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EXTINGUISHMENT OF SOLID PROPELLANT FLAMES: A THEORY BASED ON A NEW FEEDBACK LAW

(Presentation Version)

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by

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Transmitted by

Martin Summerfield
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Principal Investigator

This report is composed of reproductions of the slides presented at the Third ICRPG/AIAA Solid Propulsion Conference, Atlantic City, New Jersey, June 4-6, 1968. Additional copies of this presentation version are available from Princeton University.

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EXPLANATORY NOTE

Presentation Version

This report consists of reproductions of the slides comprising the presentation given at the Third ICRPG/AIAA Solid Propulsion Conference in Atlantic City, New Jersey on June 4-6, 1968. As such it does not include the verbal explanations that accompanied the slides. No manuscript was prepared for the Conference, but it is hoped that, despite its terseness, this document will serve as a useful summary of the material presented at the Conference. Work on this topic is still continuing and a later report will include revisions of these results along with new results.

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EXTINGUISHMENT OF SOLID PROPELLANT FLAMES:
A THEORY BASED ON A NEW FEEDBACK LAW

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This paper includes:

1. A critical examination of previous theories of extinguishment and reasons for a new approach.

2. A new theory of non-steady burning based on the KTSS flame model for an AP composite propellant.

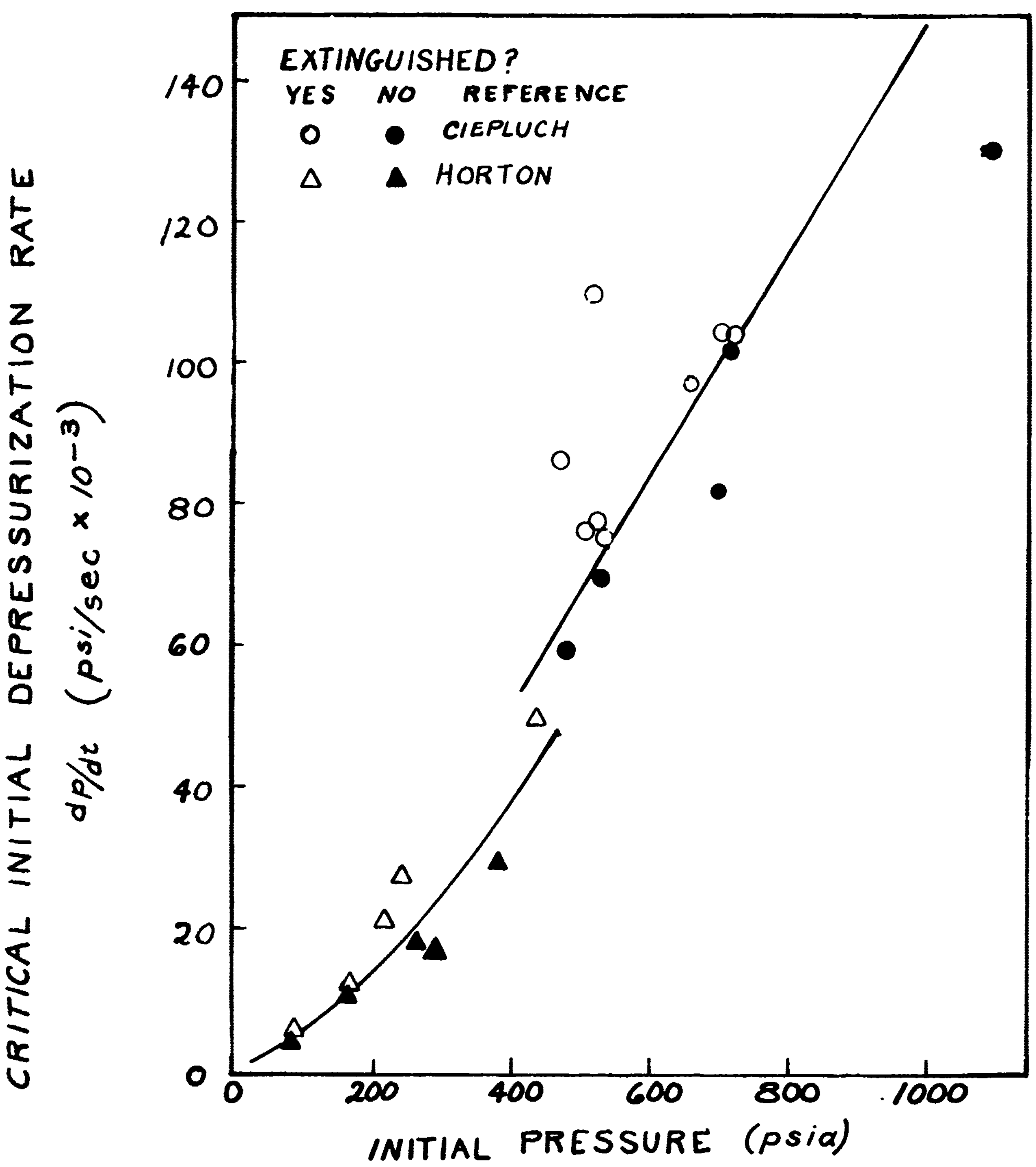
3. Predictions of the time variation of burning rate, surface temperature, and flame temperature during rapid depressurization:

   a) Extinguishment case.

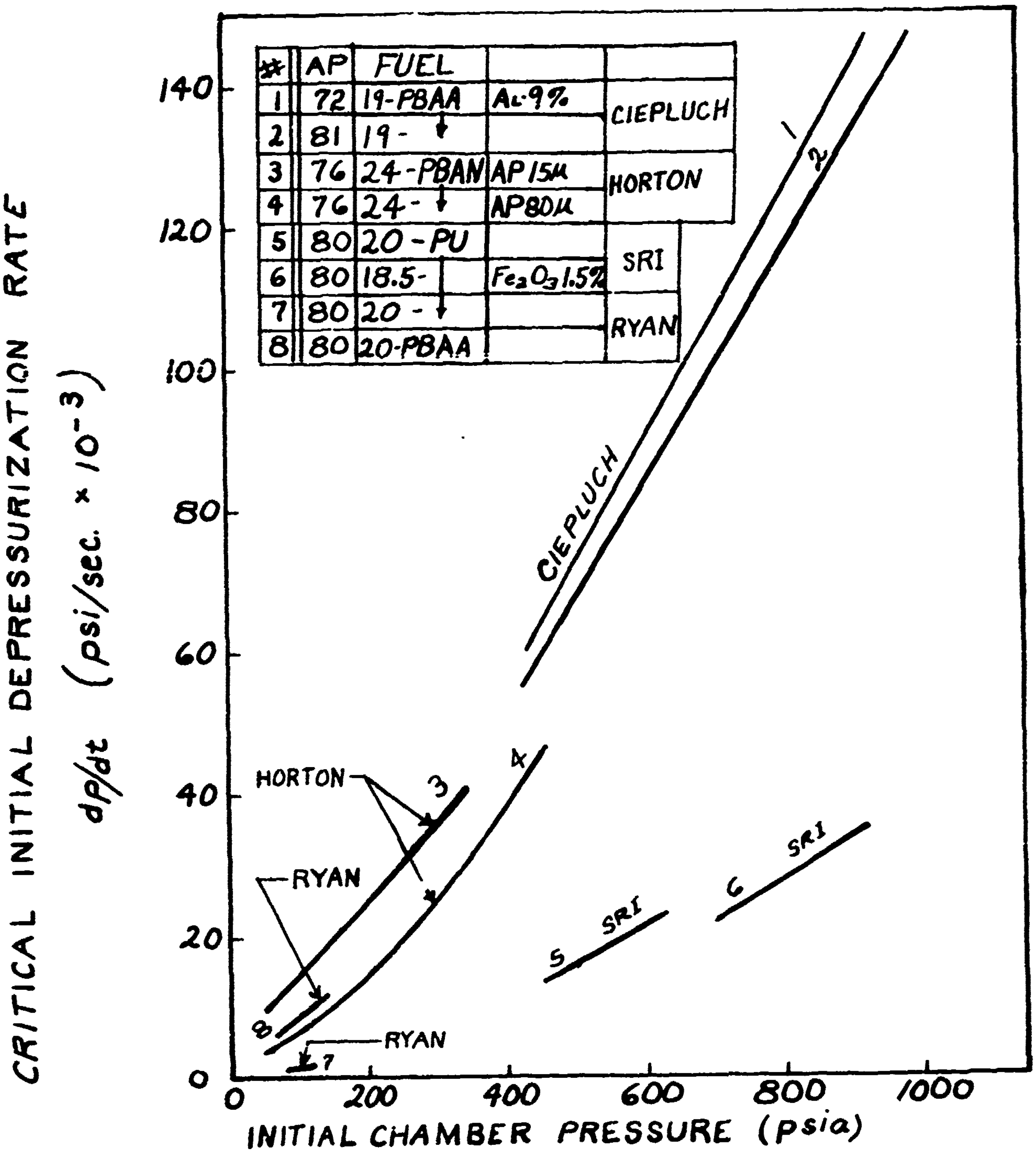
   b) Non-extinguishment case.

4. Predictions of the effects of oxidizer loading and aluminum content on the difficulty of extinguishment.

5. Comparison of the predictions with experimental results of Ciepluch and others.



DIFFICULTY OF EXTINCTION BY DEPRESSURIZATION: EXPERIMENTAL DATA

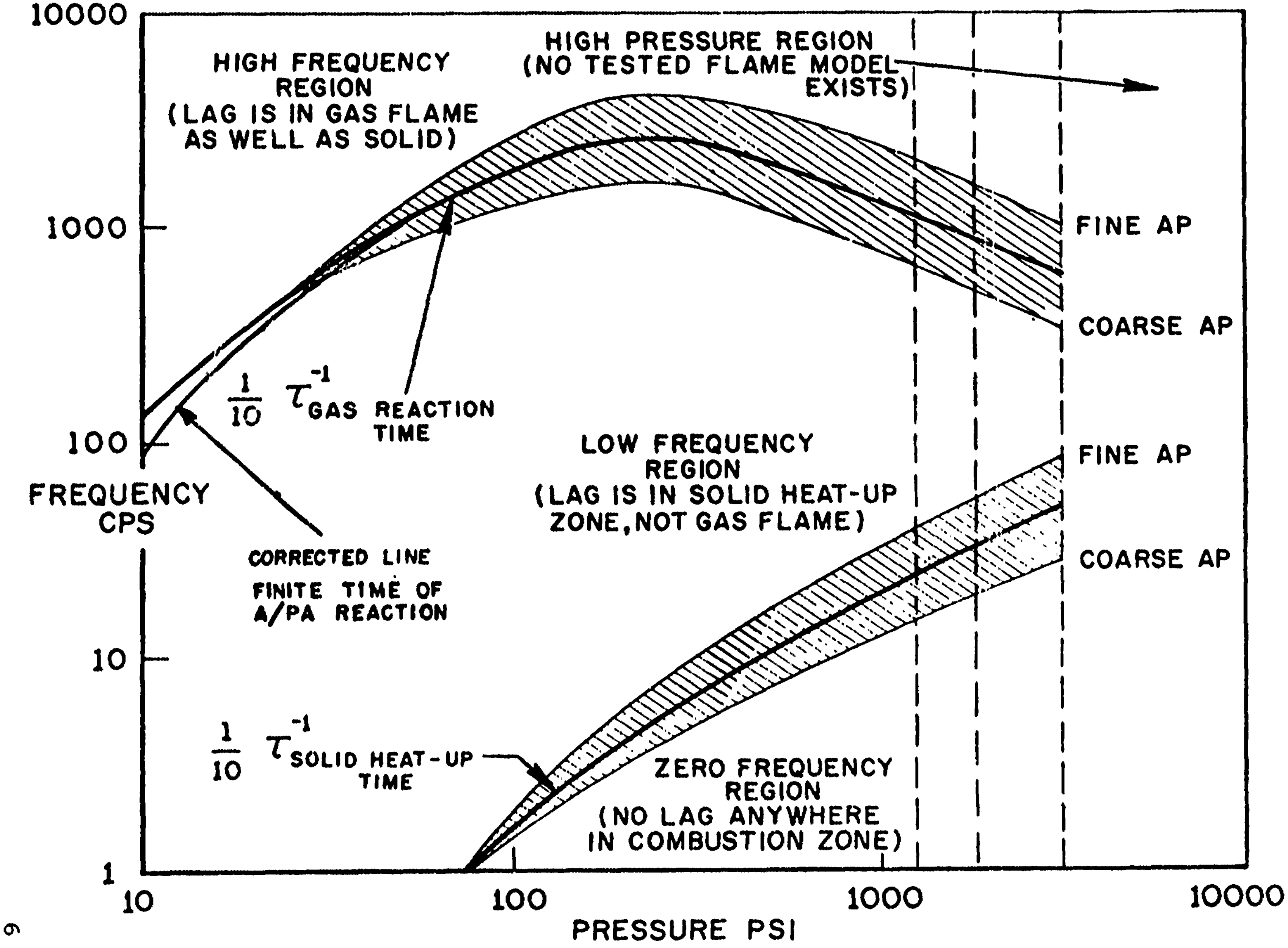


DIFFICULTY OF EXTINCTION BY DEPRESSURIZATION
COMPOSITE OF EXPERIMENTAL DATA

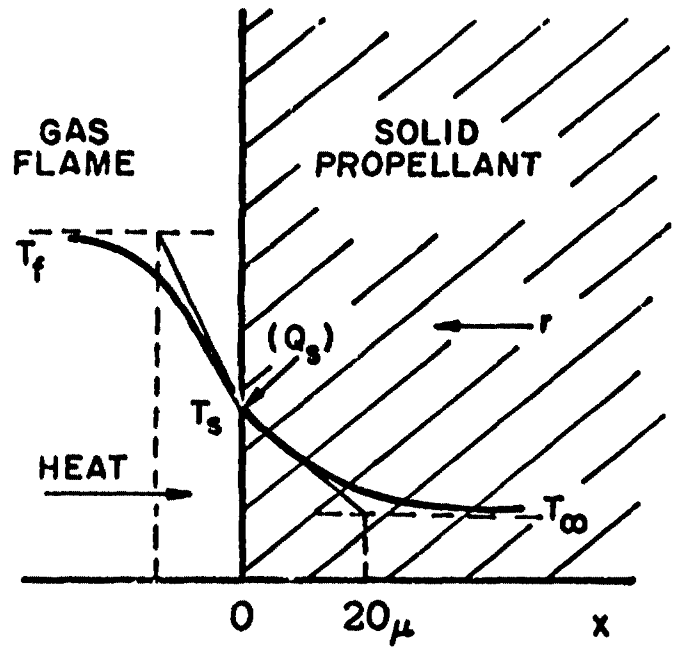
Previous theories of extinguishment:

Von Elbe	ARC	1963, 1966
Paul	Aerojet	1964
N. Ryan, Donaldson, Baer, P. Ryan and Mantyla	Utah	1966, 1967
Horton, Bruno and Graesser	BYU	1967, 1968
Marxman, Wooldridge, Dickinson and Capener	SRI	1966, 1967, 1968

PRESSURE-FREQUENCY REGIMES OF ACOUSTIC INTERACTION WITH COMBUSTION ZONE



KTSS MODEL FOR
NONSTEADY SOLID PROPELLANT BURNING



HEAT RELEASE PARAMETER

$$H = \frac{Q_s}{c_s(T_{so} - T_\infty)}$$

ENERGY EQUATION FOR GAS PHASE

$$\lambda_g \frac{d^2T}{dx^2} + r \rho_p c \frac{dT}{dx} + \rho_g Q_f \dot{\varepsilon} = 0$$

$$-\lambda_g \left(\frac{\partial T}{\partial x}\right)_s = \frac{\phi(p)}{r}[1 - \exp\{-\rho_p r^2 Q_f/\phi(p)\}]$$

$$\phi(p) = \frac{\lambda_g Q_f \rho_g}{\rho_p c \, \tau_c}$$

EVALUATION OF $\phi(p)$ AT STEADY STATE

$$q_g = \frac{\phi(p)}{\bar{r}}[1 - \exp - \rho_p(\bar{r})^2 Q_f/\phi(p)\,]$$

$$q_g = \rho_p\,\bar{r}[c(\bar{T}_s - T_\infty) - Q_s]$$

$$\bar{r} = ap^n$$

$$\phi(p) = \frac{\rho_p(ap^n)^2[c(\bar{T}_s - T_\infty) - Q_s]}{[1 - \exp\{-\rho_p(ap^n)^2 Q_f/\phi(p)\}]}$$

ENERGY EQUATION FOR SOLID PHASE

$$\frac{\partial T}{\partial t} = r(t)\frac{\partial T}{\partial x} + \alpha\frac{\partial^2 T}{\partial x^2}$$

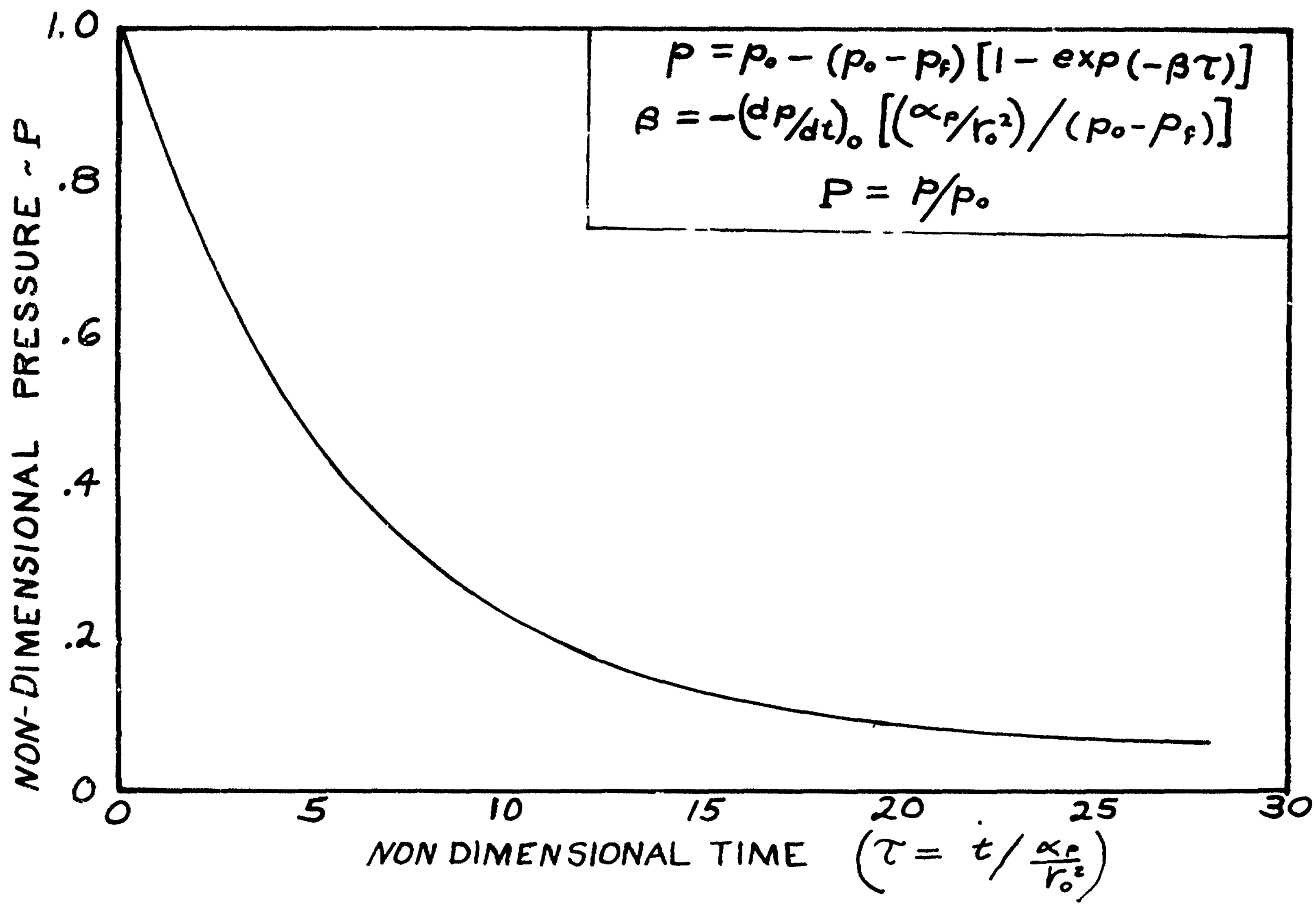
where $r(t) = A\exp(-E_s/RT_s)$

B. C.

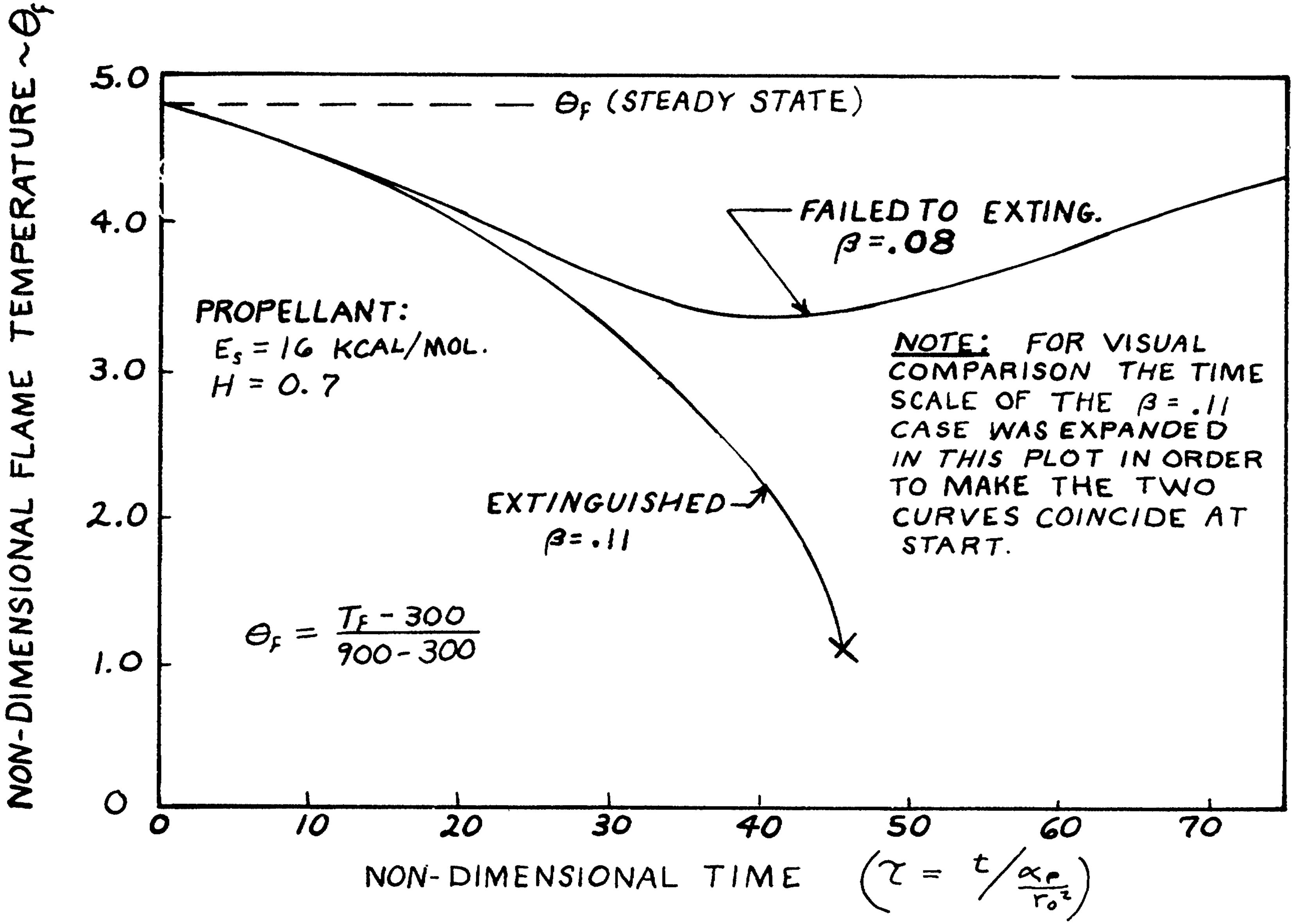
$$-\lambda_p\left(\frac{\partial T}{\partial x}\right)_s = q_g + r\rho_p Q_s$$

$$T(\infty) = T_\infty$$

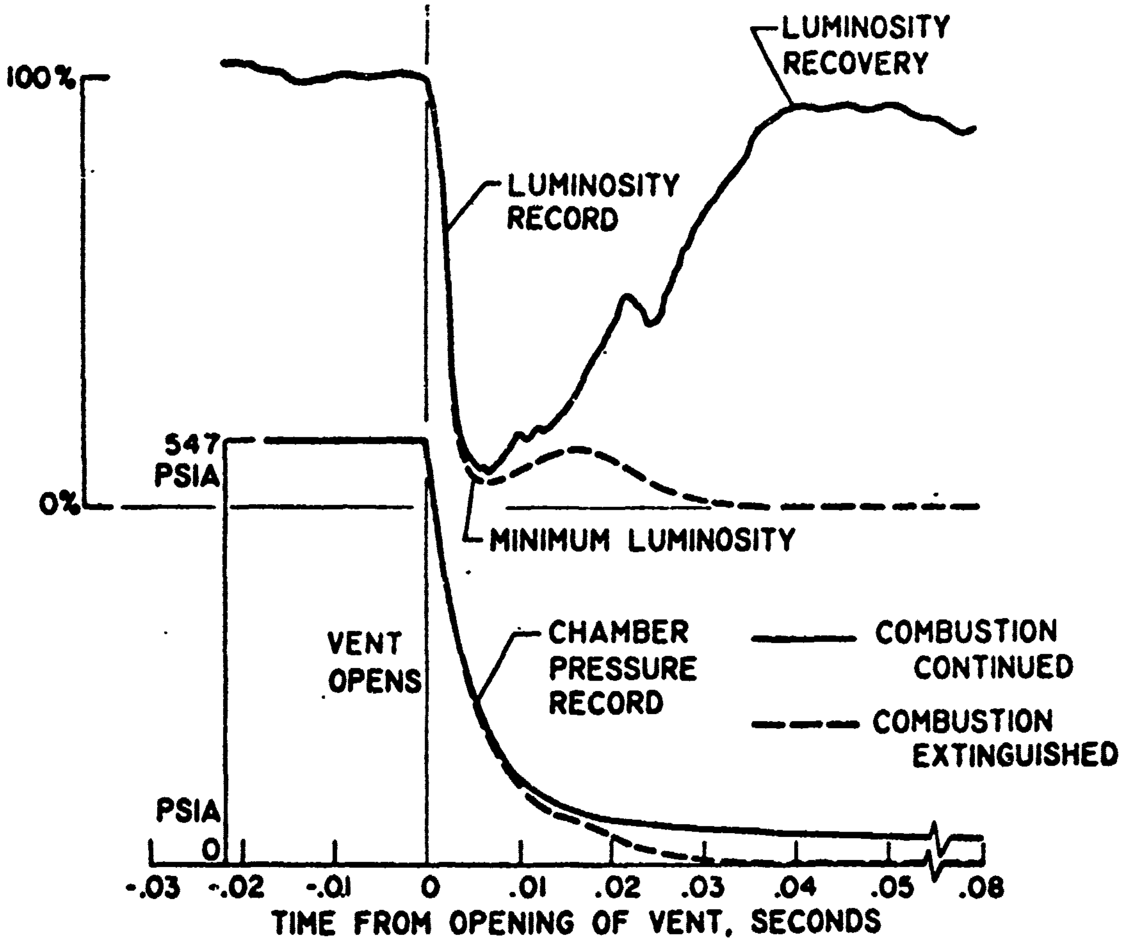
$$T(x,0) = (T_{s,o} - T_\infty)\exp(-xr_o/\alpha)$$



EXPONENTIAL PRESSURE DECAY
USED IN DEPRESSURIZATION ANALYSIS

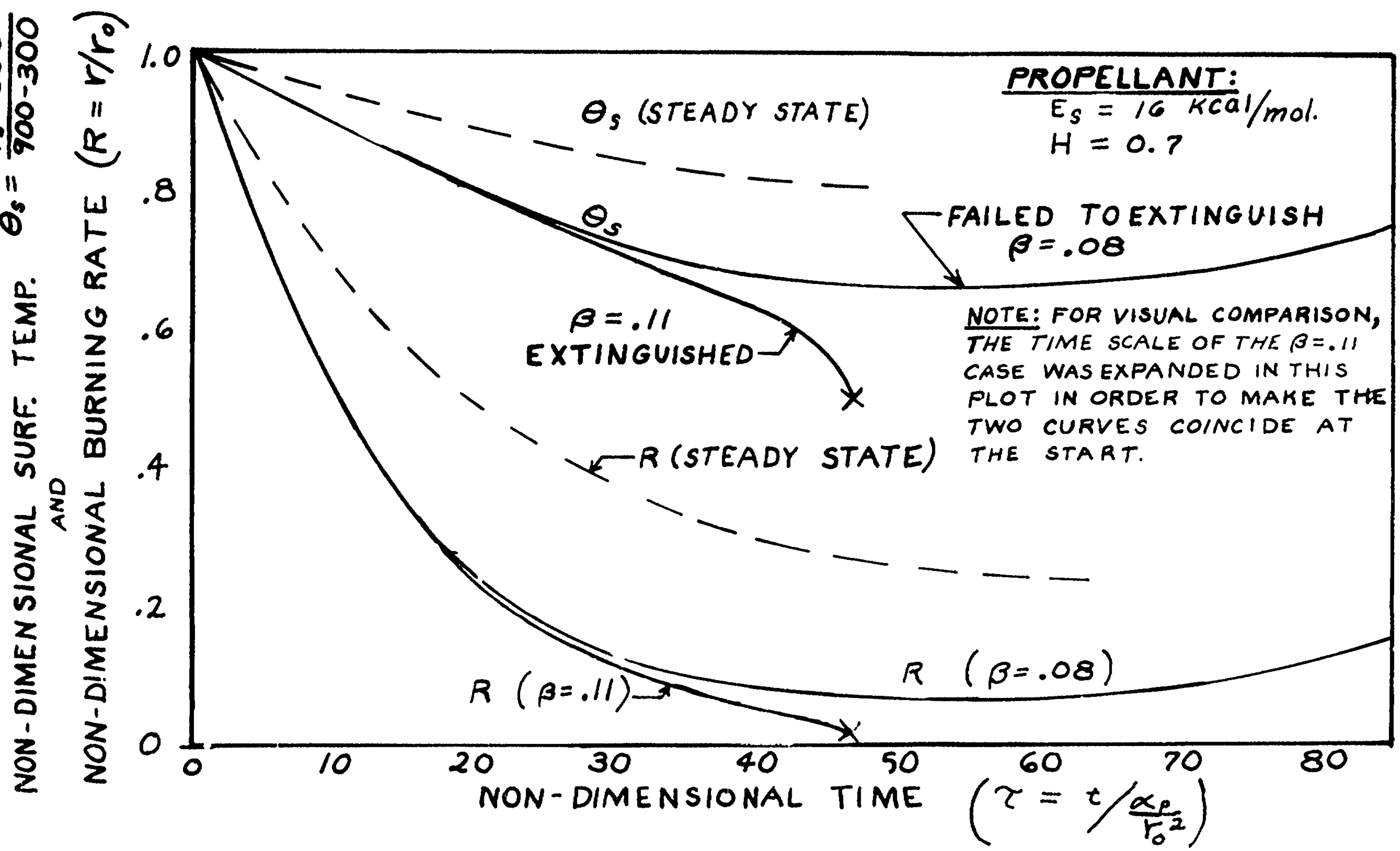


PREDICTED HISTORY OF FLAME TEMPERATURE DURING RAPID DEPRESSURIZATION

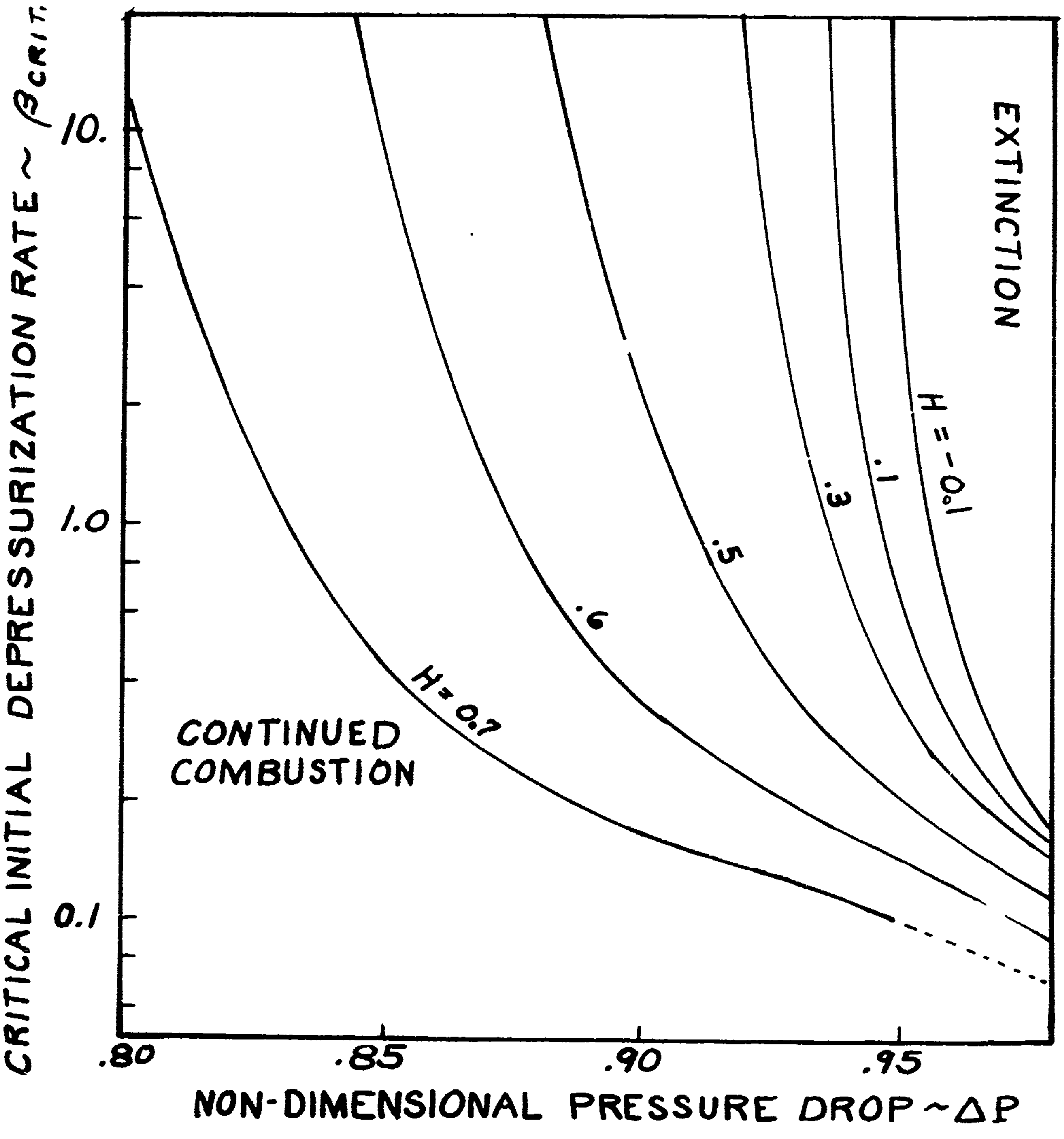


Typical luminosity and chamber pressure transient records during rapid pressure decay

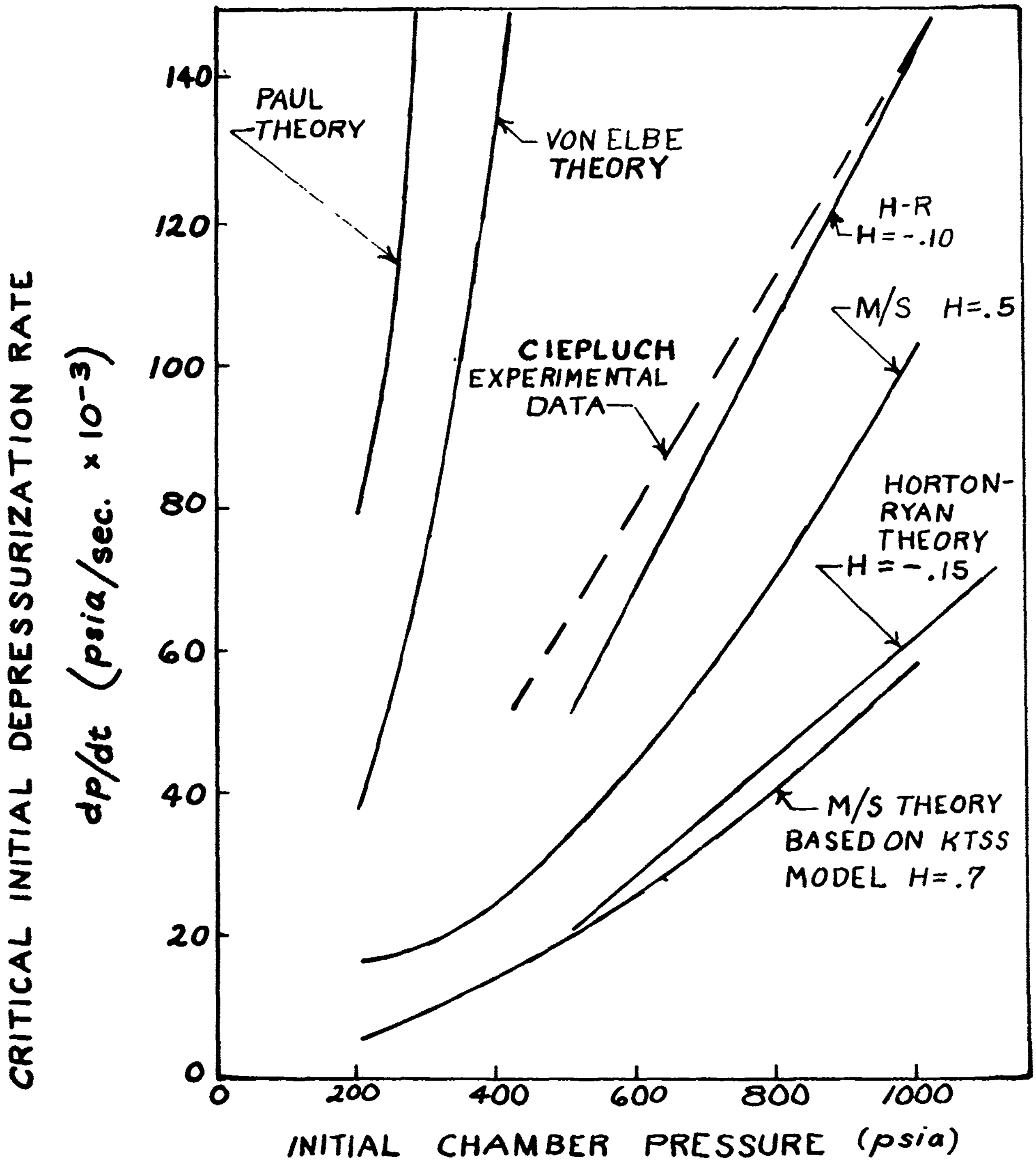
Taken from Ciepluch, ARS J.,
Nov. 1961 (His Figure 2)



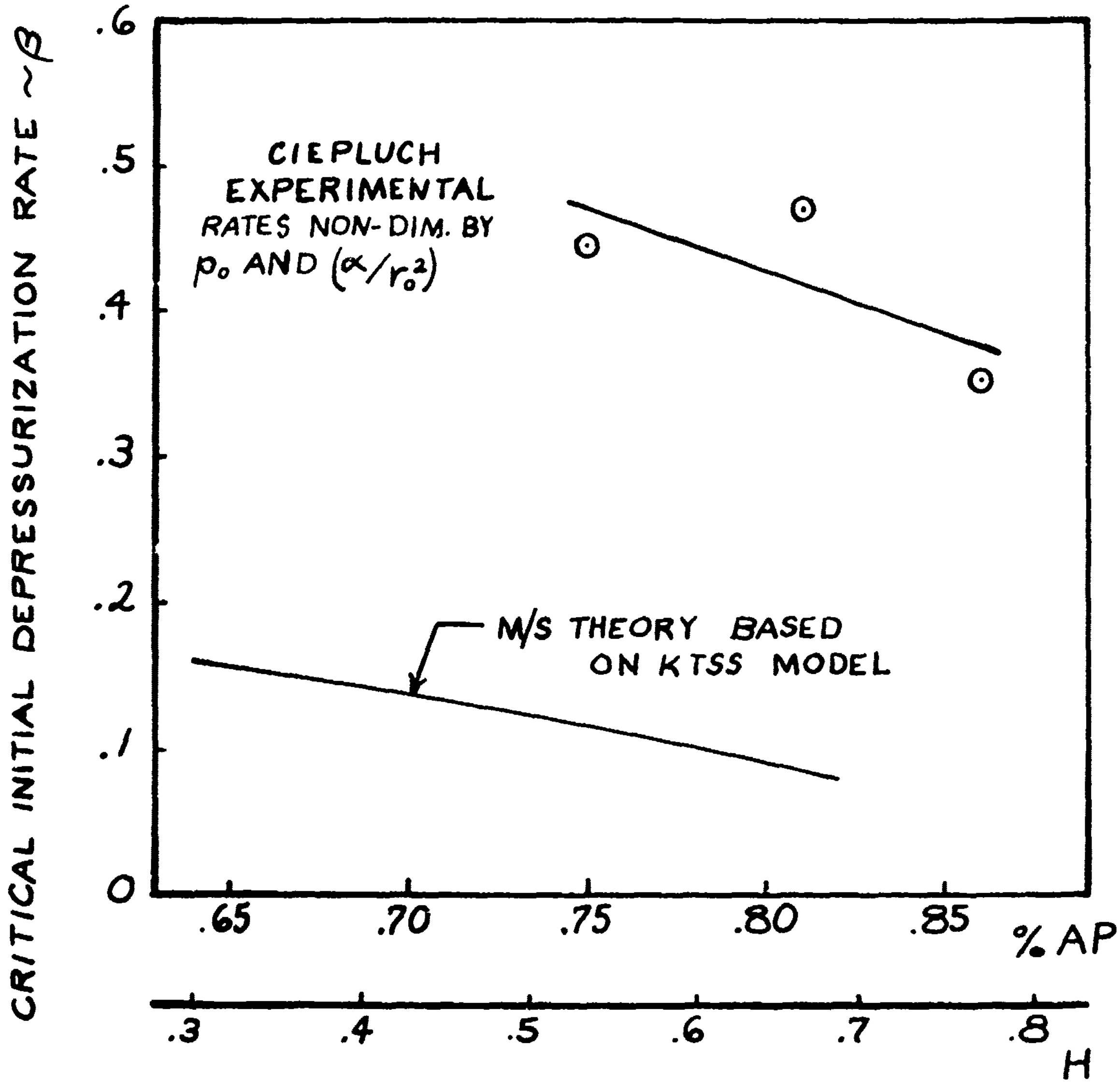
PREDICTED HISTORY OF SURFACE TEMPERATURE AND BURNING RATE DURING RAPID DEPRESSURIZATION



DIFFICULTY OF EXTINCTION BY DEPRESSURIZATION: EFFECT OF PRESSURE DROP

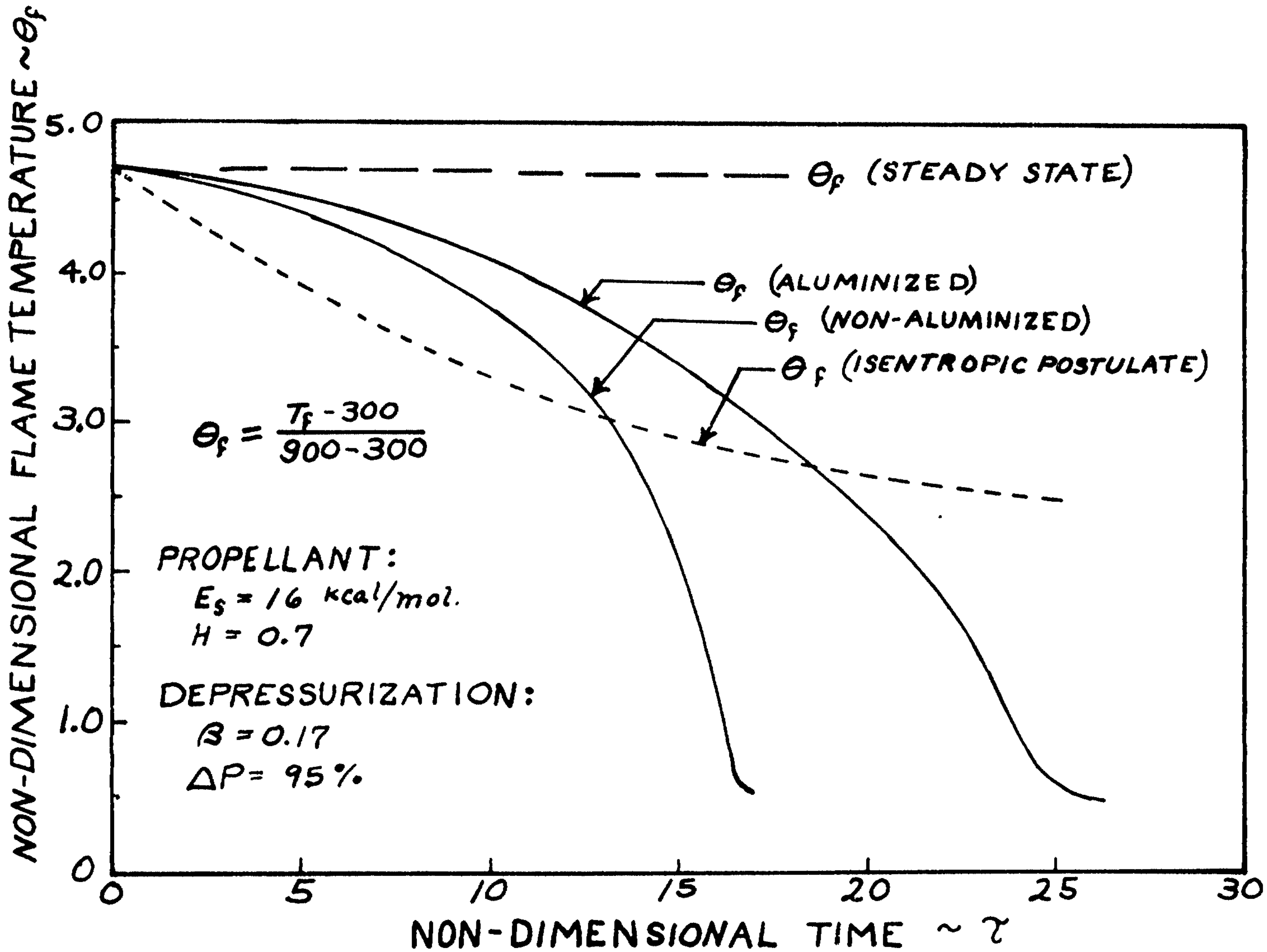


DIFFICULTY OF EXTINCTION BY DEPRESSURIZATION: COMPARISON OF THEORY AND EXPERIMENT

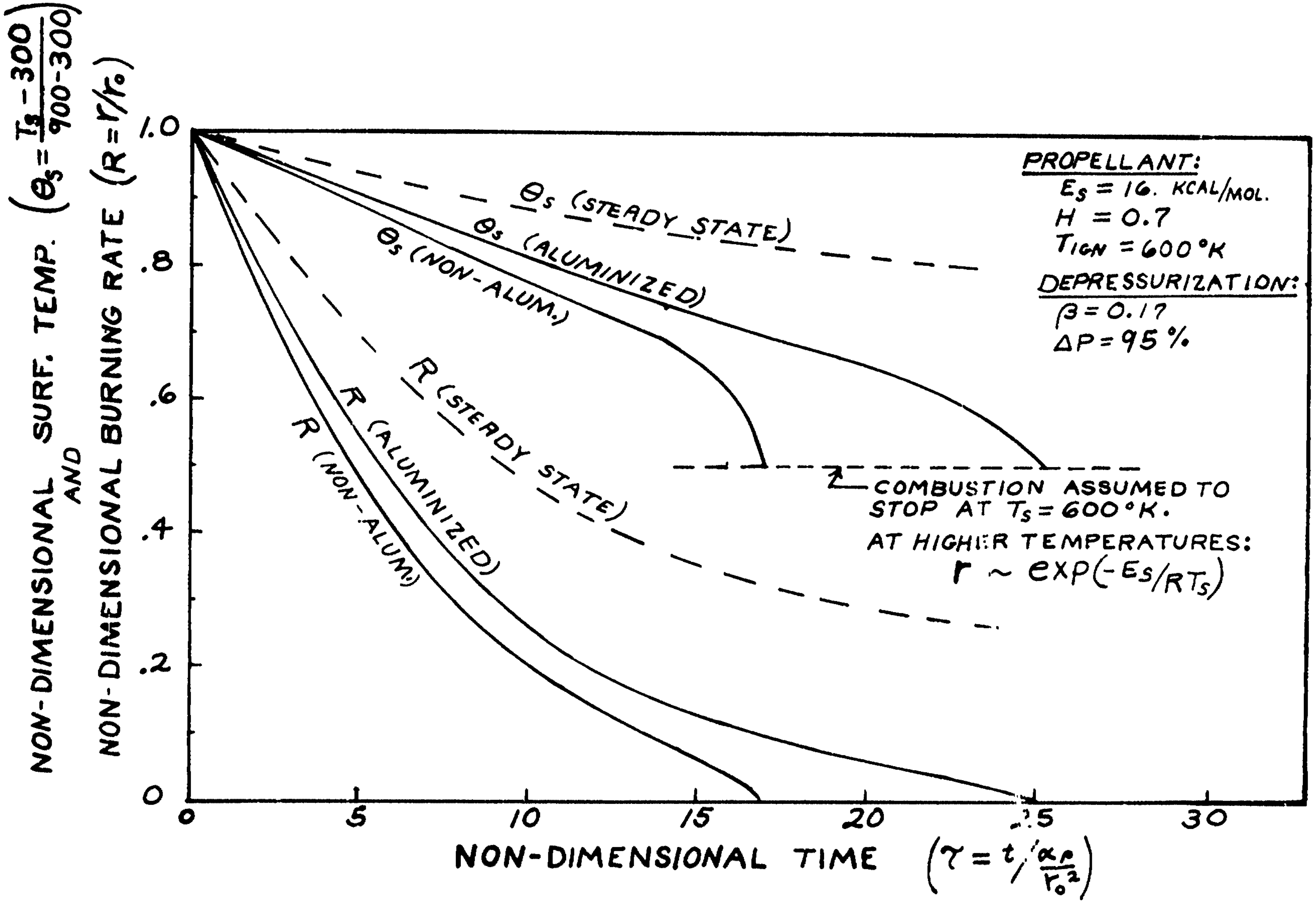


DIFFICULTY OF EXTINCTION BY DEPRESSURIZATION

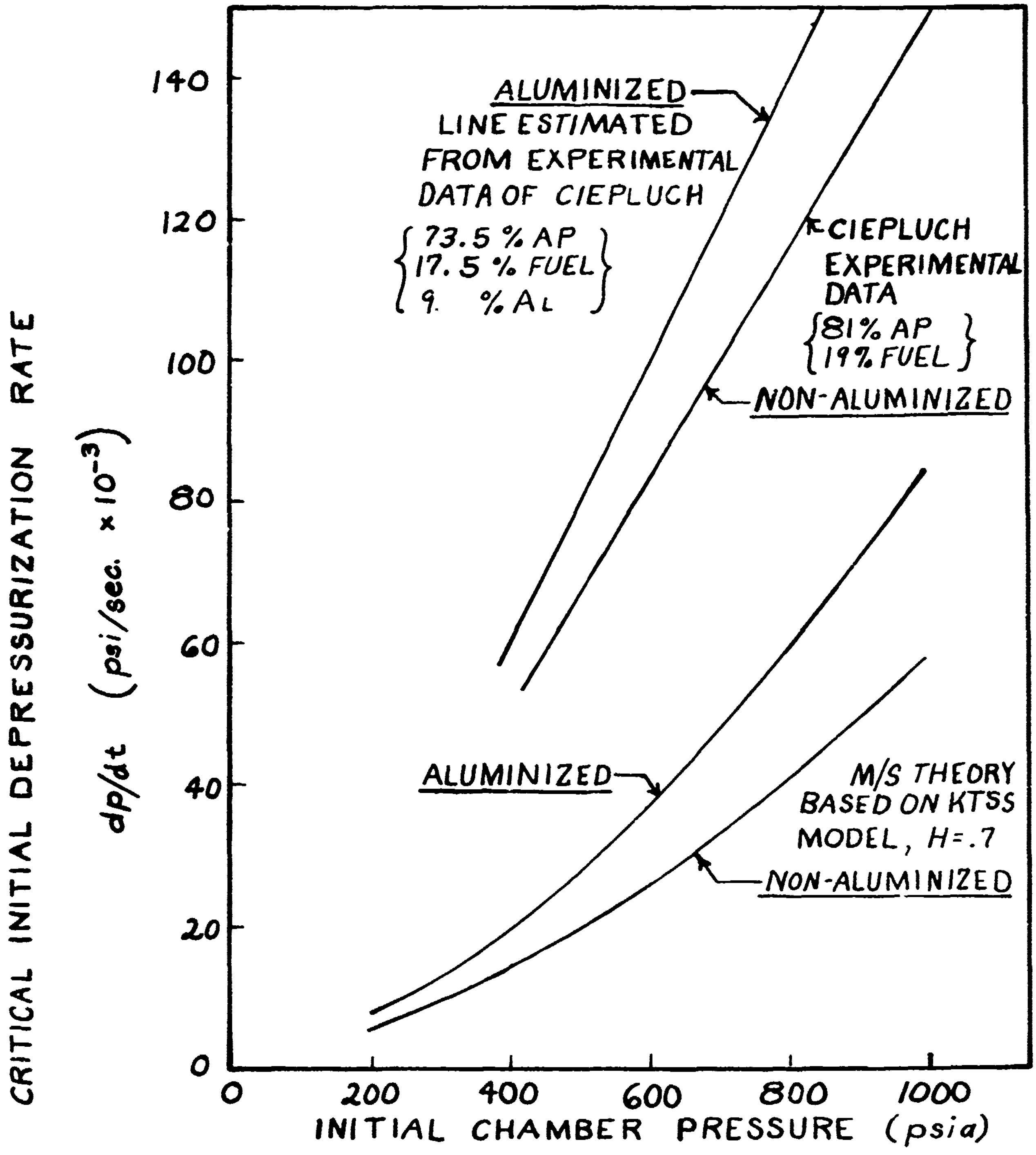
EFFECT OF AP LOADING (O/F) RATIO



PREDICTED HISTORY OF FLAME TEMPERATURE
DURING RAPID DEPRESSURIZATION TO EXTINGUISHMENT



PREDICTED HISTORY OF SURFACE TEMPERATURE AND BURNING RATE DURING RAPID DEPRESSURIZATION TO EXTINGUISHMENT



DIFFICULTY OF EXTINCTION BY DEPRESSURIZATION: EFFECT OF ADDITION OF ALUMINUM

In conclusion we have shown that:

1. A theory based on the KTSS dynamic flame model (surface heat release plus granular diffusion flame) predicts qualitatively the observed extinguishment behavior.

2. An aluminized propellant is more difficult to extinguish than a non-aluminized one having the same AP binder ratio.

3. The low pressure part of the depressurization transient is the most critical in determining whether extinction will occur.

4. To improve the predictions, the theory will have to incorporate a more exact description of the entire burning rate curve.