

FIRE SAFETY SCIENCE – PROCEEDINGS OF THE SIXTH INTERNATIONAL SYMPOSIUM

Editor

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CSTB, Marne-La-Vallée, France

**INTERNATIONAL ASSOCIATION
FOR FIRE SAFETY SCIENCE**

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

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Preface

The Sixth International Symposium on Fire Safety Science was held at the University of Poitiers, France, from 5 - 9 July 1999. There were 303 registrants attending two parallel sessions in which 85 papers were presented and three poster sessions in which 73 posters were displayed. Twenty-five countries were represented : Argentina, Australia, Belgium, Brazil, Canada, China, Denmark, Finland, France, Germany, Italy, Ireland, Japan, The Netherlands, New Zealand, Norway, Poland, Portugal, Russia, Slovenia, Spain, Sweden, Switzerland, United Kingdom and United States of America.

The opening ceremony was conducted by Mrs. E. Morin, Vice President of the Regional Council of Poitou-Charentes, Mr. J. Grandon, Vice President of the Administrative Council of the Department of Vienne, Mr. J. Santrot, Mayor of Poitiers, Mr. E. Esperet, President of the University of Poitiers, Mr. G. Rabbit, Head of the Science Department of the University of Poitiers, Mr. F. Armanet, Head of the "École Nationale Supérieure de Mécanique et d'Aérotechnique de Poitiers", Mr. M. Champion, Head of the "Laboratoire de Combustion et de Détonique" and Vice Head of the "Sciences pour l'ingénieur" department of the CNRS, Mr. P. Joulain and Mr. J.-P. Vantelon, chairmen of the Arrangement Committee. Following the opening ceremony, Professor Hasemi, University of Waseda, delivered the Howard W. Emmons Plenary Lecture entitled "Diffusion Flame Modeling as a Basis for the Rational Fire Safety Design of Built Environments".

Papers and poster abstracts were accepted on the basis of their quality and originality in the science of fire safety and its applications. Eighty-six papers from the 198 submitted were accepted after peer review. 105 posters were accepted, submitted either as posters or as papers that were invited as posters after review. In addition to these and to the plenary lecture, 6 invited papers were also presented during the course of the Symposium by Dr. J.R. Hall, Dr. P. Joulain, Mr. B. J. Meacham, Dr. H. D. Ross and Dr. F.J. Miller, Professor T. J. Shields and Dr. G. Proulx and Dr. H. Koseki.

At the Award Reception and Banquet, Dr. J. A. Rockett, Chair of Symposium Awards Committee, presented the Howard W. Emmons Lectureship Award to Prof. Y. Hasemi and the Thomas Silver Medal of Excellence for the best paper at the Fifth Symposium to Drs. R. G. Rehm, K. B. McGrattan, H. R. Baum and K. W. Cassel for their paper, "Transport by gravity currents in building fires." Prof. P. J. Pagni, Chair of the IAFSS Awards Committee, presented the Kawagoe Gold Medal for outstanding lifelong contributions to fire safety science to Harold E. "Bud" Nelson. Dr. J. E. Snell, Chair of the Forum for International Cooperation on Fire Research, presented the Sjolín Award in recognition of the founders of global fire safety science, Prof. H W Emmons (USA), Prof. K Kawagoe (Japan), Dr P H Thomas (UK) and Prof. D J Rasbash (UK). Their direct heirs were identified as staff at the following institutions: Harvard University, Worcester

Polytechnic Institute, Factory Mutual Research Corporation and the National Institute for Science and Technology in the USA, the Science University of Tokyo and the Building Research Institute in Japan and the University of Edinburgh and the Fire Research Station in the UK.

These proceedings include all papers and poster abstracts delivered at the Symposium. They are in the order of the two track sessions with invited papers collected together in an opening section. One accepted paper could not be delivered to the symposium and is not included here. Similarly, the abstracts of accepted posters that were not presented are not included.

The Association would like to record its gratitude to all the committees appointed to organize the various aspects of this successful symposium. It would particularly like to thank Dr. P. Joulain, Dr. J.-P. Vantelon and their colleagues at ENSMA for their efficient organization of an enjoyable and valuable symposium, and Prof. O. Sugawa, Dr. G. Heskestad and Prof. T. Shields who coordinated the review of the submitted manuscripts. The Chair of the Publication Committee also wishes to thank Prof. Y. Hasemi, Chair of the Publication Committee of the Fifth Symposium for his valuable advice, Dr. J.-P. Vantelon, Chair of the Organization Committee for his friendly help on many points and Mrs. B. Lemaire of CSTB for her unstinting efforts.

The Association acknowledges the support of the following organizations which, by their generous contributions, helped ensure the success of the symposium.

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University of Poitiers
Conseil Général de la Vienne
Région Poitou Charentes (Programme Com'Science)
Ville de Poitiers
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Institut de Protection et de Sécurité Nucléaire (IPSN)
Renault

Michel Curtat
Chair, Publications Committee

Marne-la-Vallée, France
July 1999

International Association for Fire Safety Science

Since the Association was founded in 1985 at its first Symposium in Gaithersburg, a series of five Symposia have been held, in Tokyo (1988), Edinburgh (1991), Ottawa (1994), Melbourne (1997), and Poitiers (1999) (this Symposium). Through these Symposia, the Association has successfully fulfilled its primary objectives of encouraging research in the science of preventing and mitigating the adverse effects of fires and of providing a forum for presenting the results of such research. Membership is open to all having these interests.

The Association, which became a registered charity in England and Wales in 1988, is governed by an elected Committee and its officers. At the general meeting held during the Sixth Symposium, the following Committee and its officers were elected.

Prof. T. Hirano (Japan), Chair
Prof. D. D. Drysdale (UK), Vice-Chair
Prof. P. J. Pagni (USA), Vice-Chair
Prof. Y. Uehara (Japan), Vice-Chair
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Prof. Y. Hasemi (Japan)	Dr. P. H. Thomas (UK)
Prof. P. Joulain (France)	Prof. R. B. Williamson (USA)
Dr. T. Kashiwagi (USA)	Dr. D. Yung (Canada)
Prof. M. Kokkala (Finland)	

The following members of the committee retired at the last meeting : the Association would like to express its appreciation for their many contributions.

Prof. V. K. Bulgakov (Russia)
Mr. H. E. Nelson (USA)
Dr. M. R. Curtat (France)

Dr. B. Karlsson (Sweden) and Dr. Sekizawa (Japan) were appointed as auditors, and Prof. J. Barnett (USA) and Dr V. Molkov (UK) were appointed as scrutineers.

During the period of 28 months between the Fifth and Sixth Symposia, the Association has lost several distinguished members, including Prof. Emmons, Prof. Horiuchi, Prof. Zukoski, and Dr. Saito. Many members of the Association will wish to remember these senior colleagues. Indeed, their contribution to the Association was great and their influence will be felt in the future. All the members of the Association will be aware of what they have done for the Association.

A Committee Meeting was held on August 1, 1998 at Boulder, Co., where the members discussed the Association's future activities. The most important item on the agenda was whether the Symposia should be held on a two-year or a three-year cycle. The discussion could not be finalised at the time, but after the meeting, there were extensive exchanges of opinions among the Committee members. Based on the discussion, the Association finally decided on a three year cycle and hold the next Symposium at Worcester Polytechnic Institute, Massachusetts, in 2002.

The Association has re-established its web site under control of our colleagues at Worcester Polytechnic Institute. This was originally established in time for the Melbourne Symposium by Prof. Barnett of WPI and is readily accessible on the following Internet address : www.wpi.edu/Academics/Depts/Fire/LA-FSS/committee.html .

Fortunately, our Association has accumulated a significant amount of money. This has resulted from the efforts of the Arrangements Committee Chairs of past Symposia, but particularly from a donation by Mrs Kawagoe. Consequently, it was possible to provide some support for a number of attendees. In particular, the Association invited two prominent fire researchers from South America, Prof. Juan de Dios Rivera (Pontifica Universidad Catolica de Chile), and Mr. Eduardo Saavedra (Jefe de la Politica Federal Argentina). Although it was not possible to provide complete support for these colleagues, they came and participated fully in the Symposium, exchanging views and ideas with other delegates. The Association appreciated the fact that they were able to attend.

After the Melbourne Symposium, the Association and/or its members organised and/or participated in several regional meetings related to fire safety science and was able to provide partial support. Thus, a sum of \$ 1,000 was given to the Second International Seminar on Fire and Explosion Hazard of Substances and the Venting of Deflagrations which was held in Moscow, August 11-15, 1997. Also, the Association offered \$1,500 to the Third Asia-Oceania Symposium on Fire Science and Technology held 10-12 June 1998 in Singapore. The latter is an important

regional activity of the Association. Awards were given for the best papers in the name of the IAFSS.

The Education Subcommittee is the most active group within the IAFSS. At its meeting during the Symposium, Prof. B. Williamson (USA) agreed to take over the chair from Prof. S. E. Magnusson (Sweden). Dr. B. Karlsson, (Sweden), Prof. F. Mowrer (USA) and Prof. J. Barnett (USA) were nominated to co-ordinate future activities. During the Poitiers Symposium, a new interest group "Structures in Fire" was formed under the chairmanship of Dr Jean-Marc Franssen (Belgium). The first meeting of this group is to be held in Copenhagen, 19 – 20 June 2000.

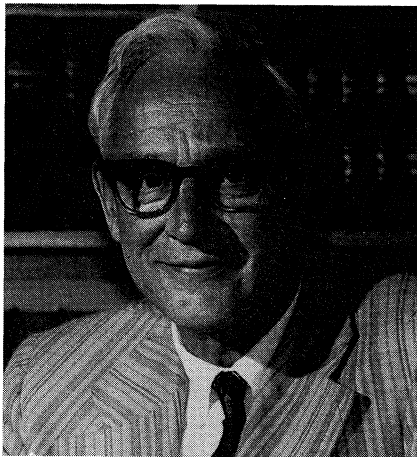
Members of the Association will have received two newsletters (Nos. 9 and 10), edited by Dr. Hall (USA). These have acted as a unique means of communication for fire researchers and engineers and have carried announcements of the activities of the IAFSS. Dr. Hall is to be congratulated on his efforts on behalf of the Association.

A report from Prof. V. Beck (Australia), the Arrangements Committee Chair of the Fifth Symposium, was received by the Association. Although the Melbourne Symposium did not generate a surplus, all those who attended will remember the success of the meeting. We should thank our Australian and New Zealand colleagues represented by Prof. Beck for their efforts.

The IAFSS is concentrating on making improvements in the way in which it operates, particularly in extending its activities to every corner of the world. Any comments to the Association are welcome.

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In Memoriam



Professor Howard W. Emmons
30th August 1912 – 20th November 1998

Professor Howard W. Emmons died of cancer in Boston on November 20, 1998. He was 86 and still an active investigator of fire-related scientific problems, e.g., he participated in the 14th Meeting of the U.S. – Japan National Resources Panel on Fire Research and Safety in Tokyo and Tsukuba, Japan, in June, 1998.

Howard Wilson Emmons was born August 30, 1912, in Morristown, New Jersey and was educated in the local public schools. He graduated as a Mechanical Engineer from Stevens Institute of Technology with a BS in 1933 and an MS in 1935. He was awarded a ScD degree from Harvard University in 1938 with a dissertation on condensation phenomena. He studied steam turbine systems at Westinghouse for two years followed by one year at the University of Pennsylvania. He was then invited to join Harvard University where he continued his technical career for 58 years. His positions at Harvard included : Assistant Professor – 1940, Associate Professor – 1944, Gordon McKay Professor of Mechanical Engineering – 1949, Abbot and James Lawrence Professor of Engineering – 1966 and Professor Emeritus – 1983.

He was honored by membership in the U.S. National Academy of Science (1966), the National Academy of Engineering (1965) and the American Academy of Arts and Sciences (1946). He was an active member of several professional societies including the International Association for Fire Safety Science that honored his contributions to our field by naming its symposia plenary lectures after him in 1985. The American Physical Society awarded him the Office of Naval Research Prize in 1982; the American Society of Mechanical Engineers gave him

the Timoshenko Medal in 1971. The Combustion Institute, presented the prestigious Egerton Gold Medal to him in 1968. Stevens Institute of Technology bestowed an honorary ScD (1963), its 100th Anniversary Medal (1970) and the Stevens Honor Award Medallion (1977). He was named Fire Protection Man of the Year by the Society of Fire Protection Engineers in 1982. Worcester Polytechnic Institute awarded him an honorary doctorate in 1983. He was a founding member of the Committee on Fire Research in the National Research Council of the National Academy of Sciences from 1956-72, serving as Chairman from 1967-70. He also chaired the National Bureau of Standards Panel 490 which had oversight responsibility for the Center for Fire Research from 1971-76. He played a critical role in the establishment of the Factory Mutual Research Corporation in 1964 and helped guide its development into a foremost industrial fire research laboratory.

We are fortunate he chose to direct his talents to Fire Research nearly 50 years ago under the urging of Professor Hoyt Hottel. In 1956, Emmons published a landmark paper on boundary layer burning which has become known as the "Emmons Problem". Shortly thereafter, he prepared the booklet "A Fire Research Program for the United States" which served as a blueprint for the U.S. over the next thirty years. He contributed to *Fire Research Abstract and Reviews* and to the seminar conference proceedings, "The Use of Models in Fire Research". In 1962, he chaired the National Academy of Science sponsored Summer Study on Fire Research at Woods Hole, which recommended a federal program in fire research as the only practical way to enlarge the then weak scientific base for fire safety design. The formal development of the fire research program at Harvard had its beginning in his world-wide survey of fire laboratories in 1966-67 and his observation of the disparity among the then nationally accepted flammability standards. As Chairman of the Committee on Fire Research, he spearheaded the effort of the scientific community to identify fire research as a national priority. He argued before Congress for a Fire Research and Safety Act, which was adopted in 1968. This act gave the National Bureau of Standards (now the National Institute of Standards and Technology) responsibility for the technical aspects of the fire problem and led to the establishment of the Center for Fire Research (now the Building and Fire Research Laboratory). The act also empowered the Presidential Commission that published "America Burning" in 1972.

The National Science Foundation under its Research Applied to National Needs program initiated funding of the "Home Fire Project" at Harvard University – Factory Mutual Research Corporation in 1972. The success of that project, under the direction of Howard Emmons along with Raymond Friedman, is well documented in its 1982 final report. One of its accomplishments was the Harvard Computer Fire Code or FIRST (Fire Simulation Technique), which predicts the growth of fire in buildings and remains a useful tool today.

Howard Emmons had major renown as both an inspiring teacher and an innovative researcher. He set the tone for the unusually scholarly community in the Division of Applied Sciences at Harvard University. His fifty doctoral students include many distinguished scientists. His research associates were attracted to

fire safety science through Professor Emmons' boundless enthusiasm. It is their consensus that the time spent with Howard is the highlight of their careers. He had the uncommon ability to ignore error and develop what was correct so that it seemed as if it were all your idea in the first place. His over one hundred research papers are hallmarks of clarity and understanding. A skillful experimentalist, as well as a theorist of unusual mathematical competence, he saw the essential concepts in complex problems and addressed them with energetic single-mindedness until he produced solutions bursting with insight and elegance.

It is not possible to properly summarize the magnitude of Professor Emmons' unique contributions to the establishment of fire safety science as a discipline, other than to call him "Mr. Fire Research". We gratefully acknowledge our debt to Professor Emmons for his insistence on technical quality, his excellent leadership, his extraordinary gift for inspiring colleagues and his many warm friendships. He will be dearly missed.

In Memoriam



Professor Saburo Horiuchi
2nd November 1915 - 9th October 1998

The world of fire safety science lost a great friend in October 9, 1998 – Professor emeritus Saburo Horiuchi, retired from the Kyoto University in Japan. The professor Horiuchi graduated from Department of Architecture of Kyoto University and worked at Fire Research Institute for 18 years from its establishment in 1948 and became professor at Kyoto University in 1966. He also joined the Japan Association for Fire Science and Engineering (JAFSE) from its foundation in 1950 and contributed greatly to the development of fire research in Japan as one of the leading fire researchers together with the late professor Kawagoe, Professor Akita, and Dr. Yokoi. He was also active in the promotion of international communication in fire research. He was active member of UJNR and a founding member of IAFSS. He was an IAFSS Committee member from its establishment in 1985 to 1994 and made great efforts for the success of the Second International Symposium on Fire Safety Science in Tokyo in 1988 as the President of JAFSE at that time. He was a pioneer in the regional fire/disaster safety planning in Japan as well as in many other fields of soft fire science such as life safety and human behavior in fire, fire risk analysis, and building fire protection. He was the recipient of The Award of Japan Association for Fire Science and Engineering in 1960 for his achievements on "the Study of Methodology for Determining Fire Cover in Cities" and also The Award of Architectural Institute of Japan in 1978 for his life time achievements. He educated numbers of active fire researchers and encouraged young researchers to make a new attempt in fire research.

He was professionally active on the project looking for the consistency of fire safety and preservation of traditional wooden structures in Kyoto until his untimely death. He played a significant role in shaping the fire safety science field we live and work in today. Prof. Horiuchi and his wife, Yoshiko who survives him, were well known for their personal warmth and made an instantly favorable impression on all people as good friends and good people. We mourn his passing but celebrate his life.

In Memoriam



Doctor Fumiharu Saito
30th March 1930 – 29th September 1997

Dr. Fumiharu Saito passed away by cancer half year after his retirement from the Tsukuba Testing Laboratory of the Center for Better Living. His fund of knowledge, skill and experience in fire experiments and combustion toxicology will be greatly missed. He initiated and led research programs on the fire safety aspect of building materials at the Japanese Building Research Institute from the 1950s to 1982 and was responsible in establishing and maintaining fire research and testing programs at the Center for Better Living from 1983 to 1997. He was a pioneer in the experimental research on the combustion toxicity and the mechanism of the generation of toxic combustion product, and led the introduction of material tests for combustion toxicity and other aspects of combustibility into the Japanese regulation. For his leadership in the evaluation of toxic hazard in fires, he was awarded the Annual Prize of the Japan Association for Fire Science and Engineering and the Scientific Award from Mainichi News Paper both in 1973, and was later honored by the Minister of Science and Technology. On the other hand, he was generous in offering research opportunities, technical advice and other conveniences for young researchers and students who otherwise had essential difficulties in making experimental studies, proceeding analytical research or validating their fire models. His technical enthusiasm, generosity and hospitality were also exhibited at international activities including the UJNR Panel on Fire Research and Safety, CIB W14 (Fire), and ISO/TC92 (Fire Safety) until the very end of his life. He will be remembered for his distinctive work in fire hazard analysis and his charming and unique character, which greatly stimulated the international and national cooperations in fire science.

In Memoriam



Professor Edward E. Zukoski
27th June 1927 – 26th May 1997

We lost one of our most valued colleagues when Professor Edward E. Zukoski died of congestive heart failure on May 26, 1997 in Pasadena California. He was born on June 27, 1927 in Birmingham, Alabama and attended Harvard University where he met Professor Emmons and received a BS in Engineering Science in 1950. He then earned an MS, 1951, and a Ph.D., 1959, from the California Institute of Technology where he was Professor Marble's third Ph.D. student. Prof. Zukoski then joined the Cal Tech faculty in the Von Karman Laboratory of Fluid Mechanics and Jet Propulsion. He became a member of the National Research Council Committee on Fire Research in the early 1960's and was active in fire research over the next 35 years. One of his primary areas of expertise was the fluid mechanics of fire. He authored over 50 papers on fire physics ; one magnus opus was the chapter "Properties of Fire Plumes" in Cox's *Combustion Fundamentals of Fire*. His correlations for entrainment rates have been incorporated into every compartment fire computer model. He was a member of the UJNR Panel on Fire Research and Safety from its inception until the 13th panel meeting in Washington, D.C. in 1996 where the "Fluid Mechanics of Fire" Symposium was held in his honor.

How do you describe someone as superb as Professor Zukoski ? His colleagues at Cal Tech tried by saying, "Ed displayed a unique ability for identifying and successfully solving experimentally, with unusual elegance and clarity, the fundamental research problems of compartment fire phenomena". In addition, he was described as one of the few scientists who are natural nurturers, offering encouragement, insight and pure wisdom to a wide variety of younger researchers.

He was the first person to experimentally determine a value for the buoyant Strouhal Number, which we now call the "Zukoski Constant" $Zu \equiv f(D/g)^{1/2}$, which is ≈ 0.5 for $0.1 \text{ m} < D < 60 \text{ m}$ where f is the vortex shedding frequency and D is the pool fire diameter. He was good company, always ready to listen, to interject a thoughtful observation and to laugh heartily. He paid close attention at technical presentations and asked polite but insightful and stimulating questions. He was a kind, guileless, conscientious, intelligent and generous member of our community of scholars, whose loss is a terrible blow to all that knew him.

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T. Hirano

R. Friedman

V. Beck

D. Fontana

Ph. Thomas

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F.X. Rongère

SUPPRESSION

Fan Weicheng

W.L. Grosshandler

G. Holmstedt

F. Mowrer

G. Heskestad

S. M. Spivak

FIRE PHYSICS AND MODELING

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J.G. Quintiere

G. Cox

N. Saito

SUPPRESSION/DETECTION

G. Heskestad

S. M. Spivak

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M. Kokkala

P. Pagni

K. Sato

DETECTION

G. M. Faeth

A. Tewarson

SMOKE

G. M. Faeth
A. Tewarson

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D.D. Drysdale

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J. Kruppa

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K. Harada
J.C. Malet

FIRE SPREAD/COMPARTMENT FIRES

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O. Sugawa

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