

FIRE SAFETY SCIENCE – PROCEEDINGS OF THE NINTH INTERNATIONAL SYMPOSIUM

Editor

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**INTERNATIONAL ASSOCIATION
FOR FIRE SAFETY SCIENCE**

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The cover flames were drawn by Prof. Yuji Hasemi of Waseda University, Japan, based on photographs taken by Prof. E.E. Zukoski, formerly of California Institute of Technology, Pasadena, California, USA.

Preface

The Ninth International Symposium on Fire Safety Science was held at the University of Karlsruhe 21-26 September 2008. The symposium was organized by the International Association for Fire Safety Science (IAFSS) and co-hosted by the German Fire Protection Association (Vereinigung zur Förderung des Deutschen Brandschutzes, VFDB), with the local organization by the Research Centre for Fire Protection Technology (Forschungsstelle für Brandschutztechnik) at the University of Karlsruhe.

Over 300 registrants attended the three parallel sessions in which 114 fully peer review papers, including six invited papers, were presented. The papers are printed in this volume and are also available at the IAFSS Bibliographic Database Site at <http://iafss.haifire.com>. Also, two poster sessions were held at the symposium where a large number of posters were presented, 88 of these are available at the IAFSS Bibliographic Database Site. Additionally, three workshops were given at the start of the symposium on the subjects of Flame Spread Modeling, Egress Modeling and Structural Fire Engineering. Twenty-five countries were represented: Australia, Belgium, Canada, China, Denmark, Finland, France, Germany, Iceland, India, Indonesia, Israel, Italy, Japan, Korea, Netherlands, New Zealand, Russia, Singapore, Spain, Sweden, Switzerland, Taiwan, United Kingdom and the United States of America.

The opening ceremony was conducted by representatives from the host country and IAFSS: Mr Heribert Rech, Minister of Interior, Baden-Württemberg State, Prof. Horst Hippler, Rector of the University of Karlsruhe, Mr Hans-Jochen Blätte, President, German FPA and Dr Craig Beyler, Chairman of the IAFSS.

Following the opening ceremony, Dr. Vytenis Babrauskas, Fire Science and Technology Inc., delivered the Howard W. Emmons Plenary Lecture entitled "Research on Electrical Fires: The State of the Art". Five other invited papers were also presented during the course of the symposium by Prof. Reinhard Grabski, Prof. Haukur Ingason, Prof. Takeyoshi Tanaka, Dr. George Hadjisophocleous and Ehab Zalok and Prof. Andy Buchanan.

At the Award Reception and Banquet, Dr. Mario Fontana, Chair of the Symposium Awards Committee, presented the Howard W. Emmons Lectureship Award to Dr. Vytenis Babrauskas. The P.H. Thomas Silver Medal of Excellence for the best paper at the Eighth Symposium was awarded to Timo Korhonen, Simo Hostikka and Olavi Keski-Rahkonen for their paper entitled "A proposal for the Goals and New Techniques of Modeling Pedestrian Evacuation in Fires." The K. Kawagoe Gold Medal for Outstanding Lifelong Contributions to Fire Safety Science was presented to Dr. Geoff Cox. The IAFSS Best Thesis Award was presented to Markus Knobloch (Europe), Ali S. Rangwala (Americas) and Johannes A. W. Dimyadi (Asia). On behalf of the Forum for International Cooperation on Fire Research, Dr. Franco Tamanini presented the V. Sjolín Award to Dr. Geoff Cox, Dr. Richard Gann and Dr. Andrew Buchanan in recognition of their pioneering work in fire safety science for the years 2006, 2007 and 2008 respectively.

The IAFSS would like to thank FM Global and the National Fire Protection Association for being the principal sponsors of the symposium. In addition, the IAFSS would like to extend its gratitude to all the organizations, committee members, and other volunteers that assisted in making this symposium so successful. A special thanks is given to Mr. Dieter Brein and the staff at the Research Centre for Fire Protection Technology (Forschungsstelle für Brandschutztechnik) at the University of Karlsruhe, as well as the members of the local Symposium Arrangements Committee. Together with the co-organizers, the German Fire Protection Association, they provided first class hospitality as well as an excellent forum for the exchange of ideas on fire safety science.

The IAFSS would also like to greatly thank all those involved in the review, selection, and editing of the papers for the conference. A special thanks is given to Dr. Anthony Hamins and Dr. Matthew Bundy, Chair and Deputy-Chair of the Program Committee, for organizing and leading the committee on the selection of papers, and all of the program committee members who interacted with authors and reviewers as well as reviewed final manuscripts to ensure all reviewer comments were addressed. Many thanks go to Mr. Kristjan Vilhelm Ruriksson, who served as Assistant-Editor, for his great effort in harmonizing the format of the papers presented in this volume. Also, the work of Mr. Terry Fay, who set up the IAFSS Bibliographic Database Site and assembled the CD-ROM containing the papers presented at the symposium, is greatly appreciated. Finally, the Editor of the Ninth IAFSS Symposium Volume wishes to

thank Dr. Daniel T. Gottuk and Dr. Brian Y. Lattimer, Editors of the Eighth IAFSS Symposium Volume, for their advice and suggestions in preparing this work.

Björn Karlsson
Editor, Ninth IAFSS Symposium Volume
Iceland Fire Authority
Reykjavik
Iceland
December 2008

International Association for Fire Safety Science (2005-2008)

The triennial symposia of IAFSS and the resulting volumes of *Fire Safety Science* continue to be the centerpiece of IAFSS activities. In the past three years, steps have been taken to develop a significant online electronic archive to further extend the impact and contributions of IAFSS to the fire science community.

The Ninth Symposium of the IAFSS was held at Karlsruhe University in Karlsruhe Germany. The symposium was a definite success with three parallel sessions of peer reviewed papers in addition to the invited lectures presented to all participants in a single session format. The poster session was expanded to two sessions and for the first time poster awards were presented. In addition, three successful workshops were held Sunday afternoon before the start of the symposium. All papers were available online prior to the meeting as preprints and all attendees received CD's of the paper preprints.

The success of the symposium is the result of significant efforts by many individuals and organizations. Special thanks are due to Dieter Brein, Chair of the Local Arrangements Committee; Anthony Hamins and Matt Bundy, Chair and Deputy-Chair of the Program Committee; Björn Karlsson and Kristjan Vilhelm Ruriksson, Volume Editor and Assistant Editor; Fred Mowrer, Coordinator for the Workshops; Charley Fleischmann, Poster Session Coordinator; Terry Fay, Symposium Website Coordinator; and Carole Franks, the IAFSS Secretariat. Thanks are due to the symposium sponsors, especially the primary sponsors FM Global and the National Fire Protection Association.

The Committee and Executive Committee elected during the 8th International Symposium on Fire Safety Science in Beijing, China, served from 2005-2008 and is as follows:

Chair:

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Prof Patrick Pagni, USA

Dr Guylène Proulx, Canada

Dr Ai Sekizawa, Japan

Dr Osami Sugawa, Japan

Prof Jose Torero, UK

Committee members Dr P Beever, Dr J Hall, Prof T Hirano, Prof J Quintiere, Prof R Williamson and Dr D Yung retired from service to the committee at the time of the Eighth Symposium. IAFSS owes a great debt of gratitude to these retiring committee members who have provided significant service to IAFSS and the fire science community.

During the 2005-2008 period, the committee met at each symposium as well as a midterm meeting in 2007. The committee met via a parallel session held at the 2007 Interflam in London and the 2007 AOFST symposium in Hong Kong. This split meeting assured maximum participation by committee members from around the world.

The newsletter, edited by Jim Mehaffey, continued to be published twice a year with substantial content from within IAFSS as well as the broader fire science community.

In late 2006, an agreement between the BRE Trust and IAFSS was reached that will make the UK Fire Research Notes collection available to researchers via the internet. BRE will maintain copyrights to the collection which will be made available to the research community. As noted by Dr. John Burdett of the BRE Trust, the availability of the Fire Research Notes collection "has been brought about by IAFSS and the BRE Trust as charities working together to provide a resource to the international fire safety and science communities." The Fire Research Notes (FRN) collection includes approximately one thousand reports produced by the UK Fire Research Station (FRS). The FRN collection will be available via the web on the online IAFSS bibliographic database in early 2009.

In early 2007 Taylor and Francis returned publication rights to IAFSS for the first three symposia at no cost to IAFSS. This generous act paved the way to make all the IAFSS symposia available electronically. All IAFSS symposium papers that were not already available electronically were scanned and citation and abstracts were indexed.

With its 2007 symposium, the Asia-Oceania Association for Fire Science and Technology (AOAFST) continues to be a vibrant regional IAFSS organization. The current Chair is Prof. W.K. Chow of Hong Kong Polytechnic University. The next symposium is planned for 2010 in Australia. Papers from all prior AOFST symposia have been scanned and are planned for inclusion in the IAFSS Online Bibliographic Database.

In early 2008 IAFSS joined CrossRef (www.crossref.org), the organization that maintains the digital object identifier (DOI) system for the scientific and technical community. All the IAFSS symposium papers from Volume 1 to the present have been assigned DOI's and are fully integrated into the DOI system. The DOI system provides a means for finding the paper and for being directed to the IAFSS Bibliographic Database online.

In 2008 the papers from all the symposium volumes, *Fire Safety Science*, were made available online. The citation and abstracts are available to the public, while the full text of the papers are available to IAFSS members. At the time of this writing, about 50 visits to the site are logged per day, indicating that this online access has enhanced use of the papers significantly. Statistics on viewing and downloading papers will be collected going forward.

Carole Franks continues as the Secretariat and continues to provide invaluable service to IAFSS.

It has been an eventful three years and there is much more to do to continue to enhance the service that IAFSS provides to the fire science community and the membership. The ongoing goal is to make membership in IAFSS more valuable and to enhance the contributions that IAFSS can make to the fire science community and to fire safety around the world.

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Award Recipients

Howard W Emmons Lectureship Award for Distinguished Achievement in Fire Safety Science

1984	J.L. de Ris
1985	E.E. Zukoski
1986	J.G. Quintiere
1988	Kawagoe (Medal associated with IAFSS for the first time)
1991	P.H. Thomas
1994	O. Pettersson
1997	T. Jin
1999	Y. Hasemi
2002	P.J. Pagni
2005	H.R. Baum
2008	V. Babrauskas

Kawagoe Gold Medal for Outstanding Lifelong Contributions to Fire Safety Science

1994	A. Robertson
1997	P.H. Thomas
1999	H.E. Nelson
2002	D. Drysdale
2005	S. Yokoi
2008	G. Cox

P.H. Thomas Silver Medal of Excellence for the Best Paper of the Previous Symposium

1988	Y. Hasemi
1991	H.R. Baum and B.J. McCaffrey
1994	A. Atreya and M. Abu-Zaid
1997	B.Z. Dlugagorski, J.R. Mawhinney and V.H. Duc
1999	R.G. Rehm, K.B. McGrattan, H.R. Baum and K.W. Cassel
2002	J.P. Garo, P. Gillard, V.P. Vantelon and A.C. Fernandez-Pello
2005	D.W. Weinert, T.G. Cleary, G.W. Mulholland and P.F. Beever
2008	T. Korhonen, S. Hostikka and O. Keski-Rahkonen

In Memoriam



Professor Robert Brady Williamson
1933 - 2007

Robert Brady Williamson, a pioneer in fire safety engineering science and professor emeritus at the University of California, Berkeley, died of melanoma on August 1, 2007 at Alta Bates Summit Medical Center in Berkeley, California at age 73. Despite the difficulty of battling cancer, he continued to be an active fire researcher to the end, attending the January 2007 conference, *Fire and Materials*, in San Francisco. Williamson's work was significant to establishing fire safety engineering science as a recognized branch of research with university level educational programs, to characterizing the fire hazards of plastics, and to improving the life safety of the building codes in use today.

Williamson was born on November 19, 1933, in New York state. He attended middle school and high school in Kansas City, Missouri. He earned a bachelor of arts in physics and a bachelor of science and a Ph.D. in applied physics at Harvard University in 1956, 1959 and 1965, respectively. While he was studying for his degrees, he worked as a research physicist at Raytheon and as a graduate assistant and teaching fellow at Harvard. His studies were briefly interrupted in 1962 when he was called into active duty as a member of the U.S. Navy Reserves, serving as an aviation electronics technician with Air Anti-Submarine Squadron 915.

After earning his Ph.D. in 1965, Williamson taught as an Assistant Professor of Civil Engineering at the Massachusetts Institute of Technology for three years. In 1968, he joined the faculty at UC Berkeley's Department of Civil and Environmental Engineering and was promoted to Professor in 1979. At UC Berkeley, aided by a National Science Foundation grant under the Research Applied to National Needs program, Williamson established a fire safety engineering science program at a time when few people considered this an appropriate area for scientific inquiry. He generously invited faculty from other engineering departments, architecture and forestry to join him in collaborating on the grants he had brought to campus. He also held appointments at the Lawrence Berkeley National Laboratory and the UC Forest Products Laboratory, and was a creative and innovative researcher, known for his kindness and generosity toward his students and colleagues. The University of California's Interdisciplinary Studies Program in Fire Safety Engineering Science, chaired for many years by Professor Williamson, has produced more PhD's dedicated to fire safety science than any other U.S. institution.

Williamson's grounding in physics in the Applied Sciences Division at Harvard led him to extract the maximum fundamental understanding from empirical evidence. His excellent experimental expertise allowed him to develop material flammability test methods which reflected full scale fire behavior. At the University of California at Berkeley's Richmond Field Station he conducted full scale fire tests and

developed his corner test for ranking material flammability. This test and an updated version, the scaled compartment corner test, are now used by international standards organizations and building codes.

Brady also had the unusual ability to interact productively with a wide range of individuals interested in fire from code officials, firefighters, fire protection engineers and fire litigation attorneys to chemical and physical scientists. He generously donated his time to NFPA committees and international standards organizations. He assisted in many fire reconstructions and served as a consultant to the U.S. Federal Trade Commission in its landmark 1973 lawsuit against the plastics industry and ASTM. As a result of this lawsuit, the industry funded the Products Research Committee which sponsored innovative material flammability research at a wide range of institutions.

In 2001, Williamson retired from UC Berkeley and was appointed a Professor of the Graduate School, a designation reserved for retired faculty who are fully engaged in research and who continue to contribute with outstanding distinction to the graduate program. He earned numerous awards and honors throughout his career, including the 2001 Arthur B. Guise Medal and the 1988 Harry C. Bigglestone Award for Excellence in Communication from the Society of Fire Protection Engineers. He was a member of the American Society of Civil Engineers, the National Fire Protection Association, the International Association for Fire Safety Science and the Society of Fire Protection Engineers.

Williamson is survived by his wife, Dr. Nancy Brown-Williamson of Berkeley, who is head of the Atmospheric Sciences Department at Lawrence Berkeley National Laboratory; their son, John Bradford Williamson of San Francisco; his children from a previous marriage, son, Robert Lowell Williamson of Incline Village, NV; and daughters, Katherine T. Bettencourt of Clio, MI, Anne L. Curtis of Belmont, MA, and Sarah T. St. John of San Jose, CA. He left before we were willing to let him go and he is sorely missed.

In Memoriam



Professor Hikaro Saito
1930 - 2006

Professor Hikaru Saito passed away on 16th November 2006. He had made a tremendous contribution to the study of fire-resistant building design and was recognized as a leading researcher in that field, especially noted for his pioneering work on the structural behavior of buildings in fires.

Professor Saito graduated from Tokyo University in 1953, but remained there as a researcher until 1960. From 1960-70, he worked at The Building Research Institute of Japan, which he left in 1970 to take up a post as professor at Chiba University, where he remained until 1996. After his retirement from Chiba, he moved to Nihon University, holding the post of professor there from 1996-2001.

The main theme of his research at Tokyo University was the structural behavior of steel encased reinforced concrete in earthquakes. At the Building Research Institute, he began research on fire-resistant structural design for buildings with Professor Kawagoe and others. Professor Saito considered the problem of structural behavior in fires from the standpoint of the thermal elongation of members and restraint of the surrounding structure and developed a theory of thermal stress and deformation in building structures exposed to fire. He showed that the buckling stress of steel column and the yielding deflection of steel beam at elevated temperature were decided by exchange the elastic modulus and yielding stress in room temperature to ones at elevated temperature. Based on these result, Professor Saito examined thermal stress and thermal deformation of member restrained at both ends and suggested the fire engineering design principle that beam should be buckled rather early and column should be maintained. On the other hand, his theory emphasized the phenomenon of explosive spalling of reinforced or pre-stressed concrete structures during fires, caused on hypothesis of thermal stress as opposed to the vapor stress.

Professor Saito served as chairman of the Japanese ISO TC92 Committee (concerned with fire safety) from 1991 - 2005, and as president of the Japan Association for Fire Science and Engineering from 1993 - 1995. He was an active and leading member of several committees concerned with the application of fire safety regulations to building structures until two months before his death.

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SOOT

Y. He

A. Tewarson

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H.Z. Yu

J. Floyd

G. Rein

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M. Knobloch

MODELING

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