NISTIR 6527

# Measurement Needs for Fire Safety: Proceedings of an International Workshop

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Technology Administration, U.S. Department of Commerce

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June 2000


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FORUM Workshop on Measurement Needs for Fire Safety
NIST, Gaithersburg, MD
April 4-7, 2000

# Heat Release Rate (HRR)

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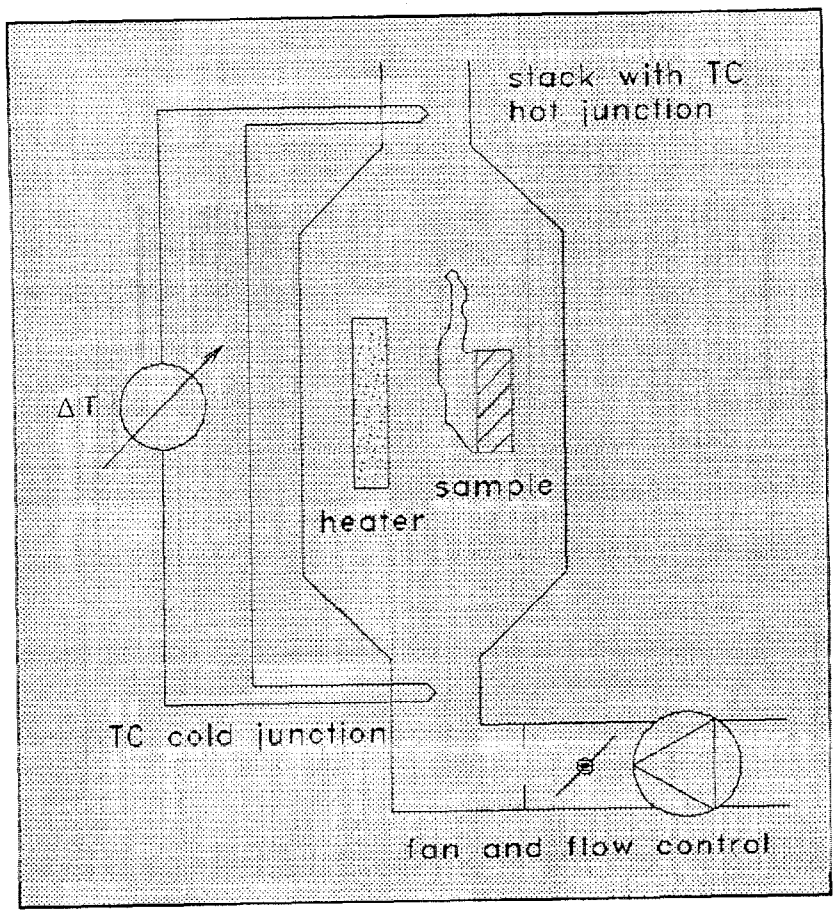
# Outline

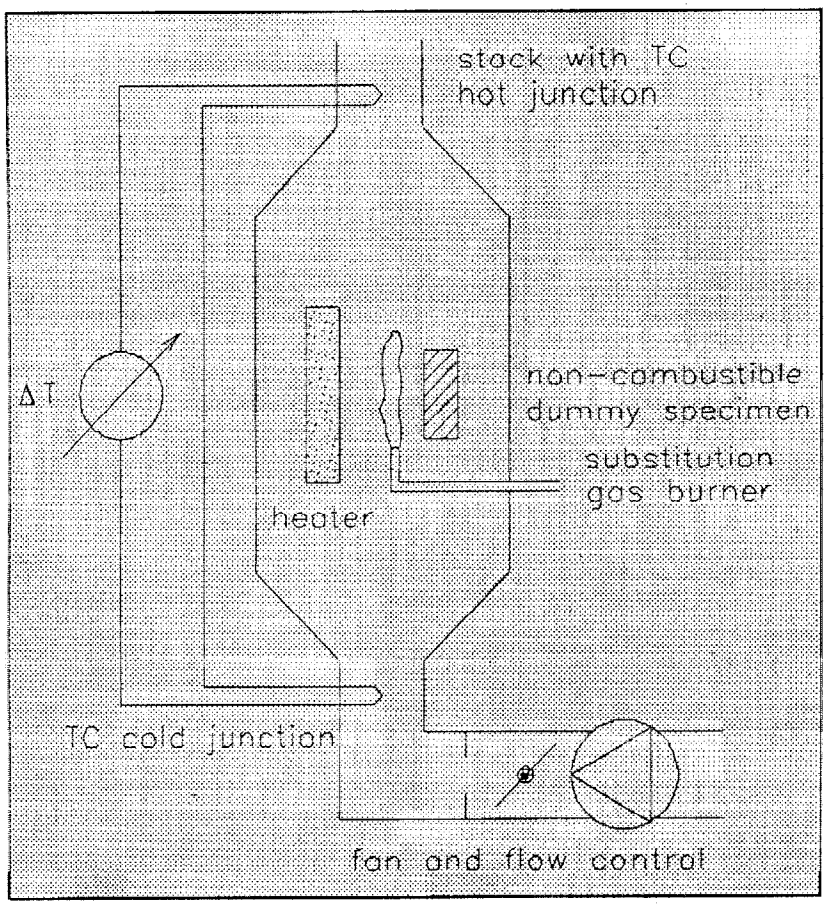
- Methods for measuring heat release rate
  - Sensible enthalpy rise method
  - Substitution method
  - Compensation method
  - Oxygen consumption method
- Heat release rate data and fire modeling
- Uncertainty Analysis
  - Terminology
  - Uncertainty of HRR measurements
- Conclusions

# Sensible Enthalpy Rise Method



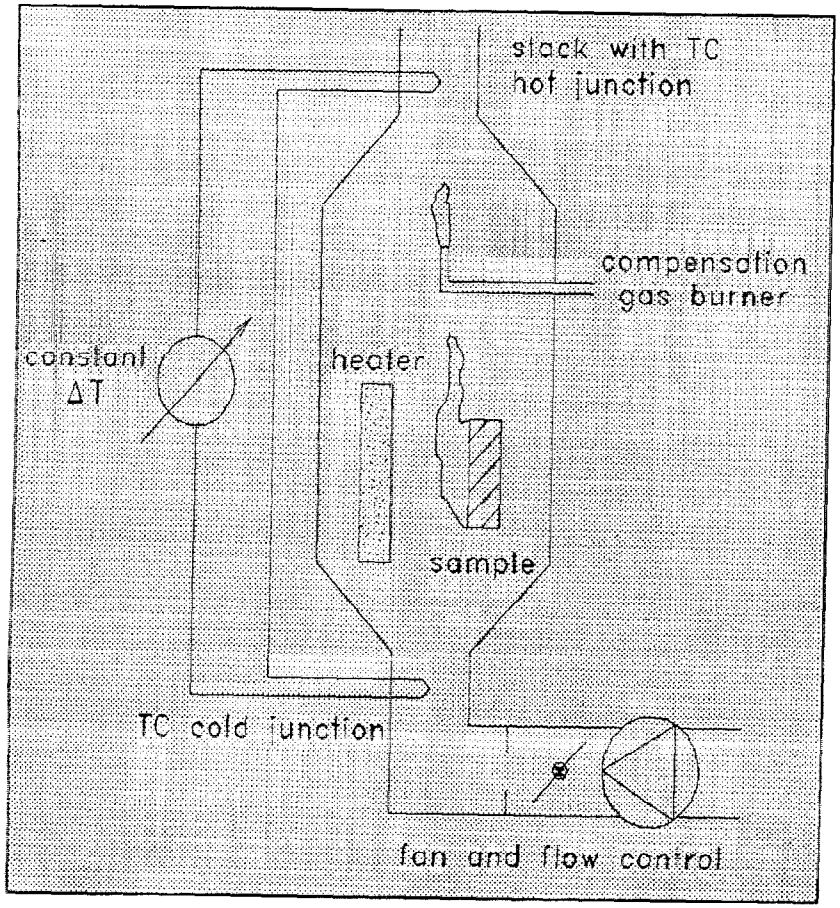

- **Examples**
  - Smith (OSU)
- **Advantages**
  - Simple
  - Inexpensive
- **Disadvantages**
  - Thermal lag
  - Radiative fraction

# Substitution Method



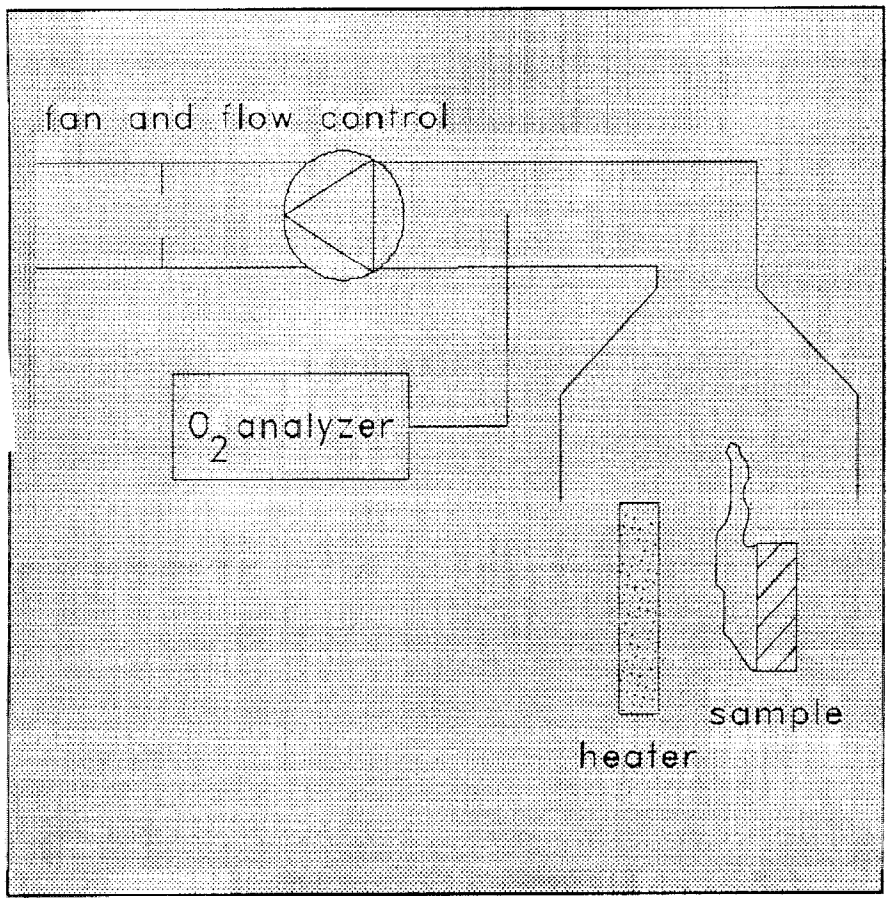

- **Examples**
  - Thompson/Cousins (FM)
  - Brenden (FPL)
- **Advantages**
  - No thermal lag problems
- **Disadvantages**
  - Complex control system
  - Double # of tests

# Compensation Method



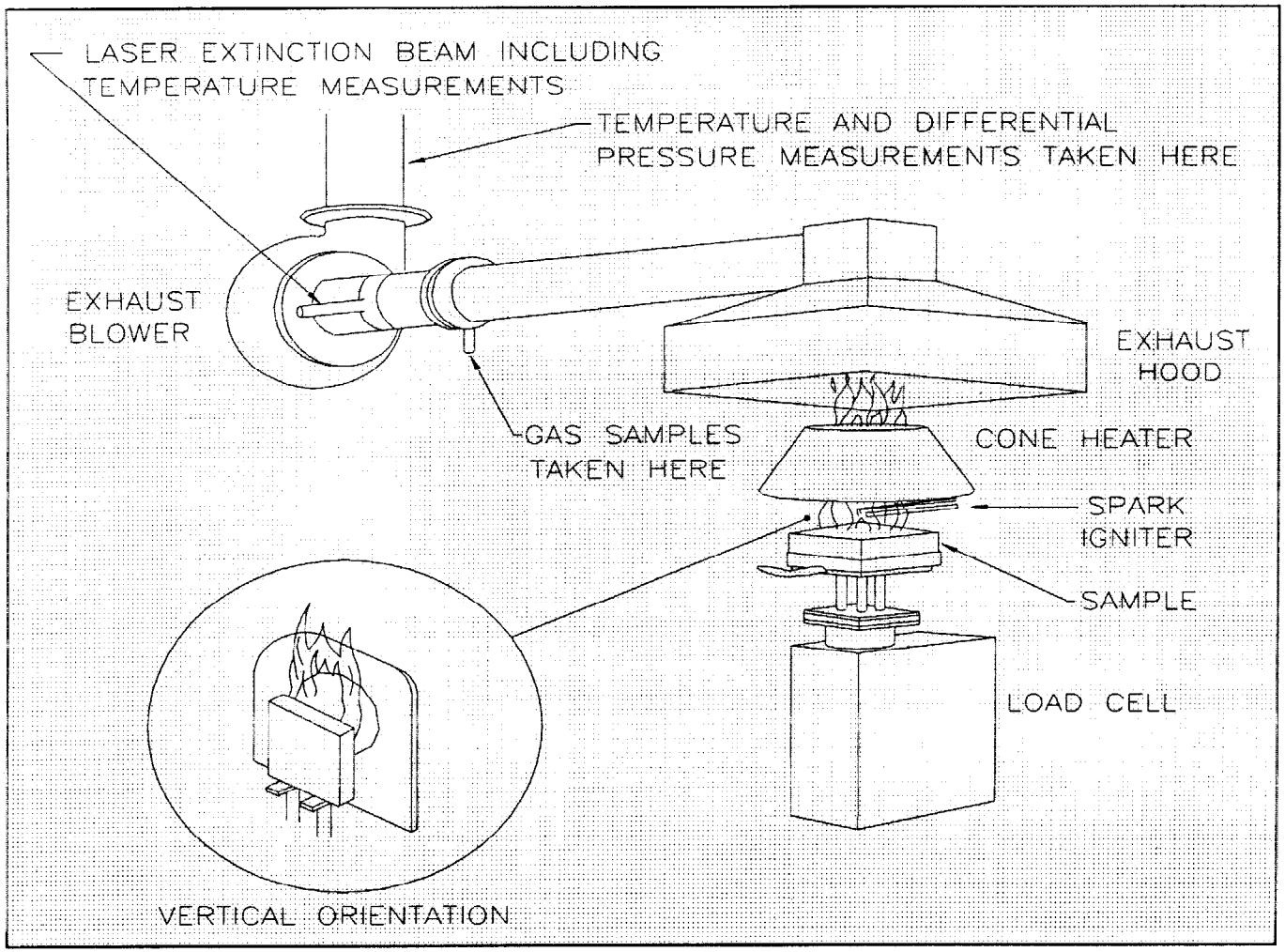

- **Examples**
  - Parker/Long (NBS)
  - Tordella (NBS)
- **Advantages**
  - No thermal lag
- **Disadvantages**
  - Very complex

# Oxygen Consumption Method




- **Examples**
  - Cone calorimeter
  - SBI
  - Room-corner test
  - Furniture calorimeter
  - ICAL
  - Large-Scale calorimeter
- **Advantages**
  - Practical
  - Accuracy
- **Disadvantages**
  - Instrumentation

# Small-Scale HRR Testing

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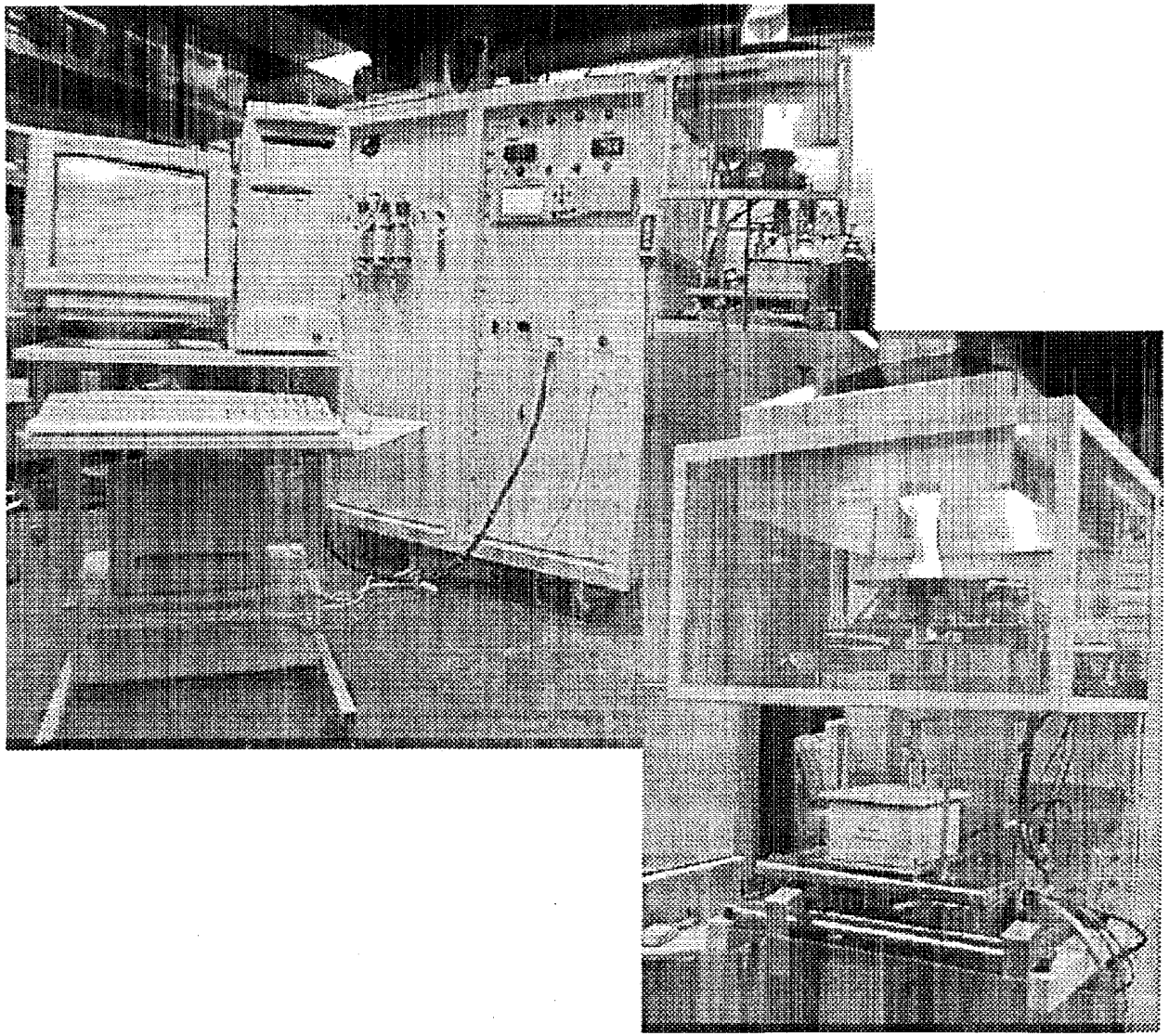
# Small-Scale HRR Testing



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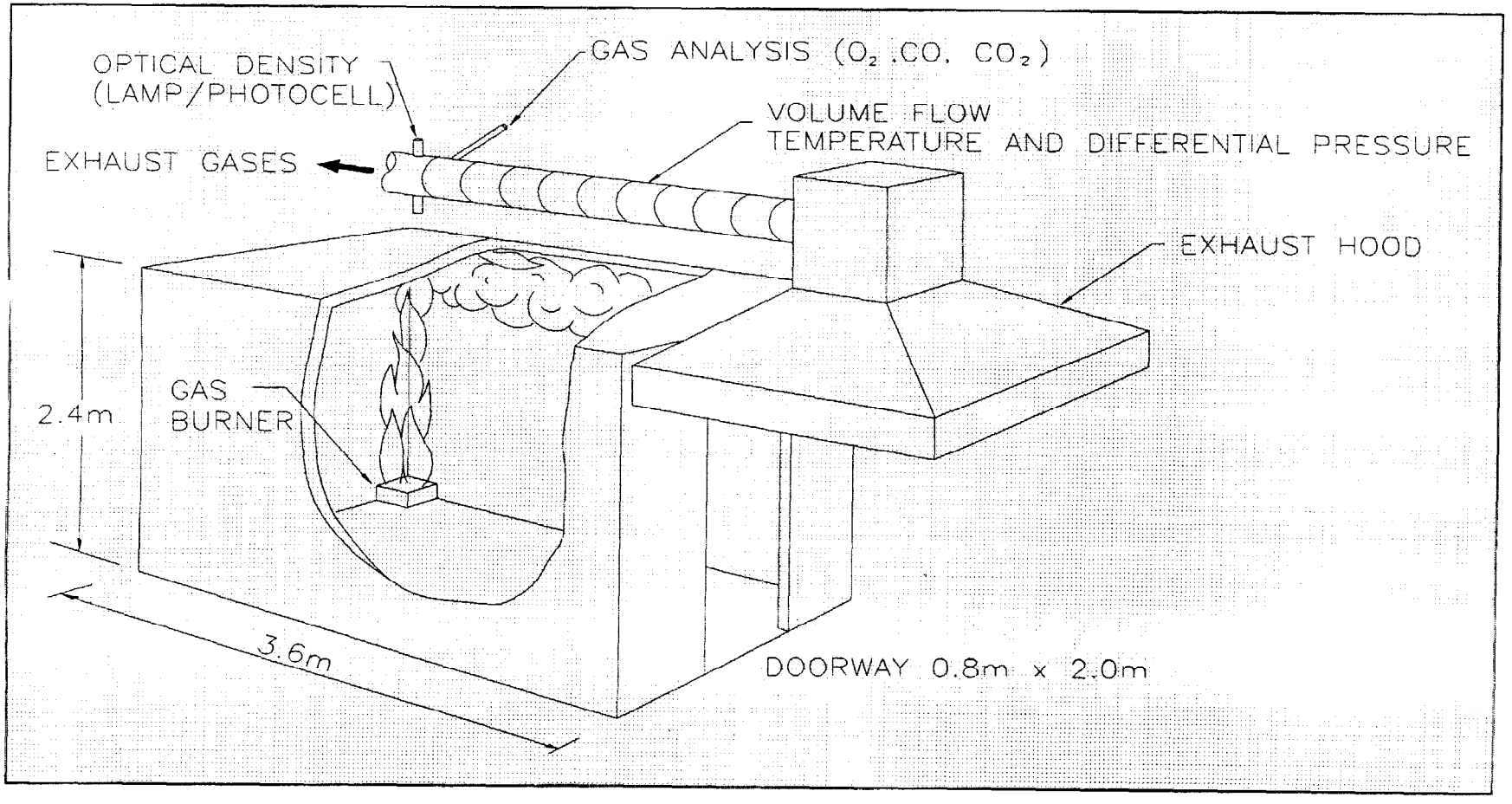
# Intermediate-Scale HRR Testing

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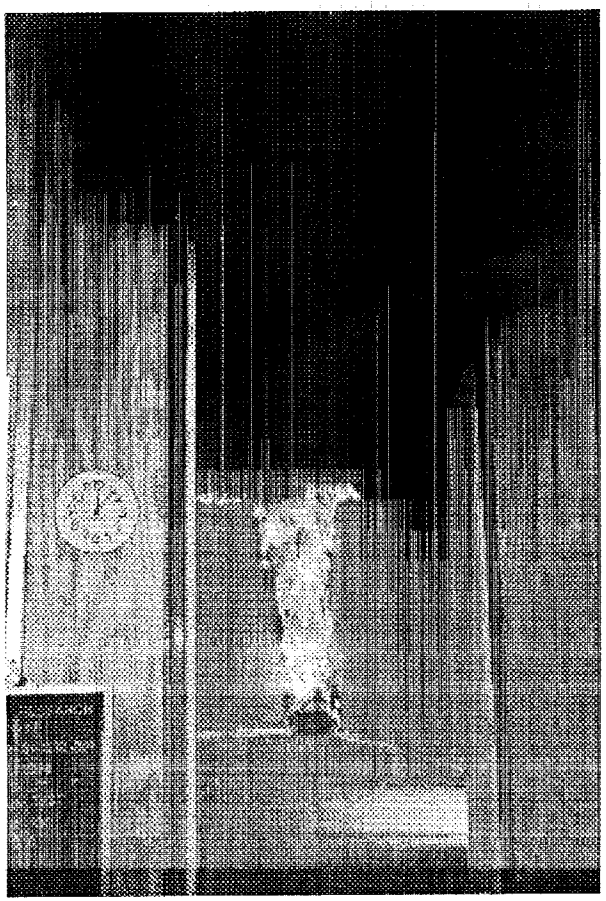
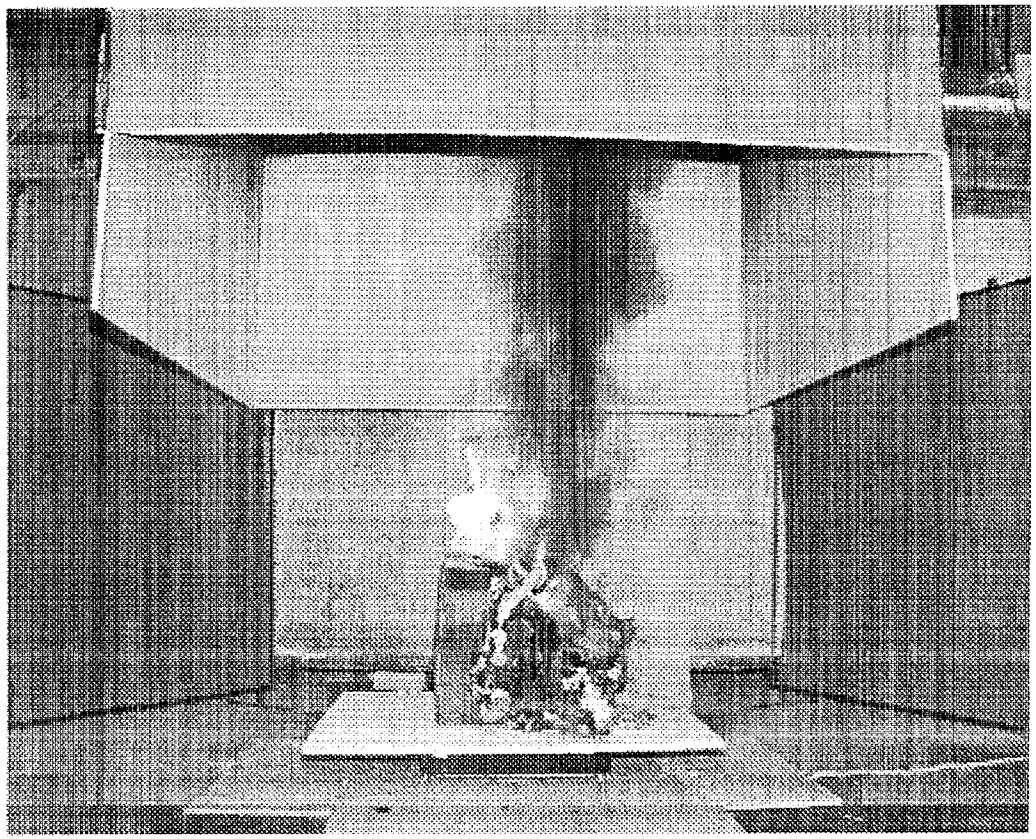
# Intermediate-Scale HRR Testing



Room-Corner Test



Furniture Calorimeter

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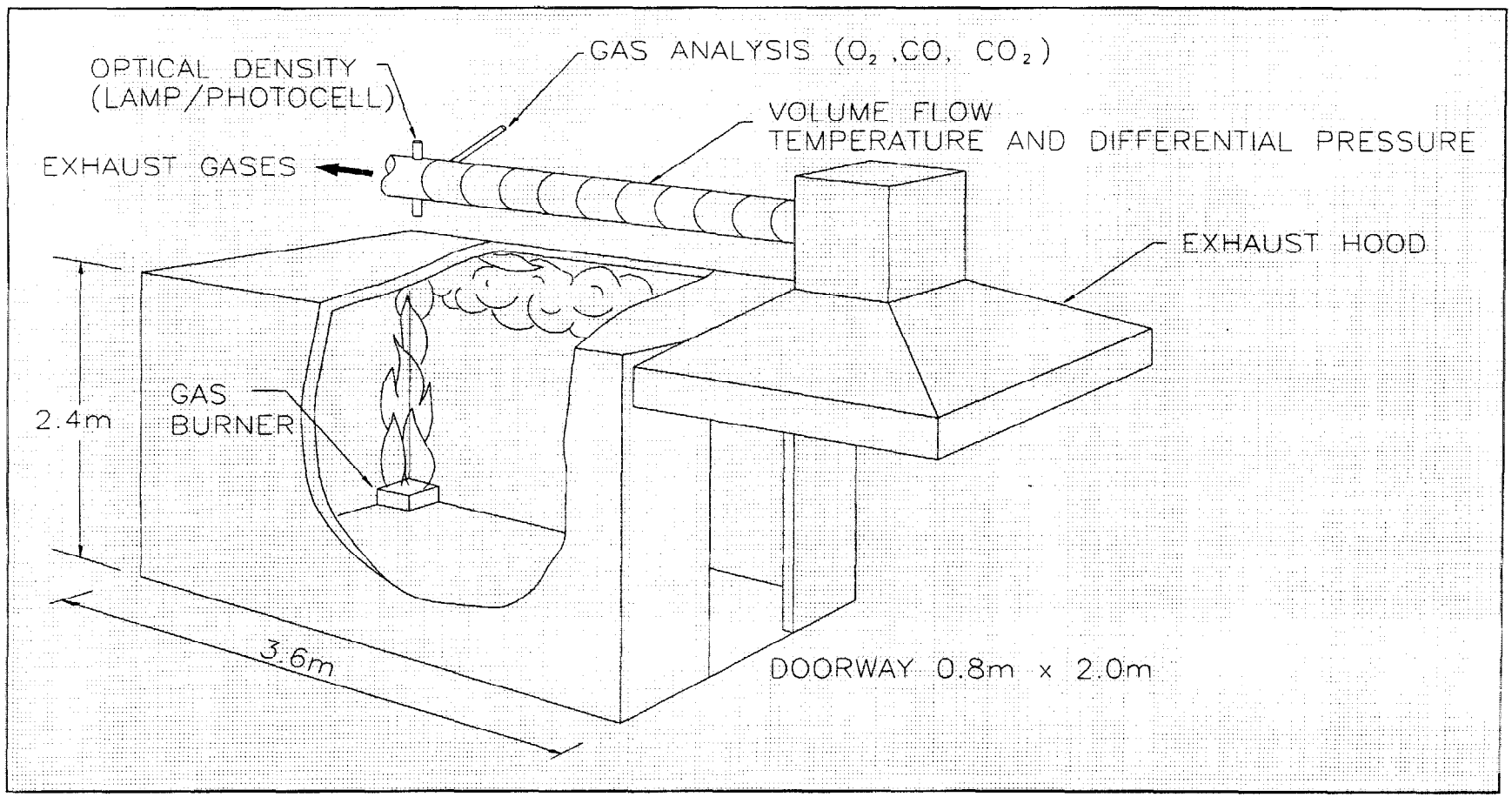
# Intermediate-Scale HRR Testing

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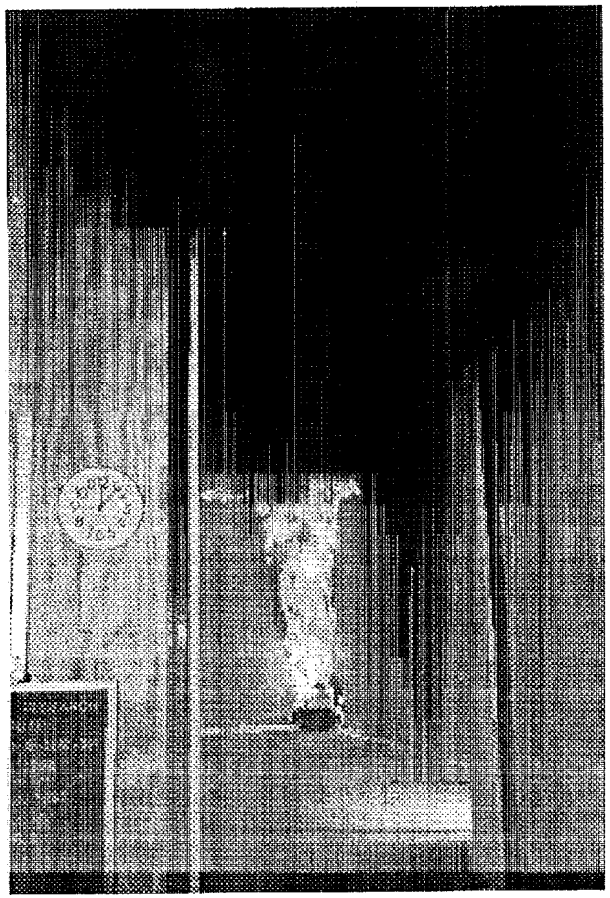
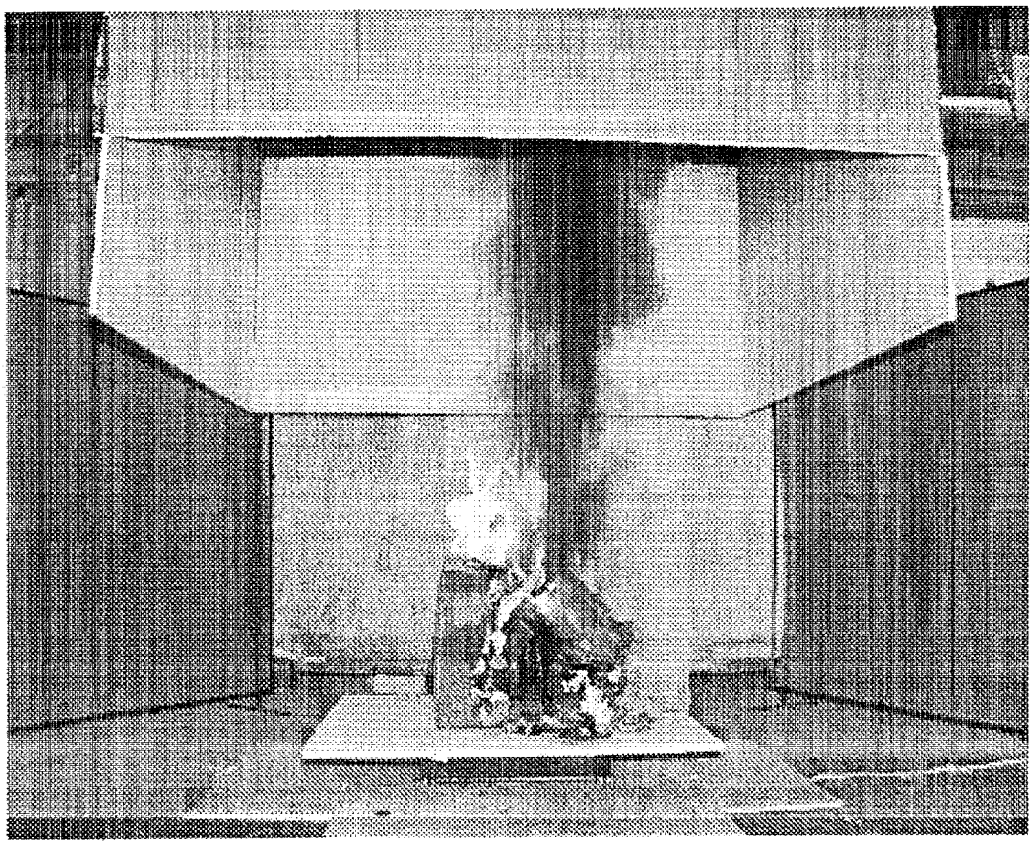
# Intermediate-Scale HRR Testing



Room-Corner Test



Furniture Calorimeter

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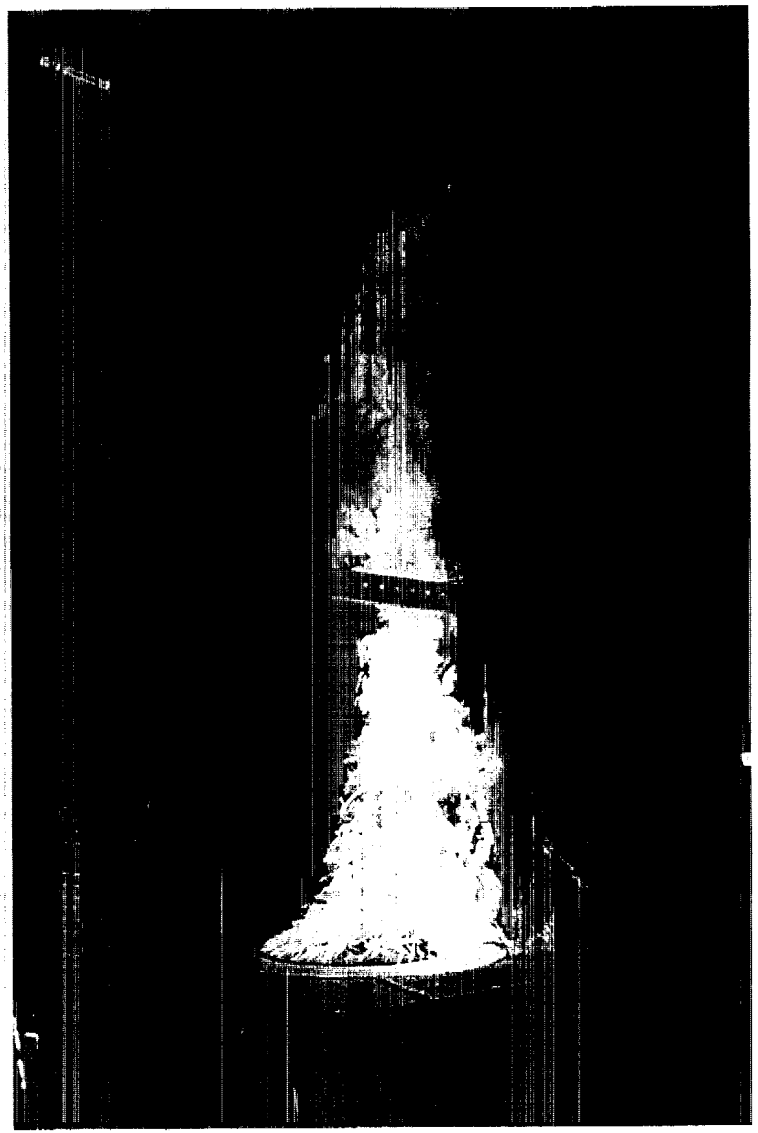
# Large-Scale Calorimeter



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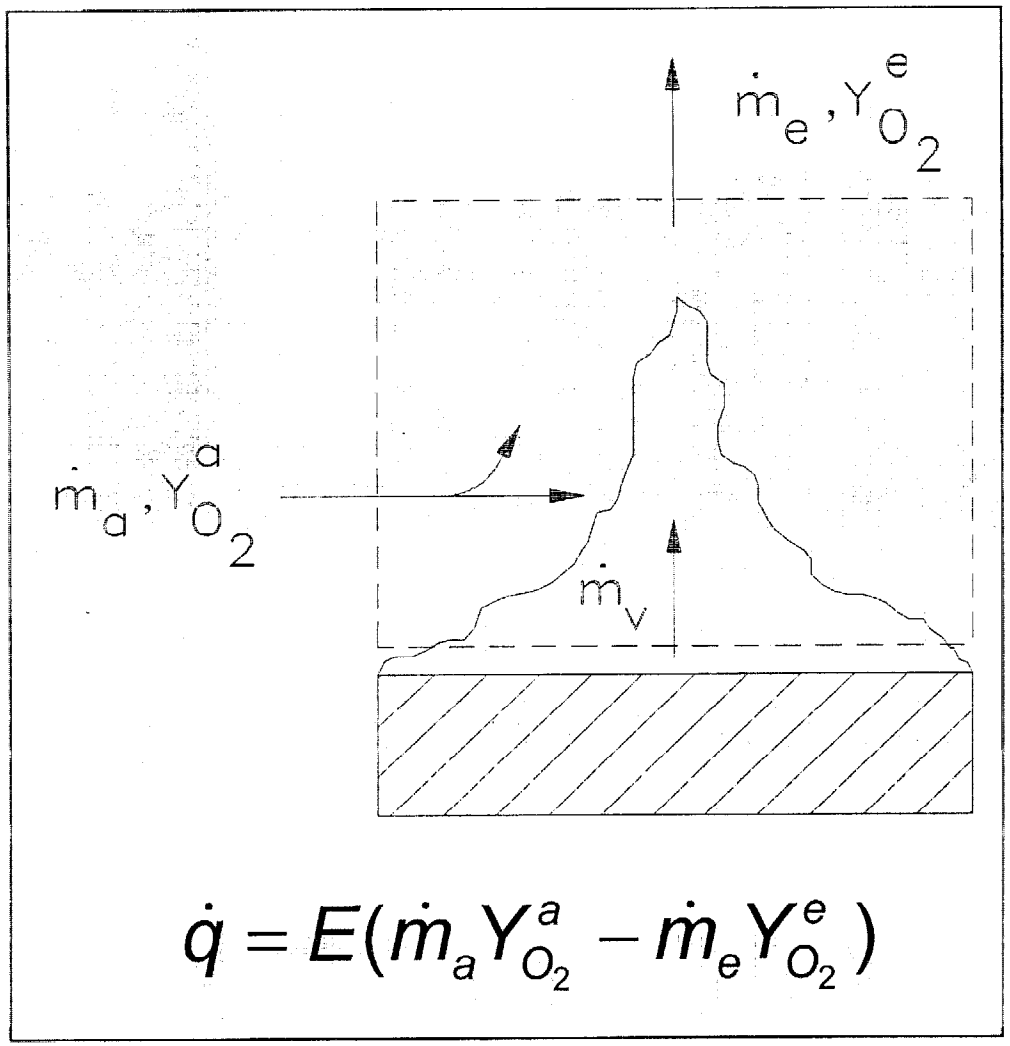
# Oxygen Consumption Method




$$\dot{q} = E(\dot{m}_a Y^a_{O_2} - \dot{m}_e Y^e_{O_2})$$

# Oxygen Consumption Method

$$\dot{q} = E \frac{\phi}{1+\alpha(\phi-1)} C \sqrt{\frac{\Delta P}{T_e}} \frac{M_{O_2}}{M_a} X_{O_2}^a$$

with

$$\phi = \frac{X_{O_2}^{A^a} - X_{O_2}^{A^e}}{(1 - X_{O_2}^{A^e}) X_{O_2}^{A^a}}$$



- Equations need to be modified if $CO_2$ is measured
- Equations can be corrected for CO and soot
- More accurate calculations can be made if water vapor is measured

# HRR and Fire Modeling

| | Model Input | Model Evaluation |
|---|---|---|
| Small-scale data | X | |
| Intermediate-scale data | X | X |
| Large-scale data | | X |

# Uncertainty Analysis – Terminology

- **Accuracy: Agreement between a measured value and the true value**
- **Error: Difference between the measured value and the true value, consisting of**
  - ↗ **Bias error: Fixed or systematic component**
  - ↗ **Precision error: Random component equal to r + R**
- **Uncertainty: Interval around the measured value within which the true value lies with C% probability**

$$X_{true} = X_{measured} \pm U = X_{measured} \pm \sqrt{U_p^2 + U_b^2}$$

# Uncertainty of HRR Measurements

$$\dot{q} = f(E, \alpha, X_{O_2}^{A^e}, X_{O_2}^{A^a}, C, \Delta P, T_e, \ldots)$$

$$U_{\dot{q}} = \sqrt{(\frac{\partial f}{\partial E} U_E)^2 + (\frac{\partial f}{\partial \alpha} U_\alpha)^2 + \ldots}$$

- Small-scale HRR: U = 5% (Enright/Fleischmann, 1999)
- Large-scale HRR: U = 7% (Dahlberg, 1994)

# Uncertainty of HRR Measurements

- Bias can be partially eliminated by calibration
  - ↗ Uncertainty of calibration standard
  - ↗ Test conditions different from calibration conditions
- Precision uncertainty from round robins

| | Year | Labs | Levels | Peak HRR | | Total HR | |
|---|---|---|---|---|---|---|---|
| | | | | r (%) | R(%) | r(%) | R(%) |
| Cone calorimeter | 2000 | 4 | 16 | 17 | 23 | 8 | 15 |
| SBI | 1997 | 16 | 30 | 38 | 54 | 47 | 71 |
| ICAL | 1999 | 3 | 8 | 56 | 67 | 72 | 118 |
| Room | 1994 | 12 | 5 | 65 | 79 | 25 | 41 |

# Uncertainty of HRR Measurements

**Discrepancies between uncertainty analyses and round robin data:**

- **Sample variability**
- **Operator variability**
- **Heat flux variability (small-scale)**
- **Random effects on fire growth (intermediate and large-scale)**
- **Dynamic errors**

# Conclusions

- HRR is the primary measure of fire hazard
- HRR is an essential input to fire models
- Databases of HRR data need to be expanded
- Measurement uncertainties need to be reported
- Uncertainties need to be reduced
  - ↗ Proficiency and training programs
  - ↗ Improved accuracy of fundamental measurements
  - ↗ Resolution of dynamic errors