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 - approx-
    imately 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 devel-
    opment. 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

$\overset{\circ}{Q}$ = Heat release rate, Kw

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

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

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

$(\overset{\circ}{Q}/A)$ = 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.
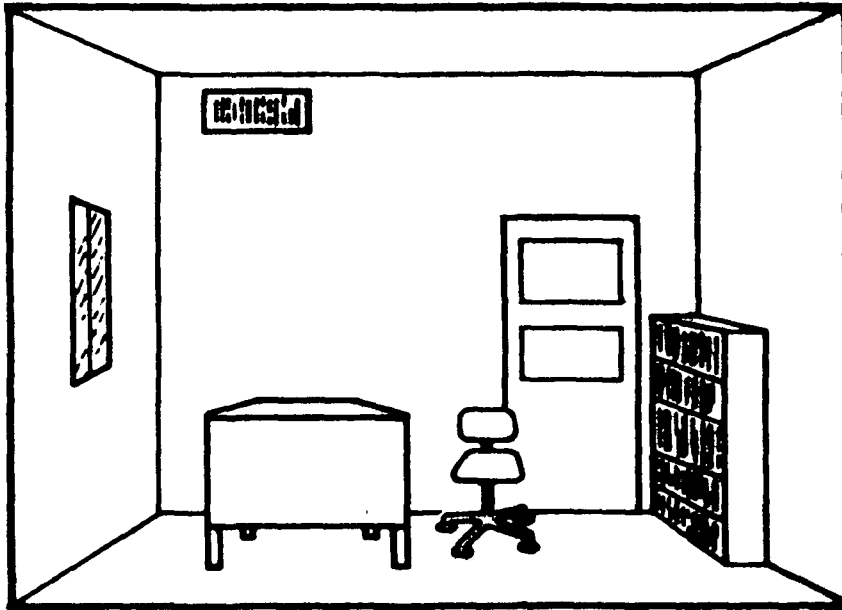
ENCLOSURE FIRE PARAMETERS	FIRE CONSTRAINTS
● ROOM VOLUME	● INITIAL AIR SUPPLY
● FUEL LOAD (MASS)	● FLAME SPREAD RATE
● FUEL SURFACE	● AIR SUPPLIED FROM OUTSIDE
● VENTS & OPENINGS	● MAXIMUM HEAT RELEASE RATE
● FORCED VENTILATION	● TOTAL HEAT RELEASED
● FUEL FLAMMABILITY	

Fig. 1
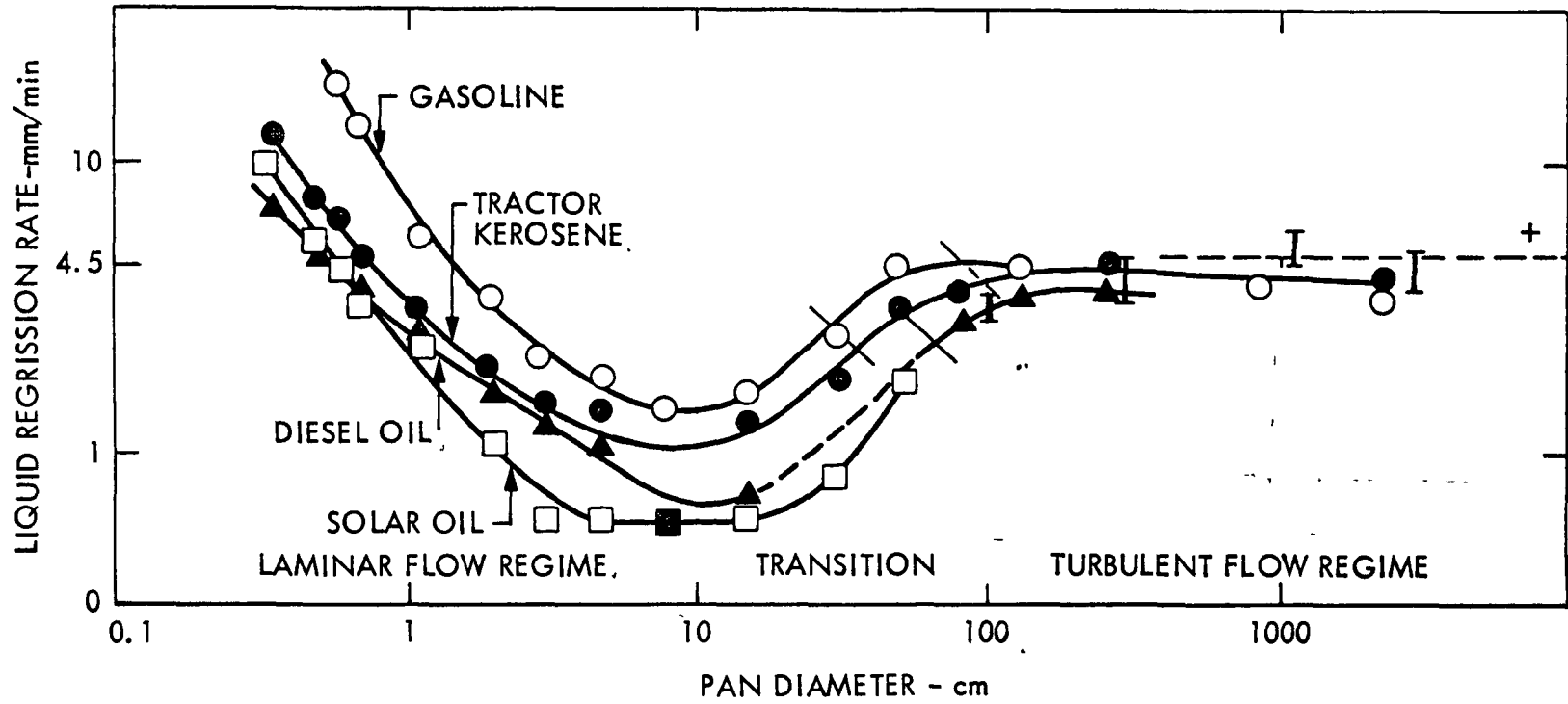
BURNING RATES OF LIQUID FUEL FIRES

Fig. 2

FLAME SPREAD RATE

$$\overset{\circ}{Q}_S = (\overset{\circ}{Q}/A)bvt \quad \text{(LINEAR)} \qquad \overset{\circ}{Q}_S = (\overset{\circ}{Q}/A)\pi v^2 t^2 \quad \text{(RADIAL)}$$

FUEL SURFACE LIMIT

$$\overset{\circ}{Q}_f = 2500\, A_f \quad \text{(GASOLINE)} \qquad \overset{\circ}{Q}_f = 100\, A_f \quad \text{(WOOD)}$$

BURNING CARPET

$$\overset{\circ}{Q}_S = (Q/A)bv \quad \text{(LINEAR)} \qquad \overset{\circ}{Q}_S = 2\pi(Q/A)v^2 t \quad \text{(RADIAL)}$$

VENTILATION LIMIT

$$\overset{\circ}{Q}_V = 1580\, AH^{\frac{1}{2}}$$

ENCLOSURE VOLUME

$$t_e = \frac{58 v_e}{\overset{\circ}{Q}}$$

NOTE: UNITS ARE:
KILOWATTS
METERS
KILOGRAMS
MINUTES

FUEL LOAD

$$t_e = \frac{Fm\Delta H}{\overset{\circ}{Q}}$$

465

Fig. 3

MIXED MEAN ADIABATIC AIR TEMPERATURE (T_M)

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

AVERAGE MASS OPTICAL DENSITY (MOD)

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

$$\text{LOG}_{10} \left(\frac{I_0}{I} \right) = (MOD) \frac{1}{V_e} \int_0^{t} \dot{m}\, dt$$

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

$$G_T \propto \frac{\Delta M_{co}}{V_e} \quad (OR) \quad \frac{\beta_2 \int_0^{t} \dot{m}\, dt}{V_e}$$

Fig. 4

966

RELATIVE ENERGY RELEASE CRITERIA
FOR ENCLOSURE FIRE DEVELOPMENT

$\dot{Q}_s = (\frac{\dot{Q}}{A})bvt$ (FLAME SPREAD RATE)

$\dot{Q}_f = K_1 RA_f$ (FUEL SURFACE LIMIT)

FIRE DATA

$\dot{Q}_v = K_2(AH^{\frac{1}{2}})$ (VENTILATION LIMIT)

$t = \dfrac{F_m \Delta H}{\dot{Q}}$ (FUEL LOAD)

$t = \dfrac{K_3(V_e)}{\dot{Q}}$ (ENCLOSURE VOL.)

HEAT RELEASE RATE - ($\dot{Q}$) KW

BURN TIME - (t) MINUTES

467
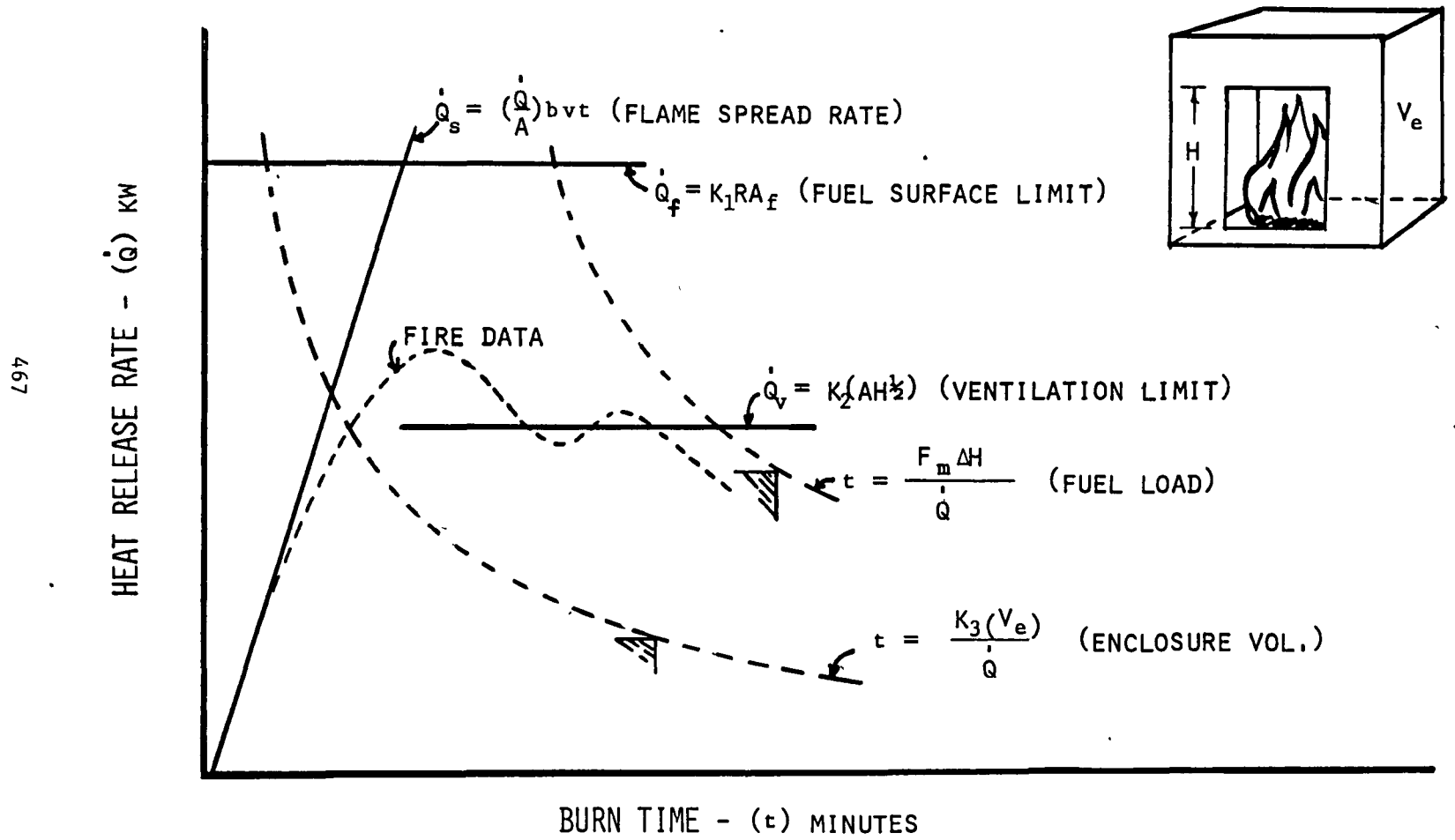
Fig. 5

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

Constant Room Volume: V_e = 1050 ft³

Four Ventilation Rates: 71, 154, 237, 348 ft³/min

Four Ventilation Patterns: A, C, D, F
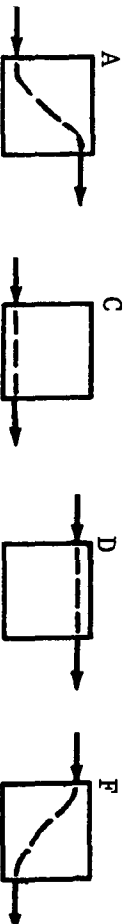
Four Types of Fuel: Load ~15 kg = 33 lb

(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)
(No gas temperature or composition)

RERC (Calculated by JPL from SRI data)

Flame Spread Rates: (Not calculated)

Ventilation Limit: $\dot{Q}_v$

$\dot{Q}_v$ = 115 kW for 71 cfm
= 250 kW " 154 cfm
= 390 kW " 237 cfm
= 570 kW " 348 cfm
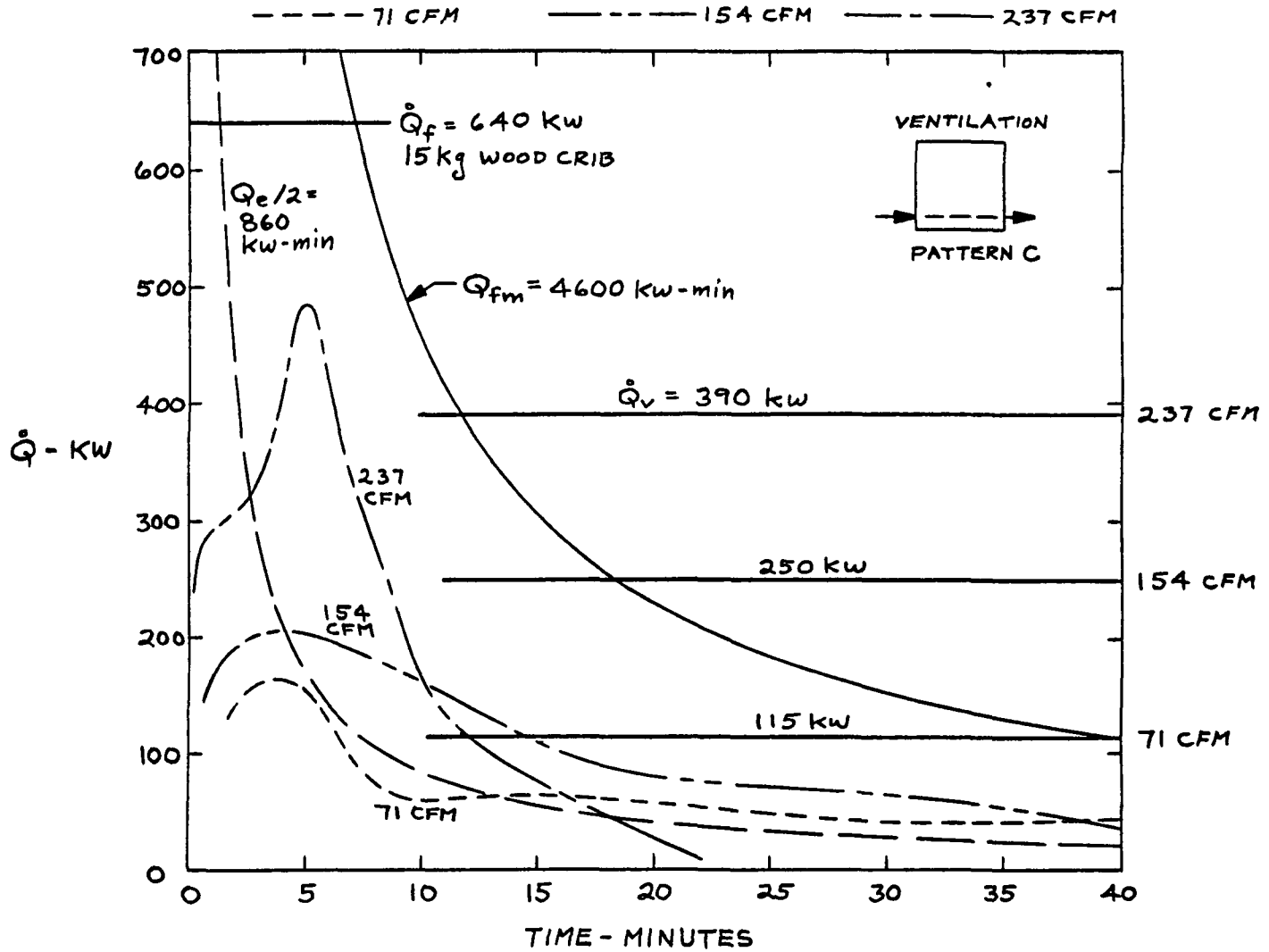
Enclosure Volume: Q_e = 1720 kW-min
$Q_e/2$ = 860 kW-min

Fuel Limits:

	Fuel Surface Limit $\dot{Q}_f$ 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)
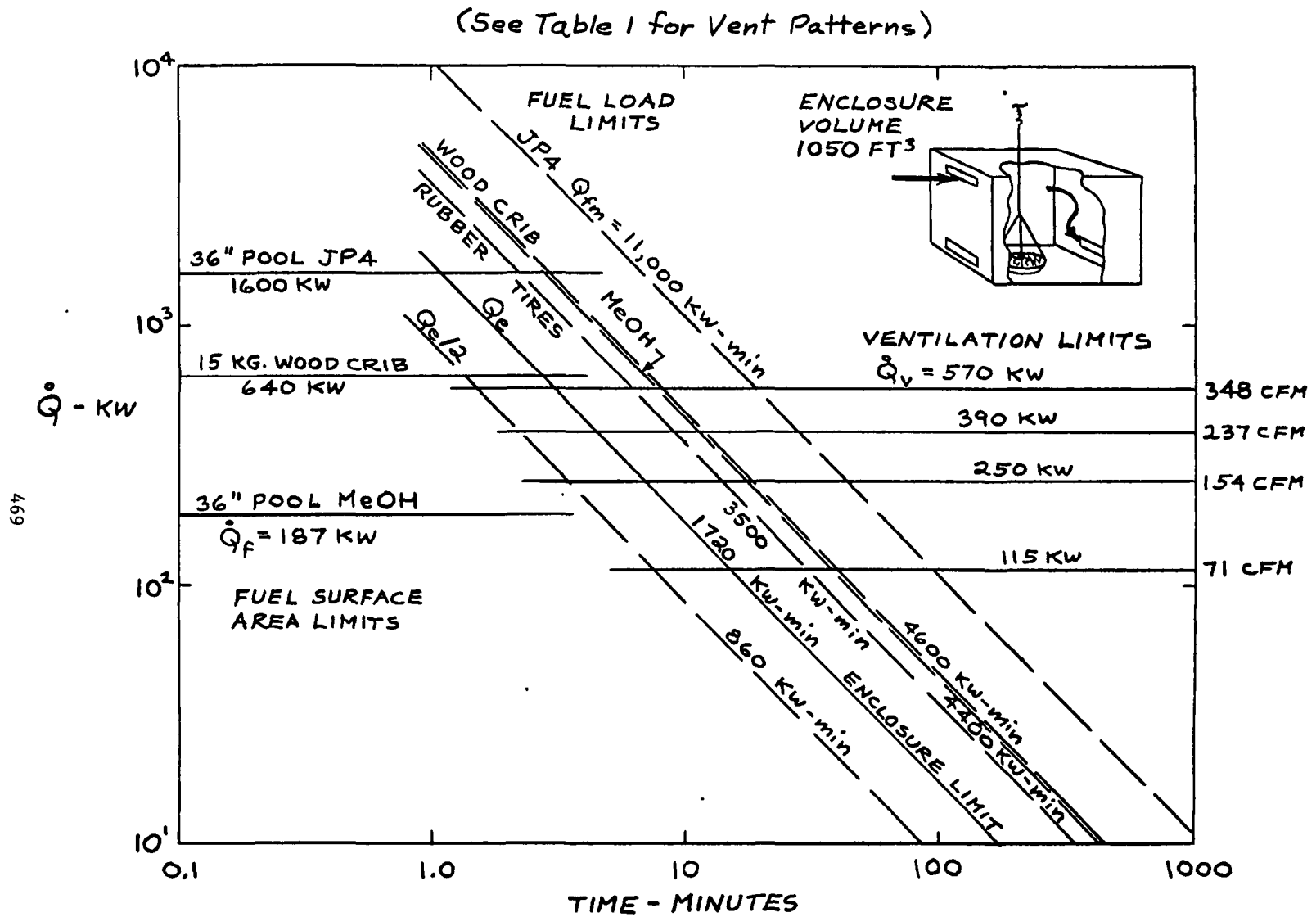
Relative Energy Release Criteria (RERC) for SRI Experiments

Fig. 6

----- 71 CFM ------ 154 CFM ------ 237 CFM

700

$\dot{Q}_f$ = 640 kw
15 kg WOOD CRIB

600

$Q_e/2$ = 860 kw-min

500

Q_{fm} = 4600 kw-min

400        $\dot{Q}_v$ = 390 kw   237 CFM

$\dot{Q}$ - KW

300

237 CFM

250 kw   154 CFM

200

154 CFM

115 kw   71 CFM

100

71 CFM

0
0   5   10   15   20   25   30   35   40

TIME - MINUTES

VENTILATION

PATTERN C

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

Fig. 7
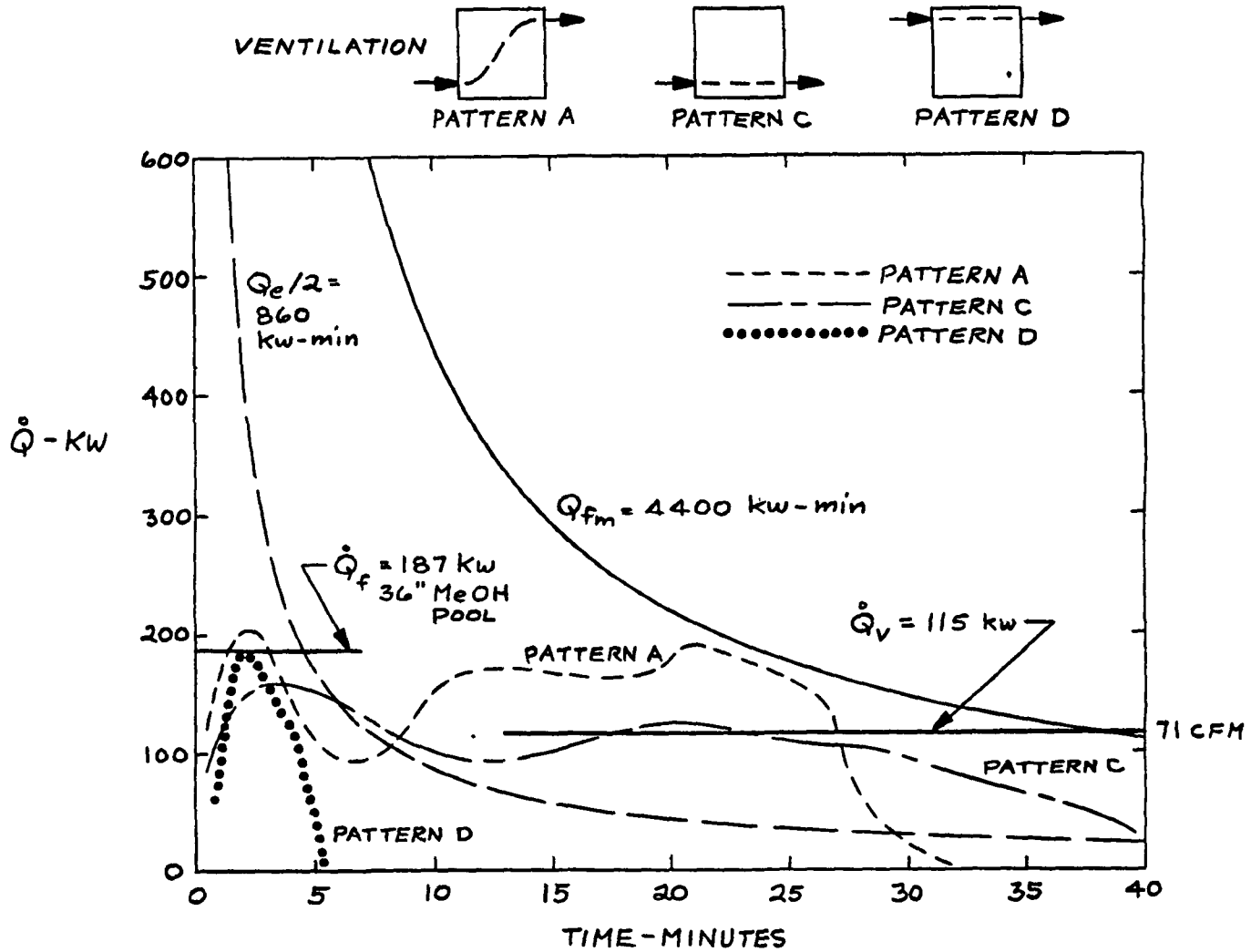
SRI Experimental Data Compared With RERC. Methanol
Pools at a Ventilation Rate of 71 cfm with Three Ventilation
Patterns. Enclosure Volume of 1050 ft³.

Fig. 8

VENTILATION

PATTERN A   PATTERN C   PATTERN D   PATTERN F

$\dot{Q}$ - KW

600

348 CFM

$\dot{Q}_v = 570$ kw

500

$Q_e/2 = 860$ kw-min

400

$\dot{Q}_f = 187$ kw
36" MeOH
POOL

300

PATTERN A

$Q_{fm} = 4400$ kw-min

PATTERN A
PATTERN C
PATTERN D
PATTERN F

PATTERN C

200

PATTERN D

PATTERN F

100

0

0   5   10   15   20   25   30   35   40

TIME - MINUTES
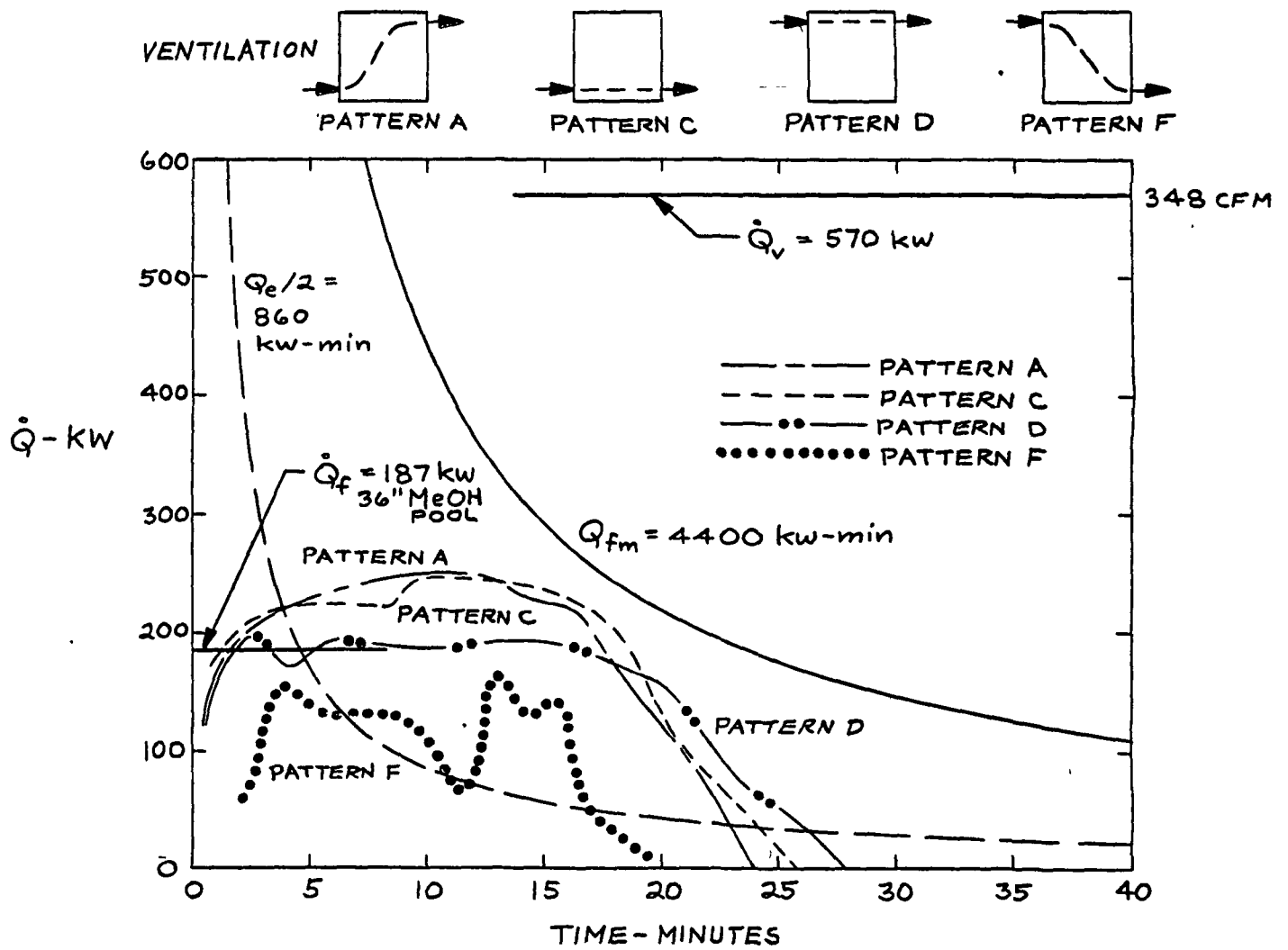
SRI Experimental Data Compared With RERC. Methanol
Pools at a Ventilation Rate of 348 cfm with Four Venti-
lation Patterns. Enclosure Volume of 1050 ft³.

Fig. 9

ENCLOSURE VOLUME 1050 FT³
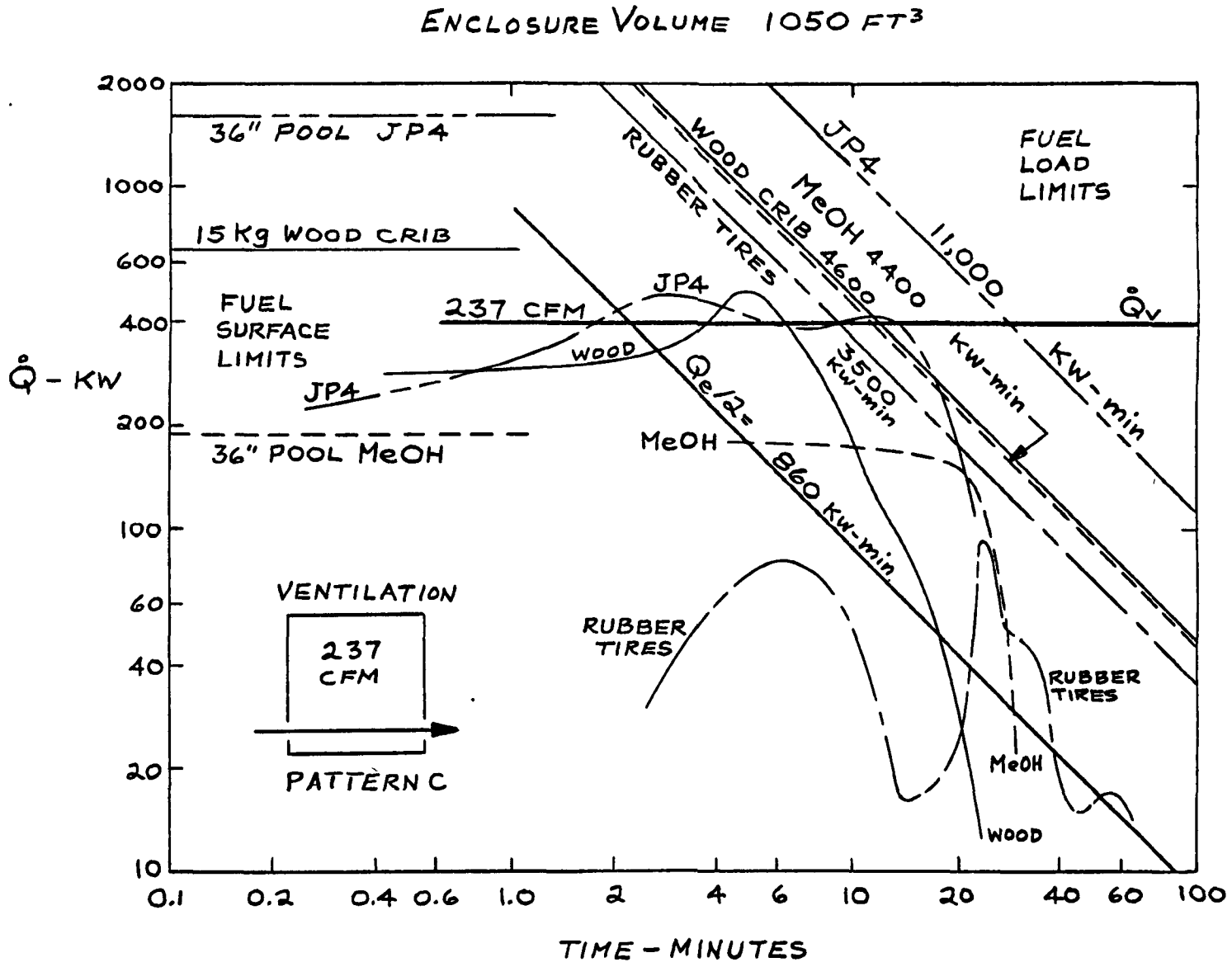
SRI Experimental Data Compared with RERC. Four Fuels
Fig. 10 with Vent Pattern C at a Ventilation Rate of 237 cfm.
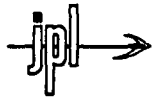
PANEL HEAT FLUX TO FUEL HEAT RELEASE CORRELATION
VENTILATION RATE ~71 cfm
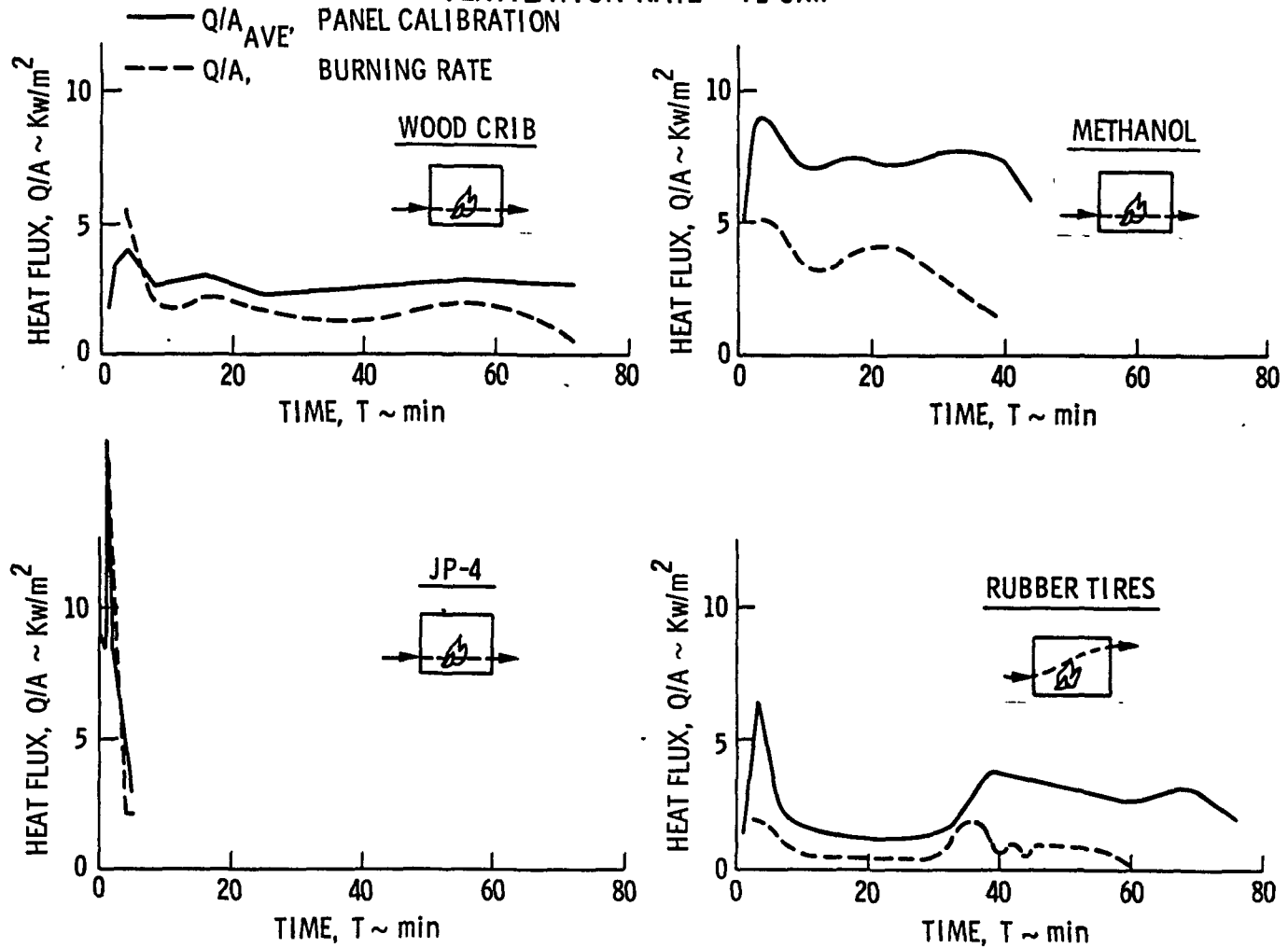
Fig. 11

PANEL HEAT FLUX TO FUEL
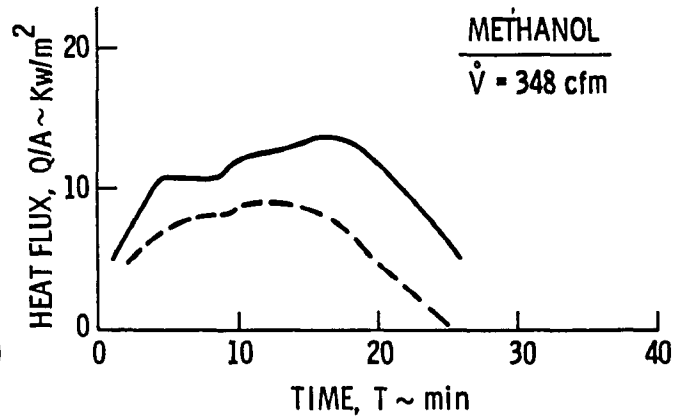HEAT RELEASE CORRELATION

VENTILATION RATE, $\dot{V}$
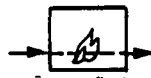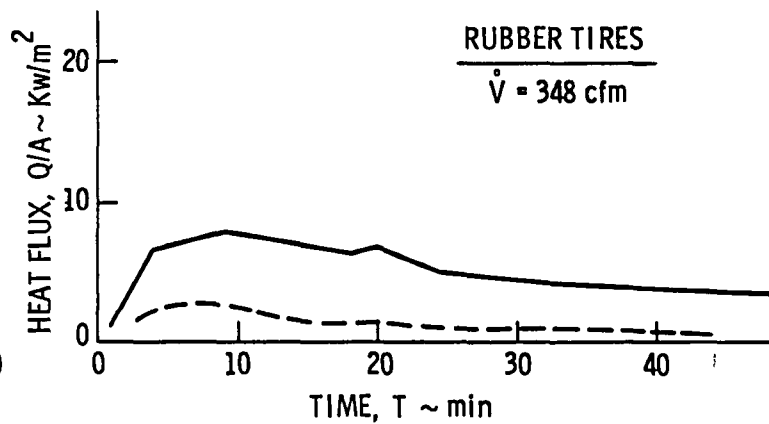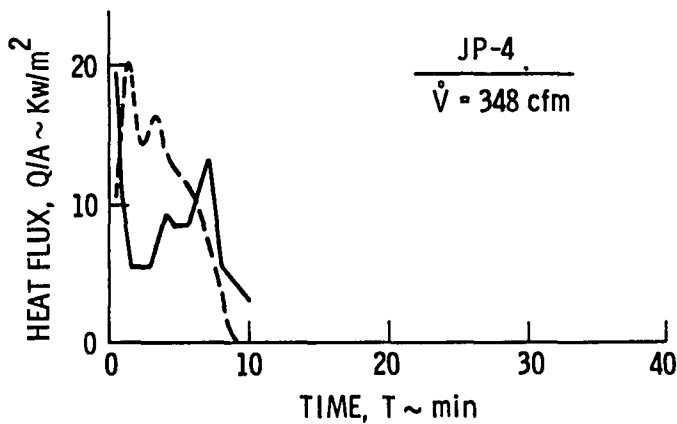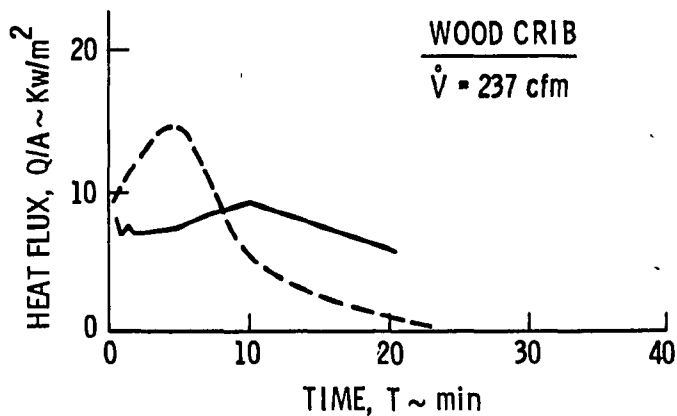
Fig. 12

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

Fig. 13

Energy Release Rate, Q -- Kw

Burn Time, T -- minutes

TEST #16 and 17

Jet-A
Fuel Surface, 4 ft^2

Ventilation
37.5 lb/min, Test | 17

36.4 lb/min, Test | 16

Volume, 3920 ft^3
Q/2 = 2900 Kw-min

Fuel Load, 4.5 lb
Jet-A
Q = 2484 Kw-min

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

Fig. 14