A Short History of HRR Testing

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Scope of talk

- I will emphasize in this talk some material that is **not** covered in the Babrauskas/Grayson book… unpublished, personal history of HRR technique development.
- If you are interested in HRR, you should have the HRR book, since it is the only available full-length book on the topic.
- The book has changed publishers 4 times, but is now available from Interscience Communications Ltd, in London (no on-line ordering; send them a fax or email).

Heat Release in Fires (1992)

Some history: 1970

- This is a good starting point for discussing the scientific basis of Fire Safety Engineering (FSE).
- SFPE was started in 1950.
  - But, until around 1970, FSE was hardly "engineering."
  - The practitioners' work was very cut-and-dry. It was straightforward application of codes & standards. It did not match the level of other engineering fields, where innovative, theory-based calculations were commonly being done by the more advanced practitioners.
  - 1970 ($\pm$ 2 years) can be taken as the very beginnings of "putting science into FSE."

What happened in 1970?...

- Prof. Howard Emmons' long-term campaign to start up some fire science activities in the US started bearing fruit.
- Around 1968, he convinced Factory Mutual (FM) management that they should set up a science-based research department. (Up to that point, they were doing a lot of testing, but this was routine testing, not really research).
- But who could they hire? Apart from Emmons and a very few other professors, there was nobody in the US who was a Ph.D. scientist working in the fire safety area.
- So FM decided to hire some good scientists, but without a fire safety background.

…What happened in 1970?...

- The scientists were sent to NBS (currently named NIST) for practical training.
- Fire safety research had been going on at NBS since 1904. But this was an exceedingly limited effort. Up to WW II, there were typically only 3 engineers on staff, and none of these were beyond the B.S. level. There were a number of technicians, however, who did a lot of fire resistance testing.
- After WW II, this group increased slightly (to about 6) and gained one Ph.D. (Alex Robertson).
- Right after WW II, a new task was added for NBS: flammable fabrics research. During 1967-68, this research was greatly expanded and a flammable fabrics group of 10 or so persons was set up.

…What happened in 1970?...

- The FM "trainees" joined small NBS fire research effort.
- In 1970, the FM "trainees" returned to FM and the FM Basic Fire Research group started doing intensive research, especially on the role of radiation in fires.
- But this cross-fertilization also served to re-animate NBS, which became seen as a place where cutting-edge fire safety research work could legitimately be done.
  - The FM group's leader, Dr. John Rockett, stayed at NBS, instead of going back to work at FM. He became the "advanced science driving force" at NBS for a number of years.

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…What happened in 1970?...

- Again, largely due to Prof. Emmons' efforts, Congress passed the Federal Fire Prevention and Control Act of 1974 act setting up a "Fire Research Center" at NBS.
- Dr. John Lyons became the first Director of the Center.
- The staff size skyrocketed dramatically and, at its high-water mark, 1975-77, numbered 125 (total staff, including support personnel)

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…What happened in 1970?...

- But the most important event that happened in 1970 was the setting up of RANN (Research Applied to National Need) by NSF, the National Science Foundation.
- Until that time, NSF focused solely on very theoretical research, in other words, not anything that could be called engineering-related.
- RANN paralleled the race-to-space and Cold War efforts and was intended to kick-start a number of engineering areas in the US.
  - Luckily, again largely due to Prof. Emmons' efforts, fire safety science/engineering got included in RANN.

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…What happened in 1970?

- RANN funded medium to large research fire safety research programs at more than a dozen universities and institutions.
  - The largest programs were at UC Berkeley, University of Utah, Factory Mutual, Harvard University, and Johns Hopkins University's Advanced Physics Laboratory.
- The fire research funding at NSF was managed by Dr. Ralph Long.
  - His untimely death in 1975 badly crimped the program; it never recovered and, instead, was handed off to NIST.
  - Ralph Long is one of the "unsung heroes" of fire safety science.

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Now, some personal history…

- I came to UC Berkeley to study for an M.S. degree in Structural Engineering in Fall 1971.
- Not being much inspired by the prospect of spending the rest of my career designing reinforcing bars in concrete beams, I met Prof. Brady Williamson in Fall 1972 and quickly became a Ph.D. student under his guidance.
- Up to that point, nobody had yet earned a Ph.D. degree anywhere in fire safety science or engineering.
- There was no published track for doing that at UC Berkeley, either, but it had an interdisciplinary program that allowed Ph.D. research to be undertaken in non-traditional fields.

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Prof. Brady Williamson

1933 - 2007

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…UC Berkeley…

- I petitioned to work towards a Ph.D. degree in Fire Protection Engineering (in those days, a distinction was not being made between fire safety science and fire protection engineering).
  - My studies were in fire endurance, obviously not a close relation to HRR.
- In 1974, Rexford Wilson came to visit Williamson's labs at UC Berkeley.
  - Wilson was a well-known envelope-pushing FPE who wanted to stimulate injection of science into the FPE profession.
  - He found me as a "bright young lad" in Williamson's lab and proceeded to share with me his vision for a science-based engineering.

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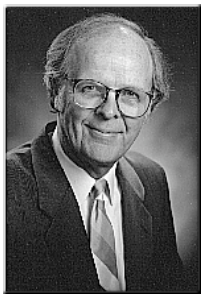
…Rexford Wilson…



- Originated the "*Stop, Drop, and Roll*" campaign at NFPA.
- Author of "*The Los Angeles Conflagration of 1961: The Devil Wind and Wood Shingles.*"
- For many years, co-taught Fire Safety Systems design course with WPI's Prof. Bob Fitzgerald.

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…UC Berkeley

- According to Rex Wilson, the most important thing missing from the capabilities of the FPE profession of that day was that "*we need to be able to measure quantitatively 'how big is the fire',*" in other words, the Heat Release Rate.
- Rex and I actually went into the lab and started to estimate the HRR of some common burning materials, such as matches.
- We did this very crudely, by measuring how long it took to burn up, how much mass was lost, looking up a theoretical heat of combustion value, and doing some arithmetic.
- He left me with the knowledge that the technology for doing this was an *Important Problem* that needed to be solved.

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Side note: FRS…

- Interestingly, fire safety science started in the UK about 20 years earlier than in the US, around 1950.
- The Fire Research Station (FRS) in the UK was the true starting point of fire safety science.
- FRS began in 1935, but as a mundane testing facility.
- Right after WW II ended, FRS, which had been doing largely military-support classified work in WW II, was refocused to become a fire science research establishment.
  - Dr. Philip Thomas (still alive today) became the most renowned of their researchers.
  - In 1949, Thomas joined FRS as brand-new Ph.D., having studied the science of high explosives under Frank Bowden, at Cambridge University.

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Side note: Prof. Frank Bowden

- Bowden wrote two books on the science of high explosives (1952, 1958).
- They are two of the most elegant books on any science that I know of.

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…Side note: FRS…

- By 1970, FRS had produced an amazing body of fire science research.
- But this body of work was nearly unknown in the US. The reason was simple: lacking fire science practitioners, fire science research documents are not of much utility.
- Despite the fact that fire safety science research was being done at FRS from 1950, curiously, FRS never tried to develop a HRR apparatus until the 1980s.

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…Side note: FRS

- FRS started getting progressively gutted by the UK Government, beginning around 1974. What remains today is a private consultancy doing almost no published research work.
- But their pride-and-glory, the Fire Research Notes (1952 – 1974), have now been preserved and made available to the public.
  - This was sponsored by IAFSS and was largely due to the hard work of Craig Beyler, its current Chairman.
  - These are currently available at:
    http://iafss.haifire.com/html/frs/Fire_Research_Notes/Index.htm

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Oldest HRR apparatus

- Rex Wilson was probably unaware that a HRR apparatus had been developed as early as 1959 at FM.
- This was the FM Roof Calorimeter. It was a massive furnace where a section of a roof deck would be dropped down onto a square opening of the furnace.
- HRR was computed by a substitution method.
- Despite its pioneering nature, it made no impact on the profession, most likely since it was cumbersome and did not lend itself to testing other types of specimens.

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NBS research…

- I never did get a chance to do what Rex asked for while I was still at UC Berkeley.
- I got my Ph.D. degree and went to work at NBS in 1977.
- When I came to NBS, there were already several projects under way where HRR was being studied.
- Bill Parker had built the "NBS-I" calorimeter in 1972. But it was obscure and had various operational problems.
  - The principle was a "substitution burner" design
- So NBS decided to make a better version.
  - Dr. John Tordella, on assignment from DuPont, was the designer.

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…NBS research…

  - Tordella was a brilliant instrument designer.
  - But the finished instrument, "NBS-II" cost $250,000 in 1978 dollars and was an industrial behemoth.
  - It was not something that NBS could hope to have industry and test laboratories install and operate.
- Next step was to see if the OSU (Ohio State University) calorimeter could be fixed up.
  - The OSU calorimeter was developed by Prof. Edwin Smith in 1972, but again did not become well-known until years later.
  - It was the first-ever calorimeter where the intention was to make it cheap enough so that industry and test labs could get them.

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…OSU calorimeter…

- Modern version of OSU calorimeter (mfg. by FTT, in London).
- Appearance greatly improved, but only the appearance…

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…NBS research…

  - Smith succeeded in making a cheap unit, but it was not very good.
  - It was a crude box, based on sensible heat flow measurements. Heat losses were ostensibly dealt with by means of calibrations, but in fact accuracy was poor.
  - My first efforts were to improve the OSU calorimeter.
  - It was clear that simply measuring heat flow (in a poorly-insulated box) by thermocouples will always give inadequate results.
  - So I tried to see if another principle could be put into use.

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Oxygen consumption calorimetry…

- In the mid-70s, at NBS Bill Parker and Clayton Huggett started exploring use of the oxygen consumption principle.
- The principle was first enunciated in 1917 by Prof. William Thornton, but had not found a practical application.
- Huggett and Parker started doing calculations to see if this might be the way to measure HRR more accurately.
- In 1980, I decided to hook up O_2 measurement equipment to the OSU calorimeter.
  - The measurement accuracy was much improved, but the hardware was still poor.

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Fixing the OSU calorimeter

- There were many other problems with the OSU instrument.
- The most serious problem was that the heat flux incident on the sample was not well controlled and would drift upwards during the test.
- But it also had no way of measuring mass loss, unreliable heating elements, unreliable smoke measuring instrumentation, etc.
- It was also personally embarrassing research … I tried to burn a polystyrene foam specimen in the OSU calorimeter. The outcome was that the insulation on the outside of the apparatus caught fire, the building filled with smoke, and Dr. John Lyons, head of CFR, was smoked out of his office.

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Relocation of fire research labs

- My OSU episode actually had an unintended positive outcome.
- Up to that time, the fire research labs were in the bottom floor of a 4-storey building. When I proceeded to smoke the management out of their offices (which were one flight up), they made a decision to move the labs.
- Very shortly thereafter, the labs were relocated to the top floor of the adjacent building.
  - Management learned empirically that smoke travels upwards!

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Developing the Cone Calorimeter…

- It was time to design a new HRR instrument, from scratch.
- This took about two years, 1980 – 1982, although smoke measurement instrumentation and some other features were not finalized until several years later.
- After the design was finalized, in 1988 the Cone Calorimeter was awarded an **R&D100** award. This is a prestigious award for the 100 best industrial inventions of the year.
  - It was the first time that a fire test apparatus was given this award.

Original NBS Cone Calorimeter

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…Cone calorimeter…

Currently-made, commercial Cone Calorimeter (FTT, London)

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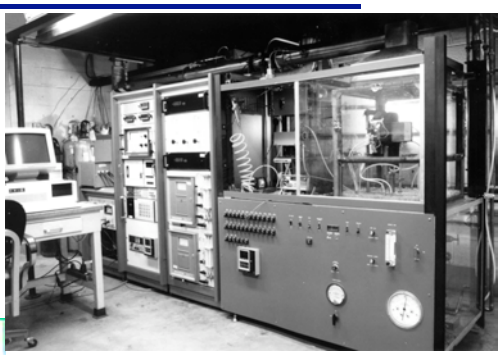
…Cone calorimeter…

- The Cone Calorimeter became the first widely-used fire test apparatus which was comprehensively engineered, not just put together.
- It was designed to provide a combustion system where there was a uniform heat flux imposed on the specimen, so that "per m^2" quantities could successfully be measured.
- One capability the original Cone Calorimeter did not have is to study burning under non-ambient atmospheres.
- So during 1989-1991, with the help of Dr. Marc Janssens and Bill Twilley, I built a controlled-atmospheres Cone Calorimeter.

Controlled-atmospheres Cone…



…Controlled-atmospheres Cone

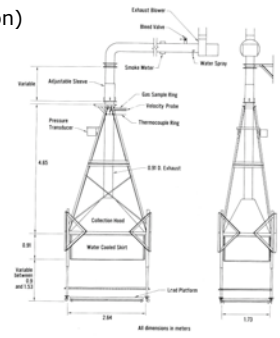
- The unit worked very well, and was the model for controlled-atmospheres Cone Calorimeters built at a number of other labs.
- NIST management celebrated this success by destroying the unit less than a year after I left NIST.

Furniture calorimeter…

- Also called open, large-scale HRR calorimeter.
- Was developed simultaneously with the Cone Calorimeter during 1980-1981.
- Became the first large-scale HRR apparatus based on O_2 consumption calorimetry.
- Was called "furniture calorimeter" since original objective was to measure the HRR of furniture.
- But such open calorimeters are now used to measure the HRR of any commodities that do not involve wall or ceiling materials.

Original NBS furniture calorimeter

(2 MW version)



6 MW NBS calorimeter

- Built soon after the 2 MW version.
- Used an existing hood facility, to which oxygen consumption instrumentation was added.
- A similar calorimeter was soon erected by SP in Sweden, then later numerous other labs installed such facilities.
- Some labs now can measure HRR in excess of 30 MW.

Room calorimeters

- Same oxygen consumption principles are used for making measurements.
- My own work in this area came a bit later.
- The first researchers to make room-scale HRR measurements with the oxygen consumption technique were Prof. Williamson (Berkeley), Jin Fang (NIST), and Billy Lee (NIST).
- Billy Lee made the first-and-only room fire study where various combustible wall/ceiling linings were simultaneously quantified for (a) HRR, and (b) actual measured instantaneous flame-covered area.
- NIST never published this landmark study, so you can find it on my web site.

Conclusions

- In order to become a "science," fire safety science had to achieve two things:
  1) Acquire the ability to measure the HRR of fires.
  2) Acquire the ability to make computations on fires, i.e., fire modeling.
- In my career, I have been fortunate to be at the "ground floor" of both of these developments.
- Both are now totally taken for granted by younger members of the profession.
- But it is interesting to note that, in 1970, both were just aspirations and not realities.

More information

- Babrauskas/Grayson book **Heat Release in Fires**
- **The SFPE Handbook**
  - Chapter 3-1: Heat release rates (Babrauskas)
  - Chapter 3-2: Calorimetry (Janssens)
  - Chapter 3-3: The Cone Calorimeter (Babrauskas)
- **Cone Calorimeter Bibliography, 2003 edition** (Fire Science and Technology Inc. publication).

QUESTIONS? COMMENTS?