NISTIR 6203

PROJECT SUMMARIES 1998
NIST BUILDING AND FIRE RESEARCH LABORATORY

United States Department of Commerce
Technology Administration
National Institute of Standards and Technology

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Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899

U.S. Department of Commerce
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FOREWORD

The Environment

The National Institute of Standards and Technology's (NIST), Building and Fire Research Laboratory (BFRL) is one of NIST's seven Laboratories. The mission of BFRL is to enhance the competitiveness of U.S. industry and public safety by developing performance prediction methods, measurement technologies, and technical advances needed to assure the life cycle quality and economy of constructed facilities. Constructed facilities include all buildings and their furnishings and the public and private utilities and public works that support business, commerce, industry, and homes. BFRL's efforts are closely coordinated with complementary activities of industry, professional and trade organizations, academe, and other agencies of government.

Construction is one of the Nation's largest industries. In 1997, new construction amounted to $577 billion; with renovation added, the total volume of construction was about $1 trillion, which is 12 percent of U.S. GDP. U.S. construction accounts for more than eight million jobs. More than 60 percent of the nation's wealth is invested in constructed facilities. Since constructed facilities shelter and support human activities, their quality and economy are vital to the competitiveness of all industry and the quality of life of its citizens.

BFRL's research is focused and linked with collaborative private- and public-sector activities to help achieve the National Construction Goals (NCGs) developed with industry by President Clinton's National Science and Technology Council's Subcommittee on Construction and Building (C&B). This Subcommittee coordinates the federal construction-related R&D to enhance the competitiveness of U.S. industry, public and worker safety, and environmental quality. BFRL is a co-chair of this 14 Federal agency body. During the past four years, C&B has had major interactions with construction industry leaders; together they have defined the NCGs. The goals are to provide cost-effective technologies and practices by 2003 that will achieve the following improvements in the life cycle performance of constructed facilities over average 1994 practices:

- 50 percent reduction in delivery time.
- 50 percent reduction in operation, maintenance, and energy costs.
- 30 percent increase in productivity and comfort.
- 50 percent fewer occupancy-related illnesses and injuries.
- 50 percent less waste and pollution.
- 50 percent more durability and flexibility.
- 50 percent fewer construction illnesses and injuries.

In 1996, groups of industry leaders representing the residential, industrial, public works, and commercial/institutional sectors developed industry strategic plans for achieving the National Construction Goals in cooperation with Federal agencies. These industry plans and direct discussions with industry leaders have helped shape the direction of BFRL research.

In 1998, BFRL in its addressing the NCGs, allocated about one-half of its funding from direct appropriations to work with industry on six Major Products. These are expected to have great impact on improving design and construction practices and a high probability of success for early benefits to the economy. They are:

1. Computer Integrated Construction Environment,
2. Cybernetic Building Systems,
3. Performance Standards System for Housing,
4. Industrial Fire Simulation System.
5. Partnership for High Performance Concrete Technology, and
6. Fire Safe Materials.

The *Project Summaries 1998*

Project Summaries 1998, leads with a review of BFRL's Major Products. The Summaries list the Project Manager and team members, the research need, product, technical approach, industry participants, results, and the on-going component BFRL research projects. Following the Major Products, the reader is introduced to BFRL's 152 research projects. These summaries are formatted by project title, the BFRL point of contact, sponsor, description of the research, and recent results.

The Laboratory

BFRL's laboratory facilities are an important resource. Facilities include: six-degree-of-freedom structural testing facility; large-scale structural testing facility with the 53 MN universal structural testing machine; environmental chambers; guarded hot-plate; calibrated hot-box; plumbing tower; building materials imaging and modeling laboratory; fire suppression test facilities; and a fire simulation laboratory. The large burn facility for conducting experimental fires in full-scale large industrial fire test facilities is currently undergoing renovation.

BFRL works closely with its international peer organizations to maintain awareness of foreign research developments, assure that generic research efforts are complementary, and represent U.S. interests in the preparation of international standards and practices. BFRL cooperates closely with other U.S. and foreign laboratories in the conduct of its research. More than 70 research associates from U.S. industry, guest researchers from foreign laboratories, and faculty members from universities work at BFRL during 1998 for periods averaging about a year. BFRL has direct linkages with industry through its more than 52 Cooperative Research and Development Agreements (CRADAs).

BFRL participates in more than 130 national and international standardization activities; provides leadership in these national and international standardization organizations and chairs more than 20 voluntary standardization activities. Annually, BFRL publishes more than 220 reports, articles for research journals and for professional and trade journals, and computer model software packages. BFRL staff annually makes hundreds of presentations at professional and technical meetings of building community organizations, is host to more than 1700 visitors to its facilities, and responds to more than 19 000 requests for information. BFRL conducts symposia

in cooperation with other organizations concerned with building research and practice and hosts biweekly Fire Research Seminars for NIST staff and colleagues from the fire community. These meetings are effective means of transferring the latest knowledge to practitioners and peer researchers. The Fire Research Information Service (FRIS) consisting of national and international fire research literature and FIREDOC, the automated database of fire research literature, is the only comprehensive national library resource for the fire community.

At the beginning of 1998, BFRL's staff totaled about 190 persons of which 121 are professional staff and 71 have Ph.D.s BFRL's budget for FY 1997 is $30 million. Funding comes from direct appropriations ($19 million), from other Federal Agencies ($9 million) and from the private sector ($2 million).

Additional information about BFRL, its facilities, opportunities for Guest Researcher assignments, collaborative programs, and contracted research, is found on BFRL's Home Page at: http://www.bfrl.nist.gov or available from BFRL's Office of Cooperative Research Programs, Building 226, Room B250, NIST, Gaithersburg, MD 20899. Persons requesting information may want to contact BFRL using facsimile number 301-975-4737 or E-mail noel.raufaste@nist.gov.

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FIRE SCIENCE

BFRL HEADQUARTERS

BFRL Major Products

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Computer Integrated Construction Environment

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NIST's Manufacturing Engineering Laboratory
NIST's Information Technology Laboratory

Need: Automation and information technologies are core components of the strategic plans of the U.S. construction industry. The 1997 Strategic Plan of the Construction Industry Institute identifies the fully automated, one time data entry, seamless integration of project life cycle work processes as the most significant currently identified trend and predicts it will revolutionize the industry. The U.S. chemical industry identifies information systems as a key technical discipline in its "Technology Vision 2020" and predicts achieving the smooth flow of information from concept through design to construction and on into plant maintenance and operation, without any need for data reentry, enabling better use of automation, and improving economic competitiveness. Advances in information and automation technologies have been identified as contributing to the National Construction Goals set within the Subcommittee on Construction and Building in the President's National Science and Technology Council. As acknowledged in "Technology Vision 2020," however, U.S. industry must develop standards for information representation, access methods, hardware and software interfaces, and telecommunications that will enable the creation and use of open systems in the real-time, distributed, heterogeneous, multidisciplinary environment that characterizes every construction project. Without these standards, industry will continue to be at a competitive disadvantage because of the lack of horizontal integration of its various vertically integrated proprietary systems. Every project will continue to require labor-intensive and error-prone manual interpretation and reentry of information at the interfaces between different partners and across the boundaries of work processes.

Product: A harmonized set of proven information technology standards; commercial software systems implementing these standards; a NIST testbed demonstrating the interoperability of these systems; re-engineered industrial practices employing these standards and systems; and a successful pilot project in industry using these practices.

Project Objective: To develop and demonstrate in partnership with U.S. industry the effective electronic integration of life-cycle work processes in the office and on the job site, in one or more significant projects such as the construction or renovation of a chemical process plant.

Technical Approach: BFRL will coordinate the development, testing, and demonstration of standards that support (1) the integration of project information throughout the project life cycle, (2) the integration of equipment and activities on the project site, and (3) the integration of the external supply chain and external knowledge sources with a project.

The research team will establish an open, distributed, virtual testbed as a prototype computer-integrated construction environment in which NIST and its industrial partners can test and demonstrate the interoperability of software and

hardware technologies based on these standards. The testbed will combine design, simulation, and planning programs; real-time site metrology, telecommunications, and tracking systems; computer-integrated knowledge systems; and project information management systems. Researchers will develop reference datasets, test and evaluation methods, and experimental hardware and software implementations, as required to complement commercial developments.
The researchers will work closely with industry to ensure the timely and effective transfer into practice of technologies developed in these projects. NIST will conduct a concomitant economic study to ensure the information is available to the industry to establish the business case for using these technologies.
NIST will create industrial and academic advisory boards to ensure the research conducted in this set of projects is consistent with industry needs and priorities, and to ensure that the research takes advantage of technologies that are emerging from university laboratories.

Industry Participation: Construction Industry Institute; PlantSTEP, Inc.; AIChE/Process Data Exchange Institute; International Alliance for Interoperability; DuPont; Merck; Eastman Chemical; Bechtel; Black and Veatch; H.B. Zachry; U.S. Army Corps of Engineers/Construction Engineering Research Laboratory; Caterpillar.

Results to Date:

BFRL and PlantSTEP, Inc., developed the standard ISO 10303-227: Application Protocol for Plant Spatial Configuration. BFRL and major CAD system vendors demonstrated experimental exchanges of plant design information using this standard, both in a BFRL testbed and in public forums. BFRL and the Process Data Exchange Institute of the AIChE initiated the development of a counterpart standard ISO 10303-231: Application Protocol for Process Engineering Data. BFRL is working collaboratively with counterpart international process plant activities such as PIEBASE and the Japanese PlantCALS. BFRL is a member of the Research Advisory Committee of the International Alliance for Interoperability and is working to harmonize the IAI definitions of its Industry Foundation Classes with ongoing STEP work.

BFRL and MEL have initiated a joint 18-month project in the National Advanced Manufacturing Testbed (NAMT) to explore the real-time metrology and communications needs of the construction site and to determine the information technology standards needed to integrate on-site activities with off-site management information systems. As a precursor to this project, BFRL developed an experimental, virtual construction site simulator that is tele-linked to equipment position and orientation sensors.

Component Projects:

Product Data Standards for the Process Plant Industries
Computer Integrated Construction Environment Testbed
Construction Site Integration and Automation
Electronic Commerce of Technical Data for the Process Plant Industries
Codes and Standards Processing for the Process Plant Industries
Economic Support for Computer-Integrated Construction Environment Products

Cybernetic Building System

Product Manager: George Kelly, Building Environment Division

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Robert Chapman, Office of Applied Economics, 301-975-2723

Need: During the next ten years, the building controls industry in the United States will be undergoing a radical change from one with the vertical structure to one with horizontal structure. NIST is at the right place and at the right time to take the leadership role in this coming "revolution" to assure that the true beneficiary is the general public and the American economy. Building control companies, equipment and system manufacturers, energy providers, utilities, and design engineers will be under increasing pressure to improve performance and reduce costs by developing cybernetic building systems that integrate more and more building services, including energy management, fire and security, transportation, fault detection and diagnostics, optimal control, the real time purchase of electricity, and the aggregation of building stock. How these systems communicate, interact, share information, make decisions, and perform in a "synergistic" and reliable manner needs to be addressed on an industry wide basis if cybernetic building systems are to be successful and if the U.S. is to obtain a significant share of the developing world wide market for such systems.

Product: A full scale demonstration of a Cybernetic Building System in a government owned office building complex.

Project Objective: To develop, test, integrate, and demonstrate an open Cybernetic Building System for improved productivity, life cycle cost savings, energy conservation, improved occupant satisfaction, and market leadership. This work will be carried out in close cooperation with the U.S. building industry, industrial partners, building owners/operators, and newly developing service companies.

Technical Approach: The word "cybernetics" comes from the Greek word "steersman" and is defined as the science of control and communication of complex systems. Unlike the field of artificial intelligence, AI, which tends to focus on how information is stored and manipulated, cybernetics takes the "constructivist" point of view that information (and intelligence) is the attribute of system interactions (communications) and is not a commodity that is stored in a computer. In the field of cybernetics, "intelligence" is determined by the "observed conversations" (i.e., interactions) among the various components making up the (cybernetic) system. In other words, if a complex system "looks, acts, and is observed communicating intelligent information" it is "intelligent", regardless of how the information is stored and manipulated internally.

A Cybernetic Building System involves energy management, fire detection, security, and transport systems, energy providers, one or more utilities, an aggregator, and numerous service providers, information and complex control at many different levels.
During the next five years, BFRL will work with industry, building professionals, ASHRAE and Trade Organizations (e.g., IFMA), university researchers, and other government agencies to develop and demonstrate a Cybernetic Building System (CBS). The work will involve the following tasks and culminate in the full-scale demonstration of a Cybernetic Building System:

1. Develop standard communication protocols which facilitate the open exchange of information among energy providers, utilities, EMCS, fire detection and smoke control systems, security systems, elevator controls, building operators, building occupants, and (newly developing) service provider companies;

2. Develop enabling technologies, such as fault detection and diagnostic (FDD) methods, a hierarchical framework for control decision making, advanced operating strategies for single and aggregated buildings, automated commissioning, and the application of fire modeling to cybernetic building response to fires;

3. Develop advanced measurement technologies, including smart multi-functional sensors and wireless sensor networks;

4. Develop performance evaluation tools for protocol compliance testing, real time monitoring, and the evaluation and documentation of interactions among cybernetic building systems;

5. Construct a Virtual Cybernetic Building System in the laboratory to facilitate the development and evaluation of new products and systems by manufacturers (including BACnet speaking EMCS, stand alone/integrated FDD systems, intelligent fire panels, and smart sensors) and external service providers;

6. Develop a Consortium consisting of manufacturers and service providers interested in producing, testing, demonstrating, and selling Cybernetic Building Systems; and

7. Conduct a full scale demonstration of a Cybernetic Building System in a government owned office building complex. It will involve the integration of energy management, fire detection, smoke control, smart fire panels, multi-functional sensors, building transport, fault detection and diagnosis, aggregation of multiple building loads, and real time communication with energy providers, the utility, an aggregator, and numerous service providers.

Tasks 1, 2, 3, 4 and 5 will be carried out during the first four years of the project. Task 6, the development of a Consortium of companies interested in producing, testing, demonstrating, and selling Cybernetic Building Systems, will be pulled together in years three and four. The Virtual Cybernetic Building System described in Task 5, will be used in years 2 and 3 to assist manufacturers in developing CBS products and in years 4 and 5 to certify system interoperability and to pre-qualify bidders for the full scale CBS demonstration project, Task 7, to be carried out in the 5th year of the project, with a preparation phase beginning in year 4.

Industry Participation:
BACnet Consortium Members: Alerton Technologies, Automated Logic, Auto-Matrix, Andover Controls, Cimetrics Technology, Cornell University, DeltaControls, Honeywell, Johnson Controls, KMC Controls, Landis&Staefa, McQuay International, Orion Analysis Corp., Pheonix Controls, PolarSoft, Siebe Environmental Controls, Simplex Time Recorder, Teletrol Systems, The Trane Company, United Technologies Carrier, and York.

BACnet Demonstration Partners (Phillip Burton Building): GSA. PG&E, DOE, LBL, Energy Simulation Specialists, Alerton Technologies, The Trane Company, Thomas Lighting, and Synergistic Controls.
IEA Annex 34 International Members: Including CANMET, Delta Controls, VTT, CSTB, Ecole des Mines de Paris, Univ. of Stuttgart, Nagoya Univ., Yamatake-Honeywell, FUJITA Corp., Obayashi Corp., Mie Univ., Korean Institute of Energy Research, KTH, Landis & Gyr, TNO, Loughborough Univ., Univ. of Oxford.

IEA Annex 34 U.S. Working Group Members: Johnson Controls, Honeywell, Purdue University, MIT, Field Diagnostic Services, and Univ. of Colorado.
FDD International Partner: Korean Institute of Energy Research (by Implementing Agreement between NIST and KIER)

FDD CRADA Partner: Johnson Controls *FDD Demonstration Partners:* Johnson Controls, Cornell Univ., and Iowa Energy Center *Participants in ASHRAE TG4.SBS on Smart Building Systems* (Established and Chaired by George Kelly)

Results to Date:

- BACnet was approved as a ANSI/ASHRAE Stand
- Demonstrated BACnet in Phillip Burton Federal Building
- Initiated a CRADA with JCI to develop FDD methods and started evaluation of advanced controls strategies.
- Created an implementing Agreement between NIST and Korea Institute of Energy Research to evaluate FDD methods and techniques
- Completed IEA Annex 25 on FDD Methods
- Started an NIST/JCI/Cornell FDD demonstration project at Cornell University
- Formed an ASHRAE Task Group TG4.SBS on Smart Building Systems, George Kelly serves as Chairman
- Continuing collaborations between BFRL and the Iowa Energy Center FDD demonstration underway

Component Projects:

- **Expansion, Certification, and Demonstration of BACnet**
- **Advanced Fire Detectors and Alarm Panels**
- **Fault Detection and Diagnostic (FDD) Systems with Hierarchical Controls**
- **Smart Multi-Function Sensors**
- **NIST Virtual Cybernetic Building System (VCBS)**
- **Economic Support for Cybernetic Building Systems**

Performance Standards System For Housing (PSSH)

Product Manager: Joel Zingeser, BFRL Headquarters, 301-975-4630

Need: The present prescriptive system for regulating housing construction is a primary barrier to innovation and limits competition both nationally and internationally. U.S. housing products, components, systems, and know-how have not been widely accepted in the global economy. The creation of a well conceived and functioning performance based standards system for the procurement and evaluation of housing will more readily allow for and should encourage the use of innovative designs, products and processes leading to improved quality, lower life-cycle costs of housing to consumers and increased competitiveness for U.S. companies. The need for a performance standards system for housing is a priority component of the Residential Sector Strategic Approach, a report prepared by the NAHB Research Center and aimed at meeting the National Construction Goals. Research is required to develop better criteria and methods for evaluating performance.

Product: A suite of industry supported, national and international housing performance standards.

Project Objective: To increase opportunities for innovation and enhance competitiveness by developing performance standard guides for housing both nationally and internationally; conducting research to advance industry's capabilities in setting performance criteria and in evaluating, measuring, and predicting performance of housing; and coordinating and partnering with U.S. housing industry in the application of the performance approach.

Technical Approach: BFRL is supporting the development of a coordinated set of individual standard guides for each of the 16 attributes identified as relevant to the specification and evaluation of the performance of housing. These individual standard guides will be based on a matrix of attributes and elements (building subsystems) and will use the objective, criteria, evaluation, and commentary (OCEC) structure. The matrix and the standard guides will be reviewed for acceptance by ASTM and ISO. The drafts of these standard guides will be prepared by individuals from BFRL, other government agencies, industry volunteers, consultants, and others as appropriate. The draft documents will be reviewed by leading industry participants and used to define specific areas of research necessary to better define the appropriate criteria and evaluation methods. Present research topics include structural safety and serviceability, indoor atmosphere, durability, and economics.

Industry Participation: Industry is participating in both the standards development and research areas. Added participation is encouraged and solicited. Such participation may be with the BFRL or through the performance programs being conducted at NAHB Research Center. Additional companies are expected to be identified with the assistance of the NAHB Research Center's Home Base program. Also, it is anticipated that companies interested in evaluation of innovations will be identified through the National Evaluation Service's Building Innovation Center (NES-BIC).

Results to Date:

A guide for preparation of performance standards and resource document has been produced and distributed to ASTM subcommittee members, E6.66, and ISO TC59/SC3/WG10.
Five individual ASTM formatted pre-standard guides (structural safety and serviceability, fire safety, durability, functionality, and accessibility) have been drafted and are in development.
Three ISO formatted pre-standard guides (fire safety, durability, and functionality) have been presented to WG10 for consideration. Work has been initiated on the related research projects; Agreements with HomeBase and NES-BIC are in place.

Component Projects:

- **Analytical Performance Prediction of Single Family Housing**
- **Next Generation Design Standard for Wind Loads**
- **Prediction of Indoor Environment Performance**
- **Coatings Service Life Prediction Consortium**
- **Economic Support for Performance Standards System Housing**
- **Building for Environment and Economic Sustainability (BEES)**

Industrial Fire Simulation System

Product Manager: David Evans, Fire Safety Engineering Division, 301-975-6863

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Leonard Cooper, Fire Safety Engineering Division, 301-975-6880

Need: Industry in the U.S. invests about $25 billion annually in fire safety systems which are installed in manufacturing, storage, commercial, and retail spaces. Requirements for installed fire safety systems are based on prescriptive codes enforced by local authorities. There is no generally accepted method to evaluate the performance of proposed or installed systems except expensive, time consuming and often impractical full scale testing. A verified fire safety performance evaluation system enabled by BFRL and built by industry is needed to stimulate the acceptance of creative new technology and more cost effective fire safety in the United States. U.S. industry needs means to perform acceptable performance based designs of products and services for competitive international trade. BFRL is the primary national source of new fire measurement and predictive methods that are the foundation of fire safety design practices, evaluations and acceptances worldwide.

Product: A second Industrial Fire Simulation System (IFS2 System) consisting of hardware measurements, fuel burning and suppression characteristics, a verified computational method capable of quantifying the performance of sprinkler, draft curtain and roof vents in industrial storage and retail-warehouse spaces and a method for effective exchange of data and results.

Project Objective: To develop and demonstrate in partnership with U.S. industry the IFS2 system by 2000 and provide for its use in United States commerce by 2003.

Technical Approach: Building a nationally (and possibly internationally) recognized system capable of predicting fire safety system performance for sprinklers, draft curtains and roof vents as accurately as can be assessed by large scale tests will require technical progress in six areas – 1) fire modeling, 2) characterizing fuel burning and suppression, 3) measurement of hardware characteristics, 4) method to verify models,(5) method to exchange data and results, and 6) demonstrating potential favorable economic impact. Previous meetings with major manufacturers and retailers have identified a lack of understanding for the role of combined installations of sprinklers, draft curtains and smoke and heat vents as a problem needing new technical insight as historically large scale testing has not provided clear design guidance. NIST will work closely with fire equipment manufacturers and national fire testing laboratories to develop and verify a system capable of predicting performance of these fire protection strategies alone and in combination and exchanging the data and results to all interested parties.

Industry Participation: American Architectural Manufacturers Association. Colt International, Ford Motor Company, General Motors, Industrial Risk Insurers, National Fire Protection Association, National Fire Sprinkler Association, Home Depot, Factory Mutual Insurance, National Association of Fire Chiefs, Underwriters Laboratories.

Results to Date:

Demonstrated the capability of BFRL's large eddy simulation (LES) based IFS2 model to predict sprinkler and draft curtain interactions and predict the major features of two existing large scale tests. Developed methods to display the model output as simulated tests using video presentations. Funding for large scale verification tests was developed through the NFPRF. The first of these experiments with gas burner fires have shown good agreement with calculation performed prior to the experiments and great agreement with those redone after the experiments.

An important short coming of the present testing method for sprinkler response in accounting for heat loss to a flowing water in a pipe system was discovered and must be overcome to enable better predictions of fringe sprinkler response. Tests with a boxed commodity have shown that the prediction for burning rate of this fuel needs to be improved and a more accurate practical vent response model is needed.

Component Projects:

- **LES Model**
- **Group A Commodity Fire Model**
- **Vent Response Model**
- **Model Verification**
- **Information Exchange**

Partnership for High-Performance Concrete Technology (PHPCT)

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Need: The national High-Performance Concrete plan published by CERF in 1993 drew attention to opportunities for development of more durable, stronger, tougher, and more easily placed concretes, and for an integrated knowledge system to deliver the technology. In 1995, an industry-endorsed white paper developed the ideas further and indicated that high-performance concrete technology had a potential for contributing to a 20-25% expansion of the $100B/year US concrete construction market. The white paper stimulated ACI to form the Strategic Development Council (SDC) – with the goal of encouraging formation of consortia to develop improved concrete technology. The formation of the SDC attests to the industry's recognition of a need for the advancement of HPC technology, and BFRL's participation in the SDC is helping it form partnerships through which its skills in building-technology-related measurements will aid the economic growth of the industry along the lines envisaged in the white paper.

Product: Deployment of the computer-integrated knowledge system, **HYPERCON**, in a commercial HPC construction project.

Program Objective: In partnership with industry, to enable the reliable application of high-performance concrete in buildings and the civil infrastructure by developing, demonstrating, and providing assistance in implementing, a computer-integrated knowledge system, **HYPERCON**, incorporating verified multi-attribute models for prediction and optimization of the performance and life-cycle cost of high-performance concrete

Technical Approach: The program focuses on development and application of performance measurements and predictive tools needed for optimizing production of reliable high-performance concrete (HPC) and making the knowledge gained available in the most effective way. The program comprises seven technical themes, **Themes 0 through 6**, all of which are needed to meet the program objective. Six of the seven themes provide the essential input to the coordinating theme, Theme 0.

- Theme 0: Development of the Computer-Integrated Knowledge System, *HYPERCON*. ***HYPERCON*** will be a prototype distributed computer-integrated knowledge system (CIKS) incorporating simulation models and databases and a knowledge-based expert system which provides easy access to the knowledge developed in this program. Where appropriate, the parts of the CIKS will be submitted for standardization.

- Theme 1: Processing of HPC, will address methods for selecting and proportioning ingredients, determining the rheological properties, and for selecting the mixing, placing, and consolidation procedures, and curing conditions to assure a product of the desired uniformity.

- Theme 2: Characterization of Concrete and Concrete Materials, will provide techniques needed for characterizing the composition and properties of concrete materials, and the composition, structure, and uniformity of an HPC produced by any process or from any source.

- Theme 3: Performance Prediction, will provide a suite of models for simulating and predicting transport and other durability-related properties of HPC.

- Theme 4: Structural Performance of High-Strength HPC in a Fire, will develop methods for predicting the effects of fire on the performance of high-strength HPC.

- Theme 5: Structural Performance, will provide knowledge needed to allow for the most rational use of high-strength concrete and take account of its performance.

- Theme 6: Economics of HPC, will provide models for calculating the life-cycle costs of HPC in infrastructure applications, beginning with bridge decks. Strong technical linkages will be maintained among the activities in the various themes and samples of materials and data will be shared among the activities.

Tasks to be performed in the next five years are:

1. Develop and demonstrate an operational prototype of ***HYPERCON*** for buildings and the civil infrastructure. It will include, but not be limited to, materials design, durability issues, mechanical properties, quality control, and life-cycle cost.

2. Provide, and assist with the application of, models guidelines, and measurement techniques for optimizing the proportioning and processing of HPC.

3. Develop, and submit for standardization, draft guidelines for curing HPC to meet strength or durability requirements and to develop a test method for in-place assessment of curing.

4. Develop and apply methods for quantitative characterization and mathematical description of the micro- and macro-structures of HPC. The methods will be used in evaluating processing procedures and for modeling performance.

5. Develop models for simulating and predicting transport and other durability-related properties of HPC, based on materials science of the materials, and to incorporate the models into ***HYPERCON*** to provide a materials-science-based design tool for HPC.

6. Facilitate the effective application of HSC in the construction of new facilities, and in the rehabilitation of existing ones, by developing knowledge, if any, needed to enhance existing codes and standards for the use of HSC.

7. Develop and apply analytical tools for assessing the fire performance of HSC and to introduce the results into code provisions for fire design of HSC.

8. Develop integrated life-cycle costing software for evaluating the cost-effectiveness of HPC in infrastructure applications.

Industry Participation: Fibermesh Company, W.R. Grace Company, Holnam Cement Company, MasterBuilders Company, National Ready-Mixed Concrete Association, Portland Cement Association.

Results to Date:

- BFRL led the development of the national plan for high-performance concrete which is being implemented by the CONMAT Council;
- BFRL developed the knowledge-based expert system, HWYCON, which the Transportation Research Board has distributed to all 50 state DOTs;
- BFRL published many models for simulating microstructure development in hardening cement pastes and also made them available on the Web through an electronic monograph;
- BFRL prepared for the Nuclear Regulatory Commission the guidelines for the design of concrete with a 500-year life;
- BFRL determined the phase compositions of the three portland cement clinkers which have been issued as Reference Materials by NIST's Standard Reference Materials Program;
- BFRL has held seven annual workshops in the continuing series on the modeling of performance-related phenomena in cement-based materials;
- BFRL, in 1997, held an international workshop on research needs for fire-exposed HPC
- BFRL developed, demonstrated, and published a description of, a prototype CIKS for "Predicting Service Life of Chloride-Exposed Steel-Reinforced Concrete";
- BFRL led the development of the first standard database formats for concrete materials (in ACI Committee 126);
- BFRL has been a major contributor to the work of the NSF Center for Science and Technology of Advanced Cement-Based Materials.

Component Projects:

Theme 0: Development of a Computer-Integrated Knowledge System, ***HYPERCON***

- Computer-Integrated Knowledge Systems (CIKS) for High-Performance Concrete

Theme 1: Processing of HPC

- Processing of High-Performance Concrete: Mixing and Flow Properties
- Processing of High-Performance Concrete: Curing

Theme 2: Characterization of Concrete and Concrete Materials

- Micro- and Macro-structural Characterization of High-Performance Concrete
- Cement and Concrete Reference Laboratory

Theme 3: Performance Prediction

- Simulation of the Performance and Service Life of HPC
- Enhancement of Computer Model 4SIGHT for Facility Performance Assessments
- Cementitious Materials Modeling Laboratory (CMML)

Theme 4: Fire Performance of High-Strength HPC

- Fire Performance of HPC

Theme 5: Structural Performance of HPC

- Structural Performance of HPC

Theme 6: Economics of HPC

- Economics of High-Performance Concrete

Fire Safe Materials

Product Manager: Takashi Kashiwagi, Fire Science Division, 301-975-6699

Team: Kathy Butler, Jeffrey Gilman, Marc Nyden, Ken Steckler, Tom Ohlemiller
Ruddy Mell, Howard Baum, Jon Martin, Tinh Nguyen, Mary McKnight,
Prof. Wilkie (Marquette), Prof. Gianelis (Cornell), Prof. Quintiere (Maryland),
Prof. Pollack (Howard).

Need: The U.S. produces about one-third of a trillion dollars in polymer products annually. Most commodity and engineering polymers are flammable, and code acceptance requirements are most often met using additives. Changing demands on both the manufacturing process and the final product necessitate new fire retardancy approaches; too, other changes in a product may inadvertently affect fire performance. For these plastics of complex formulation, the traditional trial-and-error method for achieving fire retardancy is too expensive, time-consuming, and limited by the narrow product line of an individual company. A rational methodology that produces assured fire safety performance is needed by U.S. polymer manufacturers to enable reformulation of their products and maintain their position in this large global market.

Product: A model of the burning of a bench-scale sample of a material (a) based on scientifically sound principles that are capable of implementation by industrial chemists and (b) demonstrated to be accurate at predicting improvements in fire performance at real, end-product scale.

Project Objective: To develop validated technology for the U.S. plastics industry to assure that modifications to their products will manifest the intended fire performance without significant reduction of (or even with improvement of) their physical properties and to enable new/improved U.S. products for domestic & international markets. A first case will be demonstrated by FY1999, and a general protocol will be completed by FY2002.

Technical Approach: Computational and experimental studies on the chemistry of polymer fire retardancy, as well as polymer-additive interactions, will be pursued to elucidate the relationships between chemical/physical properties and measured fire performance. New flame retardant additive systems, based on these principles, will be compounded with various commodity polymers and their properties measured in bench scale tests (Gilman, Nyden, Wilkie, Giannelis, Pollack). Their flame retardant mechanisms will be experimentally determined in selected polymers, such as polypropylenes, nylons, and vinyl esters (Gilman, Ohlemiller, Steckler, McKnight). For this we will use various analytical methods, for example, solid phase NMR. The effects to the addition of these well-characterized additives on physical properties of the selected polymers will be also determined to understand the relationship between the additive structure and the physical properties (Nguyen). A theoretical model will be developed to predict the heat release rate of various polymeric samples, with and without flame retardant additives, as measured in a small sample device such as the Cone Calorimeter. The integrated model will consist of two parts; one describes the condensed phase processes and the other describes the gas phase processes. The former will predict the gasification rate of the sample at specified external heat fluxes and it will be based on detailed degradation chemistry supported by molecular dynamic modeling and mass and energy transport processes in the samples (Butler, Nyden, Baum). The latter will predict radiative and convective energy feedback rate from the flame and the transmitted radiant flux from an external source such as in the Cone Calorimeter (Mell, Baum). These experimental and modeling studies complement each other in our goal to understand the flame retardant mechanisms, validate the model and guide the way to better flame retarded end products with better physical properties. The effectiveness of new flame retardants will be demonstrated, with industry collaboration, in full scale tests for appropriately selected end products (Steckler, Ohlemiller, Quintiere). The results of this study in forms such as new flame retardant approaches and the theoretical models will be applied as design tools to specific fire safe end products through CRADAs, consortia with U.S. industries, an MEP-like mechanism, tutorials, and demonstrations.

Industry Participation: An industry consortium cooperating on this product includes FMC Corp., AK20 Nobel, Sekisui, and PQ Corp. A Crada has been set up with Dow Corning and discussions are underway with Lucent Technology, Ashland Chemical, Great Lakes Chemical, Cibo Specialty Chemical and Albemorle.

Results to Date:

We have developed a generic molecular dynamics model (MD_REACT) which can be used to study thermal degradation in a wide range of polymers with some capability include flame retardant additives. We have also developed prototypical models of the bulk physical behavior of different aspects of materials involved in a fire. Recent work has elucidated an initial set of chemical principles for achieving fire retardancy via enhanced char formation; additives based on these concepts have been shown to reduce the rate of heat release of small samples.

Component Projects:

- New Flame Retardant Principles
- Condensed Phase Processes
- Gas Phase Modeling
- Demonstration and Products Transfer

STRUCTURES

EARTHQUAKE ENGINEERING

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Guidelines for Repair/Rehabilitation of Welded Steel Moment Frames

Principal Investigator: John L. Gross, Structures Division, 301 975-6068

Sponsor: National Institute of Standards and Technology

Objective: To develop guidelines for the repair and/or rehabilitation of welded steel moment frame buildings damaged in the Northridge earthquake.

Problem: On February 12, 1994 Public Law 103-221 was passed authorizing the Building and Fire Research Laboratory (BFRL) to conduct post-earthquake investigations of structural failures resulting from the January 17, 1994 Northridge earthquake in Los Angeles, California. The BFRL investigative team, as well as other investigators, found severe and unexpected damage to welded steel moment frame structures. While none of the steel frame structures damaged in the Northridge earthquake collapsed or caused serious injury to their occupants, their damaged condition leaves them vulnerable to future earthquakes and or aftershocks. Additionally, thousands of buildings built to the same specifications as those that suffered severe damage in the Northridge earthquake are vulnerable to an earthquake of similar or greater magnitude.

Technical Approach: During FY1998, BFRL will perform experimental investigations of full-scale beam-to-column connections to evaluate three different repair/rehabilitation strategies. These repair/rehabilitation strategies, found from SAC Phase 1 investigations to hold the most promise, include: welded haunch, bolted bracket and section reduction. The NIST tests extend previous work conducted for SAC by considering two-sided connections and the effect of the floor slab. Results of the NIST tests, combined with previous results from tests of one-sided, bare steel connections, will be used to validate design procedures for the three repair/rehabilitation procedures. Design guidelines will then be prepared with participation from the American Institute of Steel Construction.

Recent Results:

Kaufmann, E.J., Fisher, J.W., DiJulio, R.M., and Gross, J.L., "Failure Analysis of Welded Steel Moment Frames Damaged in the Northridge Earthquake," NISTIR 5944, January 1997, 166 pp.

Kunnath, S.K.,"Enhancements to Program IDARC: Modeling Inelastic Behavior of Welded Connections in Steel Moment-Resisting Frames," NISTGCR 95-673, May 1995, 74 pp.

Youssef, N.F.G., Bonowitz, D., and Gross, J.L., "A Survey of Steel Moment-Resisting Frame Buildings Affected by the 1994 Northridge Earthquake," NISTIR 5625, April 1995, 180 pp.

Theil, C.C., "Proceedings: Invitational Workshop on Steel Seismic Issues," SAC Report 94-01, Los Angeles, CA, November 1994, 155 pp

Deformation-Based Seismic Design and Performance Factors

Principal Investigators: Riley M. Chung, Structures Division, 301-975-6062
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Sponsor: National Institute of Standards and Technology

Objective: To evaluate the current and proposed use of the reduction factors and modification factors in design and to develop rational performance-based design factors that better represent the inelastic response, redundancy and over-strength for the design and evaluation of structures.

Problem: In moderate and strong earthquakes, structures can experience nonlinear behavior and dissipate a portion of the seismic energy through inelastic action. To account for the energy absorption capacity of the structure, building codes use simplified procedures that include factors (referred to as R-factors) to modify the forces and drifts computed by elastic analysis. These factors depend on several variables that contribute to the inelastic strength and deformation capacity of the structural system: over-strength, ductility, redundancy, and damping. Substantial uncertainties, however, exist concerning the accuracy and consistency of these factors. Also, the determination of the factors for structures with seismic isolation and supplemental dampers require further investigation. There is a consensus in the engineering community that a systematic and comprehensive study is needed to re-evaluate the R-factors in the current codes.
In addition, there is a major effort by the earthquake engineering community to move toward a performance based code as indicated in SEAOC VISION 2000 Performance Based Seismic Engineering of Buildings and FEMA 273 - NEHRP Guidelines for the Seismic Rehabilitation of Buildings. The latter document proposes modification factors (referred to as m-factors) instead of R-factors to account for the nonlinear behavior. Analytical and experimental studies are needed to understand and model the effects of inelastic deformation, over-strength, and redundancy on the behavior of new, existing, and rehabilitated structures to advance the state of practice of performance based design.

To facilitate the development of performance-based design, it is important to address issues related to "cumulative damage" and "reserve capacity". This may be handled using "damage" or "performance" indicators. Relationships between performance and design need to be established and to insure that the desired performance level is achieved in design.

Technical Approach: During FY1998, BFRL will perform these tasks:

1) A report will be prepared that summarizes the experimental studies on the inelastic behavior of structures and examines the data on the response of instrumented buildings. The report will initially focus on concrete and later, on steel and wood. The report will identify several structural elements and systems where additional experiments are required to model inelastic behavior. In addition, a database of experimental work for a more accurate determination of the load-deformation characteristics of columns, beams, walls, frames, and connections will be assembled.

2) Experimental program: Based on the report in task 1, several structural subassemblies and/or components will be tested. The objectives of the tests are to determine the contributions of over-strength and ductility to reduction and modification factors and to gain insight into the damage process, and to determine damage indices for measuring structural performance.

3) Analytical program: Simplified analytical procedures will be modified to include strength and stiffness degradation. The experimental data obtained in task 2 will be incorporated in existing analytical procedures to determine ductility demands in multi-degree-of-freedom systems as compared to those of an equivalent single-degree-of-freedom system. The effect of redundancy on the overall performance of buildings will also be addressed. Linear and nonlinear analyses will be used to compute the modification factors for different systems and materials and verify the ones proposed by different seismic codes and provisions. Analyses will also be carried out for structures with seismic isolation and supplemental dampers.

4) Recommendations for a more rational estimation of performance factors will be made based on the findings in tasks 2 and 3.

Recent Results: New project.

Fiber Reinforced Polymer Composites in Construction

Principal Investigator: Dat Duthinh, Structures Division, 301-975-4357

Sponsor: National Institute of Standards and Technology

Objective: To develop guidelines for the use of Fiber Reinforced Polymer (FRP) composites in repair and retrofit of infrastructure facilities.

Problem: Much of the U.S. infrastructure is in need of repair or replacement as a result of damage caused by heavy use and exposure to the environment. Additionally, some of the Nation's infrastructure facilities are in need of retrofit to either increase their capacity or to improve their seismic performance. Fiber Reinforced Polymer (FRP) composites have been demonstrated to provide an economical solution to these repair and retrofit problems.

FRP composites have proven to be efficient and economical for the repair or retrofit of structures. Bridge piers can be wrapped with FRP laminates to increase their strength and ductility and, hence, improve their seismic performance. Bridge girders have been strengthened both in shear and in flexure by the bonding of FRP laminates or FRP sheets. Shear walls can also be strengthened by bonding FRP laminates.
In moderate and strong earthquakes, structures can experience non-linear behavior and dissipate a portion of the seismic energy through inelastic action. In the inelastic range, design forces can be reduced (by factors called R) compared to their elastic levels. However, this requires the structure to have a certain amount of ductility. The use o FRP wraps has proven to be very effective in confining concrete and significantly increasing the ductility of bridge piers by mitigating shear failure, allowing greater deformations in potential plastic hinge zones and preventing premature pull-out of starter bars.

A major challenge in disaster mitigation is the assessment of the performance and the effectiveness of retrofit methods. Design standards would help answer questions such as, does the structure need retrofitting, and if yes, which retrofit method and what quantity are needed.

The ease of handling and application, the minimal disruption to the structure's function, and the versatility of the materials have all contributed to the widespread use of FRP in repair and retrofit of damaged and decaying structures. The extent to which FRP will be used depends on 1) the resolution of outstanding technical issues such as fire performance and durability, 2) the extent to which expansion in the market and automation in the manufacturing and application processes can reduce cost, and 3) the availability of validated codes, standards and guidelines which can be used as design references and tools by the civil engineering profession.

The availability of design standards will facilitate a wider use of FRP for structural repair, and this expansion of the market will in turn reduce costs which are now already competitive with more traditional methods.

Technical Approach: During FY1998, BFRL will perform a world-wide search of FRP related products. Research results, available test methods, and successful applications will be synthesized to assess the current state of practice in applying FRP to repair and retrofit infrastructure facilities. A workshop will be convened to determine the kind of standards needed, and to identify areas where the technical basis for such standards are insufficient. Guided by the workshop recommendations, analytical and/or experimental research will be conducted at BFRL to provide the technical basis for the development of guidelines and draft standards for the repair and retrofit of structures using FRP. BFRL's developed guidelines and draft standards will be proposed to the industry for consideration in the consensus standards process.

Recent Results: New project.

Seismic Performance of Cladding Systems

Principal Investigator: Riley M. Chung, Structures Division, 301-975-6062

Sponsor: Federal Emergency Management Agency
Office of Earthquakes and Natural Hazards

Objective: To evaluate seismic performance of exterior architectural cladding elements during the Northridge earthquake, and develop energy dissipating cladding systems for seismic retrofit and design of new buildings.

Problem: Although many cladding elements are not specifically designed for seismic forces, they participate in resisting lateral loads as they deform with the framing system. It has been reported that cladding systems sustained damage during the Northridge earthquake, particularly those on steel frame structures. The seismic performance of buildings could be improved by utilizing effectively the cladding system to dissipate energy. Energy-dissipating cladding can be applied to both new construction and seismic retrofit.

Technical Approach: During FY1998, BFRL will document the performance of architectural cladding systems during the Northridge and other earthquakes. Current design criteria and code requirements will be critically evaluated based on observed cladding performance. Next, BFRL will study the performance of energy dissipating cladding connector hardware. This will be primarily an experimental investigation, making use of existing test fixtures at Georgia Institute of Technology. The goal of this phase will be to determine how different types of energy dissipating connectors behave (e.g. elastomeric connectors, steel clip angles, and other specially designed steel connectors). The hysteretic properties of the connectors will be established, and desirable modes of connector performance will be defined.

The contributions of cladding to the stiffness and damping of the overall structural system will be determined. Presently, it is not clear to what degree cladding systems participate with the main structural frame of a building during earthquake shaking. This work follows naturally on the connector performance studies described above, since the energy dissipating properties of connectors have a major influence on the interaction between the cladding system and the structural frame. This third task will be carried out by comparing analytical models of buildings with observed experimental full-scale and scale-model building performance data. Since few experimental have been performed on structures with and without cladding, additional experiments may be required in this phase, either at NIST or at NCEER. Finally, based on the results of the steps above, seismic design guidelines for building cladding systems will be developed.

Results to Date:

The State-of-the-Art of Cladding Research, Cladding Research Institute, GCR-681, National Institute of Standards and Technology, September 1995.

Management of the InterAgency Committee on Seismic Safety in Construction (ICSSC)

Principal Investigator: Riley M. Chung, Structures Division, 301 975-6062

Sponsor: Federal Emergency Management Agency
Office of Earthquakes and Natural Hazards

Objective: To facilitate and expedite the work of the Interagency Committee on Seismic Safety in Construction (ICSSC), by providing the Chair and Technical Secretariat; and to assist FEMA in its implementation of the EO12941.

Problem: The National Earthquake Hazard Reduction Program (NEHRP) established the ICSSC to assist Federal departments and agencies develop, improve, and maintain seismic safety programs for all types of construction. Thirty-three Federal departments and agencies currently participate in the ICSSC. The National Earthquake Hazard Reduction Act (amended by Public Law 101-614) designates the director of NIST, or his designee, as the chair of the ICSSC. BFRL provides the Technical Secretariat to the ICSSC, to facilitate, document, and disseminate the work of the committee.

The ICSSC has published and distributed implementation guidance for Executive Order 12941, *Seismic Safety of Existing Federally Owned or Leased Buildings*. Section 2 of the Order requires all building-owning agencies to develop a seismic inventory and an estimate of the cost of achieving adequate seismic safety in their buildings. The information that is collected on the Federal government's half-million owned buildings will be used to examine potential rehabilitation programs, and to recommend to Congress an economically feasible way to upgrade the seismic safety of the Federal building population. BFRL will provide technical assistance to FEMA in its implementation of the EO.

The ICSSC guidance is aimed at ensuring that the data collected by the agencies is consistent in content and format, so that an effective seismic rehabilitation program, based on reliable and defensible data, will be proposed to Congress. The ICSSC guidance was published in two volumes including a "how-to" handbook. Continued efforts are needed on the part of the ICSSC to encourage consistent data collection, interpretation, and reporting by the agencies. The information collected by the agencies will be submitted to the ICSSC between now and 1998, for incorporation into a government-wide database, with entries on all the half-million owned buildings. The government-wide database will serve as the primary source of information for the examination of potential rehabilitation programs and the report to Congress.

Technical Approach: During FY1998, BFRL will continue serving as the ICSSC Technical Secretariat and will carry out the basic day-to-day management of the full committee and the five subcommittees: organizing and documenting meetings, maintaining rosters, disseminating information.

1. Developing cost estimating tools and methodologies. Submitted data will be used to assess vulnerability of a wide variety of building types. The *Second Edition - Typical Costs* cost estimating methodology will be adapted for use in sub-dividing cost estimates into the cost reporting categories called for in the ICSSC-developed methodologies.

2. Holding workshops to provide a forum for agencies to share successes and difficulties in implementing the order. Agency personnel will be trained in the use of the ICSSC-developed methodologies.

3. Providing additional agency-specific technical support upon request, in the form of explanation, interpretation and/or training in the ICSSC guidance documents, distribution of ICSSC documents, presentations at meetings, review and comment on proposed methodologies, and similar efforts.

4. Serving as Database Manager who will develop the basic framework for the government-wide database, and begin working with agency personnel to test protocols for transmitting data.

In addition, BFRL, in support of FEMA's effort in implementing the EO12941, will perform seismic evaluation of ten (10) FEMA buildings using *FEMA 178, NEHRP Handbook for the Evaluation of Buildings*.

Recent Results:

Conducted meetings of full and steering committees held; produced minutes.
Established data base framework.
Conducted two workshops on implementation of EO12941.

Geotechnical Characterization for Buildings and Lifelines

Principal Investigators: Ronald D. Andrus, Structures Division, 301-975-6051
Riley M. Chung, Structures Division, 301-975-6062

Sponsor: National Institute of Standards and Technology

Objective: To develop methodologies and guidelines for rapidly assessing liquefaction and deformation potential of soil deposits supporting buildings and lifelines.

Problem: Liquefaction-induced ground failure is a major cause of damage in earthquakes. Capability to delineate weak soil layers and predict their liquefaction potential are key inputs in the engineering design of new or retrofitted structures. This information is also essential for reliable estimation of economic losses during future earthquakes. When projects extend for great distances, such as lifelines and large building complexes, cost-effective evaluations of extensive areas are required. Screening techniques based on geology, hydrology, and soil conditions show promise for identifying areas requiring more rigorous analyses. Even these areas requiring further analyses can be quite large.

One promising technique for spatially evaluating the liquefaction susceptibility of granular soils is the Spectral-Analysis-of-Surface-Waves (SASW) test. This test is an in situ seismic test for determining small-strain shear wave velocity, V_S, profiles of soil deposits and pavements. The SASW test does not require boreholes, and has the advantage of providing broad areal coverage. Testing can be performed at sites where minimal disturbance is required and where soils are difficult to sample. The use of V_S as a field index of liquefaction resistance is justified since both V_S and liquefaction resistance are influenced by void ratio, effective confinement, stress history, and geologic age.

Technical Approach: During FY1998, BFRL will continue the development of the methodology for estimating liquefaction resistance using V_S by collecting additional field performance data from recent earthquakes and performing probabilistic analyses on the expanded database. In addition, the interpretation and reporting of SASW test results from the improved soil area near Pier 1 at Treasure Island, California will be completed. A draft guideline for evaluating liquefaction resistance using V_S will be prepared from the results of these studies.

Work during subsequent years will include the development of a guideline for using the SASW test to evaluate liquefaction susceptibility.

Recent Results:

Andrus, R.D., and Stokoe, K.H., II, "Liquefaction Resistance Based on Shear Wave Velocity," *Proceedings, NCEER Workshop on Evaluation of Liquefaction Resistance of Soils*, National Center for Earthquake Engineering Research, Buffalo, NY, 1998.

Andrus, R.D., Stokoe, K.H., II, Bay, J.A., and Chung, R.M., "Delineation of Densified Sand at Treasure Island by SASW Testing," *First International Conference on Site Characterization*, 1998.

STRUCTURES

STRUCTURAL EVALUATION

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Construction Automation

Principal Investigators: William C. Stone, Structures Division, 301-975-6075
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Sponsor: National Institute of Standards and Technology

Objective: 1) To develop new techniques and standards for real-time construction site metrology; 2) to develop a national standard for construction site wireless data up-link packets; and, 3) to develop, in conjunction with industry, a National Construction Automation Testbed to identify and remove barriers to automated component tracking and machine automation at construction sites.

Problem: The emergence of high speed computer communication networks (the "information superhighway") and the rapid advance of real-time, immersive, computer graphics (virtual reality) technologies presage the imminent ability to manage remote construction sites from central offices; to automate certain portions of the tasks performed by common construction machines; and to provide information on the state of such machines to operators (on-site or remote) that would significantly enhance their productivity. Limited demonstrations of this type of technology, largely relating to the control of robotic spacecraft and, more pertinently, to the tele-operation of simple machines for the handling of nuclear waste, have been conducted.

In order to achieve acceptance in the construction industry, a standard means of rapidly interfacing any piece of machinery to a construction-site database must be developed. The development of this standard may not be addressed by the construction industry itself, where corporate research budgets are limited. Nor will it be developed by equipment manufacturers who develop proprietary systems which inhibit data exchange with other systems that might be operational at a construction site. The underpinning of the above technology is the ability to know the real-time position of any piece of equipment and component on the construction site. Present surveying tools suffer from many shortcomings, the most important of which are that they must operate under line-of-sight (LOS) conditions and they don't inter-operate. The demonstrated utility of alternative surveying systems and the development of a standard technique for seamlessly trading off between various real-time metrology systems, are major objectives of the BFRL construction automation program.

Technical Approach: During FY1998, BFRL will establish a National Construction Automation Testbed facility. This testbed demonstration will establish competence within BFRL to address the larger problem of establishing standards for the modeling of all types of construction machinery and the development of means by which construction machinery manufacturers can easily convert their existing CAD data to a standard representation to be used in construction automation. The complete development of this capability will represent a multi-year project. Specific technical approach on the establishment of an initial version of a National Construction Automation Testbed are as follows:

1. Acquire, develop, characterize, and integrate sensors (and wireless communications equipment) into a real-time computer system for the testbed. The information from these sensors should be sufficient to determine the kinematic state of a representative construction vehicle (a 30-ton bridge crane converted to intelligent control) and (if possible) the state of objects being handled by the vehicle.

2. Investigate methods for representing kinematic data for both rigid bodies and for simple mechanisms (e.g. construction vehicles.) Investigate how functionality/interface aspects will influence future construction-site database development. Develop an initial specification for wireless up-link standards for rigid body components and implement it in the testbed. Evaluate the specification, and plan for future extensions.

3. Extend virtual site simulator research toward the functionality of a construction automation test bed. Integrate wireless communications system from vehicle to graphical simulator. Incorporate object and vehicle models into the site model, animated by real-time sensor data. Improve the 3-D graphic fidelity; make provisions for extension from passive monitoring to tele-operation/control.

Recent Results:

Stone, W.C. and Pfeffer, L.E., "Automation Infrastructure System for a Robotic 30-ton Bridge Crane," Proceedings of the ASCE Aerospace Division Space 98/Robotics 98 Conference, April 1998, Albuquerque, NM, (in press.)

Stone, W.C., "Electromagnetic Signal Attenuation in Construction Materials," NIST Construction Automation Program Report No. 3, NISTIR 6055, National Institute on Standards and Technologies, October 1997, 195 pp.

Stone, W.C., "Surveying Through Solid Walls," Proceedings of the Fourteenth International Symposium on Automation & Robotics in Construction, June 1997, Carnegie Mellon University. pp. 23-40.

Pfeffer, L.E., "Wireless Networking for Integration of Real-time Construction Metrology Systems," Proceedings of the Fourteenth International Symposium on Automation & Robotics in Construction, June 1997, Carnegie Mellon University. pp. 41-50.

Performance Requirements for Structural Control Systems

Principal Investigators: Michael A. Riley, Structures Division, 301-975-6065
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Sponsor: National Institute of Standards and Technology

Objective: To develop and verify guidelines for basic property, prototype, and quality control testing of structural control systems.

Problem: Seismic base isolation and passive energy dissipation have been installed in numerous buildings and bridges throughout the world, and they have proved effective in reducing the response of structures during earthquakes and strong winds. In practice, base isolation systems and passive energy dissipation devices should undergo an extensive program of prototype and quality control tests before installation. Unfortunately, there is a lack of commonly accepted testing standards for these devices. Information is needed on how to specify the procedures for testing these devices and how to interpret the test results. Furthermore, without standard testing procedures, it is nearly impossible to compare the performance of competing designs. Test standards will ensure the systematic characterization of base isolation and energy dissipater properties, and provide a method for determining the minimum level for acceptable performance.

Technical Approach: During FY1998, BFRL will perform two tasks: 1) Validate the developed testing guidelines for base isolation systems; and 2) develop testing guidelines for passive energy dissipation devices. As active, hybrid, and semi-active control systems become viable, additional efforts will focus on the development of guidelines for these systems.

In task 1, Validation of Test Guidelines for Base Isolation Systems work involves providing support for the development of a national consensus standard and a test program for assessing and evaluating the guidelines. As part of the effort to develop a national consensus standard, BFRL will assist the ASCE standards committee on testing of base isolation systems. The test program includes a number of components, including design and construction of a lateral load test frame, which will allow NIST's 53 MN universal testing machine to provide vertical loads while a separate ram is used to provide the smaller cyclic lateral forces. A test plan has been developed for the experimental program to evaluate the effect of bilateral loading on bearing performance and to develop improved methods for detecting flaws in elastomeric bearings. The first phase of this program, which involved uniaxial compression loading, has been completed and reported in NISTIR 6002. The second phase of the testing program will involve testing of bearings under simultaneous uniaxial compression and cyclic lateral shear loading. Depending on the schedule of the various tasks, results will be summarized and reported in one or more NIST reports. Research findings will also be submitted for publication in technical journals.

In task 2, Passive Energy Dissipation Devices work involves a number of steps that are similar to the procedure used in the development of the guidelines for seismic isolation. An advisory panel of experts has been formed. BFRL researchers will work with the advisory panel to improve the draft guidelines for testing passive energy dissipation devices. This will require at least three meetings of the advisory panel. The draft guidelines will also be sent to other people working in the area of energy dissipation to solicit their comments. After the advisory committee's comments are included in the guidelines, BFRL will hold a workshop to discuss them. The workshop discussions and conclusions will be summarized in a report and included in the final guidelines, which will then be issued as a report. Testing of selected passive energy dissipation devices will be conducted to develop confidence in the guidelines. The test program will be performed according to the recommendations of the advisory panel and will be listed in the final guidelines.

Recent Results:

Sadek, F., Mohraz, B., Chung, R. M., and Lew, H. S., "NIST's program for testing and evaluation of passive energy dissipation devices," Accepted for *2nd World Conference on Structural Control,* Kyoto, Japan, 1998.
Sadek, F. and Mohraz, B., "Comparison between the performance of tuned mass and tuned liquid column dampers for seismic applications," Accepted for *2nd World Conference on Structural Control,* Kyoto, Japan, 1998.

Sadek, F. and Mohraz, B., "Variable Dampers for Semi-active Control of Flexible Structures," Accepted for *6th US National Conference on Earthquake Engineering*, Seattle, WA, June 1998.

Bradley, G. L. and Chang, P. C., "Determination of the Ultimate Capacity of Elastomeric Bearings under Axial Loading," NISTIR, National Institute of Standards and Technology, (under review.)

Sadek, F. and Mohraz, B., "Semi-Active Control Algorithms for Structures with Variable Dampers," NISTIR 6052, National Institute of Standards and Technology, October 1997. Also to appear in *Journal of Engineering Mechanics,* ASCE.

Sadek, F. and Mohraz, B., "Vibration control of tall buildings using mega-subconfiguration," Discussion, *Journal of Engineering Mechanics,* ASCE, Vol. 123(6), pp. 650-651, 1997.

Bradley, G. L., Taylor, A. W., and Chang, P. C., "Ultimate Capacity Testing of Laminated Elastomeric Base Isolation Bearings under Axial Loading," NISTIR 6002, National Institute of Standards and Technology, March 1997.

Sadek, F., Mohraz, B., Taylor, A. W., and Chung, R. M., "Passive energy dissipation devices for seismic applications," NISTIR 5923, National Institute of Standards and Technology, November 1996.

Sadek, F., Mohraz, B., and Lew, H. S., "Single and multiple tuned liquid column dampers for seismic applications," NISTIR 5920, National Institute of Standards and Technology, November 1996. Also to appear in *Journal of Earthquake Engineering and Structural Dynamics.*

Shenton, H. W., "Guidelines for Pre-Qualification, Prototype and Quality Control Testing of Seismic Base Isolation Systems," NISTIR 5800, National Institute of Standards and Technology, June 1996.

Sadek, F., Mohraz, B., Taylor, A. W., and Chung, R. M., "A method of estimating the parameters of tuned mass dampers for seismic applications," NISTIR 5806, National Institute of Standards and Technology, April 1996. Also published in *Journal of Earthquake Engineering and Structural Dynamics*, Vol. 26, pp. 617-635, 1997.

Shenton, H. W. and Taylor, A. W., "Guidelines and Benchmarks for Analysis of Isolated Buildings," Proceedings, 1996 ASCE structures Congress, April 15-18, 1996.

Shenton, H. W., "Summary and Results of the NIST Workshop on Proposed Guidelines for Testing and Evaluation of Seismic Isolation Systems, July 25, 1994, San Francisco, California," NISTIR 5785, National Institute of Standards and Technology, January 1996.

Structural Performance of HPC

Principal Investigator: Dat Duthinh, Structures Division, 301-975-4357

Sponsor: National Institute of Standards and Technology

Objective: To facilitate the application of high-strength, high-performance concrete in the construction of new facilities and the rehabilitation of existing ones by developing the bases for enhancing existing codes and standards for the effective utilization of high-strength concrete. Recommended code and commentary provisions on the use of the modified compression field theory (MCFT) for computing shear strength will be produced by 1999.

Problem: High-strength concrete (HSC) offers the potential for cost savings in construction due to reduced member dimensions, the capability to accommodate rapid construction schedules, and enhanced service life. However, from a structural perspective, high-strength concrete is inherently more brittle than normal strength concrete (NSC). Therefore, failure mechanisms in structural members need to be understood before appropriate design criteria can be developed. Lacking the necessary knowledge, design codes take a conservative approach and limit the concrete strength that can be used to compute member resistance to tensile failure modes. This project aims to provide the technical basis for design criteria applicable to structural members made with high-strength concrete.

Improvement of the ACI-318 criteria for shear strength was selected as the first research area related to the structural performance of high-strength concrete. A state-of-the art report was completed in FY 1996, which reviewed past research and discussed alternative design models. Based on this review, the modified compression field theory was identified as the most rational design method to replace the empirical shear strength design method in the American Concrete Institute ACI 318 Standard. (AASHTO LRFD (American Association of State Highway Officials Load Resistance Factor Design) Specifications and the Canadian Standards Association have already adopted the Modified Compression Field Theory in 1994). In FY 1997, a parametric study of the modified compression field theory was conducted to examine the sensitivity of the predicted shear strength to the details of the shear friction and biaxial strength relationships that are used. The results indicated that in heavily reinforced members, which would be typical of most members of high-strength concrete, the predicted shear strength is not significantly influenced by the details of these relationships. Thus it has been concluded that the modified compression field theory should be applicable to high-strength concrete.

Technical Approach: During FY1998, BFRL will complete this research of shear strength by developing draft code and commentary language for including the MCFT as an alternative design method in ACI 318. There will be cooperation with practicing engineers in developing draft code provisions and in performing trial designs to demonstrate that the provisions are practicable.

Recent Results:

Duthinh, D., "Sensitivity of Shear Strength of Reinforced Concrete and Prestressed Concrete Beams to Shear Friction and Concrete Softening According to the MCFT," submitted *to ACI Structural Journal*, August 1997.

Duthinh, D., "Shear Strength of Prestressed Concrete Beams: Parametric Study of Shear Friction and Concrete Softening," Presented at Engineering Foundation Conference, July 1997, submitted for Conference Proceedings.

Duthinh, D. and Carino, N.J., "Shear Design of High Strength Concrete Beams: A Review of the State of the Art," NISTIR 5870, National Institute of Standards and Technology, August 1996, 198 pp.

Processing of High-Performance Concrete: Curing

Principal Investigators: Nicholas J. Carino, Structures Division, 301-975-6063
Kenneth A. Snyder, Building Materials Division, 301-975-4260

Sponsor: National Institute of Standards and Technology

Objective: To develop and submit for standardization draft guidelines for curing high-performance concrete to achieve strength or durability requirements and to develop a test method for the in-place assessment of curing.

Problem: Curing of concrete is a critical step in the construction process. Our state-of-the-art report on curing of high-performance concrete showed that ACI curing requirements are lagging behind developments in other countries Sufficient curing is needed to ensure that the desired concrete properties will develop and that the finished product will serve its intended function. On the other hand, unnecessary prolonged curing adds to construction costs. Existing curing standards are based on information gathered from research on ordinary concrete mixtures. These concretes contained portland cement as the only binder, had relatively high water-cement ratios, and did not include set controlling admixtures. High-performance concrete typically contains a blend of cementitious materials, has a low water-cementitious materials ratio, and often includes chemical admixtures that affect early-age hydration. Thus current prescriptive curing requirements, which are over 50 years old, may not be applicable to high-performance concrete mixtures. In addition, current standards make no distinction between curing to obtain adequate strength and curing to obtain adequate durability. Because durability is influenced highly by the near-surface layer, whereas strength is influenced by the concrete mass, different curing criteria may be needed depending on the objective. A new look at the subject of curing is critical to ensure that the potential benefits of high-performance concrete can be realized economically. Also lacking are standard test methods to evaluate whether the in-place curing is adequate to meet the project specifications. Research results will be used to develop draft curing guidelines for incorporation into ACI construction standards and as draft test method for adoption by ASTM. The guidelines will allow practitioners to estimate the duration of moist curing to achieve adequate hydration (for strength or durability) at a prescribed depth. The in-place test method will allow owners a means by which to ensure that adequate curing was performed.

Technical Approach:. During FY1998, BFRL will conduct a joint-research program involving BFRL's Structures Division and Building Materials Division to provide the basis for rational curing criteria that will ensure the required strength and durability. Research will build on past years effort involving an examination of the effect of duration of initial moist curing on the subsequent degree of hydration of cement paste under different relative humidities, and on the novel testing technique developed to evaluate the effect of different curing histories on the strength at different distances from the drying surface. Based upon this research, the minimum required duration of moist curing can be linked directly to changes in the microstructure. By combining the BFRL microstructural model with vapor permeability data obtained from a device to be developed in this project, the effect of environment can be incorporated into cement paste hydration modeling.

Tests will be performed in FY 1998 to provide data for model verification. The verified model will be used to develop a tabular or nomogram-based guideline to select minimum duration of moist curing for a specific concrete mixture and anticipated environmental conditions. Finally, quality assurance could be performed using an in-place-monitoring device, to be developed in this project, which will be based upon a temperature/humidity-measuring probe developed previously.

Research results will be synthesized into a suitable form for presentation to ACI Committees 308, 301, 318, and 363 for incorporation into guides and standards, and to ASTM Committee C9 for adoption as a test method. Members of the research team will champion the incorporation of the research results into documents of practice. Results will also be incorporated into the Computer Integrated Knowledge System being developed under another project in the high-performance concrete program.

Recent Results:

Carino, N.J., Mullings, G.M., and Guthrie, W.F., "Evaluation of ASTM Standard Consolidation Requirements for Preparing High-Strength Concrete Cylinders," High-Performance Concrete, ACI SP-172, V.M. Malhotra, Ed., American Concrete Institute, Farmington Hills, MI, 1997, pp. 733-768

Vichit-Vadakan, W., Carino, N.J., and Mullings, G.M., "Effect of Elastic Modulus of Capping Material on Measured Strength of High-Strength Concrete Cylinders," manuscript submitted to *Cement, Concrete, and Aggregates* (ASTM)

Bentz, D.P., Snyder, K.A and. Stutzman, P. E., "Microstructural Modeling of Self-desiccation During Hydration", Self-Desiccation and Its Importance in Concrete Technology, Edited by B. Person and G. Fagerlund, Proceedings of an International Research Seminar in Lund, pp. 132-140, June 1997.

Meeks, KW. and Sarkani, S, "Curing of High Performance Concrete: Annotated Bibliography," NIST GCR 97-715, National Institute of Standards and Technology, May 1997, 158 pp.

Bentz, D.P., Snyder, K.A and. Stutzman, P. E., "Hydration of Portland Cement: The Effects of Curing Conditions," Proceedings of the 10th International Congress on the Chemistry of Cement, Volume 2, Edited by H. Justnes, 2ii078 (8 pp.), 1997.

Snyder, K.A. and Bentz, D.P., "Early Age Cement Paste Hydration at 90% Relative Humidity and Loss of Freezable Water," submitted to *Cement and Concrete Research*

Fire Performance of High Performance Concrete

Principal Investigators: Long T. Phan, Structures Division, 301-975-6077
Richard D. Peacock, Fire Safety Engineering Div., 301-975-6664
Robert R. Zarr, Building Environment Division, 301-975-6436
Paul E. Stutzman, Building Materials Division, 301-975-6715
Kenneth Snyder, Building Materials Division, 301-975-4260

Sponsor: National Institute of Standards and Technology

Objective: To develop analytical tools for assessing fire performance of High Strength Concrete (HSC) and to implement research results into code provisions for fire design of HSC.

Problem: HSC is a state-of-the-art material which, due to its many advantages over normal strength concrete (NSC) and its easy availability nowadays at many concrete plants, has been found to be gaining in use for structural applications. However, in a number of recent experimental studies in which HSC specimens were subjected to elevated temperatures at high heating rate to simulate their performance in fire condition, it has been observed that there are significant behavioral differences between HSC and NSC, most notably is the sudden explosive spalling that occurred in some of the HSC specimens. Such sudden damage mechanism has not been observed in past studies where only NSC specimens were used, and thus needs to be understood to ensure that the structural integrity of an HSC structure is not inadvertently compromised in case of a fire.

These recent studies also reveal three important performance differences between HSC and NSC at elevated temperatures. They include:

1. HSC has significantly shorter fire endurance time than NSC.
2. HSC has markedly higher strength and modulus reductions at high temperature than NSC.
3. HSC is highly susceptible to sudden explosive spalling at temperature range 300 °C to 650 °C.

These differences have design consequences and give rise to the question of whether the existing U.S. fire design provisions, which were developed using data from high temperature testing of NSC, are applicable when HSC is used. Furthermore, it is believed that the higher susceptibility of HSC to explosive spalling, is linked to the different transport properties of HSC. These differences, such as the lower porosity, may have contributed to high pore vapor pressure buildup when HSC is heated. However, the current lack of experimental data for quantifying the transport-properties-related internal developments in heated HSC does not lend itself to the development or validation of behavioral models for heated HSC at present.

The current lack of experimental data on mechanical, thermal, and especially transport properties of HSC at elevated temperature, and thus the lack of analytical capability and appropriate design guidance concerning performance of fire-exposed HSC dictate the need for this research project. Also, the complexity of the problem necessitates a multi-disciplinary research approach, which calls for the expertise and facility of all four BFRL divisions to be involved.

Technical Approach: During FY1998, BFRL will perform three tasks:

1. *Experiments*: The experimental phase will be coordinated and performed by BFRL divisions, and will consist of *materials testing* (elevated temperature tests of HSC specimens for mechanical, thermal, and transport properties) and *element testing* (tests of beams, columns, slabs, walls). This phase is designed to gain an understanding of the fundamental behavior of HSC at elevated temperature and to provide experimental data for the

development predictive models which can account for the heat-induced internal developments in HSC, such as moisture migration, pore pressure buildup, and the explosive spalling phenomenon.

Work will focus on completing the acquisition and installation of the high-temperature test equipment, manufacture test specimens, and conduct measurements of mechanical properties of HSC specimens at elevated temperatures. A review will be conducted about the importance to mass transfer and storage in HSC at temperatures up to at least 800 °C, and a review of information about heat transfer and storage in HSC at temperatures up to at least 800 °C. These reviews will each cover (1) how various properties vary with temperature, pressure, and thermal history, (2) existing measurement techniques, (3) data and correlation to see how well different properties can be predicted without direct measurement, (4) identification of laboratories that have the existing capability to measure various properties, (5) identification of equipment that can be used to measure various properties, and, where necessary, (6) design of test apparatus to measure various properties. A microstructural examination will be conducted to study the residual effects of heating on HSC specimens and measurements of heat-induced mass and moisture losses. Also, a sensitivity study will be performed to aid the experimental efforts in better defining the importance of the various parameters that may affect the fire performance of HSC. This sensitivity study will be carried out using existing heat and mass transfer models, supplemented by the use of other calculations and by existing theory, experimental data, and correlation. This study will identify the important input variables and the assumptions made in various models as well as how these variables and assumptions affect the predicted temperatures, pore pressures, and other outputs.

2. *Modeling*: The data obtained from BFRL experimental phase and other studies will be used to develop a material model to predict damage of HSC due to high temperature. The basis for the model may be adopted from existing pore pressure models, but including the measured properties (permeability, moisture content, pore pressure buildup, rate of moisture loss, etc.) for HSC obtained in task 1. Data obtained from element tests in task 1 will be used for model validation. The model will be implemented in a computer program and used in parametric studies to aid in assessing the fire performance rating for HSC structural elements.

3. *Code Implementation*: The experimental and analytical results will be synthesized and tabulated into *Implementational* form, such as a practical constitutive relationship for HSC at various temperatures, suitable for design purposes, and presented to code writing organizations. This phase will be conducted in collaboration with private industry and code organizations.

Recent Results:

Phan, L.T.; Carino, N.J.; Duthinh, D.; and Garboczi, E., "International Workshop on Fire Performance of High-Strength Concrete, NIST, Maryland, February 13-14, 1997, Proceedings," NIST Special Publication 919, National Institute of Standards and Technology, October 1997, 164 pp.

Phan, L.T., "Fire Performance of High-Strength Concrete: A Report of the State-of-the-Art," NISTIR 5934, December 1996, 105 pp.

Phan, L.T. and Carino, N.J., "A Review of Mechanical Properties of HSC at Elevated Temperature," ASCE *Journal of Materials in Civil Engineering*, Vol. 10, No. 1, pp. 58-64

Next Generation Design Standard for Wind Loads

Principal Investigator: Emil Simiu, Structures Division, 301-975-6076

Sponsor: National Institute of Standards and Technology

Objective: To develop key elements of a knowledge-based improved wind load design standard that will make extensive use of site and building-specific databases and state-of-the-art computational methods for establishing site-specific design wind speeds and the corresponding steady and fluctuating structural loads.

Problem: There are a number of significant deficiencies in the wind load design provisions of current U.S. codes and standards. They include:

1. Crude simplifications of loading models due to the need in traditional standards to summarize a wide range of information in one table or even one number.

2. Extreme winds and corresponding load factors derived from outmoded estimation methods.

3. Exposure coefficients that cannot deal with complex wind exposures.

4. Gross simplifications of extreme pressures and loads that ignore the directional effects of wind.

5. No distinction between design for safety and design for serviceability.

Current data storage and computational capabilities allow the development of a new generation of standards whose provisions can be structured as knowledge-based systems. The ASCE 7-95 Standard uses reductive envelope curves resulting in designs that are not risk-consistent. Also, unlike the 1995 British Code of Practice, ASCE 7-95 does not account for wind directionality. With no additional effort on the designer's part, standards based on the knowledge-based systems approach can account realistically for climatological and aerodynamic information specifically applicable to the structure being designed.

Technical Approach: During FY1998, BFRL will work on the following tasks:

1. Develop "peaks over threshold" extreme value estimation approach to hurricane load estimation, taking wind directionality into account.

2. Develop aerodynamics data bases for a pilot module of the new type of standard.

3. Acquire information on typical frame design, development of corresponding influence line plots for the pilot module, testing of the conceptual approach to a new standard, and assessing its benefits.

4. Coordinate with BFRL's computational fluid dynamics (CFD) group potential CFD methods to supplant wind tunnel testing for loads on wind-force resisting systems.

5. Monitor the incorporation of updates to ASCE 7-95 into the BFRL developed interactive software.

6. Interact with insurance workers and standards groups on improvement of current design methodologies for hurricanes and tornadoes.

Recent Results:

Simiu, E. Discussion of paper "Prediction of Hurricane Wind Speeds in the United States," by P.J. Vickery and L.A. Twisdale, *J. of Structural Engineering*, Vol 123, November 1997, pp. 1549-1550.

Simiu, E. "Ultimate Wind Loads and Direction Effects in Non-hurricane and Hurricane-prone Regions," presented at Eighth International Environmetrics Conference, August. 1997, and submitted to *Environmetrics.*

Simiu, E., "Toward a New Generation of Standard Provisions for Wind Loads," Keynote talk presented at Eighth U.S. Conference on. Wind Engineering, June 1997, Baltimore.

Whalen, T., Simiu, E., Harris, G, Surry, D, and Lin, J., "The Use of Aerodynamic Databases to Develop Effective Wind Loading Standard Provisions: Application to Low Buildings," presented at Eighth U.S. Conference on Wind Engineering, June 1997, Baltimore; also submitted to *Int. J. of Wind Eng. and Ind. Aerod.* This paper was prepared in collaboration with a member company of the Metal Buildings Manufacturing Association and the wind tunnel laboratory at the University of Western Ontario.

Simiu, E. and Heckert, N., "Wind Direction and Hurricane-Induced Ultimate Wind Loads," Proceedings of the Second European Conference on Wind Engineering, G. Solari, Ed., June 1997, pp. 1825-1832; also submitted to *Int. J. of Wind Eng. and Ind. Aerod.*

Assessment of Methodologies for Estimating Tornado Wind Speeds

Principal Investigator: Emil Simiu, Structures Division, 301-975-6076

Sponsor: Department of Energy
Lawrence Livermore, National Laboratory

Project Objective: To provide LLNL with an assessment of current criteria on tornado wind speeds.

Problem: The Department of Energy intends to review its wind speed criteria. Little research has been performed since the early and mid 1980s on tornado wind speed estimates. The state-of-the-art needs to be updated.

Technical Approach: A group of experts including a senior BFRL researcher will review and assess the literature on the subject.

Results: New project.

Environmental Specifications for Mobile Offshore Unit

Principal Investigator: Emil Simiu, Structures Division, 301-975-6076

Sponsor: Bechtel National Inc. (for Naval Facilities Engineering Service Center)

Objective: To provide wind engineering specifications and advice on overall development of environmental specifications for use in studies for the possible design of a Mobile Offshore Unit.

Problem: The development of a mobile offshore unit of very large size is unprecedented. An exhaustive set of design criteria is needed for such development.

Technical approach: A group of experts, including a senior BFRL researcher will develop environmental specifications and provide advice on the overall set of specifications.

Results: New project.

Analytical Performance Prediction of Single Family Housing

Principal Investigators: Geraldine Cheok, Structures Division, 301-975-6074
Riley M. Chung, Structures Division, 301-975-6062
Bijan Mohraz, Structures Division, 301-975-6079
Fahim Sadek, Structures Division, 301-975-4420
Charles Yancey, Structures Division, 301-975-6073

Sponsor: National Institute of Standards and Technology

Objective: To develop methodologies for predicting and evaluating the performance of single family dwellings with traditional and non-traditional construction materials.

Problem: In the past, the performance of single family houses has been assessed using the performance of the individual components determined analytically or experimentally. In addition, the performance criteria have been based on traditional construction materials such as wood and masonry used in single family houses.

The use of non-traditional construction materials such as concrete, light gage steel, and composites may provide cost-effective alternatives. To investigate the feasibility of using these materials, baseline performance criteria of the total system (complete dwelling) with integrated components rather than from individual components need to be established.

Technical Approach: During FY1998, BFRL will develop system performance criteria for complete housing units using the traditional construction materials through the use of a three-dimensional finite element analysis. The analytical model will include the interaction of various components such as studs, beams, wall panels, roof framing, etc. Once the performance criteria for typical traditional units are established, the model will be used to examine houses constructed with non-traditional construction materials.

The research will examine the availability of data on the performance of housing components made of traditional and non-traditional construction materials. Component testing will be carried out when such information is not available and is needed for the finite element model. The study will determine the cost effectiveness of using non-traditional construction materials for single family housing and their performance under severe environmental hazards such as high winds and seismic loads.

The following tasks will be performed:

1. Literature review on past performance of single family, wood frame houses in earthquakes and hurricanes. The review will include analytical and experimental work to identify gaps where additional R & D on component and assemblages are needed.

2. Conduct experiments as identified in Item 1.

3. Select appropriate software and develop a simplified 3-D finite element model for typical single family houses.

4. Use the simplified 3-D finite element model to establish baseline performance criteria for traditional materials. The analyses will consist of a parametric study to determine the effect of different input motions and building configurations.

5. Similar to Item 3 for non-traditional materials.

Recent Results: New project.

Open Testing Contract in Support of DoD Funded Development Work

Principal Investigator: Erik Anderson, Structures Division, 301-975-5286

Sponsor: Custom Analytical Engineering Systems, Inc.

Project Objective: To conduct tests as needed in support of U.S. Navy gun launched projectile development using NIST's unique testing facilities, such as the 54MN universal testing machine.

Problem: Prototypes require testing to meet design capacities.

Technical Approach: During FY1998, BFRL will test specimen as per sponsor's specifications. BFRL will provide facilities and machine operators only. Data will be analyzed by sponsor.

Recent Results: New project.

BUILDING MATERIALS

CEMENT AND CONCRETE

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Computer-Integrated Knowledge Systems (CIKS) for High-Performance Concrete

Principal Investigators: James R. Clifton, Building Materials Division, 301-975-6707
Dale P. Bentz, Building Materials Division, 301-975-5865

Sponsor: National Institute of Standards and Technology

Objective: To develop and demonstrate an operational prototype for a computer integrated knowledge system (CIKS) for high-performance concrete (HPC) for bridges and buildings.

Problem: A major need for exploiting the benefits of HPC is making reliable information about these advanced concretes (composition and mix design, properties, performance, and economics) quickly available to the construction and building community. Owners, designers, material suppliers, and contractors will all benefit from access to information and knowledge about HPC that can be quickly retrieved. This can be accomplished by incorporating and integrating the information and knowledge in a CIKS. The CIKS for HPC will consist of knowledge bases including databases, mathematical models, artificial intelligence systems, standard practices and test methods, and guidelines. It will assist decision makers in using the most reliable and advanced knowledge in selecting and using HPC. When fully developed, this system will become the leading problem solver for HPC.

Approach: During FY1998, BFRL will develop a methodology and a protocol for interpreting, representing, and integrating knowledge into the CIKS for HPC. A terminology dictionary formats for knowledge bases and databases will be developed. Three tasks will be carried out in FY98:
Task 1) Continue the development of the prototype CIKS, made accessible on the Internet in FY97, for selecting concrete mixes to give specific service lives for reinforced concrete members, considering the major degradation processes such as corrosion, frost attack, sulfate attack, and alkali-aggregate reactivity. Since this prototype is further developed than other part of the CIKS for the service life design of HPC, it will serve as a model for the representation and incorporation of knowledge from other PHPCT projects. BFRL will collaborate with the New York State DOT and other state DOT's in developing and applying the prototype CIKS to bridges. CIKS will be modified so it can consider any appropriate mix design.
Task 2) Work with the concrete and masonry, and metals CONMAT Working Groups to assist in their participation in the CIKS test bed development. Because the availability of common or standard terminology and database formats are vital to the development of CIKS by the working groups, BFRL will continue to develop formats for concrete databases (within AC I Committee 126 on Database Formats) and will explore the need to develop lexical and knowledge models for concrete. These activities will also contribute to the development of the prototype CIKS being pursued in Task 1.
Task 3) Continue to disseminate information to the construction industry on the application of CIKS, such as continuing to add the results of BFRL's modeling activities to the electronic monograph on modeling cement-based materials. Also, BFRL will continue to explore opportunities for partnership within the ACI, including ACI Committee 235 on Knowledge Based Systems for Concrete, and with all aspects the concrete industry and opportunities for collaboration with research organizations such as the Corps of Engineers and the Federal Highway Administration.

Recent Results:

Clifton, J. R., Sunder, S., *A Partnership for a National Computer-Integrated Knowledge System Network for High-Performance Construction Materials and Systems*, NISTIR 6003, National Institute of Standards and Technology, 1997.

Enhancement of Computer Model 4SIGHT for Facility Performance Assessments

Principle Investigators: James R. Clifton, Building Materials Division, 301-975-6707
Kenneth A. Snyder, 301-975-4260

Sponsor: Nuclear Regulatory Commission

Objective: To validate the computer model 4SIGHT through comparisons with published data and the results of field studies on the durability of in-service underground concrete, and incorporate enhancements into 4SIGHT dealing with degradation of concrete prior to burial, early-age cracking, and performance of joints.

Problem: Reinforced concrete has been proposed by many concerned organizations in the United States as an engineered barrier for the isolation or containment of radioactive wastes. Most engineered concepts utilize concrete vaults below ground surface with an earth covering, to contain the wastes. When conducting performance assessments (PA) of these engineered waste facilities, one of the most important inputs that affect the predicted dose to individuals, is the hydraulic conductivity properties of the engineered barriers as a function of time. The hydraulic properties in turn are a function of the degradation of the engineered barriers. It is assumed that concrete engineered barriers will degrade with time with concomitant changes in these hydraulic properties. The degradation processes include intrinsic cracking of concrete due to plastic and/or drying shrinkage, creep, tensile and thermal stresses, sulfate attack, corrosion, and acid attack.
The computer program 4SIGHT was developed by BFRL under sponsorship by NRC to model the performance of underground concrete vault systems for the disposal of radioactive waste. The program is based upon a mechanistic simulation of multiple degradation processes, the effect of chloride ions on reinforcement steel, sulfate and acid attack, and the effects of joints and cracks. The degradation mechanisms in the program are implemented simultaneously such that synergistic effects can be determined. The outputs from the program include a time history of the hydraulic conductivities of the concrete vault that can be directly input into PA calculations for the waste facility.

Approach: BFRL will perform three tasks:
Task 1) Obtain and analyze information on the durability of underground concrete by reviewing published data and by examining field structures. Information will be sought on the extent and the cause of degradation , the age of the concrete, the mix design of the concrete, and the service environment.
Task 2) Predict crack development and its effect on the hydraulic conductivity of underground concrete vaults as full depth cracking of concrete vaults will increase its hydraulic conductivity by several orders of magnitude. Cracked concrete also facilitates passage of water through the vault resulting in contact with the waste inside and release to the environment. In the 4SIGHT program, the ACI code is used as a basis for predicting cracking in the concrete. BFRL will examine published and in-service underground concrete to determine the adequacy of the model. Also, concrete vaults may be left uncovered for substantial lengths of time before they are covered with soil. Under these conditions, the concrete exposed to the environment may be subject to degradation processes not encountered when buried, such as differential thermal stress and freeze-thaw. BFRL will modify the 4SIGHT Program to account for such degradation mechanisms based on available mathematical models and the use of published and in-service concrete measurements to test the models.
Task 3) Investigate the long-term performance of joints. The 4SIGHT code will be modified to account for the degradation of the joints based on published data.

Recent Results: New project.

Micro- and Macro-Structural Characterization of High-Performance Concrete

Principle Investigator: Paul E. Stutzman, Building Materials Division, 301-975-6715

Sponsor: National Institute of Standards and Technology

Objective: To develop and apply methods for quantitative characterization and mathematical description of the micro- and macro-structures of high-performance concretes for use in evaluating processing procedures and in modeling performance.

Problem: Application of material science to concrete requires the ability to determine and describe the micro- and macro-structures. There is a need to develop a method, including selection of analytical techniques, to characterize micro- and macro-structural features to determine the effects of processing and environmental variables on performance of concrete. Selection of cementitious materials for high performance concrete (HPC) requires an understanding of the relationships between cement composition and performance of concrete. Improved methods for determining the phase composition of clinker, portland, and blended cements will facilitate this understanding.

Approach: During FY1998, BFRL will perform two tasks:
Task 1) Develop a method to characterize micro- and macro-structure of HPC. This method will be applied in PHPC-related projects in investigating the response of HPC to fire and the effects of processing on HPC structure and performance. This method will form the basis for quality control of HPC production and for prediction of the performance of HPC. Quantitative image analysis will advance the development of concrete petrography, and will assist in evaluation of material heterogeneity, flaws, and features characteristic of deleterious physical and chemical processes.
Task 2) Develop analytical methods needed to characterize cements and associated materials. Interactions with cement manufacturers and government laboratories will be established through ASTM C 01. Modeling X-ray powder diffraction patterns of cementitious, pozzolanic materials, and hydration products will provide needed phase, chemical, and structural information. This data will aid in selection of cements for HPC and in the understanding of their performance properties.

Recent Results:

ASTM C 1356-97M, "Standard Test Method for the Quantitative Determination of Phases in Portland Cement Clinker by Microscopical Point-Count Procedure," *American Society for Testing and Materials* Vol. 4.01, 1997.

ASTM C 1365-97M, "Standard Test Method for Determination of the Proportion of Phases in Portland Cement and Portland-Cement Clinker using X-Ray Powder Diffraction Analysis," *American Society for Testing and Materials* Vol. 4.01, 1997.

Stutzman, P.E., *Guide for X-ray Powder Diffraction Analysis of Portland Cement and Clinker*, NISTIR 5755, National Institute of Standards and Technology, 1996.

Simulation of the Performance and Service Life of HPC

Principal Investigator: Edward J. Garboczi, Building Materials Division, 301-975-6708

Sponsor: National Institute of Standards and Technology

Objective: To develop computer integrated knowledge system (CIKS) for prediction of transport and other durability-related properties, based on materials science (including microstructure, chemistry, mixture design, and expected curing) of fully-saturated high-performance concrete (HPC).

Problem: The service life of HPC depends on transport properties, like resistance to chloride penetration, and other properties, like dimensional stability. These need to be quantitatively predicted at the design stage, so that HPC can be designed for durability and life-cycle cost requirements, not just strength requirements. The only accurate way that different kinds of HPC can be handled is to base such predictions on a fundamental materials science basis that includes microstructure, cement chemistry, concrete mixture design, and expected curing.

Approach: During FY1998, BFRL will refine the cement chloride resistance model using experimental data from Northwestern University, Imperial College, and Queen's University of Belfast. Recent improvements in the cement paste microstructure model make it necessary for the percolation and diffusivity aspects of the cement paste pore structure to be re-evaluated, which will lead to improvements in the chloride resistance model. BFRL, working with the Lawrence Livermore Laboratory, will improve the effective medium theory component of the model, which enables the user to avoid supercomputer computations.
It is crucial to build a multi-scale model for the chloride resistance of concrete with mineral admixtures present like fly ash and silica fume. This process has begun by incorporating fly ash into the 3-D cement paste microstructure model. BFRL will generate the cement paste chloride diffusivity in this situation and an analytical approximation. The results will be incorporated into a multi-scale model.

Recent Results:

Developed the first version of the chloride diffusivity model for fully-saturated portland cement concrete.

BUILDING MATERIALS

ORGANIC MATERIALS

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Acceleration of the Photodegradation of Polymeric Systems via High Radiant Flux Exposure

Principal Investigators: Jonathan W. Martin, Building Materials Division, 301-975-6717
Tinh Nguyen, Building Materials Division, 301-975-6718

Sponsor: National Institute of Standards and Technology

Objectives: To determine the radiant flux range for photodegradation over which the reciprocity law is valid for two polymeric coating systems.

Problem: Acceleration of photodegradation is of great practical importance to the coatings and polymer industry, since, if acceleration can be achieved in a practical manner and without changing the failure mechanism, exposure times can be greatly reduced. One of the most convenient methods for accelerating photodegradation is by increasing the radiant flux to which a polymeric material is exposed.
Although high radiant flux exposure equipment has been available for a number of years, the acceptance of these results by the coatings and plastics communities has been tentative. Acceptance could be greatly improved if exposure results were shown to have a scientific basis and if the exposure results at normal radiant fluxes could be predicted via a scientifically-based model by extrapolating from results obtained at high fluxes. One such model which has been extensively studied is the reciprocity law. The reciprocity law was first proposed by Bunsen and Roscoe in 1850's and it assumes that photochemical effect is only a function of dosage, which is the product of dose-rate and exposure time. Over the last 100 years, the photographic and medical/biological communities have performed a large number of experiments to validate this model or its derivative (e.g., Schwarzschild's law). Two experimental protocols are commonly used. In one protocol, a material is continuously irradiated over a wide range of radiant fluxes to determine if the same degree of degradation is observed for a given dosage; while, in the other protocol, the material is intermittently exposed at the same radiant flux. As an example of the range of fluxes, one medical experimenter exposed skin to radiant fluxes spanning eleven orders of magnitude in energy (the author concluded that reciprocity was obeyed). Similar experiments have been conducted on polymeric materials, but the number of experiments and the radiant flux and spectral ranges are limited.
It can be concluded from published medical/biological, photographic, and the materials studies that photodegradation can be accelerated by increasing the radiant flux and that the reciprocity law, or a modification of the reciprocity law, appears to be useful in predicting photochemical response over a wide range of radiant fluxes. However, to gain acceptance of this technology, systematic, well-controlled experiments on more polymeric materials are needed to determine the range of radiant fluxes over which the reciprocity law is obeyed.

Approach: During FY1998, BFRL will investigate the spectral photochemical response of a clear and pigmented coating system over the radiant flux range from energy levels below the maximum solar ultraviolet radiant energy spectrum (the solar ultraviolet radiant energy spectrum observed on the equator, at 12 noon, on a clear day, during the summer solstice) to approximately the solar ultraviolet spectrum at 10,000 suns. Radiant fluxes from below to approximately 50 suns will be made through extensive modifications of our existing exposure equipment; exposures of about 100 suns will be performed on the National Renewable Energy Laboratory High-Flux Solar Furnace; while exposures at the highest radiant energy levels will be performed on NIST's SURF III Synchrotron. NIST's exposure equipment will have to be extensively modified to increase radiant fluxes to 50 suns while ensuring spatial uniformity and temporal stability of the radiant flux. Exposure cells will be fabricated to maintain the temperature and relative humidity surrounding the specimens and to expose the specimens to various spectral bandwidths.

Recent Results: New project.

Characterization of Polymeric Materials and Systems Interface/Interphase

Principal Investigator: Tinh Nguyen, Building Materials Division, 301-975-6718

Sponsor: National Institute of Standards and Technology

Project Objective: To characterize and model the morphological, chemical, and physical interfacial and interphasial properties of aged and unaged polymeric composite materials and systems.

Problem: Polymeric composite materials and systems have always played an important role in the building and construction industries. Recently, this role has greatly increased with the push to replace traditional structural materials, such as reinforced concrete and steel, with high-strength fiber-reinforced polymeric composites. Polymeric composite materials and systems, like pigments in paint, paint on plastics and metals, and fiber-reinforced polymeric composites, are comprised of a polymer matrix, a substrate, and an interface/interphase between the matrix and substrate. Interface is defined as the two-dimensional boundary between the matrix and substrate, while interphase is the three-dimensional region including the interface plus a zone of finite thickness on both sides of the interface. In addition to the matrix and substrate layers, which have chemical, physical, and morphological properties that are different from the bulk, the interphase often includes impurities, unreacted molecules, or additives. It is also affected by processing conditions, which cause chemical reactions, species diffusion, volumetric changes and stresses to be generated. The resulting interphase can be a very complex structure, which is not easily analyzed or modeled.
The interface/interphase controls many of the properties of a polymeric composite material and system. It is also known as a weak link, in that failures of a system often initiate from the interface/interphase region. Efforts have been devoted to improving the strength and durability of this region through surface treatment or modification of the substrates. Considerable research on the durability of fiber-reinforced polymeric composites have been conducted. However, little progress has been made on the understanding of the morphological, physical, chemical, and mechanical properties of the interface/interphase region, how these properties change with external stresses, and how this region affects the performance and service life of a polymeric system.

Approach: During FY1998, BFRL will develop effective methods to characterize the interface/interphase and its changes with external stresses. This work will concentrate on the identification of industry needs and techniques to characterize the molecular interactions and microstructure (including defects) at polymer/substrate interface.

Recent Results: New project.

Coatings Service Life Prediction

Principle Investigators: Jonathan W. Martin and Tinh Nguyen, Building Materials Division

Objectives: To develop and validate a mathematical model that predicts the instantaneous bulk and surface moisture contents of coated structures exposed to outdoor conditions with given material and environmental data as input. Water in residential building materials is a primary cause of degradation.

Problem: The most difficult part of any service life prediction methodology is to relate field and laboratory results. To accomplish this, outdoor weathering factors need to be quantitatively characterized in the same manner that these factors are characterized in the field. The three weathering factors which are primarily responsible for the degradation of polymeric coating systems are moisture content (water), panel temperature, and spectral ultraviolet radiation. At present, two of these factors, spectral ultraviolet radiation and panel temperature, can be quantitatively and temporally characterized. The third factor, moisture content, has hitherto defied monitoring or quantitative assessment.
Water causes coated steel to corrode and accelerates the coating photodegradation. Indeed, in the absence of water, corrosion can not occur while, in the presence of moisture, the corrosion of bare steel is highly correlated with its surface moisture content. Likewise, the rate of photolysis of a coating system (appearance loss) is usually only significant when moisture is present. Thus, the inability to predict or to monitor the presence of moisture in a coating has greatly limited our ability to characterize the severity of an exposure environment, to identify which weathering factor or combination of weathering factors is causing a polymeric system to degrade, and, most importantly, to relate field and laboratory exposure results.

Approach: The technical approach to this problem involves the following: 1) refinement of a transient heat and moisture transfer model, 2) verification of the surface and bulk moisture content of a coating via near infrared (NIR) analysis, 3) development of a NIR instrument which can be taken into the field, 4) identification of the minimum set of material and environmental variables necessary to compute a coating system's moisture content, and 5) derivation of the time series for changes in bulk and surface moisture content at one or more field sites over time.
Using the modeling theory outline in the International Energy Agency (IEA) Annex 24, a one-dimensional mathematical model will be refined to predict the temperature and relative humidity of a coating system as a function of time. The coating will be assumed to be applied to a substrate (i.e., wood, plastic, or metal) having arbitrary tilt and compass orientation. The model will contain a conservation of mass equation from which the relative humidity of the coating will be calculated. The moisture equation will include both molecular diffusion and capillary transport as separate and distinct transport mechanisms. The moisture equation will use water-vapor permeability and moisture diffusivity as moisture transport coefficients.
The NIR technique has only recently become a viable means for determining bulk moisture content. NIR detects the water bands between 5000 cm-1and 5260 cm-1. The power of NIR analysis is that it is fast, non-destructive, and capable of determining the moisture content of relative thick specimens. Thus, this technique appears to be suitable for determining the bulk moisture content of a coating system. Although NIR is a well-developed technique, its use in this application has yet to be established. Assuming that NIR is capable of measuring the moisture content of coatings, then a portable NIR instrument will be developed for making field measurements.
The minimum material and environmental data required to predict a coating system's moisture content will be known and standardization of these measurements will be investigated.
The last part of the investigation will be to predict the quarterly hour bulk and surface moisture contents of a coating and perform time series analyses on the collected data.

Recent Results: New Project.

Composites for Structural Applications: Characterization of Material Durability and Service Life

Principle Investigator: Joannie Chin, Building Materials Division, 301-975-6815

Sponsors: National Institute of Standards and Technology

Objective: To develop methods to characterize degradation in polymer composites induced by moisture, temperature, ultraviolet (UV) radiation and mechanical loading, and to identify the mechanisms and controlling factors responsible for degradation.

Problem: In recent years, applications of fiber-reinforced polymer matrix composites in infrastructure and other civil engineering applications have rapidly increased. However, design codes and specifications needed for the implementation of these materials, which are necessary as input to engineering design, is lacking. Acceptance of polymer composites in civil engineering will not be forthcoming until durability data and a code of practice are available.
It is well-known that in outdoor environments, polymer composites can undergo degradation following exposure to ultraviolet (UV) radiation, moisture, temperature cycling and mechanical loading. At the present time, limited knowledge is available on factors which are most damaging and synergies which exist between the exposure factors. Without an understanding of the controlling environmental factors and their corresponding damage mechanism, little confidence can be placed in accelerated aging studies and service life prediction.

Approach: During FY1998, BFRL will perform a multivariate study of exposure variables to determine single factor exposure effects as well as 2-way (or more) interactions. This will serve to provide information on the factors and mechanisms which govern degradation. Materials studied will be those deemed to be most significant for civil engineering applications and can include glass/polyester or glass/vinyl ester composites. Environmental factors to be investigated will include UV radiation, temperature and moisture. Superimposed on the environmental exposure will be two modes of mechanical loading: static and cyclic. Static loading will be accomplished in-house with the development of a multi-sample static stress frame equipped with computer controls for measuring force, displacement and time-to-failure. Cyclic loading, or fatigue, experiments will be performed in collaboration with Virginia Polytechnic Institute and State University.
Characterization of the materials by a wide range of chemical and physical techniques will help determine which parameters should serve as degradation indicators. Degree of degradation in mechanical properties will be assessed by changes in quasi-static properties and fatigue lifetimes. Changes in chemical structure and thermophysical properties will be characterized with Fourier transform infrared (FTIR) spectroscopy, nuclear magnetic resonance (NMR) spectroscopy, differential scanning calorimetry (DSC), dynamic mechanical thermal analysis (DMTA), and thermogravimetric analysis (TGA). Changes in surface and interface characteristics will be studied with scanning electron microscopy (SEM), laser confocal microscopy and atomic force microscopy (AFM).

Recent Results: New Project

Measurement Science for Optical Reflectance and Scattering

Principle Investigators: Mary McKnight, Building Materials Division, 301-975-6714
Tinh Nguyen, Building Materials Division, 301-975-6717

Sponsor: National Institute of Standards and Technology

Objective: To 1) quantitatively characterize physical and optical properties of two pigments, 2) quantitatively characterize the microstructure of model materials having different reflectance and scattering properties, and 3) work with industry and university researchers to form an industrial/academic/government research consortium on advanced reflectance and scattering measurements.

Problem: The reflectance and scattering properties of materials (e.g., color, gloss, texture) are important in the manufacture and sale of most products. They can greatly influence a customer's judgment of the quality of a product or affect the visibility of a warning sign or a camouflage object. To enhance the development and implementation of new products, it is essential that the industry have the physical tools necessary to accurately quantify their reflectance and scattering properties, and the modeling capability to predict their appearance. Current reflectance and scattering metrology is limited. For example, it is usually based on specular or diffuse measurements from a small area of the surface. This has led to a host of specialized metrics, e.g., at least ten for gloss alone. These metrics are useful in monitoring the quality of some materials, but are inadequate for characterizing the reflectance and scattering properties of many new materials. Predictive models are also limited. Fortunately, recent advances in optical metrology, mathematical modeling and computer rendering can be applied to significantly advance measurement procedures and modeling methods.

Approach: During FY1998, BFRL will develop measurement methods for optical reflectance and scattering to advance the fundamental understanding of appearance. Researchers from NIST's Physical Laboratory, Information Technology Laboratory, and Manufacturing Engineering Laboratory, will work together with BFRL to perform experimental and modeling in four major areas: 1) material formulation, 2) microstuctural characterization, 3) reflectance measurement and modeling and 4) computer rendering. In BFRL, competence will be built in preparing and characterizing materials having desired properties. Properties will be characterized by several techniques including scanning electron microscopy, atomic force microscopy and confocal laser scanning microscopy. In parallel with the technical efforts, work to develop ties to industry and university will continue to ensure that the research is responsive to industry needs.

Recent Results:

McKnight, M., Martin, J., Nguyen, T., "Advanced Methods and Models for Describing Coating Appearance", *Progress in Organic Coatings*, to be published.

McKnight, M., Nguyen, T., "Workshop on Advanced Method and Models for Appearance of Coating and Coated Objects," Journal Research of the National Institute of Standards and Technology, July 1997.

Method for Evaluation of Performance of Lead-in-Paint Measuring Devices Under Simulated Field Conditions

Principle Investigator: Mary McKnight, Building Materials Division, 301-975-6714

Sponsor: Department of Housing and Urban Development
Office of Lead-based Paint Abatement and Poisoning Prevention

Objective: To identify and quantify factors affecting the field performance of portable x-ray fluorescence (XRF) measurements of lead in paint using a range of simulated field conditions.

Problem: Recent legislation (Housing and Community Development Act of 1992, PL102-550) will phase in requirements for lead-based paint testing for all housing built before 1978. These requirements are expected to result in several new x-ray fluorescence (XRF) devices. Because of both health and financial liabilities associated with these measurements, it is essential to have reliable estimates of the field performance parameters of the measurements (e.g., detection limit, precision, bias). For some XRF devices, research results have shown that estimates of these performance parameters obtained using existing laboratory evaluation procedures do not agree with estimates obtained using field-acquired data. Currently, field studies are being used to characterize additional devices. However, field studies are limited in several ways -- sites having parameters in the necessary ranges are difficult to find; systematic variation of the parameters is usually not possible; implementation of new technologies may be impeded; and advances in the fundamental understanding of a measurement procedure are limited.

Approach: During FY1998, BFRL will complete research including characterizing and modeling the scientific principles controlling the performance of portable XRF devices; designing and performing laboratory experiments to simulate significant field conditions, as determined by modeling and other information; performing a limited field study to determine whether the laboratory results are consistent with field results; and preparing a standard protocol for laboratory evaluation of portable XRF devices and present it to ASTM E06.23 for standardization.

Recent Results:

No published results.

Optical Properties of New and Aged Coatings

Principle Investigators: Mary McKnight, Building Materials Division, 301-975-6714
Tinh Nguyen, Building Materials Division, 301-975-6718

Sponsor: National Institute of Standards and Technology

Objective: To develop and validate models for predicting appearance parameters of a coating from formulation parameters and for predicting changes in the appearance as the coating ages.

Problem: The appearance of an object is a complex phenomenon resulting from the interaction between light and the object and the senses of the person viewing the object. It depends on many physical parameters, including the light source, optical scattering of light by the object, and the angles of illumination and viewing. Many microstructural material properties affect optical scattering, such as surface roughness, pigment particle size, pigment particle size distribution, and spatial distribution of pigment particles.
Current coating appearance modeling is based on simple models that have limited requirements for parametric descriptions of microstructure. Thus, these models are not readily linked to formulation parameters. Further for some coatings, such as those containing metallic pigments, microstructure plays a key role in the appearance of a coated object. Models that can couple formulation parameters, microstructure and appearance offer the potential of providing researchers and engineers the ability to design coatings with appropriate initial appearance and durability properties.

Technical Approach: During FY1998, BFRL will perform measurement techniques, such as confocal laser scanning microscopy to characterize coating microstructure, and develop mathematical models to predict coating microstructure based on formulation parameters. Later, BFRL will integrate the additional models (including computer rendering) and measurement methods to develop relationships among coating formulation parameters and appearance for new and aged organic coatings.

Recent Results: New project.

Performance of Tape-Bonded Seams in EPDM Roofing Membranes

Principle Investigator: Walter J. Rossiter, Jr., Building Materials Division, 301-975-6719

Sponsors: National Institute of Standards and Technology

Adco Products
Ashland Chemical Company
Carlisle SynTec Systems
Firestone Building Products
National Roofing Contractors Association
Roof Consultants Institute

Objective: To develop a test protocol and recommended criteria for evaluating the long-term performance of tape-bonded seams in EPDM roofing membranes.

Problem: EPDM is a non-polar material and, as such, it has excellent weathering properties, but care must be taken in adhesively bonding EPDM with itself, as required in the formation of a roofing seam. Liquid-applied butyl adhesives have excellent weathering properties, and have been extensively and successfully used in forming EPDM roofing seams since the mid-1980s. However, liquid-applied adhesives contain a large volumetric fraction of solvents, which are increasingly becoming environmentally unacceptable. A replacement for these liquid-applied adhesives are butyl-based tapes. Users of EPDM roofing such as contractors and consultants have expressed concern that the rheological properties be properly evaluated and data be developed to characterize the rheological performance.

Approach: During FY1998, BFRL will complete a three year project by investigating the effect of elevated test temperature and specimen configuration on rheological performance. This laboratory research includes performing an investigation of the effects of temperature on rheological performance. A draft standard test protocol for determining the time-to-failure of tape-bonded seams will be prepared and submitted to ASTM. A paper describing the results of the inspections of EPDM having tape-bonded seams will be prepared.

Recent Results:

Rossiter, W. J., Vangel, M. G., Kraft, K. M., and Filliben, J. J., "Performance of Tape-Bonded Seams of EPDM Membranes: the Effect of Material and Application Factors on Peel Creep-Rupture Response," Building Science Series 176, National Institute of Standards and Technology, May 1997.

Rossiter, W. J., Vangel, M. G., Embree, E., Kraft, K. M. Seiler, J. F., "Performance of Tape-Bonded Seams of EPDM Membranes: Comparison of the Peel Creep-Rupture Response of Tape-Bonded and Liquid-Adhesive-Bonded Seams," Building Science Series 175, National Institute of Standards and Technology, May 1996.

Rossiter, W. J., "Performance of Tape-Bonded Seams of EPDM Membranes: the Effect of Load on Peel Creep," *4th NIST/NRCA International Symposium on Roofing Technology*, 1976.

Reliability of Spot Tests for Detecting the Presence of Lead in Household Paints

Principle Investigators: Walter J. Rossiter, Jr., Building Materials Division, 301-975-6719
Mary E. McKnight, Building Materials Division, 301-975-6714

Sponsor: Department of Housing and Urban Development
Office of Lead-based Paint Abatement and Poisoning Prevention

Objective: To determine the reliability of spot test kits for detecting the presence of lead in household paints when tests are conducted by inspectors trained to perform field inspections or risk assessments for lead hazards in housing.

Problem: The U.S. Department of Housing and Urban Development estimates that lead-based paint is present in over 50 million U.S. homes. An inspection of a residence for the presence of lead is a time-consuming and, thus, costly process. In recent years, spot tests have been introduced as a relatively nonintrusive, qualitative method for determining the presence or absence of lead in paint. A spot test involves the application of reagent solution to a prepared dry paint film sample or painted surface and the subsequent observation for the presence or absence of a characteristic color change. Use of such tests in the field is relatively easy and rapid and, thus, may be less costly than other methods for screening for the presence of lead-based paint in residences. The use of spot tests may be most beneficial if they can be used as a negative screen; i.e., they reliably determine that lead is only present at levels below which corrective actions for reducing lead hazards are unnecessary. This may be especially important now that the Real Estate Notification and Disclosure Rule (Section 1018 of the Residential Lead-Based Paint Hazard Reduction Act of 1992) is in place, which may be expected to result in considerable inspections and risk assessments of residences. The question regarding the reliability of spot test kits when used by operators trained in their use has not been addressed and needs to be evaluated in a systematic controlled laboratory experiment.

Approach: During FY1998, BFRL will investigate the response of typical commercial spot test kits (i.e., positive or negative) as a function of lead concentration in laboratory-prepared paint films. The investigation will be consistent with the guidelines given in ASTM Standard Guide E 1828, Evaluating the Performance Characteristics of Qualitative Chemical Spot Test Kits for Lead in Paint. Statistical procedures will be used in making the lead concentration selection, which will be determined quantitatively using atomic spectrometry. Films of the lead-containing alkyd paint will be cast on a synthetic (i.e., nonreactive) substrate. Then, for one set of samples, the lead-containing film will be overcoated with a non-lead-containing latex paint; whereas for the second set of samples, the lead-containing film will be overcoated with a non-lead-containing alkyd paint.
Concurrent with the tests on laboratory-prepared samples, spot test kit analyses of lead in paint in samples obtained from field residences will be conducted by BFRL trained operators. Quantitative analysis of the lead concentration in the paint layer and substrate of the field samples will also be conducted. The results of the spot tests of the field samples will be compared to those obtained using the laboratory samples.
BFRL will investigate factors known to be a source of interferences for spot test kits using statistically designed experiments. The results of the investigation will be statistically analyzed to provide the importance of each of the tested factors. The factors to be investigated are expected to include: lead concentration; lead distribution in the sample; substrate type; operator; lead pigment type; the presence of metals such as Fe, Ni, Co, Cu, and Hg in the paint; and test kit shelf life.

Recent Results: New project.

Standards for Management of Lead Hazards in Buildings

Principle Investigator: Mary McKnight, Building Materials Division, 301-975-6714

Sponsor: Department of Housing and Urban Development
Office of Lead-based Paint Abatement and Poisoning Prevention

Objective: To expeditiously develop standards needed for management of lead hazards in buildings and related structures.

Problem: An estimated 57 million homes in the United States contain some lead-based paint. Although there are increasing numbers of standards for characterizing the lead concentrations in paint, dust, soil and air particulates, additional standard procedures are needed to completely address the problem. For example, there is a need for an overall standard practice or guide for assessing lead hazards in buildings and related structures, design of hazard control strategies, and conducting hazard control procedures. An ASTM Subçommittee, E06.23, chaired by NIST, was organized to meet the need for development of all the needed standards has already established 24 standards, but some difficult ones have yet to be completed.

Approach: During FY1998, BFRL will work with ASTM E06.23 in developing basic standards to support an overall practice for managing lead hazard in buildings and related structures.

Recent Results:

Prepared text for twenty full consensus standards and four provisional standards that were published by ASTM.

Surface and Bulk Relative Humidity Predictions for a Polymeric Coating System Exposed in the Field and in the Laboratory

Principle Investigators: Jonathan W. Martin, Building Materials Division, 301-975-6717
Tinh Nguyen, Building Materials Division, 301-975-6718

Sponsor: National Institute of Standards and Technology

Objectives: To develop and validate a mathematical model for predicting the instantaneous bulk and surface moisture contents of coated structures exposed outdoor given material and environmental data as input.

Problem: The most difficult part of any service life prediction methodology is to relate field and laboratory results. To accomplish this, outdoor weathering factors need to be quantitatively characterized in the same manner that these factors are characterized in the field. The three weathering factors which are primarily responsible for the degradation of polymeric coating systems are moisture content (water), panel temperature, and spectral ultraviolet radiation. At present, two of these factors, spectral ultraviolet radiation and panel temperature, can be quantitatively and temporally characterized. The third factor, moisture content, has hitherto defied monitoring or quantitative assessment.
Water causes coated steel to corrode and accelerates the coating photodegradation. Indeed, in the absence of water, corrosion can not occur while, in the presence of moisture, the corrosion of bare steel is highly correlated with its surface moisture content. Likewise, the rate of photolysis of a coating system (appearance loss) is usually only significant when moisture is present. Thus, the inability to predict or to monitor the presence of moisture in a coating has greatly limited our ability to characterize the severity of an exposure environment, to identify which weathering factor or combination of weathering factors is causing a polymeric system to degrade, and, most importantly, to relate field and laboratory exposure results.

Approach: During FY1998, BFRL will perform the following: 1) refine a transient heat and moisture transfer model, 2) verify the surface and bulk moisture content of a coating by using near infrared (NIR) analysis, 3) develop a NIR instrument which can be taken into the field, 4) identify the minimum set of material and environmental variables necessary to compute a coating system's moisture content, and 5) derive the time series for changes in bulk and surface moisture content at one or more field sites over time.
Using the modeling theory outline in the International Energy Agency (IEA) Annex 24, a one-dimensional mathematical model will be refined to predict the temperature and relative humidity of a coating system as a function of time. The coating will be assumed to be applied to a substrate (i.e., wood, plastic, or metal) having arbitrary tilt and compass orientation. The model will contain a conservation of mass equation from which the relative humidity of the coating will be calculated. The moisture equation will include both molecular diffusion and capillary transport as separate and distinct transport mechanisms. The moisture equation will use water-vapor permeability and moisture diffusivity as moisture transport coefficients.
The NIR technique recently become a viable means for determining bulk moisture content. NIR detects the water bands between 5000 $cm^{-1}$and 5260 cm^{-1}. The power of NIR analysis is that it is fast, non-destructive, and capable of determining the moisture content of relative thick specimens. Thus, this technique appears to be suitable for determining the bulk moisture content of a coating system. Although NIR is a well-developed technique, its use in this application has yet to be established. Assuming that NIR is capable of measuring the moisture content of coatings, then a portable NIR instrument will be developed for making field measurements.
The minimum material and environmental data required to predict a coating system's moisture content will be known and standardization of these measurements will be investigated. BFRL researchers will predict the quarterly hour bulk and surface moisture contents of a coating and perform time series analyses on the collected data.

Recent Results:

Burch, D. M., and Martin, J. W., "Predicting the Temperature and Relative Humidity of Polymer Coatings in the Field," *Proceedings of International Symposium on a Systematic Approach to the Service Life Prediction Problem for Coatings*, American Chemical Society, Jonathan W. Martin and David Bauer [Eds.] meeting held in Breckenridge, CO., Sept. 14 to 19, 1997, published 1998.

BUILDING MATERIALS

CONSTRUCTION MATERIALS REFERENCE LIBRARY

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AASHTO Materials Reference Laboratory

Principal Investigator: James H. Pielert, Building Materials Division, 301-975-6704

Sponsor: American Association of State Highway and Transportation Officials

Objective: To inspect soil and bituminous testing laboratories, distribute proficiency test samples, and support the voluntary standards development process.

Problem: The quality of testing in construction materials laboratories is an important concern when considering quality construction. The importance of the testing function is demonstrated by The Strategic Highway Research Program (SHRP), a $150-million highway and bridge research program, which was completed in 1994. Standardization of testing to enhance the reliability of quality assurance measurements is of paramount concern. The productivity of the testing community can be increased by the use of correct procedures and apparatus which reduce testing errors and provide a sound basis for the acceptance of materials on certificate. More efficient use of long-established construction materials and broader use of new materials are facilitated by dependable quality assurance programs.

Approach: With the support of AASHTO Research Associates working under NIST supervision, services are provided to both public and private laboratories on a voluntary basis. These services include the on-site inspection of the laboratory and the distribution of proficiency test samples. The current scope of the laboratory inspection program includes the testing of soils, bituminous materials, and plastic pipe, and the measurement of roughness and frictional properties of highways. Equipment and procedures used in performing conventional quality assurance tests are evaluated for conformance to applicable national standards. Proficiency test samples of asphalt, soils, paint, aggregates and bituminous concrete are distributed at regular intervals. Additionally, technical studies are conducted in areas related to these programs, often in conjunction with other NIST units. Specific products of this work include: (1) detailed inspection reports; (2) report on each round of proficiency sample testing; (3) input to the work of standards committees such as draft standards and precision data; and (4) reports on the results of technical studies. The AMRL programs provide the following benefits to construction materials testing laboratories and others involved with the nation's transportation systems: (1) improves the quality of laboratory testing; (2) provides data to quantify standard measurement techniques; and (3) provides direct communications between testing laboratories and standards-writing committees.

Recent Results:

Inspected over 340 bituminous and soil labs and distributed over 6500 proficiency samples.

Pielert, J., "Use of Laboratory Accreditation in Promoting the Quality of Testing of Materials Used in Transportation Systems," *ASCE Conference Proceedings*, 1997.

Cement and Concrete Reference Laboratory

Principal Investigator: James H. Pielert, Building Materials Division, 301-975-6704

Sponsor: American Society for Testing and Materials
Department of the Army Corps of Engineers

Objective: To inspect cement and concrete testing laboratories, distribute proficiency test samples, and support the voluntary standards development process.

Problem: The infrastructure represents a substantial portion of the nation's wealth. Construction of such facilities is one of the nation's largest industries usually amounting to about 10 percent of the Gross Domestic Product. Over $4 billion of hydraulic cement is produced in the United States each year with the value of the concrete construction estimated to be about $20 billion. Standardization of testing to enhance the reliability of quality assurance measurements is of paramount concern. The productivity of the testing community in the cement and concrete fields can be increased by the use of correct procedures and apparatus which reduce testing errors and provide a sound basis for the acceptance of cement on mill certificate. More efficient use of long-established construction materials are facilitated by dependable quality assurance programs.

Approach: During FY1998, BFRL will continue to produce proficiency test samples of portland cement, pozzolan, concrete, blended cement and masonry cement, and distribute them at regular intervals to obtain information on laboratory performance. Specific products of this work include: (1) detailed inspection reports; (2) report on each round of proficiency sample testing; (3) input to the work of standards committees such as draft standards and precision data; and (4) reports on results of technical studies. Additionally, technical studies are conducted in areas related to these programs, often in conjunction with other NIST units. NIST technical reports, papers in outside journals, and oral presentations are used as appropriate.

Recent Results:

Inspected over 290 cement and concrete laboratories and distributed over 3600 proficiency samples. Completed pilot automated data collection system for Laboratory Inspection Program.

BUILDING ENVIRONMENT

THERMAL MACHINERY

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Development of MicroElectroMechanical Systems (MEMS) Sensors for Building Machinery and Systems

Principal Investigator: David A. Didion, Building Environment Division, 301-975-5881

Sponsor: National Institute of Standards and Technology

Objective: To determine the feasibility of MEMS technology as applied to the Building Industry and the contribution it can make to the operation and control of building systems.

Problem: MicroElectro Mechanical Systems (MEMS) are an outgrowth of the "computer chip" industry and have been under development as a separate entity since the mid 1970's. Although they are of similar size and manufacture they are significantly different from electronic chips in that they incorporate miniature mechanical devices such as diaphragms, cantilevers, gears, etc. This industry has matured sufficiently that MEMS accelerometers act as "triggers" for most automotive air bags. MEMS have been used to control air intake rate to provide stoichiometric combustion in cars, as well. They are, in fact, showing up in a wide variety of products of all levels of expense and sophistication (e.g., gauges for checking air pressure in tires, etc.). However, to date no such devices are used in the heat pumping/air conditioning machines.
Heat pump developments of today have included a continual path towards an electronic central processor for operation and control. This digitizing system approach has been producing a product that has increased potential for increased efficiency, reliability, and comfort. These are essential factors, for competing with foreign competitors.

Approach: During FY1998, BFRL will design, fabricate, and evaluate a new MEMS to do a given task. Last year BFRL conducted studies which determined that an optimum initial MEMS design would be a vibration meter capable of providing an automatic shut down signal for any rotating machine that may spontaneously give off non-synchronous vibration. Such a design is currently being conducted under the approach known as CMOS-compatible MEMS technology. This approach is rather restrictive in the use of fabricating techniques it employs. The output will be a cost effective mass production methodology.
Once the design of the MEMS vibration meter is completed the fabrication process, based on BFRL's submission of a mask, will start at the commercial foundry and be continued in
BFRL's clean rooms for the etching processes. Next the prototypes will be evaluated for reliability (i.e. millions of vibrations in the amplitude and frequency ranges of interest). These tests will be in a new BFRL lab currently being set up for this purpose. Upon passing these preliminary reliability tests (which could include a redesign and prefabrication process), performance testing will begin. These tests will be conducted simultaneously at BFRL and the Copeland Compressor Company. This company has agreed to support in-kind research and will supply NIST with the motor-compressor system and conduct tests to determine feasibility for themselves.

Recent Results:

Didion, D., Development of an Analytic Model for the Sensitivity of a Cantilever-Type Piezo-Resistive, CMOS-Integrated Circuit Foundry Micro Electro-Mechanical Systems Vibration Sensor, National Institute of Standards and Technology, (in preparation).

Lubricant/Refrigerant Boiling Interaction and Heat Transfer Enhancements with Alternative Refrigerants

Principal Investigator: Mark Kedzierski, Building Environment Division, 301-975-5282

Sponsor: National Institute of Standards and Technology

Department of Energy
Office of Building Technology
State and Community Programs

Objective: To establish a unique measurement technique that can be used to measure fundamental lubricant/refrigerant interactions by using three tasks: (1) fluorescence-spectroscopy measurement for determining the concentration of the lubricants and additives at a pool boiling surface, (2) completion of shell-side condensation measurements for determining the influence of beneficial boiling additives on condensation performance, and (3) in-tube pressure drop correlation of previously measured evaporating R22 replacements in a micro-fin tube.

Problem: Any increase in the efficiency of a heat exchanger or reduction in the uncertainty in a heat transfer correlation could be used to lower manufacturing or operating costs of refrigeration and air-conditioning equipment. The practice of over designing a heat exchanger to ensure it meets the required duty could be curtailed if more accurate heat transfer correlations were available. Designers have comparatively little experience in the design of heat exchangers for equipment that operate with the ozone-safe replacements for R22. Accurate condensation heat transfer correlations for R22 replacements can help industry to minimize the over sizing of condensers. Most all refrigeration and air-conditioning equipment operate with refrigerant-lubricant mixtures. The lack of a clear understanding of the effect of lubricant concentration on the heat transfer performance of refrigerants contributes to the over sizing of heat exchangers.

Approach: During FY1998, BFRL will apply the fluorescence-spectroscopy measurement techniques developed at NIST during FY1997 to a boiling test surface. The fluorescence-spectroscopy technique can be used to quantifying the lubricant at the heat transfer surface. BFRL will construct a fluorescence-spectroscopy measurement procedure that can be used on a surface from which refrigerant is boiling.
Shell-Side Condensation: During FY1998, the final construction and calibration of the shell-side condensing rig will be completed. The condensing rig will be used to determine if the boiling additive degrades the condensation performance. The boiling additives were found to substantially improve the boiling performance of R123 in a previous BFRL project.
In-Tube Pressure Drop: The scope of the in-tube pressure drop investigation is to correlate the pressure drop for R22 replacements evaporating in a micro-fin tube. The intent is to develop a simple correlation that will be applicable for a wide variety of refrigerants and heat transfer conditions. A designer of new heat pumps will be able to size the evaporator using the results from this study.

Results to Date:

Kedzierski, M. A., "Effect of Inclination on the Performance of a Compact Brazed Plate Condenser and Evaporator, *Heat Transfer Engineering*, Vol. 18, No. 3, pp. 25-38, 1997.

Kedzierski, M. A., and Kim, M. S., *Convective Boiling and Condensation Heat Transfer with a Twisted-Tape Insert for R12, R22, R152a, R134a, R290, R32/R134a, R32/R152a, R290/R134a, R134a/600a*, NISTIR 5905, National Institute of Standards and Technology, 1997.

Thermodynamic Evaluation of Low-GWP Refrigerants

Principal Investigator: Vance Payne, Building Environment Division, 301-975-6663
Piotr A. Domanski, Building Environment Division, 301-975-5877

Sponsor: National Institute of Standards and Technology

Department of Energy
Office of Building Technology
State and Community Programs

Objective: To evaluate the thermodynamic performance of low-Global Warming Potential (GWP) fluids as a working medium for refrigeration systems.

Problem: With the ozone crisis ruling out the use of chlorine in the manufacturing of refrigerants, the industry is rapidly moving toward the use of hydrofluorocarbon compounds. This conversion has been and continues to be the most dramatic change this industry has ever faced. Virtually all industry resources are focused on meeting the United Nations and U.S. Environmental Protection Agency schedules. While this dramatic change in industry is underway, some reservations have already been raised, mostly outside the United States, about the most promising replacements for R-22, R-410A (R-32/125 (50/50)) and R-407C (R-32/135/134a (23/25/52)). The relatively high values of the Global Warming Potential of R-125 and R-134a are the source of concern.

Approach: During FY1998, BFRL will perform three tasks:
Task 1) Water-to-Water Heat Pump with Intracycle Heat Exchanger
The series of tests performed in FY1997 will be completed by including R-32/152a and R-290/600a. BFRL will incorporate an intracycle heat exchanger (IC-HX) and perform cooling and heating tests. These tests will address the mixtures that were found to be the most promising in the unmodified system. The system's performance will be measured in the cooling and heating modes. Several compressor RPMs will be used to map the system's performance and to evaluate relative merits of refrigerants at the constant-capacity criterion. The study will also cover evaluation of the performance of the brazed-plate heat exchangers used as evaporator and condensers in the water-to-water apparatus. The determination of the heat-transfer characteristics in the heat exchangers will be performed by applying the Wilson Plot method.
Task 2) CO_2 Evaluation
This task involve expanding the knowledge base for carbon dioxide. This will include CO_2 system and heat-transfer performance. Because of the CO_2 high pressure, a special CO_2 breadboard heat pump rig will be constructed. The rig will be versatile to allow measurements of the thermodynamic performance and heat-transfer coefficient of the heat exchangers. The goal of the first exploratory series of tests will be to debug the rig and ensure its stable operation. Several system modifications are expected to customize the rig to the unique CO_2 properties. Subsequent tests will be performed to take CO_2 evaporation heat-transfer data and to screen CO_2 performance for selected applications. An effort will be made to identify the phenomena and CO_2 properties responsible for the difficulty in accurate prediction of the evaporation heat-transfer coefficient.
Task 3) Potential of Zeotropic Mixtures in a Heat Pump with a Distillation Column
Transient and steady-state tests will be performed in FY1998. The results of these experiments will be used to validation the simulation model of the a heat pump/distillation column system. Also, the laboratory and simulation results will be used to establish the performance potential of a zeotropic heat pump with a distillation column and to indicate the mixture properties that are most desirable for good performance.

Recent Results:

Knudsen, H.J., and Jensen, P.H., "Heat Transfer Coefficient for Boiling Carbon Dioxide," *CO^2 IIR/IEA CO2Technology Workshop*, Trondheim, Norway, 13-14 May, 1997.

Kim, B.S. and Domanski, P., "Limiting Throttling Losses by Intracycle Evaporative Cooling," *3rd KSME-JSME Thermal Engineering Conference*, Kyongju, Korea, October 20-23, 1996.

D.K. Choi, P.A. Domanski, and D.A. Didion, "Evaluation of Flammable Refrigerants for Use in a Water-to-Water Residential Heat Pump," *IIR Int. Conference on Applications for Natural Refrigerants*, Aarhus, Denmark, 9/3-9/6, 1996.

Rothfleisch, P., "Accumulator Distillation Insert for Zeotropic Refrigerant Mixtures," *Patent No. 5,551,255*, September 1996.

Rothfleisch, P., *A Simple Method of Composition Shifting with a Distillation Column for a Heat Pump Employing a Zeotropic Refrigerant Mixture*, NISTIR 5689, National Institute of Standards and Technology, July 1995.

Artificial Intelligence-Aided Heat Exchanger Design Models

Principal Investigator: Piotr Domanski, Building Environment Division, 301-975-5877

Sponsor: National Institute of Standards and Technology

Objective: To develop a software package consisting of an artificial intelligence (AI)-based optimization interface and heat exchanger simulation models for designing a finned-tube evaporator and condenser working with alternative refrigerants and having an optimized refrigerant circuitry for imposed maldistributed inlet air.

Problem: A non-uniform air distribution at the heat exchanger inlet is rather a norm than an exception and can result in a significant degradation of heat exchanger's performance. An experimental BFRL study has shown that a non-uniform air distribution may degrade evaporator capacity by as much as 30 percent. The negative effect of maldistributed air can be to some degree compensated by a proper design of refrigerant circuitry. Such a design can be achieved by a highly iterative trial-and-error design process, which, if not automated, would be very time consuming and expensive.
Designing an optimized refrigerant circuitry for maldistributed air has been a problem for a coil designer. This difficulty is now compounded with the need to design heat exchangers for alternative refrigerants that replace CFCs and HCFCs. This is particularly true for R-22 replacements because thermophysical properties of the leading replacements are significantly different than those of R-22, and the R-22 expertise acquired over the years is not directly applicable to alternative refrigerants.

Approach: During FY1998, BFRL will work with artificial intelligence (AI) specialists, refrigeration researchers, and heat exchanger designers to produce a simulation model (for an evaporator or condenser) that will develop performance information for submitted heat exchangers (capacity and refrigerant and air properties at each tube). The AI interface will evaluate the results and will submit modified designs for simulation. Repeated interactions between the AI interface and simulation model will result in an optimized heat exchanger design.
The starting point for the development of the simulation models will be BFRL's EVAP5 and COND5 models of an evaporator and condenser, respectively. At this time, EVAP5 is more advanced than COND5 in that its original version for uniform air distribution has been equipped in the Visual C++ interface and was provided to 12 manufacturers for testing. Both models will be combined with a visual interface that will accommodate a non-uniform air distribution. Since heat exchanger models are essential components of a heat pump, EVAP5 and CON5 will be incorporated into the BFRL heat pump simulation model, HPSIM.
Work also includes developing, maintaining, and upgrading programs for the NIST Standard Reference Data Program (SRDP), CYCLE_D and REFLEAK. Both programs use REFPROP (SRDP database) for calculating refrigerant properties. A new version of REFPROP will be implemented to CYCLE_D and REFLEAK upon its release. Also, new features will be added to both programs based on direct requests from the user community.

Recent Results:

REFLEAK (new SRD Database) submitted for SRD review, July 1997.
Domanski, P.A., "EVAP5-V," evaporator simulation model with Visual C++ interface, submitted for testing to equipment manufacturers, April 1997.

Kim, B.S. and Domanski, P.A., "Limiting Throttling Losses by Intracycle Evaporative Cooling," Proceedings of the 3rd KSME-JSME Thermal Engineering Conference, Kyongju, Korea, October 20-23, 1996.

Domanski, P.A., Didion, D.A., and J.Chi, CYCLE_D: NIST Vapor Compression Cycle Design Program, NIST Standard Reference Database 49, National Institute of Standards and Technology, May 1995.

Kim, M.S. and. Didion, D.A., "Simulation of Isothermal and Adiabatic Leak Process of Zeotropic Refrigerant Mixtures," HVAC&R Research, ASHRAE, Vol. 1, No. 1, 1995.

Kim, M.S. and. Didion, D.A., "Simulation of a Leak/Recharge Process of Refrigerant Mixtures," HVAC&R Research," ASHRAE, Vol. 1, No. 3, 1995.

BUILDING ENVIRONMENT

MECHANICAL SYSTEMS AND CONTROLS

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Expansion, Certification, and Demonstration of BACnet

Principal Investigator: Steven T. Bushby, Building Environment Division, 301-975-5873

Sponsor: National Institute of Standards and Technology
General Services Administration
Public Buildings Service

Objective: To assist the building industry expand its capability of communication protocol standards to enable the practical use of integrated HVAC, lighting, security, vertical transport, life safety, and emergency response systems in commercial buildings; to develop procedures and standards necessary to create an industry-run certification program for BACnet conformance testing; and to demonstrate the feasibility of large-scale integrated BACnet systems in real buildings.

Problem: Today's direct digital control systems employ proprietary communication protocols that prevent systems made by different manufacturers from communicating with each other. The development and adoption of the BACnet protocol standard has eased this problem but BACnet products are only beginning to enter the marketplace and exclusively for HVAC applications. In order for the potential benefits of the BACnet standard to be realized there is a need to provide technical assistance to manufacturers, by developing testing standards and tools and identifying and addressing barriers to the use of BACnet in non-HVAC applications.

Approach: During FY1998, BFRL will complete the development of Visual Test Shell (VTS) BACnet conformance testing tools and a testing addendum to version 1.0 of the BACnet standard. This development process will proceed in conjunction with the ASHRAE SSPC 135 Task Group that is charged with completing a testing addendum to the BACnet standard. The goal is to implement all of the tests that appear in the addendum to verify the integrity of the procedure and to speed the acceptance of the addendum by industry as much as possible.
BFRL will administer and participate with industry partners in a BACnet Interoperability Testing Consortium for the purpose of developing new commercial products, and tools to test and verify performance in an integrated system environment. In conjunction with industry partners and professional organizations such as NEMA, NFPA, and UL, BFRL will identify fire and building code obstacles to the commercial viability of cybernetic building systems technology. Specific efforts will be organized to overcome these obstacles by developing design and commissioning standards, systems performance testing and analysis tools, and changing model codes as needed.
BFRL Develop tools and procedures for testing and certifying the performance of life-safety components of integrated building systems.
A laboratory facility will be created for testing integrated BACnet products in a virtual BACnet building using BFRL developed emulator/tester technology. BACnet products and prototype products will be connected to a simulated building with a multi-zone VAV system. This facility will permit testing multi-vendor communication and control interactions in environment where real building equipment and occupants cannot be adversely affected.
With GSA and/or other large building owners BFRL will develop testbed demonstration projects to prove the viability of BACnet in real buildings. Tests and demonstrations in real buildings are a critical part of making cybernetic building systems a commercial success. This has already begun with demonstrations in GSA's Phillip Burton Building, San Francisco. As the technology advances there will be a need to expand partnership in future years.

Recent Results:

Released VTS version 1.0 to BACnet consortium members.

Virtual Cybernetic Building System (VCBS)

Principal Investigator: Cheol Park, Building Environment Division, 301-975-5879

Sponsor: National Institute of Standards and Technology

Objective: To create a Virtual Cybernetic Building System (VCBS), that can be used by control manufacturers, service companies, and software developers to develop and evaluate control products using the BACnet communication protocol.

Problem: Most of building system's control products requires undergoing a series of tests before entering the market place. Although it is desirable to perform the tests on real building systems, the scope of testing is often restricted due to cost and time. Needed is a virtual cybernetic building system that simulates real building systems effectively and at a considerable reduction in cost.

Approach: During FY1998, BFRL will develop a Virtual Cybernetic Building System. The VCBS will consist of a computer model running on a high performance PC, plus a data acquisition system. The computer model will be developed using the HVACSIM+ simulation program environment. The interfacing routine with the data acquisition system will be developed in Microsoft C++. Communication interfaces for remote access will be developed using most appropriate software.
Initially, only building HVAC equipment and systems (such as air handling units, VAV boxes, boilers, chillers, and cooling towers), building zones, and the building shell will be included in the VCBS. Equipment and systems that are both fault free and which contain common faults will be emulated so that the VCBS can be used by control manufacturers to develop and evaluate either stand-alone BACnet speaking Fault Detection and Diagnostic (FDD) systems or BACnet compatible EMCS incorporating FDD routines. The VCBS will later be expanded to emulate the performance of life-safety, lighting, security, and vertical transport systems.
The possibility of creation of a Consortium of control manufactures, service industries, software developers, and utility companies interested in using the VCBS will be investigated.

Recent Results: New project.

IEA Annex 34/Building Communication Protocols

Principal Investigator: George E. Kelly, Building Environment Division, 301-975-5870

Sponsor: Department of Energy
Office of Building Technology
State and Community Programs

Objective: To demonstrate the BACnet communication protocol in real buildings and to participate in the International Energy Agency (IEA) Annex 34 Committee on *Computer-Aided Evaluation of HVAC System Performance: The Practical Application of Fault Detection and Diagnosis Techniques in Real Building.*

Problem: A large portion of energy waste in building is due to improper operation of HVAC systems and controls. As building systems become larger and more complex, it is difficult for human operators to keep up with day-to-day operation, to identify fault operation and to diagnose problems. Automated systems that independently perform fault detection and diagnosis are needed to improve building system performance and to assist human operators in analyzing the tremendous volume of data collected by most building management systems.

Approach: During FY1998, BFRL will work with control manufacturers, industrial partners, and/or building owners and operators to demonstrate the benefits of on-line performance evaluation in real building applications. The fault detection and diagnostic (FDD) methods developed in Annex 25 will be combined into robust performance evaluation systems and incorporated into either stand-alone PC based supervisors or into the outstations of a future generation of "smart" building control systems. The use of these performance evaluation systems for both commissioning and ongoing fault detection and diagnostics will be investigated.
BFRL researchers will work with DoE and GSA to demonstrate the BACnet communication protocol in the Phillip Burton Federal Building (PBFB) in San Francisco. BFRL will work with industry to assess the application of different FDD techniques to determine commercial viability and identify potential economic constraints. Simulation, laboratory, and field studies will be undertaken to determine the effect of different types of faults on energy performance and occupant comfort. Both equipment and system level faults will be considered. BFRL will represent the Department of Energy (DoE) at all Annex 34 meetings and will lead the US team of Annex 34 participants.

Recent Results:

Assisted GSA test key components of different BACnet systems before they were installed in the Phillip Burton Federal Building which resulted in greatly reducing the number of problems normally associated with the installation of new technology.

Fault Detection and Diagnostic (FDD) Systems with Hierarchical Control

Principal Investigator: John House, Building Environment Division, 301-975-5874

Sponsor: National Institute of Standards and Technology

Johnson Controls, Inc.

Objective: To develop and demonstrate methods for performing fault detection and diagnostics (FDD) on HVAC equipment and systems, fire and security systems, and unitary controllers in real time and to participate in the International Energy Agency (IEA) Annex 34 Committee on *Computer-Aided Evaluation of HVAC System Performance: The Practical Application of Fault Detection and Diagnosis Techniques in Real Buildings.*

Problem: Today's building energy management systems have the capability to monitor, trend, and log operating data for thousands of measurement and control points. These capabilities routinely exceed the capabilities of building owners and operators to process (and therefore understand) the data. Building energy management and control systems (EMCS) need to be equipped with intelligent FDD tools to enable building operators to ensure that HVAC systems are operating as expected.

Approach: During FY1998, BFRL will work with industry, academia, state energy agencies, and service companies to develop and test FDD methods for various types of systems. This effort will be focused in four areas, namely, 1) development and application of FDD methods to the reciprocating chiller serving the BFRL Temperature Control Module Laboratory; 2) development and application of FDD methods to variable-air-volume (VAV) boxes at the Iowa Energy Center (IEC) Energy Resource Station (ERS) and on the campus of Cornell University; 3) initial phases of development of an FDD Test Shell for developing, testing, comparing, integrating FDD methods; and 4) participation in Annex 34.
BFRL will begin an FDD demonstration project at the IEC ERS. The ERS is a real building with laboratory grade instrumentation on all the HVAC equipment and remote monitoring capabilities. In its initial phase, this project will focus on the development and demonstration of an FDD method for VAV boxes.
Also, BFRL will seek to develop CRADAs with several control manufacturers, a service company, and/or one or more universities to encourage FDD product development by the private sector. It is anticipated that the IEC ERS will serve as one test site for FDD products developed from the CRADAs.

Recent Results:

Lee, W. Y., House, J. M., and Shin, D. R., "Classification Techniques for Fault Diagnosis of an Air-Handling Unit," to be submitted to ASHRAE *Transactions*, 1999.

Seem, J. E., Park, C., and House, J. M., "A New Sequencing Control Strategy for Air-Handling Units," submitted to *International Journal* of HVAC&R Research, 1998.

Seem, J. E., House, J. M., and Klaassen, C. J., "Volume Matching Control: Leave the Outdoor Air Damper Wide Open," ASHRAE *Journal*, Vol. 40, No. 2, pp. 58-60, 1998.

Seem, J. E., House, J. M., and Monroe, R. H., "On-Line Monitoring and Fault Detection of Control System Performance," presented at *CLIMA 2000*, Brussels, August 31 - September 2, 1997.

Test Procedures for Heat Pumps, Air Conditioners, and Combined Appliances

Principal Investigator: Brian Dougherty, Building Environment Division, 301-975-6396

Sponsor: Department of Energy
Office of Energy Efficiency and Renewable Energy
Office of Codes and Standards

Objective: To provide equitable testing and rating procedures for determining energy performance of air conditioners, heat pumps, and combined appliances

Problem: The DOE test procedure for air conditioners and heat pumps was last revised in 1988. One component of the DOE heat pump test procedure is the evaluation of cyclic performance, which comes in the form of a cooling and heating mode cyclic degradation coefficient. This coefficient may be determined by testing or, in lieu of testing, a default value of 0.25 may be taken. The coefficient is used within the algorithm to estimate seasonal coefficients of performance. Industry members have requested that new defaults be investigated; the existing defaults date back to 1977 and most units today achieve better (i.e., lower) values. In a related issue, industry members have expressed concern about the prescribed cyclic tests on the basis of yielding sub-par repeatability, especially when comparing the results obtained at one test facility versus another.
DOE wants to propose a generic, combined appliance test procedure. BFRL is charged with developing the generic method.
BFRL's computer program (HPSIM) simulates heat pump steady-state performance. The program, which was last revised in 1989, needs to be updated to better reflect current heat pump technology while possibly being made more user friendly.

Approach: During FY1998, BFRL will revise the test procedure based on comments received at and following the 25 September 1997 DOE workshop.
BFRL will use test results from ARI certification testing to identify correlations between the cooling and heating mode cyclic degradation coefficients (C_D's) and the equipment hardware. The goal is to identify new C_D defaults for the DOE test procedure and include the new defaults in the 1998 proposed test procedure rulemaking. BFRL will attempt to quantify the repeatability and associated uncertainty of lab-derived C_D's.
BFRL will continue its active role toward revising ASHRAE Standard 37. Also, BFRL will maintain its involvement on ISO working groups that are addressing standards for ducted, non-ducted, and multi-split air conditioners and heat pumps. BFRL will lead efforts to write/rewrite a few sections of ISO Standards 5151 and 13253 to reflect U.S.-made proposals that were accepted by the working group at their September 10-12, 1997 meeting.
BFRL will evaluate differences between its-proposed test method and the method proposed by Nordyne for testing and rating combined heat pump-water heating appliances. Based on these results and input from ETL as to the associated testing burden of the different tests, BFRL will generate a generic test procedure will only cover combined appliances that are being marketed, will be supplied to DOE for consideration either for a DOE workshop, or for publishing as a proposed rulemaking.

Recent Results:

"Department of Energy Air-Conditioner/Heat Pump Test Procedure Update" August 11-12, 1997 *Heat Pumps in Cold Climates* Conference.

Test Procedures for Furnaces, Boilers and Integrated Appliances

Principal Investigator: Stanely Liu, Building Environment Division, 301-975-5880

Sponsor: Department of Energy
Office of Energy Efficiency and Renewable Energy
Office of Codes and Standards

Objective: To provide equitable testing and rating procedures for determining energy performance of furnaces, boilers and integrated appliances.

Problem: In the DOE test procedure for furnaces/boilers, procedures are proscribed for single stage and modulating (multiple firing rate) furnaces. However, there is a discrepancy in the calculated value of the AFUE for gas-fired, two-stage modulating furnaces. The AFUE value based on the two-stage calculation procedure was lower than the AFUE value based on the single stage calculation under the low firing rate condition. The discrepancy between the two AFUE values was from 0.5 to 1 percentage points with the single stage, low firing rate calculation giving the higher value. This was opposite to what was expected. Preliminary BFRL investigation showed that under the average design weather condition assumed in the test procedure, the two-stage furnace would have operated in the low firing mode for over 95 percent of the time. If the furnace is assumed to operate as a single stage furnace but at the low firing rate, the calculated AFUE values of the two cases (two-stage with 95% time at the low firing rate and single stage with 100% time at the low firing rate) should be near equal. A study of the calculation procedures is needed to find the cause of the problem and to develop possible corrections to the calculation procedures.

Approach: During FY1998, BFRL will investigate discrepancy in the AFUE values between the single stage furnace. BFRL will and two-stage modulating furnace BFRL will continue to conduct tests on the off-cycle fuel gas flow test unit with different length flue pipe and configurations to develop the needed tracer gas test procedure for incorporation in the DOE furnace/boiler test procedure. The problem encountered in conducting the tracer gas test on an induced draft, outdoor furnace is caused by the low off-cycle flue gas flow rate and the lack of space at the flue gas exit for the installation of flow and temperature measuring sensors.

Recent Results:

Provided letter reports to DOE.

Development of Revised Test Procedures for Pool Heaters

Principal Investigator: Stanely Liu, Building Environment Division, 301-975-5880

Sponsor: Department of Energy
Office of Energy Efficiency and Renewable Energy
Office of Codes and Standards

Objective: To provide testing and rating procedures for determining energy performance of pool heaters.

Problem: In FY 1993, DOE modified the test procedure for pool and spa heaters to include a calculation of energy factor and published the procedure in the Federal Register as a Proposed Rulemaking on August 23, 1993. In 1996 the proposed energy factor was revised in the draft final rule to delete the energy cost ratio of electrical to fossil fuel energy from the formulation and renamed it as the pool heater heating seasonal efficiency. BFRL will continue to assist DOE in finalizing the test procedure so it can be published as a Final Rule.
The current DOE test procedure for pool heaters covers only gas- and oil-fired pool heaters. The test procedure references ANSI Standard Z21.56 for gas-fired pool heaters and specifies certain modifications for the procedure to be applicable to oil-fired pool heaters. It does not cover electric resistance type heater or the heat pump pool heaters which are recently introduced on the market. A revision to the existing test procedure is needed to include the installation, measurements, test methods and calculation procedures for both the electric resistance type and the heat pump pool heaters.

Approach: During FY1998, BFRL will continue to assist DOE in the evaluation of public comments received after the publication in the Federal Register of the proposed revision to the existing DOE pool heater test procedure.

Recent Results:

Assisted DOE prepare of the draft final rule for pool heaters which was published in May 1997. It includes new calculation procedures to calculate a pool heating seasonal efficiency to take into account the energy consumption of off-cycle pilot light during the pool season, and the average annual energy consumption. Participated in development of the ASHRAE SPC 146P for pool and spa heaters.

Development of Revised Test Procedures for Dishwashers

Principal Investigator: Natascha Castro, Building Environment Division, 301-975-6420

Sponsor: Department of Energy
Office of Energy Efficiency and Renewable Energy
Office of Codes and Standards

Objective: To draft a new test procedure that will enable effective energy consumption testing of conventional and adaptive control dishwashers, which will be evaluated for its ability to test both models accurately and provide a means to compare their performance.

Problem: The current DOE test procedure was developed over ten years ago and does not have provisions for testing dishwashers with adaptive controls. Dishwashers equipped with these and other recent innovations cannot be accurately tested. The main features that contribute to improved energy performance are better thermal insulation, improved motor efficiency, better water distribution, improved food filtering, and improved fill controls (using float controls instead of timer controls). Other items which have energy reducing potential are improved water heating in water-heating dishwashers and innovative control schemes. In light of energy consumption reductions in dishwashers over the past decade, review of the current test procedure is in order.

Approach: During FY1998, BFRL will meet with DOE and representatives of dishwasher manufacturers. Using the results of this discussion and data collected from trials of two dishwashers, BFRL will draft a new test procedure for measuring energy consumption in residential dishwashers. This draft test procedure will be tested using at least two dishwashers to verify the effectiveness of the proposed method in testing both conventional dishwashers and adaptive control dishwashers. The results from this research will lead to the development of new significant test and rating procedures for dishwashers and to further encourage manufacturers to use control features and designs which reduce energy consumption.

Recent Results:

Castro, N.S., "Energy and Water Consumption Testing of a Conventional Dishwasher and an Adaptive control Dishwasher," *Proceedings of the 48th Annual International Appliance Technical Conference,* pp 284-296, 1997.

Compact Refrigerators

Principal Investigator: Piotr Domanski, Building Environment Division, 301-975-5877

Sponsor: Department of Energy
Office of Energy and Renewable Energy
Office of Codes and Standards

Objective: To evaluate energy test results for compact refrigerators.

Problem: DOE obtained information from some commercial test laboratories that the energy test results on compact refrigerators in volumes of 0.11 m^3 or less indicated repeatability problem. Further investigation to confirm or deny the validity of this problem is needed.

Approach: During FY1998, BFRL will assist DOE to respond to possible public comments on the externally-vented refrigerator/freezer issues and manufacturers complaints on energy test results of compact refrigerators

Recent Results:

Provided letter reports to DOE.

Testing for Compliance with Minimum Standards

Principal Investigator: James E. Hill, Building Environment Division, 301-975-5851

Sponsor: Department of Energy

Objective: To provide equitable testing and rating procedures for determining energy performance of various residential appliances.

Problem: The Energy Policy and Conservation Act (PL 94-163) (EPCA), as amended, requires the Department of Energy (DOE) to prescribe test and rating procedures and minimum performance standards for various residential appliances. In addition, the 1987 amendments to EPCA requires analysis of any test procedure amendments to determine their effect on minimum efficiency standards. DOE has, since 1975, relied on BFRL to assist in the development of the test and rating procedures.

Approach: During FY1998, BFRL will assist DOE in determining compliance with minimum standards for refrigerators, refrigerator-freezers, water heaters, small gas furnaces, mobile home furnaces, central air conditioners, room air conditioners, central furnaces, direct heating equipment, pool heaters, and fluorescent lamp ballasts. This work will involve selective testing of the appliances in question in BFRL laboratories and/or in commercial testing laboratories as appropriate.

Recent Results: New project.

Test Procedures for Lighting Fixtures and Systems

Principal Investigator: Stephen Treado, Building Environment Division, 301-975-6444

Sponsor: Department of Energy
Office of Energy Efficiency and Renewable Energy
Office of Codes and Standards

Objective: To provide equitable testing and rating procedures for determining energy performance of lighting fixtures and systems.

Problem: The Energy Policy and Conservation Act (P 94-163) (EPCA), as amended, required the Department of Energy (DOE) to prescribe test and rating procedures and minimum performance standards for various residential appliances. In additional, the 1987 amendments to EPCA requires analysis of any test procedure amendments to determine their effect on minimum efficiency standards. DOE has, since 1975, relied BFRL to assist in the development of the test and rating procedures. The Energy Policy Act of 1992 (EPACT) contained many provisions relating to lighting equipment. including labeling and minimum standards for incandescent and fluorescent lamps. The implementation of these provisions required the development or specification of appropriate test procedures, and a rigorous set of definitions for covered products and exemptions.

Approach: During FY1998, BFRL will continue to provide technical support and assist in DOE rulemaking activities. BFRL will continue the investigation of test procedures for high frequency ballasts and the development of DOE test procedures. BFRL will review the draft Lawrence Berkeley National Laboratory (LBNL) report on fluorescent lamp ballasts. BFRL also will provide technical support to DOE in obtaining resolution to outstanding technical issues, such as the identification and classification of fluorescent lamps and vibration service incandescent reflector lamps, as well as assessing the coverage status of new lighting products. BFRL will monitor Illuminating Engineering Society and ANSI test procedure activities, along with the luminaire-labeling program, the National Voluntary Laboratory Accreditation Program and ballast programs. BFRL also will review the HID lamp technical report being prepared by LBNL.

Recent Results:

Provided DOE with letter reports on electronic ballast test procedures.

Plumbing Test Procedures

Principal Investigator: Stephen Treado, Building Environment Division, 301-975-6444

Sponsor: Department of Energy
Office of Energy Efficiency and Renewable Energy
Office of Codes and Standards

Objective: To develop test procedures as required for plumbing products covered under EPACT.

Problem: The Energy Policy Act of 1992 (EPACT) specifies performance standards for a number of plumbing products, including toilets, urinals, showerheads, and faucets. The American Society of Mechanical Engineers (ASME) test procedures for measurement of hydraulic performance area are also specified and are to be adopted by the DOE. While these test procedures are in general sufficient for their intended purpose, the introduction of new plumbing products and designs, and the interpretation and application of the specific testing provisions will require DOE to continuously monitor these changes and their effects on the Department's test procedures for plumbing products.

Approach: During FY1998, BFRL will continue to provide technical support and liaison with manufacturers, Lawrence Berkeley National Laboratory (LBNL), ASME, and other related organizations, and attend industry group meetings as necessary to monitor industry progress on the test procedures for evaluating the performance of water consumption for plumbing products. Specific activities will include supporting the ongoing DOE rulemaking, reviewing and evaluating the revised ASME A112 18.1M-1994 and the upcoming A112.19.6 standard, when published, relating to provisions integral to the measurement of water consumption, and providing general technical support.
NIST will evaluate comments on proposed test procedures, especially those related to sampling issues, and will participate in public hearings and meetings on proposed rulemakings. BFRL will participate in the development and review of the Tri-Lateral North American Standards 1,2 and 3 to determine their impact on the DOE standards program, water consumption and effect on ASME standards and plumbing codes.

Recent Results:

Provided DOE with a letter report on plumbing test procedures.

Procedures for Clothes Washers

Principal Investigator: Andrew K. Persily, Building Environment Division, 301-975-6418

Sponsor: Department of Energy
Office of Energy Efficiency and Renewable Energy
Office of Codes and Standards

Objective: To understand the performance of clothes washers when tested in accordance with the new DOE test procedures in Appendix J1.

Problem: The DOE test procedure for clothes washers was revised in 1997, with the revised procedure referred to as Appendix J1 and scheduled to take effect in 1998. The Appendix J1 procedure will be used when DOE issues minimum efficiency standards for clothes washers. These new standards are scheduled to be issued as a notice of proposed rulemaking in the spring of 1998. Because Appendix J1 has been recently developed, there is little test data available to DOE for use in relating washer performance determined with Appendix J1 to that determined with the older test procedure. In addition, test data based on Appendix J1 is needed to support the development of the new efficiency standard.

Approach: During FY1998, BFRL will have a number of clothes washers tested at Intertek Testing Services (ITS/ETL) in accordance with the new test procedure in Appendix J1 (published in August 1997). The purpose of these tests will be to understand the performance of current appliances relative to the new performance parameter, MEF, and to understand the relationship of MEF to the old performance parameter, EF. In addition, these tests will provide data for use by DOE to set a new minimum standard for clothes washers in terms of MEF. BFRL will analyze the test data and a letter report will be prepared by DOE that relates the MEF values to EF values and features of the particular washers tested.
Upon completion of the testing and interpretation of the results, BFRL will then assist DOE in their development of a notice of proposed rulemaking for a minimum standard for clothes washers. BFRL's will perform the analysis and interpretation of the test results.

Recent Results: New project.

Consultation and Technical Support

Principal Investigator: James E. Hill, Building Environment Division, 301-975-5851

Sponsor: Department of Energy

Objective: To provide technical support relating to testing and rating procedures for energy performance of various residential appliances.

Problem: The Energy Policy and Conservation Act (PL 94-163) (EPCA), as amended, requires the Department of Energy (DOE) to prescribe test and rating procedures and minimum performance standards for various residential appliances. In addition, the 1987 amendments to EPCA requires analysis of any test procedure amendments to determine their effect on minimum efficiency standards. DOE has, since 1975, relied BFRL to assist in the development of the test and rating procedures.

Approach: During FY1998, BFRL will provide program support for amendments or additions to test procedures resulting from changes in legislation or policy affecting the program. BFRL will review material received from petitioners for test procedure waivers for products not covered in other appliance tasks to determine if a technically valid case is offered to justify the waiver. BFRL will Advise DOE of the reasoning and conclusions. Analyze information and data received by DOE from petitioners, industry, or others relating to the Federal Register publication of requests for waivers for products not covered in other appliance tasks. Recommend to DOE a course of action with a proposal for temporary alternate test procedure if feasible. Provide DOE with an evaluation of test procedures or procedure changes proposed by industry, trade associations, engineering societies, or consumer groups for products not covered in other appliance tasks. Provide research coordination, program review, and progress reports as required for DOE/NIST programs.

Recent Results:

Quarterly project reviews in support of the DOE Appliance Standards Program.

BUILDING ENVIRONMENT

INDOOR AIR QUALITY

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Implementation Tools for IAQ Standards

Principal Investigator: Andrew K. Persily, Building Environment Division, 301-975-6418

Sponsor: National Institute of Standards and Technology

Objective: To develop software tools and perform analyses that will support the development, implementation, and use of revisions to ASHRAE Standard 62-1989 Ventilation for Acceptable Indoor Air Quality and other indoor air quality (IAQ) standards.

Problem: Existing IAQ standards, and their future development, are playing a critical role in the building industry as they relate to building design, product development and building operation and maintenance. The revision of ASHRAE Standard 62-1989 Ventilation for Acceptable Indoor Air Quality is important; there also are other standards being developed within ASHRAE and ASTM. The development and use of these standards are in some cases being delayed, in part, for technical reasons. These reasons include inadequate methods for implementing ventilation system design procedures. For example, new ideas for ventilation system design have been developed which account for ventilation requirements based on people and building contaminant sources, accounting for the configuration of the ventilation system. However, these design approaches will be difficult to implement, and to move through the standards approval process, because of their increased complexity and the lack of methodological tools for implementing them. Other technical advances that are not being implemented in indoor air quality standards include updates of performance-based approaches and carbon dioxide based demand controlled ventilation.

Approach: During FY1998 BFRL will contribute to the revision of ASHRAE Standard 62-1989, which recently has been placed under continuous maintenance under ANSI procedures. The first of three tasks will center on developing of a proposed addendum to the standard that will contain a performance-based design procedure to serve as an update of the current IAQ Procedure. This procedure will allow designers to design based on contaminant limits using innovative IAQ control technologies for which credit can not be taken with the standard's Ventilation Rate Procedure. In the second of the three tasks related to the ASHRAE standard, BFRL will implement a ventilation design methodology that allows designers to determine ventilation requirements based on people and building sources, and on the ventilation system configuration. Reflecting the results of the latest IAQ research, this method will allow more accurate determinations of ventilation requirements than ever before possible. As part of this effort, BFRL will develop a Windows-based computer program that will allow designers to implement this design approach and will develop a proposed addendum to ASHRAE Standard 62-1989 to allow its use. The last task involves developing a proposed addendum to the standard allowing the application of carbon dioxide based demand controlled ventilation. In this effort, BFRL will perform analysis to support an approach to implementing this ventilation system control option. In addition to these activities in support of the revision of ASHRAE Standard 62-1989, BFRL will participate in the development of a new ASHRAE standard on IAQ in commercial aircraft by taking a leadership role in the contaminant measurement aspects of this standard.

Recent Results: New project.

Prediction of Indoor Environment Performance

Principal Investigator: Steven J. Emmerich, Building Environment Division, 301-975-6459

Sponsor: National Institute of Standards and Technology

Objective: To validate predictive methods intended for use in indoor environment evaluations within the framework of residential performance standards.

Problem: A major effort underway in BFRL is developing residential performance standards that address a number of building attributes, including the indoor environment. The standards relevant to the indoor environment will ultimately be based on the indoor levels of specific airborne contaminants and thermal comfort parameters. Early versions, will likely be based on performance in terms of building ventilation rates. Because measuring ventilation rates, contaminant concentrations and thermal comfort parameters in any significant number of buildings is prohibitively expensive, compliance with these criteria will involve the use of predictive methods. These predictive methods will be based on building ventilation and indoor air quality models, specifically BFRL's CONTAM model. Before a CONTAM-based compliance approach can be incorporated into a performance standard, its predictive reliability must be demonstrated through experimental validation. In addition, a version of the program that is accessible to those implementing the performance standard must be developed.
Closely related to the issue of indoor environment performance standards is the performance evaluation of specific indoor environment control technologies, such as residential ventilation systems and controls and air cleaning systems. Validated predictive methods are also needed to evaluate the benefits and impacts of such technologies, both within the context of performance standards and potentially as a means of marketing and rating these technologies. The Building Environment Subcommittee of ARI has stated the need within the building industry for such methodologies to demonstrate the impacts of IAQ controls.

Approach: During FY1998, BFRL will develop an experimental program to validate predictive methods for building ventilation rates, indoor pollutant levels and thermal comfort parameters that will be included in the indoor environment section of the residential performance standards. This research also will include the development of the CONTAM-based predictive methods for use in the standard. The development of the predictive methods will involve the creation of a front-end to the existing CONTAM model that will be appropriate to the users of the performance standards, but will not require any further development of CONTAM.
Three tasks will be performed in FY1998. First, existing experimental validation data for CONTAM, and similar models, will be assessed to determine its range of applicability in terms of contaminants, sources and building configurations. Next, an experimental plan will be developed to obtain the additional validation data needed to support the CONTAM-based evaluation method. The third task will be the instrumentation of a test facility to carry out this experimental plan. In subsequent years, the experimental plan will be implemented in the test facility and in real buildings, and the results of these tests will be analyzed to determine the range of validity of the evaluation methods. In addition, the effort in future years will include the development of a front-end for CONTAM that will serve as the predictive model for determining compliance with the indoor environment performance criteria.

Recent Results: New project.

Contaminant - Based Design Procedures

Principal Investigator: Andrew K. Persily, Building Environment Division, 301-975-6418

Sponsor: National Institute of Standards and Technology

Objective: To develop building and ventilation system design procedures based on contaminant loads.

Problem: Building ventilation systems traditionally have been based on a prescriptive method in which the outdoor air ventilation rates are determined from a ventilation requirement based on floor area or occupancy. This is the approach used in building codes and in ASHRAE Standard 62. While this design approach has been used for years, it has some serious shortcomings. First, it provides no information on other important system design parameters such as filter efficiencies and operating schedules, and it neglects other building design issues such as outdoor air quality and contaminant sources. A second major shortcoming is the inability of this design approach to account for the benefits of most indoor air quality control technology, thereby inhibiting technological innovation in many areas such as filtration, air cleaning, system controls, and low-emission materials and furnishings.

Approach: During FY1998, BFRL will develop building and ventilation system design procedures based on contaminant loads and contaminant concentration limits. The end product is a design procedure for the designer to specify contaminant loads, target concentrations, contaminant sources, and possible indoor air quality control technologies.

- During FY1998 three tasks will be performed. The first is to: complete a Windows version of the CONTAM program. The completion of the Windows version of CONTAM, will fulfill BFRL's obligation as part of a three-year agreement with the National Research Council of Canada to develop an indoor air quality simulation program. BFRL's role in this effort has been the development of the multizone airflow and indoor air quality modeling capabilities for the overall program, while NRC Canada has been responsible for developing a materials emissions database. The second task is the development of software to simulate ventilation rate control. Indoor air quality analysis to date has focused on predicting indoor contaminant levels and airflow rates based on building data, system information and contaminant source strengths. To perform contaminant-based design, this analysis will need to be performed as part of an optimization process so that one can specify the building and system parameters that will result in the desired contaminant levels. As a first step in the development of this optimization procedure, BFRL will develop the simulation tools needed to model ventilation rate control based on interior temperatures and indoor contaminant levels. The third task, is development of a database of building data relevant to the process of contaminant-based design. These data include building airflow elements (e.g. airtightness values for windows and doors), ventilation system components (e.g. fan curves), outdoor weather data, outdoor concentration data, contaminant source strengths, and filter efficiencies. Existing sources of this information will be reviewed and evaluated and entered into a database to be accessed initially by CONTAM and eventually by the building and system design software that will be developed in this project.

Recent Results: New project.

Demonstration of Residential Ventilation Systems

Principal Investigator: Andrew K. Persily, Building Environment Division, 301-975-6418

Sponsor: Synertech Systems Corporation (Contractor to New York State Energy Research and Development Administration)

Objective: To evaluate the performance of residential ventilation systems based on multizone airflow and contaminant modeling of houses in a field monitoring program.

Problem: A variety of approaches to mechanical ventilation in residential buildings exist, which are intended to control indoor contaminant levels while maintaining thermal comfort and controlling energy consumption. The New York State Energy Research and Development Administration recently sponsored a project to identify and analyze the energy and indoor air quality impacts of ventilation approaches to residential construction. This project, performed by the California Institute for Energy Efficiency and Lawrence Berkeley Laboratory, included the collection of cost and performance data for ventilation approaches from past studies and telephone surveys with HVAC contractors. These data formed the basis for detailed analyses of the most promising approaches to evaluate their ventilation characteristics, energy usage impacts and life cycle costs in new and existing buildings. The results of these analyses have identified the most effective systems in New York State and California. A Ventilation Guide discussing the issues associated with ventilation and the most appropriate system for New York State homes was developed from the results of these analyses.

Approach: During FY1998, BFRL will perform computer simulations of the ventilation systems in 26 homes with detailed monitoring with the multizone airflow and BFRL's indoor air quality model CONTAM. The houses will be set-up in CONTAM, with input values determined by site measurements. Simulations will be performed for the monitoring period to determine the ability to predict the measured values. Once this ability has been established, longer term simulations will be performed to understand the overall performance of the ventilation systems, their impact of several important indoor air quality parameters, and the existence of interactions between the ventilation systems and other building systems. The results obtained from these simulations will be compared with the trends predicted during the first phase of the effort. During FY1997 only four houses were monitored and had ventilation systems installed by the prime contractor, resulting in delays in the project schedule. BFRL entered these four buildings into CONTAM and began the process of comparing the predictions to the field measurements. During FY1998, the remaining houses will be monitored and have ventilation systems installed. NIST will perform the CONTAM simulation work and complete the project.

Recent Results:

No results to report.

Infiltration and Ventilation in Large Buildings

Principal Investigator: Andrew K. Persily, Building Environment Division, 301-975-6418

Sponsor: Department of Energy
Office of Building Technologies

Objective: To analyze energy impacts of large building infiltration and ventilation system airflows employing integrated building thermal analysis and network airflow analysis, and to participate in industry consensus standards development activities.

Problem: Previous research and field investigations have shown that despite current design goals, the envelopes of modern office buildings often fall short of design expectations in terms of airtightness performance. In addition, field testing has shown that ventilation system airflows are often quite different from their design values, leading to over- and under-ventilation as well as increasing the pressure differences that drive envelope leakage. The existence of such envelope leakage, and ventilation system airflows that are not in accordance with design, will increase the energy loads of a building. In addition to the energy penalties, envelope air leakage can also negatively impact indoor air quality, envelope material durability and occupant comfort. However, the energy implications of envelope leakage and ventilation system airflows are not known, in part due to a lack of ability of thermal analysis models to properly account for the complexities of building airflows in large, multi-zone buildings. Although sophisticated network airflow analysis programs are available, such as AIRNET developed at BFRL, thermal analysis models are currently not able to incorporate the output of such airflow models. Such an integration of thermal and airflow analysis is necessary to properly account for the energy impacts of infiltration and ventilation system airflows.

Approach: During FY1998, BFRL will perform two tasks. The first is an analysis of the energy impacts of infiltration in office buildings. This research includes the development of a simplified estimate of the energy impacts of infiltration and the development of a more rigorous approach based on the TRNSYS thermal load model. The simplified estimate is based on the use of CONTAM to generate building infiltration rates as a function of weather conditions and system operation and then the use of bin-type method for estimating the energy loads associated with these airflow rates. In addition, energy efficiency opportunities through envelope tightening or improved ventilation system control are being investigated with this approach. The TRNSYS approach is using the AIRNET program for calculating building airflow rates in combination with the thermal loads capabilities of TRNSYS. The second task centers on standards development support through staff participation in ASHRAE and ASTM activities, primarily the ASHRAE committee responsible for revising ASHRAE Standard 62 Ventilation for Acceptable Indoor Air Quality. BFRL will continue to participate in this revision, and in the activities of ASTM subcommittee D22.05 Indoor Air Quality. The primary ASTM activity will be the development of an ASTM standard guide for interpreting indoor carbon dioxide measurements.

Recent Results:

Persily, A.K., "Evaluating Building IAQ and Ventilation with Indoor Carbon Dioxide," ASHRAE Transaction, Vol. 103 (2), 1997.

Emmerich, S.J., Persily, A.K., "Literature Review on CO_2-Based Demand Controlled Ventilation," ASHRAE Transaction, Vol. 103 (2), 1997.

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BUILDING ENVIRONMENT

COMPUTER INTEGRATED CONSTRUCTION

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Codes and Standards Processing for the Process Plant Industries

Principal Investigator: Kent A. Reed, Building Environment Division, 301-975-5852

Sponsor: National Institute of Standards and Technology

Objective: To assist the U.S. industry in seamlessly integrating the use of codes and standards into the life-cycle management of a process plant

Problem: Constructed facilities are subject to a number of codes and standards that impact decisions in planning, design, construction, and operation. Automation has had little impact on this aspect of the life-cycle work processes, either in helping to identify and assemble applicable codes or in helping to assess compliance.

Approach: During FY1998, BFRL will work with the Civil and Environmental Engineering Department of the Carnegie Mellon University to complete the CMU research on standards representations and distributed, object-based standards servers that was started in a prior year, and to implement a working example based on a relevant code such as OSHA CFR 1910. BFRL and CMU will exercise and demonstrate this implementation against a process plant design model managed in the Computer Integrated Construction Environment (CICE) Testbed. BFRL and CMU will build on past and current work to develop, test, and demonstrate a loosely coupled network of distributed, heterogeneous standards servers that are representative of the U.S. standards industry. BFRL and CMU will develop a technical approach to reconciling requirements from multiple standards.

Recent Results: New project.

Building and Fire Research Laboratory
Computer Integrated Construction Environment (CICE) Testbed

Principal Investigator: Kent A. Reed, Building Equipment Division, 301-975-5852

Sponsor: National Institute of Standards and Technology

Objective: To establish an open testbed as a prototype computer-integrated construction environment (CICE); to use this testbed in collaboration with academic and industrial partners to test the technologies and standards addressed in the CICE projects; to use the testbed to demonstrate the interoperability of software systems developed based on these standards.

Problem: The U.S. construction industry is actively seeking to improve its competitiveness in the global marketplace through the integration of life-cycle work processes using information technology. The industry acknowledges the value of achieving this integration through the adoption of open protocols and standards, indeed, it is participating in the development of key standards such as ISO/STEP application protocols (APs), but it lacks an effective mechanism for testing, evaluating, and demonstrating the emerging standards-based technologies because such efforts are experimental, subject to failure, and indefinite in duration, possibly with the participation of many different players and companies over time, and they require different staff skills than do normal project design, construction, operation, and management activities. At the same time, academic researchers are developing new information technologies which they hope will aid the industry but have generally lacked a forum in which to show the worth of their research. BFRL proposes to bridge these two gaps, between worthwhile experiment and industry and between academia and worthwhile experiment by expanding its existing facility and activities to establish an open testbed as a prototype of the computer-integrated construction environment sought by industry, and conducting tests and demonstrations of current and emerging information technologies in this testbed in collaboration with academic and industrial partners.

Approach: During FY1998, BFRL will enhance the current testbed, created to support verification testing of software translators in-house, to support collaborative tests and demonstrations over the Internet. Several different data-serving technologies for supporting this collaboration will be explored, including traditional Web servers and emerging object servers. The experimental developments in the companion CICE project on electronic commerce will be accessible through the testbed. Candidate software systems such as emerging groupware products will be exercised to determine their potential for providing the improved human interactions needed for effective collaboration. The existing software systems will be ported to the new computers in the laboratory. The standards testing activity in FY 1998 will be directed toward the harmonization of different STEP application protocols that address the functional and physical description of a process plant (see the companion CICE project on STEP for the process plant industries, 863-5292). Databases representing the differing views of the STEP application protocols AP 221, AP 225, and AP 227 will be created in the testbed and populated with example data sets based on the same process plant model used in previous testing of AP 227. Tests will be conducted to determine the extent to which these views usefully can be harmonized. The merged AP 221/AP 227 schema developed in FY1997 will be tested as the possible basis for a harmonized database. A common subset of the AP225 and AP227 reference models will be identified as the basis for defining the minimal information requirements for an exchange between designer and constructor. Using this model subset, representative data sets will be extracted from the AP 227 database for exchange testing with the virtual site simulator being developed in a companion CICE project on construction automation (861-3103). BFRL will continue to participate in the Research Advisory Committee of the International Alliance for Interoperability, working to define projects of mutual interest, notably in the areas of code checking and structural steelwork. New partners will be sought to expand the scope of the testbed from information about process plants to that of other types of facilities. BFRL will work with its partners to organize a conference to identify the lessons learned in a decade of academic research on object technology and determine their relevance to the practical problem of integrating distributed information systems.

Recent Results:

Developed data sets and software tools for verifying the information models contained in STEP Application Protocol 227 and worked with its industrial partners in the PlantSTEP, Inc., consortium to develop and test their prototype translator implementations based on these data sets.

Electronic Commerce of Technical Data for Process Plants

Principal Investigators: Kent A. Reed, Building Environment Division, 301-975-5852
Thomas Kurihara, Building Materials Division, 301-975-3876

Sponsor: National Institute of Standards and Technology

Objective: To assist the U.S. construction industry, with an early emphasis on the process plant sector, in the seamless integration of project applications with external sources of information (including context, data, and knowledge) using electronic commerce.

Problem: Every project to deliver a constructed facility depends heavily on external sources of technical information. The explosion of the use of computers in the previous decade has led to the development of a number of mechanisms for representing at least some of this information electronically. Comparatively little has been done to integrate these mechanisms with decision support applications. Major strides have been taken in the development and introduction into practice of computerized applications to support various work processes, especially in the design phase. Increasingly, these applications are being integrated with one another, so that information can be shared, yet the required external information is still gathered and introduced into this integrated environment manually. In the case of components and equipment for a chemical process plant, it may take an engineering company several years to build an electronic catalog that is compatible with the computerized applications in use, which dramatically reduces the ability to respond to change on the supply side, on the client side, or in the applications themselves. If they exist at all, electronic sources of external knowledge such as the properties and behaviors of materials and recommended practices for their usage typically deliver information in a form suitable for human browsing and manual extraction, which is both slow and error prone. With the emergence of the Internet as a commercial medium, the U.S. construction industry hopes to remedy these problems using electronic commerce techniques to locate, procure, and apply external technical information seamlessly in applications, but the infrastructure required to make this usage a success is incomplete.

Approach: During FY1998, BFRL will address eight components:

1. Information requirements will be identified for selected process plant components, such as a pump, that are required for decision support applications.
2. Electronic commerce usage scenarios will be developed that involve selected decision support applications, representative component catalogs, and consensus standards used for the exchange of product information.
3. A framework for a prototype Computer Integrated Construction Environment (CICE) will be developed that represents domain specific information units in terms of context, semantics, and knowledge (know-how). The CICE framework will provide interfaces among decision support applications, product catalogs, and consensus standards-based information sources.
4. A prototype implementation of the CICE framework will be developed using available commercial and research software packages.
5. Experiments using the prototype implementation will be conducted in the CICE Testbed to evaluate the utility of the framework and the applicability to electronic commerce scenarios using consensus standard information exchange.
6. A federated approach to information access using the CICE framework will be investigated that allows decision support systems to pick and choose information providers without regard to the underlying information exchange standards being used.
7. An extended CICE framework will be developed that includes decision support applications to explore the feasibility of Internet services to the construction industry end-user with an interactive user interface.
8. Joint projects will be undertaken with industry, industry associations, academia, government, and other organizations.

Recent Results: New project.

STEP for the Process Plant Industries

Principal Investigator: Mark E. Palmer, Building Environment Division, 301-975-5858

Sponsor: National Institute of Standards and Technology

Objective: To assist the U.S. process plant industries in developing and implementing the STEP application protocols needed for exchanging and sharing information during the design, construction and maintenance of process plants.

Problem: The U.S. process plant industries seek to improve their use of computerized systems through integration of information systems, *e.g.*, automation of the exchange and sharing of information among systems. The many computerized systems in use can be integrated only at great cost because of their incompatible proprietary representations of information; information exchange today is accomplished largely through manual methods. Standard, neutral information representations and exchange methods are needed that allow system vendors to be innovative and yet allow system users to exchange and share information about process plants automatically. The evolving international standard ISO 10303-Product Data Representation and Exchange, known as STEP, is providing the base technology. STEP application protocols (APs) must be developed that meet the needs of the process plant industries.

Approach: During FY1998, BFRL will work with the industry, standards development organizations and international programs to ensure the delivery of a harmonized suite of STEP APs that meet the requirements of the process plant industries. In collaboration with pdXi (Process Data eXchange Institute of AIChE), BFRL will complete the Committee Draft of the Process Engineering AP (AP 231) and submit the Committee Draft for ISO ballot. Also in collaboration with PlantSTEP, Inc., BFRL will update the Plant Spatial Configuration AP (AP 227) to resolve the issues from the ISO Draft International Standard ballot on AP 227. Additionally, BFRL will develop the Abstract Test Suite for AP 227 and start development of the Abstract Test Suite for AP 227.
BFRL will define necessary alignments between AP 221 standard classes and the plant concepts and process concepts included in AP 227 and AP 231. BFRL will co-lead the ISO TC184/SC4 Process Plant AP Planning Project and will work with PIEBASE (Process Industry Executive for achieving Business Advantage using Standards for data Exchange) to complete an industry roadmap for delivering needed data exchange standards and to provide global coordination of industry programs to develop, demonstrate, and standardize needed data exchange standards.

Recent Results:

Defined a program to develop top priority APs and participated in the development of other APs needed by the process plant industries. Developed in collaboration with PlantSTEP, the first STEP AP for the process plant industries, Plant Spatial Configuration (AP 227).

BUILDING ENVIRONMENT

HEAT TRANSFER

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Photovoltaic Measurement Techniques

Principal Investigator: Hunter Fanney, Building Environment Division, 301-975-5648

Sponsor: National Institute of Standards and Technology

Objective: To develop measurement techniques and validated predictive performance models for residential photovoltaic building integrated products.

Problem: There is much increased interest in building integrated photovoltaic systems. The widespread use of building integrated photovoltaics has increased, as a result of the continuing decline in photovoltaic module costs, the relative ease in which photovoltaics can be incorporated within a building envelope, and buildings account for over 40 percent of the energy used within the United States. Specific examples are photovoltaic residential roofing shingles, fenestration elements that incorporate amorphous silicon technology, and curtain walls that incorporate photovoltaic cells. In addition, innovative residential roofing systems and curtain wall systems are being explored that replace conventional building materials with an integrated system that includes both solar thermal and photovoltaic energy conversion devices.
Predictive performance models for integrated photovoltaic building products are needed to quantify achievable energy savings. A test method of the performance of combined solar electric/thermal building products does not exist. The relationship between electrical conversion efficiency and elevated operating temperature, that result from incorporating photovoltaic devices into the building envelope has not been determined. The influence of photovoltaic devices on the thermal resistance of the building envelope and annual heating/cooling load have not been quantified.

Approach: During FY1998, BFRL will develop measurement techniques that accurately characterize the performance of building integrated photovoltaic devices. Working with Solarex, Siemens Solar, and Solar Design Associates, the most promising combined photovoltaic/thermal conversion devices will be identified. Various methods of test will be examined to develop a measurement procedure that accurately captures the performance of combined photovoltaic/thermal conversion devices. Experimental studies to determine the operating temperature of building integrated photovoltaic cells and the resulting degradation of solar cell efficiency will be documented. Working with the University of Wisconsin, computer simulation tools will be developed to predict the thermal and electrical contributions achievable through the use of residential photovoltaic products in various geographical locations.

Recent Results: New project.

Thermal Conductivity Measurements

Principal Investigator: Robert R. Zarr, Building Environment Division, 301-975-6436

Sponsor: National Institute of Standards and Technology

Objective: To develop the measurement tools, procedures, database, and standards to assist the building and related industries in determining the thermal performance properties of current and new building materials.

Problem: New advanced insulation systems with potentially high thermal resistance are being developed and introduced into the U.S. market. Moreover, the producers of current products require accurate sources of information for thermal data, test methods that cover extended temperature ranges, and reliable test methods for global competition.

Approach: During FY1998, BFRL will complete the development of a thermal conductivity database of building thermal insulation materials. BFRL has accumulated a valuable and comprehensive collection of thermal conductivity data from measurements performed with the 200 mm square guarded hot plate apparatus from 1929 to 1983. There exists about 2000 measurements including, several types of building materials. This data is recorded in logbooks and is not in a convenient, usable form. BFRL will compile all the usable data into an electronic format suitable for development as an electronic database by the Standard Reference Data (SRD) Program. This SRD for thermal conductivity measurements will function as a benchmark for researchers and organizations interested in thermal conductivity including ASHRAE and other building community members.
BFRL will develop the experimental techniques for assessing the thermal performance of building and industrial insulations at extended temperature ranges. Currently, BFRL's capabilities for thermal conductivity measurements are limited to a mean temperature range of 280 K to 330 K. The transfer of low- and high-temperature guarded hot plate equipment from NIST-Boulder will expand this temperature range from 100 K to 700 K. However, these apparatus require significant modifications before accurate and repeatable test results can be obtained. BFRL researchers will update the instrumentation, modify the control and data collection software, and modify, when necessary, the apparatus equipment. Test results will be compared to BFRL 1 meter guarded hot plate apparatus and other laboratories as part of an international interlaboratory comparison.
During this year, BFRL will provide assistance to industry in thermal testing of advanced insulation prototype products. The search for materials that offer thermal resistance values an order of magnitude greater than conventional materials has led to several prototypes of advanced insulation systems. By their inherent design, advanced insulation systems are not suitable for thermal measurement using conventional equipment, such as guarded-hot-plate or heat-flow-meter apparatus. An advanced insulation laboratory that incorporates a calorimetric apparatus and finite element models is being used to provide measurements and design assistance to the developers of the next generation of advanced insulation products through the use of CRADAs. This assistance will continue until advanced insulation systems are commercially realized and private sector measurements are established.
Plan, organize, and conduct an international interlaboratory comparison of guarded hot plate apparatus among Canada, France, Japan, United Kingdom, and the United States. At present national reference materials for thermal resistance measurements produced by individual countries are rarely accepted across international boundaries, particularly between North America and Europe. The goal of this interlaboratory is to investigate the variability of thermal conductivity data among these national standards laboratories and eventually provide the means and opportunity for developing an international Standard Reference Material. BFRL will take the lead role in organizing, conducting, and analyzing the interlaboratory study.

Recent Results: New project.

FIRE SAFETY ENGINEERING

LARGE FIRE RESEARCH

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Advanced Fire Fighting Technology

Principal Investigators: James R. Lawson, Fire Safety Engineering Division, 301-975-6877
David W. Stroup, Fire Safety Engineering Division, 301-975-6564
Dan Madrzykowski, Fire Safety Engineering Division, 301-975-6677

Sponsor: National Institute of Standards and Technology

Objective: To develop measurement equipment and techniques for the evaluation of 1) thermal environments experienced by fire fighters while conducting fire suppression and rescue tasks, 2) the performance of the fire fighters protective clothing and equipment, while conducting fire suppression and rescue tasks, and 3) new fire fighting/suppression tools.

Problem: The number of firefighting injuries, deaths, and occupational diseases is unacceptable.

Approach: During FY1998, BFRL will obtain input from the fire service and equipment manufacturers to identify special needs of fire fighters and industry. Researchers will develop a standard methodology for making appropriate measurements and calculating the thermal properties and performance of fire fighters' protective clothing when exposed to a range of thermal and moisture environments. A prototype portable instrumentation system will be constructed, which can be used to measure the performance of fire fighter protective clothing and equipment in various fire fighting environments. The prototype will be used to evaluate instruments and measurement techniques. With researchers at NRIFD, in Japan, BFRL will evaluate the use of durable agents under wind driven fire conditions.

Recent Results:

Lawson, J. R., Fire Fighter's Protective Clothing and Thermal Environments of Structural Fire Fighting, NISTIR 5804, National Institute of Standards and Technology, August, 1996.

Lawson, J. R., Jason, N., Firefighter Thermal Exposure Workshop: Protective Clothing, Tactics, and Fire Service PPE Training Procedures, NIST SP911, National Institute of Standards and Technology, February, 1997.

Burning of Oil Spills

Principal Investigator: William D. Walton, Fire Safety Engineering Division, 301-975-6872

Sponsor: Department of Interior
Minerals Management Service

Department of Transportation
U.S. Coast Guard

Objective: To determine conditions where *in situ* burning can be used effectively as a response method to accidental spills of crude oil on land and on water.

Problem: In support of other agency objectives to carry out burning as a response method to oil spills, predictions are needed to assess the impact of the smoke plume produced by burning on downwind locations. BFRL's Large Eddy Simulation (LES) model continues to gain acceptance for use in planning *in-situ* burns although there has been limited verification. There is a need for predictions that take into account the effect of local terrain features such as mountains. Further, the spill response planning community has shown a strong interest in using the LES model as a planning tool.
One of the most significant remaining obstacle to the acceptance of burning as a spill response technique is the lack of a standard method for evaluating a fire resistant oil spill containment boom. To develop a test method, knowledge of the thermal exposure conditions and physical stresses that the boom is expected to be exposed to, must be determined.

Technical Approach: During FY1998, BFRL will complete development of two versions of the ALOFT model. The first, ALOFT-FT, is for flat terrain, and the second, ALOFT-CT, accommodates complex terrain such as mountains. ALOFT-FT with a graphical user interface for personal computers has been developed. ALOFT-CT is operating on workstations and a GUI interface for personal computers is being developed.
The principal instrument used in the field to measure smoke particulate concentration is a real-time aerosol monitor based on the back-scattering of light. These instruments are calibrated with a well characterized dust however they have not been calibrated with smoke. NIST has obtained instruments capable of measuring real-time smoke particulate concentrations by gravimetric means. The optical and gravimetric measurements of smoke particulate will be compared to develop a calibration for the optical instruments used for field measurements.
In order to develop a method to characterize the performance of fire-resistant boom, a series of experiments have been conducted exposing representative booms to waves and a diesel fuel fire in a specially designed wave tank. The results of these experiments will be analyzed in the coming year. Recommendations for improvements to the procedure will be developed and the results published.
A workshop on *in situ* burning of oil spills was held in 1994 to review the technology and identify issues where additional research and development were needed. The results of that workshop have been used to guide the research. The understanding and acceptance of *in situ* burning of oil spills has advanced significantly since 1994 and the Minerals Management Service has indicated that a follow-on workshop in FY99 would be beneficial. During this fiscal year the workshop will be scheduled and planned.

Recent Results:

Two papers were presented at the Arctic and Marine Oil Spill Technical Seminar.
McGrattan, K. B., "Smoke Plumes Trajectory From In Situ Burning of Crude Oil: Complex Terrain Modelling (1419K)," *Arctic and Marine Oilspill Program (AMOP) Technical Seminar, 20th, Volume 2, Proceedings*, June 1997.

Walton, W. D., Twilley, W. H., Mullin J. V., "Evaluation of Propane as a Fuel for Testing Fire-Resistant Oil Spill Containment Booms (365K)," *Arctic and Marine Oilspill Program (AMOP) Technical Seminar, 20th, Volume 2, Proceedings*, June 1997.

Computational Wind Engineering

Principle Investigator: Ronald G. Rehm, Fire Safety Engineering Division, 301-975-2704

Sponsor: National Institute of Standards and Technology

Objective: To develop fundamentally based, computational model to predict the effects of winds on buildings under normal conditions and under disaster conditions (high wind or fire).

Problem: Currently within BFRL a capability exists to model from first princiles fluid flow, hot-gas transport and the effects of heat release induced by fires. This capability has evolved over a period of years and is embodied in the expertise of several staff members, in unique algorithms and in computer codes known as large eddy simulations (LES). These large eddy simulations have the potential also to provide insight into the interactions of winds with buildings (Computational Wind Engineering, or CWE), both under normal conditions and under extreme conditions characteristic of disasters, such as very high winds arising from storms or fires arising in the aftermath of an earthquake, for example.

Approach: During FY1998, BFRL will apply its LES methodology to blunt body aerodynamics, i.e., wind flow over buildings. By comparison of pressure distributions obtained from LES with those obtained experimentally either from wind-tunnel tests or from full-scale outdoor measurements, credibility in the LES methodology for this application can be established. Necessary extensions of this methodology for important wind-engineering applications will be examined in consultation with researchers in BFRL's Structures Division. A specific application of the LES methodology to fire whirls is currently underway with a NIST NRC Postdoctoral Fellow. Such fire whirls can arise during large fires and after natural disasters.

Recent Results:

Some early comparisons of pressure distributions from LES computations with wind-tunnel pressure measurements show promise.

Fire Research and Measurement Support for Arson Investigation

Principal Investigator: Daniel Madrzykowski, Fire Safety Engineering Division, 301-975-6677

Sponsor: Department of Treasury
Bureau of Alcohol, Tobacco and Firearms

Objective: To provide measurement and modeling assistance to support the research and investigation programs of the ATF, Arson Enforcement Branch.

Problem: Arson fires are a major social and economic problem in the United States. Fire investigations are currently based on pattern analysis and forensic analysis. Fire dynamics and recent developments in fire modeling need to be applied to fire investigation to provide reconstructive capabilities which were heretofore unavailable.

Approach: During FY1998, BFRL will work with ATF staff by conducting heat release rate experiments on fuel packages of interest to the ATF. BFRL will provide the technical support, instrumentation and facilities for conducting the experiments. A report of test including experimental set up, observations, and measurements will be issued for each fuel package.
BFRL will assist ATF personnel in their use of the LES model for fire simulations. BFRL will assist ATF on issues related to planning and preparing staff for their Fire Investigation Research and Education Center.

Results: New Project.

Large Fire Research Facility

Principal Investigator: Nelson Bryner, Fire Safety Engineering Division, 301-975-6868

Sponsor: National Institute of Standards and Technology

Objective: To provide large fire measurement capabilities to meet the needs of industry and government customers.

Problem: Use of BFRL's large fire research facility must be scheduled for timely performance of experimental programs. Modernization of equipment and facilities is required to address issues of environmental and work place safety.

Approach: During FY1998, BFRL will perform daily management of the Large Fire Research Facility, which includes the scheduling of tests and their timely execution, will continue along with the gradual modernization of equipment and facilities. Additional short term improvements will be developed and executed during the fiscal year, pending availability of funding. These plans will be developed in conjunction with researchers to assure that new and updated instruments fit the needs of the fire program and its customers.

Recent Results:

Renovation of BFRL's large burn facility is nearly complete. Two new calorimeters were constructed, calibration and placed into use as of Jan. 1997.

Modification of Fire Protection Requirements for NRC

Principal Investigator: David W. Stroup, Fire Safety Engineering Division, 301-975-6564

Sponsor: U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research

Objective: To support NRC in developing a new "rule" allowing utilities to use risk-informed, performance-based methods for providing fire protection in nuclear power plants.

Problem: Current regulation is based on Appendix R of 10 CFR 50 which is prescriptive. The NRC is engaged in an "expedited rulemaking" effort to develop a risk-informed, performance-based regulation for fire protection at nuclear power plants. Several national laboratories are providing technical support.

Approach: During FY1998, BFRL will identify fire models and correlations that are currently being used in nuclear power plant applications and issues associated with their use. As part of this effort, a database of information including results of validation efforts currently available to address identified issues will be assembled and used to develop responses to the applicability issues. Any limitations on applicability of models and correlations based on current validation results will be determined.

Recent Results:

Supported NRC in the preparation of a document, NUREG 1521 - Feasibility of Risk-Informed, Performance-Based Fire Protection Regulation for Nuclear Power Plants.

Office Building Fire Research Program

Principal Investigator: Daniel Madrzykowski, Fire Safety Engineering Division, 301-975-6677

Sponsor: General Services Administration
Public Building Service
Office of Property Management and Safety

Objective: To quantify the impact of large fires on buildings and their occupants, and investigate the use of current technology/resources for mitigating the hazards.

Problem: Systems furniture or "work stations" have been identified as a source of large heat release rate fires in office buildings. Because of the wide spread use of systems furniture, the potential fire hazard in an open plan office enviroment needs to be quantified. The means of egress in a long corridor adjoining the fire compartment needs to be determined. If the fire cannot be supressed in the room of origin, information about the impact that sprinklers has been demonstrated in BFRL experiments, it has not been included in the corridor flow model due to insufficient databases.

Approach: During FY1998, BFRL will compare the experimental results obtained from examining smoke flow in a corridor and characterizing the heat release rates of open plan office fuel packages with the current capabilities of BFRL's FPEtool. The final step in the program is the completion and dissemination of the technical reports.

Recent Results:

No printed reports.

FIRE SAFETY ENGINEERING

FIRE MODELING AND APPLICATIONS

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Advanced Fire Detection and Alarm Panels (Cybernetic Buildings)

Principle Investigator: Walter W. Jones, Fire Safety Engineering Division, 301-975-6887

Sponsor: National Institute of Standards and Technology

Project Objective: To develop an advanced fire annunciator panel that will isolate the location of a fire in a building, and predict the short and long term behavior and effects of fire growth and smoke spread in the building.

Problem: BFRL has developed an advanced model of fire growth and smoke spread in buildings. As sensor use in buildings becomes more wide spread, it is possible to use this information as input to the model to detect and predict the evolution of a fire in a building.

Technical Approach: During FY1998, BFRL will perform the following tasks:

1. Implement CRADA with NEMA and FDI to provide support of signal processing from current alarm panels. This CRADA will address the issues of the order in which researchers will add sensor signals. This will be a cooperative process to define for sensor manufacturers what the new generation of sensor technology should be.
2. Initiate a literature study of large object pyrolysis (full room involvement), as a precursor to development of a full room model.
3. Initiate a coordinated effort with the Advanced Sensors Group will be initiated in order to develop a standard test method and protocol for current, as well as future, sensors.
4. Orient the predictive model to start with actual data: a) improve the startup algorithm so the model will start faster than real time; b) provide the ability to set parameters arbitrarily; c) use sensor data. As an adjunct to the adaptive modeling necessary to instantiate a cybernetic building, BFRL will develop an algorithm to perform verification. This research will be performed in conjunction with NIST's Information Technology Laboratory.
5. Develop the framework for decoding sensor data by developing a model of detectors, with a lag model of current smoke detectors first.

Recent Results: New project.

Application of Zone Fire Modeling in Fire Fighter Training

Principal Investigator: Richard D. Peacock, Fire Safety Engineering Division, 301-975-6664

Sponsor: National Institute of Standards and Technology

Objective: To support the use of the CFAST model in real-time fire fighter trainers

Problem: Typical real-time video-based trainers for fire fighters utilize manual control by experts to simulate the growth and spread of fire during a simulation. Zone fire model provide a physics-based calculation to provide this simulation and provide the fire fighter with realistic fire conditions This would allow more widespread use of the trainers without direct, constant interaction required to provide a realistic fire simulation.

Technical Approach: During FY1998, BFRL will work as part of its existing CRADA to provide a callable subroutine version of the fire model CFAST and demonstrate the usability of the software with an example case appropriate for the software and operating system used by the vendor. This research will be coordinated with the existing CRADA with Loran Corporation, which will extend the subroutine with a more formal data exchange protocol for providing data to and receiving data from the model.

Recent Results: New project.

Enhanced Fire Safety Evaluation System

Principle Investigator: Richard W. Bukowski, Fire Safety Engineering Division, 301-975-6853

Sponsor: National Institute of Standards and Technology

Public Building and Service
Office of Real Property Safety

Objective: To advance the technical basis of the FSES and facilitate its evolution to a risk management tool.

Problem: Current fire safety practice within GSA is rooted in the Life Safety Code prescriptions and using the FSES for equivalency determinations. The goal of GSA HQ is to move this to a risk management basis.

Approach: During FY1998, BFRL will embed FSE calculations into the FSES in place of judgmental assignment of scores for system parameters and to recalibrate the resulting system for the risk management goals of *life safety, property protection, and mission continuity.*

Results:

Produced a Windows version of the existing FSES and embedded specific calculations as alternates to prescribed values.

Experimental Application of Fire Hazard Analysis for U.S. Passenger Train Systems

Principal Investigator: Richard D. Peacock, Fire Safety Engineering Division, 301-975-6664

Sponsor: Federal Railroad Administration
Volpe National Transportation Systems Center

Objective: To demonstrate the practicality and effectiveness of new generation test methods and hazard analysis techniques when applied to passenger rail transportation vehicle fire safety.

Problem: Considerable advances in fire safety engineering have been made in the decade since the original development of the current U.S. guidelines for passenger train material selection. Some requirements for system design, materials controls, detection, suppression, and emergency egress are included in the variety of requirements, with each applying to distinct subsets of rail transportation. New test methods and hazard analysis techniques are leading a revolution in the analysis of a material's overall contribution to fire hazard in a particular application. These advances should be incorporated in future designs of passenger trains.

Approach: During FY1998, BFRL will complete a fire hazard analysis of a passenger rail vehicle constructed of currently used materials and construction techniques. Assemblies of passenger vehicle components will be tested in full-scale to obtain inputs for modeling efforts. Currently available computer-based methods for fire hazard analysis will be employed to study specific fire scenarios, including an interior fire, exterior fire, and an interior fire on a vehicle located in a tunnel. Selected mock-up assembly tests and (if available) complete train car tests will be conducted for validation of the hazard analysis techniques.

Recent Results:

Braun, E., Peacock, R. D., *Fire Safety of Passenger Trains, Material Evaluation in the Cone Calorimeter,* NIST TN 1406, National Institute of Standards and Technology, July 1997.

Fire Data Management System

Principle Investigator: Paul A Reneke, Fire Safety Engineering Division, 301-975-6963

Sponsor: National Institute of Standards and Technology

Objective: To develop a platform independent user friendly method of distributing fire test data on a CD ROM

Problem: A unified method of accessing data is crucial to both experimental and modeling efforts in the development of the science of fire. FDMS, the Fire Data Management System, is a data format specification for organizing and presenting fire data obtained from bench-scale and real-scale tests as well as fire simulation programs. By storing available fire test values in a common format, available on a computer, this data is readily available for fire protection professionals, experimentalists, building code officials, and others concerned with the design and construction of "safe" structures.

Approach: During FY1998, BFRL will increase the number of tests included in the data set and include more links to documents. The file utility will be expanded with more tools to determine the usefulness of the data and repeatability and reproducibility for a set of Cone Calorimeter tests of the same material. To better interact with BFRL customers, a list server will be implemented for discussion of features and user needs in FASTData with a limited number of participants. A list server will create an electronic forum between developers and users so our product will be more responsive to users needs and instill in the users a sense of ownership. As experience with this forum increases, the number of users allowed to participate will increase

Results:

Generated an initial database containing 275 bench-scale and real-scale tests. Authored report, Data Structures for the Fire Data Management System, FDMS 2.0, (in review), and developed prototypes of the web pages and software for review.

Fire Forum

Principle Investigator: Richard W. Bukowski, Fire Safety Engineering Division, 301-975-6853

Sponsor: National Institute of Standards and Technology

Objective: To perform the duties of Secretary to the FORUM for International Cooperation on Fire Research

Problem: The FORUM is an international body of the Heads of fire research organizations around the world. The group of 16 represent 14 countries. The FORUM requires the support of a secretariat to ensure that assignments are performed.

Technical Approach: During FY1998, BFRL The secretary will produce a meeting report for internal distribution and an annual report for general distribution. The secretariat is responsible for disseminating information on the FORUM and its activities to appropriate organizations and to the public through INTERNET and printed media. The secretariat also assures that assignments made at the annual meeting are completed on schedule.
The 1998 FORUM meeting will be hosted by BFRL. This requires the PI, in addition to the above duties to organize the meeting and a 2-day symposium which will precede it. This includes a Call for Papers, selection, scheduling, and production of proceedings.

Results:

No reports published.

Fire Research Information Services

Principal Investigator: Nora H. Jason, Fire Safety Engineering Division, 301-975-6862

Sponsor: National Institute of Standards and Technology

Objective: To assist BFRL staff and BFRL's user community for information resource management.

Problem: It is important to collect, logically organize, and disseminate international fire literature and experimental data to the BFRL staff and the user community to capture the knowledge of the past so that it may be identified and incorporated into today's technical work thus avoiding duplication of research.

Technical Approach: During FY1998, BFRL will provide access to documents, data, and software electronically through the FIREDOC database and the FRIS Home Page. Identify and work with an organization to create and distribute the *BFRL Publications, 1997,* as a CD-ROM.

Recent Results:

Jason, Nora H., *BFRL Publications, 1996,* NIST SP 914, (CD-ROM format), National Institute of Standards and Technology, 1997.

Jason, Nora H., *Building and Fire Research Publications, 1996,* NIST SP 838-11, National Institute of Standards and Technology, 1997.

IFSPES Information Exchange

Principal Investigator: Glenn P. Forney, Fire Safety Engineering Division, 301-975-2313

Sponsor: National Institute of Standards and Technology

Objective: To develop methods for representing and exchanging data and results between manufacturers, designers, testing laboratories, fire safety engineers, insurers, and local authorities for fire safety system performance evaluations.

Problem: BFRL's large eddy simulation model (LES) is being used as the basis for calculation of fire safety system performance. This system must be used by the fire equipment manufacturing industry, fire safety engineers, testing laboratories, and local authorities in order to gain acceptance for systems based on engineering calculation rather than large scale tests. A method to exchange data needed for system evaluation and the results of calculation amongst these parties must be developed to enable the reliable use of the Industrial Fire Safety Performance Evaluation System (IFSPES). In order to effectively evaluate fire safety system performance of a building using the LES model rather than large scale tests, needed is 1) a method to identify building, content, and fire safety system hardware characteristics that are important to the model; 2) a method for specifying these characteristics; and 3) de a means for converting output from the model in a form that a building evaluator can understand.

Technical Approach: During FY1998, BFRL will meet with fire protection engineers (FPE) to better understand how the fire safety performance of building is evaluated and to understand what information is needed to make this evaluation. The next step centers on meeting with the LES modeler to better understand what information the model needs to make a calculation and what types of information the model can estimate. Finally, methods similar to those already used by the investigator to represent modeling results with web pages will be developed to represent LES model output and building characteristics.

Recent Results: New Project.

IFSS Fire Model Verification

Principal Investigator: Dan Madrzykowski, Fire Safety Engineering Division, 301-975-6677

Sponsor: National Institute of Standards and Technology

Project Objective: To conduct and support experiments directed at verifying and enhancing the capabilities of BFRL's Large Eddy Simulation (LES) fire model used in the Fire Safety Performance Evaluation System.

Problem: The existing database of results from large scale fire experiments is limited and inadequate for the purposes of evaluating the capabilities of the LES fire model. Laboratory scale model enclosure fire measurements are needed to verify and advance the LES model. As current measurement techniques for large scale fire experiments are limited to intrusive, scalar measurements, needed are methods to measure fire flows over large areas at the resolution of the fire model.

Technical Approach: During FY1998, BFRL will create a research laboratory to investigate methods for measuring fire flows in reduced scale compartments with complex geometries and will perform measurements to generate data for verification of the Industrial Fire Simulation model relevant to the sprinkler, draft curtain, and vent calculations. Although developed at laboratory scale, the measurement methods must be easily used in larger scale test facilities were model evaluation tests are conducted. Candidate measurement methods are scalar measurement matrices, infrared field measurements, laser Doppler and particle image velocimetry. Some of this work will be performed in cooperation with the University of Michigan. The first series of experiments are directed at measuring thermal response of surfaces to heat transfer from hot gases.

Results to Date: New Project

IFSS LES Model

Principal Investigator: Kevin McGrattan, Fire Science Engineering Division, 301-975-2712

Sponsor: National Institute of Standards and Technology

Project Objective: To develop a model capable of predicting the number, location and time of activation for sprinklers in a rack storage facility including the effects of sprinklers, draft curtains, and smoke and heat vents based on large eddy simulation technology.

Problem: Industry has tested and considered the role of combined installations of sprinklers, draft curtains and heat and smoke vents for more than 2 decades without any agreement as to the benefits or detriments of the combined systems.

Technical Approach: During FY1998, BFRL working with industry will improve BFRL's Large Eddy Simulation (LES) fire model to predict the outcome of large scale fire tests. The model can provide insight into the expected performance of the combined fire protection systems in industrial buildings. Once demonstrated, U.S. testing laboratories will join with BFRL through Cooperative Research and Development Agreements to develop and demonstrate the use of this modeling and the associated supporting data that constitute an Industrial Fire Simulation System (IFSS).

Results to Date:

Demonstrated effectiveness of LES model predictions of sprinkler and draft curtain interactions to predict the major features of two existing large scale tests conducted at FMRC. Methods to display the model output as simulated tests using video presentations were developed. The first of these experiments with gas burner fires have shown good agreement with calculations performed prior to the experiments, and greater agreement with calculations made after the experiments. An important short coming of the present testing method for sprinkler response is accounting for heat loss to a flowing water in a pipe system. This issue must be addressed to enable better predictions of fringe sprinkler response.

IFSS Vent Response Model

Principal Investigator: Leonard Y. Cooper, Fire Safety Engineering Division, 301-975-6880

Sponsor: National Institute of Standards and Technology

Project Objective: To develop method to accurately predict smoke and heat vent operation in boxed commodity fires in industrial facilities.

Problem: Available heat and smoke vent actuation models have been shown to be inaccurate for warehouse fires. This may be caused by poor characterization of the hardware thermal response or shortcoming in the simulation of the fire flows in and around closed vents. The primary cause of this difficulty must be determined in the development of an accurate model which is compatible with BFRL's Large Eddy Simulation (LES) fire model analysis methods and the Industrial Fire Simulation System (IFSS).

Technical Approach: In FY1998, BFRL will identify fusible link designs and mounting characteristics used in typical industrial smoke vent designs. The work involves:

- Using RTI concepts to characterize link thermal properties.
- Developing a model that takes link-mount designs into account and predicts the thermal response of an installed link, up to the time of fusing, when it and its mount are submerged in an air stream of specified time-dependent velocity and temperature.
- Obtaining hardware for experimental evaluations.
- Using the BFRL plunge-test apparatus to validate the model experimentally. In LES model simulations of ceiling vent activation, the new link model, with LES model-specified local velocity/temperature history would be used to predict link fusing.

Results to Date: New Project

Manufactured Housing Fire Safety

Principle Investigator: Richard W. Bukowski, Fire Safety Research Division, 301-975-6853

Sponsor: Department of Housing and Urban Development

Objective: To pursue fire safety strategies selected to address losses in existing and new manufactured housing.

Problem: In January of 1995, HUD and USFA entered into an agreement to consider possible improvements in fire safety for manufactured homes. Such improvements should be cost effective in that they should not unnecessarily increase the cost of manufactured housing, which serves an important role as affordable housing. Improvements, which can be applied to the existing stock of manufactured homes, are preferred, as these will have a larger impact than those limited to new units.

Technical Approach: During FY1998, BFRL will provide technical support to HUD.

Recent Results:

Developed draft report on review of smoke alarm requirements in current HUD Standard and recommendations for updating.

FIRE SAFETY ENGINEERING

GRANT SUMMARIES

FIRE MODELING

LARGE FIRE RESEARCH

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Review and Evaluation of Thermal Sensors for Use in Testing Firefighter Protective Clothing

Principal Investigators:
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College of Textiles
North Carolina State University
Raleigh, NC 27695-8301

Sponsor: National Institute of Standards and Technology

Objective: To comparatively evaluate thermal sensors used to measure heat transferred through firefighter protective clothing materials.

Problem: Thermal sensor technologies are available that can be used to measure heat transferred through firefighter protective clothing materials. Instrument readings can be translated to predict skin burn injury.

Approach: A review of state-of-the-art thermal sensor technologies has led to the identification and selection of four different sensors that are currently used for evaluating materials for firefighting applications. Each of the candidate sensors has been tested and comparatively evaluated based on a reasonably developed set of performance requirements for thermal sensors used for materials testing, or for thermal measurements in firefighting environments. Laboratory experiments have been conducted to characterize sensor response to different levels of covered heat exposure and to evaluate the accuracy of the thermal measurements. Also, a burn model has been developed to determine tolerance times for each exposure condition.
Instrument studies have successfully identified critical differences in sensor performance that is providing a useful basis for selecting the optimum sensor for this application. Conclusions from this study are being implemented in conceptual design of the new generation sensor that is tailored to applications in structural firefighting hazard evaluation.

Recent Results:

After an exhaustive search of available off-the-shelf solutions we have concluded that limited range, durability and especially concern over the proprietary nature of existing commercial sensor designs and calibrations, ruled out use of any of these technologies. An "open system" sensor which can be user calibrated and even user modified to meet specific end-use scenarios is what is required for our complex application.
Our research team has investigated methods for dynamic cooling of the sensor pack so that continuous monitoring of heat flux in the field would be possible. The initial design uses a circulating liquid medium to maintain a controllable sensor assembly temperature. An evaluation set-up, based on the cooled sensor, heat-sensing thermocouples, cooling auxiliaries and data collection has been developed.

Assessment of the Technological Requirements for the Realization of Performance-Based Fire Safety Design in the United States - Phase II

Principal Investigator:
Brian J. Meacham, P.E.
Research Director
Society of Fire Protection Engineers
508-752-8239

Sponsor: National Institute of Standards and Technology

General Services Administration
Public Buildings Service
Office of Real Property Management

Objective: To assess the availability and applicability of fire safety engineering tools and design methodologies for use within a performance-based approach to building and fire safety design.

Problem: Performance-based fire safety design methods are being used or developed in many parts of the world. The bases of several of these methods are the many fire engineering tools and methods developed in the United States. Unfortunately, these tools and methodologies are not being widely applied within the United States. There are many reasons for this, including the lack of performance-based fire and building codes in general use, and, where there are such codes or regulations, the lack of documentation on the availability and application of credible fire safety engineering tools and methodologies for fire safety design.

Approach: Building on Phase I results, in which concepts for a performance-based regulatory system for the United States and for a performance-based approach to fire safety design were outlined, Phase II efforts aim to advance the conceptual approach to performance-based fire safety engineering and begin translating it into a design guidance document, to begin producing specific quantitative engineering guidance documents, and to begin evaluating engineering tools and methods (e.g., computer fire models). Specific tasks include facilitating the development of several engineering guidance documents and evaluation reports, including: an engineering guide to performance-based fire safety analysis and design, an engineering guide on performance-based design of structural fire protection, an engineering guide to calculating the thermal radiation effects from pool fires, and an evaluation report on the fire detector activation model DETACT-QS (these are expected to be multi-year efforts). Efforts will be made to widely disseminate information regarding performance-based codes and the availability, applicability, limitations, and use of fire safety evaluation and design tools and methods.

Recent Results:

Meacham, B.J., "Performance-Based Codes and Fire Safety Design Methods: Current Situation and Future Needs," *Proceedings of the AIA Center for Building Performance & Regulations Conference, Performance Codes: How Will They Happen*, American Institute of Architects, Washington, DC, October 1997.

Meacham, B.J., "Performance-Based Building and Fire Regulatory Development Activities in the United States," *Face Au Risque*, Paris, France, October 1997 (in French).

Meacham, B.J., "Assessment of the Technological Requirements for Realization of Performance-Based Fire Safety Design in the United States: Phase I - Fundamental Requirements," *Proceedings of the 2nd International Conference on Fire Research and Engineering, NIST*, Gaithersburg, MD, August 1997.

Meacham, B.J., "Identifying and Addressing Uncertainty in Fire Protection Engineering," *Proceedings of the 2nd International Conference on Fire Research and Engineering, NIST*, Gaithersburg, MD, August 1997.

Custer, R.L.P. and Meacham, B.J., "*Introduction to Performance-Based Fire Safety*," SFPE and NFPA, Quincy, MA, June 1997.

Meacham, B.J., "Concepts of a Performance-Based Regulatory System for the United States," *Proceedings of the AIA Center for Building Performance & Regulations Conference, Building Performance: What Is It?*, Washington, DC, USA, 18-19 April 1997.

Meacham, B.J., "An Introduction to Performance-Based Fire Safety Design with Applications to Structural Fire Safety Analysis and Design," *Proceedings of the ASCE Structures Conference,* Portland, OR, April 1997.

Meacham, B.J., "Concepts of a Performance-Based Regulatory System for the United States," *Proceedings of the International Association for Fire Safety Science, 5th Symposium,* Melbourne, Australia, March 1997.

Meacham, B.J., "Report of the 1996 Activities of the SFPE Focus Group on Concepts of a Performance-Based Regulatory System for the United States," SFPE, Boston, MA, USA, January 1997.

Meacham, B.J., "Assessment of the Technological Requirements for Realization of Performance-Based Fire Safety Design in the United States: Phase I - Fundamental Requirements," SFPE, Boston, MA, January 1997.

Meacham, B.J., "*The Evolution of Performance-Based Codes and Fire Safety Design Methods*," SFPE, Boston, MA, August 1996.

Application of the ICC Performance-Based Code

Principal Investigator:
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Sponsor: National Institute of Standards and Technology

Objective: Demonstrate the application of the ICC draft performance-based code to a 40 story building.

Problem: The International Code Council is preparing a performance-based code for implementation by the year 2000. The code, while in draft form, must have an example for engineers and code officials to review and critique prior to implementation.

Approach: A high-rise building, designed by an architectural firm using the Uniform Building Code, was modified using the ICC Draft Performance-Based Code. The design focused primarily on life-safety issues. Fire scenarios for different occupancies within the building were developed and modeled using CFAST 3.1. The building design modifications were then analyzed for overall impact upon the life safety of the occupants and response team as well as property protection.
The building was specified by the International Conference on Performance-Based Codes and Fire Safety Design Methods case study requirements. Components of report include documentation of the design, fire scenario development and modeling, and an analysis of cost savings when performance-based design is compared to prescriptive design.

Recent Results:

Averill, J. D. and Bukowski, R. W., "Case Study of the United States Performance-Based Code Initiative: The International Code Council's Performance-Based Code," to be presented at the *International Conference on Performance-Based Codes and Fire Safety Design Methods*, Maui, Hawaii, 2 - 10 May 1998.

Averill, J. D. and Bukowski, R. W. and Barnett, J. R., "Performance-Based Codes: Economics, Documentation, and Design," Master's Thesis submitted to the faculty of Worcester Polytechnic Institute. Worcester Polytechnic Institute, Worcester, MA, 30 April 1998.

Evaluation of the HDR Fire Test Data and Accompanying Computational Activities with Conclusions from the Aspects of Present Code Capabilities

Principal Investigator:
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Sponsor: National Institute of Standards and Technology

Objective: To provide fundamental information about the design and performance of fire experiments in the HDR containment building in Karlstein, Germany, and to assess the performance of the NIST fire code CFAST in modeling the fire experiments and provide insights towards the goal of improving computational capabilities.

Problem: The US fire community lacks large-scale experimental data from large, complex, multiple level, industrial structures. This creates a difficulty in evaluating the performance of fire codes in modeling fires in complex structures. Providing information about the experiments in the HDR facility will improve the code evaluation capability of US fire researchers.

Approach: During FY1998, research will focus on providing documentation on a series of wood crib fires performed at the HDR facility and to perform computations of selected tests with CFAST. These fires show characteristics of under ventilated fires and therefore constitute a challenge for current fire codes. Subsequently, Test Series T52, experiments with hydrocarbon fires will be assessed and computed with CFAST.
The documentation provides a description of the facility=s compartments and their interconnections, the experimental timelines, instrumentation mappings, types of sensors used, a summary of integral and local tests results, and a discussion on key fire safety parameters for code evaluation that are obtainable from the data. CFAST computations will assess the overall performance of CFAST as well as provide an assessment of the affect of modeling decision. All input data and decks are documented in hardcopy as well as in electronic format.
Future work will provide documentation on the remaining tests groups performed in the HDR, perform further comparisons of CFAST to experimental data, and provide an evaluation of the advanced LES-code to modeling fires in complex structures.

Recent Results:

Floyd, J. and Wolf, L., A Evaluation of the HDR Fire Test Data and Accompanying Computational Activities with Conclusions from Present Code Capabilities, vol. 3: Test Series Description and CFAST Validation for HDR T51 Wood Crib Fire Test Series, NIST Contract 60NANB6D0127, Nuclear Engineering Program, Dept. of Materials and Nuclear Engineering, University of Maryland, College Park, MD, March 1998.

Floyd, J.; Wolf, L.; Krawiec, J., Evaluation of the HDR Fire Test Data and Accompanying Computational Activities with Conclusions from Present Code Capabilities, Vol. 2: CFAST Validation for T51 Gas Fire Test Series, NIST Contract 60NANB6D0127, Nuclear Engineering Program, Dept. of Materials and Nuclear Engineering, University of Maryland, College Park, MD, Oct. 1997.

Floyd, J.; Wolf, L.; Krawiec, J., Evaluation of the HDR Fire Test Data and Accompanying Computational Activities with Computational Activities with Conclusions from Present Code Capabilities, vol.1: Test Description for T51 Gas Fire Test Series, NIST Contract 60NANB6D0127, Nuclear Engineering Program, Dept. of Materials and Nuclear Engineering, University of Maryland, College Park, MD, Sept. 1997.

Floyd, J. and Wolf, L., AComparison of Measured Data from the HDR-T51 Gas Fire Tests to Predictions Made by CFAST@, 2nd International Conference of Fire Research and Engineering (ICFRE-2), Gaithersburg, MD, Aug. 10-13, 1997.

Wolf, L. and Floyd, J., ALarge-Scale Fire Experiments in the HDR Containment@, 1997 ASME National Heat Transfer Conference, Baltimore, MD, Aug. 10-12, 1997, pp. 69 -79.

Floyd, J. and Wolf, L., AComparison of Measured Data from the HDR-T51 Gas Fire Tests to Predictions Made by CFAST@, 1997, ASME National Heat Transfer Conference, Baltimore, MD, Aug. 10-12, 1997, pp. 80 - 86.

Floyd, J. and Wolf, L.,AModelling of the HDR-T51 Gas Fire Tests Using CFAST vol.3", 5th International Conference on Nuclear Engineering (ICONE05). Nice, France, May 26-30, 1997.

Numerical Analysis for a Zone Fire Model with Many Components

Principal Investigator:
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Sponsor: National Institute of Standards and Technology

Objective: To reduce the computation time of zone fire models of the type developed at BFRL for the case when the fire being simulated may ultimately involve hundreds of rooms.

Problem: BFRL zone fire models solved a system of stiff ordinary differential equations and consequently are computationally intensive, especially if a large number of rooms are involved in the fire.

Approach: The vent submodel is the key ingredient in a basic zone fire model. Round-off error attenuation is being used to make the flow computation less noisy during low flow conditions. A stiff ordinary differential equation solver with event location capabilities is being used to dynamically reconfigure the model as the fire spreads and more rooms become involved in the fire. Solution of the pressure equation can be avoided in a certain class of rooms without loss of accuracy.

Recent Results:

Forney, G. P. and Moss, W. F., "A Plan for Computing Heat Transfer Between Connected Compartments in a Zone Fire Model," in review.

Moss, W. F., "Numerical Analysis for a Zone Fire Model with Many Compartments, Preliminary Report: NIST Grant No. 60NANB7D0024, covering the period August 1, 1997 to March 17, 1998, Clemson University, 1996.

Moss, W. F., "Computational Heat Transfer for Zone Fire Modeling, Final Report: NIST Grant No. 60NANB2D1281, covering the period June 1, 1994 to March 31, 1996, Clemson University, 1996.

Characterization of Sprinkler Sprays and their Interactions with Fire Induced Flows

Principal Investigator:
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Sponsor: National Institute of Standards and Technology

Objective: To provide high resolution, large-scale planar data for validation of field models of sprinkler fire suppression; (a) drop size distribution and droplet velocities produced by a scaled pendent sprinkler head under various water flow rate conditions, (b) sprinkler and fire induced gas velocities, and (c) delivered water density to the burning surface.

Problem: An optimum sprinkler system, for a given application, suppresses the fire in the shortest time after its initiation. The design of such a sprinkler system depends on the geometrical relationship between the sprinkler(s) and the fire source, the heat release rate of the fire and the sprinkler spray characteristics. To save the expense and complexity of full-scale experiments currently required for just evaluating sprinkler systems for different fire configurations, computer models are needed

Approach: Well-instrumented, laboratory-scale experiments are being performed using various scaled pendent sprinklers. High-resolution, large-scale planar photographs are taken for both drop size distribution and drop velocity measurements using a double-pulsed PIV laser. Experiments are conducted to characterize the sprinkler sprays without the fire plume and the sprinkler-induced air flows. Measurements of drop size and velocity near the sprinkler are used to develop a sprinkler scaling criteria which is tested by measured delivered density. Experiments for studying the interaction of the sprinkler sprays with the fire plume will be conducted after the sprinklers and sprinkler-induced air flows are better understood. These experiments will provide the data for validation of theoretical models.

Recent Results:

Atreya, Arvind, "Droplet Distribution, Scaling and Delivered-Density Measurements in Reduced-Scale Sprinklers", *Fire Safety Journal*, (submitted).

Fire Safety Engineering

Principal Investigator:
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Sponsor: National Institute of Standards and Technology

Objective: To investigate fire safety engineering concerns associated with: a) properties characterization and performance evaluation of fire protection foams; b) ignition and burning of heavy oil emulsion on water; c) critical literature review, experiments and modeling of two-dimensional fire sources; and d) integration of CFAST with existing models for the analysis of complex wall assemblies.

Problem:
Fire Protection Foams. The most common active methods to mitigate and contain large industrial and petrochemical fires encompass water sprays and water films. An integrated approach to identify cost-effective, environmentally-safe agents and their application strategies are sought. In particular, the performance of water based foams, used in recent wild-fire in suburban settings to protect residential structures, is investigated.
Oil Spill. The environmental impact of oil spills at sea is mitigated by igniting and burning the spill. Ignition and flame spread characteristics of different crude oils in their natural state, weathered and emulsified is characterized . A standard test based on a modified HIFT apparatus is used to estimate the combustion self sustained capability. This project is directed by J. Torero (FPED-UMCP).
Two-Dimensional Fire Sources. The synthetic representation all the available data on point sources as well as on line sources at different burner aspect ratio is pursued. The objective is to derive a universal formulation of temperature and flame height for finite line fires. This project is directed by J. Quintiere (FPED-UMCP).
Thermal and Structural Response of Complex Wall Assemblies. The development of a more realistic model for existing compartment fire models is pursued by validating a simple one-dimensional heat transfer algorithm which can be readily implemented in CFAST with the results of the SAFIR (i.e. a three-dimensional finite element code). This project is directed by J. Milke (FPED-UMCP).

Approach:
Fire Protection Foams. The performance of fire protection foams exposed to fire has been characterized in the previous grant period. Radiant heat absorption in the foam layer was found to be the dominant parameter in the foam destruction process. The density of the foam layer is also a strong function of fire exposure transient and the radiation extinguishment coefficient is dependent on the foam density. A quasi-steady stated model is formulated on these basis to predict the temperature profile within the foam layer. The results indicate that the radiation deposition term and the evaporation term are one order of magnitude larger than the thermal diffusivity and convective terms. Further, the foam density profile causes the radiant absorption to be maximum two-to-four centimeters in the depth of the foam layer.
Careful evaluation of the radiation extinction coefficient is conducted with a newly developed testing routine for various foam expansion ratios (i.e. the volume of the foam over the volume of the original liquid solution). A testing apparatus is also developed for the measurement of the thermal diffusivity as well as for the determination of the thermal expansion characteristics of a given foam. Enhancement of the foam fire resistance is obtained via the introduction of highly reflective pigments at the foam layer exposed surface. Application of small amounts of pigments (i.e. 1-2 % by weight) are shown to produce fire resistance enhancements of the order of 100 %. Optimal foam expansion ratios and pigments loading are evaluated within a broad testing program.
Oil Spills. An experimental technique has been developed to systematically study the ignition and flame spread characteristics of liquid fuels spilled on a water bed. The hardware used for the Lateral Ignition and Flame Spread (LIFT) standard test method (ASTM-1321) has been modified to allow the used of liquid fuels deposited on water.

Flammability diagrams are obtained for different fuel characteristics typical of oil spills and for different of oil spill thickness. These flammability diagrams provide a number of essential parameters such as critical heat flux for ignition, ignition delay time and flame spread velocity as a function of the external heat flux. A series of fire properties corresponding to each fuel can also be deduced from the flammability diagrams and can be used to quantify the tendency of the fuel to ignite and to sustain flame spread.

Recent Results:

Boyd, C.F. & diMarzo, M., 1998, *The Behavior of a Fire-Protection Foam Exposed to Radiant Heating,* International Journal of Heat and Mass Transfer, in press.

Tafreshi, A.M., diMarzo, M. & Madrzykowski, D., 1998, *Foam and Gels as Fire protection Agents*, Fire Safety Journal, submitted.

Wu, N., Kolb, G. & Torero, J.L., 1998, *Piloted Ignition of a Slick of Oil on a Water Sublayer: The Effect of Weathering*, Combustion Institute Symposium, submitted.

Quintiere, J.G., & Grove, B.S., 1998, *A Unified Analysis for Fire Plumes*, Combustion Institute Symposium, submitted.

Tafreshi, A., di Marzo, M., Stubbs, L. & Floyd, R., 1997, *Characterization and Evaluation of Fire Protection Foams*, 2nd International Conference of Fire Research and Engineering, NIST, August 10-15.

Tafreshi, A., di Marzo, M., Stubbs, L., & R., Floyd, R., 1997, *Performance Enhancement Techniques for Fire Protection Foams by Utilizing Reflective Pigments*, 2nd International Conference of Fire Research and Engineering, NIST, August 10-15.

Wu, N., Baker, M., Kolb, J. & Torero J.L., 1997, *Ignition and Flame Spread Characteristics of Liquid Fuels on a Water Bed,* 2nd International Conference of Fire Research and Engineering, NIST, August 10-15.

Large Fire Analysis

Principal Investigator:
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Sponsor: National Institute of Standards and Technology

Objective: To develop a modular post-earthquake and urban/wildland intermix fire growth model.

Problem: The following elements are currently envisioned of comprising our modular fire growth model:

1. The initial fire strength.
2. The plume above the initial fire.
3. The combined ambient and fire-induced flow field.
4. The initial distribution of brands.
5. The brand combustion, heat, and mass transfer.
6. The brand dynamics.
7. Interaction with ambient atmosphere and terrain.
8. Spread mechanisms other than spotting.
9. Fuel characterization and ignition.
10. The hardening/protection of a structure fire.
11. Window glass breakage.
12. Return to 1 with a new fire.

Approach: The study focuses on four problems: 1) quantification of the lofting of brands of all conceivable shapes, compositions, and conditions; 2) the time-varying characteristics of those brands as they combust while being transported; 3) the dynamics of the brand-wind plume interaction that determines the brand deposition distribution and the pattern of the downwind ignition sites; and 4) validation of a ground fuels flame spread model. The rich forest fire literature is being fully utilized; we rely on previous work by Tarifa, Albini, and Muraszew. Our experience with the 1991 Oakland Hills Fire, the 1993 Los Angeles fires, and the 1995 Kobe post-earthquake fires provide specific case studies for the application of these models. Because of the analog between structural rubble piles and forest wood/brush piles as brand sources, this model is also capable of assessing possible post-earthquake conflagrations. Our experience working the the Baum-McCaffrey mass fire model provides the starting point for the brand lofting study. Spherical, cylindrical, and disk-shaped brands in combusting and non-combusting, maximum drag and tumbling modes are being analyzed theoretically and experimentally. We are imbedding brands in the large-scale eddy simulation plume model ALOFT to identify downwind brand-deposition contours.

Recent Results:

Mongia, P. Pagni, and D. Weise, "Model Comparisons with Simulated Wildfire Flame Spread Data," *West Coast Section/Combustion Institute - Paper 98S-68*, 1998.

Woycheese, P. Pagni, and D. Liepmann, "Brand Propagation from Large-Scale Fires," *Journal of Fire Protection Engineering*, in press.

Pagni, "Activation Mechanism of Glass Vial Sprinklers," *Journal of Fire Protection Engineering*, 1997, in press.

Woycheese, P. Pagni, and D. Liepmann, "Brand Lofting above Large Scale Fires," *Proceedings of the Second International Conference on Fire Research and Engineering, Society of Fire Protection Engineers*, Gaithersburg, MD, August 1997.

Trelles and P. J. Pagni, "Fire-Induced Winds in the 20, October 1991 Oakland Hills Fire," *Fifth International Symposium on Fire Safety Science*, Australia, March 1997.
A. Dembsey, P. J. Pagni, and R. B. Williamson, "Compartment Fire Experiments: Comparison to Models," *Fire Safety Journal*, 25:3, pp. 187-227, 1996.

J. Pagni, "Zukoski's Intellectual Progeny in Fluid Mechanics of Fires," *13th Meeting of the UJNR Panel on Fire Research and Safety,* Gaithersburg, MD, March 1996.

Woycheese, "Brand Lofting in Large Scale Fires," *Masters Thesis*, Mechanical Engineering Department, University of California at Berkeley, December 1996.

FIRE SCIENCE

ADVANCED FIRE MEASUREMENTS

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Improvement and Development of Fire Diagnostics

Principal Investigator: William M. Pitts, Fire Science Division, 301-975-6486

Sponsor: National Institute of Standards and Technology

Objective: To improve the capabilities to quantitatively characterize fire behavior using experimental measurement techniques having reliable estimates of accuracy and precision.

Problem: As the understanding of fire behavior and modeling has advanced, the need for quantitative characterization of fire properties has increased dramatically. Not only are such measurements required to improve the understanding of fire physics and chemistry, but detailed measurements are needed to validate the zone and field models which are being developed to predict fire behavior. Meanwhile, nearly all measurement techniques currently employed for fire characterization have been in use for several decades and have generally not incorporated the great strides made in instrumentation and data acquisition abilities. Compounding the problem, currently used techniques are subject to systematic and random errors which have not been adequately characterized.

Technical Approach: During FY1998, BFRL will perform two tasks. In task 1, work centers on assessing many of the currently used methods for characterizing fire properties (e.g., temperature, composition, velocity, heat release rate, radiation, and smoke mass fraction) and where appropriate, based on analysis and suitable testing, recommend modifications which will improve both precision and accuracy. In task 2, researchers will perform a systematic program of investigating potential new fire diagnostics and developing practical systems for implementation.

Recent Results:

Mulholand, G. W., Choi, M. Y., (University of Illinois, Chicago), "Measurement of the Mass Specific Extinction Coefficient for Acetylene and Ethene Smoke Using the Large Agglomerates optics Facility," accepted for publication in the Proceedings of the 27th Symposium (International) on Combustion.

Sprinkler Drop Size and Velocity

Principal Investigator: Linda G. Blevins, Fire Science Division, 301-975-3904

Sponsor: National Institute of Standards and Technology

Objective: To evaluate measurement methods for sprinkler sprays; measure drop size and velocity distributions for an existing sprinkler, evaluate the capabilities and limitations of the optical array probe, and provide information about the appropriateness of this technique and others for future measurements.

Problem: The ability to accurately predict large-scale fire test results for BFRL's Industrial Fire Simulator relies heavily on the calibration of a sprinkler computer sub-model which employs information about the distributions of water drop sizes and drop velocities. The measurements are challenging because the range of drop sizes is large (from ~10 mm down to ~5 m m) and sensitive instrumentation must be protected from large amounts of flowing water (~50 GPM typical).

Technical Approach: During FY1998, BFRL researchers will collaborate with sprinkler experts at a testing laboratory to map the drop size and velocity distributions in a fire-safety sprinkler using an optical array probe. The instrument will be evaluated and its uncertainty and limitations will be identified. Other droplet measurement techniques used in the agricultural community and in the atmospheric community (for determining raindrop size distributions) will be identified and their appropriateness for fire-sprinkler measurements will be analyzed. The findings will be summarized in a written report.

Recent Results: New Project.

Characteristics and Identification of Super-Effective Thermal Fire- Extinguishing Agents

Principal Investigator: William M. Pitts, Fire Science Division, 301-975-6486

Sponsors: National Institute of Standards and Technology

Department of Defense
Strategic Environmental R&D Program

Objective: To assess the feasibility of candidate thermal fire extinguishing agents and their properties to halon 1301.

Problem: The manufacture of the halons which were widely used for fire-fighting purposes has been banned. The search for equally effective replacement agents has met with limited success. There is a need for new approaches to identify agents having high potential for these applications.

Technical Approach: During FY1998, BFRL will conduct a systematic search of data bases to identify compounds based on their ability to extract large amounts of heat from a high temperature system and perform modeling to assess the expected thermodynamic and kinetic properties which serve to enhance the effectiveness of a potential agent. Researchers will perform an assessment of the feasibility of identifying super-effective agents. If effective thermal agents appear possible, BFRL will select potential super-effective agents by a more careful data-base search and analysis using the developed modeling approaches. The approaches will be tested using appropriate laboratory-scale tests of fire extinguishing capability. If these screening tests confirm the expectation, the chemicals will be assessed against physical properties, toxicity, storage stability, and properties and toxicities of any breakdown products for the potential agents and develop a list of the desirable properties of these chemicals and specific chemicals being recommended for additional examination.

Recent Results: New Project.

Fast Response Species Characterization During Flame Suppression

Principal Investigator: George W. Mulholland, Fire Science Division, 301-975-6689

Sponsor: National Institute of Standards and Technology

Department of Defense
Strategic Environmental R&D Program

Objective: To develop new instrumentation for measuring agent concentration during a release with a 10 ms time response, fast enough to follow the fastest fires experienced in current weapon systems.

Problem: The suppression event is a transient one taking place over a time scale of 10 ms to a few seconds, depending on whether the fire is a dry bay, a crew compartment, or an engine nacelle. The current state of the art is a 250 ms time response for the Halonyzer. Instrumentation is needed with a 10 ms time response for the real-scale tests to obtain solid performance measurements, explanations of anomalous behavior, and to verify test methods and computational models.

Technical Approach: During FY1998, BFRL will:

1. Modify the Differential Infrared Rapid Agent Sensor (DIRRACS) to remove the previously observed dependence of the instrument on the flow velocity;
2. Perform absolute calibration of the instrument for CO_2 and at least one other fire suppressant compound;
3. Perform laboratory tests using the wind tunnel pool fire;
4. Perform real-scale tests using the facilities at the Aberdeen Test Center;
5. Develop a water-cooled, air-purged fiber optic probe capable of operating and maintaining optical alignment at temperatures up to 900 °C, and verify performance of probe in real-scale tests;
6. Document the apparatus, operation procedures and experimental results.

Recent Results: New project.

Carbon Monoxide Production and Prediction

Principal Investigator: William M. Pitts, Fire Science Division, 301-975-6486

Sponsor: National Institute of Standards and Technology

Objective: To develop a fundamental understanding of the mechanisms of carbon monoxide formation in flames sufficient to produce a detailed predictive model.

Problem: CO generated by fires in enclosures is responsible for roughly two-thirds of fire deaths. The conditions necessary and the mechanisms responsible for the generation of high concentrations of CO are poorly characterized. Recent efforts have developed a predictive capability for the yield of CO exiting a room when the fire has passed the point of flashover, the most important fire condition. However, experiments have shown that further generation or destruction may occur outside the door. Thus, the current state of CO prediction may or may not be conservative.

Technical Approach: . During FY1998, BFRL will continue its research to develop a comprehensive prediction of carbon monoxide formation in enclosure fires. The work will include both fundamental and engineering investigations. Research under a grant to the Virginia Polytechnical Institute State University is producing additional insights into changes in CO concentrations outside the room of fire origin.

Recent Results:

Identified four mechanisms which are responsible for the formation of CO within an enclosure containing a fire and incorporated them into an algorithm designed to allow the user to identify which mechanisms are important for a given fire and to provide guidance on estimating the amounts of CO generated.

Particle Measurement in Support of the Semiconductor Industry

Principal Investigator: George W. Mulholland, Fire Science Division, 301-975-6695

Sponsor: National Institute of Standards and Technology

Objective: To develop a facility for accurately measuring particle size/concentration.

Problem: The detection, quantification and characterization of particulate contamination on semiconductor surfaces is essential to advanced semiconductor manufacturing. The present practical limit for particle detection is 100 nm diameter. The National Technology Roadmap for Semiconductors calls for the ability to detect and quantify particles with a 60 nm diameter by 2001. There is currently a need for accurately sized monosize particles in the size range from 60 to 200 nm for developing and calibrating improved scanning surface inspection systems.

Technical Approach: During FY 1998, BFRL will perform work that will accurately size 80 nm spheres and measure the width of the size distribution of particles in the size range of 70 to 100 nm in support of the Duke Scientific RADA. Researchers will adapt an electrical spray system developed at TSI and the University of Minnesota for the production of a constant output polystyrene sphere aerosol with sizes as small as 30 nm and with little contamination from nonvolatile impurities in the water. The smallest size possible with current spray technology is about 70 nm.

Recent Results:

Modified the aerosol inlet, which sets the stage for higher resolution size distribution measurements, and improved the aerosol generator and the software for analyzing the DMA data.

FIRE SCIENCE

FIRE SENSING AND EXTINGUISHMENT

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Fire Suppression Chemistry

Principal Investigator: Gregory T. Linteris, Fire Science Division, 301-975-2283

Sponsor: National Institute of Standards and Technology

Objective: To develop an understanding of how particles which form in a flame inhibited by $Fe(CO)_5$ act to influence the extinction process and develop the next generation of suppression agents and technologies.

Problem: Fire suppressants and their application methods should be effective, fast-acting, economical, have low toxicity, permit a habitable environment during suppression, and cause no collateral damage to the protected space. Existing suppressants, however, are non-ideal for various reasons. There exists a continuing need for better suppressants and suppression methods, but limited scientific understanding of existing chemical inhibitors hinders development of new agents. Some chemical inhibitors have been found to be up to 100 times more effective than CF_3Br in inhibiting premixed hydrocarbon-air flames. Nonetheless, their mechanism of inhibition is not clearly understood.

Technical Approach: During FY1998, BFRL will study the behavior of $Fe(CO)_5$ in detail so an understanding of its extraordinary effectiveness can help in the search for new agents. BFRL researchers will investigate the particles formed in $Fe(CO)_5$-inhibited flames using two complimentary methods: 1) laser light scattering and extinction, and 2) thermophoretic sampling. In addition, BFRL will conduct additional premixed and diffusion flame experiments to isolate the effects of temperature and inhibitor mole fraction on the suppression effectiveness. Numerical modeling will be performed to estimate effectiveness of condensed phase particles on radical recombination.

Recent Results:

Linteris, G. T., Burgess, D. R., Babushok, V., Zachariah, M. R.,Westmoreland, P. R., and Tsang, W., "Inhibition of Premixed Methane-Air Flames by Fluoroethanes and Fluoropropanes," accepted for publication in *Combustion and Flame*, July 1997.

Babushok, V., Tsang, W., Linteris, G. T. and Reinelt, D., "Chemical Limits to Flame Inhibition," submitted to *Combustion and Flame*, Feb. 1997.

Reinelt, D., Babushok, V., and G.T. Linteris, "Numerical Study of the Inhibition of Premixed and Diffusion Flames by Iron Pentacarbonyl," *Eastern States Section Meeting/The Combustion Institute*, S. Carolina, Dec., 1996.

Babushok, V., Tsang, W., Linteris, G.T., and Reinelt, D. "Chemical Limits to Flame Inhibition," *Eastern States Section Meeting/The Combustion Institute*, S. Carolina, Dec., 1996.

"Numerically predicted flame structure and burning rates of premixed CO-Ar-O_2-H_2 flames inhibited by CF_3H," *Combustion and Flame*, 107, pp. 72-84, 1996.

Low Environmental Impact Fire Suppression

Principal Investigator: William Grosshandler, Fire Science Division, 301-975-2310

Sponsor: National Institute of Standards and Technology

Objective: To facilitate the development and adoption of promising low environmental impact fire suppression technologies by: (1) establishing scientifically defensible test methods for evaluating the fire suppression performance of proposed alternatives, and (2) supplementing research in the Next Generation Program (NGP).

Problem: Currently fielded technologies for suppressing fires can adversely effect the local or global environment. Proposed halon alternatives containing chlorine or iodine have a non-zero ozone depletion potential; fluorine containing alternatives may have very long atmospheric lifetimes. Other approaches to fire protection such as inert gas, powder or aqueous systems are not without occupant risk or have features that make them less desirable from an operational standpoint. Development of new technologies is hampered by a lack of understanding of new chemical routes to flame extinction and the physical processes controlling dispersion, and by the absence of metrics for establishing agent/system effectiveness.

Technical Approach: During FY1998, BFRL will perform an assessment of the state of understanding of droplet and spray dynamics to identify (a) appropriate existing models, and (b) areas where new phenomenological sub-models are required for meaningful CFD and zone-type predictions of physical suppression processes (up to the point of significant flame/suppressant interactions). New test methods will be developed, in collaboration with the telecommunications industry and NFPA 2001, to quantify the impact of an energy source on the amount of a gaseous suppressant required to control a class-C fire.
BFRL's research for the NGP will focus on:

1. Development of screens for aerosol and gas generator-based agents;
2. Review methods used to predict negative interactions between the suppressant and man, matter, and the environment;
3. Investigate potentially high efficiency thermal suppressants;
4. Develop new instrumentation for measuring agent concentration;
5. Determine potential for nozzle design to increase dispersion of liquid suppressants;
6. Determine the relation between suppressant application and the flare-up of pool fires.

Recent Results:

Grosshandler, W., and Gmurczyk, G., "Suppression of High Speed Flames and Quasi-detonations," in *Fire Safety Science -- Proceedings of the Fifth International Symposium*, accepted for publication, 1997.

King, M., Yang, J., Chien, W., and Grosshandler, W., "Evaporation of a Small Water Droplet Containing an Additive," ASME National Heat Transfer Conference, Baltimore, August 1997.

Braun, E., Womeldorf, C., and Grosshandler, W., "Determination of Suppression Concentration for Clean Agents Exposed to a Continuously-energized Heated Metal Surface," Halon Options Technical Working Conference Proceedings, Albuquerque, May 1997.

Chien, W., Yang, J., King, M., and Grosshandler, W., "Evaporation of a Small Aqueous Suppressing Agent Droplet," Annual Conference on Fire Research: Book of Abstracts, K. Beall, editor, NISTIR 5904, National Institute of Standards and Technology, October 1996.

Dispersed Liquid Agent Fire Suppression Screen

Principal Investigator: Jiann C. Yang, Fire Science Division, 301-975-6662

Sponsor: Department of Defense
Strategic Environmental R&D Program

Objective: To develop a bench-scale suppression screen suitable for comparing the performance of dispersed fluids in extinguishing a laboratory-scale flame.

Problem: Halon 1301 (CF_3Br) has properties that make it particularly effective as a fire extinguishing agent. In addition to the chemical activity attributable to the bromine atom, halon 1301 is a gas at room temperature and pressure. It is stored as a liquid under high pressure making it superheated at atmospheric conditions. When discharged, halon 1301 flashes to a gas and quickly disperses throughout the volume being protected. Replacements are sought which perform equally well in applications critical to the Department of Defense. This project will contribute to the overall goal of attaining effective, environmentally responsible alternatives to the ozone depleting substance, halon 1301.

Technical Approach: During FY1998, BFRL will select fluids that span a variety of anticipated operating conditions. These include pure water; water plus an additive (dissolved gas or salt); a low viscosity non-aqueous, zero ODP fluorocarbon (e.g., C_6F_{14}); and a high viscosity, higher boiling point compound (unspecified). They will be suspended in air streams at modest velocities and transported to a propane diffusion flame. Gaseous agents also will be used to characterize and calibrate the performance of the burner. This will allow comparisons of the performances of gaseous agents with those of aerosols.
Two different methods of generating aerosols are envisioned. For larger, close-to-mono-dispersed aerosols (25 to 250 μm), a multiple orifice piezoelectric droplet generator will be built. The literature will be scanned to identify candidate techniques for generating droplets in the 0.25 to 25 μm range. Aerosols generated in these manners can be introduced directly into the burner air stream. However, no existing technique may be suitable for some fluids such as slurries, emulsions, or chemically-generated aerosols. A separate aerosol chamber will be needed in which high concentrations of agent can be produced using whatever technique is envisioned in practice. The aerosol will be transported from the generating chamber to the burner where it can be metered into the air stream. Extinction experiments will be conducted with and without obstacles in the air stream just ahead of the flame. This will further complicate the flow but may be necessary to more closely emulate a cluttered environment.

Recent Results:

Constructed a laboratory flow facility, a vertical wind-tunnel, and a porous cylindrical burner.

Combustion of a Polymer (PMMA) Sphere in Microgravity

Principal Investigator: Jiann C. Yang, Fire Science Division, 301-975-6662

Sponsor: National Aeronautics and Space Administration
Lewis Research Center

Objective: To determine the burning rates of PMMA spheres in a low gravity environment under various ambient oxygen conditions and using various sphere sizes.

Problem: The need to use polymeric materials that may be flammable cannot be totally eliminated aboard the space shuttle or the future manned permanent space-station. This study is pertinent to the problem associated with the potential fire threat caused by the presence of polymeric materials. The use of spherical geometry has many advantages because a spherical flame, which is one-dimensional, is amenable to simple mathematical analysis and facilitates a detailed examination of the many interesting phenomena associated with the combustion of a solid phase material without involving the complications of flame-spread, which is still an active research area.

Technical Approach: During FY1998, BFRL will perform fire experiments involving polymetric materials in low gravity aboard the NASA Reduced Gravity KC-135 Aircraft. The sphere will be ignited using a pair of heating coils. Experiments using suspended spheres will be conducted. Suspended spheres will be obtained by supporting the spheres using a 75 μm wire. Results will be compared with those obtained under normal gravity condition. A global combustion model will be developed to facilitate data analysis.

Recent Results:

Yang, J.C., Hamins, A., Glover, M., and M. King, "Experimental Observations of PMMA Spheres Burning at Reduced Gravity," *Fourth International Microgravity Combustion Workshop*, Cleveland, Ohio, May 1997.

Chemical Inhibitor Effects on Diffusion Flames in Microgravity

Principal Investigator: Gregory T. Linteris, Fire Science Division, 301-975-2283

Sponsor: National Aeronautics and Space Administration
Lewis Research Center
Space Systems Branch

Objective: To determine the effects of flame inhibitors on the physical characteristics and stability limits of gaseous diffusion flames in the presence of halogenated fire suppressants in microgravity; and to develop quantitative analytical models for the observed behavior, including chemical kinetic effects, in order to understand the mechanisms of inhibition of halogenated compounds in gaseous diffusion flames in microgravity.

Problem: Fire safety in space is one of the main reasons to investigate combustion phenomena in microgravity. Since halogenated compounds will remain the fire suppressant of choice in many space missions, there is a need for experimental evidence on the effectiveness of these compounds for diffusion flames under zero buoyancy conditions.

Technical Approach: During FY1998, BFRL will perform experiments consisting of normal and microgravity studies of laminar jet and co-flow diffusion flames inhibited by halogenated suppressant in the air or fuel stream. In microgravity, visual and temperature diagnostics will be used to detect flame shape, dynamics, and stability limits (ignition, extinction, lift-off and blow-off). Normal gravity experiments will use additional chromatographic and spectroscopic diagnostics in addition to visual and temperature experiments. Analytical and computational work will be performed using existing general 2-D codes with chemical kinetic models for comparison with the observed results.

Recent Results:

VanDerWege, B.A., O'Brien, C.J., and Hochgreb, S.,"Quantitative Shearography In Axisymmetric Gas Temperature Measurements", Applied Optics, submitted July 1997.

Payload Specialist on STS-83/94

Principal Investigator: Gregory T. Linteris, Fire Science Division, 301-975-2283

Sponsor: National Aeronautics and Space Administration
Marshall Space Flight Center

Objective: To perform post-flight debrief and appearance duties as required by NASA to fulfill the mission objectives.

Recent Results:

Duties successfully performed as required.

Lean Flammability Limit as a Fundamental Refrigerant Property, Phase III

Principal Investigators: William Grosshandler, Fire Science Division, 301-975-2310
Carole Womeldorf, Fire Science Division, 301-975-4415

Sponsor: Air-conditioning and Refrigeration Technology Institute.

Objective: To provide industry with a high precision, repeatable method for measuring flame limits based upon a counter-flow burner design.

Problem: CFCs have been phased out of production for use as refrigerants because of their destructive effect on stratospheric ozone. Replacing halogen atoms in the molecule with hydrogen atoms can transform a nonflammable CFC into a potentially flammable material. The efficiency and flammability of R-32 and other alternative refrigerants must be carefully balanced in mixtures to provide safe and environmentally friendly refrigerants. ASTM Standard E 681-94 identifies test equipment and methods for measuring the flammability limits. For strongly flammable gases it provides a well defined limit of flammability; however, for weakly flammable alternative refrigerants, the test method gives results with a larger uncertainty due to its sensitivity to ignition conditions, wall quenching effects, and operator interpretation of the flammable condition. This ambiguity hinders attempts to optimize the efficiency and safety of alternative refrigerant mixtures.

Technical Approach: During FY1998, BFRL will perform work to determine the effect on the zero-strain limit by varying nozzle spacing and geometry and to confirm that the design chosen for the BFRL burner is appropriate for the purposes of the refrigeration industry. The opposed flow burner will be modified to operate at inlet gas temperatures up to 100 °C. Measurements of the lower flammability limit of R-245ca in air at room temperature and 100 °C will be attempted using the extrapolation-to-zero-strain approach developed in Phase I. If a stable flame can not be obtained, the initial conditions will be varied to enhance the combustion process. A new burner and flow control system will be designed for industrial use and an operating procedure formalized based upon experience with the current BFRL burner.

Recent Results:

Womeldorf, C., and Grosshandler, W., "Flame Extinction Limits in CH_2F_2/air Mixtures," submitted to *Combustion and Flame*, May 1997, (under revision).

Womeldorf, C., Grosshandler, W., and King, M., "Refrigerant Flammability: A New Application of the Opposed-flow Burner," Eastern States Section Combustion Institute, Hilton Head, Dec. 1996.

Multi-function Building Environment Sensing Evaluator

Principal Investigator: William Grosshandler, Fire Science Division, 301-975-2310

Sponsor: National Institute of Standards and Technology

Objective: To permit fire and indoor air quality sensor designers to demonstrate the feasibility of new concepts, and to provide the critical link between sensor input and output required for meaningful numerical simulations

Problem: Current test protocols and certification processes have been developed to accommodate specific fire sensor technologies. In the past, sources used in these test methods were optimized for a unique fire or smoke property to quantify detector response. Very little has been done to determine the impact of test methods on the development of innovative IAQ sensors. To improve detection sensitivity and reduce inappropriate responses, industry has developed new sensors. Some designs are based on the measurement of different aspects of the fire source than those traditionally evaluated by current test methods. Other designs are based on specific combinations of sensors that can help in distinguishing a real fire source from a false reading. Existing test methods may not be able to evaluate and quantify the performance of new sensing methods or multi-detector systems for fire detection or IAQ monitoring.

Technical Approach: During FY1998, BFRL will perform the following tasks:

1. Identify the parameters that define the environment (normal/abnormal air quality, fire/non-fire);
2. Quantify their levels (average, variance, rate of change) under normal and upset conditions;
3. Design, fabricate, and evaluate a physical environment simulator;
4. Measure the response of different sensor types to simulated field environments representing normal, hazardous and likely nuisances.

A fire protection systems industry workshop will be held to review progress and to develop a strategy for quantifying interfering environments which lead to nuisance alarms. The potential for synergism between fire sensing and IAQ sensing will also be explored. The fire-emulator/detector-evaluator (FE/DE) currently under development will be used to examine the issue of smoke/gas detection in close-to-stagnant regions in a room or air duct, and a means to measure the effective diffusivity through the detector body to the sensing element will be developed. Sensor input/output data will be provided in a form amenable to further analysis by those responsible for developing an algorithm for detector response.

A similar approach will be used in the area of IAQ sensing. The levels of carbon dioxide, carbon monoxide, water vapor, and organics such as formaldehyde are of direct interest for both managing indoor air quality and detecting the presence and growth of an unwanted fire; hence, they are good candidates for multi-function building . The literature will be examined to glean what is known about indoor and outdoor concentrations of these species. An IAQ sensing industry workshop will be held to identify the state of the technology, the opportunities for sharing information among fire and other building control systems, and the advantages and barriers hindering the adoption of emerging technologies such as micro-electronic gas sensor arrays, MEMS, and wireless communication sensing.

Recent Results: New project.

Technical Support for the Study of Droplet Interactions with Hot Surfaces

Principal Investigator: Jiann C. Yang, Fire Science Division, 301-975-6662

Sponsor: Department of Defense
Strategic Environmental R&D Program

Objective: To provide technical support for the study of the dynamics of droplet/surface interaction and its effect on burning cessation in the DoD program.

Problem: Fundamental understanding of how small droplets and particles interact with burning surfaces at different temperatures characteristic of current weapon systems is lacking and is needed for identifying, evaluating, and optimizing fire suppression systems using droplets or particles.

Technical Approach: During FY1998, BFRL will conduct a survey on suppressant fluids and compile a list based on the information from ARL, NRL, AFRL, NMERI, and chemical manufacturers. The extensive NIST property database will be searched for thermophysical properties of these fluids. If they are not available, these properties will be estimated. Laboratory visits and frequent discussion with other Principal Investigators on technical issues will be carried out to achieve collaborative and concerted effort. If needed by other PIs, single droplet/surface interaction experiments will be performed. A piezoelectric droplet generator or a small gage hypodermic needle, depending on the desired droplet diameter, will be used for droplet generation. Droplet impact dynamics will be speed movie camera.

Recent Results: New project.

High Heat Flux Measurement Standards

Principal Investigator: William Grosshandler, Fire Science Division, 301-975-2310

Sponsor: National Institute of Standards and Technology

Objective: To characterize the capabilities of the convective heat transfer facility for calibrating heat flux gauges, to complete a gas phase conduction facility for calibrations up to 100 kW/m^2, and to develop for industry new techniques for applications to critical technologies.

Problem: Standard methods exist for calibrating thermal radiation detectors at flux levels extending to 10 kW/m^2 using controlled blackbody cavities, and up to 40 kW/m^2 using a monochromatic laser radiation source. However, heat flux transducers are often used under conditions where convection is dominant, where radiation emanates from a source with different spectral character, or where the flux levels exceed 40 kW/m^2.

Technical Approach: During FY1998, BFRL will complete an experimental facility consisting of a wind tunnel with a heated wall in which a heat flux transducer can be flush mounted. Air at a cooler temperature will flow through the duct in a precisely controlled manner. The gas temperature and velocity will be variable, with heat fluxes at the surface designed to be preset between 0.5 and 5.0 kW/m^2 within an uncertainty of less than " 5%. Flow visualization, hot-wire probing, thermocouples, and temperature sensitive liquid crystals will be used to measure the temperature fields in the air and on the surface adjacent to the flux gauge. Numerical simulations will be performed by co-workers in NIST's Chemical Science and Technology Laboratory and in its Electronics and Electrical Engineering Laboratory of the energy transfer to refine the design and minimize uncertainties. In a second facility, the guarded hot-plate concept will be extrapolated to produce heat fluxes up to 100 kW/m^2. A 1.0 mm thick layer of helium will separate two flat, polished copper plates maintained at a temperature difference of several hundred degrees. This type of construction should minimize the contribution of radiation and convection to the conductive heat transfer.

Recent Results:

Grosshandler, W., and Blackburn, D., "Development of a High Flux Conduction Calibration Apparatus," invited presentation at the ASME International Mechanical Engineering Congress and Exposition, Dallas TX, November 1997.

Steckler, K., Holmberg, D., and Womeldorf, C., "Facility for Calibrating Heat Flux Sensors in a Convective Environment," invited presentation at the ASME International Mechanical Engineering Congress and Exposition, Dallas TX, November 1997.

Steckler, K., "NIST Heat Flux Competence Project," presentation to ISO TC92/SCI Task Group Heat Fluxmeter Calibration Meeting, Boras, Sweden, October 1996.

Screening of Transient Agent Effectiveness (3A/2)

Principal Investigator: William Grosshandler, Fire Science Division, 301-975-2310

Sponsor: Department of Defense
Strategic Environmental R&D Program

Objective: To develop a bench-scale suppression screen suitable for comparing the performance of gas generators and other extinguishing fluids applied in a transient laboratory-scale flame.

Problem: Some applications of fire suppression require the agent to be supplied to the threatened space in less than a second to ensure adequate protection against a fast growing flame. Alternatives to halon 1301 include a number of gas generator concepts. Current bench-scale suppression effectiveness screens are limited to quasi-steady applications, and are unable to evaluate adequately the highly transient effects of sudden agent addition. Also, recirculating flows and hot surfaces can lead to situations more difficult to control and the possibility of the fire re-lighting. The problems addressed in this project are how to simulate a stable recirculating zone, and how to provide a realistic re-ignition source that is repeatable, and that will lead to an unbiased evaluation of different transient suppression approaches and agents.

Technical Approach: During FY1998, BFRL will construct a 0.1 m by 0.15 m wind tunnel with a capability for visualizing the flow over a cavity in which gaseous propane or liquid pool fires are stabilized. A hot surface downstream of the fire will be included to act as a re-ignition source. Computational fluid dynamics modeling will be performed and bench-marked against velocity, temperatures and the general flame shape, and a stability map of the flame as a function of geometric and flow parameters will be generated. A suppression delivery system will be designed and fabricated to produce a controlled, rapid release of a gaseous or powdered agent, and which will accommodate small quantities of solid propellant gas generating materials. The required mass, rate and duration of agent delivery to extinguish fires under standard conditions will be determined for the materials being considered, along with each agent's susceptibility to re-ignition on the hot surface. The design parameters and choice of agents will be based upon the results from other parts of the NGP effort (1A/1, 2C/7 and 5D/1 in particular). A portion of the funds ($25k) will be used by the PI to support his TCC obligations.

Recent Results: New project.

An Integrated Assessment of Performance-Based Design for Buildings

Principal Investigator: Kathy A. Notarianni, Fire Science Division, 301-975-6883

Sponsor: National Institute of Standards and Technology

Objective: To develop an integrated assessment model that demonstrates the value added to society from the development and implementation of performance-based fire and building codes under various legal, economic, political, and technological frameworks.

Problem: It has been theorized that a performance standard will provide for an equal or greater level of safety at an equal or lower cost. This theory is validated intellectually by a mental exercise where it is postulated that forced adherence to many prescribed code regulations is wasteful since it is unlikely that all buildings will benefit from the full application of all prescriptions. A performance standard would state an objective and allow for individual building designs to meet that objective in ways unique to the building. Based on this theory, many countries have developed and adopted performance-based codes and standards for buildings, including fire protection. The United States is currently working on both a performance building code (through ICC) and a performance fire code (through ICC and NFPA). Involved in this process are many organizations including building owners, architects, fire protection engineers, and AHJ. External factors such as economics, responsibility, liability, technical predictive ability, and public policies will determine the effectiveness of a performance-based code and the value added to society by the performance-based code. These external factors are unique to each body of government. A model of this complex scenario is needed to answer the following questions: 1) Can performance-based codes add value to society?; 2) What policies need to be in place for performance codes to be effective in the United States ?; 3) What areas of technology investment most heavily support performance-based design?

Technical Approach: During FY1998, BFRL will begin a multi-year effort to build a complex integrated assessment model to calculate the value added to society from a performance-based code. This model will: 1) Test policy statements; 2) Determine the impact of new technologies; 3) Determine the value of additional information; 4) Determine the impact of uncertainty in fire protection engineering design; 5) Evaluate other types of regulatory reform.

During FY1998, BFRL will identify current social, economic, political, and technological megatrends (national and global) that could effect implementation of performance-based codes. A search of the international literature will be conducted to identify regulations adopted by other countries and to evaluate effectiveness of these regulations in light of their unique external framework. A list of all the parameters that can affect the value added from a performance-based design and associated reasoning will be generated. Quantitative and qualitative methods will be used to determine a crucial sub-set of parameters to be modeled. The model will make explicit the importance of each parameter and the relationship between the parameters.

It is expected that one crucial parameter will be technical predictive ability. Technical/ engineering issues addressed in this research will be methodologies to allow for predictions for design, and the ability to verify that a given design meets performance objectives. It is known that there is a large degree of uncertainty associated with current predictive tools; therefore, a method of identifying, quantifying, and propagating uncertainty in a performance-based design will be established for fire protection engineers.

Recent Results: New project.

FIRE SCIENCE

MATERIALS FIRE RESEARCH

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New Flame Retardant Principles

Principal Investigators: Takashi Kashiwagi, Fire Science Division, 301-975-6699
Jeffrey Gilman, Fire Science Division, 301-975-6573
Marc Nyden, Fire Science Division, 301-975-692
Tinh Ngyuen, Building Materials Division, 301- 975-6718

Sponsor: National Institute of Standards and Technology

Objective: To develop and demonstrate successful application of new flame retardant principles for reducing the flammability of commodity polymers; to understand the flame retardant mechanism and their effect on physical properties of commodity polymers; and develop theoretical models to describe crosslink formation, mass loss rate, products composition, and relative heat release rate from polymer burning.

Problem: Many inexpensive, large volume commodity polymers have excellent physical properties. However, almost all of them are highly flammable. Therefore, flame retardant additives are commonly used in the end application when good fire performance is required. The development of new environmentally friendly, inexpensive flame retardant additives is expensive and time consuming for U.S. industry. Instead of the traditional trial-and-error approach, a more scientific approach, based on new flame retardant principles for reducing the flammability of commodity polymers, is needed for the industry to make fire safe, environmentally friendly end products. This requires appropriate, bench-scale methodology to determine relevant flammability properties of candidate materials and their relationship to fire performance of the specific end products made from these materials.

Technical Approach: During FY1998, BFRL will prepare clay-nanocomposites with delaminated and intercalated structure using organic modified montmorillonite clays. The flame retardant, mechanical, and rheological properties will be determined. Researchers also will determine the flame retardant mechanism of zirconia-borate additives. The organic polymers examined will include thermosets, engineering polymers, and thermoplastics. Also, a molecular dynamics model will be developed to describe the thermal degradation of commodity polymers with these potential flame retardant additives to determine the effects of the additives on thermal stability of the polymers and the formation of stabilizing crosslinks. These calculated results will be compared with the experimentally measured changes in the polymers with the additives during thermal degradation.

Recent Results:

Gilman, J., Kashiwagi, T., Lichtenhan, T., Flammability Studies of Polymer Layered Silicate Nanocomposites. 43rd SAMPE Symposium and Exposition, Preceedings, Anaheim meeting, May 1998.

Gilman, J., Lomakin, S., Kashiwagi, T., Giannelis, E., Manias, E., Lichtenhan, J., and Jones, P., Nanocomposites: Radiative Gasification and Vinyl Polymer Flammability, Fire Retardancy of Polymers : The Use of Intumescence, The Royal Society of Chemistry, Cambridge, in press (1998).

Nyden, M., Gilman, J., Molecular Dynamics Simulations of the Thermal Degradation of Nano-Confined Polypropylene, Computational and Theoretical Polymer Science, in press (1998).

Condensed Phase Processes

Principal Investigators: Takashi Kashiwagi, Fire Science Division, 301-975-6699
Thomas Ohlemiller, Fire Science Division, 301-975-6481
Kenneth Steckler, Fire Science Division, 301-975-6678
Kathryn Butler, Fire Science Division, 301-975-6673
Marc Nyden, Fire Science Division, 301-975-6692
Mary McKnight, Building Materials Division, 301-975-6714
Howard Baum, Fire Safety and Engr. Division, 301-975-6668

Sponsor: National Institute of Standards and Technology

Objective: To understand condensed phase processes during burning of polymeric materials by measuring thermal properties, gasification rates and temperatures in the polymer samples, by deriving global degradation kinetics from molecular dynamic calculation, by characterizing polymer residues, and to develop gasification model including heat and degradation products transport processes.

Problem: The gasification processes of polymeric materials during their burning are not well understood. It is not well understood how to model the effects of flame retardant additives on gasification rate of the polymeric materials by the formation of char, in situ formation of interference barrier near the surface, or other processes. Also, it is not well understood how to determine the transport process of degradation products through the polymer sample on gasification rate. And, thirdly, information is lacking about the effects of bubbles on heat transport process through the polymer sample.

Technical Approach: During FY 1998, BFRL will measure the gasification rates and temperatures of PE, PP, and PS in nitrogen using the gasification apparatus. These results will be compared with theoretically calculated data. Gasification rates of PP with silica gel and nanocomposites and nylon 6 with nanocomposites will be measured. Gasification rate of PP and PE will be calculated by s new gasification model based on molecular dynamic calculation and the results will be compared with TGA data. The importance of transmissivity of external thermal radiation through PP will be determined. The effects of melt viscosity on gasification rate will be determined.

Recent Results:

Ritchie, S. J., Steckler, K.D., Hamins, A., Cleary, T.G., Yang, J.C., and Kashiwagi, T., "The Effect of Sample Size on the Heat Release Rate of Charring Materials", Fire Safety Science-Proceeding of the Fifth International Symposium, IAFSS, p.177-188 ,1997.

Effects of Melt/Drip Behavior on Fire Growth

Principal Investigators: Kathryn Butler, Fire Science Division, 301-975-6673
Thomas Ohlemiller, Fire Science Division, 301-975-6481

Sponsor: National Institute of Standards and Technology

Objective: To investigate the flow phenomena that are an integral part of the growth of a fire on a thermoplastic object; and to model these phenomena.

Problem: Many real products, whose fire growth behavior need to be modeled, exhibit complex physical phenomena during burning that are a barrier to quantitative description. The worst examples of such items are beds and upholstered chairs, typically containing large volumes of thermoplastic polyurethane foam, which undergo major changes in shape as they burn due to the melting of the foam. Less drastic but still challenging is the melt/flow behavior of simpler plastic components, as in automobile fires, for example. No model of fire growth has incorporated these phenomena, even though they have a major effect on the heat release behavior.

Technical Approach: During FY1998, BFRL will perform experiments and modeling of an idealized situation to facilitate close model comparisons to measured behavior. Uniform radiant heating will be applied to a vertical thermoplastic polymer slab, and will measure the time-dependent weight loss of material from the slab by downward flow. These measurements will be supplemented by limited temperature and melt flow velocity monitoring. Effects of melting and dripping on heat and mass transport for this simple geometry will be modeled computationally using an approach capable of handling moving boundaries and thermal effects.

Recent Results: New Project.

IFSPES Group A Commodity Fire Model

Principal Investigator: Anthony Hamins, Fire Science Division, 301-975-6598

Sponsor: National Institute of Standards and Technology

Objective: To predict the burning rate of a standard rack-storage commodity fire, with and without water sprinkler application.

Problem: The arrangement of polystyrene jars in cardboard cartons with the cartons stacked in racks is the Standard Group A fuel load used in testing performance of industrial fire sprinkler systems. To model the performance of these fire suppression systems with large eddy simulations technology, a method must be developed to quantify the burning of the commodity both with and without water spray at relatively high spatial resolution. Verification of the micro-scale combustion sub-models will be needed. The model should be capable of future expansion to other configurations.

Technical Approach: During FY1998, BFRL will conduct a series of small scale experiments to improve the burning rate/water application model. Experiments, such as in the cone calorimeter, will investigate the combustion characteristics of wet and dry cardboard and the effect of sample orientation. The burning of single micro-box units will be conducted to observe key fire phenomena such as heat release rate. The effect of water on these parameters also will be investigated for the standard and tri-wall commodities. The absorption and flow pathways of water applied on cardboard will be investigated. Large scale validation tests (funded separately) will be used to evaluate the model at large scale. The study of heat transfer in a vertical flue will be conducted through discussions/collaboration with Factory Mutual and BFRL.

Recent Results:

Developed information on flammability of corrugated paper, heat release and radiative emission of unit boxes and assemblies, and information on incident heat fluxes and the burning rate per unit surface area in 10 cm size samples during initial and early burning times.

Screening Methods for Agent Compatibility with People, Materials, and the Environment

Principal Investigator: Marc Nyden, Fire Science Division, 301-975-6692

Sponsor: National Institute of Standards and Technology

Department of Defense
Strategic Environmental Research and Design Program

Objective: To identify for adaptation those test methods to obtain data on the toxicity, environmental impact, and materials compatibility of new suppressants and their principal degradation products during the fire extinguishment process in current weapon systems.

Problem: Needed are new, cost-effective technologies for fire suppression in the highly space- and weight-constrained environment of current and future weapon systems. Technically sound and efficient methods are needed to evaluate recommendations for using new chemicals. There lacks measures for evaluating fire suppression effectiveness, and to identify screening methods for other key indicators of acceptability.

Technical Approach: During FY1998, BFRL will develop a report of a workshop at BFRL of experts assembled to evaluate available methods for screening fire suppression agents. The report will include specific recommendations for further research

Recent Results:

Developed a web page containing a summary of the results of the workshop that is available at **http://flame.cfr.nist.gov/ngp**.

Combustion of Silicone

Principal Investigators: Takashi Kashiwagi, Fire Science Division, 301-975-6699

Sponsor: Dow Corning Corporation

Objective: To understand the combustion mechanism of siloxane and specifically why the heat release rate (as measured in the cone calorimeter) of burning siloxane is nearly independent of external thermal radiant flux.

Problem: The heat release rate (HRR) of burning materials increases significantly with an increase in external thermal radiant flux applied to the burning surface. This is true for non-charring materials and also for charring materials. However, the burning behavior of siloxanes differs markedly from carbon-based materials. Perhaps most significant, the HRR for siloxanes (chain length > 15 S_i-O units) does not increase significantly with an increase in external thermal radiant flux. Whereas carbon based materials may form products of incomplete combustion such as soot and carbonaceous chars, siloxanes form very minimal char but produce substantial amounts of solid amorphous silica (S_iO_2) as a major product of combustion. Previous studies suggest that amorphous silica plays a significant role in mediating the burning behavior of siloxanes.

Technical Approach: During FY1998, BFRL will measure gasification rates of silicone fluids in nitrogen as a function of a well-defined simulated silica layer in the fluid. The addition of MS-75 silica will be well mixed in 60,000 cS fluid and its effect on the gasification rate will be compared with the previously measured results when silica was added on the fluid surface. Another type of inorganic additives will be examined. The distribution of temperatures and particle volume fraction in silicone flames will be measured by the IR transmission and emission method. IR transmission and scattering of the collected silica particles generated from silicone flame will be measured.

Recent Results:

Buch, R., Hamins, A., Konishi, K., Mattingly, D., and Kashiwagi, T. "Radiative Emission Fraction of Pool Fires Burning Silicone Fluids" *Combustion and Flame*, 108: 118-126(1997).

Austin, P. J., Buch, R. R., and Kashiwagi, T., "Gasification of Silicone Fluids under External Thermal Radiation", NISTIR 6041, July 1997.

Flame Retardant Mechanism of SI Additives

Principal Investigator: Takashi Kashiwagi, Fire Science Division, 301-975-6699

Sponsor: Dow Corning Corporation

Objective: To understand the flame retardant mechanism of SI powders in high density polyethylene.

Problem: Using a cone calorimeter, it has been observed that the addition of SI powders to thermoplastics and engineering resins results in substantial reductions in heat release rate and rate of formation of combustion products, i.e. smoke particulates and carbon monoxide. Preliminary pyrolysis experiments with polypropylene, conducted in NIST's radiative gasification device, indicated the formation of a thin silicon based layer at the sample surface during gasification in nitrogen. It appeared that the sample weight loss rate was lower in samples with the additive than that seen in samples without the SI powders at about the same time this layer was formed. However, the flame retardant mechanism of SI powders in various commodity polymers has not been well understood. It is important to determine if the SI powders act as a condensed phase flame retardant or as a gas phase flame retardant.

Technical Approach: During FY1998, BFRL will perform these tasks:
1. Fire properties of the HDPE and SI powder system samples will be measured in BFRL's cone calorimeter at 40 kW/m^2 (external heat flux). These results will be compared to the data obtained by Dow Corning to ensure that both laboratories produce the same results and also to confirm the flame retardant effectiveness of the SI powders. Comparison of the measured effective heats of combustion with and without the SI powders will provide some indication of the importance of gas phase flame retardant effects.
2. The same combination of samples will be tested in BFRL's radiative gasification device to measure sample mass loss rate in nitrogen at two fluxes (40 kW/m^2 and 75 kW/m^2). Since there will be no flaming in these experiments, the results will be based on the processes in the condensed phase. The gaseous degradation products will be trapped at 40 kW/m^2 and analyzed to assess any change in the composition of the pyrolysis products resulting from the addition of the SI powders. Analyses (GLC, GPC, MS, silicon content) of the collected (trapped) pyrolysis products will be provided by Dow Corning.
3. Test samples will be prepared by compressing several thin layers of the samples on a heated press. Fine thermocouples will be imbedded between the thin layers and temperature histories in the samples will be measured. The difference of the temperature distribution in the sample with and without the SI powders will reveal the effects of the expected SI-based thin layer at the sample surface and whether the layer acts as an insulation layer.

Recent Results: New project.

Vehicle Fire Initiation and Propagation

Principal Investigators: Thomas G. Cleary, Fire Science Division, 301-975-6858
Thomas J. Ohlemiller, Fire Science Division, 301-975-6481

Sponsor: General Motors Corporation
Research and Design Center
Automotive Safety Research Department

Objective: To provide a better understanding of the dynamics of post-collision fires that threaten the safety of vehicle occupants and to develop realistic, repeatable ignition protocols for vehicle fire safety testing.

Problem: Approximately 1-2% of all high-speed vehicle crashes result in a fire; these cause an estimated 300 vehicle occupant deaths per year due to fire in otherwise survivable crashes. It is unknown whether cost-effective solutions (less flammable materials substitution, active suppression, etc) could be devised to improve the death and injury rate from post-collision fire.

Technical Approach: During FY1998, BFRL will analyze a series of instrumented high-speed crashes performed by GM for clues suggesting ignition sources, the distribution of flammable fluids and the potential for ignition. Plausible ignition scenarios will be hypothesized, then, repeatable fire initiation protocols will be developed that mimic ignition scenarios in terms of the initial fire insult to the vehicle. The crashed vehicles will be heavily instrumented (video, temperature, heat flux, and gas analysis) and burned according to a predetermined initiation protocol to examine the role which specific vehicle components play in the fire growth and spread into the passenger compartment. From these results, intervention (active or passive) strategies could be proposed and tested, leading to safer vehicles.

Recent Results:

No reports published.

Production and Certification of Cone Calorimeter SRMs

Principal Investigator: Kenneth Steckler, Fire Science Division, 301-975-6678

Sponsor: National Institute of Standards and Technology

Objective: To produce and certify two standard reference materials for heat, mass, and smoke release rates in the Cone Calorimeter.

Problem: There are about 140 Cone Calorimeters in the world and their number is increasing annually. This device and attendant test method were developed at BFRL in the middle 1980s to measure simultaneously three different flammability properties of a single end-product specimen: heat release rate, mass loss rate (burning rate), and smoke production. The method is used widely by testing companies, materials/chemical companies, and end-products producers to evaluate fire performance of existing materials as well as new, exploratory materials. However, there often is substantial scatter in lab-to-lab results, and there are no standard reference materials to calibrate the entire system in a manner which closely mimics the behavior of a real sample (a methane burner currently is used for heat release rate). Therefore, realistic calibration samples in slab form are critically needed to make certain that the device measures heat release rate, mass loss rate, and smoke production accurately, repeatably, and reproducibly.

Technical Approach: During FY1998, BFRL will certify and produce two standard reference materials; one will be a thermoplastic which forms no char during burning; it will tend to generate a nearly steady, high heat release rate (and burning rate), with high smoke production. The other standard sample will be a char-forming material which tends to generate an unsteady, low heat release rate (and burning rate), typically with two different peak heat release rates during burning, and with low smoke production. Several materials will be assessed, including polystyrene and phenolics, and two will be selected for certification and production as SRMs.
The samples' heat release rates, mass loss rates, and smoke production will be measured accurately and their repeatability will be determined to a measured statistical tolerance. It is expected that 100 standard reference samples will be produced.

Recent Results:

No reports published.

Evaluation of Potential Fire Intervention Materials and Technologies

Principal Investigator: Anthony Hamins, Fire Science Division, 301-975-6598

Sponsor: General Motors Corporation
Research and Design Center
Automotive Safety Research Department

Objective: To identify and evaluate fire protection and suppression technologies that could improve fire safety of vehicles.

Problem: Heat transfer, transport of toxic gases, and flame propagation into the passenger compartment lead to fatalities associated with post-accident vehicle fires.

Technical Approach: During FY1998, BFRL will study the progression of fires in vehicle tests and determine where active and passive fire protection systems can effectively intervene. Identification of superior materials and appropriate fire protection technologies will be sought from industry. Intermediate and full-scale testing of selected materials and technologies will continue to be conducted using representative fire scenarios.

Recent Results:

Identified passive and active fire intervention technologies for testing.

Investigated the effectiveness of a solid powder agent in extinguishing representative fires was investigated.

Fire Safe Aircraft Interior Materials

Principal Investigators: Jeffrey Gilman, Fire Science Division, 301-975-6573
Marc Nyden, Fire Science Division, 301-975-6692

Sponsor: Federal Aviation Administration
Fire Safety Branch

Objective: To determine the effects of pre-ceramic polymers and clay-nanocomposites on the flammability of polymers useful in aircraft interiors, and to develop theoretical models to describe thermal degradation behavior of a variety of polymers including crosslink formation, products composition, and relative heat release rate from polymer burning.

Problem: Advancement of materials to be used in the interior of commercial aircraft is urgently needed to gain more egress time for passengers to escape from fire which may occur as a result of crash landings. However, the current capability to predict the flammability of aircraft materials on the basis of their molecular structure is limited. In this laboratory, molecular dynamics modeling has been developed to explore mechanisms of thermal degradation and crosslink formation in vinyl polymers. Development of a new code that extends this model to include gas phase reactions and also to apply to engineering plastics will bring a new tool to aid in the design of new generation fire resistant aircraft materials. Inorganic polymers which convert to a ceramic are new advanced material that may be useful in fire retarding organic polymers. These "pre-ceramic polymers" when heated to high temperature pyrolyze to form a ceramic residue in high yield, this thermally insulates the underlying material. Indeed, this concept has proved promising in initial studies, and a US patent application has been filed. The clay-nano-composite approach is another important new method which has shown promise for flame retarding polymers. Information is lacking about the mechanism by which these new systems function and determine if these approaches will work in polymers useful in aircraft interiors.

Technical Approach: During FY1998, BFRL will enhance the time domain of its molecular dynamics model to allow for the simulation of transport of gaseous fragments through the polymer melt. This will be accomplished by appending a third stage (following the initiation and propagation stages which constitute the present model) to the calculations in which only the mean field nonbonding interactions (computed from the time averaged atomic and charge densities) between the fragments and the melt are computed. The effect of pre-ceramic polymers and clay-nano-composites on the flammability properties of organic polymers will be determined. Polysilsesquioxanes will be evaluated for their compatibility with various organic polymers and the mixtures and blends prepared. Clay-nano-composites with both delaminated and intercalated structure will be prepared using organic modified montmorillonite clays. The organic polymers examined will include thermosets, engineering polymers, and thermoplastics. The blends will be prepared and the degree of mixing will be evaluated using special solid state CP/MAS ^{13}C-NMR techniques and SEM (to determine the effects of the degree of mixing on flammability properties). Graft copolymers and blends with pre-ceramic oligomers and clay-nanocomposites which show significant improvement in flammability will be studied in detail to determine the FR mechanism.

Recent Results:

Flammability Studies of Polymer Layered Silicate Nanocomposites. 43rd SAMPE Symposium and Exposition, Preceedings, Anaheim meeting, May 1998.

Nanocomposites: Radiative Gasification and Vinyl Polymer Flammability, Fire Retardancy of Polymers : The Use of Intumescence, The Royal Society of Chemistry, Cambridge, in press (1998).

Molecular Dynamics Simulations of the Thermal Degradation of Nano-Confined Polypropylene, Computational and Theoretical Polymer Science, in press (1998).

Nanocomposites: A Revolutionary New Flame Retardant Approach, SAMPE Journal, Vol. 33, No. 44, July/August 1997.

Radiative Ignition and Subsequent Flame Spread in Microgravity

Principal Investigators: Takashi Kashiwagi, Fire Science Division, 301-975-6699

Sponsor: National Aeronautics and Space Administration
Microgravity Science Project

Objective: To extend BFRL's theoretical model of ignition and subsequent flame spread over a thermally thin material in microgravity to a thick material and participate conducting experiments in drop towers for comparison of the predicted results with the experimental observation.

Problem: Fires in spacecraft pose significant dangers to the crew due to toxic combustion products and over pressurization by heat release. Momentary ignitions due to electrical shorts or overheating might be an acceptable and recoverable hazard, but a transition from the ignition to flame spread is an acceptable risk. However, the transition mechanism has not been well understood.

Technical Approach: During FY1998, BFRL will conduct a parametric study to examine the effects of many physical and chemical parameters on transition from ignition and flame spread and flame growth using the newly developed code based on full Navier-Stokes equations (time-dependent and 2D/3D). BFRL will continue to analyze experimental results obtained in the USMP-3 flight and also in JAMIC II. Researchers will design and develop diagnostic measurement techniques of a new JAMIC rig and determine the test matrix of planned JAMIC IV tests.

Recent Results:

McGrattan, K.B., Kashiwagi, T., Baum, H.R., and Olson, S.L., "Effects of Ignition and Wind on the Transition to Flame Spread in a Microgravity Environment," *Combustion and Flame*, 106:377-391 (1996).

Kashiwagi, T., McGrattan, K.B., Olson, S.L., Fujita, O., Kikuchi, M., and Ito, K., "Effects of Slow Wind on Localized Radiative Ignition and Transition to Flame Spread in Microgravity", *Twenty-Sixth Symposium (International) on Combustion*, The Combustion Institute, pp.1345-1352 (1996).

A Numerical Model for Combustion of Bubbling Thermoplastic Materials in Microgravity

Principal Investigator: Kathryn Butler, Fire Science Division, 301-975-6673

Sponsor: National Aeronautics and Space Administration
Microgravity Science Project

Objective: To extend BFRL theoretical model of the behavior of burning thermoplastic materials in microgravity.

Problem: Recent microgravity experiments on combustion of thermoplastics, including Velcro made of nylon and electrical wire insulation, have pointed out a fire hazard unique to low gravity. Chemical reactions within the bulk of certain burning thermoplastic materials generate internal bubbles, which grow and migrate until they burst at the surface and eject fuel and fuel vapor into the surroundings. Under normal gravity conditions, the primary danger of fire spread by contact with burning thermoplastics is from the dripping of the molten material. In microgravity, however, the forcible ejection of molten fuel droplets and fuel vapor uniquely enhances fire growth by transporting burning material in random directions, threatening the safety of the crew and spacecraft.

Technical Approach: During FY1998, BFRL will develop a time-dependent, three-dimensional numerical model to predict the temperature field, burning rate, and bubble bursting characteristics of these materials. The model will include the dynamics of bubble growth and migration, heat transfer through the condensed material, the chemistry of gasification, and coupling to the gas phase. In this model, the thermoplastic material is initialized as a volume of highly viscous material in which a number of bubble nucleation sites (up to 10000) are randomly distributed. A heat flux is applied to the outer surface and the energy equation is solved to determine the temperature field. When the temperature at a given bubble site exceeds the degradation temperature of the polymer, the bubble begins to grow at a rate determined by the relevant chemistry and physics. The migration of each bubble due to the effect of the local temperature gradient on viscosity and surface tension, to the flow fields of surrounding bubbles, and to buoyancy (when gravity is a factor) is computed, and the loss of mass due to expulsion of fuel vapor and liquid droplets at the outer surface is modeled. A separate model will study details of the bursting process. Gas phase mechanisms will be calculated in sufficient detail to adequately represent the coupling between the flame and the surface of the burning thermoplastic sample.
Model results will be compared with experimental results from the NASA sponsored BFRL research on "Combustion of a Polymer (PMMA) Sphere in Microgravity," and with ground-based experiments performed using BFRL's cone heater. Values that will be compared include temperature as a function of time at the locations of thermocouples embedded in the samples, growth and migration of bubbles with time, and bursting rate, given by the number of bubbles that arrive at the sample surface as a function of time. Microgravity experiments performed on the NASA Lewis DC-9 Reduced-Gravity Aircraft have demonstrated that fuel vapor jets are produced during bursting of bubbles in both PMMA and PP, but molten fuel droplets occur only for PP. A parametric study of the model will investigate the effects of variations in material properties and combustion conditions on burning rate and combustion behavior.

Recent Results:

Butler, K.M., "Numerical Modeling for Combustion of Thermoplastic Materials in Microgravity," Proceedings of the Fourth International Workshop on Microgravity Combustion, NASA Conference Publication 10194, 249-254, 1997.

Demonstration and Products Transfer

Principal Investigators: Takashi Kashiwagi, Fire Science Division, 301-975-6699
Jeffrey Gilman, Fire Science Division, 301-975-6573
Marc Nyden, Fire Science Division, 301-975-6692
Thomas Ohlemiller, Fire Science Division, 301-975-6481

Sponsor: National Institute of Standards and Technology

Objective: To demonstrate assurance of achieving the intended fire performance of the modified end products and to transfer the results of BFRL fire research in flame retardant principles to industry.

Problem: U.S. industry is reducing its budget for basic research. To maintain competitiveness of U.S. industry, generic information and understanding obtained from BFRL's fire research in flame retardant principles must be transformed to U.S. industry timely and effectively. The measurement of appropriate flammability properties of the modified end products relevant to fire safety is critically needed and such measurement could be changed by future implementation of a new type of fire code based on fire performance instead of traditional pass-fail code.

Technical Approach: During FY1998, BFRL will present its findings on fire research in flame retardant principles at various industrial meetings. Consortiums with industrial members will be formed to work closely with industry. Theoretical models such as MD_REACT code (molecular dynamic calculation) will be made available to industries interested in using it. In collaboration with industry, large-scale fire tests will be conducted to assure fire safety of new experimental end products based on our new flame-retardants.

Recent Results: New project.

Development of Environmentally-Friendly, New Flame Retardants Consortium

Principal Investigators: Takashi Kashiwagi, Fire Science Division, 301-975-6699
Jeffrey Gilman, Fire Science Division, 301-975-6573
Marc Nyden, Fire Science Division, 301-975-6692

Sponsor: Consortium Members (FMC, PQ Corp., Sekisui America)

Objective: To understand the mechanisms of char formation and heat release rate reduction due to the addition of silica gel in polypropylene, PP.

Problem: Many inexpensive, large volume commodity polymers have excellent physical properties. However, almost all of them are highly flammable. Therefore, flame retardant additives are commonly used in the end application when good fire performance is required. Some of the most common additives contain halogens, chemicals that have raised some environmental concerns, especially in Europe. U.S. manufacturers are seeking new, environmentally friendly flame retardants in order to manufacture the same products for export as well as domestic sale. Polypropylene is a commodity polymer which is used for fabric in upholstered furniture, carpets, cables, in automobile and so on. One environmentally-friendly flame retardant approach is to alter the thermal degradation processes so as to enhance char formation during polymer burning. Char formation reduces the amount of carbon containing, combustible, volatile, degradation products; char also insulates the underlying polymer, due to the char's low thermal conductivity.
However, PP does not generate any char during its burning. We know that the addition of silica gel in PP generates a significant amount of char and reduces heat release rate. We do not yet understand the mechanisms for the formation of char, in this system. A thorough investigation of these mechanisms should allow us to optimize the structure and composition of silica gel to generate more char and enhance the reduction in heat release rate.

Technical Approach: During FY1998, BFRL will perform experimental and theoretical analysis. The Cone Calorimeter will be used to evaluate the effect of particle size, pore size, pore fraction, and silanol content of the silica gel on the flammability properties of PP. The Cone Calorimeter data will assist in determining what parameter of the silica gel controls the flammability of PP. BFRL will also use the gasification apparatus to measure gasification rate and temperatures in the sample in nitrogen atmosphere to determine the effects of the silica gel structure/composition on the gasification processes of PP. Polymer residues generated from the gasification apparatus or our nitrogen flow reactor at various temperatures will be analyzed by ^{1}H, ^{13}C, and ^{29}Si solid state NMR. Changes in the thermal degradation processes of PP with the addition of the silica gel will be measured using FTIR evolved gas analysis. A series of computer experiments will be conducted using BFRL's developed molecular dynamics model to elucidate the mechanism by which the presence of silica gel alters the thermal degradation chemistries or physical gasification processes of PP. Combined analysis of the computational results with the experimental data will reveal the char formation mechanism and also will determine the optimal structure/composition of silica gel for the formation of char and reduction in heat release rate in PP.

Recent Results: New project.

FIRE SCIENCE

GRANT SUMMARIES

MATERIALS FIRE RESEARCH

ADVANCED FIRE MEASUREMENTS:

FIRE SENSING AND EXTINQUISHMENT

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Cross-Linking of Polystyrene by Friedel-Crafts Chemistry to Enhance Resistance to Thermal Degradation

Principal Investigators:
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Marquette University
414-288-7239
Michael A. McKinney
Department of Chemistry
Marquette University

Sponsor: National Institute of Standards and Technology

Objective: To develop a suitable system for Friedel-Crafts chemistry to achieve cross-linking of polystyrene only under conditions which approximate those which may be encountered in a small fire.

Problem: It is usually assumed that a cross-linked polymer will be more thermally stable than is a thermoplastic material. One may easily cross-link the majority of polymers but they lose all processability upon cross-linking. The goal of this work is to maintain the processability of polymers by incorporating materials which will promote the cross-linking of polymers only under thermal conditions which exceed those which would be used during the processing of the polymer.

Technical Approach: Any cross-linking scheme must take advantage of the functional groups which are present on the polymer. In the case of polystyrene, the only functional group which is present is the aromatic ring and this means that a reaction must be performed on this ring to achieve cross-linking. One chemical reaction which may occur on aromatic rings is Friedel-Crafts alkylation and acylation reactions. In the typical reaction, one uses aluminum chloride as the catalyst with an alkyl halide as the alkylating agent. This is unsuitable because the catalyst is hygroscopic; it will erode the characteristics of the polymer and because hydrogen chloride is evolved as a byproduct of the reaction. An additional problem is that an alkyl halide will alkylate benzene at room temperature when aluminum chloride is used as the catalyst. We have incorporated the alkylating agent into the polymer by copolymerization and are designing catalysts which will be effective only at elevated temperatures and which will not have an adverse effect on the properties of the polymer.

Recent Results:

Li, J., and Wilkie, C. A., AImproving the Thermal Stability of Polystyrene by Friedel-Crafts Chemistry,@ *Polymer Degrad. Stab.*, 57, 293-299 (1997).

Z. Wang, D. D. Jaing, M. A. McKinney, and C. A. Wilkie, ACross-linking of Polystyrene by Friedel-Crafts Chemistry to Improve Thermal Stability,@ *Polym. Degrad. Stab.*, (in press.)

A Fire Growth Simulation Model for Materials

Principle Investigator:
James Quintiere, Professor
Fire Protection Engineering
University of Maryland
301-405-3993

Sponsor: National Institute of Standards and Technology

Objective: To develop and assess a simulation model to predict the fire growth on commercial materials used in building construction and interior finish applications.

Problem: Many standard regulatory test methods are intended to assess and control the flammability of interior finish and construction materials. While these tests vary, room-corner tests of wall and ceiling materials have emerged as an alternative and more universal measure of material performance. The standard tests provide no universal measure of flammability, and no basis for making predictions. A prediction of the a room-corner test scenario is a first step at establishing an engineering method for assessing flammability through test data.

Approach: In 1992 a simulation model was published which had good success at predicting the performance of materials in the ISO DP 9705 room corner test protocol. Since then 24 materials have been assessed by the model and compared to its actual test performance. Encouraging results were obtained. Subsequent analysis of UBC room-corner test protocol results for textile wall materials demonstrated the model's versatility and its reasonably accurate predictability. The model offers the framework for fire growth prediction within the context of building fire and smoke models such as CFAST.
The model is a system approach to fire growth. The approach has been to maintain simplicity but completeness. Simplicity is needed in order to easily accommodate material data from standard tests. Property data for the model are derived from tests results of the Cone Calorimeter and the LIFT apparatus. Data over a heat flux range are needed to adequately develop the needed property data to predict ignition, flame spread and burning rate. Other needed model input data include the heat flux and flame height characteristics of the corner ignitor burner. This controls the heat flux during flame spread in the corner. Recent studies of the heat flux characteristics of corner burners can provide more accurate and more general data inputs for the model. Currently the model consists of four differential equations for flame spread and burnout fronts in two directions, an integral equation for room surface temperature, and an algebraic equation for smoke layer temperature. A complete documentation and reassessment of the model is underway. New data from full-scale corner tests will be examined. These include 12 materials tested in the ISO standard, former work by Kokkala in a much larger test, NIST data for a composite material in a non-standard corner test, and a link to data from the Building Research Institute (BRI) of Japan on 19 more materials studied in the ISO room-corner test with supporting data.
The goals are to present a clear description of the model so that others might consider its use, to improve the physical basis for the model in view of recent research, and to assess the accuracy of the model against new full-scale data.

Recent Results:

Quintiere, J. G. and Lee, C., "Ignitor and Thickness Effects on Upward Flame Spread", *Fire Technology*, Vol. 34, No. 1, March, 1998, pp. 18 - 38.

Kim, W. H. and Quintiere, J. G., "Applications of a Model to Compare the Flame Spread and Heat Release Properties of Interior Finish Materials in a Compartment", International Symposium on Fire Science and Technology, Seoul, November 12-14, 1997.

Quintiere, J. G., Haynes, G., and Rhodes, B. T., " Applications of a Model to Predict Flame spread over Interior Finish Materials in a Compartment", *Journal of Fire Protection Engineering*, Vol. 7, No. 1, 1995.

Quintiere, J. G., Hopkins, M., and Hopkins, D. Jr., "Fire Hazard Prediction for Textile Wall Materials", report for the American Textile Manufacturers Institute, January 1995.

The Development of Novel Low Flammability Siloxane-Based Impact Modifiers for Cyanate Ester Resins

Principle Investigator:
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Department of Chemistry
Howard University
202-806-6892

Sponsor: National Institute of Standards and Technology

Objective: To develop siloxane polymers terminally functionalized with cyanate ester group capable of being compounded with commercial cyanate ester resins such that they impart higher impact resistance with no increase or with a decrease in flammability.

Problem: Cyanate ester resins (CERs) have been proposed as a potentially useful matrix material for airframes. CERs have seen their widest use in printed circuit wiring board (PCWB) technologies. Their use in radomes and for application in near earth orbit has also seen a recent increase. However, commercial CERs do not currently have the appropriate fracture toughness for applications such as airframe construction. Standard techniques for improving the performance of brittle polymer matrices would include the addition of a phase separated rubbery materials as impact modifiers. These serve to induce microfracturing in a controlled fashion and the rubbery particles then act as energy dispersing elements in the matrix. Thus a rubber-modified matrix will fail "gracefully" rather than catastrophically. A major concern for the increase in the use of polymeric materials in commercial airline construction is their potential for combustibility. The CERs have flammability comparable to conventional phenolic resins and possess excellent processibility. Added impact modifiers must not lead to increases in flammability or to the release of toxic materials during combustion.

Technical Approach: We are developing compositions of cyanate functional siloxanes and determine the appropriate formulations to provide optimal mechanical performance with combustion properties as good as or better than pure CERs.
We have synthesized a number of cyanate terminated siloxane polymers. This involves the synthesis of disiloxanes functionalized with terminal phenol groups. These dimers are then equilibrated with the cyclic trimer or tetramer of dimethylsiloxane and in some formulations with the addition of diphenylsiloxane, the latter intended to improve the solubility of the siloxane in the CER resins. After formation of the phenol terminated oligomers, they are reacted with cyanogen bromide to create the final CER-siloxane. This is then blended with oligophenol derived commercial cyanate ester resins. Blending studies have to date shown good phase separation between the glassy CER resins and the rubbery siloxane phases with 30-40 micron diameter rubber particles dispersed uniformly in the glassy resin.

Recent Results:

Fu, Zhidong, Ph.D. Thesis, Howard University, October 1998.
Pollack, S.K. and Fu, Z.,"Telechelic Aryl Cyanate Ester Siloxanes As Impact Modifiers For Cyanate Ester Resins", Polymer Preprints, 33(1), 452, 1998

Fu, Z, and Pollack, S.K., "The Base-Catalyzed Equilibration of 1,3-Bis(p-Tetrahydropyranyloxy-Phenyl)-1,1,3,3-Tetramethyldisiloxane And D_4", Polymer Preprints, 33(1), 577, 1998

Fire Retardant Polymer Nanocomposites

Principal Investigator:
Emmanuel P. Giannelis
Materials Science and Engineering
Cornell University
(607) 255-9680

Sponsor: National Institute of Standards and Technology

Objective: To develop and evaluate a new generation of flame retardant polymer nanocomposites. The proposed work will provide a framework for rationally developing new fire-resistant materials for a variety of commercial applications.

Problem: As use of synthetic polymers has grown dramatically over the last three decades so have efforts to control polymer flammability. However, some of the currently available approaches do not address all the materials, environmental and cost requirements. New environmentally-benign approaches and materials are needed that combine flame resistance with superior properties, processability and low cost.

Approach: Nanocomposites with varying amounts of silicate (1 - 10 vol%) will be synthesized by melt extrusion. Nanodispersion will be characterized by X-ray diffraction and transmission electron microscopy. Mechanical testing will include tensile modulus, strength and elongation. Thermal stability will be determined by TGA in air and in an inert atmosphere. Fire resistance will be evaluated by cone calorimetry measurements in collaboration with the BFRL researchers.

Recent Results: New project.

Evolution of Compartment Exhaust Gases in Buildings: Providing Evaluation Criteria and Design Tools

Principal Investigator:
Uri Vandsburger
Virginia Polytechnical Institute, State University
Mechanical Engineering Department
540-231-4459

Sponsor: National Institute of Standards and Technology

Objective: To develop correlations for the prediction of the levels of species yields for conditions leading to the transport of incomplete combustion products to locations remote from a burn room, and to provide design tools for fire safety engineers related to the formation and transport of CO and UHC away from a burning compartment into a building interior.

Problem: The number of fire fatalities due to CO inhalation rises annually. Without preventive action through improved design methods for building interior construction and fire control systems this trend threatens to continue due to an increased population occupying nursing homes and the increased use of wood paneling, floors, ceilings and walls in new upscale homes. Therefore, there is an urgent need for tools which could assist in estimating the levels of CO, and other combustion products throughout a structure with a room containing an underventilated fire.

Technical Approach: The methodology chosen includes execution of parametric studies on reduced scale burn compartment-hallway and burn compartment-hallway-target room configurations. The parameters included geometrical factors, upper layer characteristics, fuel types and chemical and physical processes. To date two facility configurations have been built. A reduced scale compartment-hallway facility with a metered air inflow and an exhaust vent to the hallway. The second and newer facility consists of a ½ scale ISO compartment with a fluid mechanically (residence time) scaled door and heat transfer scaled walls. The data acquired includes temperature distributions, species inside and post compartment and hallway and heat transfer in hallway. During the reporting period data for the first compartment and hallway were scaled to result in nondimensional scaling laws for air entrainment into the upper layer in the hallway and species yield at the hallway exit.
The air entrained into the upper layer of compartment exhaust gases was scaled with the exit Froude number, h_o/z where h_o is the height of the opening and z the distance from the ceiling to the bottom of the opening to the hallway, and w_o/w_{wall} where w_o is the opening width, and w_{hall} the hallway width. An expression for the normalized entertainment rate was obtained in the form of

$$\frac{\dot{m}_e}{\dot{m}_o} = 0.1\left[Fr^{0.2}\left(\frac{h_o}{z}\right)^{-1.6}\left(\frac{w_o}{w_{wall}}\right)^{-0.8}\right]$$

$\dot{m}_o$

where is the mass flow rate entering the hallway from the burning compartment. The CO yield at the hallway exit was correlated with

$$\dot{m}_{o,fuel} = \left[1-\left(\frac{1}{\phi}\right)\right]\frac{Q}{\Delta H_c}$$

Where

$\dot{m}_{fuel}/\dot{m}_o$ and $\dot{m}_e/\dot{m}_o$

is the ideal fire size (power) and D H_c is the heat of combustion of the fuel burning inside the compartment. The correlation for the CO yield was obtained as

$$y_{CO} = 0.18\left(\frac{\dot{m}_{fuel}}{\dot{m}_o}\right)^{0.4}\left(\frac{\dot{m}_e}{\dot{m}_o}\right)^{-0.55}$$

A study of heat transfer from the upper layer in the hallway revealed a direct correlation between low heat flux rates and high CO levels and vice versa. This indicates that heat flux is a measure of the completion of CO to CO_2 conversion rather than a driver of this process.

A new compartment has been constructed and has undergone testing. Efforts are made to devise a simple method for the measurement of the air entrained into the compartment using a radiatively shielded velocity probe. Characterization of the compartment and the development of correlations for species yields at the compartment exit will be done by early summer for three fuels—hexane, wood and polyurethane. The results will be compared with the present standard method of using a cone calorimetry. If needed the standards will be updated.

Recent Results:

Lattimer, B. Y., Vandsburger, U., Roby, R. J., "Carbon Monoxide Levels in Structure Fires: Effect of a Wood Lined Ceiling in the Burning Room," under review *J. Fire Technology*, January 1998.

Marshakov, A. V., McKay, C., Vandsburger, U. and Roby, R. J., "Heat Transfer Aspects of the Transport of High Concentrations of CO in Building Fires," *ICFRE2,* August 1997.

Lattimer, B. Y., Vandsburger, U. and Roby, R. J., "Development of Scaling Parameters for Estimating CO Levels in Structure Fires," 2nd International Symposium on Scale Modeling, June 1997.

Comparison of Near and Mid-infrared Tunable Diode Laser Absorption Spectroscopy for the Analysis of Combustion Gases

Principal Investigator:
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Department of Chemistry
The George Washington University
(202) 994-7474

Sponsor: National Institute of Standards and Technology

Objective: To evaluate the sensitivity and selectivity of tunable diode laser absorption diagnostics in combustion systems in the near infrared spectral region through application in model laboratory flames.

Problem: The need for reliable, rapid and accurate measurements of species concentrations in and near fires has been a motivation for the development of laser diagnostics for more than 20 years. Visible and ultraviolet laser diagnostics have been hampered by interferences from both other molecular species sand particulate. Absorption spectroscopy in the mid infrared, although less sensitive than visible/ultraviolet fluorescence techniques, has shown promise for the analysis of many molecules and can be selective. Unfortunately, these lasers require cryoscopic cooling which adds expense (and size) to the instrumentation. Further, the availability of fiber optics, required in many "remote sensing" applications is extremely limited. Near infrared diagnostics are free from many of these disadvantages, but diagnostics here must overcome weaker signal levels.

Approach: In conjunction with similar BFRL in-house efforts, we are constructing a near infrared laser system which will be applied to measurements of well characterized bench scale fires. Diagnostics for CO, CO_2, and H_2O will be made side-by-side in the near and mid-infrared for comparison. Further, spectral simulation and fitting programs are being developed to aid our work and those of our BFRL colleagues.

Recent Results:

Tolocka, M.P, and Miller, J.H., "Measurements of Formaldehyde Concentrations and Formation Rates in a Methane/Air, Non-Premixed Flame and Their Implications for Heat Release Rate". *Twenty-seventh Symposium (International) on Combustion* (submitted.)

Mixing and Radiation Properties of Buoyant Luminous Flame Environments

Principal Investigator:
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Sponsor: National Institute of Standards and Technology

Objective: To measure the radiation and mixing properties of luminous buoyant turbulent flame environments and use these results to improve fire models.

Problem: Radiation and turbulent mixing of luminous flames affect fire spread, growth and combustion rates and are important elements of fire models. Available information about soot optical properties is limited even though continuum radiation from soot dominates radiation in fires. Similarly, information about the properties of buoyant turbulent flow typical of fire environments is limited which impedes of the development of fire models. Thus, the problems being studied include the optical properties of soot and the mixing properties of buoyant turbulent flows.

Approach: Past work has shown that soot optical properties approximate Rayleigh-Debye-Gans scattering of polydisperse fractal aggregates of primary soot particles (RDG-PFA theory); thus, current work is addressing soot refractive index properties and how they vary with fuel type and flame condition. RDG-PFA theory is being used for *in-situ* measurements of the optical properties in the visible and infrared of soot emitted from liquid-and gaseous-hydrocarbon fueled buoyant turbulent diffusion flames (benzene, toluene, cyclohexane, n-heptane, acetylene, butadiene, propylene and ethylene). Measurements for liquid-fueled flames in the visible (351-633 nm) have been completed yielding the following results: dimensionless extinction coefficients are independent of fuel type and wavelength and are in the range 8-9 which is in excellent agreement with earlier measurements at BFRL, fractal dimensions have a mean value of 1.78 and a standard deviation of 0.02 which is in good agreement with earlier work; and soot refractive indices are relatively independent of fuel type and are somewhat larger than the widely used results of Dalzell and Sarofim (1969). Current work involves measurements of similar properties for the gas fueled flames in the visible and extension of these findings for both types of fuels into the infrared.
Past studies of buoyant turbulent flows established the properties of self-preserving round buoyant turbulent plumes and used these results to show that existing turbulence models gave effective mean property predictions even though predictions of turbulence properties were not effective. This deficiency is a concern because predictions of rapidly-developing flow typical of fire environments require good estimates of turbulence properties. Similar measurements have been completed for self-preserving plane free line plumes, finding that earlier studies were not carried out far enough from the source to reach self-preserving conditions and that these flows are narrower than previously thought. The same techniques are now being applied to adiabatic wall plumes as models of flames and other buoyant turbulent flows along surfaces. Work thus far has been limited to measurements of scalar mixing (mean and fluctuating mixture fractions) and confirms and extends earlier work on the self-preserving properties of these flows. Subsequent work will concentrate on mean and fluctuating velocities.

Recent Results

Sangras, R., Dai, Z. And Faeth, G.M., "Mixing Structure of Plane Self-Preserving Buoyant Turbulent Plumes," *J. Heat Trans.*, submitted.

Faeth, G.M., "Optical and Radiative Properties of Soot in Flame Environments," *Prog. Energy Combust. Science*, invited.

Faeth, G.M., "Combustion Fluid Mechanics (Tools and Methods)," *Proceedings of the Workshop on Fuels with Improved Fire Safety,* National Academy Press, Washington, DC, 81-96, 1997.

Wu, J.-S., Krishnan, S.S. and Faeth, G.M., "Refractive Indices at Visible Wavelengths of Soot Emitted from Buoyant Turbulent Diffusion Flames," *J. Heat Trans.* 119:230-237, 1997.

Dai, Z. and Faeth, G.M., "Measurements of the Structure of Self-Preserving Round Buoyant Turbulent Plumes," J. *Heat Trans* 118:493-495, 1996.

Farias, T.L., Carvalho, M.G., Koylu, U.O., and Faeth, G.M., "Total Scattering and Absorption Cross Sections of Carbonaceous Soot Particles," *International Symposium on Radiative Heat Transfer* (M.P. Menguc, ed.), Begell House, Inc., New York, 296-308, 1996.

Faeth, G.M., and Koylu, U.O., "Structure and Optical Properties of Flame-Generated Soot," *Transport Phenomena in Combustion* (S.H. Chan, ed.), Taylor & Francis, Washington, vol. 1, 19-44, 1996.

Gas Generator Induced Flow and its Effect on Fire Flame Extinction

Principal Investigator:
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Sponsor: National Institute of Standards and Technology

Objective: To conduct a literature search on recirculation zones induced by either a bluff body, a baffle, a backward facing step or a trench inside a wind tunnel, perform some preliminary computations using Large Eddy Simulation (LES) code developed at BFRL and compare the results with the literature data for validation.

Problem: A limiting factor to the development of new suppression technology is the lack of appropriate screening methods. Among the new technologies intended to replace Halon1301 are Solid Propellant Gas Generators, (SPGG's). To date there is no adequate screening method for SPGG's. The flow originating from burning a solid propellant reduces the DamkØ hler number by decreasing the residence time and increasing the chemical time. If the DamkØ hler number decreases below a critical value sudden extinction of the flame occurs. A facility that will serve to assess the performance of SPGG's has to be able to evaluate the combined effects of the gas discharge. Several alternatives have been proposed for an adequate flame and enclosure that will represent a "worst case" scenario for extinction and subsequent re-ignition. Among these alternatives is the recirculation zone induced by either a bluff body, a baffle, a backward facing step or a trench inside a wind tunnel. These configurations provide a controlled increase in the residence time, thus an increase in the DamkØ hler number.

Approach: During FY1997 a preliminary evaluation of the above mentioned configurations by means of a literature search and some preliminary computations using Large Eddy Simulation (LES) code were conducted. The literature review showed that the proposed configuration is adequate for the present application since it creates a recirculation zone with enhanced mixing, entrainment from the main stream and product evacuation. The flow parameters can be adjusted to provide a stable recirculation zone in a broad range of main stream velocities. Limitations to this approach together with a series of design criteria have been determined. Preliminary calculations with the LES code showed qualitative agreement with reported experimental data while the literature showed that k-e codes seem inappropriate to model the recirculation zone. Different diagnostic techniques used for similar experiments have been evaluated as candidates for characterization of the experimental facility, emphasis is given to velocimetry.

Recent Results: New project.

Water Mist Penetrations Through Complex Openings of Compartments

Principal Investigator:
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Sponsor: National Institute of Standards and Technology

Objective: To understand the phenomena, to reveal the mechanisms, and to correlate the results of the mist penetration through openings of compartments during fire extinguishment.

Problem: During equipment fires, water mist are difficult to penetrate the compartment openings. This complex transport process is strongly influenced by both the structures of the openings which could be screens or slots etc. and the water mist conditions which are droplet sizes, velocities and number densities etc.

Approach: The direct-penetration efficiency of the mist to the compartment can be predicted according to the blockage ratio, which is the cross-sectional ratio of the obstacle to the overall surface, and the impaction efficiency of the mist to the obstacle, where the obstacle is described in a simple geometry and the inertial impaction of drops to the wire is considered. Furthermore, the impaction efficiency of the mist to the obstacle, which is of a simple geometry, can be correlated by a non-dimensional impaction Parameter. For example, the direct-penetration efficiency of a mist flow through a screen is calculated by evaluating the blockage ratio of the screen first, then the impaction efficiency of mist to a single wire is calculated by knowing the Impaction parameter of the mist to the wire. This method of prediction is general and has been validated by 3-D computer simulation.
For the droplets which are intercepted by the structures, they can still penetrate through the screen eventually after forming a film and then detaching as large drops. This is the indirect-penetration. The impaction phenomena in this process are studied experimentally. Single droplets are produced from a monosize droplet generator at controlled conditions. The study covers wide range of the incoming droplet Weber number, the drop to wire size ratio, for wires and screens. The final results of impaction process is shown in regime map and the size of the resulting large-drops is correlated accordingly.

Recent Results:

Hung, L. S. and Yao, S. C.,"Experimental Investigation of the Impacting Water Droplets on Cylindrical Objects", (under review of International Journal of Multiphase Flow.)

Hung, L.S. and Yao, S.C.,"Experimental Studies of Water Droplets Impacting on Cylindrical Wires", Accepted to 3rd International Conference on Multiphase Flows, Lyon, France, 1998.

Hung, L.S. and Yao, S.C.,"Numerical Studies on the Transport of Water Mist for Fire suppression Application", presented at ASME IMECE, 1997.

Hung, L.S. and Yao, S.C.,"Study of Droplet Impaction on Wires for Fire Suppression Applications", Presented at National Heat Transfer Conference, 1997.

A Theoretical and Experimental Investigation on Physical, Thermal and Chemical Effects of Condensed Phase Fire Suppressants

Principal Investigator:
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Sponsor: National Institute of Standards and Technology

Objective: To quantify the physical, thermal and chemical effects of condensed-phase fire suppressants in extinguishing counterflow laminar flames by experimental and computational techniques.

Problem: The production of chemical fire suppressants containing Br-atoms (e.g. CF3Br -- halon 1301) has been banned because of its adverse effects on the upper-atmospheric ozone layer. However, on a mass basis, sodium bicarbonate (NaHCO3) is known to be more effective than halon 1301, and certainly far more effective than most alternate gas-phase fire suppressants. Recent experiments aimed at quantifying the effectiveness of NaHCO3 particles of varying sizes have shown counter-intuitive trends in suppression effectiveness. In order to understand these results and provide information valuable in the search for alternative fire suppressants, a comprehensive experimental and theoretical approach is adopted in the present work.

Approach: A hybrid Eulerian-Lagrangian model developed previously to describe the interaction between droplets/particles with flames was used to quantify the physical, thermal and chemical effects of condensed phase fire suppressants in extinguishing counterflow flames. For fine-water droplets, ranging in size from 0-50 micron, these results have indicated that thermal effects account for about 65% of flame extinction condition, while dilution (i.e. oxygen displacement by water vapor) account for about 25%, and chemical effects accounts for the remainder. This model will be next extended to understand the physical, thermal and chemical contributions of sodium bicarbonate particles in extinguishing flames.
In the supporting counterflow experiments, the flame extinction data based on global extinction strain rates have indicated that effectiveness of sodium bicarbonate particles increases monotonically with decreasing particle size, for the entire size range of 0-50 micron investigated. These results contradict previous non-intuitive results reported in the literature. The accuracy of the observed effectiveness with particle size will be further examined by measuring the flow velocities and local strain rates using an LDV system. In addition, supporting experiments to validate the predicted flame extinction results with fine-water droplets will be carried out using a newly acquired monodisperse water droplet generating nozzle plate.

Recent Results:

Lentati, A.M. and Chelliah, H.K., ``The Dynamics of Water Droplets in a Counterflow Field and its Effect on Flame Extinction," Eastern States Section Meeting, The Combustion Institute, Hilton Head, SC, December, 1996, and Combust. and Flame, 1998 (in press).

Lentati, A.M. and Chelliah, H.K., ``Physical, Thermal and Chemical Effects of Fine-Water Droplets in Extinguishing Counterflow Diffusion Flames," Eastern States Section Meeting, The Combustion Institute, Hartford, CT, October, 1997, and submitted to Twenty-Seventh International Symposium on Combustion, Boulder, CO, 1998.

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Building for Environmental and Economic Sustainability (BEES)

Principal Investigator: Barbara C. Lippiatt, Office of Applied Economics, 301-975-6133

Sponsor: National Institute of Standards and Technology

Objective: To develop and standardize a methodology for designing buildings to achieve the most appropriate balance among life-cycle environmental, economic, and technical performance.

Problem: Environmental and economic performance are two key factors in building product selection decisions. The environmental performance of building products, however, is not readily assessable and comparable to economic performance. A methodology is needed for assessing and comparing environmental against economic performance. To maximize technology transfer, the methodology should be implemented in publicly-available, user-friendly, decision-support software.

Approach: During FY1998, BFRL will work with the building community to develop a standard methodology for designing economically viable, technically sound, green buildings. The BEES methodology, currently aimed at environmental and economic performance at the building element level for the United States, will be expanded to include regional specificity, technical performance, and the whole building.

Recent Results:

Lippiatt, B. C., "The BEES Model for Selecting Environmentally and Economically Balanced Building Products," *Environmental and Economic Balance: The 21st Century Outlook*, Conference Proceedings, Miami, Florida, November 6-9, 1997.

Purchasing Environmentally Preferable Products

Principal Investigator: Barbara C. Lippiatt, Office of Applied Economics, 301-975-6133

Sponsor: Environmental Protection Agency
Pollution Prevention Division

Objective: To develop decision-support software for purchasing products that achieve the most appropriate balance between life-cycle environmental, economic, and technical performance.

Problem: In October 1993, President Clinton signed Executive Order 12873, Federal Acquisition, Recycling, and Waste Prevention, which directs Federal agencies to evaluate the environmental attributes of the $200 billion in products and services they purchase each year. EO 12873 directs EPA to provide guidance to Federal agencies on incorporating environmental preferability into their purchase decisions. EPA is recommending that the environmental life-cycle analysis (LCA) approach be used to assess environmental performance. While LCA provides a comprehensive examination of a product's environmental effects throughout its lifetime, it is difficult to implement and its environmental performance results are sensitive to a number of key parameters. Furthermore, to be practical, environmental performance must ultimately be balanced against economic and technical performance. To carry out the mandate of EO 12873 while not overwhelming Federal purchasers or exceeding purchasing budgets, a flexible LCA technique that incorporates economic and technical performance needs to be developed and implemented in user-friendly decision-support software for the Federal procurement community.

Approach: During FY1998, BFRL will develop a flexible methodology for selecting products that achieve the most appropriate balance between life-cycle environmental, economic, and technical performance. BFRL will implement this methodology in Windows-based decision-support software tailored to the Federal procurement community. The EPP system will contain environmental and economic performance data for a variety of products that typify decisions facing Federal purchasers. The methodology will be developed by building on BFRL's expertise in environmental life-cycle assessment, multi-attribute decision analysis (MADA), and life-cycle costing (LCC). It will follow ASTM standards for LCC and MADA, and the latest ISO 14000 draft standards for environmental life-cycle assessment.

BFRL researchers will develop a demonstration version of the EPP software with performance data for two major product categories. A methodology will be developed for balancing the environmental and economic performance of products using the LCA and LCC approaches. The methodology will involve assessing, synthesizing, and balancing multiple environmental and economic attributes, all of which are measured in different units. These attributes include five important global and regional environmental impacts (global warming, acidification, nutrification, natural resource depletion, and solid waste), as well as product costs over the economic life cycle (first costs and future costs).

An Alpha version of the EPP software will be developed that will expand the system and its product coverage. The EPP system will be expanded by developing an approach permitting integrated sensitivity analysis for efficiently testing the influence on study results of changes in the values of key parameters. Because the Phase I methodology permits the user to customize parameter values, sensitivity analysis can be conducted through an iterative procedure by repeatedly changing parameter values and displaying the new results. In Phase II, sensitivity testing will be automated and made more explicit by integrating uncertainty directly into the results. The user will be able to set a range of possible values for a given parameter, and have the computed results clearly reflect this uncertainty range. The EPP methodology will be refined and a Beta version of the software will be developed. The EPP methodology by incorporating U.S. region specificity. Local environmental impacts such as photo-chemical oxidant formation (smog) will be developed and added to the system, as will U.S. region-specific study parameters such as the sulfur content of coal. Complete data sets for up to six new products will also be developed. These new methodology refinements and products will be incorporated into a Beta version of the EPP software.

Recent Results:

Lippiatt, B.C. "Selecting Environmentally and Economically Balanced Building Materials," *OECD Green Goods IV: International Conference on Greener Public Purchasing*, Conference Proceedings, Biel-Bienne, Switzerland, February 24-26, 1997.

Decision Support Software for Hospitals Financed by HUD-Guaranteed Loans

Principle Investigator: Stephen F. Weber, Office of Applied Economics, 301-975-6137

Sponsor: U.S. Department of Health and Human Services
Health Resources and Services Administration

Objective: To develop a comprehensive decision support software system for the hospitals and health care facilities financed by the Department of Housing and Urban Development (HUD) guaranteed loans.

Problem: The Division of Facilities and Loans of the Health Resources and Services Administration (HRSA) manages a large portfolio of HUD-guaranteed loans made to hospitals and health care facilities. Previous software was used solely for manual recording and reporting on the current status of outstanding loans and did not support optimization of decisions on operation, maintenance, repair, and expansion expenditures over the life cycle of the facilities. Moreover, the system was not integrated with other critical HUD data about the current condition of the hospital facilities themselves. HRSA sponsors need a new system that can access all relevant data to support critical decisions, such as when to survey hospitals for compliance with the Life Safety Code, when an energy conservation audit is advisable, and whether to renew or refinance a loan in light of the facility's operation and maintenance performance.

Approach: During FY1998, BFRL will conduct a study to determine the appropriateness and feasibility of read-only remote access to the data by HUD Hospital Mortgage Insurance Staff as a substitute for the existing centrally printed quarterly reports. This access at the local level will make possible more cost-effective decisions about the health care facilities. BFRL will work with HRSA and HUD staff to determine the possible options for remote access to the data. BFRL researchers will develop small software modules to test remote access using these options.

Recent Results:

Developed and delivered to HRSA a new Windows software system, "Loan Manager," it computes the current balances of all loans in the portfolio and the interest and principal portions and the estimated final payment date.

Minimizing Compliance Costs of the Life Safety Code for Correctional Facilities

Principal Investigator: Stephen F. Weber, Office of Applied Economics, 301-975-6137

Sponsor: National Institute of Standards and Technology

Objective: To develop a systematic procedure for finding low-cost, safety-equivalent solutions compliant with the Life Safety Code for Detention and Correctional Facilities and to incorporate that procedure into Windows software.

Problem: The Fire Safety Evaluation System (FSES) for Detention and Correctional Facilities (Chapter 4 of the NFPA 101A Guide to Alternative Approaches to Life Safety) offers the managers and fire safety engineers of such facilities many alternatives equivalent to prescriptive code compliance. This flexibility makes possible major cost savings when achieving compliance with the Life Safety Code. Needed is a systematic procedure for finding a practical set of low-cost, safety-equivalent solutions from which the building owner can choose.

Approach: During FY1998, BFRL will develop a comprehensive list and detailed specifications for all construction retrofits that apply to each of the 13 fire safety parameters included in NFPA 101A for Detention and Correctional Facilities. A cost minimization model will be developed with supporting algorithms capable of systematically evaluating the costs of all safety-equivalent alternatives to quickly identify the least-cost alternative for any given building zone. Software will be designed and developed to permit easy user specification of the current safety conditions for each of the 13 fire safety parameters and for the quantities of each construction retrofit to be considered for evaluation by the cost minimization model and algorithms. The software will allow users to apply the cost minimization model and supporting algorithms to identify the least-cost alternative for any zone in the correctional facility. Other modules of the software will generate a list of low-cost safety-equivalent solutions for any zone in the correctional facility and another list of simultaneous solutions for all zones in the facility compatible with selected facility-wide design criteria. A User Manual also will be developed. The software and manual will be distributed to Beta testers, revised accordingly, and published.

Recent Results:

Completed review of NFPA 101A provisions for Detention and Correctional Facilities and developed a draft Work Statement to specify the construction retrofits and developed cost data for them.

Cost-Effective Decisions for Police Patrol Vehicle Disposal

Principal Investigator: Stephen F. Weber, Office of Applied Economics, 301-975-6137

Sponsor: National Institute of Standards and Technology
Office of Law Enforcement Standards

Objective: To develop a systematic procedure and supporting Windows software for cost-effective disposal and replacement of police patrol vehicles.

Problem: The disposal and replacement of police patrol vehicles have major cost consequences for law enforcement budgets. Most current approaches to vehicle disposal/replacement decisions use average costs to predict future repair costs for an entire class of vehicles (defined by model and year). But this approach is useful only if every vehicle's repair history closely follows the average repair history of the class. More sophisticated repair models are needed to produce significant cost savings compared with the current approaches.

Approach: During FY1998, BFRL will apply its statistical model that permits estimation of the number of failures expected to occur in the coming planning period. This model will be applied to help fleet managers make cost-effective decisions regarding the disposal and replacement of vehicles. A prototype version of software called AutoRank also was developed to test the feasibility of the statistical model. The approach consists of applying data on the frequency of repairs for a vehicle class to estimate a generalized model of vehicle repairs based on the Weibull distribution, widely used for reliability analysis. Then, for each vehicle in the fleet, the model will use data on the particular vehicle's pattern of repairs to estimate expected repair costs for that vehicle over the coming period. Vehicle repair estimates can be grouped by repair category. The model will then rank all vehicles for disposal based on expected repair costs, operation and maintenance costs, and loss of resale value. The fleet manager would then dispose of those vehicles with the highest predicted costs, resulting in a cost-effective strategy for vehicle disposal and replacement.

Recent Results:

Created procedure for statisticians to develop the necessary algorithms for computing parameters of the Weibull distribution and estimates of the probabilities of future failures and repairs. Completed evaluation of computational algorithms for estimating four of the six statistical functions needed for the model.

Internet Support for Cost-Effective Selection of Police Vehicles

Principle Investigator: Stephen F. Weber, Office of Applied Economics, 301-975-6137

Sponsor: National Institute of Standards and Technology
Office of Law Enforcement Standards

Objective: To develop an interactive web site to assist police department fleet managers make cost-effective decisions in the acquisition of police patrol vehicles.

Problem: A microcomputer system called AutoBid was developed by BFRL to help police fleet administrators select the patrol vehicle that is best suited to the needs of their department. The system is based on vehicle performance data for police patrol models published annually by the Michigan State Police. The system is currently distributed by request to police departments by mailing diskettes with all the data files and software.

Approach: During FY1998, BFRL will prepare the data files on police patrol vehicle performance data compatible with AutoBid for the 1998 model year. BFRL will develop and implement a JAVA applet which will offer visitors an interactive data entry form to specify their own particular weighting factors that determine the relative importance of each performance variable. The software would compute an overall score for each vehicle, weighted by the user's specified relative importance of each performance variable. The software would then generate a graphical report displaying these performance scores.

Recent Results:

Maintained the AutoBid software and included the performance data for the most recent model year police patrol vehicles during past eight years. Developed a small JAVA applet to permit viewing of the hardware specification data for any set of vehicles selected by the user.

Economic Support for Performance Standards System for Housing

Principal Investigators: Robert Chapman, Office of Applied Economics, 301-975-2723
Harold Marshall, Office of Applied Economics, 301-975-6131

Sponsor: National Institute of Standards of Technology

Objective: To support BFRL through the provision of standard economic methods and software that help decision makers in the housing industry choose the most cost-effective designs, materials, and equipment that satisfy housing performance standards.

Problem: When making cost-effective choices among alternative housing designs, materials, and systems that would satisfy a performance standard, decision makers must have data on benefits and costs associated with each alternative and tools (methods and software) for measuring those benefits and costs. These are critical elements for helping and encouraging the housing industry to develop, introduce, and accept innovative housing products and systems. Having a package of economic tools (methods and software) that helps users identify and measure the benefits and costs from choosing new-technology products and systems will accelerate the introduction and acceptance of new technologies in the U.S. and abroad.

Approach: During FY1998, BFRL will develop a benefit and cost classification format that will help decision makers identify potential benefits and costs from alternative design, material, and system selections. In addition, the researchers will identify and illustrate, in case examples, methods for evaluating those economic benefits and costs of alternative housing designs, materials, and systems. To assure industry acceptance, the methods will be made consistent with ASTM's published standard methods on building economics. Two methods will be emphasized. One is the life-cycle cost (LCC) method, which helps the user select the least-cost alternative that meets the performance standard. The second is the analytical hierarchy process (AHP) method, which allows the user to consider in addition to LCC data both qualitative and quantitative (non-monetary) data in choosing the best technology. Case illustrations of how to use the LCC and AHP methods in seeking the optimal alternative to meeting a housing performance standard will be submitted to ASTM to be included in ASTM standards. To complete the economic evaluation package, user-friendly, decision-support software will be developed to encourage and facilitate implementation of the economic measures in practice.

Recent Results:

Chapman, R. E., and Fuller, S. K., *Benefits and Costs of Research: Two Case Studies in Building Technology,* NISTIR 5840, National Institute of Standards and Technology, July 1996.

Chapman, R. E., and Weber, S., *Benefits and Costs of Research: A Case Study of the Fire Safety Evaluation System,* NISTIR 5863, National Institute of Standards and Technology, July 1996.

Economic Support for Computer-Integrated Construction

Environment Products

Principal Investigator: Robert Chapman, Office of Applied Economics, 301-975-2723
Harold Marshall, Office of Applied Economics, 301-975-6131
Amy Boyles, Office of Applied Economics, 301-975-6136

Sponsor: National Institute of Standards and Technology

Objective: To provide economic support to BFRL on how to identify industries affected by BFRL's Computer-Integrated Construction Environment (CICE) related research, estimate economic impacts resulting from BFRL's CICE-related research, and estimate the return on BFRL's CICE-related research investment dollars.

Problem: The measurement of economic impacts of research is a major BFRL objective. Improved methods for measuring economic impacts are essential to BFRL to help select the "best" among competing research programs, to evaluate how cost effective are existing research programs, and to defend or terminate programs on the basis of their economic impact.

Approach: During FY1998, BFRL researchers will plan and initiate an *ex ante* impact assessment. The *ex ante* impact assessment will be completed in FY1999 with a scheduled follow-up in FY 2002. The FY1998 effort will be centered about a formal study of the anticipated CICE-related impacts. The study will include a system for identifying and classifying benefits (savings) and costs and for documenting which CICE-users and stakeholders will be affected and how. Particular emphasis will be placed on documenting how the seamless electronic integration of work processes will affect users (e.g., cost savings due to reductions in construction cost or benefits in the form of higher profits due to reductions in cycle time) and stakeholders (e.g., producing interface protocols which allow equipment manufacturers to achieve economies of scale in the production of proprietary products). Researchers will seek to leverage two efforts currently underway at the Construction Industry Institute (CII). The first effort involves the CII Benchmarking and Metrics Committee (BMC). The goal of the CII BMC is to develop metrics and measure their value for key construction processes, including integration and automation. BFRL's past and current participation in the CII BMC will promote collaboration on topics related to integration and automation. CII's second effort is the newly established Sloan Project being carried out in collaboration with the University of Texas at Austin. BFRL will leverage these two efforts by facilitating interactions between the CII BMC and the Sloan Project.
This work will help actual and potential CICE users (e.g., building/facility owners and contractors) and stakeholders (e.g., equipment manufacturers) identify and measure the benefits and costs associated with CICE-related new-technology products. By providing facts and data which demonstrate the value of CICE-related new-technology products to key users and stakeholders, BFRL will serve to accelerate the introduction and acceptance of these products in the U.S. and abroad.

Recent Results:

Chapman, R. E., and Fuller, S. K., *Benefits and Costs of Research: Two Case Studies in Building Technology,* NISTIR 5840, National Institute of Standards and Technology, July 1996.

Chapman, R. E., and Weber, S., *Benefits and Costs of Research: A Case Study of the Fire Safety Evaluation System,* NISTIR 5863, National Institute of Standards and Technology, July 1996.

Economic Support for Cybernetic Building Systems

Principal Investigators: Robert Chapman, Office of Applied Economics, 301-975-2723
Harold Marshall, Office of Applied Economics, 301-975-6131
Amy Boyles, Office of Applied Economics, 301-975-6136

Sponsor: National Institute of Standards and Technology

Objective: To provide economic support to BFRL on how to identify industries affected by BFRL's Cybernetic Building Systems (CBS) related research, estimate economic impacts resulting from BFRL's CBS-related research, and estimate the return on BFRL's CBS-related research investment dollars.

Problem: The measurement of economic impacts of research is a major BFRL objective. Improved methods for measuring economic impacts are essential to BFRL to help select the "best" among competing research programs, to evaluate how cost effective are existing research programs, and to defend or terminate programs on the basis of their economic impact.

Approach: During FY1998, BFRL will conduct an economic impact assessment of BFRL's CBS-related research, monitor outcomes, and conduct a follow-up economic impact assessment. The research approach will follow the basic structure of the economic impact assessments completed in FY 1996. It will use standardized methods to measure and evaluate economic impacts and a format for concisely summarizing economic impacts. In addition, a detailed sensitivity analysis will be performed. The sensitivity analysis will be used to demonstrate the likely range of impacts of BFRL's research contribution. This economic impact assessment differs from those conducted in FY 1996 in two ways. First, the previous impact assessments were conducted on projects which had been completed and for which all benefits (savings) and costs attributable to BFRL's contribution had already accrued. Second, the scope of each previous impact assessment was on a single project, not a collection of efforts aimed at delivering a major product and a variety of sub-products to industry. Consequently, uncertainty enters the analysis in two ways which were not present in the previous impact assessments: (1) the magnitude of cash flows (i.e., benefits (savings) and costs are not based on actual achieved levels or *ex post* estimates of these levels); and (2) the timing of cash flows (i.e., some benefits (savings) can not occur until a specific deliverable is produced). Consequently, researchers will conduct an *ex ante* impact assessment in FY1998 with a scheduled follow-up in FY2001.
Staff will plan, initiate, and carry out an *ex ante* impact assessment of BFRL's CBS-related research. The FY1998 impact assessment effort will include a system for identifying and classifying benefits (savings) and costs and for documenting how beneficiaries (i.e., users and stakeholders) will be affected. Particular emphasis will be placed on estimating how CBS-related research will affect users (e.g., potential savings to building owners due to systems integration and optimization capabilities) and stakeholders (e.g., better load-leveling capabilities for utilities and energy providers, increased productivity and comfort for building occupants, increased sales by equipment manufacturers which can better package their proprietary products--potentially achieving economies of scale in production). In carrying out the impact assessment, a two-pronged strategy will target organizations--associations, societies, and advocacy groups (e.g., ASHRAE and the BACnet Consortium)--which can leverage contacts with beneficiaries. The strategy for reaching beneficiaries is driven by the fact that BFRL's CBS-related research seeks to produce a series of products, which impact different sets of beneficiaries. Consequently, the strategy is designed to seek information and data for estimating and/or documenting CBS-related benefits (savings) and costs and to promote awareness and shape expectations of the beneficiaries, and to leverage the dissemination of findings.

Recent Results:

Chapman, R. E., and Fuller, S. K., *Benefits and Costs of Research: Two Case Studies in Building Technology,* NISTIR 5840, National Institute of Standards and Technology, July 1996.

Chapman, R. E., and Weber, S., *Benefits and Costs of Research: A Case Study of the Fire Safety Evaluation System,* NISTIR 5863, National Institute of Standards and Technology, July 1996.

Economics of High Performance Concrete

Principal Investigator: Mark A. Ehlen, Office of Applied Economics, 301-975-4522

Sponsor: National Institute of Standards and Technology

Objective: To develop integrated life-cycle costing software for evaluating the cost effectiveness of high-performance concrete (HPC) in highway bridge applications.

Problem: The rapid and costly deterioration of concrete highway bridges is encouraging those that do preliminary design to select HPCs that make bridges less costly to build and last longer. HPC impacts the life-cycle cost of bridges along important dimensions, many of which are investigated by BFRL's thrust in Partnership for High Performance Concrete Technology (PHPCT). Optimal HPC designs reduce bridge material and installation costs when higher strength allows for a structure with fewer bridge members. HPC curing can take less time than conventional concrete curing, thereby shortening construction schedules and traffic delays. HPC's durability can produce structures with longer service lives. Bridge designers need an economic tool which allows them to compare, and quantify in life-cycle cost terms, these technical advantages of HPC.

Approach: During FY1998, BFRL will provide for, in the short run, a stand-alone economic tool for designers and, over the longer term, for an economic component in Computer Integrated Knowledge Systems for HPC. The short-run plan involves completing BridgeLCC version 1.0 which will allow bridge designers to make basic life-cycle cost comparisons between HPC and conventional concrete bridges. Version 1.0 will include: two studies as examples of how analyses are done; a small database of bridges with typical bridge spans, traffic levels, concretes, and service lives; and the PHPCT service life prediction tool. This will provide an initial framework for the next four years during which additional PHPCT design, processing, curing, and service life tools, along with more sophisticated economic decision tools, will be integrated into BridgeLCC. The BridgeLCC product will be a stand-alone, user-friendly application that preliminary designers can use to select optimal HPC designs for their structure and compare the resulting HPC life-cycle costs to conventional concrete structures.
Over the five year period, BridgeLCC will provide a real-world design tool for developing the Computer Integrated Knowledge Systems for HPC taxonomy and knowledge structure. This tool also will serve as a vehicle for fully integrating the life-cycle costing knowledge structure into Computer Integrated Knowledge Systems for HPC.

Recent Results:

Ehlen, Mark A. "Life-Cycle Costs of New Construction Materials," *Journal of Infrastructure Systems*, Vol. 3 No. 4, December 1997.

Economic Support to NIST Advanced Technology Program

Principle Investigator: Stephen F. Weber, Office of Applied Economics, 301-975-6137

Sponsor: National Institute of Standards and Technology

Objective: To support the economic and program evaluation missions of NIST's Advanced Technology Program (ATP) by providing reviews of economic impact proposals; providing economic modeling and analysis services; designing and developing economic questionnaires; and implementing questionnaires in software to permit electronic submission by ATP awardees of a variety of periodic reports on economic progress and economic impacts.

Problem: ATP management is developing and administering questionnaires to track the technological and economic progress of awardees. Economic consulting is needed to help develop and review the questions, and software is needed to implement the questionnaires in electronic form. ATP also needs help in conducting economic impact assessments of its projects, including application of the REMI simulation and forecasting econometric model, as well as in reviewing proposals from economists outside of NIST.

Approach: During FY1998, BFRL will support ATP by helping to develop economic questions, working with ATP economists to specify data requirements, and designing efficient ATP awardee questionnaires to support economic impact models as well as REMI analyses. BFRL also will provide technical support for the existing economic questionnaire software and to the awardees filling out the questionnaire.
BFRL will work with ATP economists to develop methods to estimate economic impacts of ATP funded research and to apply econometric forecasting and simulation tools such as REMI to case studies of ATP projects. BFRL economists will conduct a REMI analysis of a selected ATP technology and publish a report on the analysis results.

Recent Results:

Restructured ATP's existing questions and data from the Quarterly and Anniversary Report system into the new format for baseline questions, annual questions, and close-out questions.

Provide Economic Support to NIST Manufacturing Extension Partnership

Principal Investigator: Stephen F. Weber, Office of Applied Economics, 301-975-6137

Sponsor: National Institute of Standards and Technology

Objective: To support the economic evaluation mission of NIST's Manufacturing Extension Partnership (MEP) by identifying data sources, developing economic data analysis software, developing economic maps, modeling economic impacts, and developing tools for benchmarking Manufacturing Extension Center (MEC) programs' performance.

Problem: MEP management needs economic consulting support for planning, reporting, and program evaluation.

Approach: During FY1998, BFRL will continue to apply state-level REMI models to several state MEC programs to estimate economic impacts of MEC activities. BFRL will revise and publish on national economic impacts of productivity improvements in manufacturing and present several seminars at MEP meetings and REMI conferences on the economic impacts of the Pennsylvania MECs. BFRL also will conduct REMI macroeconomic analysis at the national level on the 1996 MEP client survey data and present results to MEP.

Recent Results:

Ehlen, M., and Weber, S., *Estimating Economic Impacts of Government Technology Programs: Manufacturing Studies Using the REMI Model,* NISTIR 6107, National Institute of Standards and Technology, December 1997.

How to Select Research Projects and Measure Their Impacts

Principal Investigator: Robert Chapman, Office of Applied Economics, 301-975-2723

Sponsor: National Institute of Standards and Technology

Objective: To provide economic support to BFRL on how (1) to select appropriate research projects for funding and (2) to identify industries affected by BFRL research, estimate economic impacts resulting from BFRL research, estimate the return on BFRL's research investment dollars, and report the results.

Problem: The measurement of economic impacts of research is a major BFRL objective. Improved methods for measuring economic impacts are essential to BFRL to help select the "best" among competing research programs, to evaluate how cost effective are existing research programs, and to defend or terminate programs on the basis of their economic impact.

Approach: During FY1998, BFRL will produce two Analytical Hierarchy Process (AHP)-based resource allocation models for use by BFRL senior management in selecting among two types of competing research projects. The first type includes the major products and other high-impact projects. The second type includes competence projects. Second, BFRL will revise ASTM Standard Practice E 1765, Applying Analytical Hierarchy Process to Multi-attribute Decision Analysis of Investments Related to Buildings and Building Systems.
Many research investment alternatives differ in characteristics that decision makers consider important but that are not readily expressed in monetary terms. To achieve the desired outcome or goal when non-financial characteristics are important, decision makers need a method that accounts for these characteristics when choosing among alternative research investments. The analytical hierarchy process is a method that considers non-financial characteristics, in addition to common economic evaluation measures, when evaluating project alternatives against a stated goal. In the context of the AHP, non-financial characteristics, economic evaluation measures, and other key factors are referred to as criteria. A key advantage of the AHP is that its use is facilitated by available software and an ASTM Standard Practice. BFRL was instrumental in the production of the first ASTM Standard Practice, E 1765, on the use of the AHP and has subsequently participated in an ASTM-supported software development effort.
BFRL will revise and expand the AHP-based resource allocation model developed in FY 1997. This model may be used for rating projects and allocating the budget among the major products and other high-impact projects. Resource allocation models will be produced in time for use in the FY 1999 budget allocation process. BFRL will prepare a white paper outlining the approach and the two resource allocation models.
BFRL will revise ASTM's AHP Standard Practice, E 1765, to incorporate enhancements resulting from the production of an ASTM-supported, AHP-based software product. The revisions will promote a broader use of both ASTM Standard Practice E 1765 and the software product. Revisions to ASTM Standard Practice E 1765 are needed now because ASTM will begin marketing the AHP-based software product early in 1998.

Recent Results:

Chapman, R. E., and Fuller, S. K., *Benefits and Costs of Research: Two Case Studies in Building Technology,* NISTIR 5840, National Institute of Standards and Technology, July 1996.

Chapman, R. E., and Weber, S., *Benefits and Costs of Research: A Case Study of the Fire Safety Evaluation System,* NISTIR 5863, National Institute of Standards and Technology, July 1996.

Life-Cycle Costing Methodology

Principal Investigator: Sieglinde Fuller, Office of Applied Economics, 301-975-6134

Sponsor: Department of Energy
Federal Energy Management Program

Objective: To provide, on a continuing basis, economic analysis methods, data, software, training, and consulting to the Federal Energy Management Program in support of energy and water conservation projects in federal buildings and facilities.

Problem: The National Energy Conservation Policy Act directs BFRL to provide expert consulting to DOE related to economic analysis of energy conservation projects in federal buildings. Executive Order 12902 of March 8, 1994, requires that energy usage in federal facilities be reduced by 30% by the year 2005 relative to 1985 levels, in a cost-effective manner.

Approach: During FY1998, BFRL will continue providing DOE a continuing stream of products.
Methodology: BFRL is responsible for assisting DOE in the development and modification of FEMP LCC rules, as promulgated in 10 CFR 436 Subpart A. BFRL is amplifying these rules and procedures in NIST Handbook 135, *Life-Cycle Costing Manual for the Federal Energy Management Program.*
Data: Each year BFRL computes the discount rate to be used in the analysis of federal energy and water conservation projects, using the procedure specified in 10 CFR 436. In addition, BFRL computes tables of discount factors and energy price indices, based on this discount rate and on energy price projections received from DOE/EIA for this purpose. These data are published each October 1 in the *Annual Supplement to Handbook 135*, and included in electronic form with the NIST LCC software.
Software: BFRL has developed five computer programs for economic analysis of energy and water conservation projects: BLCC, Quick Input, DISCOUNT, ERATES, and EMISS. These programs are maintained, updated, and enhanced with new analytical capabilities annually. They are distributed by DOE and numerous private-sector software vendors. User manuals are provided with each program. The BFRL software have been incorporated into several other software projects outside NIST, under the sponsorship of DOE and DoD. A new initiative focuses on integrating these programs with BLCC into a new windowed software package that could serve as a standard for all government LCC analyses.
Training: BFRL has developed a basic LCC workshop which it has conducted several times each year at locations throughout the United States, primarily for federal engineers and energy managers, but attended by representatives from state and local government, utilities, and consultants from the private sector. To extend access to the methodology to a wider audience, OAE has developed and teaches a teleconference course that DOE broadcasts to up to 30 locations several times each year.
Consulting: BFRL provides consulting to DOE, related to methods of economic analysis for federal energy and water conservation projects on a continuous basis. For example, changes to the FEMP LCC rules in 10 CFR 436 are made in consultation with BFRL economists; users of these publications and software frequently call with technical questions related to these materials and to interpretation of 10 CFR 436.

Recent Results:

Fuller, Sieglinde K., *Life-Cycle Costing Methodology,* Module 8 of Energy Manager Training Workshop, Teleseminar of US Department of Energy, Oak Ridge Institute for Science and Eduction, June 1997.

Petersen, Stephen R., *BLCC--The NIST "Building Life-Cycle Cost" Program, Version 4.51,* National Institute of Standards and Technology, April 1997.

Fuller, Sieglinde K., and Petersen, Stephen R., *Life-Cycle Costing Workshop for Energy Conservation in Buildings: Student Manual,* NISTIR 5165, National Institute of Standards and Technology, April 1997.

Fuller, Sieglinde K., *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis--April 1997: Annual Supplement to NIST Handbook 135 and NBS Special Publication 709,* NISTIR 85-3273-12, National Institute of Standards and Technology, April 1997.

Fuller, Sieglinde K., and Petersen, Stephen R., *Life-Cycle Costing Manual for the Federal Energy Management Program,* NIST Handbook 135, National Institute of Standards and Technology, February 1996.

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BFRL HEADQUARTERS

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Program to Assist Other Nations in the Adoption and Use of U.S. Building Codes and Standards

Principle Investigator: Joel Zingeser, BFRL Headquarters, 301-975-4630

Sponsor: National Institute of Standards and Technology
National Conference of States on Building Codes and Standards
Model Codes and Standards Development Organizations

Objective: To assist the U.S. construction industry in major developing markets to avoid technical barriers to trade and to promote the application of U.S. technology in international construction markets through the development and adoption of appropriate building and construction practices, codes, specifications, and standards.

Problem: Market share of U.S. companies in the international construction market has been on the decline and faces increased stiff competition from European and Japanese contractors who have shown substantial increases. The European Union (EU) and individual European governments have made concerted efforts to reduce U.S. market share in many markets. As part of this effort, the EU is attempting to establish European, rather than U.S., building and construction codes and standards.

Approach: This program is being conducted under a National Institute of Standards and Technology (NIST), Memorandum of Understanding (MOU) with the National Conference of States on Building Codes and Standards (NCSBCS). The program is the outgrowth of an initial request from the Kingdom of Saudi Arabia. A Memorandum of Understanding between NIST and the Saudi Arabia Standards Organization (SASO) has been extended and includes this building code project.
During FY1998, BFRL will continue the coordination of the Program Steering Committee to help guide the U.S. participants through planning and implementation phases. Additional interest in similar technical assistance has been expressed from the Caribbean Basin/Central America Region and a workshop to better define their needs will be held in October 1998 with the assistance of the Conference of World Region's Subcommittee on Building Codes and Standards, the organization of American States, the International Bank, and other co-sponsors. Additional countries in the Middle East, Asian-Pacific Region, and South America also represent potential opportunities for future assistance.

Results:

No publications produced.

Performance Standards System for Housing

Principle Investigator: Joel Zingeser, BFRL Headquarters, 301-975-4630

Sponsors: Department of Housing and Urban Development
Office of Program Development and Research
National Institute of Standards and Technology

Project Objective: To support the development of a comprehensive national and international performance standards system to guide the procurement, evaluation and acceptance of innovative housing products and systems.

Problem: The present prescriptive system for regulating housing construction is a primary barrier to innovation and limits competition both nationally and internationally. U.S. housing products, components, systems, and know-how have not been widely accepted in the global economy. The creation of a well conceived and functioning performance based standards system for the procurement and evaluation of housing will more readily allow for and should encourage the use of innovative designs, products and processes leading to improved quality, lower life-cycle costs of housing to consumers and increased competitiveness for U.S. companies. The need for a performance standards system for housing is a priority component of the Residential Sector Strategic Approach aimed at meeting the National Construction Goals. Research is required to develop better criteria and methods for evaluating performance.

Approach: During FY1998, BFRL will continue to support the development of a coordinated set of individual standard guides for each of the 16 attributes identified as relevant to the specification and evaluation of the performance of housing. These individual standard guides will be based on a matrix of attributes and elements (building subsystems) and will use the RCEC (requirements, criteria, evaluation, and commentary) structure. The matrix and the standard guides will be reviewed for acceptance by ASTM and ISO. The drafts of these standard guides will be prepared by individuals from BFRL, other government agencies, industry volunteers, consultants, and others as appropriate. The draft documents will be reviewed by leading industry participants and used to define specific areas of research necessary to better define the appropriate criteria and evaluation methods. This year's areas of related research include wind, structural performance, indoor air quality, durability, and economics. Industry participants are expected to include those companies involved in the Coatings Service Life Prediction Consortium and the structural performance programs being conducted at NAHB Research Center. Additional companies are expected to be identified through the NAHB Research Center=s HomeBase program. Also, it is anticipated that additional companies interested in evaluation of innovations will be identified through the National Evaluation Service=s Building Innovation Center (NES-BIC). Finally, participants in the PATH program pilot projects will be candidates for further cooperation under the PSSH.

Results:

Developed and distributed a guide for preparation of performance standards. Drafted five ASTM formatted pre-standard guides.

Subcommittee on Construction and Building

Principle Investigator: Andrew Fowell, BFRL Headquarters, 301-975-6865

Sponsor: National Institute of Standards and Technology
Department of Energy
Office of Energy Efficiency and Renewable Energy
Department of Transportation
Federal Highway Administration
Department of Housing and Urban Development
Office of Research, Evaluation, and Monitoring
Department of Health and Human Resources
National Institute of Occupational Health and Safety
General Services Administration
Public Building Service
National Science Foundation
Civil and Mechanical Systems Division
Department of Defense
Office Sec. Defense
Department of Defense
Corps of Engineers
Department of Labor
Occupational Safety and Health Administration
Department of Veterans Affairs

Objective: To coordinate federal agency programs in support of their enhancing the competitiveness of U.S. industry, public safety and environmental quality through research and development, in cooperation with U.S. industry, labor, and academia, for improvement of the life cycle performance of constructed facilities.

Problem: The construction industry comprises about 13% of the Gross Domestic Product, and yet it lags other business sectors on R&D investment. This is partly because only a few firms have the capability to conduct significant R&D, and in order to make competitive bids few construction firms can absorb the risk inherent in the pursuit and development of innovation. Most innovation in the industry is done by manufacturers of products that are used in buildings. For the construction industry to be competitive in a global economy, where Japan and Western Europe are making significant investments, it must overcome the slow pace of introduction of innovative technology. The industry is disagregated, lacks leadership, and faces many barriers to the use of new technology. There has been a lack of coordination between government and industry, and between agencies within the Federal government involved in construction. The regulatory process has been blamed for increasing the overall time for delivery of constructed facilities. Many authorities have made process improvements which could well be adopted by other authorities. Residences are major energy users thereby contributing to global warming. Improvements in the quality of housing including lower energy consumption, greater durability, can be viable only if they can be achieved at no addition to the monthly cost of housing.

Technical Approach: During FY1998, BFRL will continue co-chairing and providing the Secretariat to the Subcommittee on Construction and Buildings, (C&B), of the National Science and Technology Council Committee on Technological Innovation. C&B coordinates activities within the Federal government and works with the construction and building industry to stimulate research and adopt both process and product innovations. Fourteen Federal agencies are represented on the Subcommittee, which meets monthly. The Building Economics Group of BFRL will continue to search and analyze available data relating to current practices to provide baseline data on the goals. A study to document the relationship between building performance and worker productivity will be continued. We will coordinate the work of the federal agencies to provide technical support for each sector of the

industry in striving to achieve the National Construction Goals. We will work with ASME to develop a joint government/industry program for mechanical and electrical systems industries similar to CONMAT. The brochure describing the National Construction Goals and federal R&D support to the construction and building industries will be updated. C&B will provide federal agency liaison support to PATH. The potential for an initiative on improving the civil infrastructure will be explored.

Results:

Developed a brochure describing federal R&D support to the construction and building industries

Provided grant to NCSBCS to collect case studies of successful efforts to streamline the building regulatory process.

Initiated a contract was let with the Board on Infrastructure and the Constructed Environment to document the relationship between building performance and worker productivity.

Secretariat U.S.-Side Panel on Wind and Seismic Effects

Principle Investigators: Noel J. Raufaste, BFRL Headquarters, 301-975-5905

Sponsor: National Institute of Standards and Technology

National Science Foundation
CORPS Department of Army
Bureau of Reclamation
Department of Energy
Federal Highway Administration
Mineral Management Services
Agency for International Development
Center for Disease Control

Objective: To provide the U.S. Secretariat of the U.S.-Japan Panel on Wind and Seismic Effects

Problem: Loss of life and property result from insufficient knowledge to adequately design and construct building and other structures cost-effectively against high winds and seismic loads. Improved mitigation practices are in early stages of development. Technical collaborations between experts in the U.S. and Japan continue to produce findings that improve natural hazard mitigation practices. Such improvements are possible through joint working relations with experts from the U.S. and Japan through performing joint research projects and exchanges of research personnel, technical data & information, and research equipment. [This Panel is part of the US-Japan Natural Resources Development Program under the aegis of the US-Japan Cooperative Science Program of 1961.]

Approach: During FY1998, BFRL will continue providing the U.S. Secretariat:

4. Planning U.S.-side activities (19 Agency membership) through hosting two US Panel's domestic meetings.
5. Managing the US delegation's technical contributions to Annual Joint Meetings.
6. Planning and coordinating technical activities of the 11 Task Committees.
7. Managing U.S.-delegation to Japan-side hosted Meetings and Workshops and developing technical programs for US hosted meetings.
8. Maintaining liaison with US and Japan Panel members and other experts associated with the Panel's activities.
9. Planning Japan Panel member visits to the US under the auspices of the Panel, e.g., post disaster investigations, special studies, data gathering.
10. Maintaining administrative and technical records.
11. Preparing and distributing periodic activities reports, and other materials as appropriate to U.S.-side Panel and Task Committee members.
12. Participating in Joint Panel meetings and Task Committees.
13. Preparing and publishing annual Proceedings.

Results:

Wind and Seismic Effects Proceedings of the 29th Joint Meeting of U.S.-Japan Panel, UJNR, Public Works Research Institute, Ministry of Construction, May, 1997.
Wind and Seismic Effects Technical Bulletin Winter 1998, Public Works Research Institute, Ministry of Construction.

Computing and Network Resources

Principle Investigator: Darren L. Lowe, BFRL Headquarters, 301-975-6667

Sponsor: National Institute of Standards and Technology

Objective: To provide day to day support and long range planning for the BFRL network, Web site, intranet services, manuscript database and BFRL users.

Problem: Efficient computing requires a uniform and consistent environment for both scientific and administrative services. PC users need expert day to day support to configure and install new software, and to minimize any software problems during use. Currently workstations operating on the UNIX system have no central support. It is necessary for each user to contract for support services for UNIX systems. The World Wide Web is rapidly becoming a means for communicating the results of BFRL activities to the user audience. BFRL needs to maintain a comprehensive website of its research.

Technical Approach: During FY1998, BFRL will configure, purchase, and install new hardware and operating software to ensure that the local area networks continue to provide a uniform and reliable service. Software will be added to local area networks to enable all BFRL staff to send Fax messages directly from their computers. The BFRL site on WWW will be continually updated and kept user friendly and informative. The BFRL intranet will be developed as a user friendly information resource to the staff. A well-managed Intranet will be maintained for BFRL staff.

Results:

BFRL's external and internal websites have been enhanced. 100 MB/second Ethernet service has been provided to all of BFRL staff.