice: Rattner and Hoffman, 1984; American kestrels: Wiemeyer and Sparling, 1991; red-winged blackbird: Grue 1982;). Animals were carefully observed for evidence of toxicity for 24 hours and then all survivors were euthanized and critical tissues collected for chemical and biochemical analysis.

For the subacute dietary toxicity testing, chemicals were administered via feed for 8 consecutive days. Animals were observed for evidence of toxicity for the 8 days and then survivors were euthanized and critical tissues sampled for chemical and biochemical analysis. This test deviated from the standard 5-day subacute test to allow collection of blood samples from animals consuming contaminated feed and to generate information to define the acceptable interval between chemical application and small mammal population surveys in the field test.

Testing on earthworms was conducted using standardized methods as established by the European Economic Community for estimating the toxicity of chemicals to earthworms (Beyer et al., 1990). The earthworm bioassay was conducted in artificial soil consisting of 10% peat, 20% kaolin clay, 69% fine sand, and about 1% calcium carbonate. The calcium carbonate was added to adjust the pH to between 6 and 7, and water was added to give a 35% moisture content. The soil was added to one-liter glass jars. Half of the jars had the fire retardants mixed into the soil and half had the fire retardants spread on top. Surviving earthworms were counted after two weeks.

Field Study

In May 1993, studies were initiated to evaluate the response of the terrestrial communities associated with prairie wetland habitats to several fire-fighting chemicals. The terrestrial system was exposed to the retardant, Phos-Chek G75-F, and a foam suppressant, Ansul Silv-Ex. The purpose of this phase of the study was not only to provide information on terrestrial responses to fire-fighting chemicals in a wetland environment, but also to develop field assessment methods that could be used to determine the effects of these chemicals in a more complex ecological system such as the Great Basin area of Nevada, a study planned and implemented during the summer of 1994.

Twelve 1-acre (0.4 ha) plots (6 controls and 6 treated with Silv-Ex) were sampled for approximately three months. (May-August 1993). Small mammal sampling was conducted using standard capture-recapture methodology (Pollock et al. 1990). A total of 1200 small mammal live traps were checked daily for 5 consecutive days at 2 week intervals. All animals were tagged, weighed, and their reproductive status recorded.

Insect populations were monitored by sampling ant mounds. Ants from control and treated mounds were collected using adhesive tape. Ants were sampled one week prior to treatment, and immediately post-treatment and then again 2 weeks later. Three samples per mound were collected each time. Avian nestling survival data could not be collected because an unusually cool spring and early summer delayed nesting.

Description of study site

The 1993 field study was conducted at the Woodworth Station, a research facility of the Northern Prairie Science Center, Jamestown, North Dakota. The Station is located in Township 142N, Range 68W, on the Missouri Couteau physiographic region of central North Dakota. The region is characterized by thick deposits of glacial till with knob-and-kettle topography. The Station was established in 1963 as a field laboratory for the study of effects of land-use practices on wildlife. Records of land-use practices throughout the Station have been maintained since its establishment. Prior to 1960, the study area was sporadically grazed and hayed. The 65-ha field containing the study site has never been plowed. Biologists burned the field in 1969, 1970, 1971, 1972, 1976, 1979, 1981, and 1990; it has not been grazed since 1974. Currently, vegetation in the study area is dominated by *Poa pratensis*, an exotic cool-season grass. Other grass species found during previous studies on the site include *Stipa viridula*, *S. comata*, *Agropyron repens*, *Muhlenbergia cuspidata*, and *Bromus inermis*. *Rosa arkansana*, *Elaeagnus commutata*, and *Symphoricarpos occidentalis* are common woody plants.

Results and Discussion

Acute Tests

The single-dose 24-h median lethal dosage (LD_{50}) for all five chemicals to adult northern bobwhite was determined to be above the pre-determined 2000 mg (active ingredient) per kg body mass limit criteria for significant acute toxicity (Bascietto, 1985). No mortalities were observed and all animals appeared alert and active at all times post dosage (Table 1).

Initial tests of American kestrels were inconclusive because they regurgitated the chemical capsules. Further testing determined that time of dosing was the cause of regurgitation rather than the chemical substance. Kestrels at Patuxent Environmental Science Center were conditioned to being fed in the morning. Initial testing (1993) had been conducted in the morning. Kestrels and other birds of prey normally regurgitate (pellet) bones, feathers, and fur to make room for their next meal. The Patuxent Environmental Science Center kestrels were regurgitating the chemical in response to their routine morning feeding. Future testing on kestrels was conducted in the afternoon. The limit test uses one dose level of 2,000 mg (active ingredient) per kg body mass. In a series of tests, kestrels regurgitated all chemicals except Silv-Ex. This test demonstrated that the chemicals Fire-Trol GTS-R, Phos-Chek D75-F, and Fire-Trol LCG-R and Phos-Chek WD-881 induced regurgitation. Birds exposed to Silv-Ex exhibited signs of toxicity similar to those in the initial testing including periods of stupor and lack of coordination. Since no mortalities were observed during the 24-h observation and Silv-Ex was not regurgitated, the LD_{50} for Silv-Ex was determined to be greater than 2,000 mg (active ingredient) per kg body mass (Table 1), which is the limit criteria for significant acute toxicity. The LD_{50} was not quantifiable for Fire-Trol GTS-R, Phos-Chek D75-F, and Fire-Trol LCG-R and Phos-Chek WD-881 because the birds regurgitated the chemicals (Table 1).

Initial testing of all chemicals on red-winged blackbird was conducted in outdoor pens at doses of 2,000 mg (active ingredient) per kg body mass. Tests resulted in mortality of 1 of 10 Phos-Chek D75-F treated birds and 3 of 10 Fire-Trol GTS-R treated birds. No mortalities occurred for the remaining three chemicals. Based on this study, we could not determine whether the mortalities resulted from the chemical substance, the cold ambient temperatures, or both. To eliminate cold temperature effects, additional testing on red-winged blackbirds was conducted outdoors

Table 1. Acute single dose oral toxicity[1] of selected fire retardants and foam suppressants to terrestrial wildlife. All chemicals are of a comparatively low order of acute toxicity.

	CHEMICAL				
SPECIES	**Fire-Trol GTS-R**	**Phos-Chek D75-F**	**Fire-Trol LCG-R**	**Silv-Ex**	**Phos-Chek WD-881**
American kestrel	NQ[2]	NQ[2]	NQ[2]	>2,000	NQ[2]
Red-winged blackbird	2,197	>2,000	>2,000	>2,000	>2,000
Northern bobwhite	>2,000	>2,000	>2,000	>2,000	>2,000
Earthworm	>1,000	>1,000	>1,000	>1,000	>1,000
White-footed mouse	>2,000	>2,000	>2,000	>2,000	>2,000

[1]Toxicity reported as LD_{50} in mg active ingredient per kg body mass.
[2]Test not quantifiable (NQ) because birds regurgitated the chemicals as presented in gelatin capsule.

during warmer weather. Birds were exposed to the following treatment levels: 1,300, 1,580, 1,900, 2,300 and 2,800 mg (active ingredient) per kg body mass. All 10 birds exposed to 1,300 mg (active ingredient) per kg body mass survived while 9 of 10 birds exposed to 2,800 mg (active ingredient) per kg body mass died. Thus, the LD_{50} using the probit method is 2,197 mg (active ingredient) per kg body mass [95% CI: 1892 - 2574 mg (active ingredient) per kg body mass] and the slope of the dose response is 8.52 (95% CI: 3.5 -13.5). The LD_{50} for all five chemicals was greater than 2,000 mg (active ingredient) per kg body mass (Table 1) indicating that all of these chemicals are of a comparatively low order of acute toxicity (Smith, 1987).

Testing with white-footed mouse was conducted using Fire-Trol GTS-R, Fire-Trol LCG-R, and Phos-Chek D75-F, and Phos-Chek WD-881, and Silv-Ex. No dose-related mortalities were observed. The LD_{50} for all three chemicals was greater than 2,000 mg (active ingredient) per kg body mass, which is the limit criteria for significant acute toxicity (Table 1).

In tests with earthworms, the LD_{50} for all five chemicals was above the pre-determined 1000 ppm (active ingredient) limit criteria for significant acute toxicity (Table 1).

Subacute Dietary Toxicity Tests

Subacute dietary toxicity testing of Phos-Chek D75-F and Silv-Ex was conducted on white-footed mouse. These chemicals were designated for testing because of their selection in the field study in Nevada during summer 1994. No mortalities or overt signs of toxicity were observed. This test also determined that the first post-application small mammal population survey could be conducted 8 days post-chemical application for both chemicals.

Field Studies

Small mammal population data were analyzed following procedures outlined by Pollock et al. (1990). Analysis revealed no exposure effect on small mammal populations. Although this is supported by laboratory information that suggests a relatively low level of acute toxicity for these chemicals, our field results are confounded by the extremely low population densities that likely resulted from the unusually cold and wet weather in North Dakota during summer 1993. Analysis of ant population data also revealed no dose-related effect.

Overall, interpretation of this information for management purposes must be guarded due to the unseasonal events of the 1993 summer. However, development of methods during this study greatly benefitted the experimental design and method selection for the 1994 field season in the Great Basin.

Literature Cited

Bascietto, J. 1985. Avian single dose oral LD_{50}. Standard Evaluation Procedure EPA - 540/9-85-001. Environmental Protection Agency p.10.

Beyer, W.N., G. Miller, and J.W. Simmers. 1990. Trace elements in soil biota in confined disposal facilities for dredged material. Environ. Pollut. 65: 19-32.

Grue, C.E. 1982. Response of common grackles to dietary concentrations of four organophosphorus pesticides. Arch. Environ. Contam. Toxicol. 11: 617-626.

Hill, E.F. and M.B. Camardese. 1984. Toxicity of anticholinesterase insecticides to birds: Technical grade verses granular formulations. Ecotoxicol. Env. Safety 8: 551-563.

Pollock, K.H., Nichols, J.D., Brownie, C., J. Hines. 1990. Statistical inference for capture-recapture experiments. Wildlife Monographs. No. 107. p.97.

Rattner, B.A., and D.J. Hoffman. 1984. Comparative toxicity of acephate in laboratory mice, white-footed mice and meadow voles. Arch. Environ. Contam. Toxicol. 13: 483-491.

Smith, G. J. (1987). Pesticide Use and Toxicology in Relation to Wildlife: Organophosphorus and Carbamate Compounds (U.S.F.W.S. Resource Publication No. 170). Washington DC: U.S. Government Printing Office.

Wiemeyer, S.N. and D.W. Sparling. 1991. Acute toxicity of four anticholinesterase insecticides to American kestrels, eastern screech-owls and northern bobwhites. Environ. Toxicol. Chem. 10: 1139-1148.

Toxicity of fire retardant chemicals to aquatic organisms: Progress report

Steven J. Hamilton, Susan F. McDonald, Mark P. Gaikowski, and Kevin J. Buhl
U.S. National Biological Survey, Midwest Science Center, Field Research Station
RR 1 Box 295, Yankton, South Dakota, USA 7078

Abstract

*Fire retardant and suppressant chemicals used extensively in North America are often applied in environmentally sensitive areas that may contain endangered, threatened, or economically important plant and animal species. We conducted laboratory acute toxicity tests in both hard and soft waters with five commonly used fire control chemicals (Fire-Trol LCG-R, Fire-Trol GTS-R, Phos-Chek D-75-F, Phos-Chek WD-881, and Silv-Ex). Organisms used in the tests included two fish (rainbow trout and fathead minnow), two aquatic invertebrates (*Daphnia magna *and* Hyalella azteca*), and a green algae (*Selenastrum capricornutum*). In general, the green algae was substantially more sensitive to the three non-foam fire chemicals than the animals, the* Daphnia *were the most sensitive test organism in exposures with foams. The two foams (Silv-Ex and Phos-Chek WD-881) had similar toxicity and were more toxic than the three non-foams. Water quality did not seem to modify the toxicity of the five fire chemicals in a consistent manner.*

Résumé

*Les produits chimiques d'ignifugation et d'extinction largement utilisés en Amérique du Nord sont souvent appliqués sur des milieux sensibles qui peuvent abriter des espèces animales et végétales menacées ou en voie de disparition ou celles qui présentent une grande valeur économique. Nous avons mené des essais en laboratoire afin de déterminer la toxicité aiguë, dans des eaux douces et des eaux dures, de cinq produits couramment utilisés dans la lutte contre les incendies : Fire-Trol LCG-R, Fire-Trol GTS-R, Phos-Chek D-75-F, Phos-Chek WD-881 et Silv-Ex. Les organismes éprouvés comprenaient deux espèces de poisson (truite arc-en-ciel et tête-de-boule), deux invertébrés aquatiques (*Daphnia magna *et* Hyalella azteca*) et une algue verte (*Selenastrum capricornutum*). En général, l'algue verte a montré une sensibilité beaucoup plus marquée que les animaux aux trois produits liquidès d'extinction, et le* Daphnia *était l'organisme le plus sensible aux mousses. Les deux mousses (Silv-Ex et Phos-Chek WD-881) présentaient un degré comparable de toxicité et se sont révélées plus toxiques que les trois autres produits. La qualité de l'eau ne semblait pas modifier, de manière consistante, le degrée de toxicité des cinq produits chimiques.*

Introduction

Fire retardants and suppressants are used extensively in the United States for suppression and control of range and forest fires. Each year, fire control agencies utilize millions of gallons of these mixtures on a wide array of ecosystems. These chemicals are often applied in environmentally sensitive areas of the United States which may contain endangered, threatened, or economically significant plant and animal species. Relatively little information is available on the toxicity of these chemicals to aquatic and terrestrial life; less information is available concerning impacts at the community and ecosystem level.

The extensively used ammonium compounds - essentially dry or liquid fertilizer formulations - have long been considered to have minimal toxicological or ecological impact. Several authors have reported on the toxicity to fish of the active ammonium salts found in most fire retardants (Pramanik and Sarkar 1987, Ram and Sathyanesan 1986, Sheehan and Lewis 1987, Singh et. al. 1985). There have been very limited studies concerning the toxicity of actual fire retardant chemicals to aquatic animals (Johnson and Sanders 1977). Information on the toxicity of fire-fighting foams to aquatic organisms is limited to a few reports from manufacturers of fire-fighting chemicals.

Based upon the paucity of reported studies on the toxicity of fire retardant chemicals and formulations, it is impossible to ascertain their impact on aquatic organisms without additional research. Research in these areas will provide valuable information to fire managers and policy developers to insure that sound decisions are made concerning the effects of fire-fighting chemical use near aquatic habitats on private, state, and federal lands. The purpose of this research was to determine the acute toxicity of five commercially available and commonly used wildland fire retardant and foam products on specific aquatic species.

Methods and Materials

The toxicity of five fire retardant chemicals and foams were determined for two species of fish, two aquatic invertebrates, and one algae. The test organisms were rainbow trout (*Oncorhynchus mykiss*), fathead minnow (*Pimephales promelas*), *Daphnia magna* (daphnid), *Hyalella azteca* (amphipod), and the algae (*Selenastrum capricornutum*).

The specific chemicals tested were determined based on a critical review of the literature and interactions with qualified personnel familiar with use of various chemical and foam retardants. Studies were conducted with three retardants: Fire-Trol GTS-R (powder; lot number 84-FT-232), Fire-Trol LCG-R (liquid; lot number 91FT11), Phos-Chek D-75-F (powder; lot number 2468762-A); and two foams: Phos-Chek WD-881 (liquid; lot number 3616836A, batch number 18227) and Silv-Ex (liquid; lot number 75451, batch number US6203).

All tests were conducted under the existing quality assurance program of National Fisheries Contaminant Research Center (NFCR-Columbia, Missouri, USA). Eyed-eggs and juvenile fish were handled so as to minimize stress in accordance with the NFCR-Columbia Animal Welfare Plan (Animal Welfare Committee 1991). This research involved conducting several 96-hour acute toxicity studies with fish, adult *Hyalella azteca*, and algae (log-growth phase), and 48-hour studies with <24-hour-old *Daphnia magna*.

Acute toxicity tests with fish and *Daphnia magna* were conducted according to established methods (ASTM 1989). In each test, 10 organisms were exposed to each of seven to eight toxicant concentrations plus a control treatment for a total of 80-90 organisms per test. For *Hyalella azteca*, individual animals were tested instead of groups of 10 animals per test vessel. Each test apparatus was a 20 cm x 26 cm plexiglass sheet with 20 holes for holding 30-mL "shot-glass" vials containing 20 ml of test water. A group of 10 vials, each containing one animal, was used for each concentration of a test chemical tested. Other conditions in *Hyalella* tests followed those of ASTM (1989).

The exposures were conducted in test solutions under static conditions in glass jars and continued for 48 or 96 hours duration. The test temperature was maintained at 25°C for fathead minnow, 20°C for *Hyalella azteca*, 20°C for *Daphnia magna*, and 12°C for rainbow trout. The test water for the studies were blended to simulate ASTM soft and hard water (Table 1; ASTM 1989). Test water was prepared by addition of salts to ultra-pure water prepared by reverse osmosis and deionization. The test waters were analyzed using standard methods (APHA et al. 1975) to insure that the water quality met the criteria of the experimental design in terms of hardness, alkalinity, and concentrations of major cations (calcium, magnesium) and anions (chloride, sulfate) before it was used in tests with fish and aquatic invertebrates. Observations on mortality were recorded daily. The moving average-angle method (Peltier and Weber 1985) was used to calculate 48-hour EC50 or 96-hour LC50 values.

Table 1. Water quality characteristics of ASTM soft and hard waters (ASTM 1988)

	Water type	
Characteristic	**Soft**	**Hard**
pH	7.3-7.5	7.8-8.0
Hardness (mg/L as $CaCO_3$)	40-48	160-180
Alkalinity (mg/L as $CaCO_3$)	30-35	110-120

Acute toxicity tests with algae were conducted according to established methods (ASTM 1990). In each test, $2x10^4$ cells/mL were exposed to each of five to six toxicant concentrations plus a control treatment. The exposures were conducted in ASTM algal assay medium test solutions under static conditions in glass jars and continued for 96 hours duration. The test temperature was maintained at 24°C. Observations on cell counts, biomass dry weight, and chlorophyll *a* were recorded at the end of the test. The moving average-angle method (Peltier and Weber 1985) was used to calculate 96-hour IC50 values for reduced cell counts, biomass dry weight, and chlorophyll *a*.

Results and Discussion

Although several batches of ASTM soft and hard waters were made between March and August, 1993, all were within acceptable limits (Table 1). A description of fish life stages tested is given in Tables 2 and 3.

All data are tentative and may change with further evaluation and review. This manuscript is a modification of the 1993 annual progress report submitted to the U.S. Department of Interior Fire Coordination Committee.

Fish

In general, the egg life stage of both species was the least sensitive to the five fire retardants tested and the swim-up stage was the most

Table 2. Life stages of rainbow trout tested with five fire retardant chemicals in ASTM soft and hard waters. Sizes are mean (range in parentheses) of 10 control fish

Life stage	Water type	Age[1]	Weight (g)	Length (mm)
Egg	Soft	373[2]	0.0898 (0.0896-0.0899)	0.095 ml[4] d=5.66 mm
	Hard	373[2]	0.0898 (0.0896-0.0899)[3]	0.095 ml[4] d=5.66 mm
Embryo-larval	Soft	527[2]	-	-
	Hard	527[2]	-	-
Sac-fry	Soft	5	0.101 (0.076-0.120)[5]	21 (19-22)[5]
	Hard	5	0.101 (0.076-0.120)[5]	21 (19-22)[5]
Swim-up	Soft	21	0.094 (0.069-0.114)[5]	25 (23-26)[5]
	Hard	21	0.094 (0.069-0.114)[5]	25 (23-26)[5]
60 day	Soft	65	0.622 (0.252-1.002)[6]	44 (34-52)[6]
	Hard	58	0.415 (0.220-0.663)[6]	39 (33-45)[6]
90 day	Soft	90	1.496 (0.798-2.296)[7]	57 (47-64)[7]
	Hard	83	1.189 (0.813-1.735)[7]	53 (49-60)[7]

Fish source: Ennis NFH, Ennis, MT. Strain: McConaghy.
[1] = Days post median hatch day to test initiation; [2] = Daily temperature units (DTU) to test initiation. 1 DTU = 1°F for 24 hours; [3] = Average of 2 pools of 10 eggs each; [4] = Volume displacement; d = diameter; [5] N = 20 (pool of hard and soft control treatments); [6] N = 20; [7] N = 30.

Table 3. Life stages of fathead minnow tested with five fire retardant chemicals in ASTM soft and hard waters. Sizes are mean (range in parentheses) of control fish

Life stage	Water type	Lot no.	Age[1]	Weight (g)	Length (mm)
Egg	Soft	1	3[2]	0.009[3]	-
	Hard	1	3[2]	0.009[3]	-
Swim-up	Soft	2	1	0.008[4]	6 (5-6)[5]
	Hard	3	1	0.003[4]	5 (4-5)[5]
30 day	Soft	4	32-38	0.041 (0.023-0.076)[5]	18 (16-22)[5]
	Hard	4	30-36	0.032 (0.011-0.050)[5]	16 (13-19)[5]
60 day	Soft	4	53-59	0.118 (0.034-0.298)[6]	24 (17-32)[6]
	Hard	4	53-59	0.118 (0.034-0.298)[6]	24 (17-32)[6]

Fish source: NFCRC, Columbia, MO.
[1] = Days post hatch day to test initiation; [2] = Days post fertilization to test initiation; [3] = Pooled weight of 10 eggs; [4] = Pooled weight of 10 fry; [5] N = 10; [6] N = 20 (pool of hard and soft control treatments).

sensitive (Tables 4 and 5). The 60- and 90-day-old rainbow trout and 30- and 60-day-old fathead minnow were only slightly less sensitive than their respective swim-up life stage.

The five fire retardants were more toxic to several life stages of rainbow trout, especially for Fire-Trol GTS-R and Silv-Ex, and fathead minnow, especially Fire-Trol GTS-R and Phos-Chek D-75-F, in hard water than in soft water, which is unusual (Tables 4 and 5). Typically, the toxicity of toxicants, especially inorganics, is greater in soft water than in hard water (Rand and Petrocelli 1985).

The rank order from most toxic to least toxic of the chemicals tested for rainbow trout was: Phos-Chek WD-881 > Silv-Ex > Phos-Chek D-75-F > Fire-Trol GTS-R > Fire-Trol LCG-R. The rank order from most toxic to least toxic of the chemicals tested for fathead minnow was: Phos-Chek WD-881 > Silv-Ex > Fire-Trol GTS-R > Phos-Chek D-75-F > Fire-Trol LCG-R. The two foams were clearly much more toxic to both fish than were the three non-foam chemicals.

Ammonia

Ammonia concentrations in the low, medium, and high test concentrations of each fire-fighting chemical were measured and used in regression analysis to determine the total ammonia concentration as nitrogen that would have been present at the 96-hour LC50 concentration and are reported elsewhere (Gaikowski 1994). The concentrations of ammonia and unionized ammonia in tests with the swim-up life stage of rainbow trout and fathead minnow are given in Tables 6 and 7. The three non-foam chemicals (Fire-Trol LCG-R, Fire-Trol GTS-R, and Phos-Chek D-75-F) had substantially more ammonia than the two foam chemicals (Phos-Chek WD-881 and Silv-Ex). Fire-Trol LCG-R had the highest total ammonia concentration as nitrogen of the three non-foam chemicals.

Unionized ammonia concentrations were estimated by determining the NH_3-N concentration from regression equation coefficients and the 96-hour LC50 concentration. The percentage of unionized ammonia was estimated by using the high and low measured pH recorded at test initiation.

The unionized ammonia predicted at the 96-hour LC50 for the three non-foam retardants for both fish species was very close to those reported in toxicity tests with NH3 alone. Thurston and Russo (1983) reported a 96-hour LC50 of 0.23-0.47 mg NH_3/L for 0.12-0.15 g rainbow trout, which is nearly identical to our results with 0.09 g fry in soft water (0.32-0.50 mg NH_3/L) and in hard water (0.24-0.56 mg NH_3/L). Thurston and Russo (1983) also reported acute toxicity NH_3 concentrations for other sizes of rainbow trout that are similar to concentrations in the present study. Thurston et al. (1983) reported a 96-hour LC50 for fathead minnow of 1.1-1.5 mg NH_3/L for 0.09 g fish and 0.75 mg/L for 0.13 g fish. These values are nearly identical to our results with 0.12 g fish in soft water (1.22-1.28 mg NH_3/L) and in hard water (0.95-2.77 mg NH_3/L). Based on these results, it is most likely that the toxicity of the non-foam fire-fighting chemicals is due to unionized ammonia.

Toxicity of the fire-suppressant foams Phos-Chek WD-881 and Silv-Ex may be due to the surfactant portion of their formulation. Various authors have reported on the toxicity of surfactants, with results comparable to the 96-hour LC50s determined in this study. Muller (1980) reported a 24-hour LC50 of 8.5 mg/L for a commercial, non-ionic surfactant using 8-g rainbow trout as the test organism. Muller determined that surfactant toxicity was related to the surface tension reduction caused by the surfactant. The greater the reduction in surface tension, the greater the toxicity of the surfactant. In Muller's study, surface tension was reduced to approximately 45-60 dynes/cm at the 24-hour LT50 (LT50 is the concentration at which 50% of the population survives exposure for the specified time period). In comparison, the 0.6% Silv-Ex field application mixture has a surface tension of 22.92 dynes/cm (Ansul 1991), about half the surface tension reduction that caused mortality as reported by Muller (1980). Reduction in surface tension has also been shown to have adverse effects on gill epithelia, ranging from epithelial swelling to complete destruction of the gill epithelia (Bock 1967, as cited in Muller 1980). Holman and Macek (1980) determined the 96-hour LC50s for three different chain length linear alkylbenzene sulfonate (LAS) surfactants with 2-3 month-old fathead minnow juveniles tested in soft water (40 mg/L as $CaCO_3$). The 96-hour LC50s ranged from 0.86 to 12.3 mg/L, with increasing chain length directly increasing toxicity. Although the exact surfactants used in Phos-Chek WD-881 and Silv-Ex were not known, the 96-hour LC50 of the $C_{11.7}$ chain length LAS surfactant (12.3 mg/L) was extremely close to the 96-hour LC50s determined in this study for Silv-Ex and Phos-Chek WD-881.

The surfactants used in the fire-suppressant foams pose another threat to aquatic organisms besides their acute toxicity. Surfactants have been shown to alter the permeability of biological membranes (Helenius and Simons 1975). This change in

Table 4. Acute toxicity (96-hour LC50; mg/L; 95% confidence interval in parentheses) of five fire retardant chemicals to rainbow trout exposed at 12° C in ASTM soft and hard waters at five life stages. Astericks denote a significant difference (p=0.05) between soft and hard water for a test formulation. Letters in common denote no significant difference (p=0.05) among life stages within a test formulation and water quality

		Life stage				
Chemical	**Water type**	**Egg**	**Embryo-larval**	**Swim-up**	**60 day**	**90 day**
Fire-Trol LCG-R	Soft	>10,000[a]	>3600[b]	910[c]	1080[cd]	1413[d*]
				(722-1115)	(880-1353)	(1105-1724)
	Hard	>10,000[a]	2642[1b]	872[c]	1413[d]	1006[4c*]
			(2117-3249)	(685-1066)	(1105-1724)	(780-1300)
Fire-Trol GTS-R	Soft	>3600[a]	718[b]	363[4c*]	390[c*]	363[4c*]
			(589-918)	(280-470)	(316-489)	(280-470)
	Hard	>6000[a]	606[b]	207[2c*]	234[c*]	234[c*]
			(490-749)	(170-280)	(191-291	(191-291)
Phos-Chek D-75-F	Soft	>1700[a]	266[3b]	279[4b]	234[b]	218[4b]
			(213-327)	(216-360)	(191-291)	(170-280)
	Hard	>3600[a]	235[3b]	218[4b]	218[4b]	218[4b]
			(183-287)	(170-280)	(170-280)	(170-280)
Phos-Chek WD-881	Soft	44[5a]	13[4b]	13[4b]	15[b]	20[c]
			(10-17)	(10-17)	(12-19)	(16-25)
	Hard	22[a]	10[b]	11[b]	13[4b]	13[4b]
		(18-27)	(8-13)	(9-14)	(10-17)	(10-17)
Silv-Ex	Soft	>78[a]	15[b*]	20[bc*]	22[4c*]	22[4c*]
			(12-20)	(16-25)	(17-28)	(17-28)
	Hard	47[a]	11[b*]	13[4b*]	14[b*]	15[b*]
		(38-62)	(9-14)	(10-17)	(11-18)	(12-19)

[1]LC50 calculated with 1300 mg/L test concentration omitted; [2]LC50 calculated using binomial test; [3]Tests were started with true sac-fry; [4]= No partial kills; 95% confidence interval: lower limit = highest test concentration with 0% mortality, and upper limit = lowest test concentration with 100% mortality; [5]= LC50 calculated by binomial test; less than 70% mortality in highest test concentration.

Table 5. Acute toxicity (96-hour LC50; mg/L; 95% confidence interval in parentheses) of five fire retardant chemicals to fathead minnow exposed in ASTM soft and hard waters at four life stages. Astericks denote a significant difference (p=0.05) between soft and hard water for a test formulation. Letters in common denote no significant difference (p=0.05) among life stages within a test formulation and water quality

		Life stage			
Chemical	**Water type**	**Egg[1]**	**Swim-up**	**30 day**	**60 day**
Fire-Trol LCG-R	Soft	2317[a*]	1080[b]	1676[3c]	1797[ac]
		(1802-2830)	(880-1353)	(1300-2160)	(1466-2247)
	Hard	6705[a*]	519[b]	1181[c]	1676[3c]
		(5720-8281)	(389-654)	(1255-1924)	(1300-2160)
Fire-Trol GTS-R	Soft	787[a*]	233[b*]	494[c*]	605[3ac*]
		(529-1025)	(184-301)	(432-573)	(470-780)
	Hard	363[2a*]	135[b*]	193[c*]	320[a*]
		(280-470)	(105-165)	(153-235)	(252-392)
Phos-Chek D-75-F	Soft	2250[a*]	420[b*]	572[bc*]	612[c]
		(1736-2748)	(320-532)	(455-780)	(444-770)
	Hard	1569[a*]	168[b*]	237[c*]	490[d]
		(1255-1924)	(136-207)	(194-296)	(378-597)
Phos-Chek WD-881	Soft	32[24a]	14[b]	22[3a*]	22[3a*]
		(10-47)	(11-17)	(17-28)	(17-28)
	Hard	26[a]	14[b]	13[3b*]	13[3b*]
		(21-33)	(11-17)	(10-17)	(10-17)
Silv-Ex	Soft	32[a]	22[3b]	20[b]	22[3b]
		(25-39)	(17-28)	(16-25)	(17-28)
	Hard	28[a]	20[ab]	19[b]	22[3ab]
		(23-37)	(16-25)	(15-24)	(17-28)

[1]Test temperature was 20°C for all tests with eggs; all other life stages were tested at 25°C; [2]LC50 calculated using binomial test. [3]No partial kills; 95% confidence interval: lower limit = highest test concentration with 0% mortality, and upper limit = lowest test concentration with 100% mortality; [4]LC50 determined with low concentration omitted.

Table 6. Summary of ammonia characteristics of five fire chemicals in tests with rainbow trout at the swim-up life stage

	Water type	LC50 mg/L	Total ammonia NH_3-N mg/L	pH range	Unionized ammonia mg/L
F-T GTS-R	Soft	363	77	7.61-7.74	0.83-1.11
	Hard	207	35	7.65-8.08	0.41-1.10
F-T LCG-R	Soft	910	120	7.00-7.20	0.32-0.50
	Hard	872	93	6.98-7.36	0.24-0.56
P-C D-75-F	Soft	279	57	6.43-7.42	0.04-0.40
	Hard	218	49	6.39-7.80	0.03-0.80
P-C WD-881	Soft	13	0.04	-	-
	Hard	11	0.03	-	-
Silv-Ex	Soft	20	0.20	-	-
	Hard	13	0.15	-	-

Table 7. Summary of ammonia characteristics of five fire chemicals in tests with fathead minnows at the swim-up life stage

	Water type	LC50 mg/L	Total ammonia NH_3-N mg/L	pH range	Unionized ammonia mg/L
F-T GTS-R	Soft	233	41	7.39-7.66	0.69-1.27
	Hard	135	26	7.39-7.66	0.43-0.80
F-T LCG-R	Soft	1080	105	6.95-7.15	0.64-1.02
	Hard	519	53	6.94-7.29	0.33-0.74
P-C D-75-F	Soft	420	71	6.48-7.33	0.15-1.04
	Hard	168	29	6.72-7.72	0.10-1.02
P-C WD-881	Soft	14	0.04	-	-
	Hard	14	0.03	-	-
Silv-Ex	Soft	22	0.23	-	-
	Hard	20	0.18	-	-

permeability may be detrimental in situations in which multiple stressors are being placed upon an aquatic organism. LAS surfactants increased the uptake of cadmium across the perfused rainbow trout gill above that of gills exposed to cadmium without LAS (Part et al. 1985).

LAS can modify the toxicity of various substances, as well as change their uptake. Solon and Nair (1970) reported an increase in the toxicity of various phosphorothionate pesticides, such as parathion, by as much as 49% when fathead minnows were exposed to the pesticide in the presence of a sublethal (1 mg/L) LAS concentration. Thus, in aquatic ecosystems which are degraded by certain inorganic or organic pollutants, fire-suppressant foam toxicity may be altered, or may alter the uptake and toxicity of the additional pollutants.

Aquatic Invertebrates

Daphnia magna

The toxicity of the two foam chemicals to *Daphnia* was 10-200 times greater than that of the three non-foams (Table 8). This difference in toxicity of the five chemicals was similar to that observed in fish tests. There was no consistent effect of water quality on the toxicity of the five fire retardant chemicals: no difference for Fire-Trol LCG-R, Fire-Trol GTS-R, or Silv-Ex; the toxicity of Phos-Chek D-75-F was increased in soft water; the toxicity of Phos-Chek WD-881 was decreased in soft water (Table 8). From most toxic to least toxic the rank order of the five chemicals was: Silv-Ex = Phos-Chek WD-881 > Phos-Chek D-75-F > Fire-Trol GTS-R > Fire-Trol LCG-R. This rank order was similar to that for fish.

Hyalella azteca

The toxicity of the two foam chemicals to *Hyalella* was 5-50 times greater than that of the three non-foams (Table 9). Although this pattern was similar to that observed with *Daphnia* and fish, the magnitude of difference was not as great, especially for soft water tests. All five fire retardant chemicals were consistently more toxic in soft water than in hard water (Table 9). For the three non-foam chemicals the increase in toxicity in soft water was substantial. The

Table 8. Acute toxicity (48-hour EC50; mg/L; 95% confidence interval in parentheses) of five fire retardant chemicals to neonate *Daphnia magna* exposed in ASTM soft and hard waters. Asterisks denote significant difference (p=0.05) between soft and hard water for a test formulation. Letters in common (a-e for comparisons in soft water; w-z for comparisons in hard water) denote no significant difference (p=0.05) among test formulations

Chemical	Water type	48 hour
Fire-Trol LCG-R	Soft	848^{b} (662-1036)
	Hard	813^{x} (627-992)
Fire-Trol GTS-R	Soft	257^{a} (211-327)
	Hard	339^{w} (270-418)
Phos-Chek D-75-F	Soft	140^{c*} (113-177)
	Hard	280^{w*} (224-386)
Phos-Chek WD-881	Soft	11^{d*} (9-14)
	Hard	4^{y*} (3-5)
Silv-Ex	Soft	7^{e} (6-9)
	Hard	7^{z} (5-8)

Table 9. Acute toxicity (96-hour LC50; mg/L; 95% confidence interval in parentheses) of five fire retardant chemicals to adult *Hyalella azteca* exposed in ASTM soft and hard waters. Asterisks denote significant difference (p=0.05) between soft and hard water or a test formulation. Letters in common (a-d for comparisons in soft water; w-y for comparisons in hard water) denote no significant difference p=0.05) among test formulations

Chemical	Water type	LC50 (mg/L)
Fire-Trol LCG-R	Soft	73^{b*} (42-115)
	Hard	535^{x*} (424-654)
Fire-Trol GTS-R	Soft	127^{a*} (92-172)
	Hard	363^{w*} (292-450)
Phos-Chek D-75-F	Soft	53^{b*} (49-65)
	Hard	394^{wx*} (310-519)
Phos-Chek WD-881	Soft	10^{c*} (6-17)
	Hard	22^{y*} (17-28)
Silv-Ex	Soft	24^{d} (20-30)
	Hard	27^{y} (22-35)

rank order from most toxic to least toxic in soft water was: Phos-Chek WD-881 > Silv-Ex > Phos-Chek D-75-F = Fire-Trol LCG-R = Fire-Trol GTS-R. In hard water the rank order was: Phos-Chek WD-881 = Silv-Ex > Fire-Trol GTS-R = Phos-Chek D-75-F = Fire-Trol LCG-R.

Ammonia

The concentration of total ammonia in tests with aquatic invertebrates were measured in the low, medium, and high test chemical concentrations and used in regression analysis to determine the total ammonia concentration as nitrogen that would have been present at the 96-hour LC50 concentration (Tables 10 and 11). The three non-foam chemicals (Fire-Trol LCG-R, Fire-Trol GTS-R, and Phos-Chek D-75-F) had substantially more ammonia than the two foam chemicals (Phos-Chek WD-881 and Silv-Ex).

Unionized ammonia concentrations were estimated by determining the NH_3-N concentration from regression equation coefficients and the 96-hour LC50 concentration. The percentage of unionized ammonia was estimated by using the high and low measured pH recorded at test initiation.

The unionized ammonia predicted at the 96-hour LC50 for the three non-foam retardants for both aquatic invertebrates was close to those reported in toxicity tests with NH_3 alone. Studies conducted by Williams et al. (1986) reported 96-hour LC50s ranging from 0.71 to 2.95 mg NH_3/L for 11 aquatic invertebrates. USEPA (1985) reported 48-hour LC50s for daphnids of 2.4-2.8 mg NH_3/L in hard water and 0.53-0.90 mg NH_3/L in soft water. These values are close to our results with daphnids in soft water (0.56-2.7 mg NH_3/L for two Fire-Trol compounds) and in hard water (0.57-4.86 mg NH_3/L for two Fire-Trol compounds). In our tests with Phos-Chek D-75-F, the amounts of unionized ammonia were lower but still relatively close to toxic concentrations (0.15-0.32 mg NH_3/L in soft water; 0.48-0.89 mg NH_3/L in hard water). Williams et al. (1986) reported a 96-hour LC50 of 2.05 mg NH3/L to *Gammarus pulex* (related to *Hyalella azteca* used in our tests) in hard water, which is substantially higher than unionized ammonia concentrations in tests with the three non-foam retardants, except Fire-Trol GTS-R tested in hard water. The toxicity of these compounds to *Hyalella* was probably due to other constituents in the retardant formulations.

Table 10. Summary of the ammonia characteristics of five fire retardant chemicals used in tests with neonate *Daphnia magna* exposed in ASTM soft and hard waters. A regression equation (in parenthesis) was fitted for each chemical tested using the total ammonia as nitrogen (NH_3-N) concentrations determined at test initiation (N=4). Each regression model was used to predict NH_3-N (mg/L) at the 48-hour EC50

Chemical	Water type	Regression equation	EC50 (mg/L)	Total ammonia[1] (NH_3-N, mg/L) EC50	pH[2] range	Un-ionized[3] ammonia (mg/L)
Fire-Trol GTS-R	Soft	NH_3-N=-0.736 + 0.205 x EC50 Adj R^2 = 0.9996	257	51.95	7.55-7.68	0.73-2.70
	Hard	NH_3-N=-0.249 + 0.240 x EC50 Adj R^2 = 0.9999	339	81.11	7.74-8.03	1.96-4.86
Fire-Trol LCG-R	Soft	NH_3-N=-1.541 + 0.109 x EC50 Adj R^2 = 0.9996	848	90.89	7.10-7.17	0.56-2.37
	Hard	NH_3-N=-2.822 + 0.119 x EC50 Adj R^2 = 0.9993	813	94.74	7.05-7.15	0.57-2.15
Phos-Chek D-75-F	Soft	NH_3-N=-0.244 + 0.175 x EC50 Adj R^2 = 0.9998	140	24.26	6.91-7.27	0.15-0.32
	Hard	NH_3-N=2.032 + 0.179 x EC50 Adj R^2 = 0.9998	280	52.15	7.10-7.75	0.48-0.89
Phos-Chek WD-881	Soft	NH_3-N=0.0799 + 0.000234 x EC50 Adj R^2 = -0.4525	11	0.08	7.90-7.90	0.00
	Hard	NH_3-N=0.0509 + -0.000207 x EC50 Adj R^2 = 0.9782	4	0.05	8.28-8.29	0.00
Silv-Ex	Soft	NH_3-N=0.0705 + 0.00748 x EC50 Adj R^2 = 0.9995	7	0.12	7.97-7.97	0.00-0.01
	Hard	NH_3-N=0.0521 + 0.00768 x EC50 Adj R^2 = 0.9994	7	0.11	8.29-8.29	0.01-0.02

[1]NH_3-N = total ammonia as nitrogen (mg/L) used as dependent variable in regression model; EC50 = 48-hour EC50 (mg/L) used as independent variable in regression model; adjusted R^2 = 1-(1-R^2)(n-1/df error); [2]pH range = lowest and highest pH measurements for each test at test initiation; [3]Un-ionized ammonia = total ammonia adjusted for temperature and pH.

Table 11. Summary of the ammonia characteristics of five fire retardant chemicals used in tests with adult *Hyalella azteca* exposed in ASTM soft and hard waters. A regression equation (in parenthesis) was fitted for each chemical tested using the total ammonia as nitrogen (NH_3-N) concentrations determined at test initiation (N=4). Each regression model was used to predict NH_3-N (mg/L) at the 96-hour LC50

Chemical	Water type	Regression equation	EC50 (mg/L)	Total ammonia[1] (NH_3-N, mg/L) EC50	pH[2] range	Un-ionized[3] ammonia (mg/L)
Fire-Trol GTS-R	Soft	NH_3-N=-0.386 + 0.197 x LC50 Adj R^2 = 1.0000	127	24.63	7.49-7.58	0.13-0.79
	Hard	NH_3-N=-1.834 + 0.215 x LC50 Adj R^2 = 0.9999	363	76.21	7.72-8.00	0.53-2.40
Fire-Trol LCG-R	Soft	NH_3-N=-0.366 + 0.107 x LC50 Adj R^2 = 0.9999	73	7.44	6.78-7.04	0.02-0.08
	Hard	NH_3-N=-1.291 + 0.108 x LC50 Adj R^2 = 0.9996	535	56.49	6.99-7.03	0.24-1.09
Phos-Chek D-75-F	Soft	NH_3-N=-0.382 + 0.197 x LC50 Adj R^2 = 1.0000	53	10.06	6.98-7.43	0.09-0.25
	Hard	NH_3-N=5.257 + 0.192 x LC50 Adj R^2 = 0.9971	394	80.90	7.29-7.84	0.38-1.01
Phos-Chek WD-881	Soft	NH_3-N=0.0597 + -0.000151 x LC50 Adj R^2 = -0.2944	10	0.06	7.44-7.45	0.00
	Hard	NH_3-N=0.0418 + -0.000141 x LC50 Adj R^2 = -0.2072	22	0.04	8.14-8.19	0.00
Silv-Ex	Soft	NH_3-N=0.0230 + 0.00784 x LC50 Adj R^2 = 0.9995	24	0.21	7.47-7.47	0.00-0.01
	Hard	NH_3-N=0.0270 + 0.00719 x LC50 Adj R^2 = 1.0000	27	0.22	8.09-8.10	0.00-0.02

[1]NH_3-N = total ammonia as nitrogen (mg/L) used as dependent variable in regression model; EC50 = 96-hour LC50 (mg/L) used as independent variable in regression model; adjusted R^2 = 1-(1-R^2)(n-1/df error); [2]pH range = lowest and highest pH measurements for each test at test initiation; [3]Un-ionized ammonia = total ammonia adjusted for temperature and pH.

Algae

The 96-hour IC50s for algae ranged from 10 mg/L for Fire-Trol LCG-R to 79 mg/L for Phos-Chek D-75-F (Table 12). Fire-Trol compounds were substantially more toxic to algae than aquatic invertebrates. The difference in toxicity ranged from 7 times more toxic to algae than *Hyalella* to 80 times more toxic to algae than *Daphnia*.

Critical nutrients for algal productivity are phosphorus and nitrogen (Shiroyama et al. 1975). The optimum ratio of nitrogen to phosphorus is about 11:1 to support optimal algal growth. Fire retardant chemicals contain nitrogen and phosphorus in the form of ammonium and diammonium compounds. These chemicals are not considered to be a threat to the environment because their constituents contain fertilizer elements. Without proper nutrient balance, these chemicals can stress aquatic plant species such as algae by limiting their growth and maturity, forcing them to become nitrogen or phosphorus limited. Inadequate nitrogen or phosphorus accounts for the majority of nutrient limitations experienced by algae. Addition of both nitrogen and phosphorus will support growth relative to the phosphorus content in water. Based on the ammonia analysis conducted on algal test concentrations at 0 and 96 hours (Table 13), algae could have been nutrient limited, either by phosphorus or other essential nutrients such as carbon when there was still nitrogen available. Carbon limitation is indicated by increased pH values (Fitzgerald 1975). Because pH values of lower test concentrations were frequently above pH 8.0, carbon limitation could be a strong possibility.

An alternative explanation might be that there were some toxins present in the compounds to adversely affect algae (Miller et al. 1978). Because phosphorus concentrations were not measured, inhibition due to nutrient limitation can not be determined.

Table 12. Acute toxicity (95-hour IC50; mg/L; 95% confidence interval in parentheses) of five fire retardant chemicals to *Selenastrum capricornutum* exposed in ASTM algal assay medium. Values with different letters are significantly different (p=0.05)

Chemical	IC50
Fire-Trol GTS-R	18[a] (17-20)
Fire-Trol LCG-R	10[b] (10-11)
Phos-Chek D-75-F	79[c] (72-87)
Phos-Chek WD-881	24[d] (22-27)
Silv-Ex	15[a] (12-18)

Because ASTM algal assay medium is phosphorus limited, stimulation in response to the addition of ammonium and phosphorus compounds would be expected. Some stimulation was evident in four of five test chemicals. Phos-Chek WD-881 produced a stimulation in lower chemical concentrations even though the chemical did not contain ammonium or phosphorus, based on available information. Stimulation suggests the presence of additional phosphorus or a response to CO_2 evolving from biodegradation of the chemical. Addition of phosphorus will increase algal biomass when in the presence of excess nitrogen (Miller et al. 1978), whereas addition of CO_2 did not change algal productivity or decrease pH substantially in other tests (Fitzgerald 1975).

The greatest stimulations occurred in long-term retardant chemicals. Fire-Trol GTS-R stimulated twice as much growth in the two lowest concentrations as Fire-Trol LCG-R in similar concentrations, whereas the lowest Phos-Chek D-75-F treatment produced the greatest stimulation of all five test chemicals. The ammonium and phosphorus constituents are essentially identical in Phos-Chek D-75-F and Fire-Trol GTS-R, therefore a smaller stimulation in Fire-Trol GTS-R could be due in part to toxicants present in the test chemical as well as a lesser concentration of these constituents in the chemicals.

Comparison to Published/Manufacturer Data

There is very limited information on the toxicity of the five fire fighting compounds tested except for studies conducted by the manufacturers or their contract testing facilities (Table 14). Most of the results of these tests are within a factor of four of our values, which is within the typical range of interlaboratory variation for acute toxicity data (Schimmel 1981). However, our acute toxicity data tended to be lower than those reported by the manufacturers or their contract laboratories, and one of our results was greater than 4-fold different. Our test with Phos-Chek D-75-F tested in soft water with 0.6-g rainbow trout resulted in a 96-hour LC50 of 234 mg/L, which was greater than 4 times lower than the manufacturer's value of >1000 mg/L.

Relation to Environmental Conditions

Foam chemicals are applied at about 1% foam, which is equivalent to 1 g/100 ml. This field application rate can be related to our toxicity values by converting

Table 13. Summary of the ammonia characteristics of five fire retardant chemicals used in tests with *Selenastrum capricornutum* exposed in ASTM algal assay medium

Chemical	Concentration (mg/L)	IC50 (mg/L)	Total ammonia (mg/L) 0-hour	Total ammonia (mg/L) 96-hour	Un-ionized ammonia[1] (mg/L) 0-hour	Un-ionized ammonia[1] (mg/L) 96-hour
Fire-Trol GTS-R	3.6	18	0.74	0.01	0.00	0.00
	17		3.39	0.12	0.01	0.00
	47		9.57	7.83	0.03	0.02
Fire-Trol LCG-R	3.6	10	0.39	0.01	0.00	0.00
	17		1.79	1.31	0.00	0.00
	47		5.08	4.70	0.01	0.01
Phos-Chek D-75-F	10	79	1.72	0.11	0.00	0.02
	47		7.96	3.95	0.01	0.00
	130		21.83	20.14	0.02	0.03
Phos-Chek WD-881	2.16	24	0.04	0.02	0.00	0.00
	10		0.03	0.02	0.00	0.00
	28		0.03	0.02	0.00	0.00
Silv-Ex	3.6	15	0.06	0.01	0.00	0.00
	17		0.13	0.01	0.00	0.00
	47		0.34	0.01	0.00	0.00

[1]Un-ionized ammonia = total ammonia adjusted for temperature and pH.

Table 14. Acute toxicity (96-hour for fish and algae; 48-hour for *Daphnia magna*) reported by manufacturers or their contract laboratories. Acute toxicity values from this study (YFRS, SD 1993) are included for comparison

	Species	Weight (g)	Water quality	LC50 mg/L	Source
P-C WD-861	RBT	0.83	Soft	18	ABC Labs 1986c
P-C WD-881	RBT	0.57	Soft	22	ABC Labs 1988
		0.1 (fry)	Soft	13	YFRS, SD 1993
		0.09 (swim-up)	Soft	13	YFRS, SD 1993
		0.6 (60 DPH)	Soft	15	YFRS, SD 1993
P-C WD-861	Daphnia	<24 hour	Hard	7.8	ABC Labs 1986d
P-C WD-881	Daphnia	<24 hour	Hard	4	YFRS, SD 1993
P-C WD-861	S. capric.	- (dry wt)	-	7.6	Monsanto 1987
P-C WD-881	S. capric.	- (Chl. a)	-	24	YFRS, SD 1993
P-C D-75-R	RBT	0.44	Soft	>1000	ABC Labs 1986b
P-C D-75-F	RBT	0.6 (60 DPH)	Soft	234	YFRS, SD 1993
		1.5 (90 DPH)	Soft	218	YFRS, SD 1993
P-C D-75-R	FHM	0.15	Soft	>1000	ABC Labs 1986a
P-C D-75-F	FHM	0.1 (60 DPH)	Soft	612	YFRS, SD 1993
	Daphnia	<24 hour	Hard	>1000	ABC Labs 1986a
	Daphnia	<24 hour	Hard	280	YFRS, SD 1993
F-T LCG-R	RBT	?	?	790	Chemonics (MSDS) 1992b
F-T GTS-R	RBT	?	?	1000	Chemonics (MSDS) 1992a
	RBT	0.5 g	V. soft	899	C. Chang 10/92 Chemonics
		0.09 (swim-up)	Soft	363	YFRS, SD 1993
		0.09 (swim-up)	Hard	207	YFRS, SD 1993
		0.6 (60 DPH)	Soft	390	YFRS, SD 1993
		0.4 (60 DPH)	Hard	234	YFRS, SD 1993
		1.5 (90 DPH)	Soft	363	YFRS, SD 1993
		1.2 (90 DPH)	Hard	234	YFRS, SD 1993
Silv-Ex	RBT	0.37	Soft	25	Springborn Bionomics 1986
	RBT	0.1 (sac-fry)	Soft	11	YFRS, SD 1993
		0.09 (swim-up)	Soft	13	YFRS, SD 1993
		0.6 (60 DPH)	Soft	14	YFRS, SD 1993

96-hour LC50 values to the same units. For example, the 96-hour LC50 of Silv-Ex to swim-up rainbow trout is 20 mg/L, which is equivalent to 0.002 g/100 ml. Thus, the 96-hour LC50 value is equivalent to a 0.002% foam solution. This acute toxicity value is 500 times less than the 1% foam field application rate. Consequently, if a 1% foam solution came in contact with an aquatic environment it would have to be diluted 500 fold to reach the 96-hour LC50 concentration – a concentration which would cause a substantial amount of mortality in an aquatic environment.

A safety factor may be applied to toxicity data to estimate a safe concentration for aquatic organisms. A safety factor for acute toxicity data is usually 100. Applying a safety factor of 100 to the above toxicity information would require a 50,000 dilution (100 x 500) of the 1% foam field application solution to approach a safe concentration. Similar approaches could be used with toxicity values for other fire-fighting chemicals.

Summary

Overall, the toxicity of the five fire retardant chemicals to these four species is remarkably similar. The two foams, Silv-Ex and Phos-Chek WD-881, have very similar toxicity and are substantially more toxic than the three non-foams. Of the non-foams, Fire-Trol GTS-R and Phos-Chek D-75-F have similar toxicity, which was substantially higher than Fire-Trol LCG-R except for the amphipod *Hyalella azteca*.

Water quality did not seem to modify the toxicity of the five fire retardant chemicals in a consistent manner, except for *Hyalella* which were consistently more sensitive in soft water.

For the three non-foam chemicals, *Hyalella* was the most sensitive species in soft water, whereas fathead minnow was the most sensitive species in hard water (Table 15). For the two foam chemicals, *Daphnia* in three tests and *Hyalella* in one soft water test were the most sensitive species.

In 8 out of 10 tests *Daphnia* were more sensitive than the swim-up life stage of rainbow trout. The greatest difference in sensitivity associated with water quality was shown by *Hyalella*. In 4 out of 5 soft water tests *Hyalella* was the most sensitive species, but in 4 out of 5 hard water tests it was the least sensitive species.

Acknowledgment

This project was funded by the U.S. Department of Interior Fire Coordination Committee (Bureau of Land Management, Bureau of Indian Affairs, Fish and Wildlife Service, and National Park Service). Art Bullard is thanked for excellent technical assistance and Karen Faerber for typing the manuscript.

Table 15. Comparison of species sensitivity to five fire retardants tested in ASTM soft and hard waters. The swim-up life stage of fish (most sensitive life stage) was used in the comparison. Species with a common underline are not significantly different in toxicity sensitivity (p = 0.05; non-overlapping 95% confidence intervals)

Chemical	Water type	Rank order (most sensitive to least sensitive)
Fire-Trol LCG-R	Soft	Hyalella Daphnia Trout Minnow
	Hard	Minnow Hyalella Daphnia Trout
Fire-Trol GTS-R	Soft	Hyalella Minnow Daphnia Trout
	Hard	Minnow Trout Daphnia Hyalella
Phos-Chek D-75-F	Soft	Hyalella Daphnia Trout Minnow
	Hard	Minnow Trout Daphnia Hyalella
Phos-Chek WD-881	Soft	Hyalella Daphnia Trout Minnow
	Hard	Daphnia Trout Minnow Hyalella
Silv-Ex	Soft	Daphnia Trout Minnow Hyalella
	Hard	Daphnia Trout Minnow Hyalella

References

ABC Laboratories (Analytical Bio-Chemistry Laboratories, Inc.). 1986a. Acute toxicity of PC-D75R to fathead minnows (*Pimephales promelas*). ABC Laboratories, Columbia, MO. Contract report submitted to Monsanto Co., St. Louis, MO. Unpublished data. Report No. 34902. 14 pages.

ABC Laboratories (Analytical Bio-Chemistry Laboratories, Inc.). 1986b. Acute toxicity of PC-D75R to rainbow trout (*Salmo gairdneri*). ABC Laboratories, Columbia, MO. Contract report submitted to Monsanto Co., St. Louis, MO. Unpublished data. Report No. 35089. 14 pages.

ABC Laboratories (Analytical Bio-Chemistry Laboratories, Inc.). 1986c. Acute toxicity of PC-WD861 to rainbow trout (*Salmo gairdneri*). ABC Laboratories, Columbia, MO. Contract report submitted to Monsanto Co., St. Louis, MO. Unpublished data. Report No. 34904. 14 pages.

ABC Laboratories (Analytical Bio-Chemistry Laboratories, Inc.). 1986d. Acute toxicity of PC-WD-861 to *Daphnia magna*. ABC Laboratories, Columbia, MO. Unpublished data. Report No. 35088. 9 pp. (Contract report submitted to Monsanto Co., St. Louis, MO)

ABC Laboratories (Analytical Bio-Chemistry Laboratories, Inc.). 1988. Acute toxicity of PC-WD881 to rainbow trout (*Salmo gairdneri*). ABC Laboratories, Columbia, MO. Contract report submitted to Monsanto Co., St. Louis, MO. Unpublished data. Report No. 36856. 17 pages.

Animal Welfare Committee. 1991. Animal Welfare Plan. U.S. Fish and Wildlife Service, National Fisheries Contaminant Research Center, Columbia, MO.

Ansul. 1991. Extinguishing Agent Data Sheet, Silv-Ex "Class A" fire control concentrate. Ansul Fire Protection, Marinette, WI.

APHA (American Public Health Association), American Water Works Association, and Water Pollution Control Federation. 1975. Standard Methods for the Examination of Water and Wastewater, 14th Edition. American Public Health Association, Washington, DC.

ASTM (American Society for Testing and Materials). 1989. Standard guide for conducting acute toxicity tests with fishes, macroinvertebrates, and amphibians. Annual Book of ASTM Standards. Vol. 11.04. Pages 378-397.

ASTM (American Society for Testing and Materials). 1990. Standard guide for conducting static 96-hour toxicity tests with microalgae, E 1218-90. American Society for Testing and Materials. Philadelphia, PA, pp. 1-12.

Chemonics (Chemonics Industries, Inc). 1992a. Fire-Trol GTS-R material safety data sheet. Chemonics Industries, Inc., Phoenix, AZ. 6 pages.

Chemonics (Chemonics Industries, Inc). 1992b. Fire-Trol LCG-R material safety data sheet. Chemonics Industries, Inc., Phoenix, AZ. 5 pages.

Fitzgerald, G.P. 1975. Factors affecting the algal assay procedure. U.S. Environmental Protection Agency Office of Research and Monitoring. PO no. P5J 11912-J. ROAP/Task No. 21 AJF/03. Program Element 1BA 031. Washington, DC. 31 pp.

Gaikowski, M.P. 1994. The acute toxicity of three fire-retardant and two fire-suppressant foam formulations to the early life stages of rainbow trout (*Oncorhynchus mykiss*) and fathead minnow (*Pimephales promelas*). Master's thesis. University of South Dakota, Vermillion, SD. 100 pages.

Helenius, A., and K. Simons. 1975. Solubilization of membranes by detergents. Biochimica Biophysica Acta 415: 29-79.

Holman, W.F., and K.J. Macek. 1980. An aquatic safety assessment of linear alkylbenzene sulfonate (LAS): Chronic effects on fathead minnows. Transactions of the American Fisheries Society 109:122-131.

Johnson, W.W., and H.O. Sanders. 1977. Chemical forest fire retardants: Acute toxicity to five freshwater fishes and a scud. Technical Papers of the U.S. Fish and Wildlife Service, Number 91.

McDonald, S.F. 1994. Acute toxicity of fire retardant and foam suppressant chemicals to two aquatic invertebrates and a green algae. Master's thesis. University of South Dakota, Vermillion, SD. 88 pages.

Miller, W.E., J.C. Greene, and T. Shiroyama. 1978. The *Selenastrum capricornutum* Printz algal assay bottle test. U.S. Environmental Protection Agency Publication EPA-600/9-78-018, Corvallis, OR. 126 pp.

Müller, R. 1980. Fish toxicity and surface tension of non-ionic surfactants: Investigations of antifoam agents. Journal of Fish Biology 16:585-589.

Pärt, P., O. Svanberg, and E. Bergström. 1985. The influence of surfactants on gill physiology and cadmium uptake in perfused rainbow trout gills. Ecotoxicology and Environmental Safety 9:135-144.

Peltier, W.H., and C.I. Weber. 1985. Methods for Measuring the Acute Toxicity of Effluents to Freshwater and Marine Organisms, 3rd Edition. U.S. Environmental Protection Agency Publication EPA-600/4-85-013. Cincinnati, OH.

Pramanik, A., and S.K. Sarkar. 1987. Comparative study of the sensitivity of egg spawn and fry of cyprinus - carpio exposed to ammonium sulfate at different temperature. Geobios 14:229-230.

Ram, R.N., and A.G. Sathyanesan. 1986. Inclusion bodies formation and degeneration of the oocytes in the fish channel-punctatus in response to ammonium sulfate treatment. Ecotoxicology and Environmental Safety 11:272-276.

Rand, G.M., and S.R. Petrocelli. 1985. Fundamentals of Aquatic Toxicology. Hemisphere Publishing, Washington, D.C. 666 pages.

Schimmel, S.C. 1981. Results: Interlaboratory comparison-acute toxicity tests using estuarine animals. U.S. Environmental Protection Agency Publication EPA-600/4-81-003, Gulf Breeze, FL. 14 pp.

Sheehan, R.J., and W.M. Lewis. 1987. Influence of pH and ammonia salts on ammonia toxicity and water balance in young channel catfish. Transactions of the American Fisheries Society 115:891-899.

Shiroyama, T., W.E. Miller, and J.C. Greene. 1975. Effect of nitrogen and phosphorus on the growth of *Selenastrum capricornutum.* Pages 132-142 *in* Processes of Biostimulation and Nutrient Assessment Workshop, 16-17 October 1973, U.S. Environmental Protection Agency EPA-660/3-75-034, Corvallis, OR.

Singh, H.R., Dobriyal, A.K., and R.C. Pokhriyal. 1985. Toxicity of diammonium phosphate of the hill stream minor carp barilius benedelisis. Uhar Pradesh Journal of Zoology 5:89-92.

Solon, J.M., and J.H. Nair III. 1970. The effect of a sublethal concentration of LAS on the acute toxicity of various phosphate pesticides to the fathead minnow (*Pimephales promelas* Rafinesque). Bulletin of Environmental Contamination and Toxicology 5:408-413.

Springborn Bionomics, Inc. 1986. 96-Hour Acute (LC_{50}) with Rainbow Trout. Springborn Bionomics, Inc. Wareham, MA. Contract report submitted to Wormald CDN, Thurso, Quebec, Canada. Unpublished data. Report No. BW-86-10-2044. 7 pages.

Thurston, R.V., and R. Russo. 1983. Acute toxicity of ammonia to rainbow trout. Transactions of the American Fisheries Society 112:696-704.

Thurston, R.V., R. Russo, and G. Phillips. 1983. Acute toxicity of ammonia to fathead minnows. Transactions of the American Fisheries Society 112:705-711.

USEPA. 1985. Ambient water quality criteria for ammonia-1984. U.S. Environmental Protection Agency Publication EPA 440/5-85-001, Washington, DC. 217 pp.

Williams, K.A., D.W.J. Green, and D. Pascoe. 1986. Studies on the acute toxicity of pollutants to freshwater macroinvertebrates. 3. Ammonia. Archiv fur Hydrobiologie 106(1):61-70.

Effects of fire suppressant foams on a prairie wetland ecosystem – A study of a North Dakota prairie wetland community

Barry C. Poulton and Susan E. Finger
Midwest Science Center, 4200 New Haven Road, Columbia, MO 65201

Abstract

During spring 1993, two field exposures were conducted to determine the effects of fire suppressant foams (Silv-Ex and Phos-Chek WD-881) on aquatic life. Exposure #1 was performed in Fish Lake at the Woodworth Field Station, Stutsman County, North Dakota. Exposure #2 was performed in an experimental pond at the National Fisheries Contaminant Research Center in Columbia, Missouri. Twenty-four limnocorrals were designed to enclose approximately 2500 L of water so that chemical dosage could be applied without leakage. Within each limnocorral, fathead minnows and water boatmen (Cenocorixa) were placed in separate environmental chambers to assess effects on single species. Community effects were evaluated by examining aquatic macroinvertebrates that had colonized artificial substrates trays in each limnocorral.

Similar to observations in the laboratory, field studies showed that Silv-Ex was more toxic to aquatic organisms than was Phos-Chek WD-881. Although, in these field studies, no appreciable mortality occurred in fathead minnows exposed to the lowest observed effect concentration (calculated from laboratory data), complete mortality did occur at concentrations approximating the LC50. Analysis of information on macro-invertebrate community responses to these chemicals is in progress.

Résumé

Le printemps 1993, on a mené deux essais d'exposition sur le terrain pour évaluer les effets des mousses carboniques (Silv-Ex et Phos-Chek WD-881) sur la vie aquatique. Le premier essai s'est déroulé au lac Fish, à la Woodworth Field Station, dans le comté de Strutsman, dans le Dakota-Nord. Le deuxième essai a été effectué dans un bassin expérimental, au National Fisheries Contaminant Research Center, à Columbia, dans le Missouri. On a disposé vingt-quatre enceintes limnologiques conçues pour contenir environ 2500 litres d'eau, ce qui permettait d'utiliser le dosage prévu de produits chimiques sans risque de fuite. À l'intérieur de chaque enceinte, on a placé des têtes-de-boule et des corises (Cenocorixa) dans des chambres climatiques distinctes afin d'évaluer les effets du produit sur chaque espèce. On a déterminé les effets sur les populations en étudiant les macro-invertébrés qui ont colonisé les substrats artificiels placés dans chaque enceinte limnologique.

À l'instar des observations en laboratoire, les études sur le terrain indiquaient que le produit Silv-Ex était plus toxique pour les organismes aquatiques que le produit Phos-Chek WD-881. Bien que dans le cadre de ces études sur place, on n'ait pas enregistré un taux important de mortalité chez les têtes-de-boule exposées à la concentration minimale à laquelle des effets sont observés (concentration calculée selon les données de laboratoire), tous les spécimens exposés à des concentrations proches de la DL50 sont morts. On analyse actuellement les données recueillies sur la réponse des populations de macro-invertébrés à ces produits chimiques.

Introduction

Fire retardants and suppressants are widely used in the United States to extinguish wildfires occurring in a wide variety of habitats. These chemicals are often used in locations where aquatic habitats contain sensitive biological communities or threatened and endangered species. Little information is available on the effects of these chemicals on aquatic species. To minimize the probability of producing significant effects on aquatic species, resource managers need to know the environmental risk associated with chemical application. During 1992, toxicity of two fire suppressant foams and three retardants were determined in laboratory exposures. Results from this research suggest that foam suppressants are more toxic than liquid retardants to aquatic organisms under laboratory conditions.

In May 1993, field studies were initiated to evaluate the response of the aquatic community associated with prairie wetland habitat to the foam suppressants, Silv-Ex and Phos-Chek WD-881. In addition, laboratory and field results were compared, this being an essential link in formulating management options. The purpose of this phase of the study was not only to provide information on aquatic community responses to fire-fighting chemicals in a wetland environment, but also to develop field assessment methods that could be used to determine the effects of these chemicals in a more complex ecological system such as the Great Basin area of Nevada, a study planned and implemented during the summer of 1994. An additional exposure to evaluate the effectiveness of sampling methods and to better define the sensitivity of fish to Silv-Ex was conducted in experimental ponds at the Midwest Science Center. Specific objectives for these studies were:

1) To determine the response of the aquatic invertebrate community to two foaming agents, Silv-Ex and Phos-Chek WD-881, in a wetland environment
2) To evaluate the survival of fish and invertebrates after exposure to Silv-Ex and Phos-Chek WD-881, two foam suppressants.

Description of Study Site

The 1993 study was conducted at the Woodworth Station, a research facility of the Northern Prairie Science Center, Jamestown, North Dakota. The Station is located in Township 142N, Range 68W, on the Missouri Couteau physiographic region of central North Dakota. The region is characterized by thick deposits of glacial till with knob-and-kettle topography. The Station was established in 1963 as a field laboratory for the study of effects of land-use practices on wildlife. Records of land-use practices throughout the Station have been maintained since its establishment. Prior to 1960, the study area was sporadically grazed and hayed. The 65-ha field containing the study site has never been plowed. Biologists burned the field in 1969, 1970, 1971, 1972, 1976, 1979, 1981, and 1990; it has not been grazed since 1974. Currently, vegetation in the study area is dominated by *Poa pratensis*, an exotic cool-season grass. Other grass species found during previous studies on the site include *Stipa viridula*, *S. comata*, *Agropyron repens*, *Muhlenbergia cuspidata*, and *Bromus inermis*. *Rosa arkansana*, *Elaeagnus commutata*, and *Symphoricarpos occidentalis* are common woody plants.

This aquatic study was conducted in Fish Lake, a permanent wetland located on the Woodworth Station. In the recorded history of Woodworth Station, including the drought of the 1930's, Fish Lake has never dried completely.

Methods

Two field exposures were performed in 1993 to examine the effects of two fire suppressant foams, Phos-Chek WD-881 and Silv-Ex, on aquatic life. These tests were conducted as 96-h limnocorral exposures in both North Dakota and Missouri during summer 1993. The first field exposure was performed June 5-9 in Fish Lake, a permanent wetland, at the Northern Prairie Science Center's Woodworth Field Station near Jamestown, North Dakota. The second field exposure was performed August 2-6 in an experimental pond (0.4 ha) at the Midwest Science Center in Columbia, Missouri.

Limnocorral Exposures

Portable limnocorrals were used for both field exposures. Octagonal limnocorrals were designed to enclose approximately 2500 L of water so that chemical dosage could be accomplished without leakage into the surrounding open water area. They were constructed from 1.5″ schedule 40 polyvinyl chloride (PVC) pipe and fittings with a bottom edging of polyethylene to create a seal during placement into soft sediments. The limnocorrals were 2.5 m wide x 1.0 m high, and were encircled with 10-mil clear polyethylene plastic. The limnocorrals were built with a 4-way PVC center cross to strengthen the frame and divide the limnocorral into 4 quadrants. A 5-cm hole was drilled in the center to aid in positioning each limnocorral onto 1″ galvanized conduit pipe. Limnocorrals were consecutively numbered.

For the North Dakota field exposure, 24 locations with depths ranging from 55-60 cm were identified by placing 1″ galvanized conduit pipe at each location along a single transect in Fish Lake . This pipe was used for anchoring and positioning the limnocorrals and for attachment of the artificial substrates. The 24 limnocorrals in this field exposure (8 Silv-Ex, 8 Phos-Chek WD-881, 8 control) were positioned to enclose previously colonized artificial substrates 24 hours before chemical addition.

For preparation of the field exposure at the Midwest Science Center, conduit pipe was placed at 9 locations in a 3 x 3 block at 30-55 cm depths in the experimental pond. Nine limnocorrals (3 Silv-Ex at 6 mg/L, 3 Silv-Ex at 24 mg/L, 3 control) were anchored and positioned in the same manner as in the Fish Lake exposure, 24 hours before chemical addition.

Chemicals and Dosage

Based on laboratory tests conducted by the Yankton Field Research Station (Hamilton, 1993 Progress Report) using fire retardant liquids and suppressant foams, we determined that the foams Silv-Ex and Phos-Chek WD-881 were more toxic to aquatic organisms than the liquid retardants tested. For use in field exposures, concentrations representing the lowest observable effect level (LOEL) for these chemicals were calculated based on this laboratory test data for *Daphnia magna*. The LOEL was calculated as 6 mg/L for Silv-Ex, and 4.7 mg/L for Phos-Chek WD-881. These concentrations were used during the Fish Lake exposure.

To further delineate the effects of foams on aquatic communities, we conducted the second field exposure at the Midwest Science Center. Two exposure concentrations of Silv-Ex were used during this field exposure, one representing the LOEL (6 mg/L) and one representing 4 times the LOEL (24 mg/L). The highest concentration also approximated the laboratory-derived LC50 (concentration expected to induce 50% mortality in a population) for daphnids.

Chemicals were pre-weighed in the laboratory using a Mettler PE360 top-loading balance. Chemical doses were added as a liquid to a 23 L polyethylene container of lake water, then mixed and poured slowly into each limnocorral to avoid agitation. Chemical dosage was added to numbered limnocorrals in a randomized fashion in both field exposures.

Water Chemistry

Continuous Water Quality Monitoring – The variables of pH, dissolved oxygen, conductivity, and water temperature were measured at hourly intervals throughout the study period with DataSonde II units (Hydrolab Inc., Austin, Texas), self-contained submersible dataloggers. One unit was placed outside the limnocorrals in Fish Lake, and 6 units were deployed within randomly selected limnocorrals (2 Silv-Ex, 2 Phos-Chek WD-881, 2 control). Hydrolab units were suspended in the limnocorrals at mid-depth using stainless steel cable clamps. During the second field exposure at the Midwest Science Center, units were deployed in the same manner in each of the three treatments and in open water areas.

Dissolved Oxygen – A YSI dissolved oxygen meter was also used to measure dissolved oxygen between 0700-0900 daily in each limnocorral and in the open water (and the MSC experimental pond) throughout the test period during both field exposures.

Nutrients – One liter water samples were also collected from each limnocorral and the open water areas between 0700-0900 daily during both field exposures. Ammonia (APHA 1985) and orthophosphorus were measured daily throughout the test period. EPA method 365.1 (Colorimatic Automated Ascorbic Acid Method) was used for orthophosphorus determination. Nitrate and nitrite were measured once before and once after each 96-h exposure (APHA 1985).

Other Parameters – The pH was also measured daily from 1-L water samples. Chlorides, sulfates, alkalinity, and hardness were measured once before and once after each 96-h field exposure (APHA 1985). Depth-integrated chlorophyll a samples were collected daily throughout both field exposures with a 45.7 cm acrylic tube placed vertically in each limnocorral and plugged on the top with a rubber stopper. The fluorimetric technique with acetone extraction (APHA 1985) was used for chlorophyll a determination in both exposures. Filters used in this procedure were frozen for further laboratory analysis at the Midwest Science Center.

Single Species *In-Situ* Exposures

Cenocorixa – The water boatman *Cenocorixa* sp. (Hemiptera: Corixidae) was collected from Fish Lake in sufficient numbers for use in the first in-situ field exposure. Winged adults were collected on June 5 prior to chemical addition. Exposure chambers were constructed of 15-L polyethylene containers. For each chamber, 10 x 20 cm windows were cut and fit with 1-mm mesh polypropylene netting. One chamber with 10 Cenocorixa sp. was placed in each of the 24 limnocorrals 1 h after chemical addition. Chambers were suspended from each limnocorral frame. Number of organisms remaining alive was recorded daily throughout the 96-h exposure, with the exception of June 7; inclement weather with extremely high winds made access to the exposure chambers impossible on this day.

Fathead Minnows – An in-situ field exposure with 48-h old fathead minnows (*Pimephales promelas*) was also conducted in an experimental pond at the Midwest Science Center to better define the distribution of mortality for Silv-Ex exposure. Logistical constraints had prohibited use of these organisms in the North Dakota study. Environmental exposure chambers to contain the larval fathead minnows were constructed of 16 x 18 cm cylindrical polyethylene containers fit with stainless steel 0.5-mm mesh screening. The chambers were covered and placed on square polystyrene floats so that the screened portion of each chamber was below the water. Three chambers were placed in each of the 9 limnocorrals, and 3 additional chambers were placed outside the limnocorrals in the test pond. Twenty fathead minnow larvae were placed in each chamber and acclimated to pond water temperature for 2 hours. Chambers were placed inside each limnocorral 1 h after chemical addition. Number remaining alive was recorded daily throughout the 96-h exposure.

Community Effects

Aquatic Macroinvertebrates – The response of the macroinvertebrate community was evaluated in both the North Dakota and the Midwest Science Center studies using artificial substrate trays that were constructed of 1/2" mesh aquaculture netting (Memphis Net & Twine, Memphis, TN) with a base of PVC pipe and fittings. The tray base was designed specifically for placement into soft sediments. A 30-cm circle of knotless nylon netting was positioned underneath the trays to eliminate organism loss during sampling. The trays contained 5 g of pre-weighed, air-dried Cottonwood (*Populus deltoides*) leaves. Substrate trays were deployed with a PVC pole by pushing the base into the sediment, with tray and netting attached. A nylon pull cord attached to each substrate tray was fastened to the center conduit pipe that anchored and positioned the limnocorral. Substrate trays were sampled by pulling the nylon cord vertically, and placing the tray into a white pan. Substrate trays and nylon netting were placed in zip-lock bags and preserved with 90% ethanol.

For the field exposure in North Dakota, a total of 120 substrate trays were deployed during May 10-11 and allowed to colonize with organisms for 4 weeks before the 96 h dose on June 5. Five substrate trays were deployed at each of the 24 limnocorral locations. Single trays were placed in each limnocorral quadrant (Figure 1), and an additional tray was located immediately outside the corral area. The 24 trays outside the limnocorrals were sampled on June 4 before corral placement. One tray from each limnocorral was also randomly sampled on June 5 after limnocorral placement and before chemical addition to determine disturbance effects associated with limnocorral placement. The remaining 3 trays in each limnocorral were sampled at the end of the 96-h exposure.

For the field exposure at the Midwest Science Center, a total of 116 substrate trays were deployed in the experimental pond on June 20-21, and allowed to colonize with organisms for 6 weeks before the 96-h dose on August 2. Twelve substrate trays were deployed at each of the 9 limnocorral locations (3 for each quadrant), and 8 additional trays were deployed at locations around the outside of the exposure area. The 8 external trays were removed on August 1 before limnocorral placement. One tray from each limnocorral quadrant removed on August 2 after limnocorral placement and before chemical addition to determine disturbance effects. One tray from each quadrant was removed 24 h after chemical addition, and again after the end of the 96-h exposure. Substrate trays that were sampled after chemical addition were immediately washed, processed, and sorted with a #40 brass sieve and white pan to separate dead organisms from the sample before preservation. For a period of 10 min., dead organisms were removed and placed in a separate sample bottle, then preserved in 80% ethanol.

Zooplankton – An 18 x 25 cm aquarium net mounted on a PVC handle at a 100° angle was used to sample zooplankton from each limnocorral and the main lake during the North Dakota field exposure. The net was positioned at a 45.7 cm depth and drawn to the surface. Samples were washed into a bottle and preserved with 80% ethanol. One sample was taken from each limnocorral and 3 samples were taken from the main lake on June 5 before chemical addition. An additional sample was taken from each limnocorral 24 h and 96 h after chemical addition.

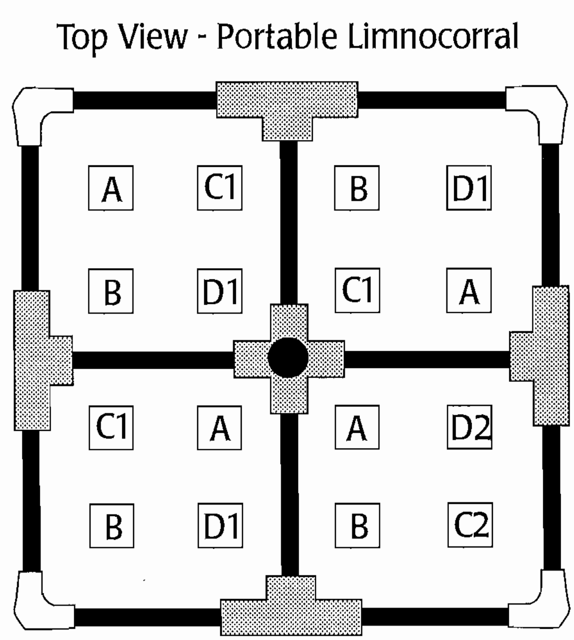


Figure 1. Schematic diagram of limnocorral illustrating placement of artificial substrate trays within each corral. Additional trays were also deployed in open water areas.

Results

Single Species Exposures

Cenocorixa – After 24 h, exposure to Silv-Ex at 6 mg/L resulted in significantly higher mortality of water boatmen (*Cenocorixa* sp.) than in controls ($p = 0.003$) (Figure 2A). The most dramatic decrease in survival (69%) occurred during the first 24 h, but survival continued to decrease throughout the 96-h exposure to Silv-Ex until only 11% of the organisms remained. Contrastingly, the 4.7 mg/L Phos-Chek WD-881 treatment did not cause mortality significantly different from that of controls during the 96-h experiment. However, organisms showed impaired movement that suggested a sublethal response related to chemical exposure.

Fathead Minnows – After 24 hours, the highest Silv-Ex treatment, 24 mg/L, resulted in significantly higher mortality than in the controls ($p = 0.02$) (Figure 2B). As was the case in studies with *Cenocorixa*, survival decreased markedly (64%) during the first 24 hours. After 96 h of exposure, 70 % of the fish had died. The 6 mg/L Silv-Ex treatment, which caused mortality of *Cenocorixa*, did not significantly reduce survival of fathead minnows as compared with controls during the 96-h experiment. In addition, survival of fish in the control limnocorrals was similar to survival of fathead minnows in the open pond, indicating no effects directly attributable to the limnocorral enclosures.

Water Chemistry

Fish Lake is an alkaline, extremely hard, well-buffered aquatic system. The pH ranged from 8.3 to 8.7 with mean hardness and alkalinity of 1345 and 766 mg/L as $CaCO_3$, respectively. In the North Dakota study, water quality conditions among limnocorrals were similar. Hourly data from Hydrolab units indicated that daily patterns in temperature, pH, dissolved oxygen, and conductivity did not differ among limnocorrals or between the corrals and the open water of Fish Lake during the exposure. Water temperatures dropped from 19 to 13°C during the study; this decrease in temperature was caused by a strong cold front on 7 June and resulted in below normal conditions for June in North Dakota. However, this temperature depression did not occur until day 3 of the study and thus, did not coincide with the high mortality observed after a 24-h exposure to Silv-Ex. Dissolved oxygen remained above saturation throughout the exposures and never represented a hazard to aquatic life. No dose-related fluctuations in phosphates, sulfates, chlorides, chlorophyll a, conductivity, or pH occurred during the exposure.

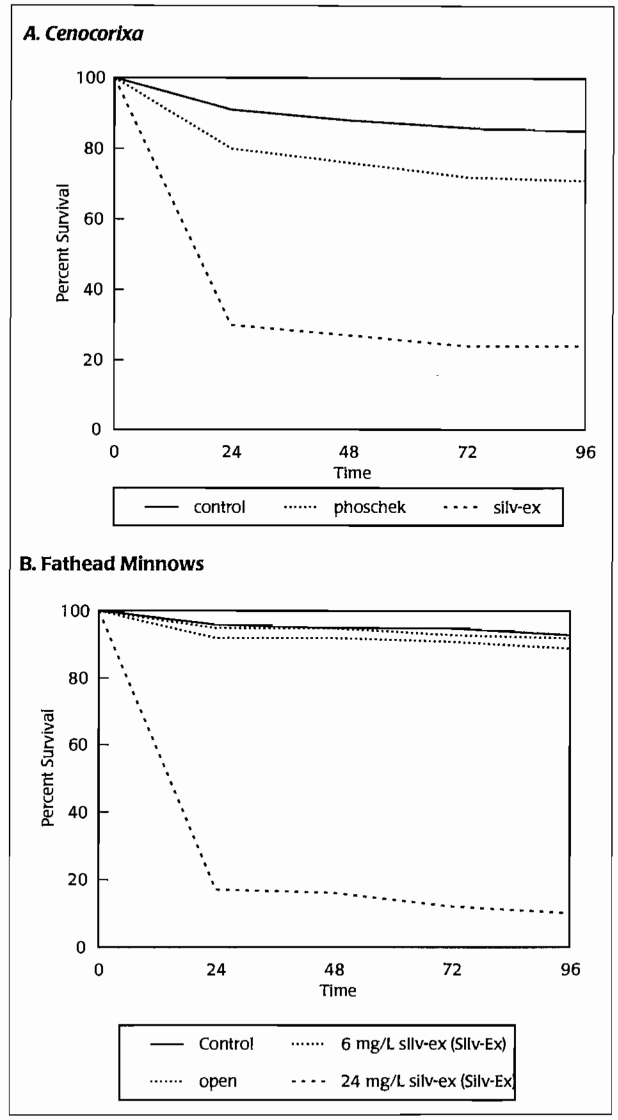


Figure 2A. Survival of *Cenocorixa* sp. (water boatmen) after 96-h exposure to Silv-Ex and Phos-Chek WD-881.

Figure 2B. Survival of fathead minnow larvae after 96-h exposure to treatments of 6 mg/L and 24 mg/L Silv-Ex.

Water quality patterns were also similar among limnocorrals as well as between the corrals and the open water during the study conducted in the Midwest Science Center's experimental pond. This pond is a hard, well-buffered aquatic system with pH ranging from 7.5 to 8.3, a mean hardness of 138 mg/l as $CaCO_3$, and a mean alkalinity of 133 mg/L as $CaCO_3$. Temperature during this exposure ranged from 21 to 26°C. Ammonia was the only water quality variable measured that was affected by treatment. Ammonia in limnocorrals containing the high dose of

Silv-Ex (24 mg/L) increased with time; this trend was not evident in controls or other treatments. However, unionized ammonia in the highest treatment never exceeded concentrations known to be acutely toxic to fish or invertebrates. No dose-related fluctuations in phosphates, sulfates, chlorides, chlorophyll a, conductivity, or pH occurred during the exposure.

Community Effects

Diversity of the aquatic macroinvertebrate community of Fish Lake was extremely low. About 80% of the organisms collected in the artificial substrate trays were chironomids and of these chironomids, two genera dominated the samples. No community-level effects resulting from either Silv-Ex or Phos-Chek WD-881 were evident after the 96-h exposure. Total number of organisms and relative abundance of organisms did not differ among treatments. The Pinkham and Pearson Similarity Index, a similarity index highly sensitive to community disturbance, indicated that for both total number of organisms and relative abundance, treatments did not differ from controls (Figure 3).

Macroinvertebrate samples from the Silv-Ex studies in the Midwest Science Center experimental pond have been sorted and sample identification is about 95% complete.

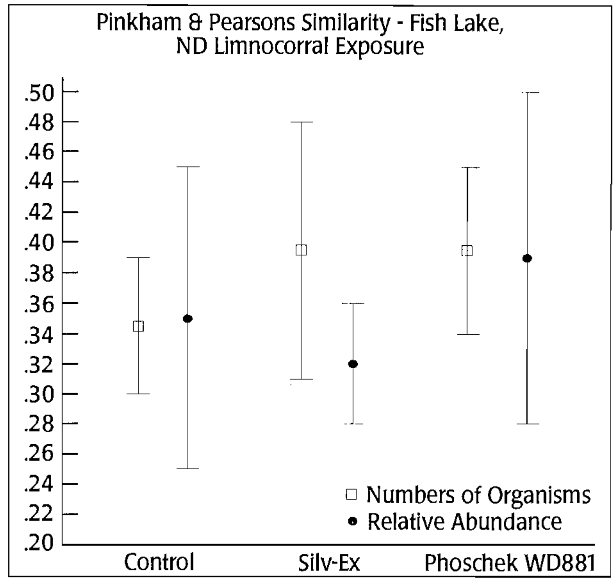


Figure 3. Pinkham and Pearsons Similarity Index calculated for total number of macroinvertebrates and for relative abundance in the North Dakota limnocorral study with Silv-Ex and Phos-Chek WD-881.

Discussion and Management Implications

Under field conditions, the toxicity of Silv-Ex to fathead minnows was similar to that observed in laboratory exposures. For fathead minnows, the Silv-Ex exposure (24 mg/L) that caused significant mortality under field conditions was within the confidence interval of the calculated laboratory LC_{50} for hard water (22 mg/L; 95% CI=17-28) (S. Hamilton 1993 Progress Report). In both instances, the highest mortality occurred during the first 24 hours (Figure 2). In the event of an actual spill or accidental overspray, an organism's response during the first 24 h is an ecologically relevant measure of the severity of a chemical effect. Chemical concentration would be highest at this time because degradation begins immediately; under laboratory conditions, Silv-Ex degrades by 42% in about 20 days (Norecol 1989). However, under natural conditions, that degradation may be accelerated.

In an actual field application example, the acutely toxic concentration of 24 mg/L Silv-Ex identified in our study is equivalent to a spill of 12 L (2.6 gallons) of an 0.5% Silv-Ex (500 mg/L) mixture directly into one 2500 L limnocorral (550 gallons). This equates to a dilution factor of 208 in a natural aquatic system. Therefore, in a pond or wetland environment one would expect mortality of larval fish to occur if a 0.5% Silv-Ex spill was not diluted more than 208 fold. Accordingly, if the Silv-Ex was applied at 1% (10,000 mg/L), the amount of Silv-Ex required to reach the acutely toxic concentration demonstrated in this study would be 6 L in the 2500 L limnocorral; the dilution factor would double to 416. Similar dilution factors are also suggested by Hamilton's data (1993 Progress report) for aquatic invertebrates such as amphipods.

A safety factor is often applied to toxicity data to estimate a "safe" or maximum acceptable toxicant concentration (MATC) for the protection of aquatic organisms. A safety factor of 100 is commonly used (Rand and Petrocelli 1984). Thus, a safety factor of 100 applied to toxicity information for a 1% Silv-Ex mixture from our study would require a 41,600-fold dilution. For example, in a one acre pond with an average depth of 10 feet, use of a safety factor of 100 would estimate that about 78 gallons of 1% Silv-Ex spilled directly into the pond would represent minimal hazard to aquatic organisms. Use of this safety factor provides a conservative value for the protection of larval fish based on results from our study. In the limnocorral exposures, no mortality of fish occurred at a concentration that would be equivalent to a spill of about 1600 gallons of 1% Silv-Ex in a one-acre pond. However, this same concentration resulted in significant mortality of water boatmen (*Cenocorixa*). It is likely that the mortality of Silv-Ex is related to the surfactants present in the formulation. In rainbow trout, Müller (1980) demonstrated that the toxicity of surfactants was related to their effect on surface tension. As surfactant concentration increased, surface tension decreased and toxicity to trout increased. Because the mobility of water boatmen is dependent on the surface tension of the water, it is likely that their mortality was directly related to the reduction of surface tension caused by Silv-Ex.

Another scenario through which fire-fighting chemicals affect the aquatic environment is by incidental overspray. If this were to occur with Silv-Ex and one were to assume the coverage across the water surface was even, the application of a 0.5% Silv-Ex mixture would result in a 23.6 mg/L chemical concentration in a 2500-L limnocorral. This exposure is similar to the concentration that resulted in significant mortality of larval fathead minnows in both field and laboratory exposures. However, it is highly unlikely that the entire surface of an aquatic system would be covered by a foam such as Silv-Ex. Thus, dilution of the area affected by overspray would occur rapidly. It is unlikely that a concentration as high as that predicted (23.6 mg/L) would actually occur. Nonetheless, organisms such as water boatmen and other invertebrates that utilize the water surface would suffer adverse effects from direct exposure resulting from the chemical application. These organisms along with other important invertebrates such as daphnids and amphipods must be considered as important components contributing to the integrity of an ecosystem. Although aquatic invertebrates are neither economically or recreationally important aquatic resources, they are an integral part of the food chain essential to the support of higher trophic levels such as fish.

Literature Cited

American Public Health Association (APHA) 1985. Standard Methods for the Examination of Water and Wastewater. 16th ed. Washington, D.C.

Müller, R. 1980. Fish toxicity and surface tension of non-ionic surfactants: Investigations of antifoam agents. J. Fish. Biol. 16:585-589.

Norecol Environmental Consultants, LTD. 1989. Toxicological review of fire fighting foams. (Report prepared for Manager, Fire Management Forest Protection Branch, Ministry of Forests and Lands, Victoria, BC, Canada.

Rand, G.M. and S.R.Petrocelli (eds.). 1984. Fundamentals of Aquatic Toxicology. Hemisphere Publishing, Washington, D.C.

Wildland fire extinguishing foams in Québec: The environmental aspect

Robert Langevin and Pierre-M. Marotte

Ministère des Ressources naturelles du Québec, Direction de l'environnement forestier, Service du suivi environnemental, 930 chemin Sainte-Foy, 6e étage, Québec (Québec), Canada G1S 4X5

Abstract

In the province of Québec, aerial applied forest fire extinguishing foams have been used since 1988. The Ministère des Ressources naturelles du Québec (MRN) is officially appointed to insure its safe use for the environment, in compliance with forest and environmental protection provincial laws. Its activities also include human health protection. Four products, Phos-Chek WD 881, Silv-ex, Forexpan, and Firefoam 103, are authorized for use by the Québec Environment and Wildlife Ministry.

Among the main achievements of the MRN was the publication, in 1991, of a "Fire Extinguishing Foams User's Guide," putting forward recommendations for workers and environmental protection during routine operations and accidental events, with Phos-Chek WD 881, the only product used so far. According to these recommendations, workers on information sessions as well as operational headquarters inspection take place periodically. Equally important, is the thorough hazard evaluation of all four authorized foams realized in 1992.

In the meantime, the MRN has conducted five field studies to evaluate Phos-Chek environmental impact and contamination. The effects of a spill on aquatic invertebrates living in a stream and foam phytotoxicity were studied. Waterbodies contamination by CL-215 or helicopter while bailing, and during regular firefighting operations with foam were investigated.

Résumé

Dans la province du Québec, on utilise depuis 1988 des mousses carboniques appliquées par voie aérienne pur lutter contre les incendies de forêt. Le ministère des Ressources naturelles du Québec a été officiellement chargé de veiller à ce que les produits utilisés soient sans danger pour l'environnement, conformément aux lois provinciales sur la protection de l'environnement et des forêts. Son mandat s'étend aussi à la protection de la santé humaine. Le ministère de l'Environnement du Québec et le Service canadien de la faune ont autorisé l'utilisation de quatre produits : Phos-Chek WD 881, Silv-ex, Forexpan et Firefoam 103.

Parmi les grandes réalisations du ministère des Ressources naturelles, en 1991, mentionnons la publication du Guide d'utilisation des mousses carboniques *contenant des recommandations en matière de protection des travailleurs et de l'environnement lorsque le produit Phos-Chek WD 881, le seul produit employé à cette époque, est utilisé dans le cadre des opérations courantes et des interventions d'urgence. Aux termes de ces recommandations, il faut organiser des séances d'information à l'intention des travailleurs et mettre sur pied un programme rigoureux d'inspection opérationnelle périodique effectué par l'administration centrale. Il faut également souligner l'évaluation approfondie des dangers qui a été menée sur les quatre produits autorisés en 1992.*

Dans l'intervalle, le Ministère a entrepris cinq études sur le terrain afin d'évaluer les effets sur l'environnement de Phos-Chek et le risque de contamination du milieu naturel par ce produit. On a étudié les effets d'un déversement sur les invertébrés aquatiques d'un cours d'eau et la phytotoxicité de la mousse. On a aussi étudié la contamination des plans d'eau par les mousses épandues par un CL-215 ou un hélicoptère pendant le largage du produit et au cours des opérations normales de lutte contre l'incendie.

Introduction

Since 1988, the ministère des Ressources naturelles du Québec (MRN) has been using the foam agent Phos-Chek™ as a short-term forest fire retardant. Within the MRN, the Direction de l'environnement forestier (DEF) has carried out several projects to ensure that the use of the product, and of several other brands of fire-extinguishing foams, could be safe for the environment or human health.

Legislative Context

Fire-extinguishing foams are generally made up of surfactants, solvents and various additives the use of which, either singly or in combination, is not governed by any specific standards in Québec. The DEF division of the MRN ensures, however, that they are used in compliance with the province's **Act respecting occupational health and safety** (R.S.Q., chapter S-2.1) and **Environmental Quality Act** (R.S.Q., chapter Q-2).

The main object of Québec's **Act respecting occupational health and safety** is to inform workers and ensure that they apply the information provided by product labels and material safety data, as well as follow the work procedures and use the safety equipment needed for safe product handling. The Environment Quality Act, in turn, states that "No one may emit ... into the environment ... a contaminant likely to affect ... human beings, ... the soil, vegetation, wildlife or property", and that "No one may ... carry on an activity ... if it seems likely that this will result in an emission ... of contaminants ... unless he first obtains from the Minister a certificate of authorization."

The certificate of authorization granted to the MRN gives it the right to use four brands of fire-extinguishing foam, Phos-Chek™ WD881, Silv-ex™, Firefoam™ 103 and Forexpan™ in its forest fire-fighting activities throughout Québec. These products may be dropped from an aircraft, at a maximum concentration of 0.6%. In return, the MRN has undertaken to follow the recommendations contained in the "Guide d'utilisation de la mousse extinctrice" (Guide for use of fire-extinguishing foam), that it published (MFO, 1991). The MRN has also undertaken to carry out an environmental monitoring program to ascertain, among other things, whether the buffer zones recommended in the guide, around watercourses, are adequate.

Guide for the Use of Fire-Extinguishing Foams

The guide for use of fire-extinguishing foams consists mainly of recommendations and working safety procedures directed at the various groups of workers potentially exposed to the foam concentrate or solution, in order to ensure both their protection and that of the environment during routine operations or accidents. In brief, the guide states that:

A A 100-metre buffer zone should be provided around every aquatic environment and residence, and no fire-extinguishing foam should be dropped in ecological reserves or national parks, except as a last resort.

B Sites where foam concentrate is handled or stored, and vehicles used to transport the product, must be equipped with the product safety data, a list of emergency telephone numbers, first aid equipment and the equipment needed for recovering the product in the event of spillage.

C Storage sites must be clearly identified, protected and, where possible, provided with a waterproof floor. The product label and date of purchase must appear on all containers which, in addition to being placed in double rows, must be inventoried regularly.

D Depending on their particular duties, employees involved in handling the product must wear cotton overalls, rubber gloves and boots as well as protective goggles, and have ready access to masks protecting against organic vapours, if needed.

E Water bombers loaded with foam concentrate should be inspected internally on a regular basis to detect any leaks. Scooping operations should not be carried out near a residential zone or a drinking water intake. Foam concentrate should be injected into the plane's water tanks at a distance from any body of water. After foam dropping is completed, water bombers must first be rinsed out over the forest, followed by a scooping with overflow.

Lastly, the guide gives a brief description of the procedure to be followed in cases of accidental spillage of the product or contact with workers skin, by swallowing or inhalation. All accidental spillages of the product in the environment (including inhabited zones or zones in which humans are present), all injury to a worker's health and all complaints from the public directly concerned with the use of foam must be reported to government authorities, on the appropriate forms.

Workers Training

The various recommendations and procedures included in the guide for use of fire-extinguishing foams form the basis of the training that should be provided for all workers involved in fighting forest fires using foam. The training is completed by a brief description of the toxicity of the product and the foam solution as well as of pathology and potential impact of exposure to either, whether for animals of humans.

Airbases Inspection

Inspection of water bomber bases where foam concentrate is stored allows to check whether the safety measures set out in the guide are being applied on the sites, and to suggest corrective measures where necessary.

Because of recent observations made during visits to airbases, the DEF now recommends that, beginning in 1994, foam concentrates that have remained unused for over a year be homogenized at the beginning of each season to prevent product stratification and potential loss of effectiveness. Furthermore, containers of concentrate should not be kept only partly filled, for this leads to product crystallization and thus to a potential loss of product effectiveness and blockage of the foam concentrate injection system aboard water bombers. Moreover, since foam concentrate injection systems seem to be less precise with time, the MRN intends to proceed to their regular re-calibration.

Bibliographical and Laboratory Studies

In 1992, in collaboration with the ministère de l'Environnement et de la Faune du Québec (MEF), the DEF assessed the ecotoxicological hazard (Bernier and Martel, in preparation) associated with the four fire-extinguishing foams the MRN is authorized to use. The assessment was based, on the one hand, on data provided by available scientific literature bearing on the degradability, mobility, bioaccumulation and toxicity (for mammals and aquatic organisms) of the individual components of each type of foam and, on the other hand, on the results of the bioassays carried out by the MEF, on each formula, in order to determine its toxicity in relation to various aquatic organisms and land plants.

The results of this assessment carried out in a conservative fashion, since available literature data was limited, show that the four formulae present an average level of ecotoxicological hazard. The products are characterized by rapid degradation of most of their components (except for the solvent), by average mobility and by low bioaccumulation potential. Their toxicity was found to be low in relation to land organisms and relatively high in relation to aquatic organisms.

Following the health concerns expressed by some ground fire fighters, the DEF asked the Centre de toxicologie du Québec (CTQ) to assess the foam combustion gazes toxicity. Although available literature data is limited, the CTQ considers that the combustion gases of the four foams authorized in Québec do not add any extra toxicological hazard to fire-fighters to those of the combustion gases of the forest.

Environmental Monitoring

Since 1988, the DEF has carried out several on-site studies in order to assess environmental contamination by foam and/or the impact of foam on the forest biota, either following actual fire fighting operations using fire-extinguishing foam or during simulations.

Phos-Chek™ 861 was dropped from a low altitude, in the absence of fire, on a healthy forest stand composed of trees, bushes, grasses and mosses, in order to assess the phytotoxicity of the product. The stand was monitored for 11 months after the drop, and only a discolouring and yellowing of the leaves of certain plants was observed after the first week following the operation. The year after, flowering and fruit growth were found to be normal (Cimon, 1991).

To assess environmental contamination by Phos-Chek™, the MRN organic chemistry laboratory developed a method to analyze water for its content of alfa olefin sulfonate (AOS), the main component of the formula. AOS being, however, rapidly biodegradable, a method was later developed to analyse air and water for their content of hexylene glycol, an important component of the formula characterized by its low biodegradability (Marmarbachi and Carmichael, 1990 and 1992).

Following the health concerns expressed by some water bomber pilots, the DEF assessed the cockpit air contamination of two planes used to transport Phos-Chek™ WD 881 during 11 forest fire fighting missions. Hexylene glycol was found in only one of the air samples, at a level 744 times lower (0.168 μg/1) than the working standard established by OSHA (125 μg/1) (Bertrand and Rousseau, 1990).

The DEF also carried out three studies to assess the contamination of a lake by fire-extinguishing foam following various sequences of dropping and scooping, using either a CL-215 or a helicopter. In the first case, none of the water samples taken from the scooping trajectory and from the shoreline contained a detectable quantity of AOS (detection limit = 300 μg/l), after a sequence of scooping and dropping operations with Phos-Chek™ WD 861, using a CL-215 (Parent and Cimon, 1989). In the second case, none of the water samples taken from the rinsing trajectories contained a detectable quantity of AOS, after a sequence of scooping and dropping operations with Phos-Chek™ WD 881, followed by a rinsing operation with overflow, using a CL-215 (Cimon, 1990). In the third case, none of the water samples taken from the scooping trajectory contained a detectable quantity of hexylene glycol (detection limit = 50 µg/l), after a sequence of scooping and dropping operations with Phos-Chek ™ WD 881, using a helicopter equipped with a bambi (Dostie, 1992).

Small forest streams covered with vegetation, which water bomber pilots can find hard to detect, could be accidentally sprayed with a foam solution during dropping operations. The results of the ecotoxicological hazard assessment performed jointly by the DEF and the MEF having shown the particular sensitivity of the aquatic environment to the foam, such an event was simulated by injecting Phos-Chek™ WD 881 concentrate into a small stream, in order to assess its impact on aquatic insects. When compared to data collected in a control station, the results showed that injection of the concentrate led to a temporary but highly significant increase in insect drifting and death rate, limited, however, to the four hours immediately following the dropping. During the same period, the highest concentration of hexylene glycol measured at the drifting sampling site was 51 ppm (Savignac, 1994).

Lastly, since 1993, the DEF has carried out environmental monitoring of regular forest fire fighting activities using Phos-Chek™ WD 881. The monitoring involved sampling the soil and water near or on the site of foam dropping operations. The objective was to assess both the effectiveness of the buffer zones around bodies of water and the toxicological risk for land and aquatic fauna following dropping fire-extinguishing foam. Up till now, almost 50 composite soil samples and 25 (triplicate) water samples have been collected. Analysis of the latter for their hexylene glycol content, and interpretation of the results, has yet to be completed. In parallel with the environmental monitoring, observations of worker safety in relation to the use of fire-extinguishing foam are being carried out (protective equipment, work procedures, health hazards).

Conclusion

The MRN believes that the greatest attention should be paid to preserve human and environmental health, when using forest fire-extinguishing foam. Therefore, the MRN, first, stresses the importance of acquiring adequate data on the fate and toxicity of the formulae to be used and their components. Proper preventive measures should then accordingly be set up and communicated to the foam users. Moreover, environmental monitoring as well as foam equipment and ground installations inspection should be performed on a regular basis. As far as the four products authorized in Québec are concerned, further research is particularly needed on their bio-degradability, fate and persistence as well as on the frequency and extent of exposure of the foam users and the aquatic environment. Special attention should be paid to the aquatic environment exposure and the subsequent impact on its various trophic levels.

Bibliography

Bernier, N. and L. Martel, in preparation. Étude écotoxicologique de quatre mousses extinctrices utilisées pour lutter contre les feux de forêt, Québec, gouvernement du Québec, ministère des Ressources naturelles, Direction de l'environnement forestier, Service du suivi environnemental, et ministère de l'Environnement et de la Faune, Direction des laboratoires, Module d'expertise écotoxicologique et d'orientation.

Bertrand, N. and G. Rousseau, 1990. Concentrations d'hexylène glycol retrouvées dans l'air à l'intérieur de la carlingue d'avions CL-215 utilisant un agent moussant pour la lutte contre les feux de forêt, Québec, gouvernement du Québec, ministère de l'Énergie et des Ressources, Direction de l'évaluation environnementale, publ. n° ER90-3138, 13 p.

Cimon, A., 1990. Rinçage avec débordement d'un avion-citerne CL-215 après usage de mousse extinctrice: impact sur un plan d'eau naturel, Québec, gouvernement du Québec, ministère de l'Énergie et des Ressources, Service des études environnementales, 5 p.

Cimon, A., 1991. Évaluation de la phytotoxicité de la mousse extinctrice Phos-ChekMD WD 861, Québec, gouvernement du Québec, ministère de l'Énergie et des Ressources, Service des études environnementales, 13 p.

Dostie, R., 1992. Utilisation de la mousse extinctrice par un hélicoptère pour le combat des feux de forêt, Québec, gouvernement du Québec, ministère des Forêts, Direction de l'environnement, Service du suivi environnemental, 8 p.

Mamarbachi, G. and M. Carmichael, 1990. Méthodes d'échantillonnage et d'analyse de l'hexylène glycol dans l'air, Québec, gouvernement du Québec, ministère de l'Énergie et des Ressources, Direction de la conservation, Service des études environnementales, publ. n° ER90-3127, 11 p.

Mamarbachi, G. and M. Carmichael, 1992. Méthode d'analyse de l'hexylène glycol dans l'eau de surface, Québec, gouvernement du Québec, ministère des Forêts, Direction de la recherche, Service des laboratoires, 5 p.

MFO (ministère des Forêts), 1991. Guide d'utilisation de la mousse extinctrice dans la lutte contre les feux de forêt au Québec, Québec, gouvernement du Québec, ministère des Forêts, publ. n° FQ91-3036, 18 p.

Parent, G. and A. Cimon, 1989. Évaluation des concentrations et de la persistance de la mousse extinctrice Phos-ChekMD WD 861 en milieu aquatique, Québec, gouvernement du Québec, ministère de l'Énergie et des Ressources, Service des études environnementales, publ. n° 3379, 10 p.

Savignac, R., 1994. Évaluation de l'impact d'un largage simulé de mousse extinctrice sur la communauté des insectes aquatiques d'un ruisseau, Rapport préliminaire, Cap-de-la-Madeleine, Qué., G.D.G. Environnement Ltée. pour le gouvernement du Québec, ministère des Ressources naturelles, Direction de l'environnement forestier, Service du suivi environnemental.

Group Recommendations

Group Recommendations
Thunder Bay Symposium Participants

Recommendations	Rank	Time to Complete	Chance of Success	Cost Estimate U.S. Dollars
Foam properties Group				
1. Develop an end-use matrix, by product, for all properties, including storage.	H	Ongoing	Good	Supplier Cost
2. Develop a technical use matrix, by product, for all properties. Include all uses (Fixed Systems).	H	Ongoing	Good	Supplier Cost
3. Educate or train end users on properties to level required using existing training materials. Include NFPA 298.	L	Done— Now Need Implementation	Excellent	Low
4. Concentrate the concentrate to facilitate logistics.	L	Long-Time 5-10 Years	Fair	———
Foam Effectiveness Group				
1. Tie performance of foam products to existing list of properties ("X") through continuing tests of all sorts.	H	1-3 Years	Excellent	----
2. Educate or train end users	H	1-3 Years	Excellent	----
Foam and the Environment Group				
1. Biodegradability (Spec. 298).	H	1 Year	High	$50K
2. Inhalation Toxicity				
—Foams	L	1 Year	High	$60K
—Combustion/smoke interaction	M	1 Year	High	$100K
—Vapor toxicity concentrates	M	1 Year	High	$60K
3. Mobility (fate, persistence and entry to water systems) —Concentrates —Materials as applied —Soils (Geographic variations) (Costs based on 8 products).	H	3 Years	Medium	$3-500K
4. Monitoring water body contamination operationally by bucketting, scooping, engines, and other operations.	H	5 Years	High	$200K/Year
5. Interaction of foam/retardants on aquatic and terrestrial systems, (how prevalent is this operationally).	M	3 Years	High	$200K/Year
6. Foams that are more environmentally friendly.	Inform/monitor market developments.			

Recommendations	Rank	Time to Complete	Chance of Success	Cost Estimate U.S. Dollars
7. Better communication/exchange between wildland fire chemical researchers. Input/interchange between researchers and tactical 'operations' types.	H	Ongoing	High	Negative cost
8. Faster technology transfer of interim and final results. Investigate electronic mail/bulletin board options. Retain the Foam Newsletter. Poll researchers regularly for updates on research.				
9. Broaden Interior studies to include all approved retardants and foams. Need to share retardant formulations. (Could look at selection of chemical in study to choose a foam more representative of those in field.) Should conduct chinook tests.	VH	Ongoing	High	$25K
10. User Guidelines (interim/ updates). Spot and/or Fixed Operations—Mobile Operations (engines/portable equipment). On-site applications.	H	1 Year	High	Program Funding
Foam Application & Use – Ground Group				
1. Environmental Effects Video	H	1.5 Years ++	++	$30K (USP)
2. Foam Equipment Guide				
3. A broad review of International Foam Specifications to be distributed to Foam Newsletter recipients.	H	2 Years	Good	$8K (camera ready)
4. Foam Chemicals Properties Matrix	H	2-5 Years	Good	$2K (camera ready)
5. Technology transfer between agencies including continuing Foam Newsletter.	H	Ongoing	Good	---
6. Expand H2O handling. USA Position (ICS) to include technical foam knowledge.	H	2-4 Years	Good	*
7. Encourage manufacturers to produce desired products such as: lightweight accurate proportioners and CAFS unit.	H	Ongoing Workshop Objective	High	---
8. Decision/ring/Users' Guide	M	1-2 Years	Good	$3-10K
9. Field kit for testing proportioners (test proportioners direct from manufacturers).	L	2 Months	High	$2K equipment

* Close coordination w/NWCG TWT/ICS WT

Recommendations	Rank	Time to Complete	Chance of Success	Cost Estimate U.S. Dollars
Foam Application and Use - Air Group				
Review of International Foam Specifications to Address:				
1. Product testing with water temperature to 0°C/32°F.	H	OVERDUE		
2. Product testing with product flow at 0°C/32°F.				
3. Product testing with deep-cycle freezing to -30, -40°C.				
4. Product shelf life up to 3 years.				
5. Address compatibility of products. (What happens when mixed together).				
6. Address corrosion problems. Experienced with some applications.				
7. Container recycling issues.				
Development of Foam vs. Fire (Aerial Application) Guidelines:	H	10/95		$15K Plus Travel
1. Establish Canada/U.S. working group to complete guidelines.				
2. Environmental application considerations.				
3. Optimum drop height/speed.				
4. Optimum load application.				
5. System calibration.				
Effectiveness Study of Coverage Levels, Load Size vs. Fuel Types and Fire Intensity:	H			
1. Foam use in F/W airtankers in U.S. should be studied with the purpose of issuing a specification and authorization for use.	M			
2. Support the continued study and testing of foam and long-term retardant mixes.	L			
3. Recognizing the value of the exchange of information occurring through the Fire Equipment Working Group and the Foam Workshop, recommend that an Air Operation and Air Attack International Working Group be established at the operational level.	H	1995		

List of Participants

List of Participants

Karan Aquino, Director
Aviation, Flood and Fire Mgmt Centre
Ministry of Natural Resources
70 Foster Drive, Suite 400
Sault Ste. Marie, Ontario, P6A 6V5
705-945-5700

Peter Armstrong
210-301 Weston St.
Winnipeg, Manitoba R3E 3H4
204-784-2030; fax 204-956-2398

Eric Astley
Aviation, Flood and Fire Mgmt Centre
Ministry of Natural Resources
70 Foster Drive, Suite 400
Sault Ste. Marie, Ontario P6A 6V5
705-945-5769

R.P. (Bob) Bailey
Dept. of Renewable Resources
P.O. Box 7
Fort Smith, NT X0E 0P0
403-872-7700; fax 403-872-2077

Cynthia Bailor
Labat-Anderson Incorporated
2200 Clarendon Blvd, Suite 900
Arlington, VA 22201
703-525-5300 ext 520

Klaus Barth
Dept. of Natural Resources & Energy
Forest Fire Management Branch
P.O. Box 6000
Fredericton, N.B. E3B 5H7
506-453-2530

Judi Beck
B.C. Ministry of Forests Protection Branch
2nd Floor, 31 Bastion Square
Victoria, B.C.
604-387-5787

Bob Beck
c/o Ministry of Forests
1265 Dalhousie Dr.
Kamloops, B.C., V2C 5Z5
604-371-6584; fax 604-828-4863

Charles Bedsoe
Texas Correctional Industries
P.O. Box 99
Huntsville, Texas 77342
409-294-6032
Fax 409-294-6040

Richard Bielen
National Fire Protection Research Foundation
1 Batterymarch Park
Quincy, MA, 02269
617-984-7279

Christine Boivin
Labat-Anderson Incorporated
2200 Clarendon Blvd, Suite 900
Arlington, VA 22201
703-525-9400

Ed Bons
Ontario Ministry of Natural Resources
Northwest Regional Office
1580 West Arthur Street
Thunder Bay, Ontario P7C 5G6
807-473-2227
Fax 807-473-5823

Roger Boutot
Dept. of Natural Resources & Energy
21 Costigan St., Edmunston, N.B. E0L 1W7
506-735-2040; fax 506-735-2042

Dave Brown
Alberta Environmental Protection
Land & Forest Service
P.O. Box 175
Spirit River, Alberta T0H 3G0
403-864-3865

Bill Carey
Underwriters Laboratories, Inc.
333 Pfingsten Road
Northbrook, IL 60062
708-272-8800 ext 42219; fax 708-272-2020

E. Sven Carlson
New Hampshire Forest Protection
RFD #1, Box 479
Center Harbor, N.H., 03226
603-253-6482

Mike Crowley
U.S. Forest Service
Aerial Fire Depot
Box 6, Airport
Missoula, Montana 59802, USA
406-329-4956

Terry Curran
Fire Science Specialist
Ministry of Natural Resources
108 Saturn Avenue
Atikokan, Ontario P0T 1C0
807-597-2734

Bogdan Z. Dlugogorski
National Research Council, Canada
Institute for Research in Construction
National Fire Laboratory
Ottawa, Ontario K1A 0R6, Canada
613-993-9727; fax 613-954-0483
emaiL: BODZIO@NFL.IRC.NRC.CA

Hank Dominguez
USDA Forest Service
Rocky Mountain Region
Broomfield, Colorado 80021, USA
303-275-5724

Sam Duncan, US Dept. of the Army
Tank - Automotive Research
Development and Engineering Centre
Fire Research & Development
Fort Belvoir, VA 22060-5818
703-704-1840

C. Bruce Edwards
Firetech Engineering Inc.
1373 St East 15 St
N. Vancouver, B.C.
604-983-3774; burn site: 604-547-6470

Roger D. Erb
NIFC - USFWS
3905 Vista Ave.
Boise, Idaho 83705
208-387-5595

Alice R. Forbes
Assistant Director OPNS
USDA Forest Service
6101 Airport Rd.
Redding, CA 96002
916-246-5270

Chuck George
USDA Forest Service
NWST, P.O. Box 8089
Missoula, Mt. 59807
406-329-4815

John Hadley
Ministry of Natural Resources
70 Foster Drive, Suite 400
Sault Ste. Marie, Ontario
705-945-5799

David Hahn
Training and Standards Officer
Territorial Forest Fire Centre
Dept. of Renewable Resources
Box 7, Fort Smith, NWT X0E 0P0
403-872-7700; fax 872-2077

Steven J. Hamilton, Ph.D
National Biological Survey
R.R. 1, Box 295
Yankton, South Dakota 57078
605-665-9217

Mark Heathcott
Jules Leger Building
25 Eddy Street
Hull, Quebec K1A 0M5
819-994-2912; heathcottm@ncr.dots.doe.ca

Ed Herrington
Ministry of Natural Resouces
P.O. Box 5000
Thunder Bay, Ontario P7C 5G6
807-473-2204

Doug Higgins
CFS, PNFI
Chalk River, Ontario K0J 1J0
613-589-3182

Elwood F. Hill
Patuxent Wildlife Research Centre
11510 American Holly Dr.
Laurel, MD 20708-4017
301-497-5720

Tom Irving
R.R. 3 Lakeshore Rd.
Port Alberni, BC V9Y 7L7
604-723-6225

Bob Joens
HCR 7, Box 280
Houston, Mo 65483
417-967-4959

Cecilia Johnson
USDA Forest Service
NWST - P.O. Box 8089
Missoula, Mt 59807
406-329-4819

Ralph Kermer
Forest Fire Mgmt. Officer
Renewable Resources, Box 240
Fort Simpson, NWT X0E 0N0
403-695-2231

R. Randy Lafferty
MacMillan-Bloedel Ltd.
65 Front St.
Naniamo, B.C. V9R 5H9
604-755-3426

Robert Langevin
Min. Ressources Naturelles
Dir. Environnement Forestier
930 Ch. Ste-Foy, 6e
Québec, Québec G1S 4X5, Canada
418-646-9026

Dr. Diane Larson
Northern Prairie Science Centre
National Biological Survey
Rt. 1, Box 96C
Jamestown, ND 58401
701-252-5363

François Lefebvre
Société de protection des forêts contre le feu
Aéroport intn'l Jean-Lesage
715, 7ième rue
Sainte-Foy, Québec G2E 5W1
418-871-3341

Gaetan Lemaire
Société de protection des forêts contre le feu
Aéroport intn'l Jean-Lesage
715, 7ième rue
Sainte-Foy, Québec G2E 5W1
418-871-3341

Gord Luke
Ministry of Natural Resources
P.O. Box 5000
Thunder Bay, Ontario P7C 5G6
807-475-4472

Daniel Madrzykowski
National Institute of Standards & Technology
Bldg 224, Rm A345
Gaithersburg, MD 20899
301-975-6677; fax 301-869-3531

Wayne Martin
Sup. Fire Mgmt. and Co-ordinator
NFLD Forest Service
Box 2006
Corner Brook, NFLD A0L 1K0
709-637-2416

Dan W. McKenzie
USDA Forest Service
Technology and Development Center
444 E. Bonital Ave.
CA, 91773
909-599-1267

Wayne Mitchell
CA Dept. of Forestry & Fire Protection
P.O. Box 944246, Room 1646-1
Sacramento, CA, 94244-2460
916-653-5708

Tim Norman
Superior Nat. Forest
Gunflint Range District, Box 790
Grand Marais, Mn, 55604
218-387-1750

C.J. Ogilvie
5320 - 122 Ave.
Edmonton, Alberta, T6H 3S5
403-435-7283; fax 403-435-7359

Ken O'Neal
P.O. Box 907
UFSFS, Baker City, OR 97814
503-523-1415

Sig Palm
USDA Forest Service
444 East Bonita Ave.
San Dimas, CA 91773
909-599-1267

Rick Pedersen
Manager, Air Operations
Territorial Forest Fire Centre
Dept. of Renewable Resources
Box 7, Fort Smith, NWT X0E 0P0
403-872-2103

Serge Poulin
Canadian Interagency Forest Fire Centre
210-301 Weston Street
Wnnipeg, Manitoba R3E 3H4
204-784-2030; fax 204-956-2398

Gordon Ramsey
CFS, PNFI
Chalk River, Ontario K0J 1J0
613-589-3183

Steve Raybould
USDA Forest Service
444 East Bonita Ave.
San Dimas, CA 91773
909-599-1267

John V. Reid
Bombardier Inc./Canadair
Amphibious Aircraft Division
400 Cote Vertu Road
Dorval, Quebec H4S 1Y9
514-855-7631

Bob Sabol
12852 Park One Drive
Sugar Land, TX 77478
713-240-8828

Paul M. Schlobohm
BLM - NIFC
3905 Vista Ave.
Boise, ID, 83705
208-334-1317

Roger A. Spaulding
US Fish & Wildlife Service - NIFC
3905 Vista Ave.
Boise, Idaho, 83705
208-387-5595

Joe Stam
State of Alaska DNR
P.O. Box 35005
Ft. Wainwright, Alaska 99703
907-356-5529

Mark Stanford
Texas Forest Service
Highway 59 South
Lufkin, TX 75901
409-639-8100

Tom Staydohar, DNR
Assitant Fire Cache Manager
402 SE 11th St.
Grand Rapids, MN 55744
218-327-4579

Jim Stumpf
4200 N. Westview Wy.
Boise, ID 83704
208-327-0604

Reidar Vollebekk
Ministry of Natural Resources
70 Foster Drive, Suite 400
Sault Ste. Marie, Ont. P6A 6V5
705-945-5772

Nimish Vyas
Patuxent Wildlife Research Center
Wildlife Toxicology Group
11510 American Holly Dr.
Laurel, MD 20708
301-497-5721

Gordon Watkins
Box 900
Banff, Alberta T0L 0C0
403-762-1423

Keith Watts
Forest Fire Protection Specialist
Dept. of Forestry and Agriculture
North West River, Labrador A0P 1M0
709-497-8485

Bill Wiedenhoeft
Ministry of Natural Resources
Box 850, Dryden, Ont. P8N 2Z5
807-937-4402

Brian Wotton
Department of Natural Resources
Box 2019
Steinbach, Manitoba
204-326-4471

Appendix 1

Exchange of information brief

Presented by Klaus Barth

on Behalf of the New Brunswick Forest Service to the
International Wildland Fire Foam, Symposium and Workshop in Thunder Bay, Ontario

May 3-7, 1994

The Province of New Brunswick is only a small area when compared to the land mass of Canada, and even smaller on the map of North America. However, the Province has a colourful history and some dubious distinctions. Earlier presentations this week mentioned the Miramichi fire. It occurred about 165 years ago, burned over an area of 1.8 million hectares, is the largest recorded fire in North America, and telltale signs of that event are still visible today.

Wildfires are still common today in New Brunswick, however they are no longer tolerated and we don't let them burn over the winter any more. New Brunswick today practices intense Forest Management and the annual allowable cut is more or less the same as the annual growth. Today, about one in eight New Brunswickers' livelihood is tied to our forests. So, we have tailored our Fire Management activities to protect our forests to the highest degree. This meant the inclusion of the use of foams to fulfil our mandate.

Foam use in New Brunswick is divided into two chapters, with 1988 representing the turning point. Prior to 1988 we experimented with educators. As of 1988, we turned the use of foam into a fireline tool, when efficient discharge side proportioners came on line.

Since Research and Development in Fire is not supported by funding in my province per say, we rely on the Canadian Committee on Forest Fire Management; Equipment Working Group, the Petawawa National Forestry Institute and to an ever increasing degree on the National Wildfire Co-ordinating Group for our progress. We do have a research system. We are most fortunate that this system is supported by senior management and I will call it the TGIF system.

The fact that it is Friday today has nothing to do with it and "To Greatness In Foam" is coincidental. TGIF actually means:

T - TRAVEL
G - GLEAN
I - INVESTIGATE
F - FORMALIZE

In short, R & D to us means "Glean and Adopt".

Our operational foam use began through the Petawawa National Forestry Institute and set the stage. There are two individuals from that Institute in this room who have acted as the catalysts and mentors: Mr. Gordon Ramsey and Mr. Doug Higgins. It was their invaluable assistance that pointed us in the direction we have followed since.

Why did we decide to use foam:

A. Cost Reduction
B. Increased Efficiency

Implementation

New Brunswick's initial attack system consists of a fleet of 66 fire tankers and our air tanker fleet. Our aircraft are the well known TBMs. I know for the aircraft enthusiasts in this room it may be of interest (and I hope I am correct) that New Brunswick owns and operates the largest intact fleet of TBMs in the world. And yes, they fly too. They drop only retardant, foam or a mixture thereof.

Efficient water use is critical to be cost effective. Therefore, we opted to upgrade our tanker fleet first since funds were limited. The refits began in 1988. We selected The Flow Mix 500 Proportioners as our standard. It is at this point that I would like to thank a third person in this room, Mr. Dan McKenzie, USDA Forest Service, San Dimas, CA. Dan's comprehensive and up-to-date knowledge in foam generation systems has proven not only to be accurate and most beneficial, but it continues to be so.

The rationale was and still is to pay more for efficient hardware and use less foam concentrate, rather than let the foam concentrate compensate for the less efficient hardware.

Now that our tanker fleet conversion program is all but complete, we are beginning to turn our attention to pumps and mop up. The first 6 Flow Mix 500 field units are now on line.

This process may seem slow and deliberate and, in fact it is, but we have only limited financial resources. More importantly, we learned very early in the process that training is the key to cost efficient use of foam. Training is time consuming and constantly in a catch-up position.

The prevailing practice has always been, when using straight water, that a little is good and a lot is much better. Now that foam has entered into wide spread use in my Province, we expected a change in thinking. But, as it turned out, old habits have enormous stamina.

We selected the Flow Mix 500 for cost effectiveness. It was, and we believe it still is, the most versatile unit for our application. It is, if properly used, more environmentally friendly then the educator types, because it uses less foam concentrate. It requires in our case no additional manpower and it has no negative impact on our fireline practices. For example, the pump operator can maintain both the pump and the proportioner and the hose line pressure loss to add foam is not noticeable. In our case, one unit type does pump and fire tankers, just as we had planned and hoped.

Foam does have limitations: (1) chip piles; (2) peat bogs.

Foam does help, but alone cannot do the job.

Most, if not all, aspects of foam use have been said this week, so a repeat is not required.

However, we still have concerns.

1. Personal Health and Safety

This area is now in the forefront, and we do NOT have all the answers. For example, is the product we are using the same one that received approval? Does our mixing of concentrates create new compounds? Are we storing it correctly?

We have documented cases where a few individuals had very unpleasant side effects after the exposure to concentrates and in some cases solutions.

We have and will continue to monitor all future undesirable occurrences very closely.

2. Environmental Impact

New Brunswick may be unique. For almost 40 years aerial spraying has been conducted to keep the spruce budworm in check. We prefer that foam not become the next controversy. In fact, we will do whatever is necessary and take any precautions required and feasible to limit the environmental impact.

However, I do not want to end on this note.

Foam is a valuable fire fighting tool and will prove to be the next best thing to sliced bread.

We believe that so strongly, that the New Brunswick Forest Service actively coaches and encourages municipal and rural fire departments to get involved. There is success, but resistance to change is a hard thing to overcome. I would like to report on the success. Fire departments, that have converted to foam using discharge side proportioning system are now enthusiastic supporters of foam.

To conclude, I strongly believe, manufacturers and end users of foam must work closely together on one major concern. We all want to remain in good health, and we only have one mother earth to do it on. So the health and safety aspects as well as environmental concerns must continue to be in the forefront.

Thank you.

Appendix 2

How to use a standard conductivity meter to determine foam solution percent

Dan W. McKenzie

Mechanical Engineer, USDA Forest Service, San Dimas Technology & Development Center

Jim Bronner

Bronner Chemical, Glendale, California

In the last issue of "Foam Applications for Wildland & Urban Fire Management", information was provided on where to purchase standard conductivity meters for use in determining the percent of Class A foam concentrate in a foam solution. Instructions for using a conductivity meter to determine foam solution percent were not included. There are two methods that can be used, a "field method" (sometimes known as a "quick and dirty method") and a more accurate and time consuming "laboratory method".

To use the "field method", take the conductivity of the water and the conductivity of the foam solution made from the water. Now subtract the conductivity of the water from the conductivity of the foam solution and divide by 500. This will give the percent of foam concentrate in the foam solution.

$$\frac{\text{Conductivity of foam solution} - \text{Conductivity of water}}{500} = \%\ \text{foam}$$

Note: 500 is used assuming that the conductivity meter units are uS/cm (microsiemens/cm). The divisor 500 is also used assuming the foam concentrate is Silv-Ex, Fire Foam 103, Phos-Chek WD 881, or ForExpan S. The number 500 may work with other foam concentrates but they have not been tried. The Cole-Parmer conductivity meter, G-19800-20 reads in uS/cm, reading from 0 to 1990 uS/cm. Other units of conductivity can be used but the 500 number must be changed.

The more time consuming, but more accurate, "laboratory method" is to make known samples of foam solution using the water available and measure the conductivity of each known sample. Then plot the known percent of foam concentrate against the measured conductivity and obtain a calibration curve. Now the percentage of foam concentration is an unknown foam solution can be determined by measuring the conductivity of the unknown foam solution (the unknown foam solution must have been made from the same water as the test samples) and the percent of foam concentrate in this unknown solution can now be determined from the calibration curve.

In making up the known samples two methods can be used. The easier method is to use a very accurate scale so only small amounts of water and foam concentrate are used. These scales are expensive and cost about $1000. Another method is to use a graduated cylinder and a pipette. In using this method, a 1000-ml graduated cylinder and pipette reading to 1 ml work well. Add 1 ml of foam concentrate to 999 ml of water, measure conductivity of the foam solution, record, and discard. The measured conductivity is the conductivity of a 0.1 percent foam solution made from the available water. Now 2 ml of foam concentrate can be added to 998 ml of water, the conductivity measured, recorded, and the foam solution discarded. The measured conductivity is the conductivity of a 0.2 percent foam solution made from the available water. Repeat this process until you reach 1.0 percent.

To use the scale method, make a series of foam concentrations ranging from 0.1 to 1.0 percent of a specific class A foam concentrate. Look at the data sheet or the MSDS for the product density. The density in this example is 1.04.

To make one liter of 1 percent foam concentration by weight, make the following calculation:

0.01 x 1000 g x 1.04 = 10.4 g of foam concentrate

Weigh 10.4 g of foam concentrate into a 1000-ml beaker

Weight 990.0 g of water into the beaker and stir thoroughly

(In the metric system 1 gram mass of water is 1 ml in volume)

The beaker now contains one liter of accurately measured 1 percent foam solution.

Next weigh 10.0 g of this solution and 90.0 g of water into a 150-ml beaker. The new beaker contains 100-ml of 0.1 percent foam solution.

Follow this same procedure to make 0.2 through 0.9 percent concentrations. This results in an accurately measured range of foam solutions from 0.1 to 1.0 percent on which to base the calibration curve.

Take the conductivity of each sample and record. Now make a calibration curve. See example on next page of a calibration curve which has been developed from information obtained by this method.

Equipment required:

Gram scale, 1500 gram capacity accurate to 0.1 g

One 100-ml beaker, several 150-ml beakers

Stirring rods

1500-ml of water that represents, as closely as possible, the water that will actually be used in operations.