ENCLOSURE FIRE MODELING

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Description of Figures (viewgraphs)
used in Firemen Program Review
presentation by C. D. Coulbert, JPL

"Enclosure Fire Modeling"

Figure

1. Introductory orientation summarizing the quantities describing an enclosure fire and its constraints.

2. The liquid fuel burning rate becomes effectively constant - approximately 4.5 mm/min -- for pools greater than one meter in diameter, independent of type of fuel. The rates are variable for pool diameters less than one meter.

3. The various relative energy release criteria (RERC) are listed and defined by simple analytic formulae having empirical constants in the stated metric units where applicable. For nomenclature see attachment from Reference 2.

4. Global quantities are analytically defined which provide potential scaling parameters for enclosure fire characterization. They are measures of the enclosure temperature rise, smoke density, and toxic gas concentration. For nomenclature see 3. above.

5. The application of the RERC for enclosure fire development is illustrated graphically. Each criterion is independent of the others.

6. A specific example of RERC application to tests is introduced by the description of Stanford Research Institute (SRI) enclosure fire experiments and the listing of corresponding JPL determined RERC values.

7-10. The corresponding specific titles are sufficient descriptions for the comparisons of SRI experimental data with RERC. See Reference 1, pages 19 & 20 for discussions.

11&12. The total heat fluxes, as determined from the average value at a calibrated test panel, are correlated with the burning rates of four fuels over the burning time of each SRI experiment for specified ventilation rates and patterns.

13. The RERC indicates for NASA-JSC/BOEING full-scale test No. 18 with trash fuel that the fuel load is the main constraint on fire development. The enclosure volume is great enough that the ventilation rate would not constrain the fire growth with the limited fuel available.

14. The RERC indicates for NASA-JSC/BOEING full-scale tests Nos. 16 & 17 with Jet-A fuel that the fuel surface is the initial and main constraint followed by the fuel load and then the enclosure volume in the later stages and that the ventilation rate is not controlling the fire development nor the maximum heat release.

References

1. Roschke, E. J. and Coulbert, C. D., "Application of the Relative Energy Release Criteria to Enclosure Fire Testing," Jet Propulsion Laboratory, to be published.

2. Coulbert, C. D., "Enclosure Fire Hazard Analysis Using Relative Energy Release Criteria," Jet Propulsion Laboratory, to be published.

3. Coulbert, C. D., "Energy Release Criteria for Enclosure Fire Hazard Analysis--Parts I & II," Fire Technology, Vol. 13, Nos. 3 & 4 August & November 1977.

NOMENCLATURE

A_f = Fuel surface area, meters^2

A = Ventilation opening area, m^2

b = Flame front length, m

c = Specific heat at constant pressure, KW-min/Kg-°C

D_s = Smoke specific density

F_m = Fuel mass, Kg

g = Gravitational constant, 9.8 m/sec^2

H = Vertical dimension of ventilation opening, m

ΔH = Heat of combustion, Kw-min/Kg

K_1, K_2, K_3 = Proportionality factors in consistent units

I_o/I = Radiant intensity ratio

$\mathring{Q}$ = Heat release rate, Kw

$\mathring{Q}_s$ = Heat release rate during flame spreading, Kw

$\mathring{Q}_f$ = Fuel surface controlled heat release rate, Kw

$\mathring{Q}_v$ = Ventilation controlled heat release rate, Kw

$(\mathring{Q}/A)$ = Heat release rate per unit area; a material property Kw/m^2

Q = Total heat released, Kw-min

Q_e = Total heat released by complete combustion of air in enclosure Kw-min

(Q/A) = Total heat released by complete combustion of unit area of fuel carpet: A material property Kw-min/m^2

U_{air} = Mass flow of air, Kg/sec

v = Flame spread velocity, m/min

R = Fuel burning rate, Kg/min

T = Temperature, °C

NOMENCLATURE (Continued)

ΔT_m = Mixed mean adiabatic temperature rise, °C

t = Burning time, min

t_e = Fire duration, min

V_e = Enclosure volume, m^3

ρ = Air density, Kg/m^3

Γ = Fraction of fuel evolved as smoke

t_s = Time for fire to spread to total fuel surface, min

m = Fuel mass loss, Kg

L = Optical path length, m

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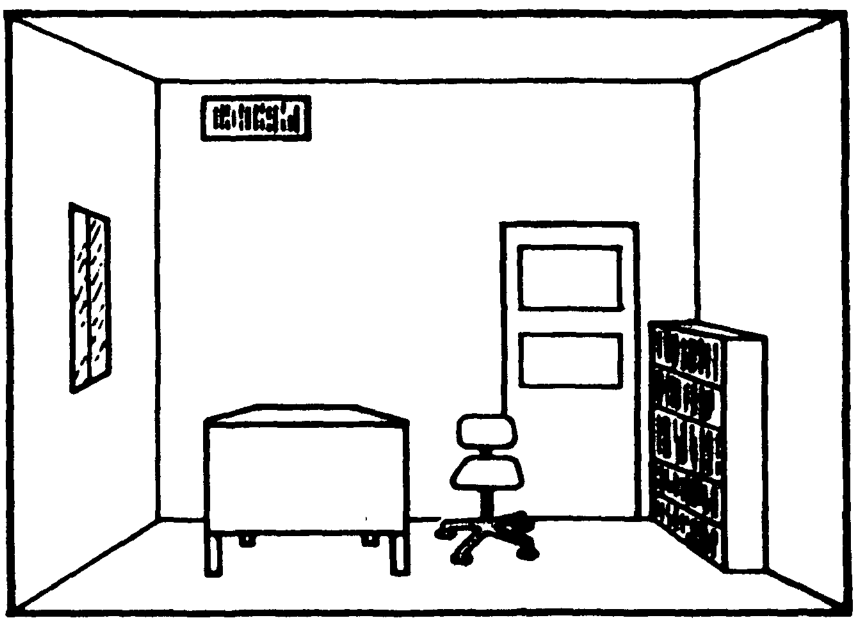
ABSTRACT

JPL has developed a fire characterization methodology which for the first time provides a unified analysis framework for the integration of all fire test data on a common basis. This fire characterization approach provides a basis for relating fire temperatures, smoke densities, toxic gas concentrations and heat fluxes to material properties, enclosure geometry, and ventilation factors. This fire characterization concept also provides a basis for utilizing small-scale and laboratory material test data in full-scale fire models (such as the cabin fire model developed by Dayton Research for FAA) to predict the response of aircraft components or whole cabin interiors to various fire scenarios.

The JPL fire characterization methodology in its present stage of development has already been used to develop an enclosure fire hazard analysis procedure capable of predicting the probable course of fire development in an enclosure and indicating which fire parameters would control fire development during its critical phases. Fire test data on burning rates from a wide variety of sources, fuels, and test methods have been compiled and correlated on a common basis and have revealed heretofore unrecognized interrlationships and a potential basis for improved predictions of material response to fire.

*This abstract represents one phase of research performed by the Jet Propulsion Laboratory, California Institute of Technology sponsored by the National Aeronautics and Space Administration, Contract NAS7-100.



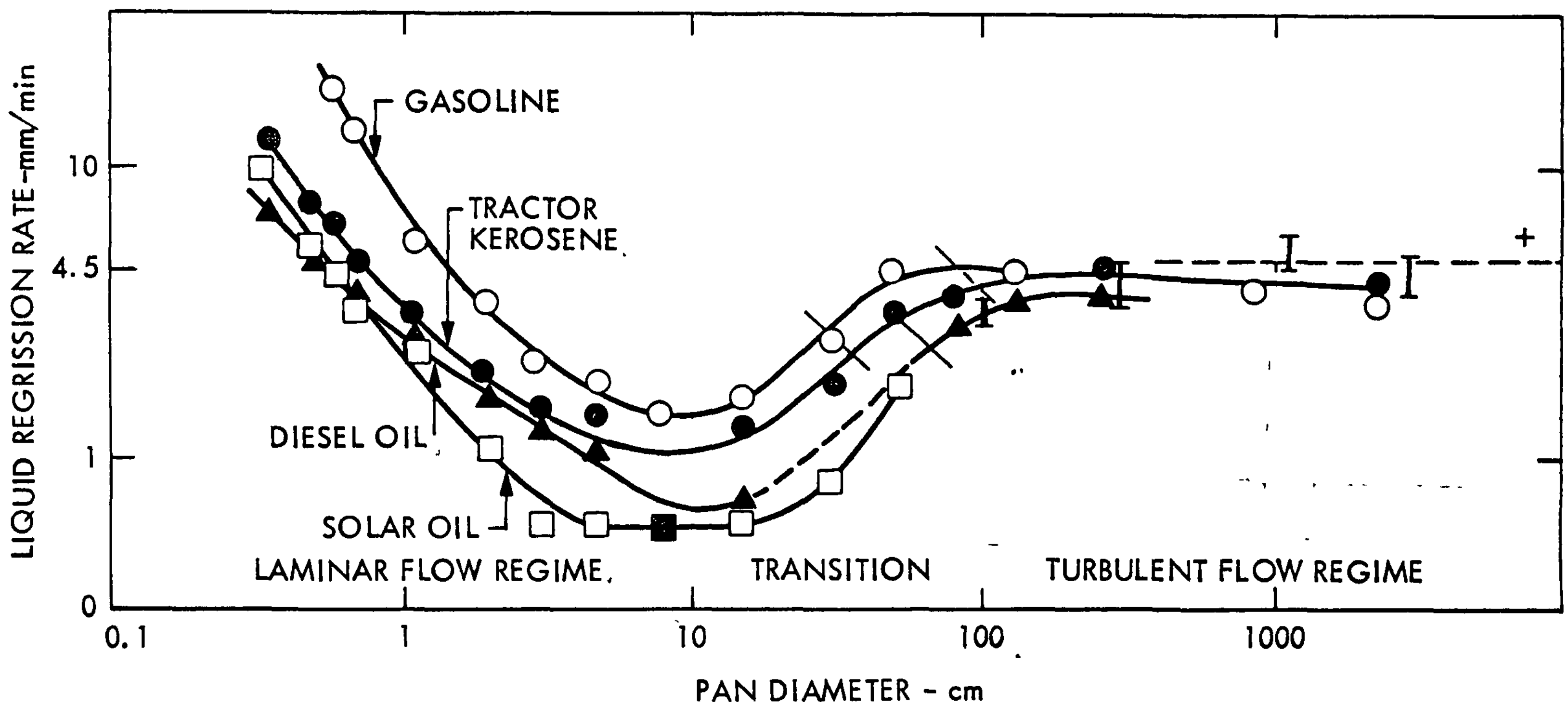
ENCLOSURE FIRE PARAMETERS

- ROOM VOLUME
- FUEL LOAD (MASS)
- FUEL SURFACE
- VENTS & OPENINGS
- FORCED VENTILATION
- FUEL FLAMMABILITY

FIRE CONSTRAINTS

- INITIAL AIR SUPPLY
- FLAME SPREAD RATE
- AIR SUPPLIED FROM OUTSIDE
- MAXIMUM HEAT RELEASE RATE
- TOTAL HEAT RELEASED

Fig. 1



BURNING RATES OF LIQUID FUEL FIRES

Fig. 2

ENCLOSURE FIRE ANALYSIS
RELATIVE ENERGY RELEASE CRITERIA

FLAME SPREAD RATE

$\dot{Q}_S = (\dot{Q}/A)bvt$ (LINEAR)

$\dot{Q}_S = (\dot{Q}/A)\pi v^2 t^2$ (RADIAL)

FUEL SURFACE LIMIT

$\dot{Q}_f = 2500\ A_f$ (GASOLINE)

$\dot{Q}_f = 100\ A_f$ (WOOD)

BURNING CARPET

$\dot{Q}_S = (Q/A)bv$ (LINEAR)

$\dot{Q}_S = 2\pi(Q/A)v^2 t$ (RADIAL)

VENTILATION LIMIT

$\dot{Q}_V = 1580\ AH^{1/2}$

ENCLOSURE VOLUME

$$t_e = \frac{58 V_e}{\dot{Q}}$$

FUEL LOAD

$$t_e = \frac{F m \Delta H}{\dot{Q}}$$

NOTE: UNITS ARE:
- KILOWATTS
- METERS
- KILOGRAMS
- MINUTES

Fig. 3

ENCLOSURE FIRE CHARACTERIZATION

MIXED MEAN ADIABATIC AIR TEMPERATURE (T_M)

$$\Delta T_M = \frac{\int_0^{t_0} \mathring{Q}\,dt}{c\rho V_e} \quad \text{OR} \quad \frac{\beta_1 \int_0^{t} \mathring{m}_f\,dt}{V_e}$$

AVERAGE MASS OPTICAL DENSITY (MOD)

$$MOD = \frac{D_s A_f}{m} = \frac{V_e}{mL} \, LOG_{10} \left(\frac{I_0}{I}\right)$$

$$Log_{10} \left(\frac{I_0}{I}\right) = (MOD \; \frac{1}{V_e} \int_0^{t} \mathring{m}\,dt$$

AVERAGE TOXIC GAS CONCENTRATION ($\dot{G}_T$)

$$G_T \propto \frac{\Delta M_{CO}}{V_e} \quad \text{(OR)} \quad \frac{\beta_2 \int_0^{t_0} \mathring{m}\,dt}{V_e}$$

Fig. 4

RELATIVE ENERGY RELEASE CRITERIA FOR ENCLOSURE FIRE DEVELOPMENT

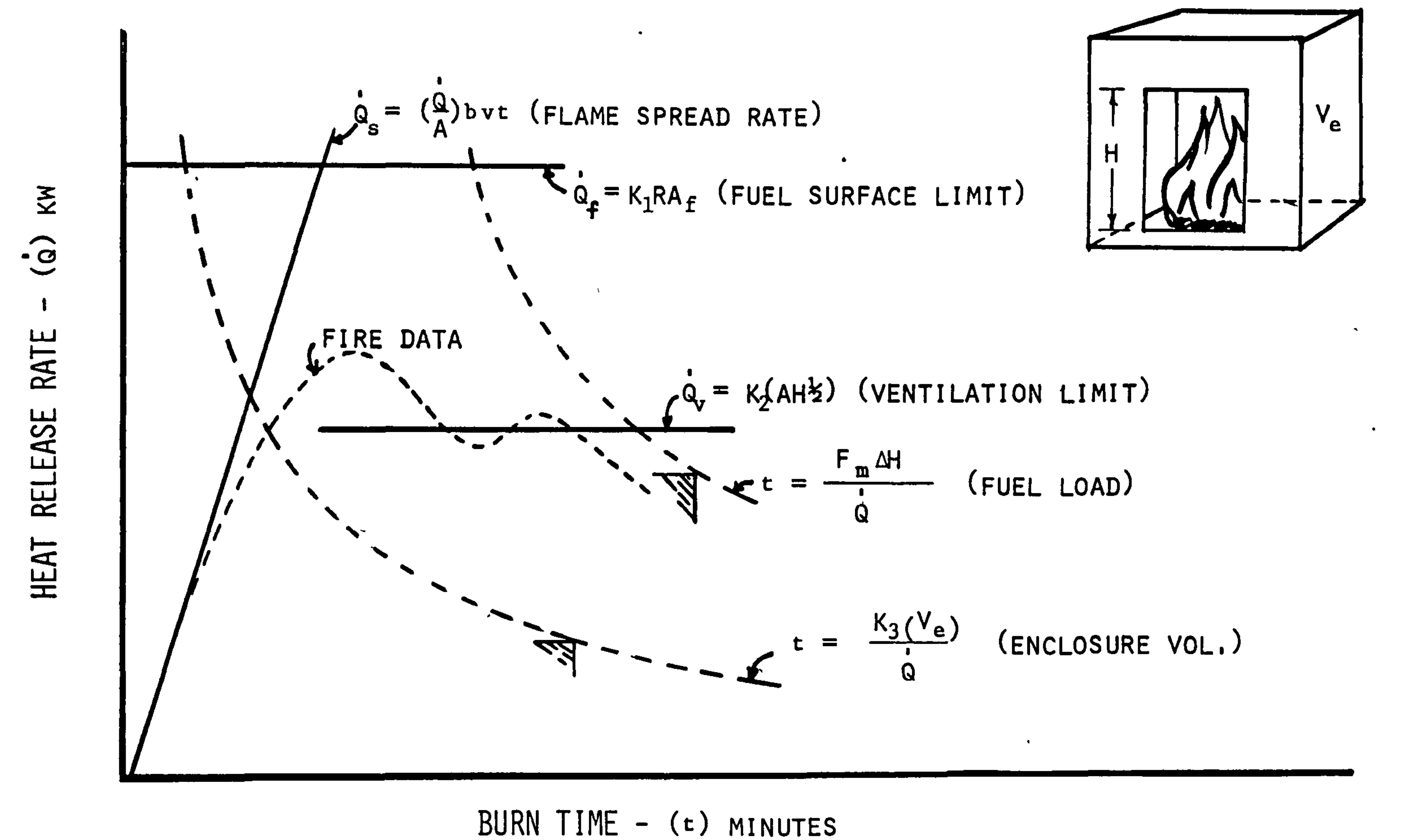


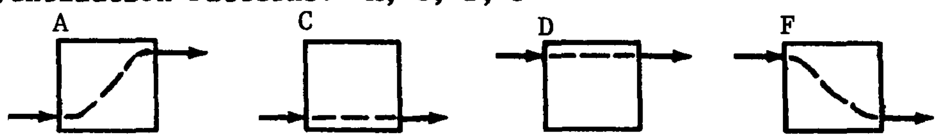
Fig. 5

Table 1. The Description of SRI Enclosure Fire Experiments and the Determination of RERC

Constant Room Volume: $V_e = 1050\ ft^3$

Four Ventilation Rates: 71, 154, 237, 348 ft^3/min

Four Ventilation Patterns: A, C, D, F



Four Types of Fuel: Load ~15 kg = 33 lb

(Liquid) MeOH and JP4-36" Diam Pools

(Solid) { Wood Cribs - 3/4" Square Sticks; Rubber Tire Segments - Pyramid Piles }

Basic Data from SRI: Fuel Weight Loss with Time
Heat Flux Data (Radiometers)
(<u>No</u> gas temperature or composition)

<u>RERC</u> (Calculated by JPL from SRI data)

<u>Flame Spread Rates</u>: (Not calculated)

<u>Ventilation Limit</u>: $\mathring{Q}_v$

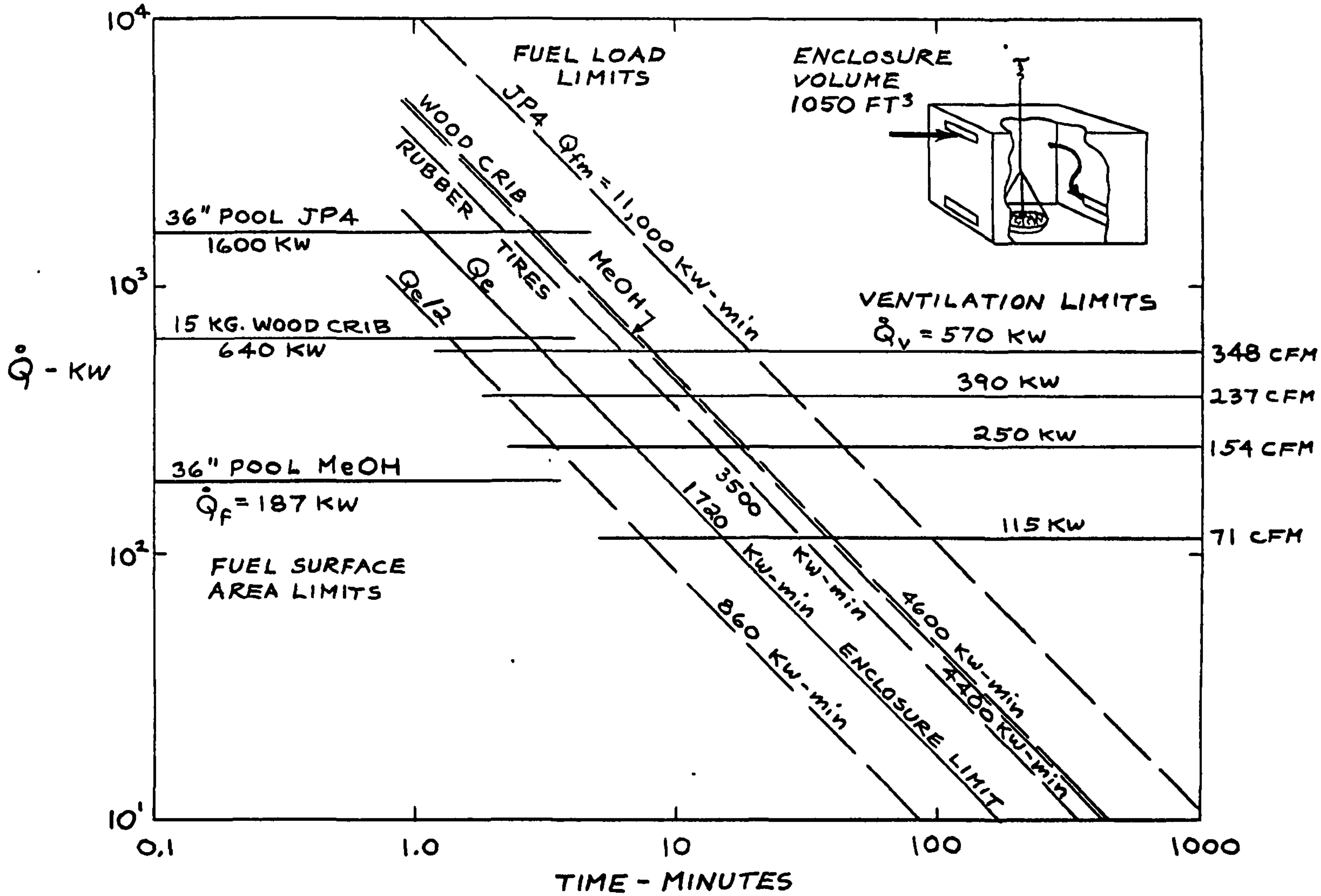
$\mathring{Q}_v$ = 115 kW for 71 cfm
= 250 kW " 154 cfm
= 390 kW " 237 cfm
= 570 kW " 348 cfm

<u>Enclosure Volume</u>: Q_e = 1720 kW-min
$Q_e/2$ = 860 kW-min

<u>Fuel Limits</u>:

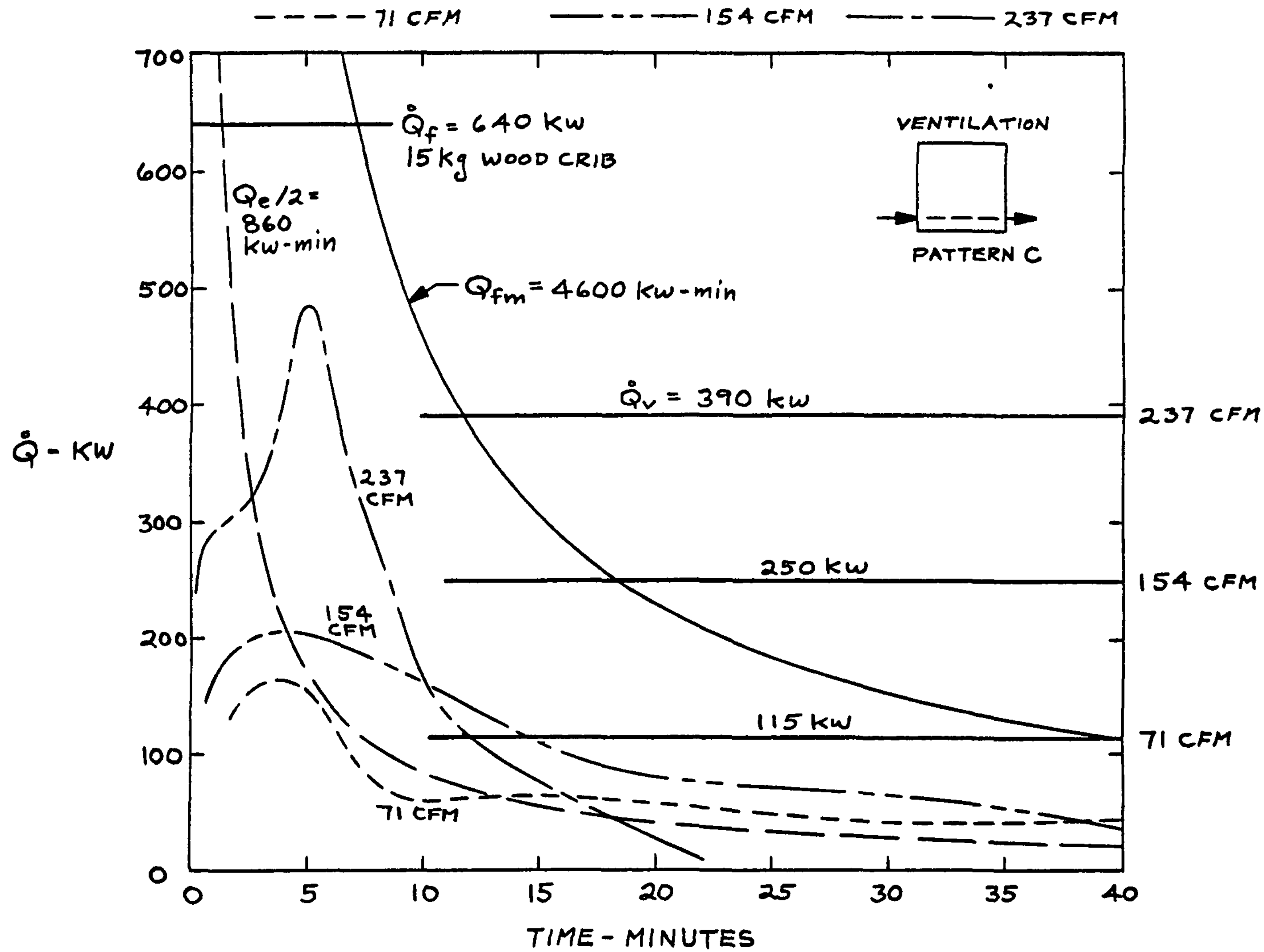
	Fuel Surface Limit $\mathring{Q}_f$ kW	Heat of Combustion ΔH (kW-min)/kg	Fuel Load Q_{fm} kW-min
Wood Cribs	640	308	4600
MeOH Pools	187	297	4400
JP4 Pools	1600	736	11,000
Rubber Tires	-	234	3500

(See Table 1 for Vent Patterns)



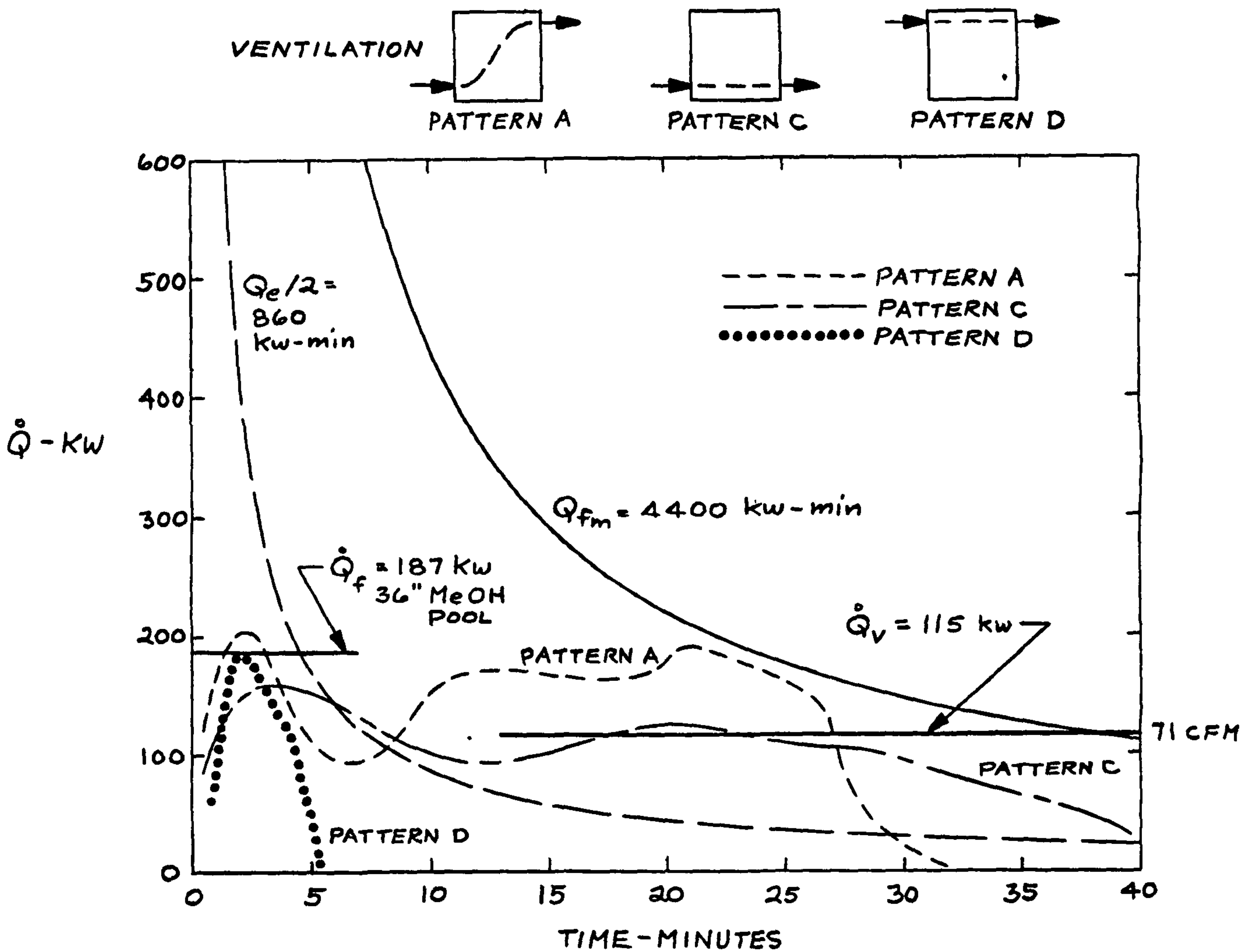
Relative Energy Release Criteria (RERC) for SRI Experiments

Fig. 6



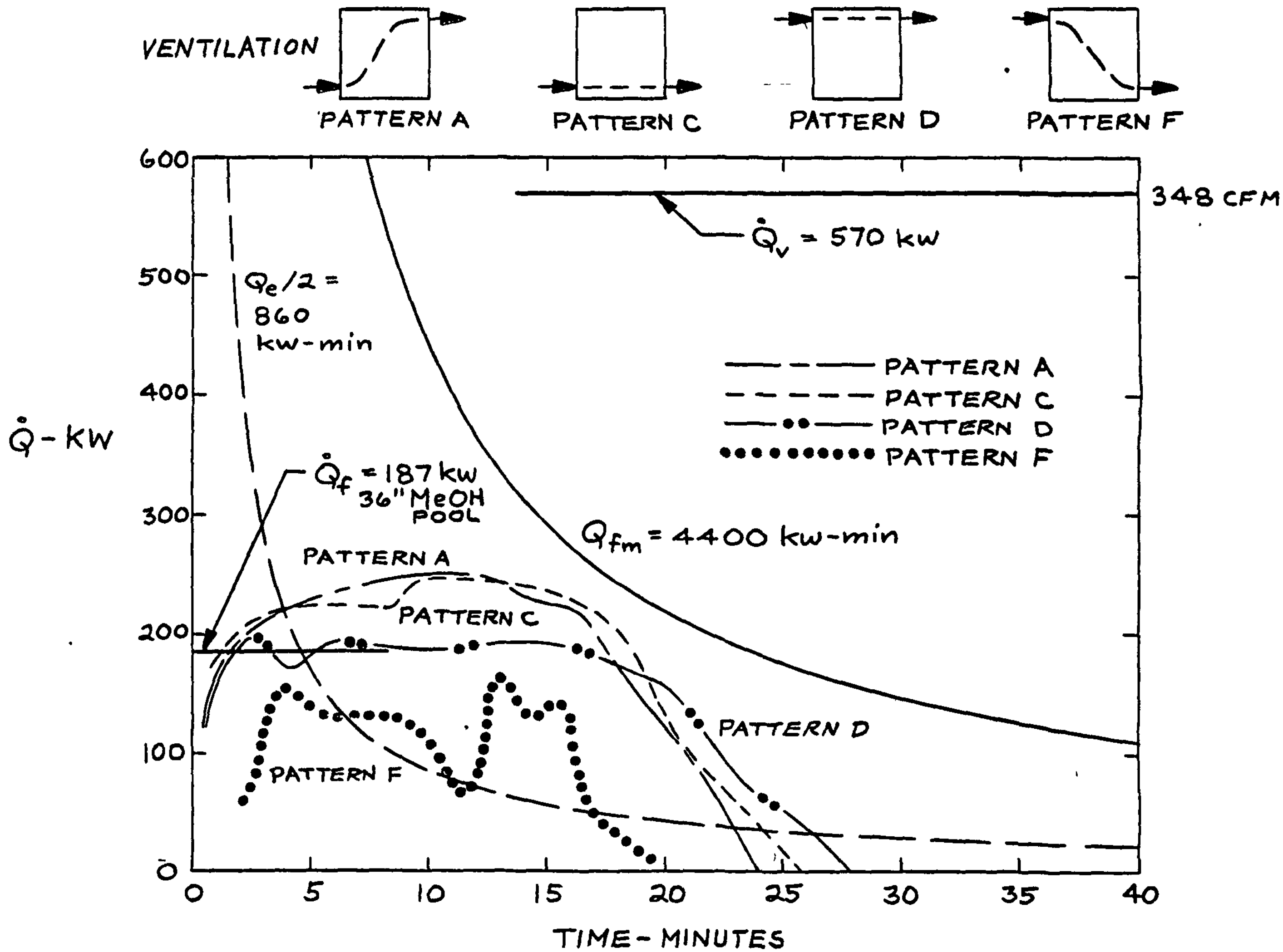
SRI Experimental Data Compared With RERC. Wood Cribs with Vent Pattern C at Three Ventilation Rates. Enclosure Volume of 1050 ft^3.

Fig. 7



SRI Experimental Data Compared With RERC. Methanol Pools at a Ventilation Rate of 71 cfm with Three Ventilation Patterns. Enclosure Volume of 1050 ft^3.

Fig. 8



SRI Experimental Data Compared With RERC. Methanol Pools at a Ventilation Rate of 348 cfm with Four Ventilation Patterns. Enclosure Volume of 1050 ft^3.

Fig. 9

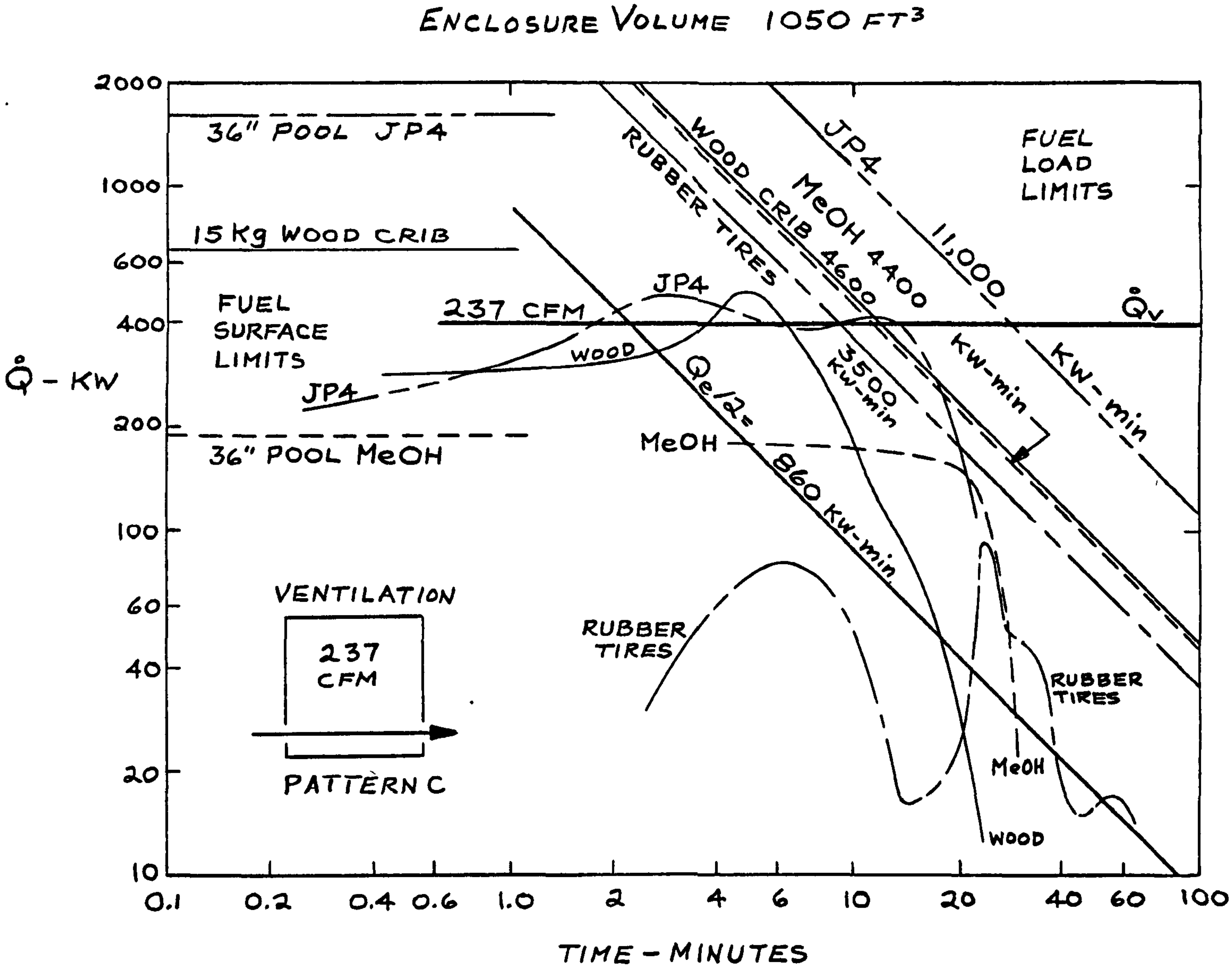


Fig. 10 SRI Experimental Data Compared with RERC. Four Fuels with Vent Pattern C at a Ventilation Rate of 237 cfm.

PANEL HEAT FLUX TO FUEL HEAT RELEASE CORRELATION

VENTILATION RATE ~71 cfm

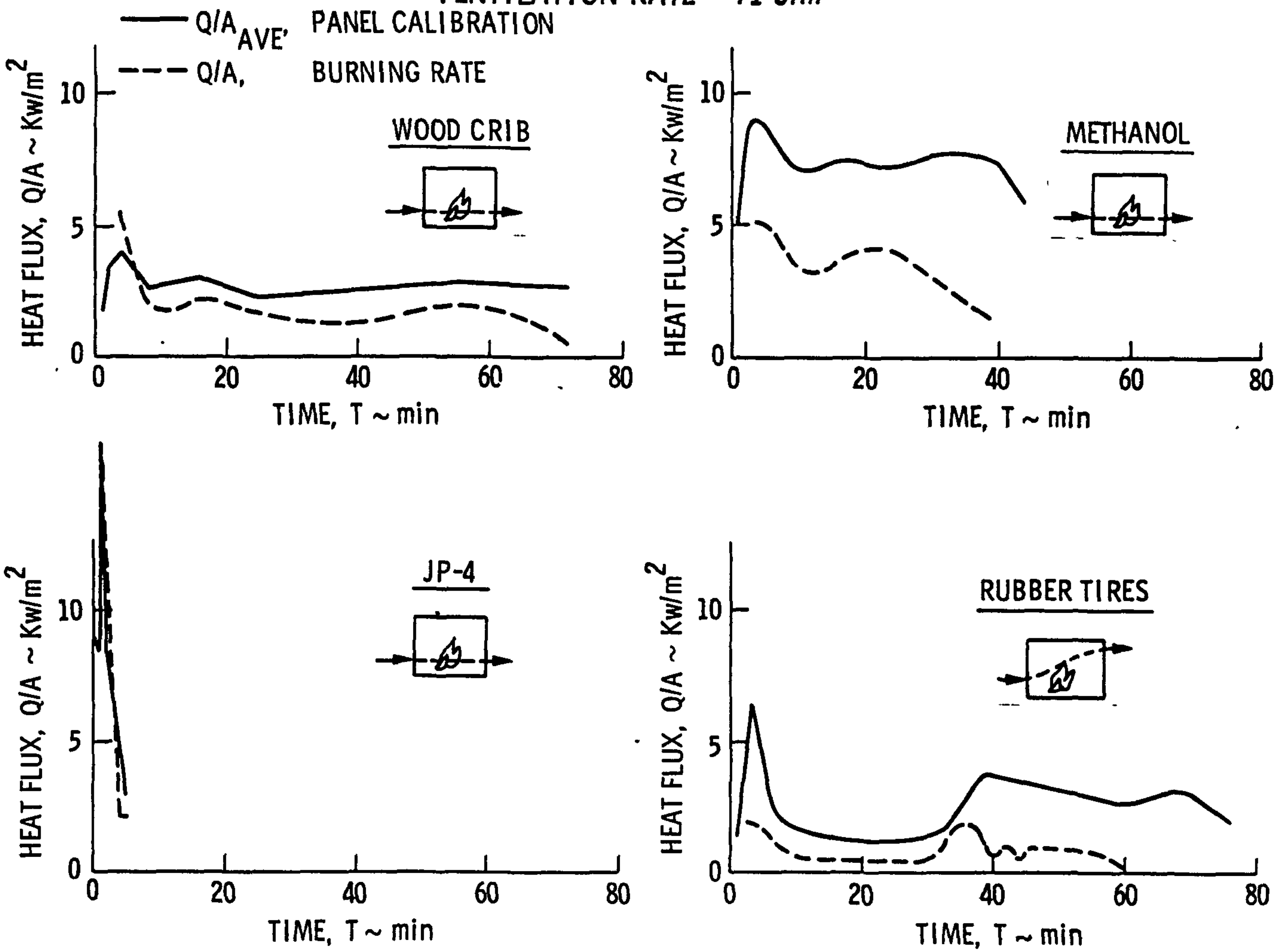


Fig. 11

PANEL HEAT FLUX TO FUEL HEAT RELEASE CORRELATION

VENTILATION RATE, $\dot{V}$

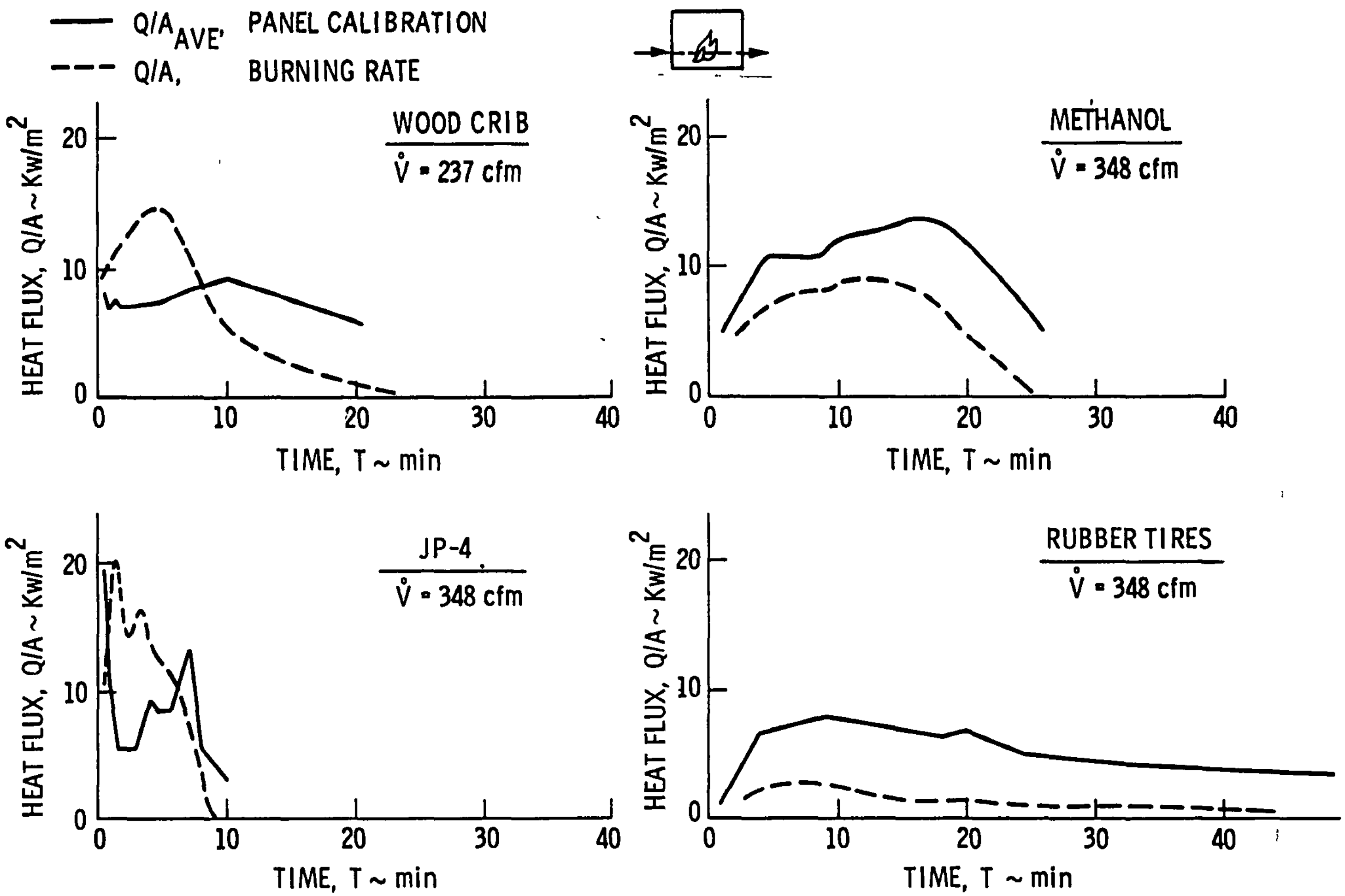
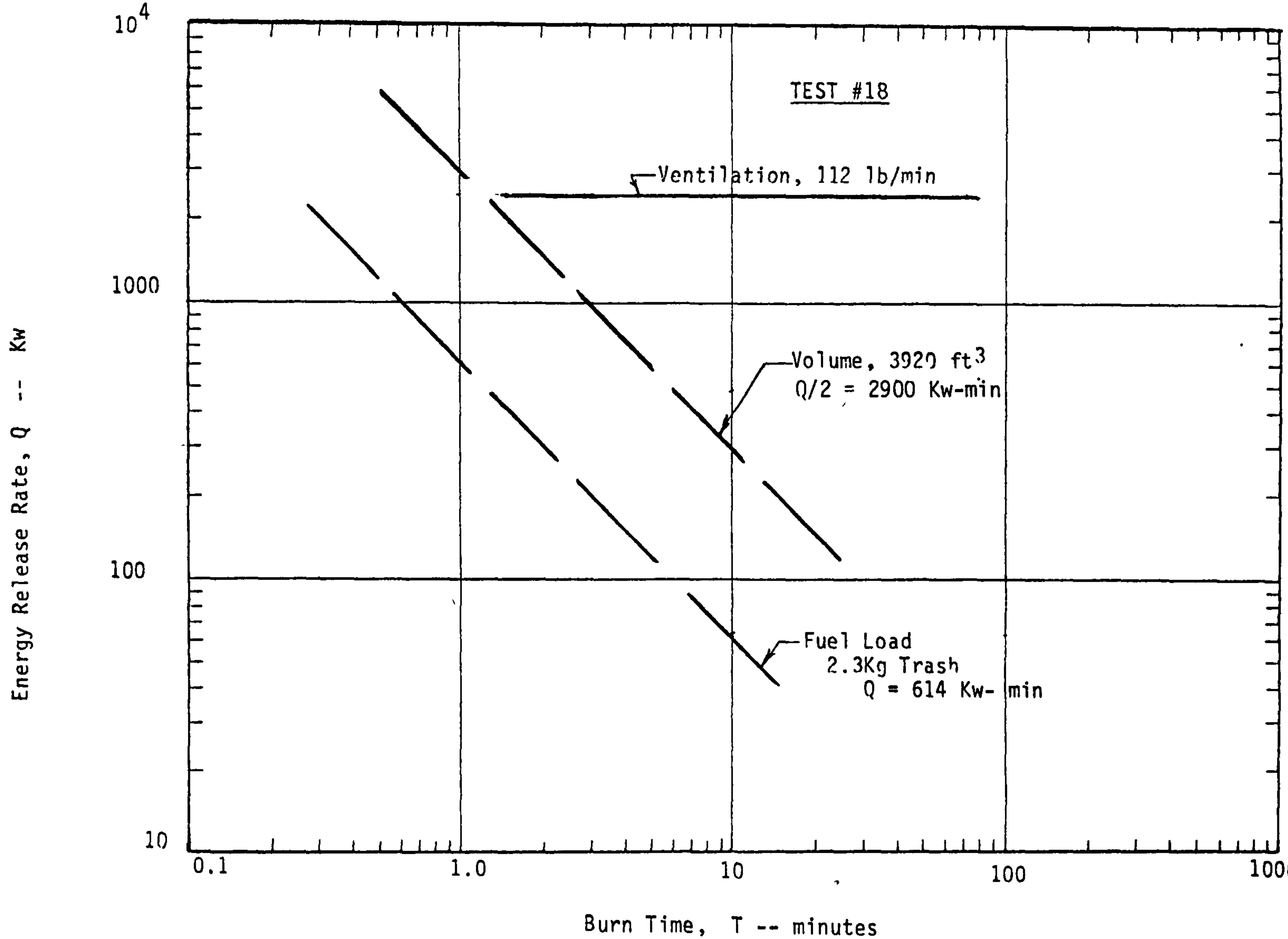
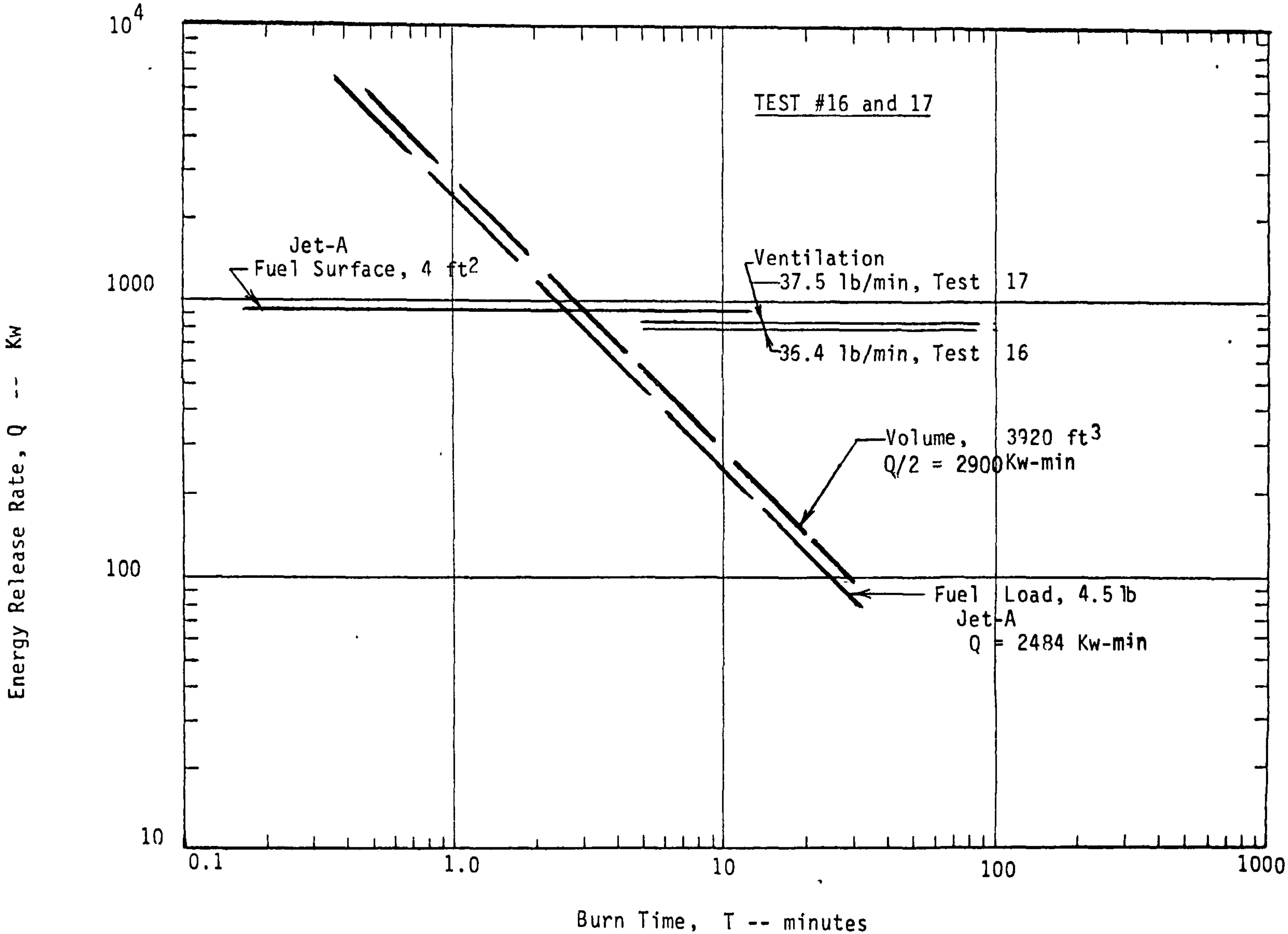


Fig. 12



RERC for Enclosure Fire Development
for NASA-JSC/Boeing Full-Scale Tests

Fig. 13



RERC for Enclosure Fire Development
for NASA-JSC/Boeing Full-Scale Tests

Fig. 14