Cone Calorimeter Annotated Bibliography
1982 — 1991

Vytenis Babrauskas
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1 At Boulder, CO 80303.
2 Some elements at Boulder, CO 80303.
Technical Note 1296

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Vytenis Babrauskas

Building and Fire Research Laboratory
Gaithersburg, MD 20899

September 1992

U.S. Department of Commerce
Barbara Hackman Franklin, Secretary

Technology Administration
Robert M. White, Under Secretary for Technology

National Institute of Standards and Technology
John W. Lyons, Director
Cone Calorimeter Annotated Bibliography

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National Institute of Standards and Technology
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Abstract

An annotated bibliography is presented of published papers and reports on the topic of Cone Calorimeter apparatus, test data, and engineering applications of the test data. While most of the material surveyed is in English, the known foreign-language publications are also included. The annotations include a brief description of the work reported, however, the data are neither critically evaluated nor assessed.

KEYWORDS: ASTM E 1354; bibliographies; Cone Calorimeter; fire tests; ISO 5660.
Introduction

The first NIST\textsuperscript{1} report describing the development of the Cone Calorimeter was published in 1982. The apparatus was then in preliminary stage, and further work continued over a number of years. The American Society for Testing and Materials (ASTM) issued a draft standard (P 190) based on this apparatus in 1986. At the same time, a round robin was also started. This resulted in some further improvements to the apparatus and to the testing procedures. ASTM approved the Cone Calorimeter standard in 1990, issued as ASTM E 1354.

A parallel development was taking place in the International Organization for Standardization (ISO). A draft international standard (DIS 5660) was published in 1990. This was approved and the final standard (ISO 5660) was published in 1992.

A specialized application standard—one devoted to testing upholstered furniture composites using the Cone Calorimeter—was issued by the National Fire Protection Association in 1990 as NFPA 264A. NFPA have also drafted a general standard, paralleling ASTM E 1354; this has been assigned the number NFPA 264, but is still only in draft form.

NIST was presented an R&D 100 award in 1988 for the development of the Cone Calorimeter. This is noteworthy because it was the first time an apparatus for conducting reaction-to-fire tests has been so honored.

Six commercial instrument manufacturers, from four countries, have produced Cone Calorimeters, although not all of them are currently active.

Scope

The scope of this bibliography includes all credible, technical references to research pertinent to the Cone Calorimeter that are known to the compiler. Specifically excluded are:

- manufacturers' promotional literature
- reports that are proprietary or unavailable to the general public
- publications that comprise an abstract only, not accompanied by data
- references of ephemeral or nontechnical interest.

It may be noted that the criteria for inclusion became somewhat more strict as time went on. For the early years, some works are included where research plans are described, test methods enumerated, etc. For the more current literature, works have been excluded unless they contain quantitative data, engineering analyses, or other information that is more than ephemeral or transitory.

Each entry is accompanied by a short annotation where the main results, as pertinent to Cone Calorimeter studies, are stated. For papers where Cone Calorimeter data do not constitute the main emphasis of the study, only the Cone Calorimeter findings are annotated, not the main theme of the project.

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\textsuperscript{1} Prior to 1988 the name was National Bureau of Standards.
This bibliography will be updated in the future. It is requested that authors send a copy of their reports and reprints, together with details of publication, to:

Dr. Vytenis Babrauskas  
National Institute of Standards and Technology  
Bldg. 224, Room A345  
Gaithersburg, MD 20899, USA

Disclaimer

The quality of the data is not evaluated in this bibliography; thus, listing in this bibliography should not be taken in any way to construe a recommendation on the validity of data, suitability of experimental techniques, or correctness of conclusions.

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Technical journals and conference proceedings cited in this bibliography can be consulted at many major engineering libraries.

U.S. government publications, including those published by NIST, can be ordered from:

National Technical Information Service  
5285 Port Royal Road  
Springfield, VA 22161  
Phone: 703-487-4650  
Fax: 703-321-8547

and are available as either paper or microfiche copies.

For reports of other research institutions, please contact the institutions cited directly for information about price and availability of their publications. Some addresses for research institutions and publishers cited are given below.

Intl. Conf. on Fire Safety Proceedings  
c/o: Product Safety Corp.  
P.O. Box 2338  
1457 Firebird Way  
Sunnyvale, CA 94087

Interscience Communications Ltd.  
24 Quentin Road  
London SE13 5DF  
UNITED KINGDOM
Statens Provningsanstalt (SP)
Div. of Fire Technology
P.O. Box 857
S-501 15 Borås
SWEDEN

Technomic Publishing
also: Fire Retardant Chemicals Association
851 New Holland Avenue
Box 3535
Lancaster, PA 17604

TräteknikCentrum
Box 5609
S-114 86 Stockholm
SWEDEN

Valtion Teknillinen Tutkimuskeskus (VTT)
Kivimiehentie 4
SF-02150 Espoo
FINLAND
Technical productivity

The number of publications on a year-by-year basis are shown below.

Yearly number of publications

The above list can be compared to the list of Cone Calorimeters that have been built, as shown on the next page. After a research instrument has been acquired, it typically takes 2 or 3 years before papers can be published. In the next few years, it can readily be hypothesized that there should be a very substantive acceleration seen in Cone Calorimeter-related papers.
It should not be surprising that NIST has the largest number of publications. It is interesting, however, that, as of 1991, there have been a large number of papers from testing institutions, but a small number from universities. This situation can understood when it is realized that Cone Calorimeters typically have been acquired by universities only quite recently.

The breakdown below takes into account the laboratory where the work, or else the association of the first author; work conducted jointly by several laboratories is assigned to the laboratory of the first author only.
<table>
<thead>
<tr>
<th>Papers</th>
<th>Institution</th>
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<td>Clemson Univ.</td>
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<td>Univ. of California, Berkeley</td>
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<td>Worcester Polytechnic Institute</td>
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<td>BASF</td>
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<td>LSF (Italy)</td>
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<td>22</td>
<td>Others</td>
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Bibliography

The bibliography is arranged in a reverse-chronological order, year-by-year. An author index is given at the end.

1991


Wide-ranging review of wire and cable flammability tests and research studies. Includes section on Cone Calorimeter studies.


Compares results obtained in the French Épiradateur test against ignitability data from the Cone Calorimeter. Finds that for non-melting products the Épiradateur ignition times are similar to Cone data when 35 kW·m⁻² irradiance and horizontal orientation are used.


Existing ignitability data from the Cone Calorimeter and other radiant-heat tests are reviewed. An analysis method is offered for correlating data according to ignition theory. Derivation of values for effective thermal properties (thermal inertia and surface temperature at ignition) from ignitability curves is discussed.


Measurements on small cribs made in the Cone Calorimeter are reported and are compared to measurements on large cribs taken in the furniture calorimeter. The cribs tested included wood, wood combined with gypsum wallboard, and a wood/wallboard/ABS combination.

Brief results are presented on polyetherimide, polyethersulfone, polycarbonate, polyphenylene oxide, high-impact polystyrene, polybutylene terephthalate, polypropylene, polyethylene, polystyrene, and PVC tested at various irradiances. Ignition data of the 3.2 mm thick specimens were correlated by a first-power relationship. Critical irradiance for ignition ranged from 12.5 kW·m⁻² for polystyrene to 35.8 kW·m⁻² for polyetherimide.


Cone Calorimeter results taken at an irradiance of 30 kW·m⁻² are presented for some British chairs where concomitant data were also obtained in full-scale tests, although only semi-quantitatively.


In further pursuit of a heat-release-rate based measure of noncombustibility, Cone Calorimeter experiments were conducted at the FMPA laboratories on acoustic panels and aluminum-covered facade boards. Tests were conducted at an irradiance of 75 kW·m⁻². Finds that, when stripped of the aluminum facing, the facade boards burned up completely and registered a heat release consistent with oxygen bomb measurements.


A number of small ignition sources were tested using the Cone Calorimeter, but with zero irradiance. Data are presented for small wood cribs, paper balls, paper 'pillows' stuffed with wadded paper, PMMA cribs, and methenamine pills.


Cone Calorimeter data on various (vinyl ester, epoxy, bismaleimide, phenolic, polyimide, polyphenylene sulfide, polyether ether ketone) fiber reinforced composites tested according to MIL-STD-2202 are reported. Brief results are given for 25, 50, 75, and 100 kW·m⁻² irradiances.

Results of Cone Calorimeter testing as a means of determining the 'degrees of combustibility' of products and materials are presented. The tests were conducted at irradiances of 40 and 50 kW·m⁻² at the Forintek laboratories, and form a part of a Canadian effort to replace the current noncombustibility test with a more useful method. Certain preliminary recommendations are made.


Contains additional experimental details and toxicological information from tests conducted using a Cone Calorimeter-heater based toxicity apparatus.


The effects of three fire retardants (alumina trihydrate, magnesium hydroxide, and an organohalide/antimony oxide) on EPDM rubber were examined using the Cone Calorimeter, the ASTM E 662 smoke chamber, and the ASTM D 2863 LOI test.


Presents a model and data demonstrating the utility of correlating the incident flux against ignition time to the -0.547 power.


Presents a simple charring rate model which is verified against Cone Calorimeter data.


Describes results of burning various materials in vitiated atmospheres (oxygen levels < 21%). The effects on CO production are quantified, but these are shown to be of minor importance in regards to toxic fire hazard.

*Provides an approximate formula, based on Cone Calorimeter data, by which it may be estimated whether thin wall lining materials will or will not lead to room flashover.*


*Proposes a computational method for determining the heat release rates from combustible wall coverings, based on test data obtained from the Cone Calorimeter and the LIFT apparatus.*


*A small amount of Cone Calorimeter data on glass-fiber reinforced phenol-resorcinol formaldehyde resins are provided. The effects of using a hydrated aluminum filler and of varying the amounts of fiber are explored. A limited comparison of fire-retardant treated polyester resin is made.*


*Presents a more recent summary of features of the Karlsson/Magnusson model of combustible wall linings; this uses Cone Calorimeter for some of its input.*


*An empirical model is able to predict the 80 kW limit results of the full-scale T.B.133 test for upholstered furniture from bench-scale Cone Calorimeter data.*


*Additional measurements on certain wood products are reported. This is an extended abstract in Japanese.*

Use is made of Cone Calorimeter and LIFT data to predict real-scale fires involving wood products as room wall linings. Details of a method for systematic treatment of ignitability data are presented which allows the determination of the thermal inertia and the surface temperature at ignition. Also, effect of moisture is analyzed and a procedure is detailed which allows time-dependent curves of heat of gasification to be computed. The concept of an Upward Flame Spread Index is shown to have promise.


Presents Cone Calorimeter and LIFT data on a number of foam plastics and analyzes the data in format used by the Cleary/Quintiere surface burning model.


Cone Calorimeter data are reported on pine boards, medium density fiberboard, newspaper sheets, and cribs (No. 5 according to BS 5752 Part 2 standard).


Provides results for CO yield of PMMA and Douglas fir, measured in the Cone Calorimeter at various irradiances. The CO yield for PMMA is seen to be independent of irradiance, but for Douglas fir the CO yield decreases monotonically with increasing irradiance.


Documents details for wood specimens how flames issue primarily at fissures and not uniformly over the surface. Documents some procedures for mounting specimen thermocouples and optical pyrometers. Finds a typical convective coefficient of approximately 0.028 kW·m⁻²K for vertically oriented specimens.

A simple thermal model is developed to predict the time to start charring in a wood structural member that is located under a metal joint plate. This model was tested against specimens of laminated veneer lumber using the Cone Calorimeter at irradiances of 25, 50, and 75 kW·m².


Makes a comparison between existing Nordic reaction-to-fire test requirements and the new methods espoused by ISO. Compares results from the Cone Calorimeter to those from the NT FIRE 004 test. Recommends that the Cone Calorimeter be used to replace both the NT FIRE 004 test and the ISO ignitability test (ISO 5657).


Compares furniture composites using old-type PVC covers and melamine-treated polyurethane foams against other commercial materials.


This article collects the needed expressions for evaluating the heat release rate by oxygen consumption for various measuring environments, both in bench scale and in large scale. The equations are based on the same principles as the earlier presentation by Parker, but are presented here in an easier-to-use format.


Compares Cone Calorimeter results on wall/ceiling linings to results of some huge-scale tests in a room/corner geometry.


This paper is a further development of the Göransson/Wickström model for predicting room lining HRR from Cone Calorimeter data.
An interim progress report is made on smoke analysis from Cone Calorimeter results.


This is the first-ever study where Cone Calorimeter data were used in making predictions with a three-dimensional field model (KAMELEON).


A cooperative study between NIST and Forintek has been directed at coming up with methods for using Cone Calorimeter HRR data to replace existing building code requirements for ‘noncombustibility’ and ‘degrees of combustibility.’


This is a very brief summary of the Karlsson/Magnusson room fire model.


This data report presents results obtained on 11 wall/ceiling products during the course of the EUREFIC research program.


Early studies conducted by the British Rubber Manufacturers Association are reported; a number of difficulties with program formulation precluded predictive correlations from being obtained.


Finds a generally good correlation between results from the two methods. For certain specimens, the dipping pilot in the ISO Ignitability Test is seen as a limitation to being able to determine an accurate ignition time. Attributes some of the differences seen between the methods as being due to convective heat components.

A general-purpose intumescent flame retardant is described which can be used in polymer blend systems of polyolefin/elastomer (not specifically described). Cone Calorimeter results are given. Also data using the cone corrosimeter are provided.


Data are presented for polyethylene formulations tested in the Cone Calorimeter at an irradiance of 25 kW·m⁻². Three different FR additives were used: decabromodiphenyl oxide, ethylene bis(tetrabromophthalimide), and Dechlorane Plus 25. Comparative data are also given for UL 94 and LOI tests. The data are analyzed using the Coaker, Hirschler, Shoemaker correlations for predicting passing performance in vertical cable tray tests.


Reviews test methods for wire and cable and presents Cone Calorimeter data.


Provides extensive data for low-density polyethylene, PVC, ethylene-propylene rubber, and chloroprene rubber, with each material being tested plain and with FR additives at heat fluxes of 32 - 51 kW·m⁻². Plotted against irradiance, the values of 1/tₐₕₚ are seen to be linear. Discusses certain problems of specimen preparation; also provides comparative data for a 6 mm thickness sample of newspaper.


Provides HRR data for cotton toweling, FR cotton cloth, Nomex fabric, epoxy/glass circuit board, and Lexan at irradiances of 20, 30, 45, and 60 kW·m⁻².

Compared the behavior of smoke particles in the Cone Calorimeter versus the DIN dual-chamber smoke box. Finds that smoke measurements in the Cone Calorimeter are more repeatable and do not suffer from a premature loss of the larger-sized particles.


A review of available wood data, including Cone Calorimeter measurements.


Develops two parameters for representing the hazard due to smoke emission; compares smoke data obtained with the Cone Calorimeter vs. that obtained with the OSU apparatus.


Provides some results from a test program conducted at Underwriters Laboratories where various metal targets were exposed to corrosive gases generated by burning PVC samples in the Cone Calorimeter.


The National Building Code of Canada is to be revised to include improved measurement methods for noncombustibility and other 'degrees of combustibility.' As part of the development effort, Forintek laboratories conducted Cone Calorimeter tests on numerous building products and offer a proposed classification method based on these results.

*Provides data taken on the Cone Calorimeter and illustrates that substantive improvements in the peak heat release rate are not registered by the limiting oxygen index test nor by the UL 94 test.*


*Discusses the general principles for the design of competent HRR measuring equipment; provides illustrations of upholstered furniture and cables; also provides summary data for a number of different plastics formulations.*

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**1990**


*A brief review of oxygen consumption principles, bench-scale HRR calorimeters, the CONERUN computer program for collecting data, and the computer program FDMS for analyzing and interchanging fire test data.*


*This Naval standard mandates the use of Cone Calorimeter testing for qualifying of composite materials for submarine applications.*


*Cone Calorimeter data for several fire-retardant polypropylene formulations are shown; a comparison is made to oxygen index (LOI) and UL 94 data.*

Examines the performance of various furniture fabric/foam composites. Finds that an irradiance of 25 kW·m⁻² is acceptable for testing but a lower value of 17.5 kW·m⁻² does not give meaningful results. Finds very substantial effect of fabric type of the performance of the composite. The general performance trends seen in the Cone Calorimeter and in the OSU were similar, under the given test conditions.


Provides comparative data for smoke measured in the Cone Calorimeter and in room fire tests. The agreement is generally good, but certain difficulties are seen in making reliable smoke measurements in room fires. Also, in the Cone Calorimeter tests, a white light measuring system was investigated, alongside the laser photometer. The results were highly similar.


This paper provides some of the background on the Cone Calorimeter testing procedures incorporated into the new military standard MIL-STD-2031 (SH).


This is a journal publication of the APME project results listed in report format below.


Examines numerous technical and operational aspects of various tests that are currently in use for measuring smoke emission from building products. Recommends the Cone Calorimeter as the most suitable of the bench-scale methods.

Cone Calorimeter data for the Megolon brand of polyolefin wire compound are presented in comparison with data for a PVC formulation identified as T12 in the British Standard BS 6746.


Develops data needs from the Cone Calorimeter for the Karlsson/Magnusson room fire model. Finds that there is a theoretical basis for weighting the HRR curve according to $q''(t)/t^n$, where $n=0.79$.


This brief note outlines the difference between complete Cone Calorimeter tests, as used by approvals laboratories, and an abbreviated testing procedure which could be used for factory production control.


The report describes a computational model used to predict the results obtained from the LIFT test solely from the basis of Cone Calorimeter data. The report is accompanied by a computer program and illustrative examples.


Develops procedures for preparing data input into the HAZARD-I computer model. This includes obtaining appropriate information from Cone Calorimeter and furniture calorimeter tests. The procedures are realized as a ‘macro’ program for the Lotus 1-2-3 spreadsheet.

The APME conducted an extensive series of Cone Calorimeter tests on 28 different types of specimens; most were tested at 4 irradiance levels. The project was conducted largely to familiarize APME members with the issues, procedures, and problems involved in Cone Calorimeter data. The large amount of data reported, however, will be useful to others seeking generic performance indicators.


Reports data on cables measured in a large-scale heat release rate rig (using the arrangement of the CSA FT-4 test) and also in the Cone Calorimeter. Finds that Cone Calorimeter data can be successfully used to predict full-scale results.


Reports results of 10 vinyl cables tested in the Cone Calorimeter and in the OSU apparatus and compares against larger-scale data obtained in several cable tray tests (UL 1581, CSA FT-4, and ICEA T-29-520). Finds certain predictive relations for heat and smoke.

Mikkola, E., Kartiokalorimetri (Research Notes 1087), Valtion Teknillinen Tutkimuskeskus, Espoo, Finland (1990).

Provides a basic explanation of Cone Calorimeter operations in Finnish.

Kallonen, R., FTIR kartiokalorimetristä myrkyllisten kaasujen mittarina, Palontorjuntatekniikka, 28-30, No. 3 (1990). [Note: ‘kartiokalorimetristä’ is a misspelt word, it should be ‘kartiokalorimetrissä,’ instead.]

This is a journal publication in Finnish, describing the work which is written up in English in the next item, below.

Describes the efforts of VTT to implement an FTIR spectrometer for use in gas analysis on the Cone Calorimeter. They have measured CO₂, CO, HCN, HCl, NO₂, SO₂, and acrolein, using a simple peak analysis rather than multi-component quantitative analysis methods.


This report describes the instrumentation and construction of a fire gallery used for large scale experiments. Results are reported for horizontal PMMA tests and for tests on parallel surfaces of particle board. By use of Cone Calorimeter measurements made on the same materials, predictions of flame spread are performed.


Examines effects of polymer molecular weight on Cone Calorimeter results. Finds no effect for polystyrene. For PMMA, however, high MW specimens show faster ignition and more rapid burning than do low MW specimens.


Provides Cone Calorimeter, LIFT, and Furniture Calorimeter data on these types of foams.


Describes the pivotal role of heat release rate in determining fire hazard and illustrates how Cone Calorimeter data can be used for successful predictions; by contrast, older tests such as the limiting oxygen index, or bunsen burner tests such as UL 94 are seen to be very limited in predictive capability.

This is a toxicity study where Cone Calorimeter data were reported for 3 materials—Douglas fir, rigid polyurethane foam, and PVC. A limited comparison is made to data obtained in other experiments.


In a study restricted to wood products and to vertical orientation testing only, finds that ignition data obtained in the Cone Calorimeter, the LIFT apparatus, and a modified OSU apparatus are highly similar. A similar comparison for heat release rates between the Cone and the OSU, however, showed substantive differences. A limited comparison is also made to full-scale fire data on room wall linings.


Continuation of the development of the room fire model described in the 1985 Magnusson/Sundström citation, below.


Reviews a number of methods for measuring smoke production from materials; provides Cone Calorimeter data on 7 plastics.


Smoke measurements in the Cone Calorimeter were compared to ones taken in an NBS smoke chamber which was modified by the installation of a conical heater and a load cell. Data for primarily wood materials showed that peak values of specific extinction area observed in the smoke chamber were only about 1/3 of those seen in the Cone Calorimeter, but data averaged over longer time periods were substantially in better agreement.

*Finds that Cone Calorimeter and ISO 5657 test results are generally similar; systematic differences can be accounted for by differences in apparatus design and test procedure. Recommends that the Cone Calorimeter be preferred for ignitability testing.*


*Investigates the use of non-standard specimen sizes and edge frames in the Cone Calorimeter. Finds that highest heat release rate values are seen for the case when a special edge frame made of a low-density insulating material is used.*


*Describes the further improvements to the 1987 Wickström/Göransson method for predicting the heat release rates in the full-scale room/corner test, based on material property data taken in the Cone Calorimeter.*


*Provides comparative data for upholstered chairs taken in the FRS and the NORDTEST furniture calorimeters and in the Cone Calorimeter.*


*Provides Cone Calorimeter data for EVA specimens taken at 30, 40, and 50 kW·m² irradiance levels. Comparative limiting-oxygen-index (LOI) data show the latter technique not capable of predicting trends seen with the Cone Calorimeter.*


*Gives flux levels proposed by the laboratories participating in the EUREFIC project for doing exploratory tests in the Cone Calorimeter. 50 kW·m² is the primary flux, with 35, 75, and 25 being also used, depending on certain ignition conditions.*
Presents a simplified calculational model for the charring rate of wood; experimental data from the Cone Calorimeter are used.


This is a Cone Calorimeter standard which contains testing details specifically oriented towards upholstered furniture and mattress composites.


Presents comparative results on full-scale chairs burned in room fires and in the furniture calorimeter, compared to data obtained in bench-scale with the Cone Calorimeter.


Foam/fabric composites were tested in the Cone Calorimeter at an irradiance of 25 kW·m⁻². Two types of foam — standard polyurethane, and melamine-treated polyurethane — were used, along with 18 fabrics, primarily vinyls. The same combinations were also tested in the BS 5852 Part 2 test, using the No. 4, 5, and 7 cribs. A comparison between the performance was made on the basis of a ranking scale (details not given).


Provides data for mass loss rates and effective heats of combustion, measured on PMMA and polystyrene samples of two different molecular weights.


Gives a color close-up photo showing the controlled-atmospheres Cone Calorimeter in operation.

*The ASTM standard for the Cone Calorimeter. Note that ASTM E 1354 and ISO DIS 5660 are functionally identical, with the exception that the ISO standard does not incorporate the smoke measurements.*


*Provides Cone Calorimeter data on bus seat composites, along with larger-scale results obtained in the Furniture Calorimeter. The results are consistent with the conclusions of Parker, et. al. (1990, above) in that specimens with a 180 s average HRR < 100 kW·m² do not lead to propagating fires (i.e., HRR > 80 kW) in full scale. The converse was not necessarily true, suggesting that certain products tested in the full scale might have led to propagating fires if the ignition source were slightly different.*

Tran, H.C., Modifications to an Ohio State University Apparatus and Comparison with Cone Calorimeter Results, AIAA/ASME Proceedings, Seattle (1990).

*Compared HRR and ignition times measured in the Cone Calorimeter with those in the OSU apparatus. The ignition times are roughly similar. The HRR in the OSU, however, shows an under-reporting error when thermopile sensing is used; additionally, the irradiance to the specimen is not controlled but rises during test. Finally, certain specimen holder relationships are explored.*


*Compares the features of the Cone Calorimeter and the OSU calorimeter.*


*Presents data on several plastics collected in full-scale room/corner burns and compares to measurements made in the Cone Calorimeter.*


*Toxicity results using animal exposures are reported on a combustion system described by Caldwell and Alarie, below.*

An experiment is described whereby an enclosed, highly modified Cone Calorimeter is used to generate a gas mixture for the toxicity testing using mice.


A brief overview and introduction to the Cone Calorimeter, intended for technical specialists not in the area of fire.


Discusses some of the newer fire test methods; places the Cone Calorimeter in context of these.


Demonstrates how Cone Calorimeter data can be used to classify wall/ceiling linings into groups which correctly relate to full-scale fire test results.


Provides Cone Calorimeter data for PVC, FR PVC, chlorosulphonated polyethylene, PTFE, ATH-filled thermoplastic EVA, and ATH-filled cross-linked EVA. Also compares results to those obtained in other small-scale tests, including tests for smoke and corrosivity.


Cone Calorimeter results for smoke and CO production of a furniture foam are compared against a full-scale chair test.


This was the ISO draft version of the Cone Calorimeter standard.

One of the common solutions for meeting the requirements of the new British furniture flammability regulations is to adopt a melamine-containing polyurethane foam. This study finds that melamine addition slows down not only the heat release rate, but also the yields of CO and of smoke.


Provides Cone Calorimeter heat and smoke data on a number of PVC formulations intended for plenum cable use. Data are compared against older PVC formulations and against PTFE and a new polyethylene formulation based on organosilicon technology.


Provides correlations for heat release and smoke in the Cone Calorimeter, versus various larger-scale cable tray tests.


Gives Cone Calorimeter data for some several types of polymers used as wire and cable insulation. Also shows a good correlation for smoke production of the Cone Calorimeter versus the '3 m Cube' test used in the United Kingdom.


This article describes a world-wide round-robin and testing program on several materials of construction; Cone Calorimeter data will be collected as part of this program.


Set up a gas pilot ignitor in addition to the normal electric spark ignitor. Tested liquids hexadecane and crude oils with both igniters. Found ignition times to be very slightly shorter for the gas pilot.

*Describes procedures for measuring HCl with the Cone Calorimeter. Recommends the use of the infrared GFC-type continuous analyzer.*


*Presents some data on cellulosic samples tested with and without the edge frame; also discusses the need for proper oxygen analyzer installation when testing materials producing NO₂."


*A mathematical model is developed for computing the upward spread of flame on a vertical surface. Material data from the Cone Calorimeter are used; the mass loss rate curve is generalized by a mathematical transformation so that its values at irradiances other than those during test could be computed."


*Presents data on yields of various combustion products, as measured from a number of building boards tested in the Cone Calorimeter.*


*Physical and electrical data for some new PVC wire insulation compounds are given along with Cone Calorimeter results.*
Cone Calorimeter data are used to demonstrate that the fire performance of the latex backing can dominate the total fire performance of the carpet on which it is applied.


Reports on vertical-orientation Cone Calorimeter tests of wood products; diagnostic measurements were made using a heat flux meter viewing the specimen surface. This is an extended abstract in Japanese.


An extensive presentation is made of light scattering theory and of the factors influencing smoke opacity. This is then applied to analyze the data from an experimental study on five building materials where three different smoke measuring systems were installed on the Cone Calorimeter: the standard laser system, a commercially available white light system (the 'Maurer photometer,' DIN 50 055) and a custom-made white light system.


This paper introduces thermal analysis specialists to the utility of the Cone Calorimeter. The role of heat release rate is emphasized and sample data are given.


The NORDTEST group of laboratories participated in the ISO round robin on the Cone Calorimeter. This report documents some of their data.


Describes a model for burning of combustible wall linings which uses Cone Calorimeter data for heat release rate.

Proposes classifications for distinguishing grades of polyurethane foams used for upholstered furniture padding. The criteria are based on measurements in the Cone Calorimeter.


Determines optimum irradiance for testing carpet tiles (25 kW·m⁻²). Ranks products according to the q"/t_oign variable group, as was earlier found to be useful for combustible wall linings.


This document discusses concepts of fire risk and fire hazard. The available ‘tool kit’ of reaction-to-fire tests is described, including the Cone Calorimeter.


Provides some Cone Calorimeter data for several insulating materials; compared results to data from UL 94, ASTM E 662, ISO DP 9306, and IEC tests 332-1, 695-2-1 and 695-2-2.


Describes how rate of heat release data from the Cone Calorimeter can be used as input to the HAZARD I computer fire hazard assessment method.


Compares ignitability results obtained with the Cone Calorimeter to theoretical predictions. Provides data for a number of woods, plus several plastics. Includes thermally thin and thermally thick specimens, but excludes considerations of diathermanous ones.

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Examines the effect of wire grid type on the ignition time of polyurethane foam tested in the Cone Calorimeter. The effect is seen to be proportional to effective mass of the grid. Suggests that the use of 1 mm diameter rods spaced 20 mm apart will have a negligible effect on ignition times (this is based on thermal mass considerations alone — the actual grid needed will also be determined by the thermostructural behavior of the specimen).


Examines heptane, heptene, and heptine for potential use as standards for smoke measurement. Finds specific extinction areas of approx. 100 m^2/kg for hexane, 350 for heptene, and 1000 for heptine. The mass loss rates are comparable (0.05 - 0.06 g/s) for all, under conditions of zero irradiance.


Reports detailed test results on 13 building products which have been widely studied in the Nordic countries. The data include heat release rate, mass loss rate, effective heat of combustion, yields of CO and CO2, and smoke (both standard laser measurements and measurements with a white light photometer).


Compares test results for five different combustible wall linings tested in an ASTM-type standard room against bench-scale data. The bench-scale tests used were the Cone Calorimeter and the LIFT apparatus. The bench-scale tests are seen to have predictive value.


A summary of the data obtained on the FRCA research project (full project report cited below).


Derives values of ignition temperature, thermal inertia (kpC), and effective heat of gasification from the irradiance/ignition time curve obtained in the Cone Calorimeter in the horizontal orientation. For this purpose, the (small) convective component in the heat transfer was experimentally determined to correspond to a heat transfer coefficient $h_c = 0.0115 \pm 0.0045 \text{ kW} \cdot \text{m}^{-2} \cdot \text{K}^{-1}$. Data for PMMA and particle board are given.

Presents data for textile wall coverings obtained with the Cone Calorimeter. The data can be used to judge the effect of the textile materials on creating fire hazard conditions in a room.


A brief introduction into the use of some modern fire testing concepts, including the Cone Calorimeter.


Presents extracts from the Ph.D. dissertation given below.


Presents an improved method for predicting flashover in rooms with combustible wall linings, based on using Cone Calorimeter data, and including an additional term for the density of the material.


Outlines role of the Cone Calorimeter as an essential bench-scale tool, useful for predicting full-scale fire behavior.


Compares smoke and soot values in medium scale studies to values obtained in the Cone Calorimeter.


Presents data on rate of heat release and related quantities measured on eight different types of cables used by the U.S. Navy.

Presents results of a systematic study on effects of fire retardants on PMMA, polypropylene, and polyethylene. The data include heat release, heat of combustion, and yield of CO, CO₂, and CH₄, as measured in the Cone Calorimeter.

Babrauskas, V., Smoke and Gas Evolution Rate Measurements on Fire-retarded Plastics with the Cone Calorimeter, Fire Safety J. 14, 135-142 (1989).

Provides Cone Calorimeter data showing how performance of plastics having a high degree of successful fire-retardant treatment can be distinguished from those treated with less effective fire retardants.


Finds that smoke measurements taken in the NBS smoke density chamber are not capable of predicting smoke results obtained in full-scale room/corner experiments, primarily because the specimen’s burning rate is not taken into account in the smoke chamber procedure. Finds that data obtained with the Cone Calorimeter do not suffer from this drawback.


Presents a model for predicting the HRR of wood; the results agree closely with actual measurements made using the Cone Calorimeter.


A very brief introduction to the Finnish audience about what the Cone Calorimeter is.

PVC-latex copolymer backcoatings for polypropylene carpets were examined in the Cone Calorimeter, in the flooring radiant panel test (ASTM E 648), and in the Motor Vehicle Safety Standard MVSS 302 test. Comparative results were also reported for the latex materials alone as plaques. An SBR (styrene-butadiene rubber) latex was seen to produce much more smoke than the PVC samples.

1988 R&D 100 Award Winners, Research & Development. 30, 62-104 (October 1988).

Describes the award given to the Cone Calorimeter as one of the 100 most significant products of the year.


Summarizes results obtained on composite (glass fiber or graphite fiber) panels intended for Navy shipboard use.


Illustrates use of Cone Calorimeter data in applications to fire modeling.


Provides mounting and specimen preparation instructions pertinent to the testing of cable specimens in the Cone Calorimeter; also shows some typical test results for various cable types.


Shows the use of Östman's 2X size Cone Calorimeter being used to obtain gamma ray wood density measurements; also gives some heat release rate data for wood products.

> Developed an experimental apparatus for measuring heats of gasification; the apparatus uses portions of the Cone Calorimeter. Determined the time-varying value of the heat of gasification for PMMA.


> This dissertation reports detailed studies on smoke measurement errors in five different test apparatuses. The results are summarized in the note by Morgan and Geake, below.


> Compares the smoke measurement errors due to selective losses of various smoke particle sizes in the DIN dual-chamber smoke test (ISO DTR 5924), the NBS Smoke Chamber, the Rohm & Haas XP2 chamber, the Arapahoe chamber (ASTM D 4100), and the Cone Calorimeter. Finds that the Cone Calorimeter has the fewest measurement problems and errors of the instruments examined.


> Discusses modern tools for measuring fire properties and ways to analyze and present data. Historical developments leading to the Cone Calorimeter are pointed out.


> A formulation for polyurethane foam of lowered smoke emission is characterized with Cone Calorimeter data.


> Gives data on combustible wall linings, showing how times for room flashover can be predicted from Cone Calorimeter data.


> Discusses some recent Cone Calorimeter data obtained at Queen Mary College; also illustrates aspects of data presentation and storage methods.

Presents data on a variety of silicone liquids and polymers, identifies some unique properties of silicones, and compares results to those for organic substances.


Explains role of mass loss rate and ignitability measurements in determining the toxic fire hazard; illustrated with data taken on the Cone Calorimeter.


This preprint is now published as Elam, et. al., see above (1990).


Discusses differences in calibration data obtained in early runs made at Londonderry, versus values obtained at NBS. Also, develops ignition parameters for PMMA, particle board, and five types of mine conveyor belts.


Cone Calorimeter data obtained on a variety of polymers are compared to heat and smoke release data for 7 different vinyl formulations obtained in the Ohio State University apparatus. Oxygen index (LOI) data are shown to be misleading when comparing dissimilar polymer types.


Final report on work sponsored by the Fire Retardant Chemicals Association (FRCA), in which measurements on 5 different types of products were compared between the Cone Calorimeter, furniture calorimeter, and full-scale room fire tests.


This document supplements the ASTM and ISO standards being developed, and provides more detailed operating and maintenance instructions.

Documents problems involved in commissioning a commercial unit (many have been due to the instrument not having been tested on 50 hz mains). Also provides PMMA data and results on tests of electrical cables and mine conveyor belt materials.


Comparison between Cone Calorimeter and large-scale results for smoke and soot generation on materials of interest to nuclear winter studies.


Proposes that wall and ceiling lining flammability be classified according to results from the Room/Corner test and from the Cone Calorimeter. Also presents correlations for flashover time between the Room/Corner test and the Cone Calorimeter.


Evaluates the fire performance of various experimental and improved composite materials using the Cone Calorimeter. Also, analyzes data in terms of response parameters originally proposed by Kanury and Martin.


Illustration of uses of the Cone Calorimeter for predicting full-scale heat release rates.


Describes further results on scaling Cone Calorimeter data.

As part of these studies, a novel way to normalize Cone Calorimeter data has been devised. This allows results collected at varying irradiance conditions to be represented in terms of a single, normalized curve.


Provides smoke data on a number of materials. Also finds that the Cone Calorimeter represents a substantial improvement over static box-type (i.e., NBS Smoke Chamber) instruments.


Compares difficulty of use and errors of measurement of the currently-used paramagnetic oxygen analyzers with the older high-temperature cell type.


Summarizes the use of the Cone Calorimeter for rating materials to be used as room wall linings. A satisfactory prediction of full-scale room fire results is demonstrated.


Compares the mass loss rates of some materials measured in the Cone Calorimeter at several irradiiances.


A brief discussion of the development of the Calorimeter, along with a discussion of its role in testing flame retardant grades of plastics.

Comparing results of heat release, smoke, and mass loss rate for a number of plastics heated at 20 or 25 kW·m² fluxes.


Results of a systematic study on the effects of several fire retardants, conducted with the use of the Cone Calorimeter.


Results on the rate of heat release and smoke emission on a wide range of plastics, measured in the Cone Calorimeter using a 20 kW·m² irradiance.


Short description of the smoke measuring techniques used, along with some data.


A pilot data base which includes Cone Calorimeter data.


Method for using Cone Calorimeter data in fire hazard prediction.


This was the first version of the method developed at SP (Statens Provningsanstalt, Sweden) for predicting full-scale results on room wall fires, based on Cone Calorimeter data. For a later version, see Göransson and Wickström, above.

A technical description of the smoke and soot measuring instruments incorporated into the Cone Calorimeter, along with a description of the shortcomings of older test methods for smoke.


Contains some illustrative uses of Cone Calorimeter data.


Presents the first experimental effort in comparing the toxicity generated in full-scale room fires to the values determined from making gas measurements in the Cone Calorimeter.

Janssens, M., Some Experience with the Cone Calorimeter, an Instrument to Measure the Rate of Smoke and Heat Release, pp. 111-125 in Fundamental Aspects of Polymer Flammability, G. Cox and G. Stevens, eds. Institute of Physics, London (1987).

Describes some results obtained from the Cone Calorimeter at the University of Ghent, Belgium.


Describes a wide variety of ignitability experiments conducted in the Cone Calorimeter, and compares the data to theory, models, and the data from other experiments.


A comparative study on several plastics materials done at the University of Ghent, Belgium.

The draft Cone Calorimeter test method, now superseded by ASTM E 1354.


A semi-technical, summary view of the development, the features, and the uses for the Cone Calorimeter.


Illustration of uses of the Cone Calorimeter for predicting full-scale heat release rates.


A study comparing the performance of several different aircraft panel types in several bench-scale instruments, including the Cone Calorimeter, the standard OSU apparatus, an OSU apparatus modified for oxygen consumption calorimetry, the Factory Mutual flammability apparatus, and an experimental method used by J. Quintiere; also includes a comparison to full-scale data.


Results are given from the experimental apparatus described by Levin and co-workers in 1985.


Presents a method for approximating the shape of the full-scale rate of heat release curve for upholstered furniture fires, based on Cone Calorimeter data.


Presents results of a testing program on the heat release rate behavior of several rock wool and glass wool insulation materials. Specimens were tested at several irradiance levels, up to as high as 90 kW·m².

*Compares the results obtained in the Cone Calorimeter with data from an experimental apparatus where 200 mm x 200 mm specimens were used.*


*A comparison between actual heat release rate measurements on wood materials in the Cone Calorimeter and a state-of-the-art computer model of wood combustion.*


*A presentation of some parallel bench-scale data obtained in three apparatuses, including the Cone Calorimeter.*


*Contains descriptions of how Cone Calorimeter data may be used to predict the full-scale fire behavior of upholstered furniture.*


*A data compilation on five different aircraft panels, including extensive measurements in the Cone Calorimeter.*


*A study on the actual fire hazard that can be expected from using electrical non-metallic tubing. Bench-scale data were taken from the Cone Calorimeter, these data were then used in the Harvard Fire Code to make predictions, which were verified by full-scale room fire tests.*

A brief summary of the findings by these same authors, given in their 1984 report (cited elsewhere in this bibliography).


An experimental system for fire gas toxicity measurement is described which used the Cone Calorimeter as the combustion module for generating the products of combustion.


Preliminary results from the smoke measuring instrumentation incorporated into the Cone Calorimeter.


Proposes a model for room fires where data from the Cone Calorimeter can be used as part of the needed material properties on combustible wall/ceiling linings.


Prediction of full-scale rate of heat release peak heights, based on Cone Calorimeter data.


Brief presentation of smoke measurement capabilities being developed for the Cone Calorimeter.


The initial results obtained in the development of a state-of-the-art model of wood combustion are compared to actual data taken from the Cone Calorimeter.

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*An overview presentation on the early development of the Cone Calorimeter.*

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1984


*The original description of the design of the Cone Calorimeter, not including smoke and soot measurements.*


*Provides predictive correlations between full-scale and Cone Calorimeter data for two separate applications: upholstered furniture and combustible wall linings. Also illustrates the general method to be used in order to obtain a predictive correlation.*


*A comparison between full-scale data on solar collector panels and the results from several bench-scale test methods, including the Cone Calorimeter.*


*Comparative full-scale and Cone Calorimeter data are given on some materials used in rail vehicle interiors.*

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*The basic equations necessary for doing oxygen consumption calorimetry are given here and are used in the data analysis software for the Cone Calorimeter.*

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Recommends that the Cone Calorimeter be adopted as the apparatus for making bench-scale rate of heat release measurements on materials used in coal mines.


Comparative Cone Calorimeter heat release rate and ignitability measurements are reported on several fire retarded and non-fire retarded polyurethane foams.


A study commissioned by ISO to determine upon which available rate of heat release apparatus it should focus its work.


The original NBS report on the apparatus.

The original publication presenting oxygen consumption calorimetry as a general-purpose engineering technology. Even though it precedes the start of the development work on the Cone Calorimeter, it is included since the principle described was fundamental to the Cone Calorimeter.
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An annotated bibliography is presented of published papers and reports on the topic of Cone Calorimeter apparatus, test data, and engineering applications of the test data. While most of the material surveyed is in English, the known foreign-language publications are also included. The annotations include a brief description of the work reported, however, the data are neither critically evaluated nor assessed.
Periodical

Journal of Research of the National Institute of Standards and Technology—Reports NIST research and development in those disciplines of the physical and engineering sciences in which the Institute is active. These include physics, chemistry, engineering, mathematics, and computer sciences. Papers cover a broad range of subjects, with major emphasis on measurement methodology and the basic technology underlying standardization. Also included from time to time are survey articles on topics closely related to the Institute's technical and scientific programs. Issued six times a year.

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