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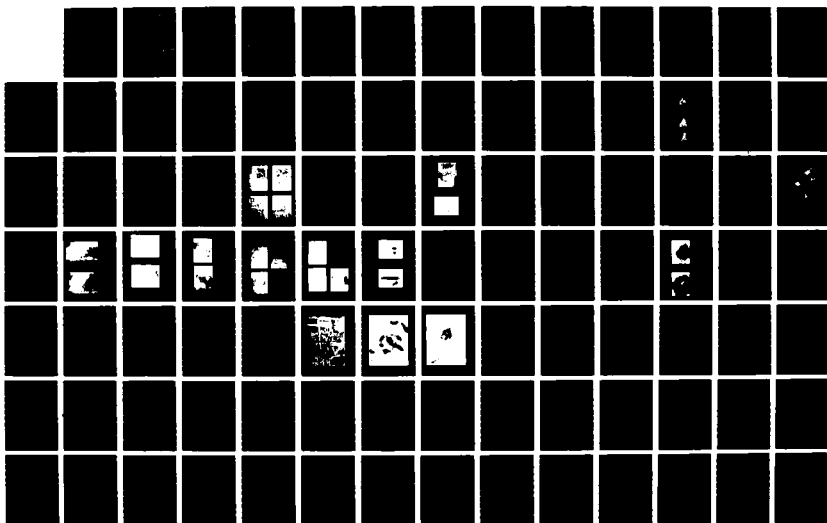
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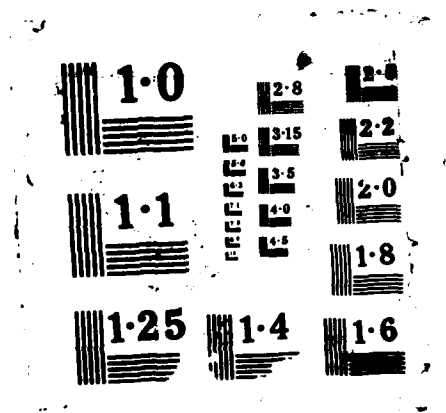
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**TECHNICAL PAPERS PRESENTED AT THE DEFENSE
NUCLEAR AGENCY GLOBAL EFFECTS REVIEW**

Volume II

**Kaman Tempo
Alexandria Office
Huntington Building
2560 Huntington Avenue
Alexandria, VA 22303-1410**

15 May 1986

Technical Report

CONTRACT No. DNA 001-82-C-0274

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**Prepared for
Director
DEFENSE NUCLEAR AGENCY
Washington, DC 20305-1000**

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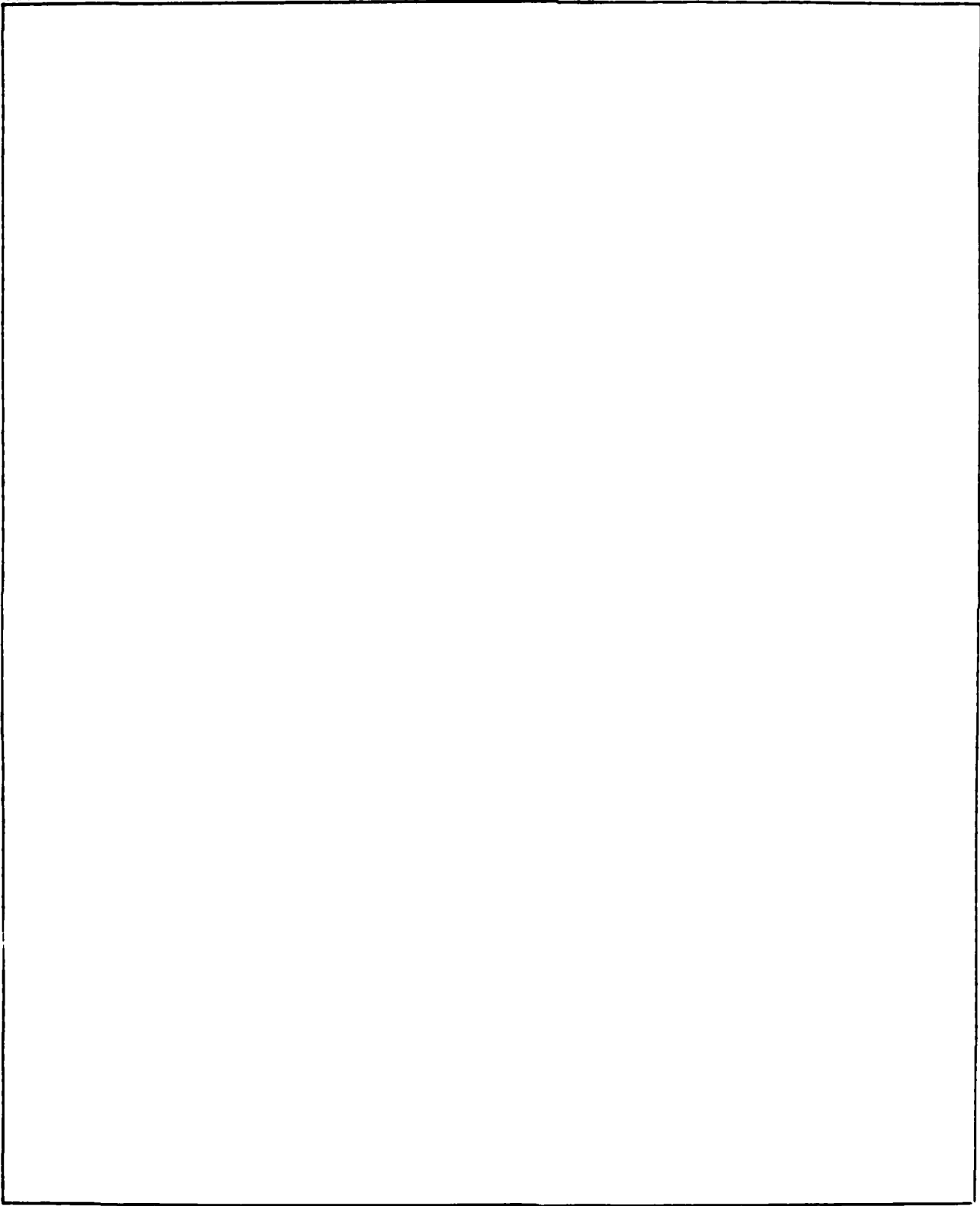
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This document contains technical papers presented at the Defense Nuclear Agency Review of Global Effects held at NASA Ames Research Center 25-27 February 1986. <i>Remarks:</i>				
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PREFACE

The Defense Nuclear Agency has collected and printed the attached papers from the February 25-27 1986 Global Effects review as a service to the community. The Defense Nuclear Agency takes this opportunity to express its gratitude to the numerous participants in the Global Effects review.

The technical papers enclosed include all those which were received by DNA prior to the closing date of 28 April 1986. Where papers are missing their place is occupied by the abstract received prior to the meeting.

The inclusion of a paper in this proceeding does not necessarily imply endorsement of the results of the research reported or conclusions which might be drawn from that research. It is the opinion of the Defense Nuclear Agency that, while good progress is being made in improving our understanding of Global Effects, the results to date are tentative and preliminary and should not be used for planning beyond the planning of future research.



TABLE OF CONTENTS

	Page
PREFACE	iii
SECTION 1 <u>Chemistry and Microphysics</u>	1
15. Laboratory Study of Wet Coagulation - Carrier, Fendell, Kwoh, Lake	2
16. Microphysical Properties and Removal Processes of Soot - Hallett, Gardiner, Lamb, Rogers, Pitter, Hudson	21
17. Chemical Scavenging in the Atmosphere: Smoke-Ozone Reactions - deHaas, Fristrom, Linevsky, Silver	49
18. Reaction of Stratospheric Carbon Aerosol With Ozone - Martin, Judeikis, Cohen	60
19. Heterogeneous Reactions in a Soot Laden Atmosphere - Golden, Rossi, Brouwer, Stephens	70
20. Proposed Modeling Studies on Removal by Cloud Process of Massive Emissions of Particles - Lee	85
21. Rolla Cloud Simulation Chambers - White, Hagan, Carstens	90
SECTION 2 <u>Plume Dynamics and Cloud Physics</u>	98
22. Scavenging of Submicron Aerosols by Clouds - Pueschel	99
23. The Role of Buoyancy Induced Turbulence in Scavenging Particulates from Large Scale Fires - Edelman	100
24. On the Scavenging of Aerosol Particles by Snow Crystals - Wang	118
25. Cloud Model Sensitivity Studies on the Vertical Penetration of Soot - Banta	141
26. Multiple Plume Flow Fields - Baum	167
27. Physical Simulation of Large Area Fire Plumes - Poreh, Cermak, Peterka	187
28. Smoke Plumes from Large Area Fires - Karagozian, Remetch, Small	210
29. Tropopause Response to Large Area Fires - Bacon	225
30. The Numerical Simulation of Smoke Plume Dynamics in Intense Fires - Bradley	251

TABLE OF CONTENTS (Continued)

	Page
SECTION 3 <u>Mesocale Modeling</u>	261
31. Regional-Scale Interactions Between Atmospheric Dynamics and Aerosols - Westphal, Toon	262
32. Algorithms for Computations of Aerosol Physics and Radiative Transfer - Toon	273
33. Mesoscale Modeling of Coastal Flows During Periods of Extended Solar Obscuration - Molenkamp	286
34. A Numerical Simulation of the Possible Effects of Nucleation Scavenging on Plume Injection - Tripoli, Chen, Cotton	309

SECTION 1
CHEMISTRY AND MICROPHYSICS

LABORATORY STUDY OF WET COAGULATION

GLOBAL EFFECTS PROGRAM TECHNICAL MEETING

FEBRUARY 26, 1986

GEORGE CARRIER*
FRANK FENDELL
DAN KWOH
BRUCE LAKE

*Harvard University, Cambridge, Massachusetts 02138

TRW SPACE AND TECHNOLOGY GROUP
ONE SPACE PARK
REDONDO BEACH, CALIFORNIA 90278

OBJECTIVE

Do laboratory experiment:

- (1) To see if light extinction by soot particles changes after confinement in a cloud
- (2) To measure size distribution and number density of soot particles before and after confinement in a cloud

APPROACH

- (1) Introduce soot particles and moist air into cloud chamber
- (2) Measure extinction, number density and size distribution of soot particles
- (3) Expand cloud chamber adiabatically to form cloud
- (4) Sit for sometime for scavenging, wet coagulation to take place
- (5) Compress cloud chamber to evaporate cloud
- (6) Measure extinction, number density and size distribution of soot particles again

PROBLEMS TO BE SOLVED

(1) Cloud Chamber

Wall temperature must closely match gas temperature to prevent condensation, convection

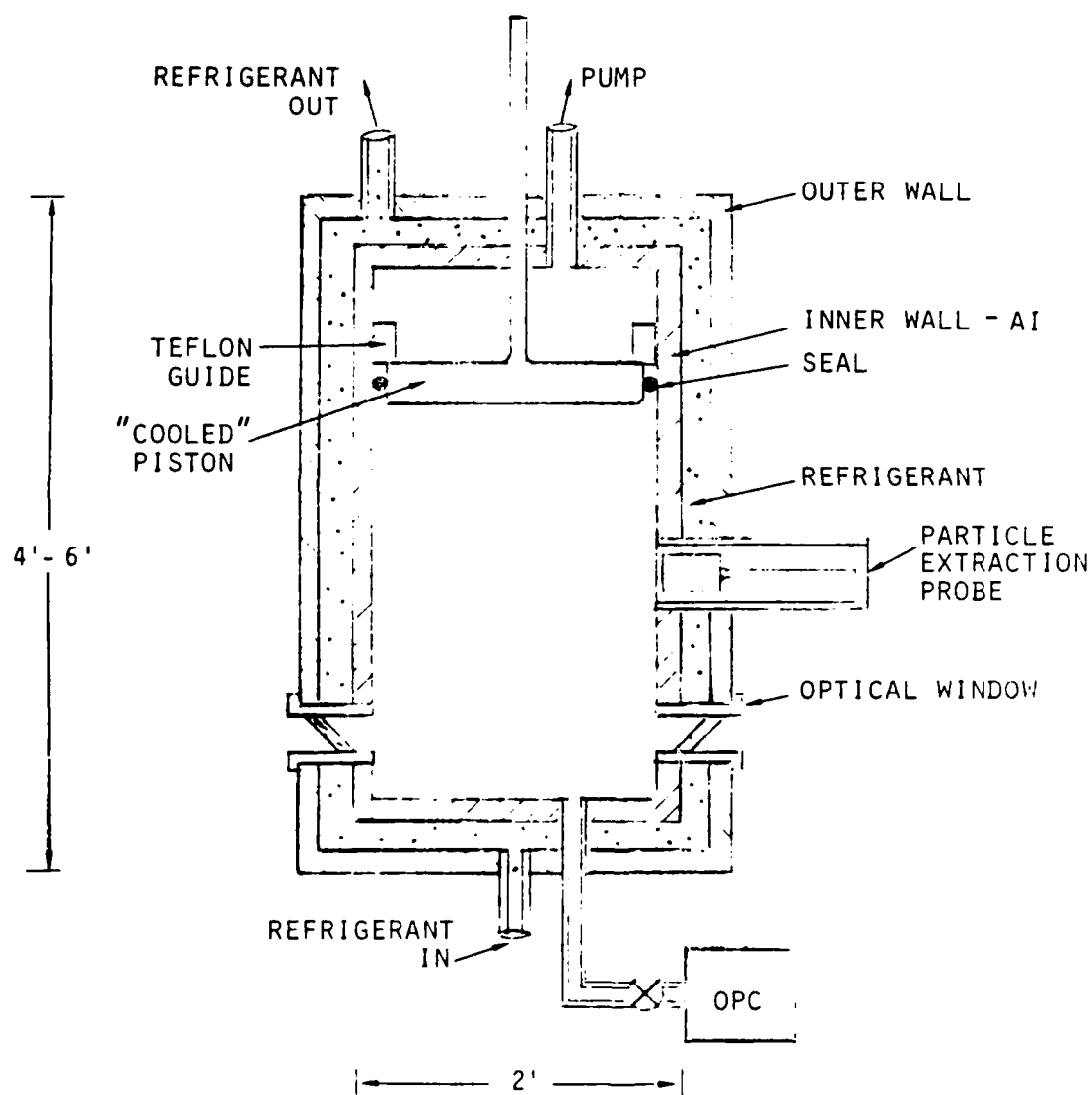
(2) Extinction Measurement

Low number density of soot particles $\Rightarrow$ low extinction which is hard to measure

(3) Soot Particles' Number and Size Measurements

Submicron particle size and number measurements are non-trivial

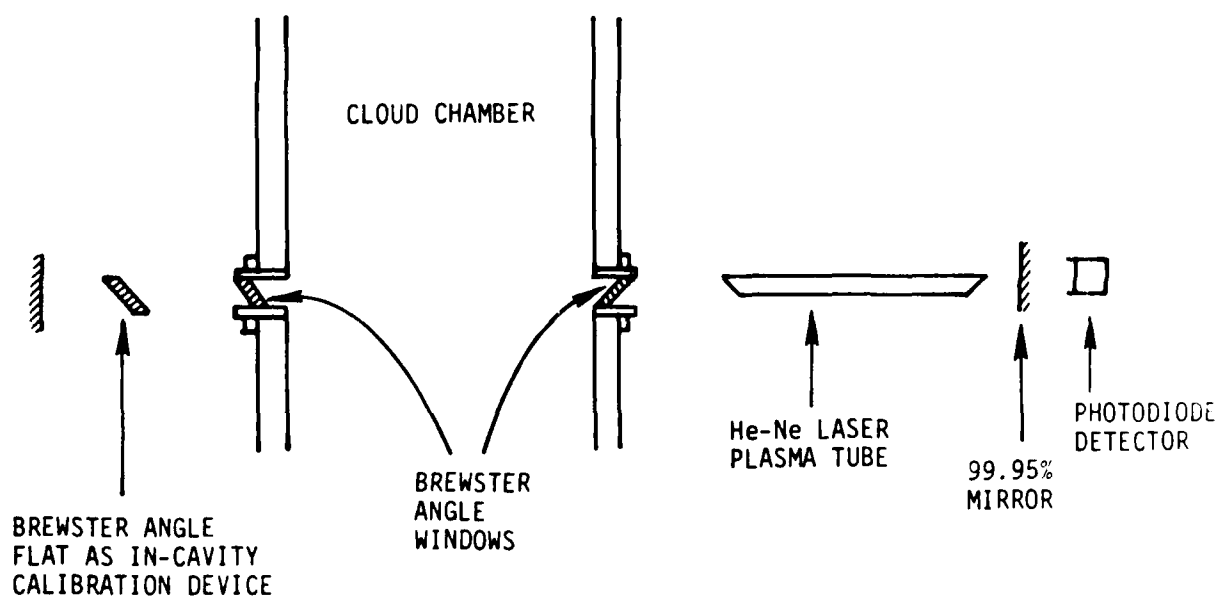
CLOUD CHAMBER: SCHEMATICS



CLOUD CHAMBER: APPROACH

- Wall cooling by simply passing refrigerant through at controlled cold temperature and flow rate. Cool from R.T. to $\sim -60^{\circ}\text{C}$ in 1/2 hour.
- Gas cooling by adiabatic expansion using piston. Expansion ratio $\sim 1:3$
- Minimize leakage by piston by evacuating and equalizing pressure on back side of piston
- Monitor wall and gas temperature by thermocouple or transistor thermometer
- Make gas temperature to follow wall's
- Aim for wall $0.1\text{-}0.3^{\circ}\text{C}$ warmer than gas to prevent condensation
- Make top of chamber warmer than bottom to suppress convection

EXTINCTION MEASUREMENT: SCHEMATICS



EXTINCTION MEASUREMENT: APPROACH

- 10^4 - 10^5 0.1μ particles/c.c. $\Rightarrow$ 10^{-4} - 10^{-3} /m extinction coefficient
- Use "laser-cavity extinction" method:
 - make soot-laser air part of laser cavity
 - laser output highly non-linear function of cavity loss
 - equivalent measurement pathlength $\sim$ kilometers
 - use variable Brewster angle flat as in-cavity calibration device
 - evacuate chamber either before or after dust measurement for calibration

LASER OUTPUT VS. CAVITY LOSS

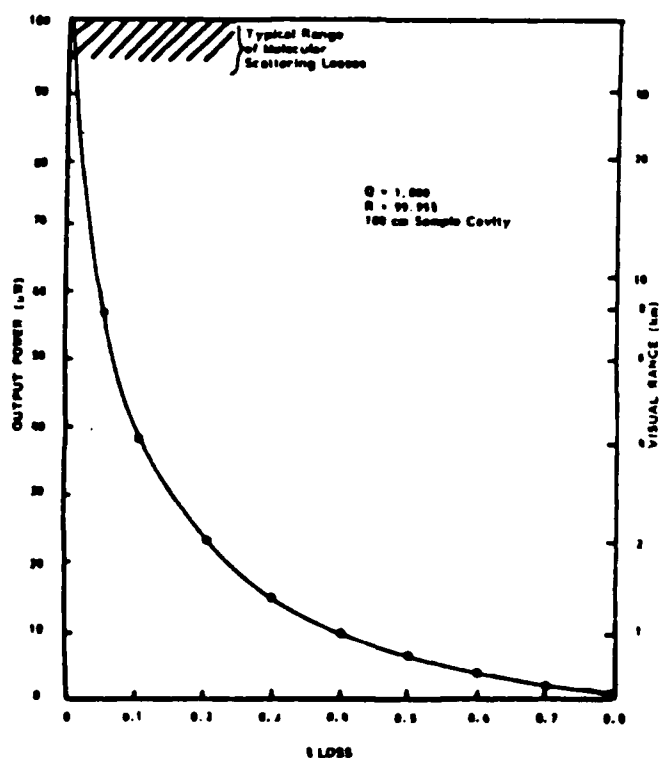


FIGURE 2. Visual range and output power versus percent cavity loss. The prototype uses a 100-cm sample cavity length. With current state-of-the-art high reflectivity mirrors, the sample cavity length can be reduced to less than 30 cm with a Q of 2,000 to 5,000.

BREWSTER ANGLE FLAT AS IN-CAVITY CALIBRATION STANDARD

<u>Incident Angle</u>	<u>Loss</u>
56.0	4×10^{-7}
56.5	6.4×10^{-5}
57.0	2.4×10^{-4}
57.5	5.3×10^{-4}
58.0	9.7×10^{-4}
58.5	1.53×10^{-3}
59.0	2.25×10^{-3}
60.0	4.18×10^{-3}

SOOT PARTICLE NUMBER AND SIZE MEASUREMENTS

Primary Measurement — Extraction + electron
microscopy

Secondary Measurement — Optical scattering methods

EXTRACTION AND ELECTRON MICROSCOPY

Methods of Extraction:

- (1) Impaction — many lose small particles X
- (2) Suctioning and filtration — agglomeration may occur in suctioning probe or filter? X
- (3) "Grabbing" and gravity settling — disturb particles the least. 0.1μ particles settle in 3 hours ✓

Methods of Electron Microscopy:

- (1) Scanning electron microscopy (SEM) — 0.1μ resolution may be difficult, need to coat particles with 100-300 Å gold layer?
- (2) Transmission electron microscopy (TEM) — sample preparation more involved but well developed. Mount Collodian film on screen or slide.

OPTICAL METHODS AVAILABLE FOR MEASURING NUMBER DENSITY
AND SIZE

Ensemble Measurement (beam measurement)	{ Scattering extinction ratio 2 angle intensity ratio diffusion broadening spectroscopy 2 wavelength extinction ratio polarization ratio
Particle Measurement (focused measurement)	{ 2 angle intensity ratio 2 beam interferometry white light integrated forward scattering

COMMON SOURCES OF ERROR FOR ALL OPTICAL TECHNIQUES

1. Non-sphericity

maximum error ~ 40%

2. Index of Refraction Uncertainty

for highly absorptive particles like soot,
a few percent

3. Depth of Field (for focused measurements)

broadens size distribution, < 30%

TWO-ANGLE INTENSITY RATIO - PARTICLE MEASUREMENT COMPARISON WITH SEM

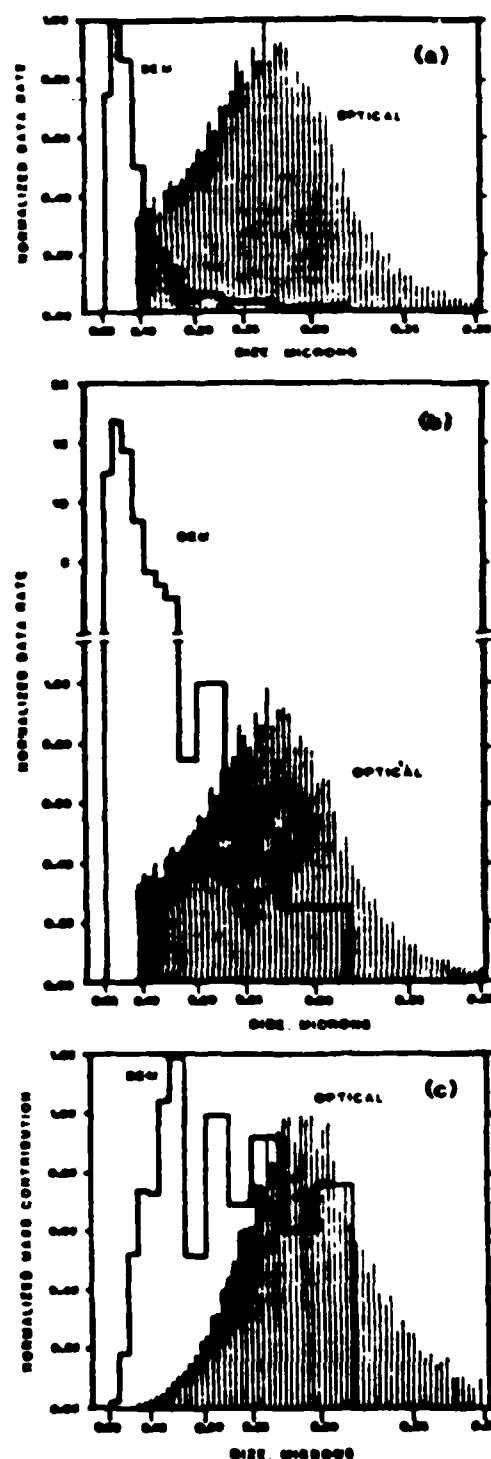


Fig. 8 Validation of (a) Scanning Electron Microscopy, (b) Optical, (c) number density, (d) number density renormalized, (e) mass density

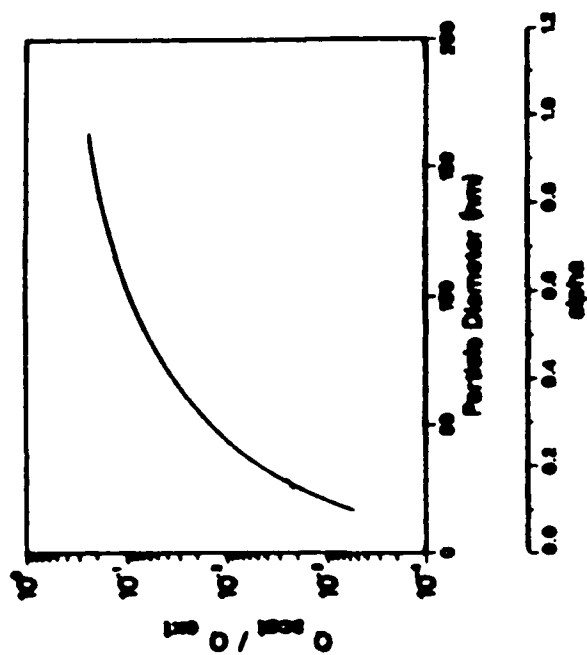
OPTICAL METHODS SELECTED

For small particles ($< 0.1 \mu$) — extinction/scattering
ratio or 2 angle intensity
ratio (large angle pair)

For large particles ($> \text{several } \mu$) — 2 angle intensity
ratio (small angle pair)

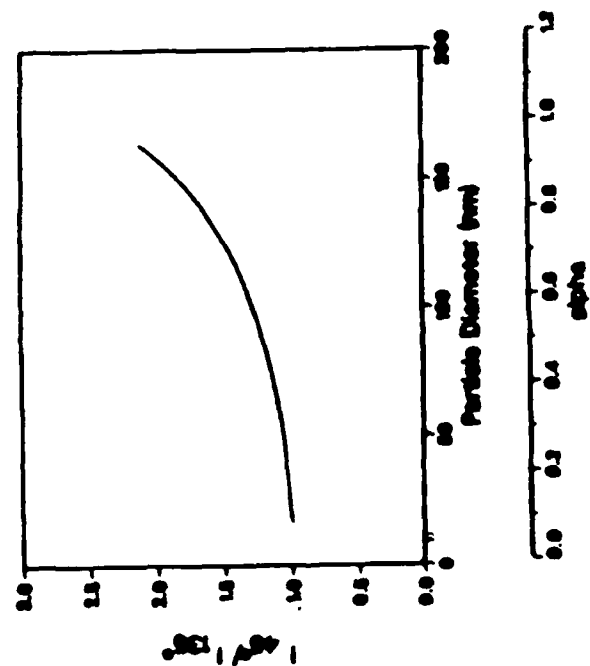
MIE SCATTERING

Scattering/Extinction Ratio



MIE SCATTERING

Two-Angle Intensity Ratio



SUMMARY OF WHAT WE PROPOSE TO DO

- (1) Measure extinction accurately
- (2) Measure particle size distribution and number density accurately by extraction and TEM
- (3) Use other optical techniques for real time monitoring and as secondary measurements

MICROPHYSICAL PROPERTIES AND REMOVAL PROCESSES OF SOOT

John Hallett, Barry Gardiner, Dennis Lamb,
Fred Rogers, Richard Pitter, Jim Hudson

Desert Research Institute
Reno, Nevada 89506

Viewgraphs - February 1986

NASA AMES DNA Meeting

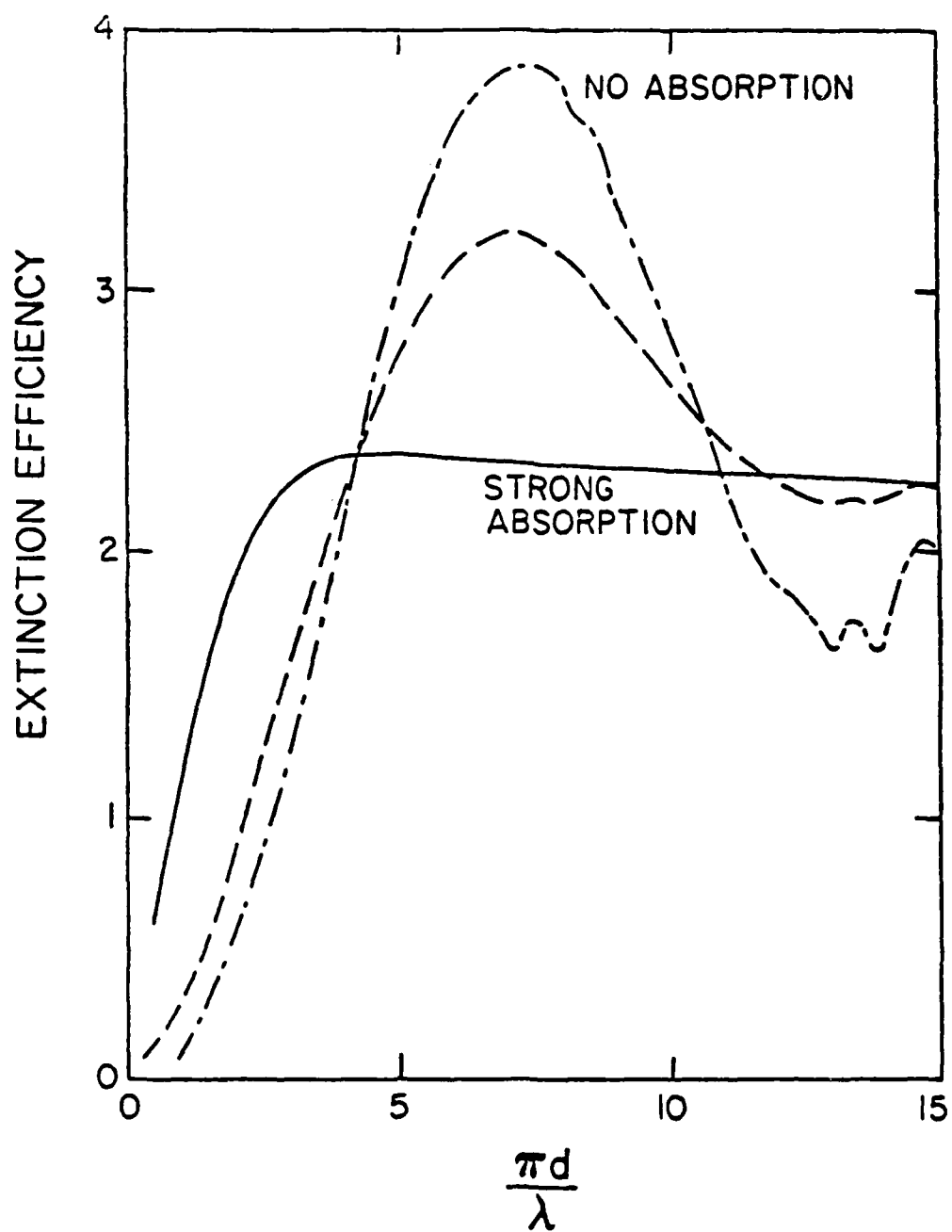
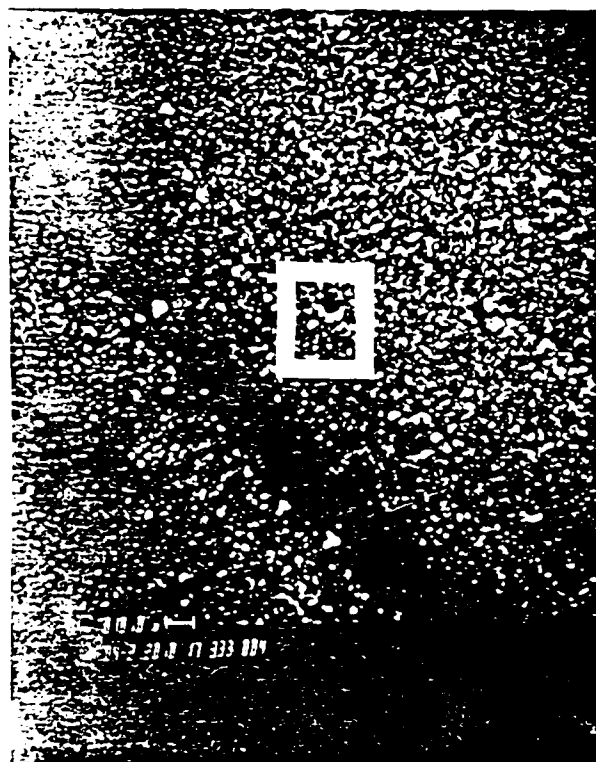
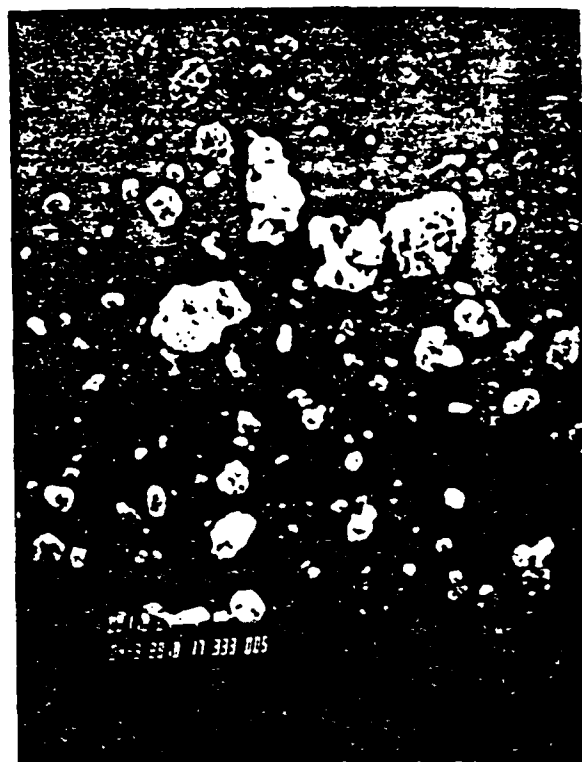


Fig. 1: Extinction efficiency for water spheres with different absorption.

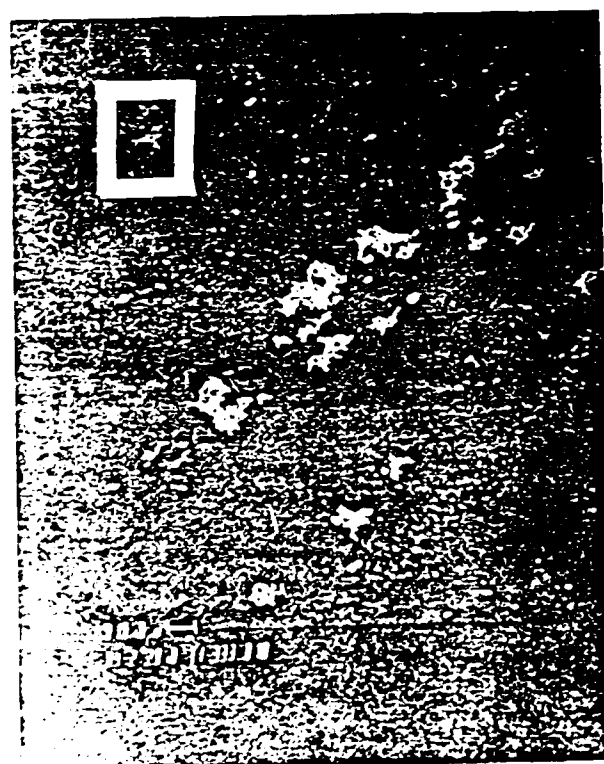


(a)

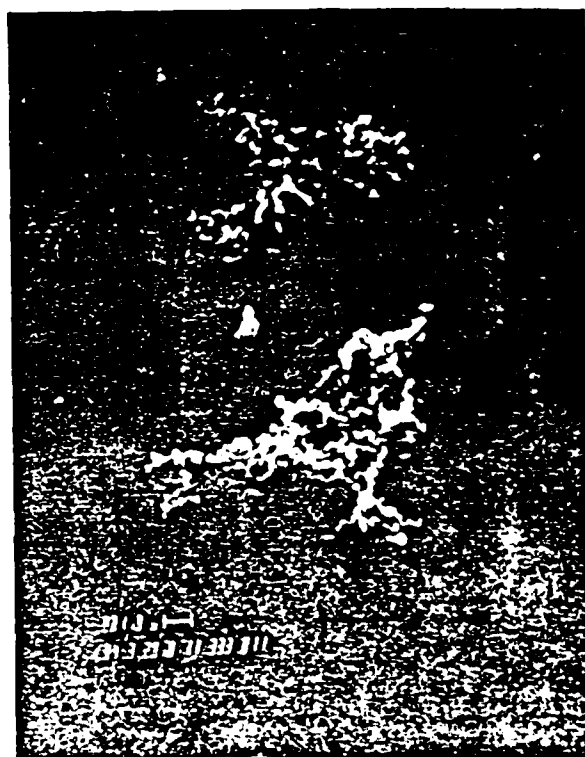


(b)

Figure 2



(c)



(d)

CCN SPECTRA FROM SOOTY ACETYLENE

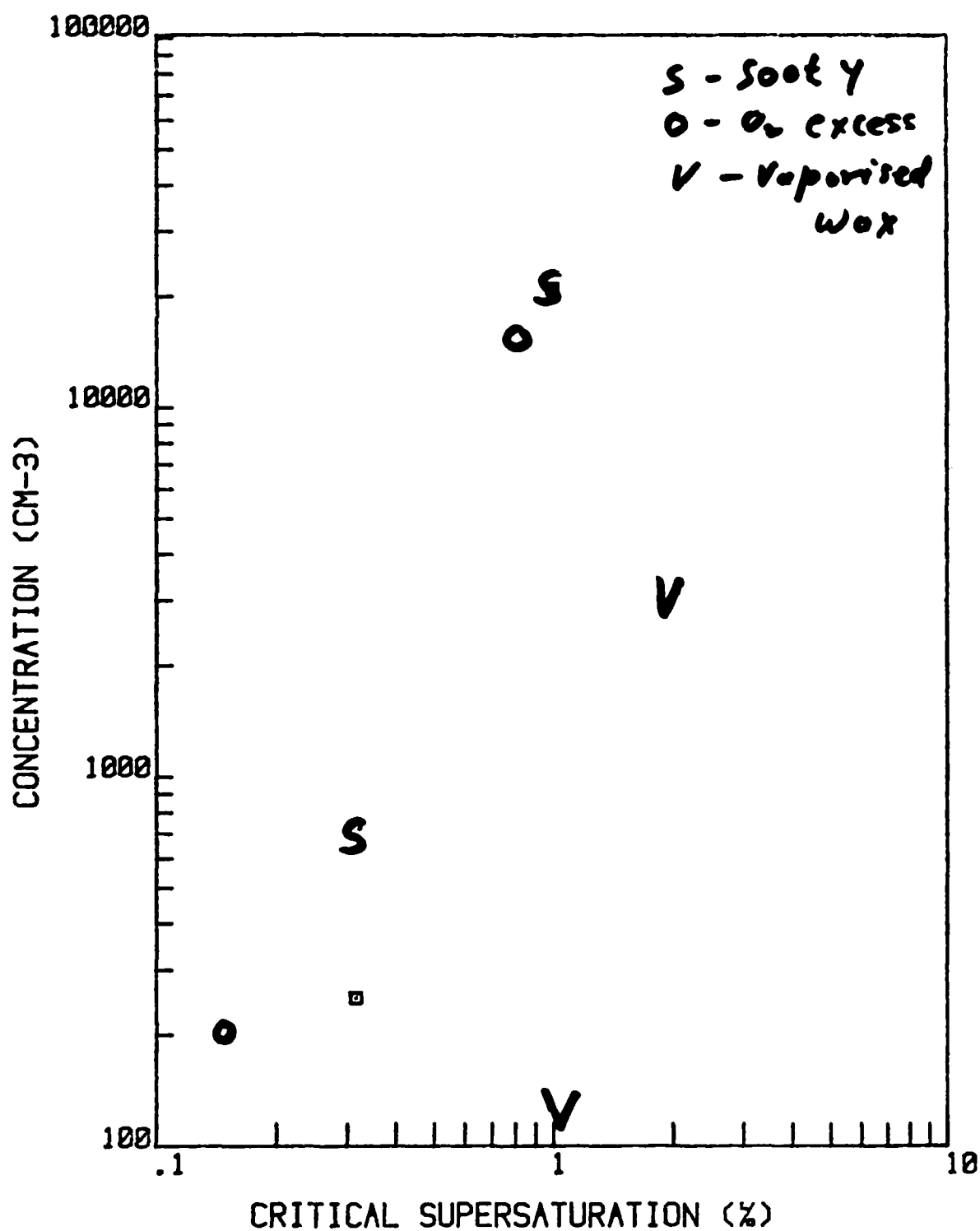


Figure 3 CCN spectra with immediate dilution.

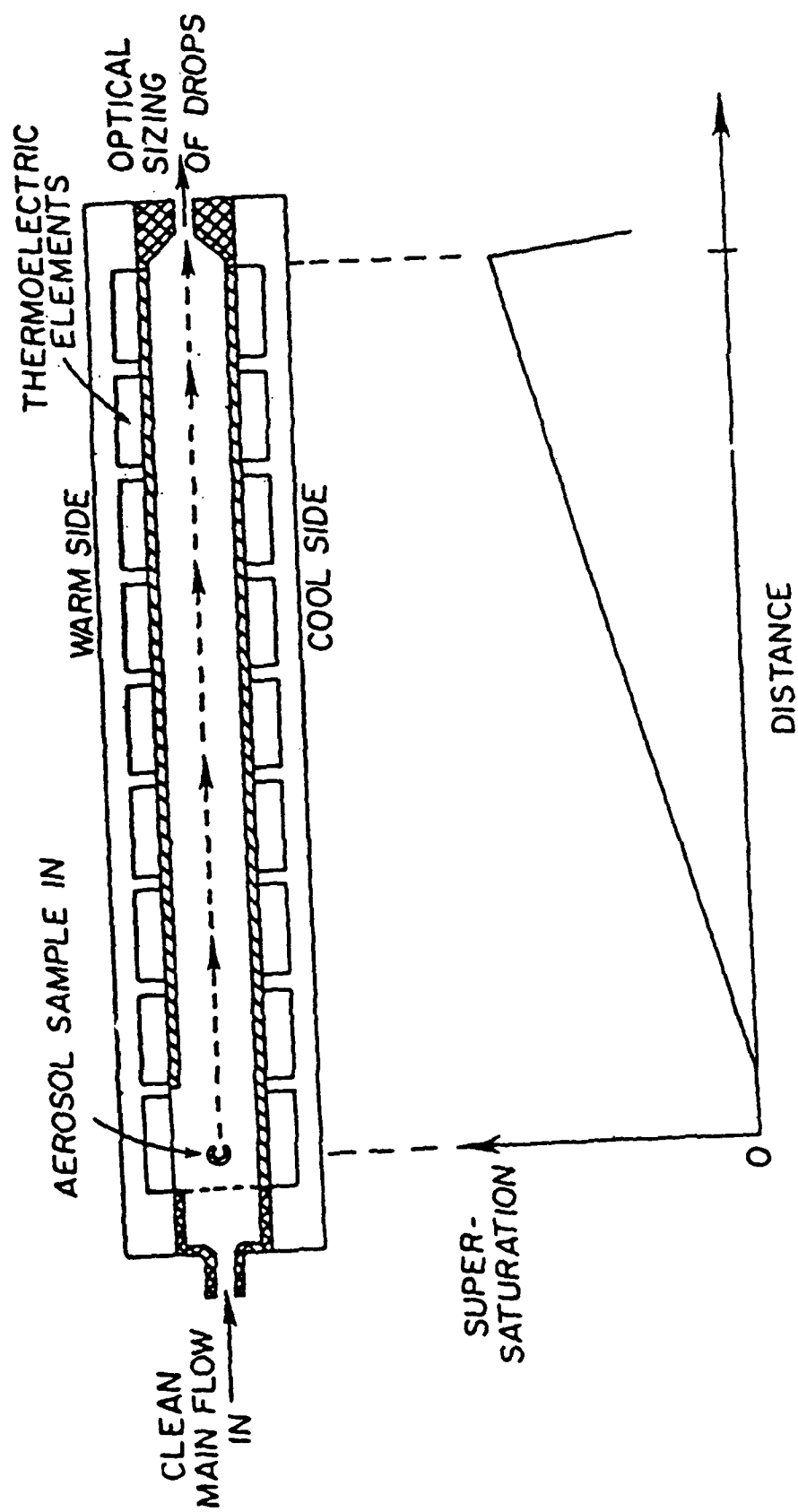


Figure 4 Diagram of the CCN thermal gradient spectrometer.

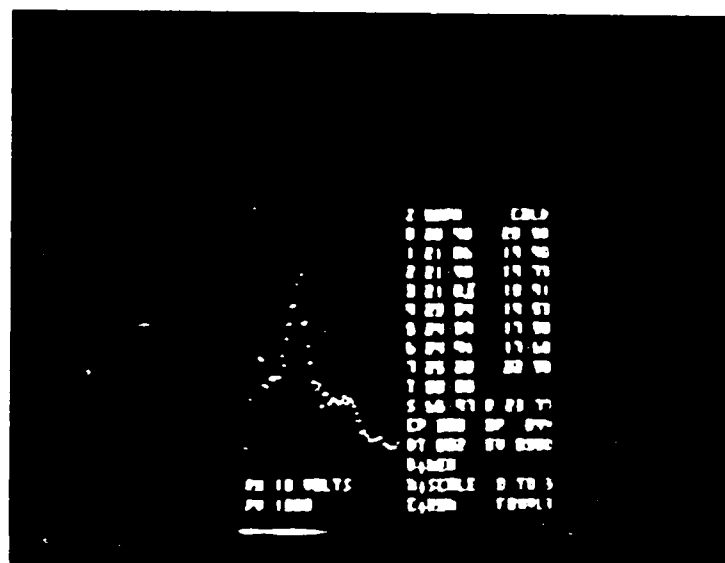


FIG 5: CCN CHAMBER AND SPECTRA

RECNUM = 353
 TIME = 02 15 02 56 36.0
 REC TIME PRIS SF DUR CP P0 P1 P2 P3 P4 P5 P6 P7 REP
 HON SD 7190 10101 C30 C40 C50 C60 C70 C80 C90 C100 C110 C120
 259.26.0 821 62.21 579.5 268 6.12 0.92 1.83 0.81 2.95 5.47 6.35 7.84 40
 40 9 82 105 94 57 6 1 1 1 0 0 0
 TIME = 02 15 02 59 50.5
 5000

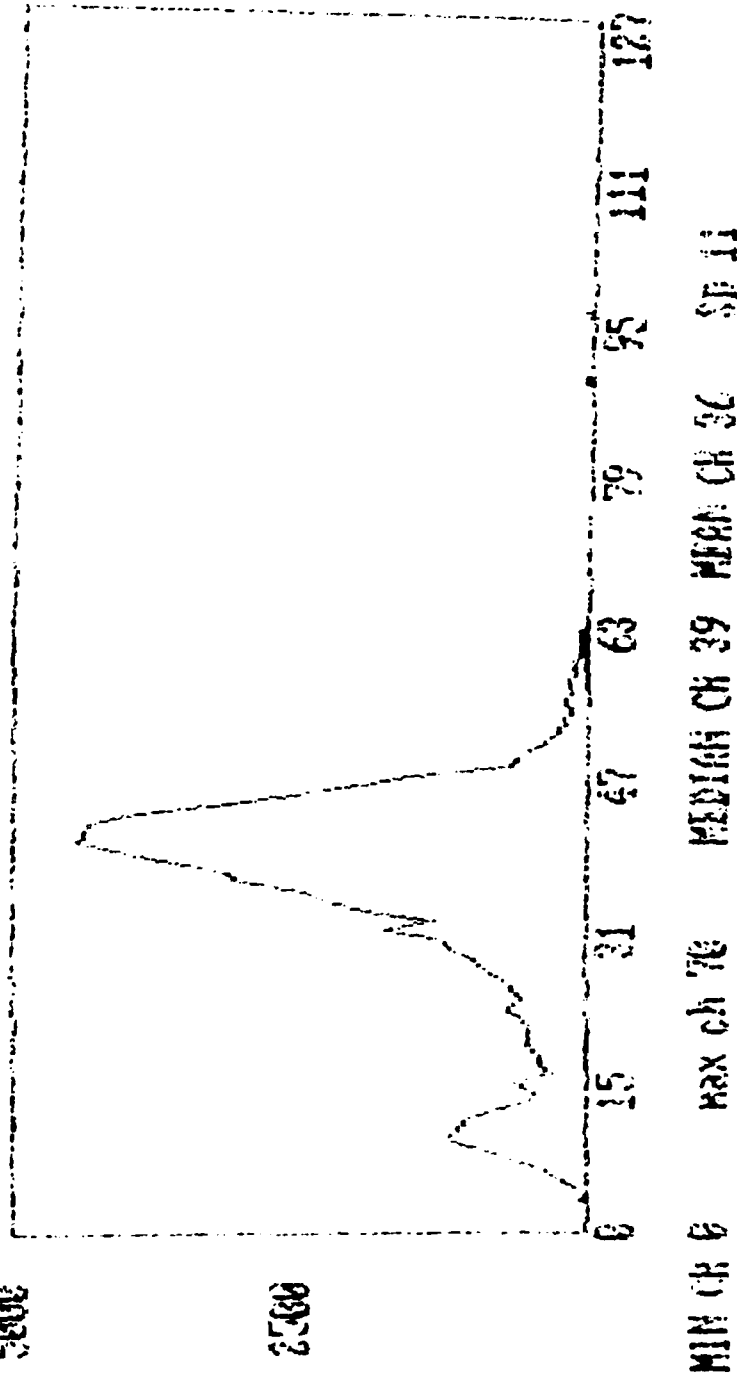
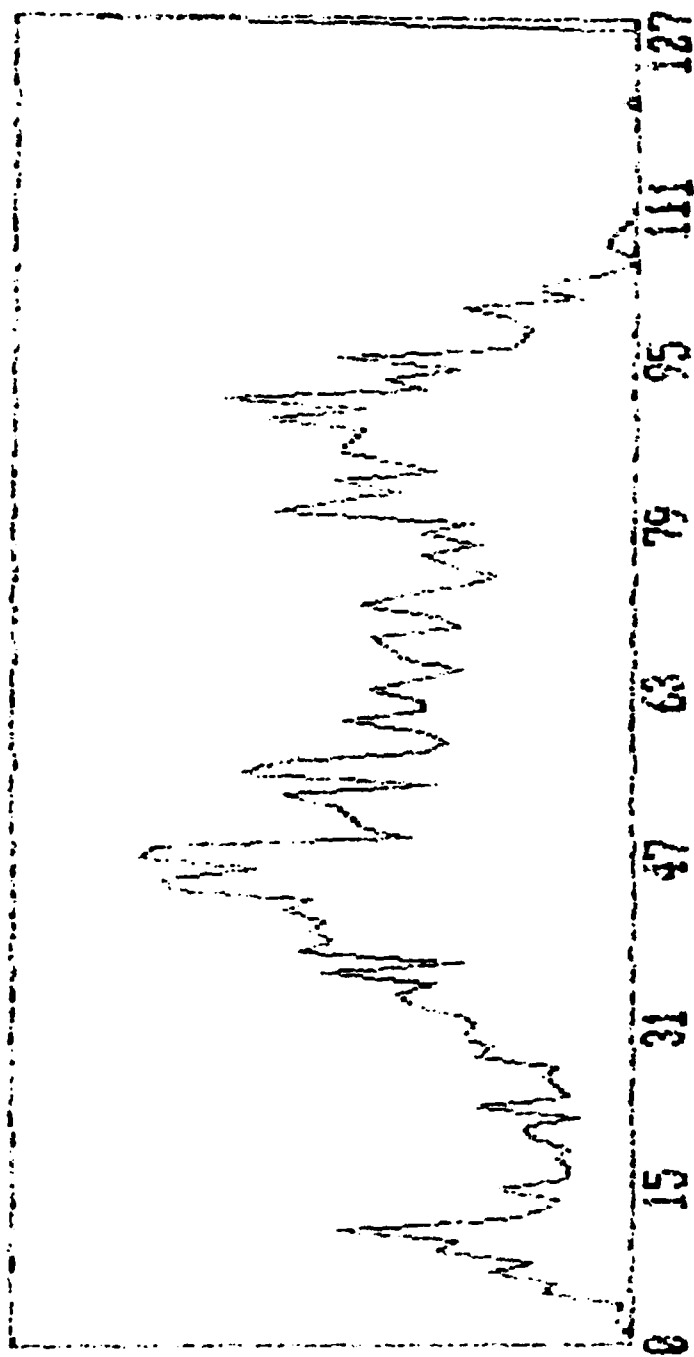


FIG. 6:

CALIBRATION AFROSOL

NaCl 0.80 % S.

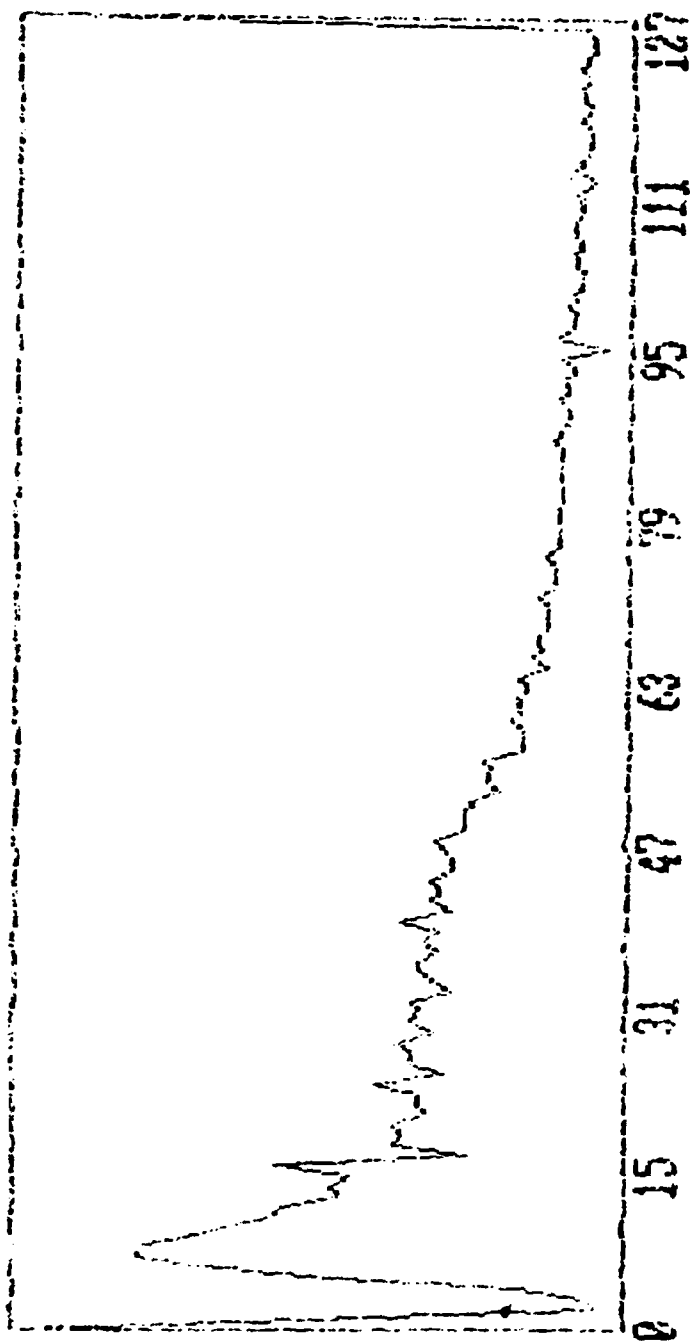
RECONUM = 299
 TIME = 02 15 12 20 24.0
 REC TIME PRES SF
 SD MSD TOTAL C30
 MEAN 226:24.0 824 63.82 30.8 289 0.06 1.03 1.67 3.11 3.98 6.40 7.20 8.77 60
 64 25 89 101 96 84 65 52 40 31 16 6 4 9
 TIME = 02 15 10 20 54.5
 100



MIX CH 1 MEDIAN CH 56 MEAN CH 60

FIG. 8:
back ground

RECORD = 306
 TIME = 02 24 15 56 20.5
 REC TIME PRES SF
 MEAN SD 21SD TOTAL C30
 556.20.5 844 43.07 23.6 364.0 33-0.32 4.73 5.60 4.02 5.40 5.17 5.39 53
 64 35 63 6604 5451 4469 3556 2889 2414 2031 1697 1404 1133 894
 TIME = 02 24 15 56 43.5
 5300



MIN CH 1 MEDIAN CH 39 MEAN CH 49

FIG. 9:

Acetylcholine Soot

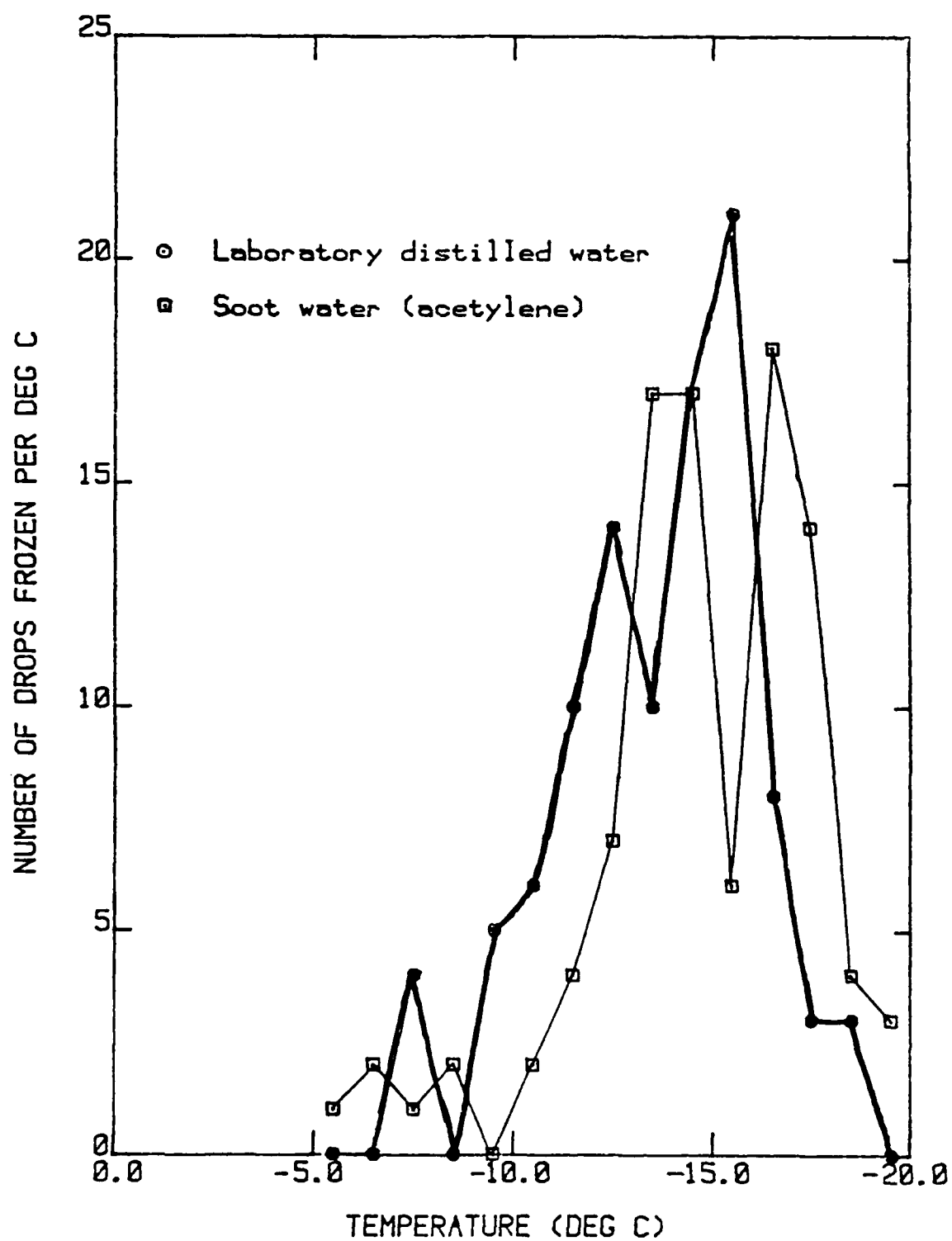


Figure 10. Number of drops frozen per degree temperature change as a function of temperature.

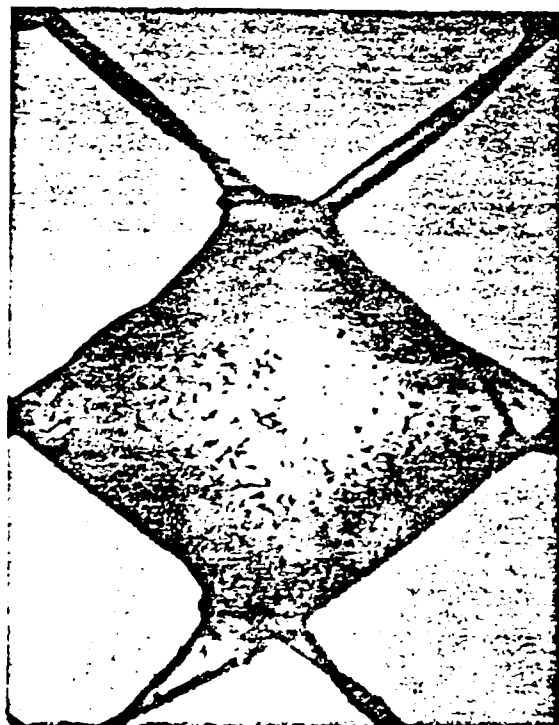
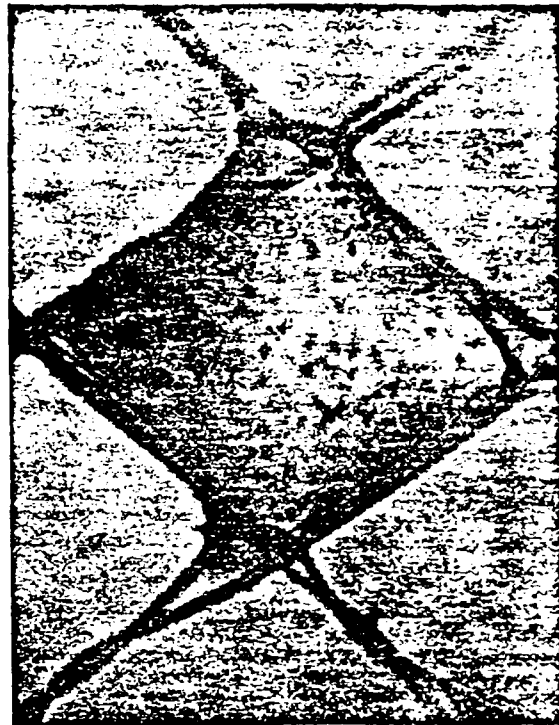
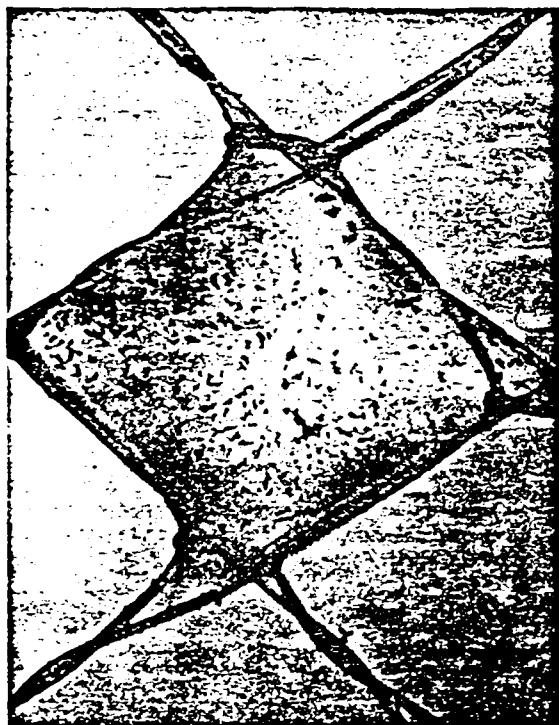


FIG. 11: ACETYLENE SOOT ON WATER DROP SURFACE

FIG. 12: COAGULATION RATE OF AEROSOL WITH CLOUD
DROPLETS, TIME CONSTANT ~ 1000 S

$$\frac{dn}{n} = \frac{dt}{\frac{3\pi r^2}{kT\lambda N} \cdot \frac{1}{F}}$$

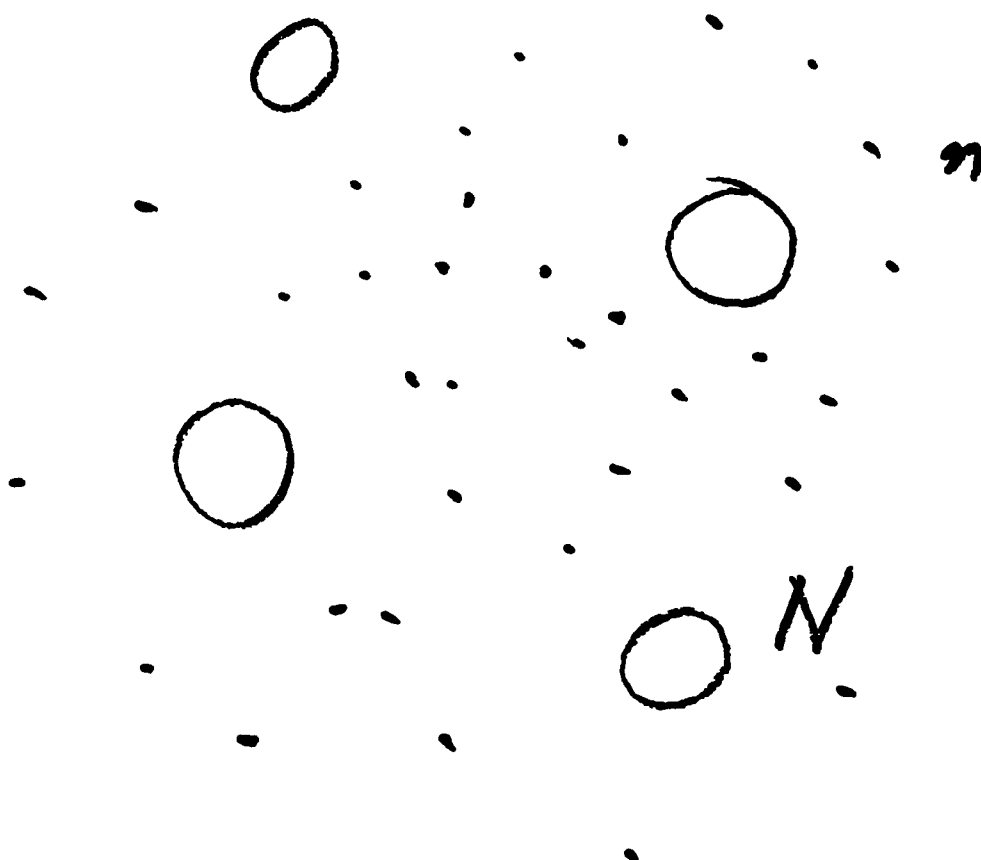


FIG. 13: SAMPLING OF RENO POOL FIRE

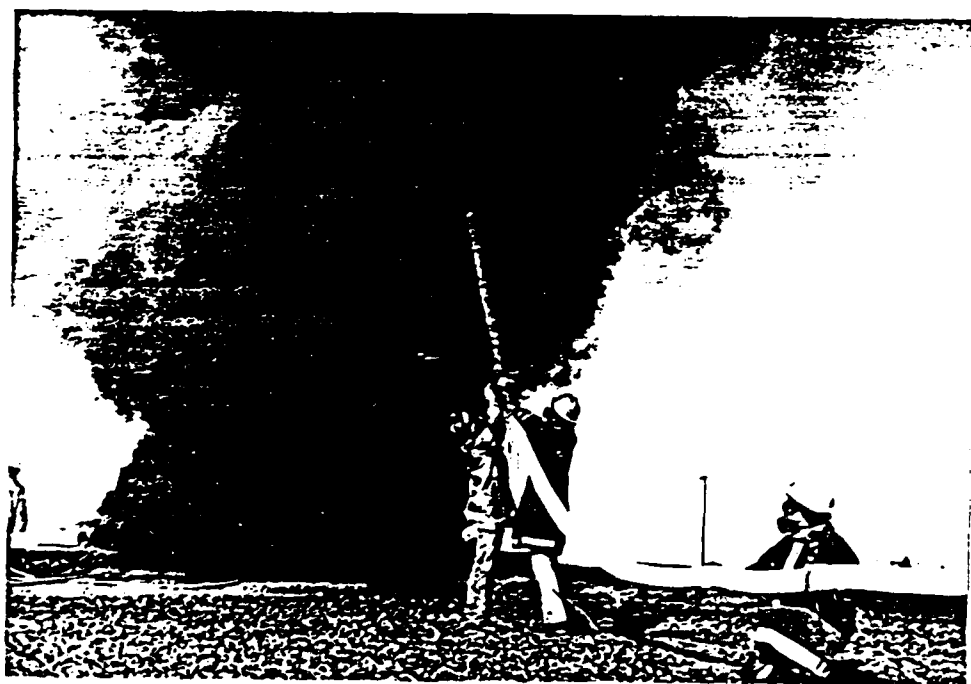




FIG. 14: SEM PICTURE OF FORMVAR REPLICATED SOOT FLAKE

Acetylene torch and air gun. 1/2



1 mm



1 mm

4

FIGURE 15:

Soot particles from acetylene on the surface; (a) and protruding from the periphery; (b) of a 2 mm waterdrop.

FIGURE 16:

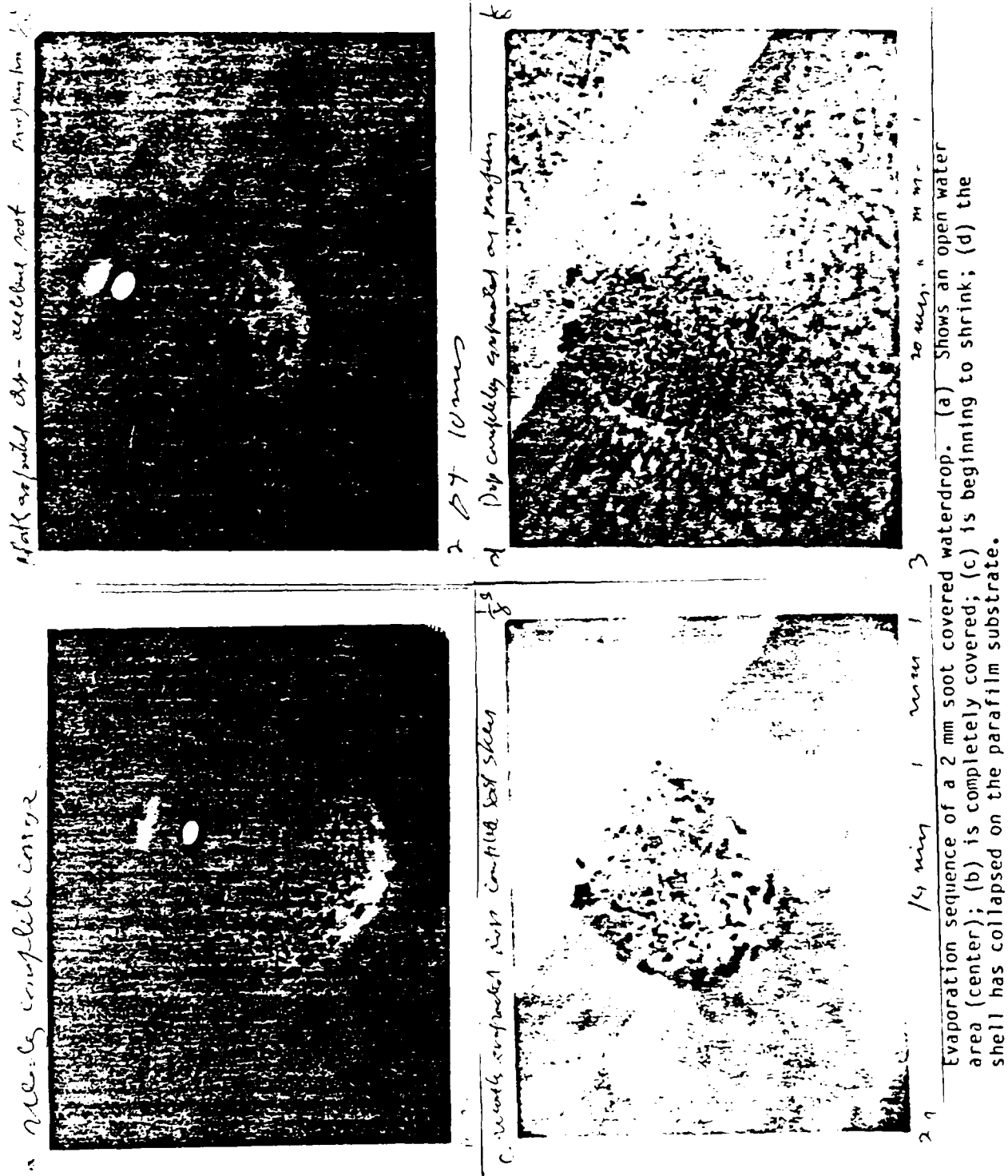
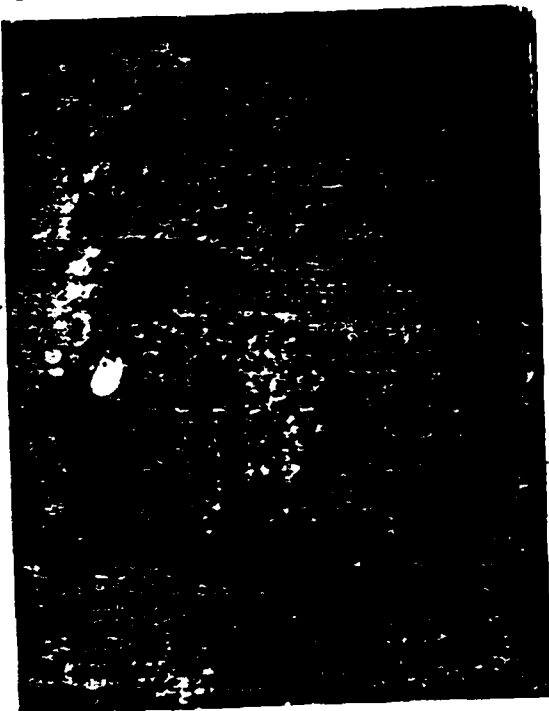


FIGURE 17:

a. *Control No. 5*



5

b. *Control No. 6*



6

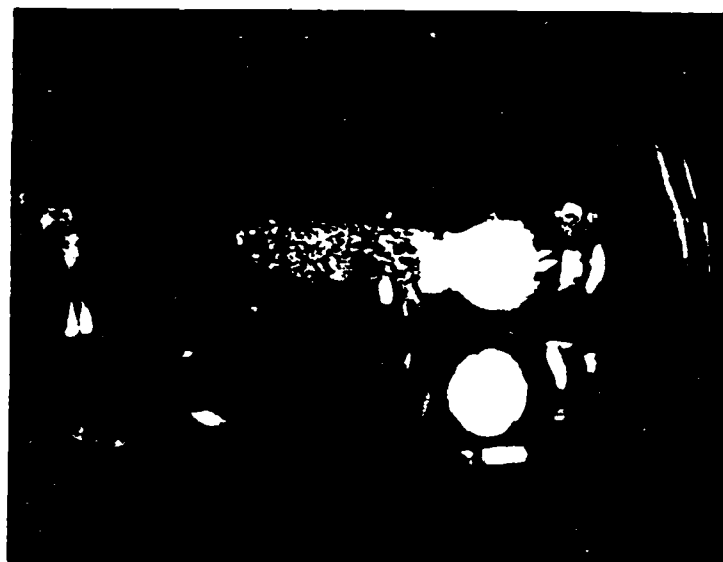
c. *Control No. 7*



7

- a. an open lead produced by a hypodermic needle in a soot covered waterdrop.
- b. The lead persists even after the drop has dried out.
- c. The dried skin is resuspended on another drop but fails to break up.

a



2"

b

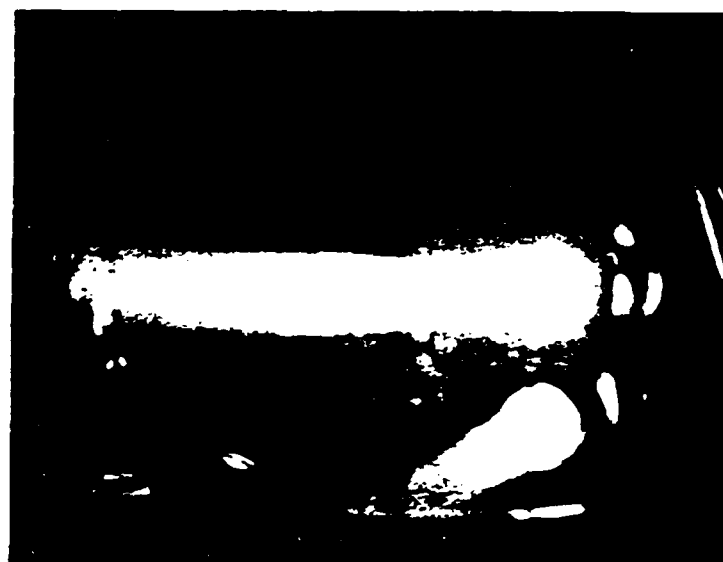


Figure 18 a) Cloud produced on natural aerosol in an expansion cloud chamber.
b) Cloud produced on acetylene soot in an expansion cloud chamber.

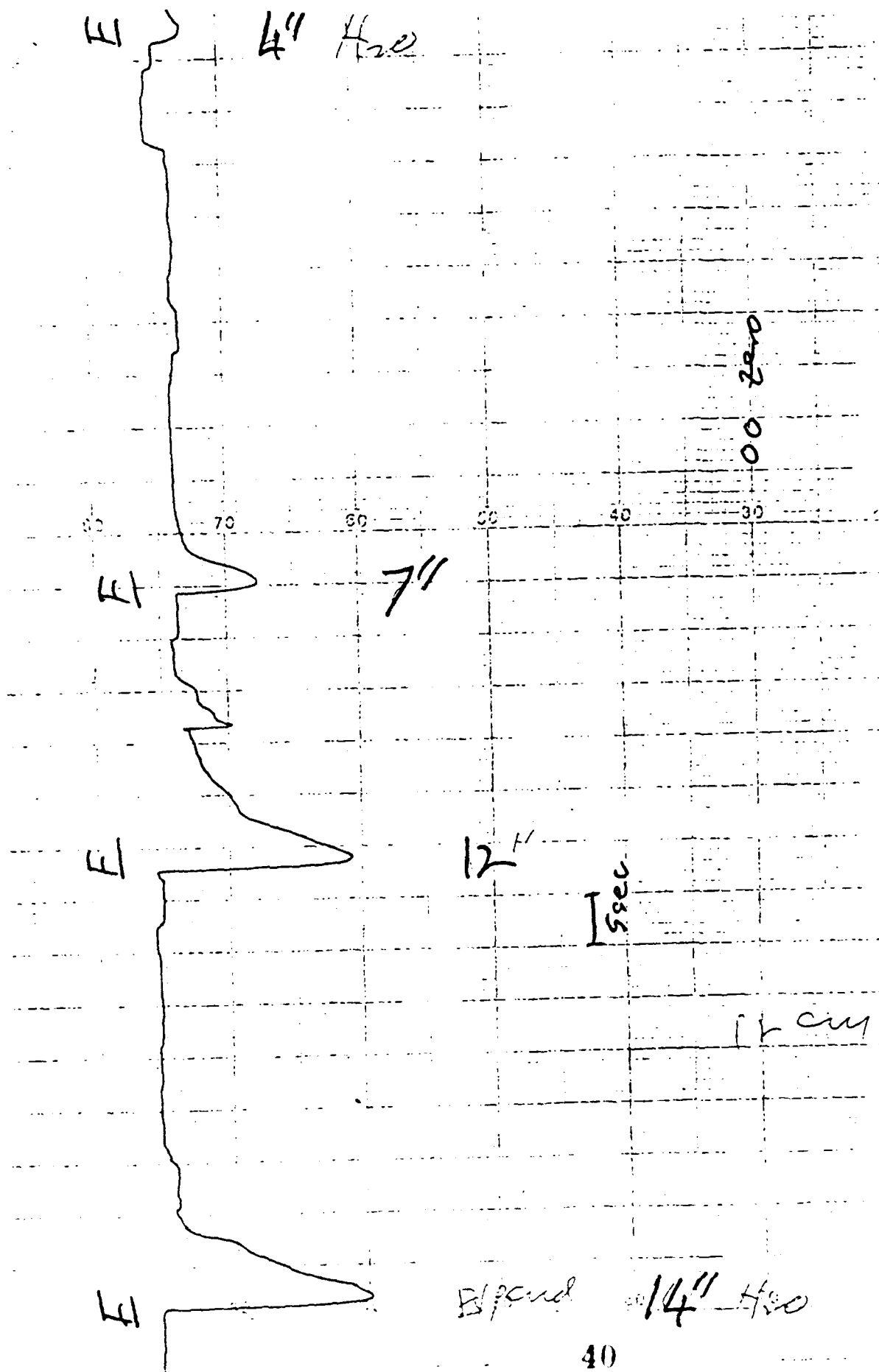


FIG. 19: EXTINCTION MEASUREMENT AFTER EXPANSION AND RECOMPRESSION FOR A ACETYLENE SOOT NUCLEATED WATER CLOUD

SOOT PARTICLE DISTRIBUTION (23-25 OCT '85)

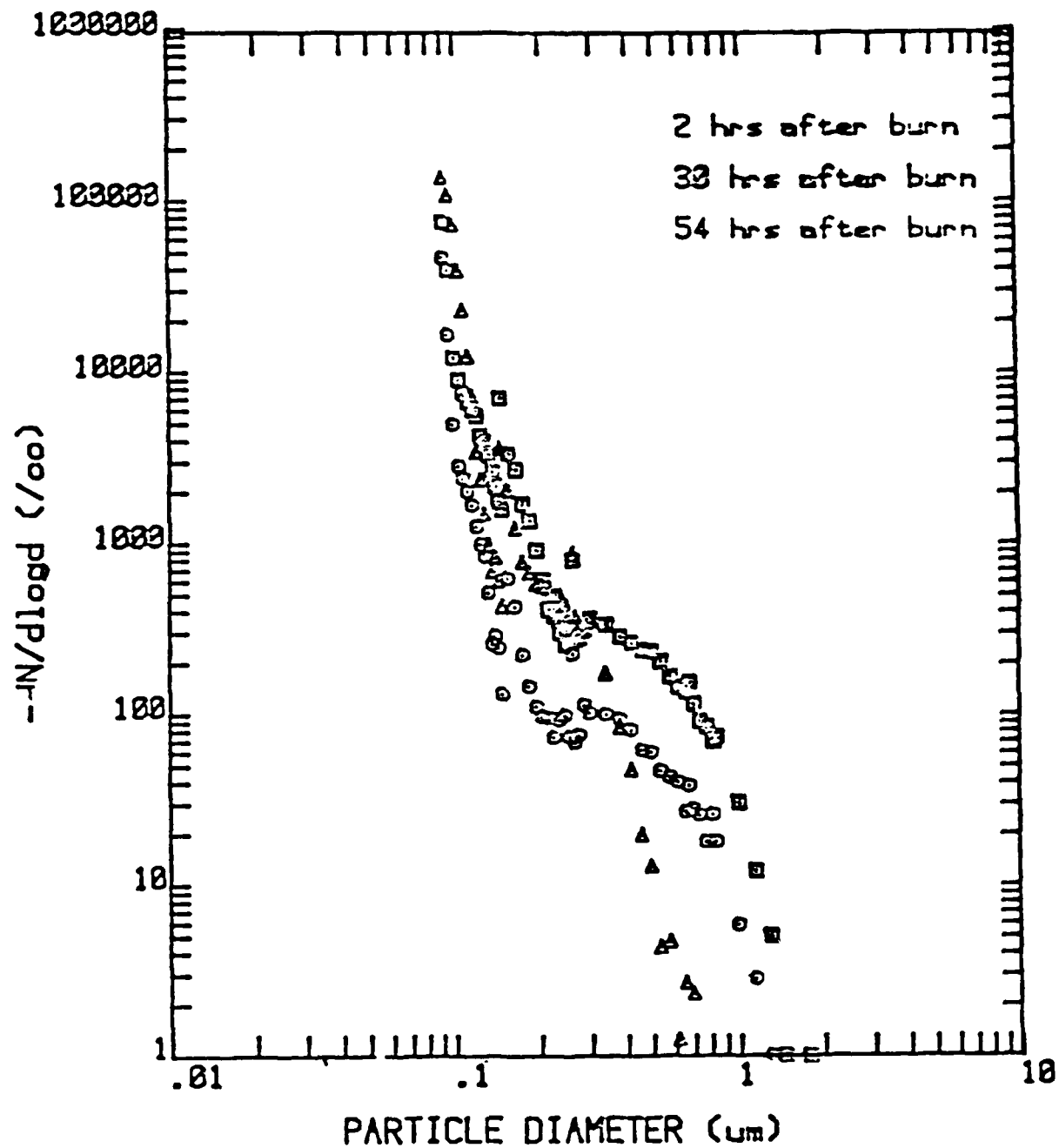
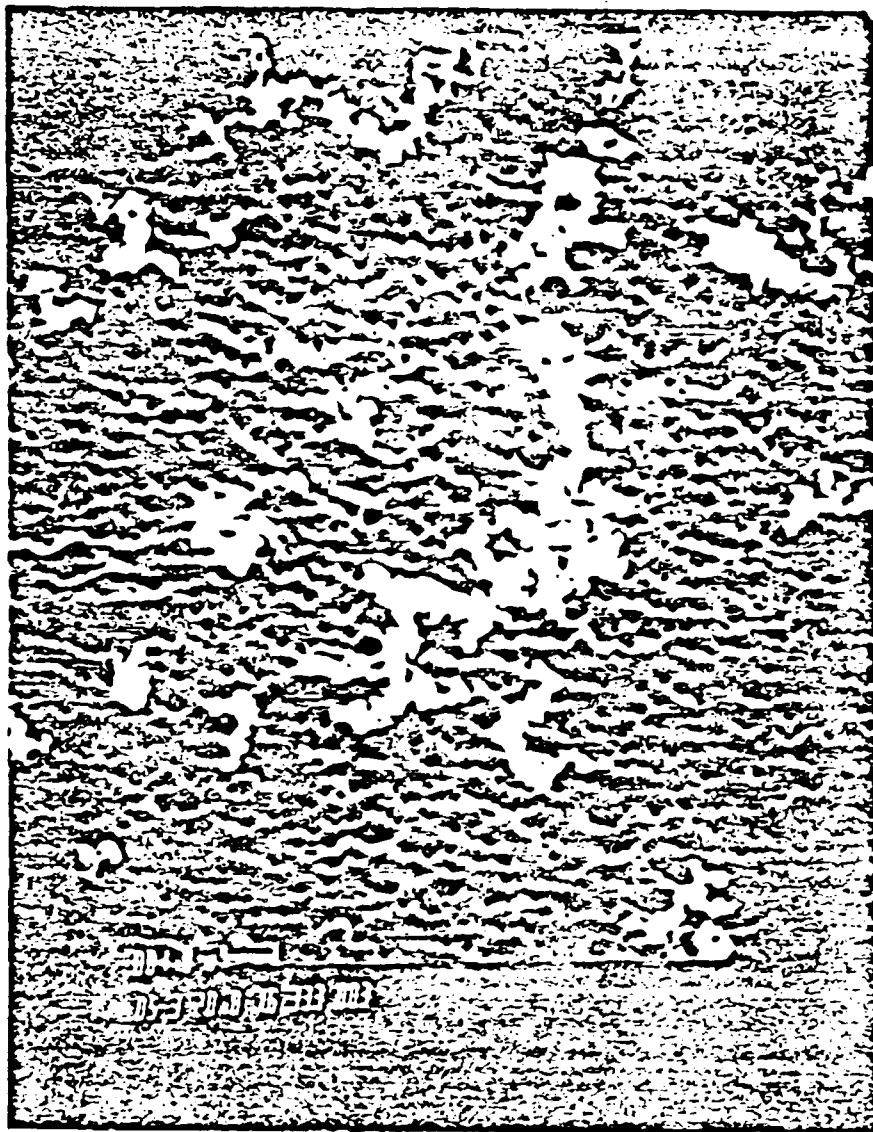


Figure 20: ASASP-X size spectra



FILTER 26

Figure 21: October 23, 1985 sample. Filter exposed
at 5.5 hours, from 8 m³ bag.

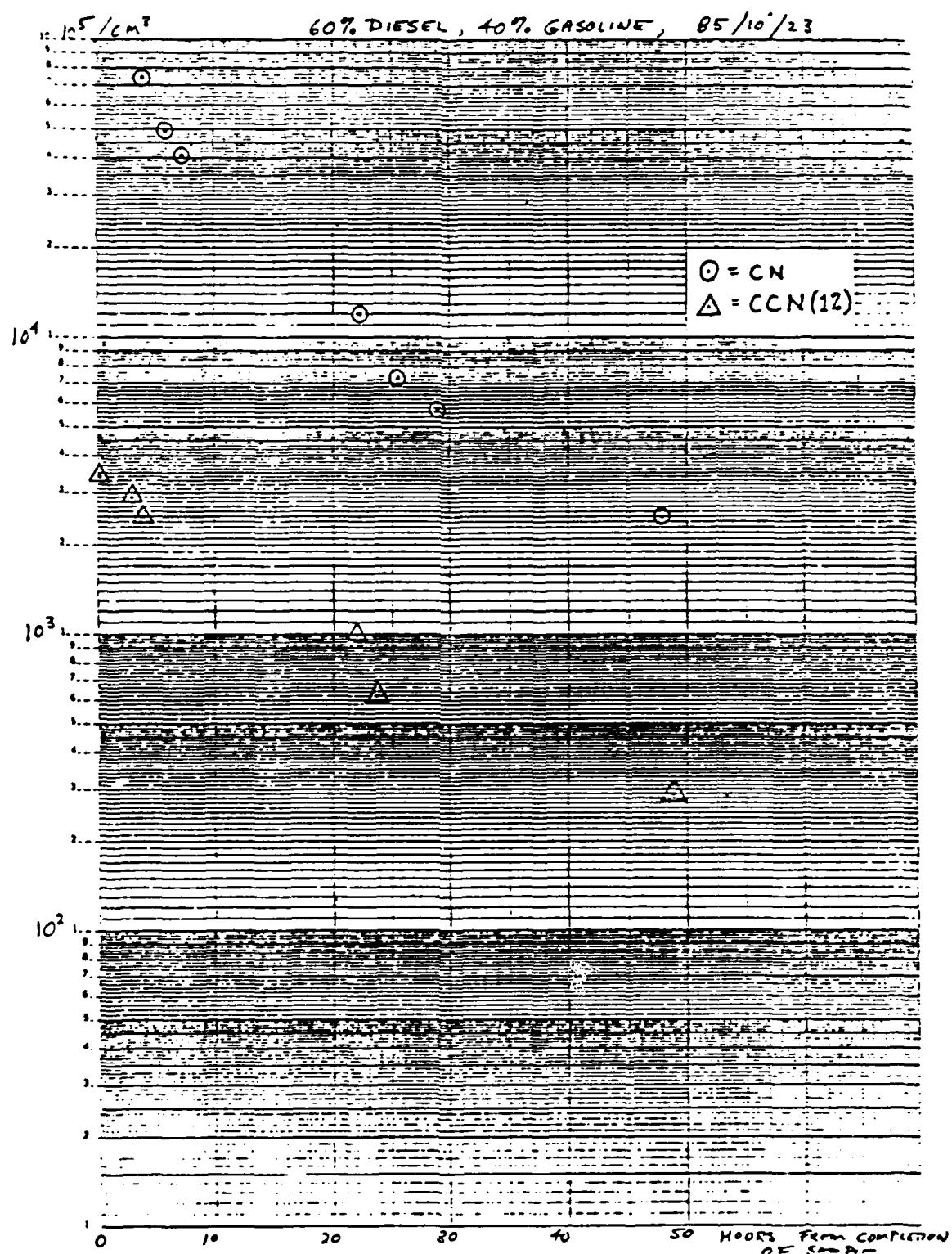


Figure 22: CN and CCN active at 1%; October 23, 1985 sample.

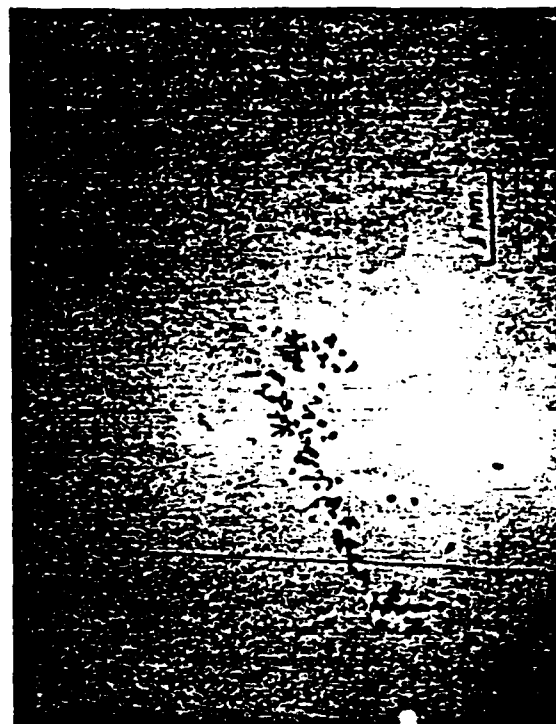
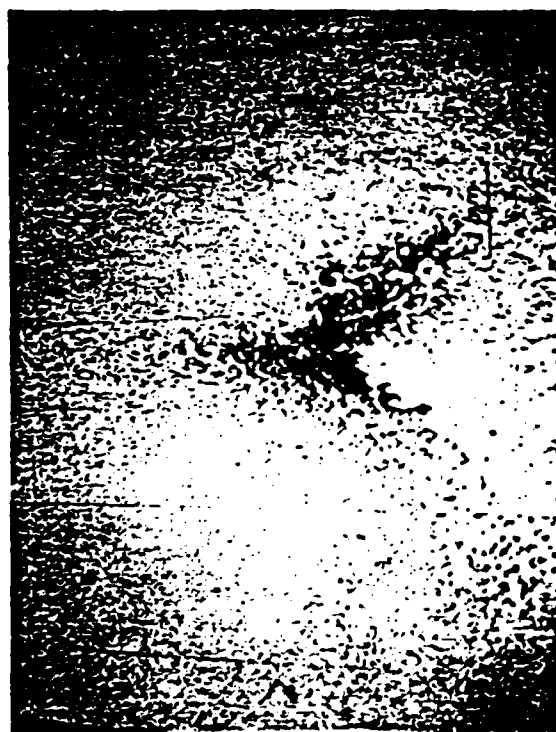


FIGURE 23: SOOT FLAKES FROM ACETYLENE COLLECTED ON FORMVAR
REPLICATOR. LABORATORY TEST.

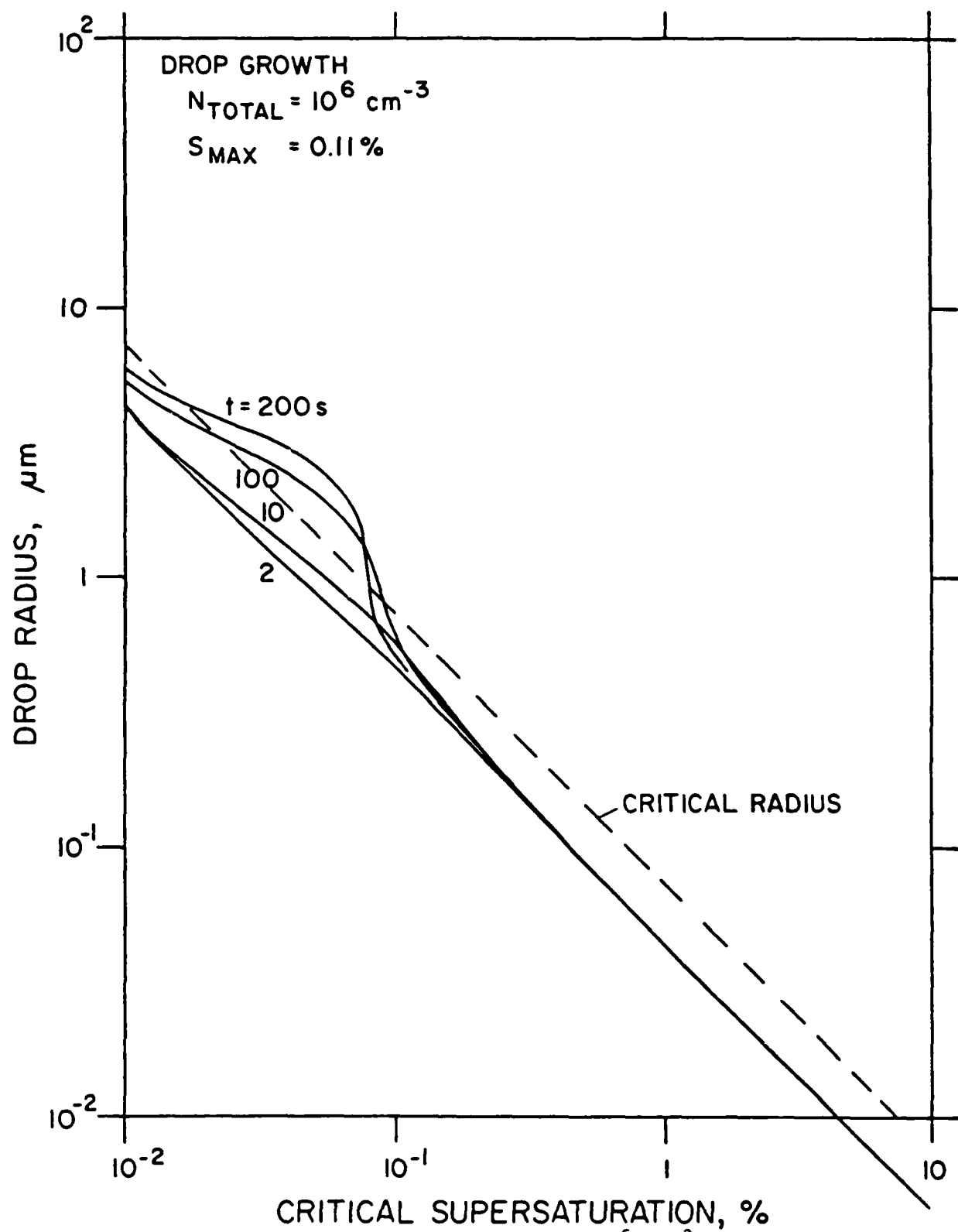


FIG. 24: MODEL DROPLET GROWTH 10^6 cm^{-3}

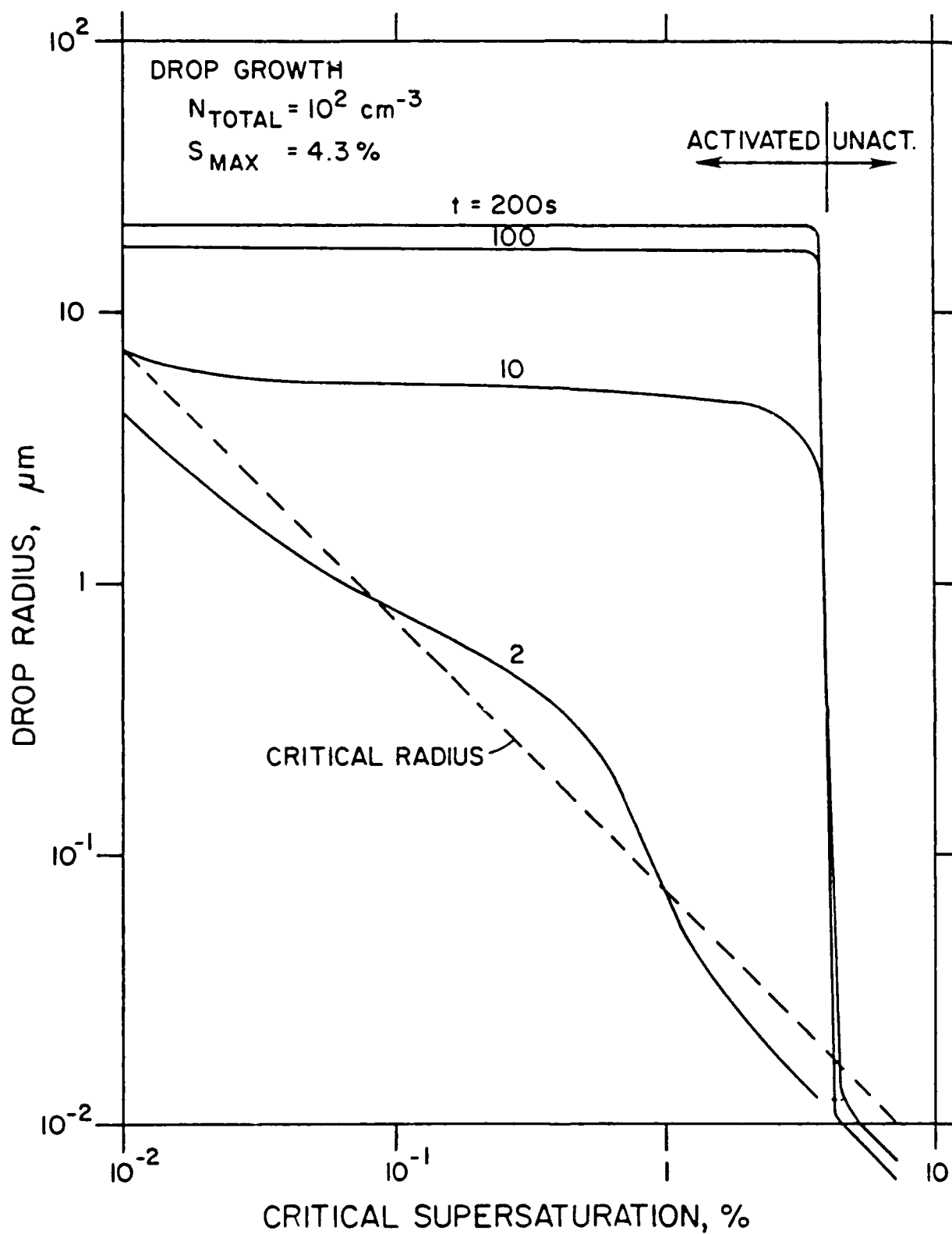


FIG. 25: MODEL DROPLET GROWTH 100 cm^{-3}

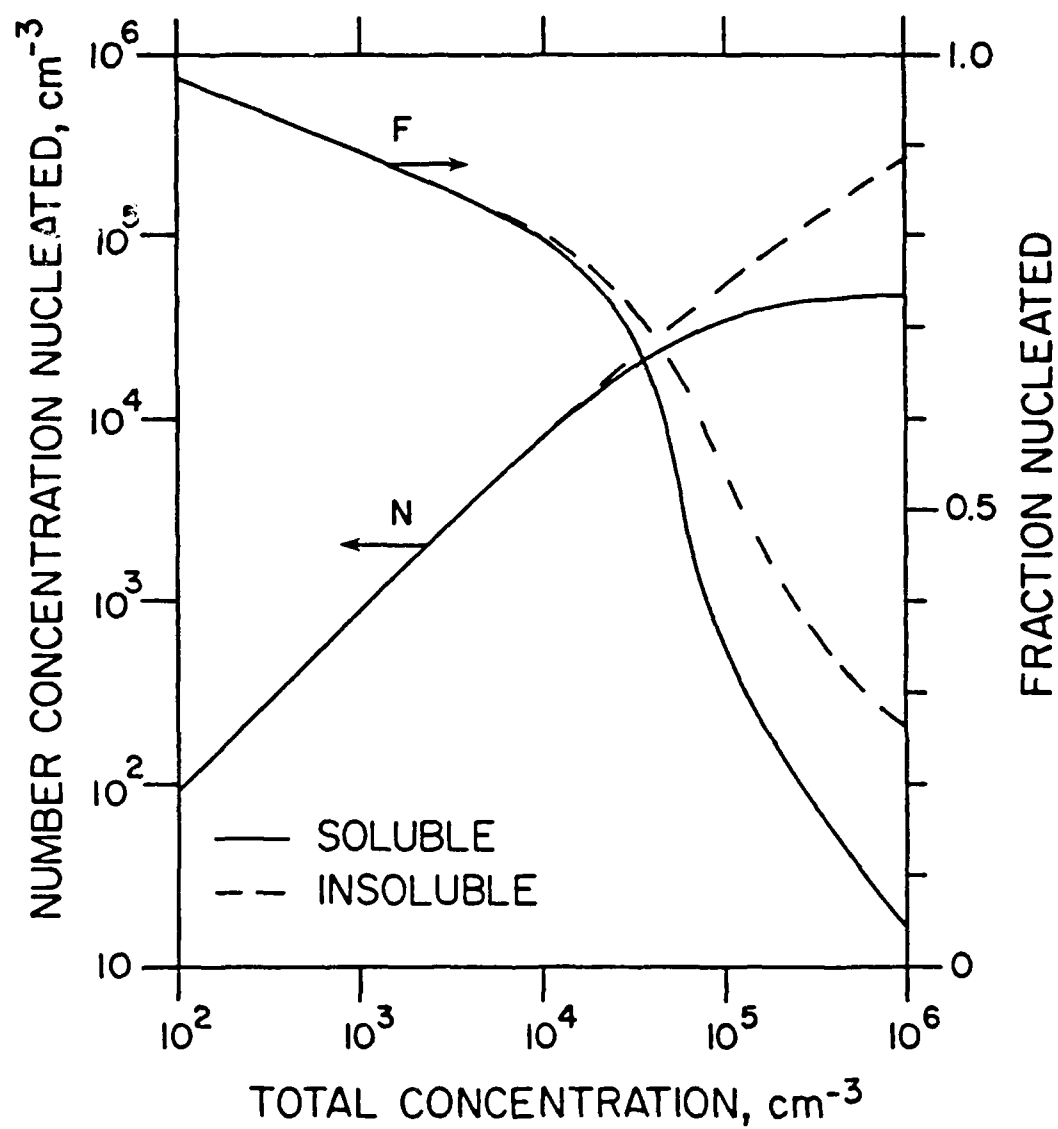


FIG. 26: MODEL NUMBER AND FRACTION ACTIVATED

CONCLUSIONS FROM OUR STUDY:

- 1). Lab/field soot complex; 0.1 to 100 μm .
- 2). Lab soot acetylene/crude oil $\frac{\text{CCN}}{\text{CN}}$ ratio few to 10% increasing with time.
- 3). Ice nucleation unexciting.
- 4). Soot collects on outside of drops mm - 50 μm as evaporation proceeds.
 - (i) Independent particles
 - (ii) lily pads
 - (iii) solidified surface
 - (iv) collapsed soccer ball
 - (v) surface resuspension
- 5). Sooty cloud doesn't change extinction over 10^3s by scavenging.
- 6). CCN - cloud droplets - ice removal or coalescence; only partial pluvial constipation.

FUTURE WORK:

- i. evaporated cloud droplets and soot coagulation.
- ii. scattering + extinction of sooty cloud.
- iii. role of growth/evaporation in scavenging process (a) droplets, (b) ice
- iv. soot in a supercooled cloud - rime growth.

FIELD:

- i. soot from oil fire. CN, CCN, replica.
- ii. cloud droplets on replica, modification and scavenging in cap cloud. (Lodi?)
- iii. deeper cloud and ice role in scavenging. Ice from replica (Chapleau?)

MAJOR PROBLEM:

Firestorm dynamics to give right microphysics for maximum scavenging.

Chemical Scavenging in the Atmosphere: Smoke-Ozone Reactions.

N. deHaas, R. M. Fristrom, M. J. Linevsky and D. M. Silver
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Laurel, Maryland 20707

ABSTRACT

A laboratory apparatus has been constructed to examine the reaction of smoke particles with ozone. A stopped-flow experimental procedure has been developed that permits (1) a measurement of the total extinction of a He-Ne laser beam by ozone (Chappuis band) and/or by various sub-micron smoke particles; (2) a measurement of the right-angle scattering of a Nd-Yag laser by the smoke particles; and (3) a sampling of particulates for examination under the scanning electron microscope. Ozone (without smoke) is stable in the apparatus over a period of hours; smoke (without ozone) is also stable over a period of hours. Smoke-ozone mixtures begin decaying immediately and, under the experimental conditions employed, they have half-lives of a half-hour to two hours depending on the fuel source of the smoke particles. Specifically, the half-life is defined to be the time in which the optical extinction at 6328 Å is reduced to one-half its initial value. Translating these results to "nuclear winter" atmospheric conditions yields half-lives in the range of a month. These experiments provide solid qualitative evidence for the existence of atmospheric chemical scavenging of smoke and ozone.

This work was supported in part by the Naval Sea Systems Command under Contract N00024-85-C-5301.

Submitted for presentation at the DNA Global Effects Program Technical Meeting, 25-27 February 1986 by D. M. Silver, (301) 953-6265.

TABLE V - SOOT CLOUD SCAVENGING (LIMITED BY TURBULENT ENTRAINMENT WHICH
IN TURN IS DIFFUSION LIMITED BELOW THE MINIMUM MIXING SCALE LENGTH)

Alt (Km)	$t_{1/2} (O_3)$ Scale 1 Meter sec	$t_{1/2} (O_3)$ Scale 10 Meters sec
8	1170	1.2×10^5 (1 1/2 da)
10	500	5×10^4 (1 1/2 da)
12	160	1.6×10^4 (5 hrs)

1/2 Number of C atoms in Minimal Eddy

$$t_{1/2} = \frac{\text{Minimal Eddy Area} \cdot \text{Diffusion Velocity} \cdot \text{Concentration} \cdot \text{Reaction Probability}}{1/2 v_E \cdot f \cdot N_T}$$

$$t_{1/2} = \frac{1/2 v_E \cdot f \cdot N_T}{A_E \cdot v_D \cdot N_i}$$

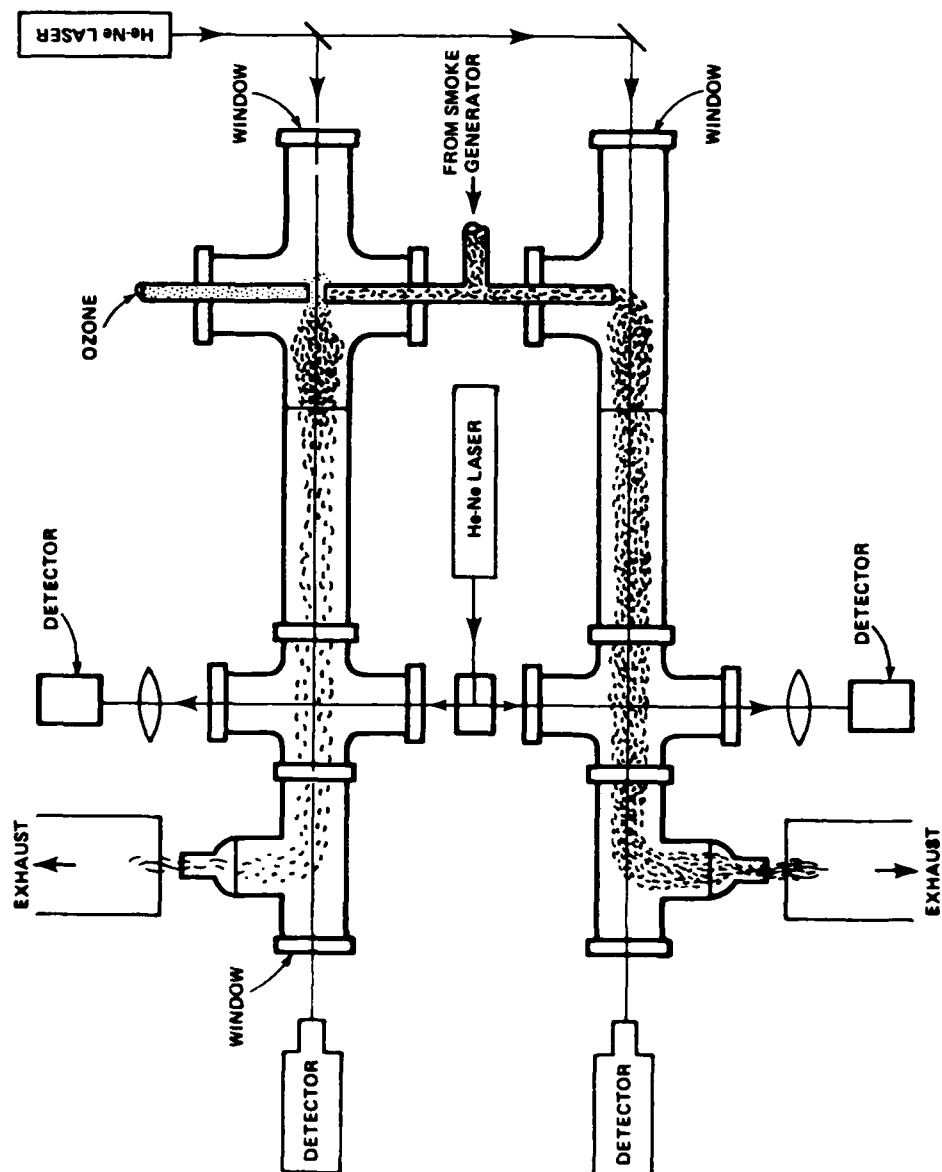
$$t_{1/2} = 1 \times 10^{-4} p \cdot (300/T)^{1.67} \cdot n_T/n_i \cdot d_E^2$$

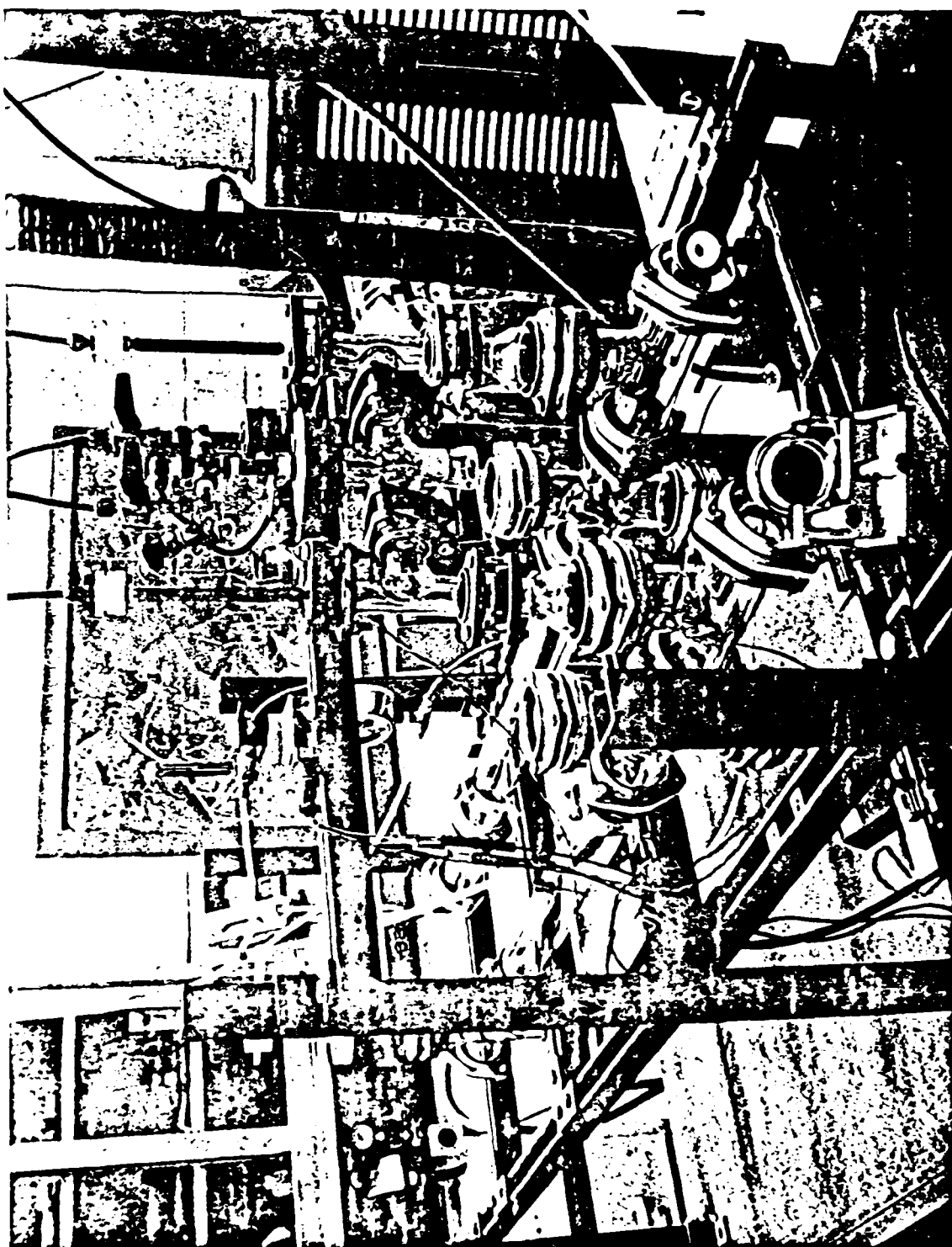
$$v_E/A_E = d_E/6$$

$$f = 4.8 \times 10^{-3} \text{ (Ref. C. Fenimore, Chemistry of Premixed Flames, Pergamon (1964) p. 65)}$$

$$v_D = 2D_i/L_c = \left(\frac{2D_0}{P_{LC}}\right) \left(\frac{T}{300}\right)^{1.67}$$

SMOKE-OZONE APPARATUS





Smoke - Ozone Apparatus



Cellulosic Smoke (SEM 3600 x)



Xylenic Smoke (SEM 3600x)

Transmission of light through smoke column

$$I = I_0 \exp(-a b c_s)$$

a = extinction coefficient

b = length of smoke column

c_s = concentration of smoke

$\ln(I_0/I)$ is linearly proportional to
smoke concentration

$$\ln(I_0/I) = a b c_s$$

Rate of disappearance of smoke

$$-\frac{dC_s}{dt} = k C_o C_s$$

k is second-order rate constant

C_o is concentration of ozone

C_s is concentration of smoke

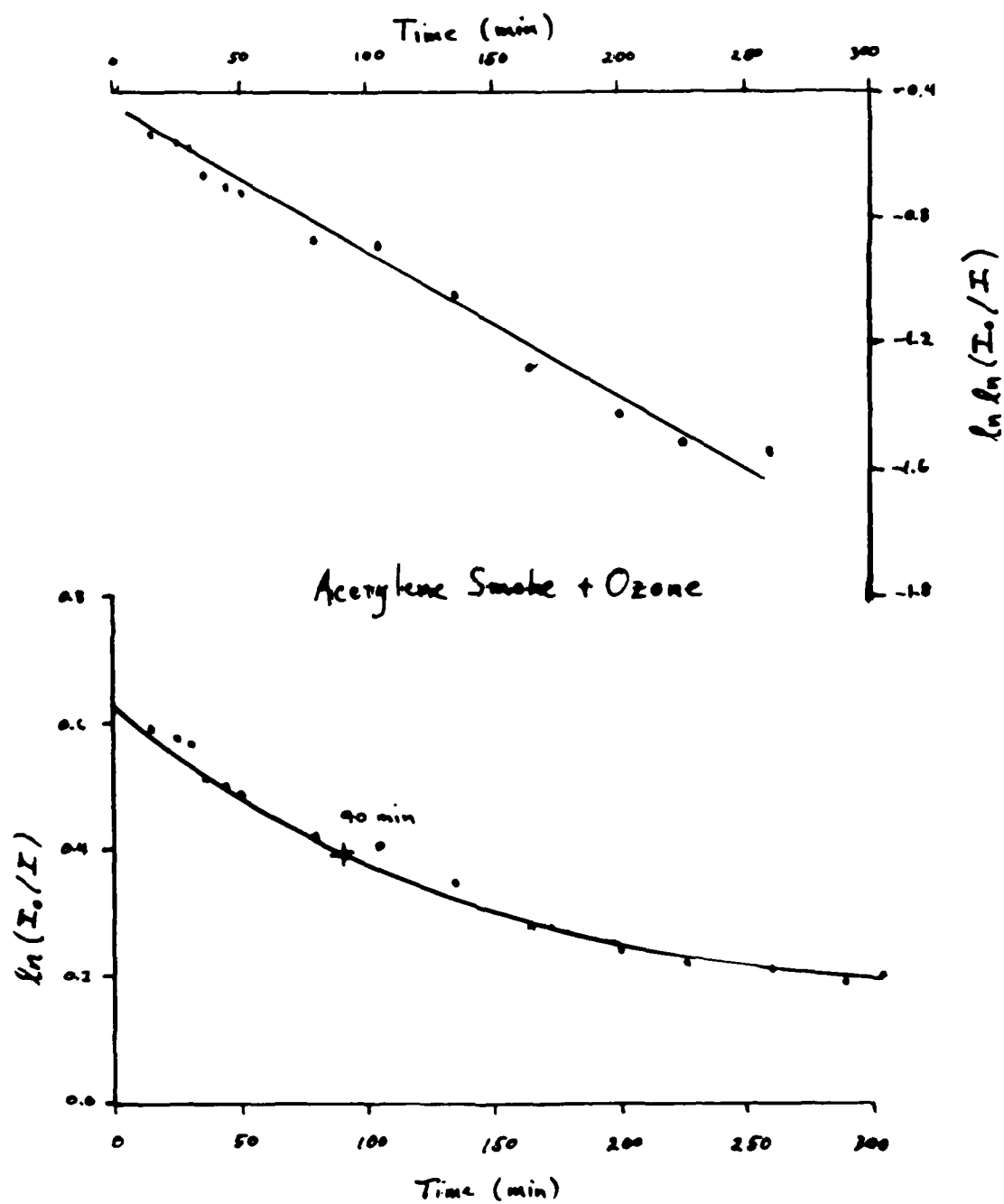
With excess ozone, rate is pseudo first-order in smoke concentration: (C_o assumed constant)

$$\therefore C_s = A \exp(-k C_o t)$$

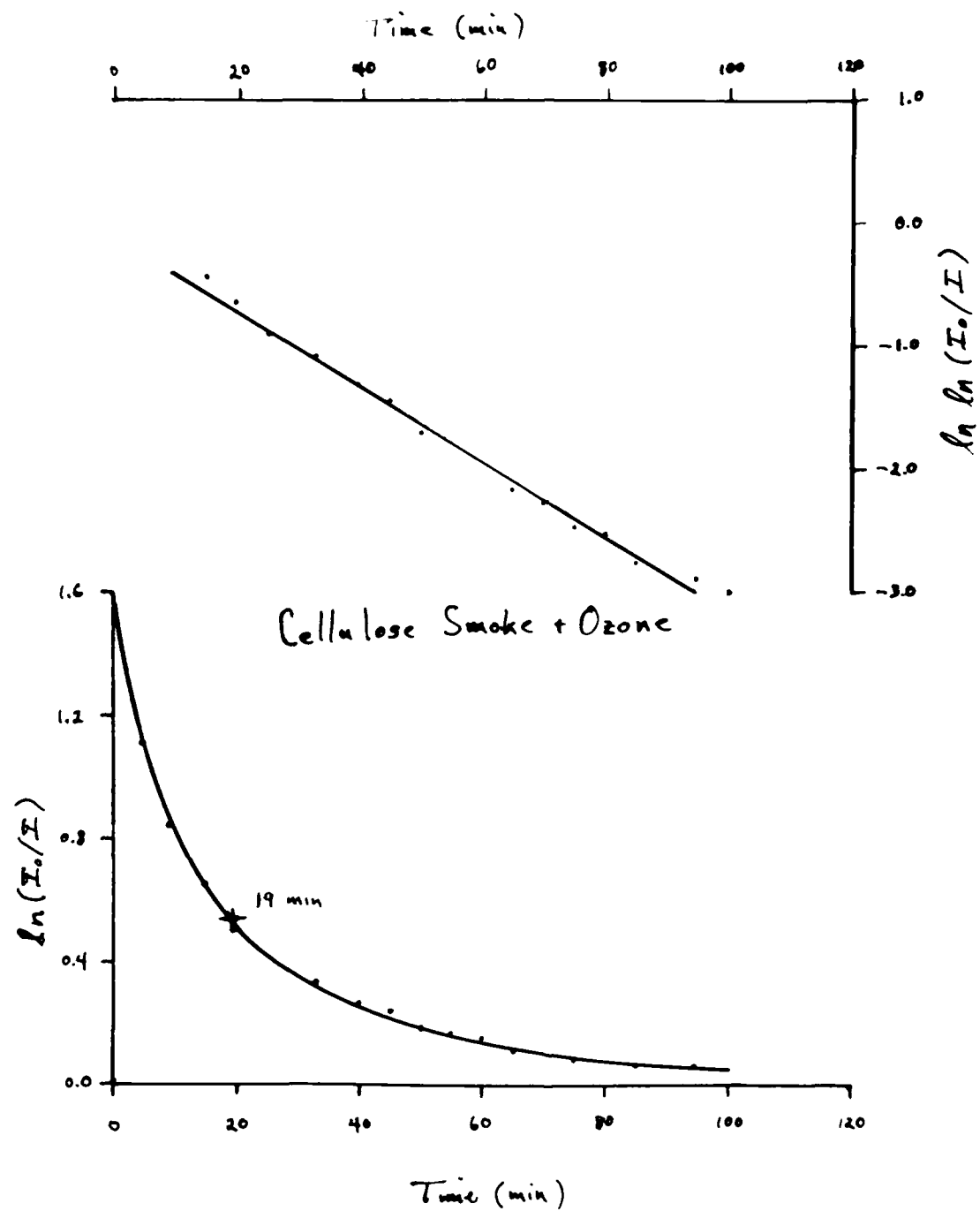
But $\ln(I_o/I)$ is proportional to C_s

$$\therefore \ln \ln(I_o/I) = A' - k C_o t$$

is., linearly proportional to time
if the reaction is pseudo
first-order in smoke concentration



1.24



1.20

Ozone (without smoke) is stable in apparatus over a period of hours (no change in absorption in the Chappuis bands).

Smoke (without ozone) is stable in apparatus over a period of hours (no change in optical extinction at $6328 \text{ \AA}$).

Smoke-ozone mixtures show a time-dependent decay in optical extinction at $6328 \text{ \AA}$

- Half-life depends on source of smoke
- Kinetics appear to have first-order dependence on smoke concentration

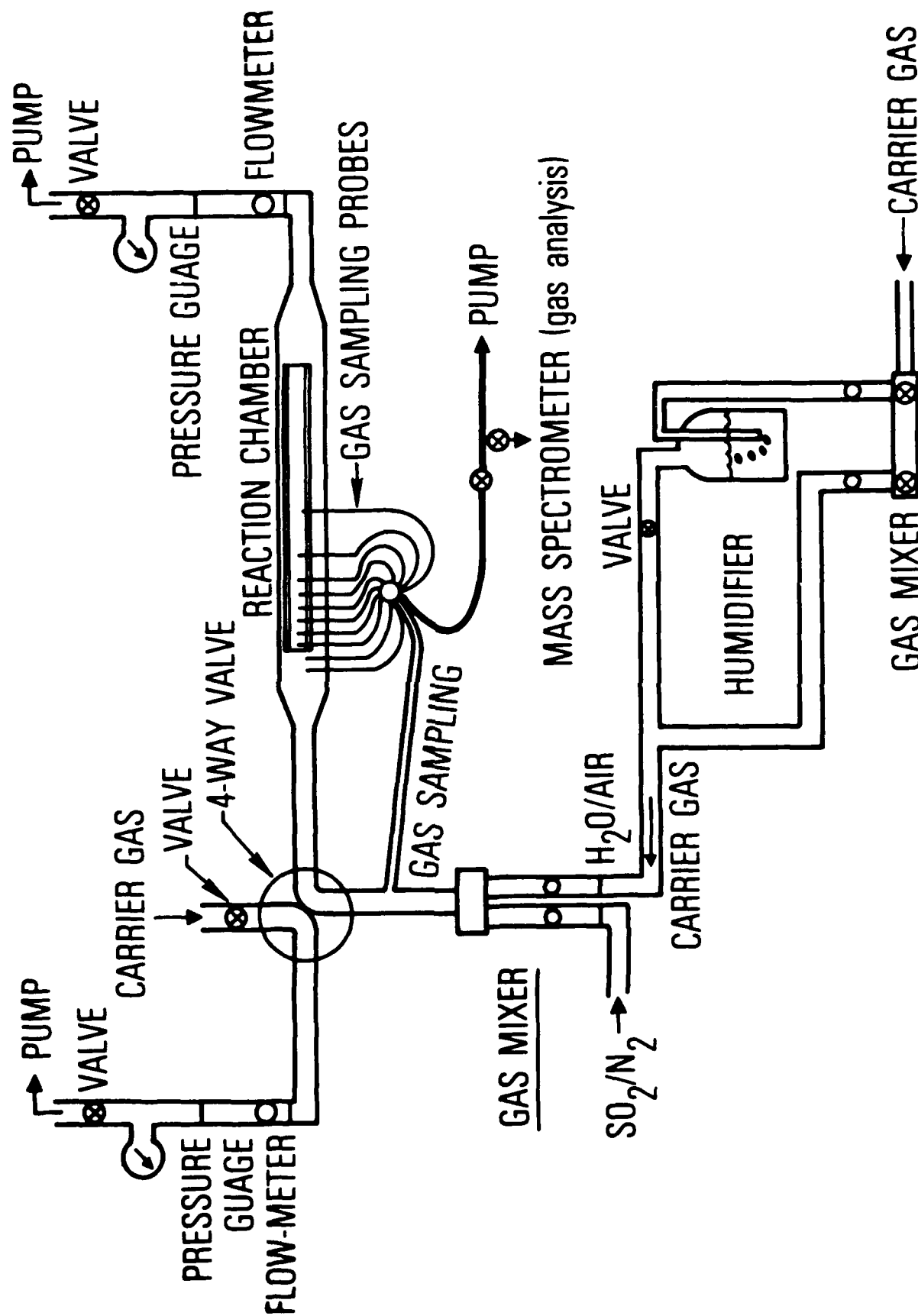
Translated to "nuclear winter" atmospheric conditions, optical extinction is estimated to be reduced to one-half its initial value in a time range of a month.

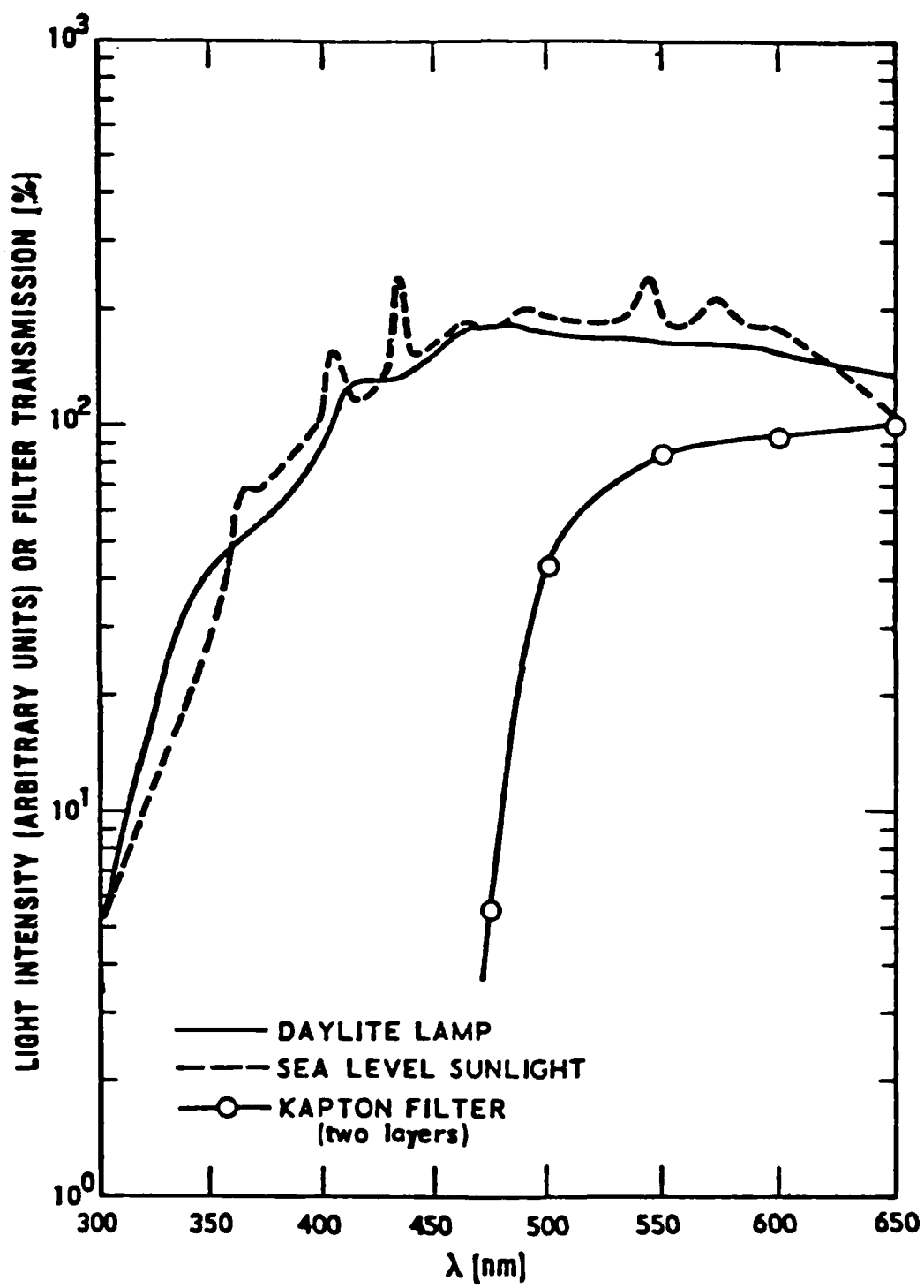
REACTION OF STRATOSPHERIC CARBON AEROSOL WITH OZONE

L. R. MARTIN, H. S. JUDEIKIS, R. B. COHEN

THE AEROSPACE CORPORATION







CHEMICAL ANALYSES

- GAS PHASE
 - ON-LINE MASS SPEC
 - CO, CO₂, OTHERS
- ADSORBED PRODUCTS
 - DESORPTION AND MASS SPEC
 - DISSOLUTION AND HPLC

$$D \left(\frac{\partial^2 C}{\partial R^2} + \frac{1}{R} \frac{\partial C}{\partial R} + \frac{\partial^2 C}{\partial Z^2} \right) - V_Z \frac{\partial C}{\partial Z} = 0$$

WHERE

$$C = \frac{[SO_2]}{[SO_2]_0}$$

BOUNDARY CONDITIONS

$$C = 1 \quad \text{AT} \quad Z = 0$$

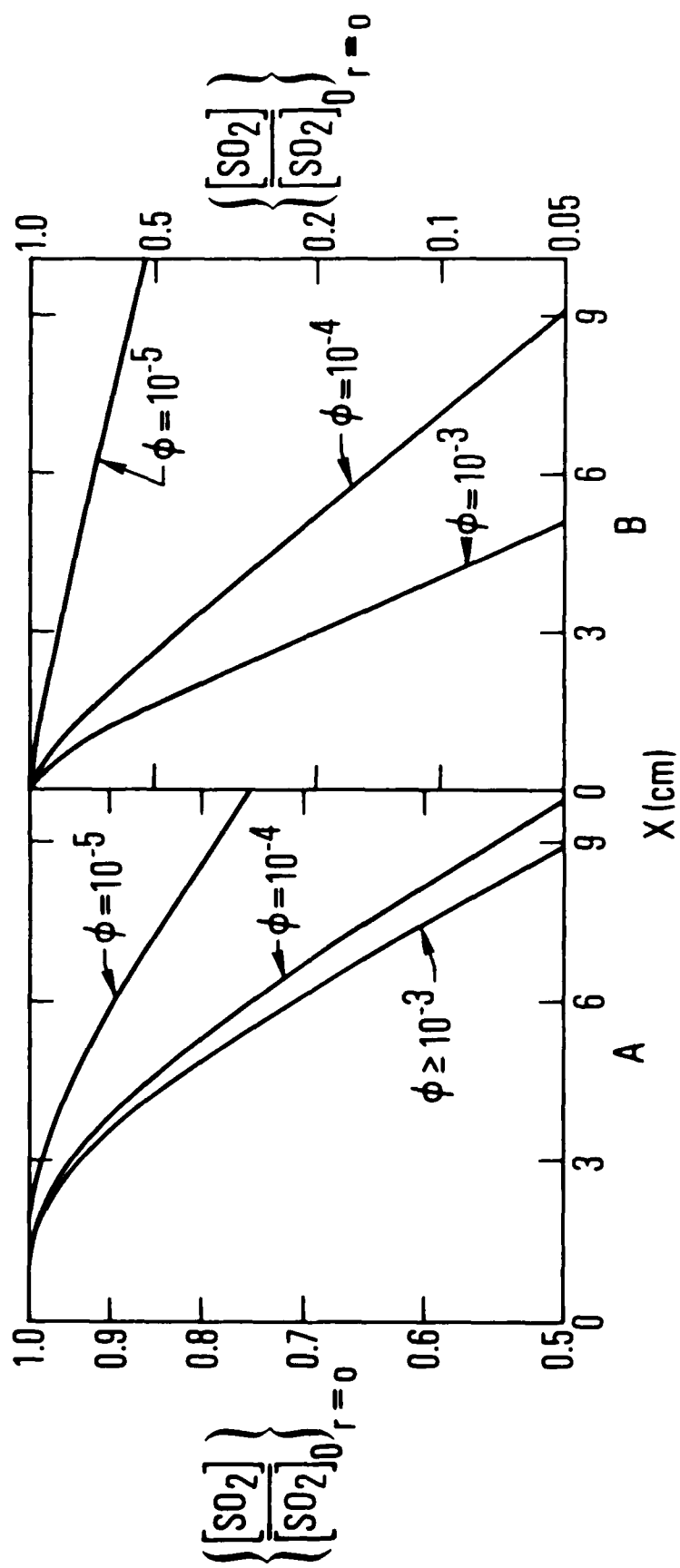
$$C = 0 \quad \text{AT} \quad Z = \infty$$

$$\frac{\partial C}{\partial R} = 0 \quad \text{AT} \quad R = 0$$

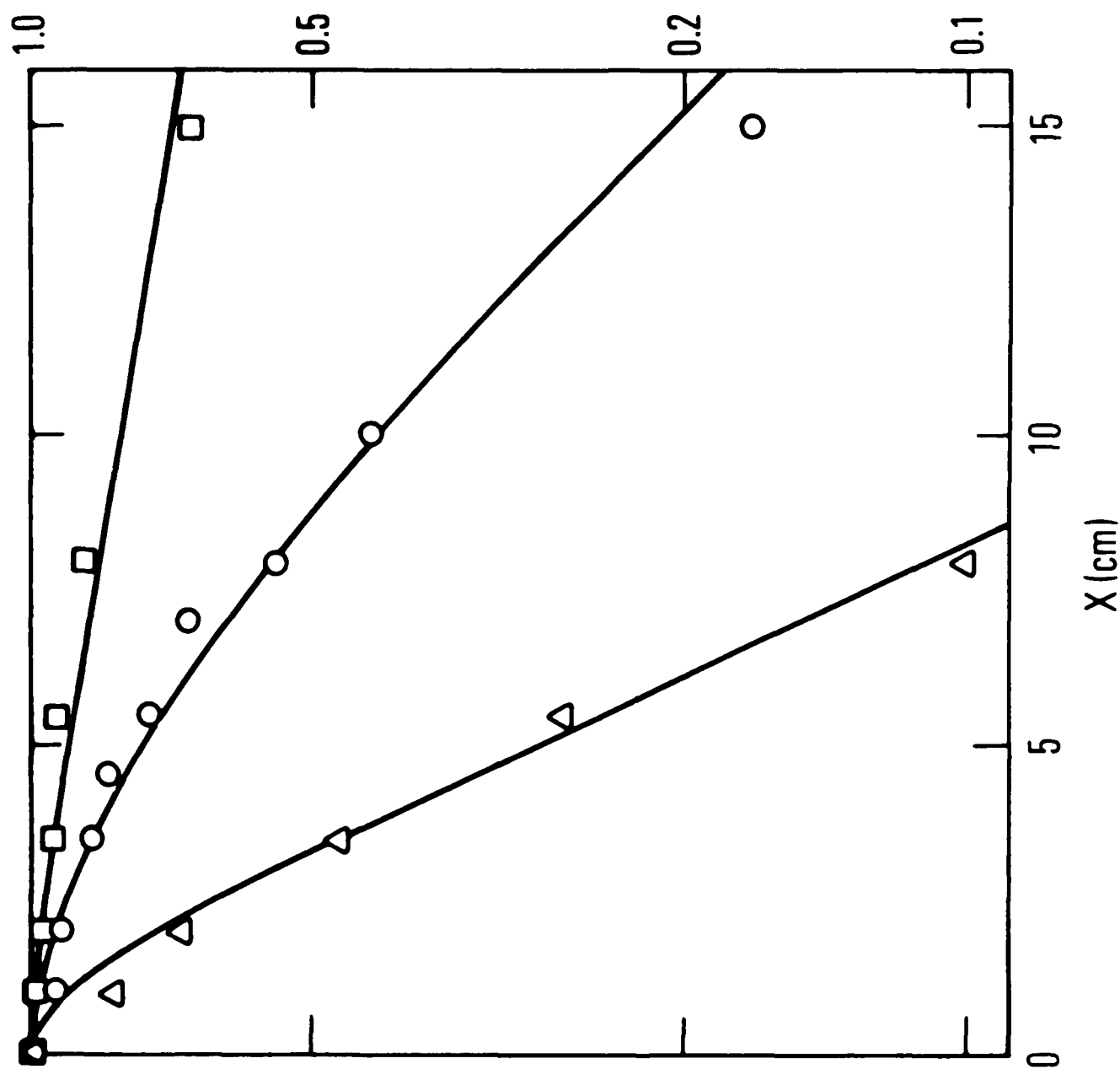
$$D \frac{\partial C}{\partial R} = \phi K_R C \quad \text{AT} \quad R = R$$

GENERAL SOLUTION

$$C = \sum_1 F_1(R) E^{-\beta_1 Z}$$



$$\left\{ \left\{ \frac{[SO_2]}{[SO_2]_0} \right\}_{r=0} \right\}$$



ATMOSPHERIC MODEL

$$\text{AEROSOL REACTION RATE} = \frac{3 \text{ AD}}{R^2} \quad G \text{ C}_{\text{O}_3}$$

$$G = 1 \left[+ K_N \left(\frac{1.33 + 0.7 K_N^{-1}}{1 + K_N} + \frac{4}{3} \frac{1-\gamma}{\gamma} \right) \right]^{-1}$$

FOR $K_N \gg 1$

$$\frac{C}{C_0} = (1 - 0.009 \frac{\gamma}{R_0} \tau)^3$$

$$\frac{R}{R_0} = (1 - 0.009 \frac{\gamma}{R_0} \tau)$$

AEROSOL DESTRUCTION

	DESTRUCTION TIME FOR R_0 (μ) =		
γ	0.1	0.2	0.5
10^{-3}	3 HR	6 HR	15 HR
10^{-4}	1 DAY	2 DAYS	5 DAYS
10^{-5}	13 DAYS	26 DAYS	65 DAYS
10^{-6}	4 MOS.	8 MOS.	20 MOS.
10^{-7}	4 YRS.	8 YRS.	20 YRS.

AEROSOL DESTRUCTION

$$D_0 = 0.3 \mu$$

$$\gamma = 1 \times 10^{-5}$$

$$O_3 = 3 \times 10^{12}/cc$$

<u>T (DAYS)</u>	<u>AEROSOL RADIUS (μ)</u>	<u>% AEROSOL MASS REMAINING</u>
0	0.30	100.00
3	0.28	78.44
6	0.25	60.22
9	0.23	45.07
12	0.21	32.70
15	0.18	22.83
18	0.16	15.18
21	0.14	9.46
24	0.11	5.40
27	0.09	2.70
30	0.07	1.10
33	0.04	0.30
36	0.02	0.03
39	0.00	0.00

**HETEROGENEOUS REACTIONS
IN A SOOT LADEN ATMOSPHERE**

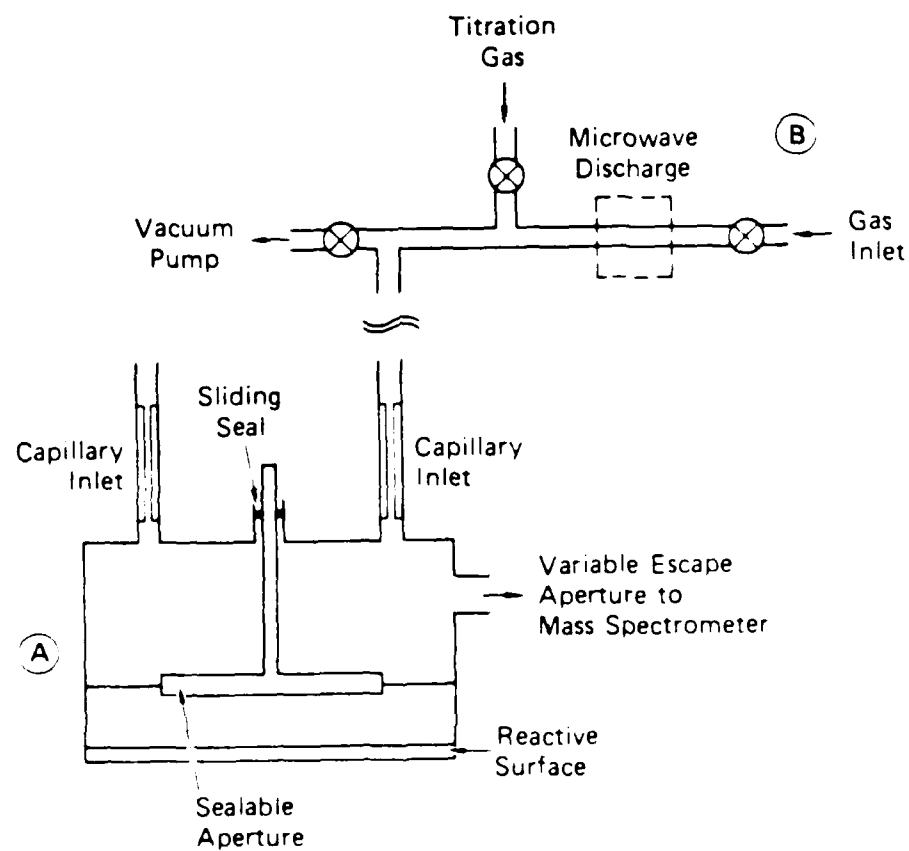
DAVID M. GOLDEN

MICHEL J. ROSSI

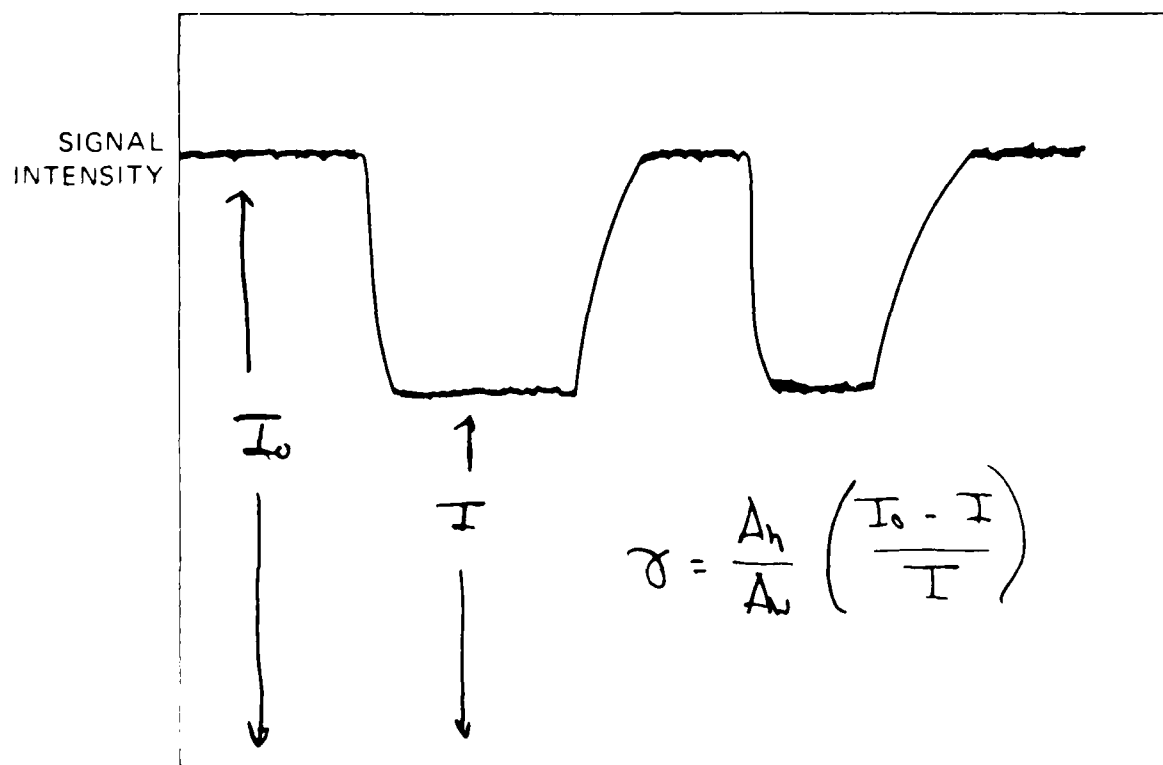
LUDWIG BROUWER

SHERRY STEPHENS

**DEPARTMENT OF CHEMICAL KINETICS
CHEMICAL PHYSICS LABORATORY
SRI INTERNATIONAL**



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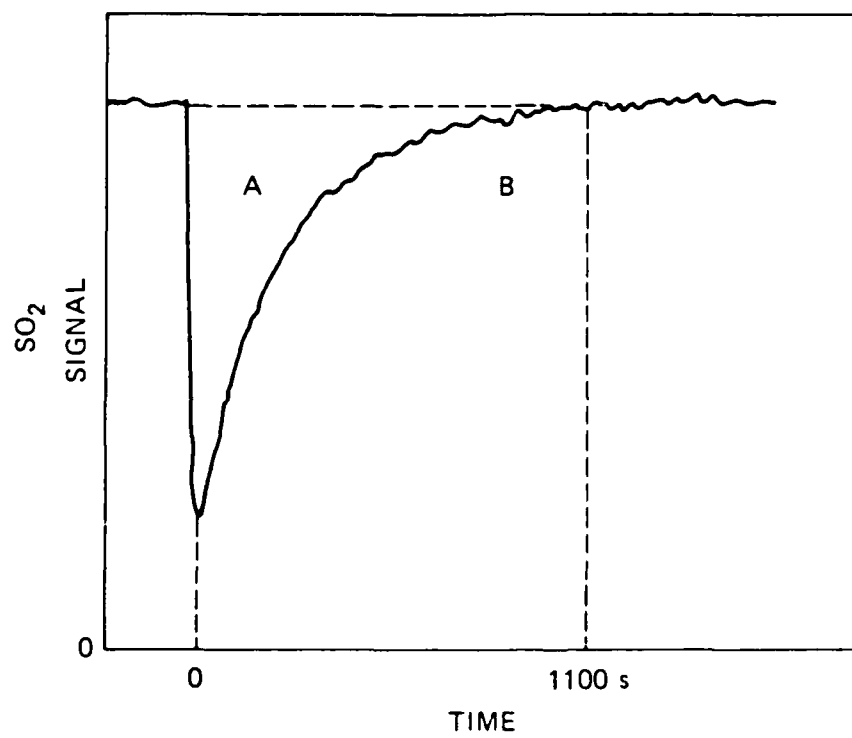


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FIGURE TYPICAL EXPERIMENTAL DATA

Table 1. Collisional reaction probabilities on a H_2SO_4 surface at 300 K.

Species	Collisional reaction probability (γ)
H_2O_2	7.8×10^{-4}
HNO_3	$\geq 2.4 \times 10^{-4}$
HO_2NO_2	2.7×10^{-5}
ClONO_2	1.0×10^{-5}
N_2O_5	$\geq 3.8 \times 10^{-5}$
H_2O	$\sim 2.0 \times 10^{-3}$
NH_3	$> 1.0 \times 10^{-3}$
OH	4.9×10^{-4}
O_3	$< 1.0 \times 10^{-6}$
NO	$< 1.0 \times 10^{-6}$
NO_2	$< 1.0 \times 10^{-6}$
SO_2	$< 1.0 \times 10^{-6}$
Alkenes	$< 1.0 \times 10^{-6}$
Alkanes	$< 1.0 \times 10^{-6}$
CF_4	$< 1.0 \times 10^{-6}$
CCl_2F_2	$< 1.0 \times 10^{-6}$
$\text{O}(^3\text{P})$	$< 1.0 \times 10^{-6}$
N	$< 1.0 \times 10^{-6}$

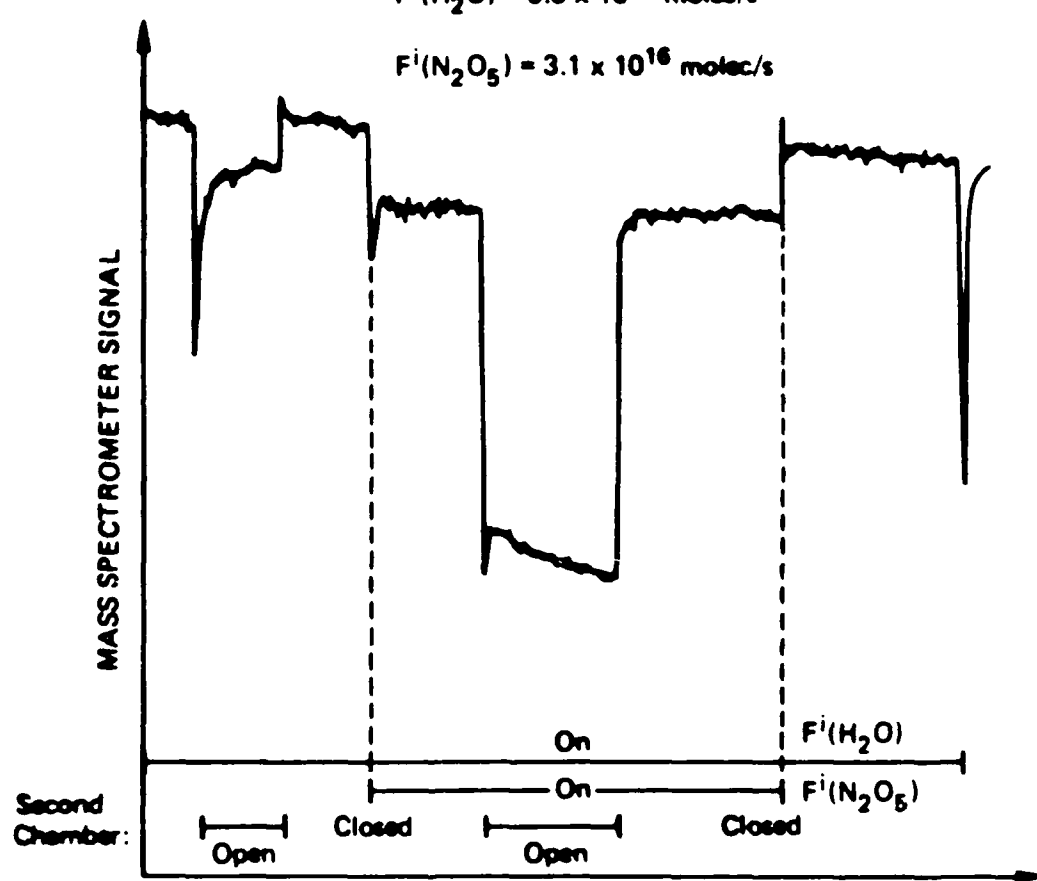


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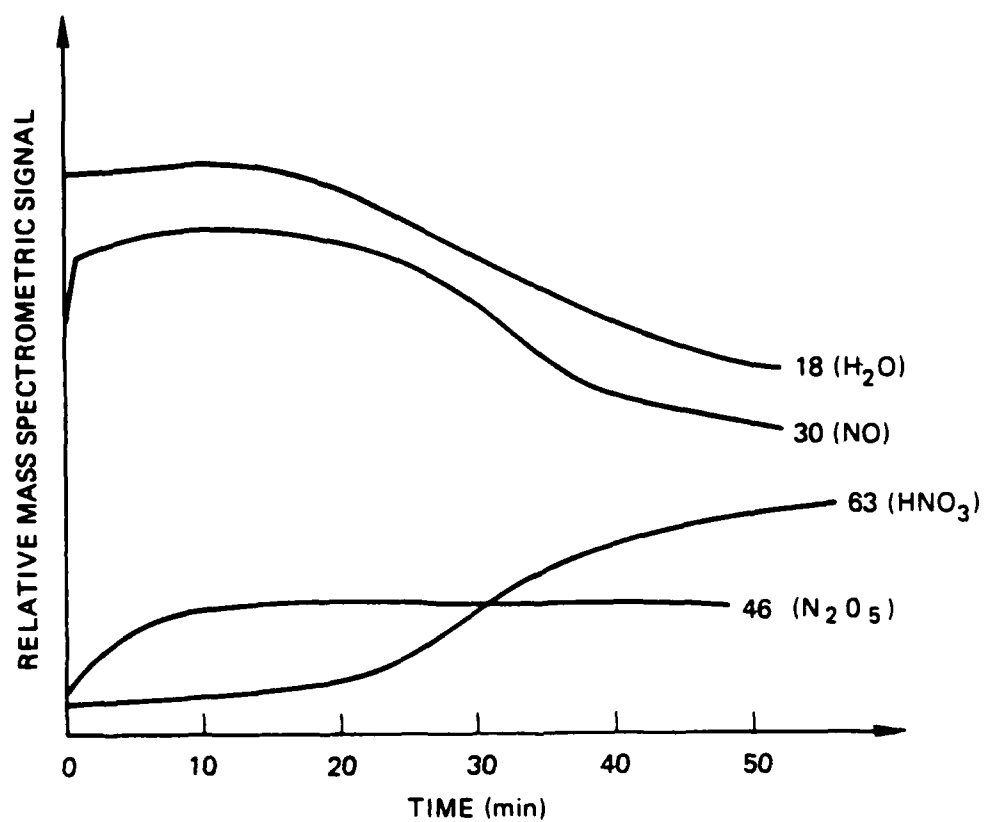
**H₂O MASS SPECTROMETER SIGNAL (m/e = 18) IN THE SYSTEM
N₂O₅/H₂O ON CARBON**

$$F^i(\text{H}_2\text{O}) = 5.8 \times 10^{15} \text{ molec/s}$$

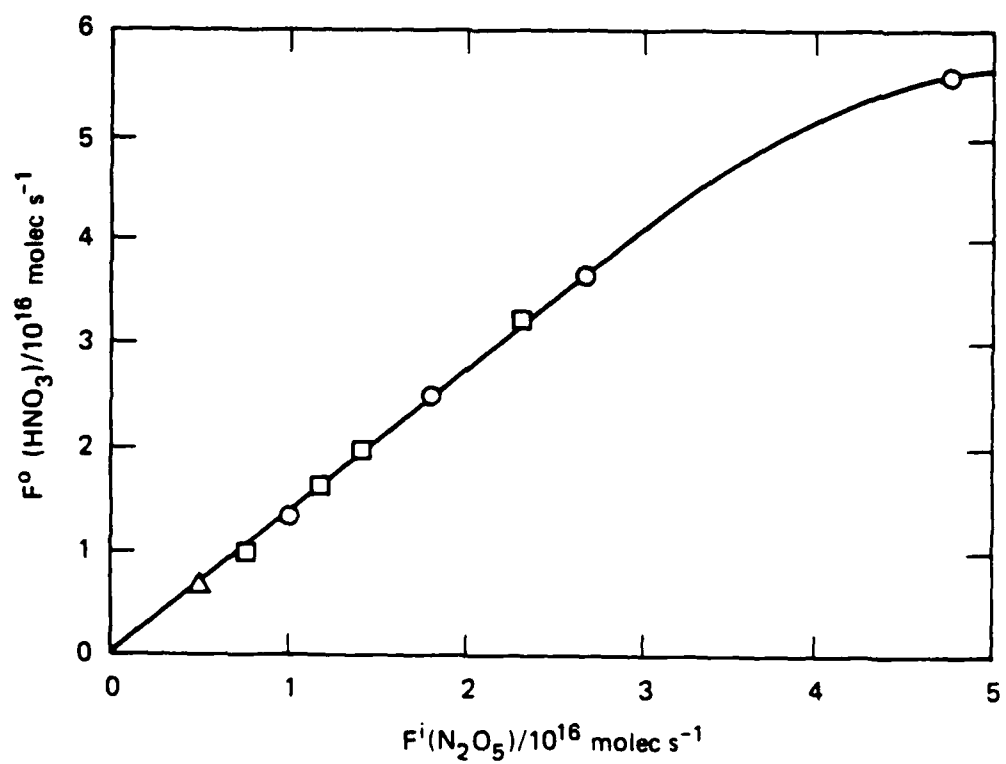
$$F^i(\text{N}_2\text{O}_5) = 3.1 \times 10^{16} \text{ molec/s}$$



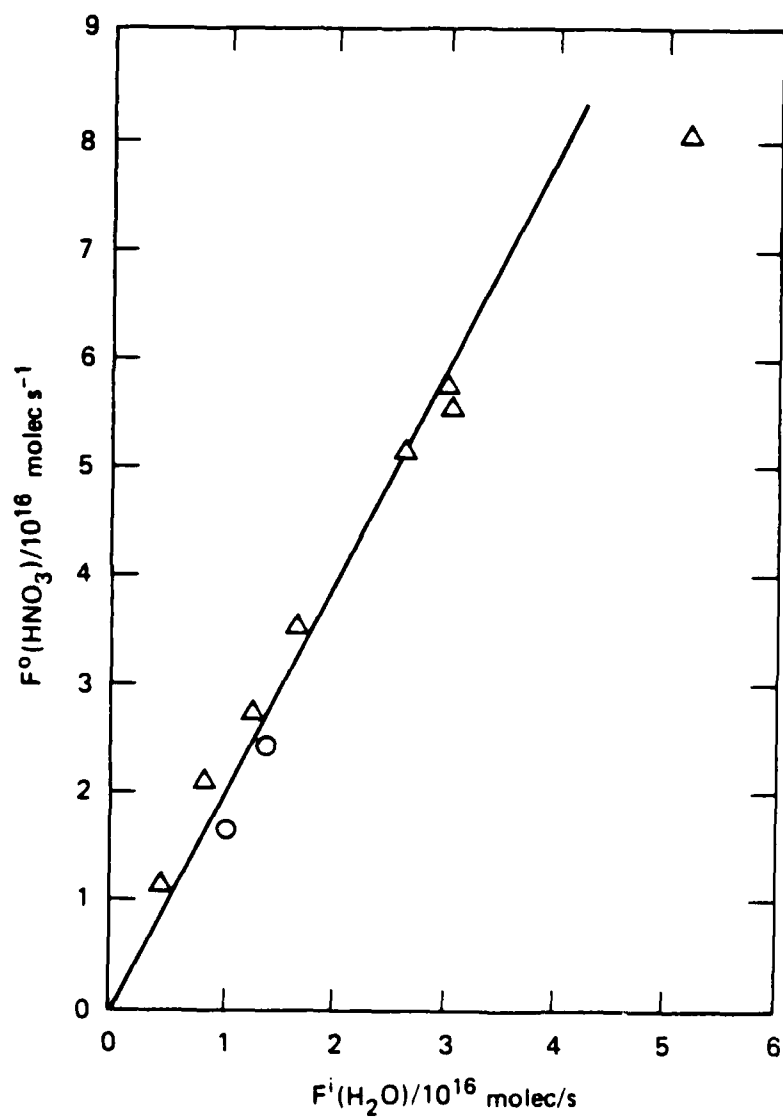
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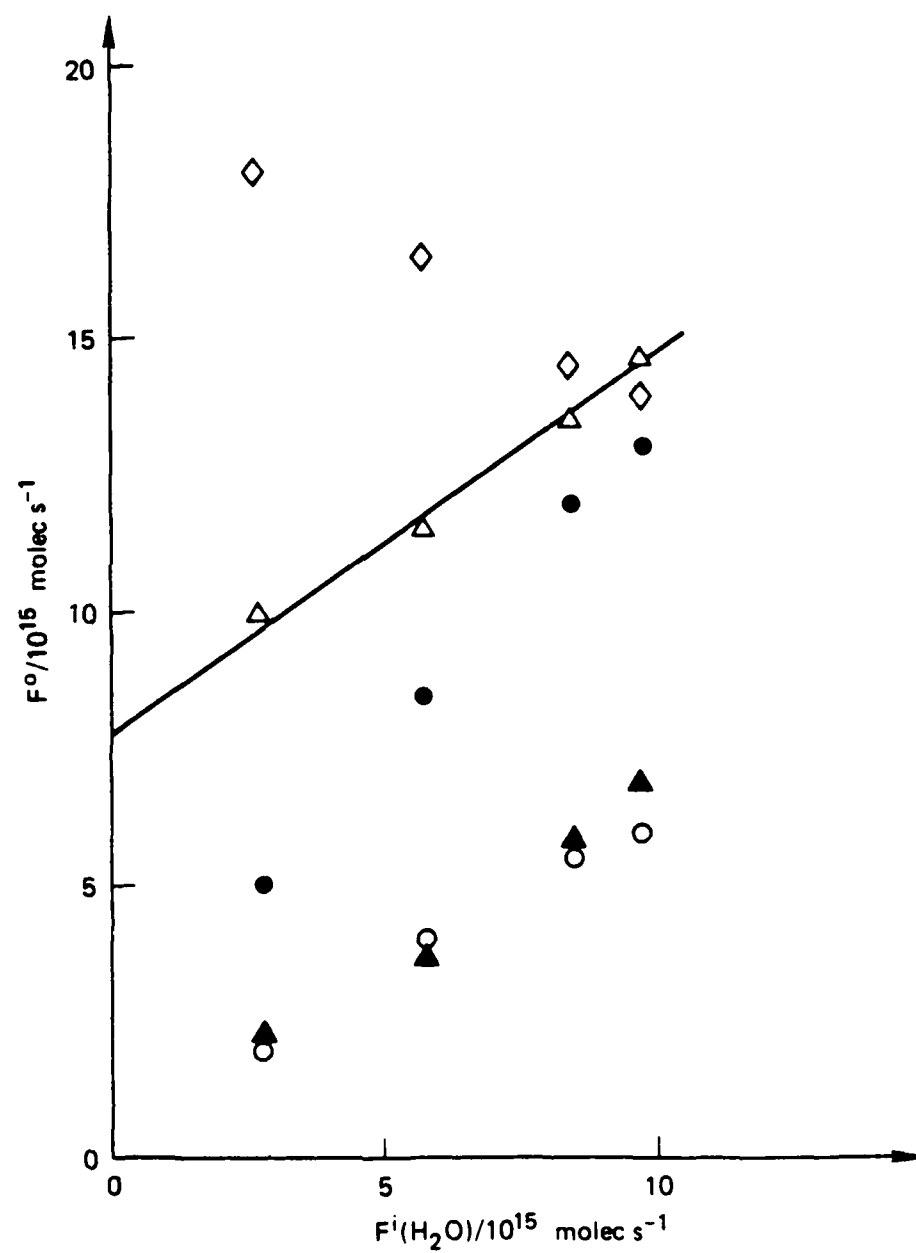
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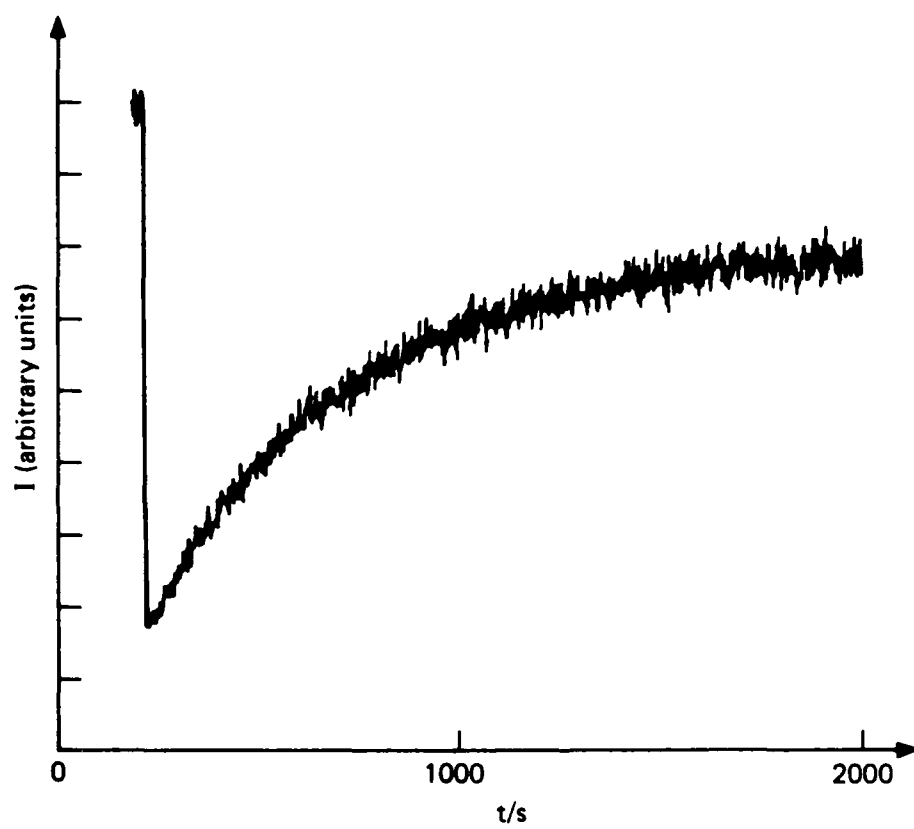
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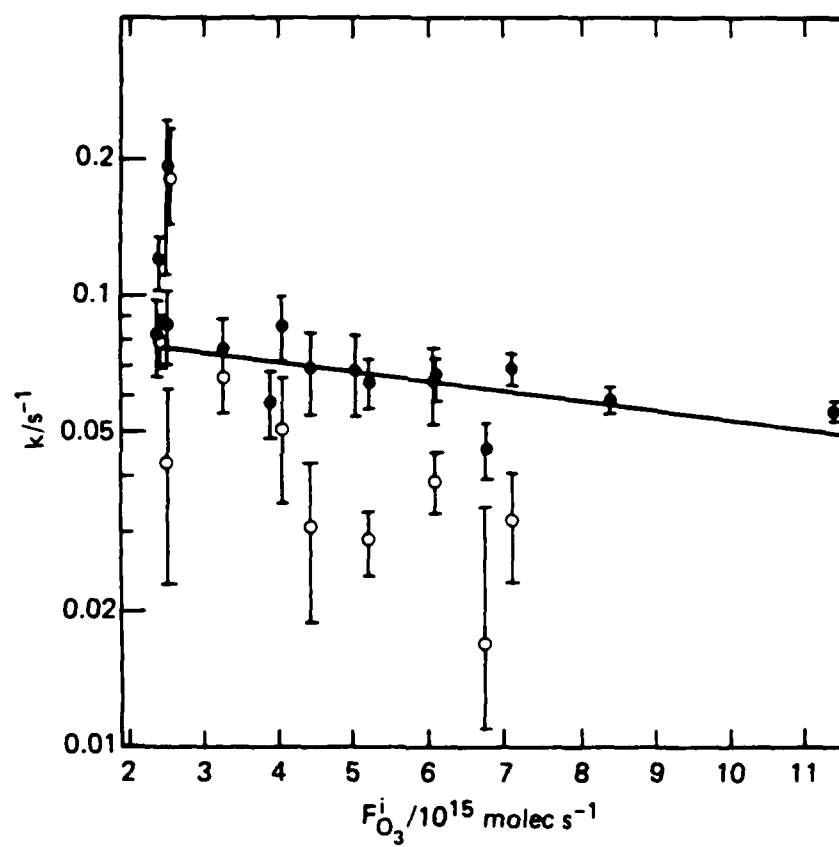
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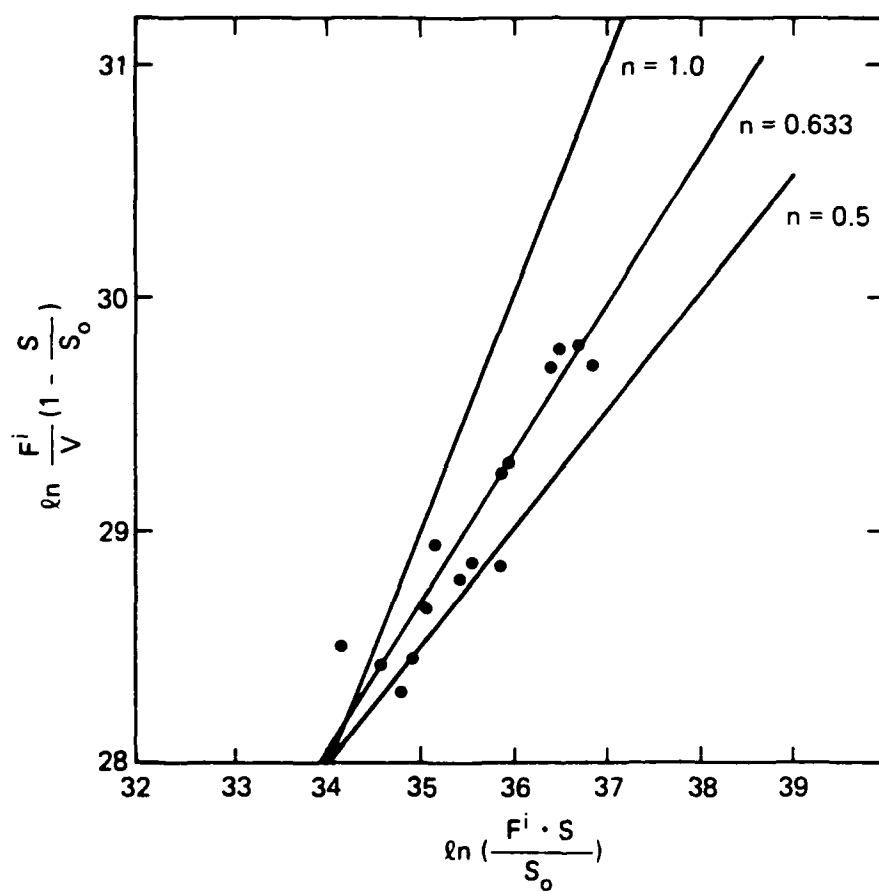
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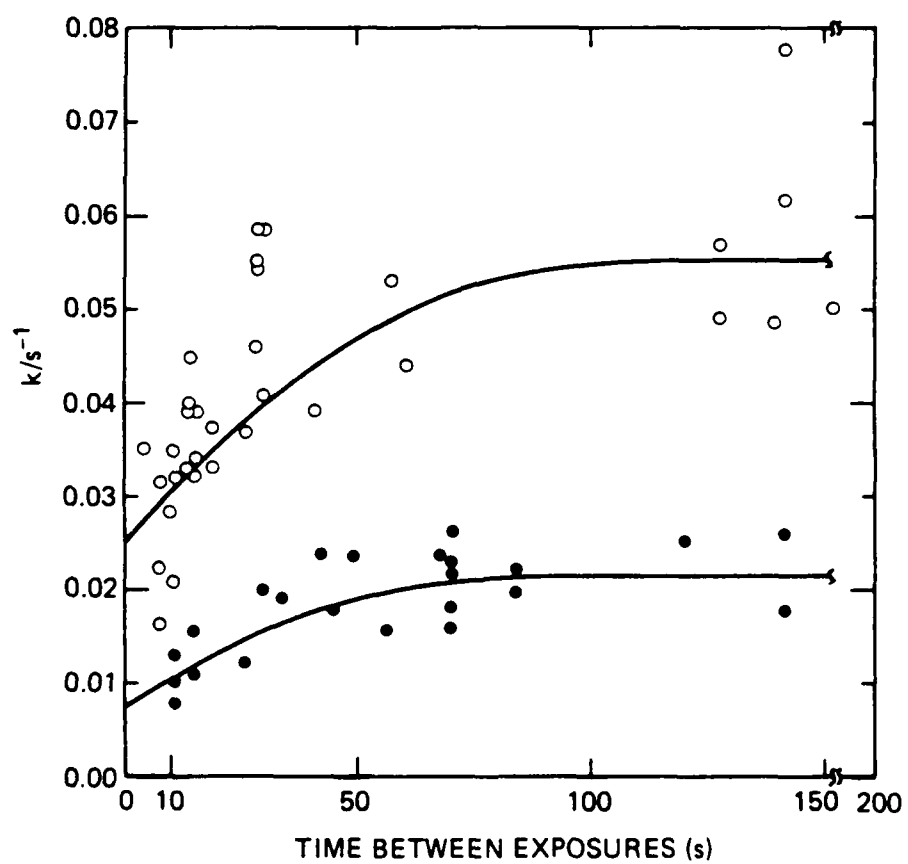
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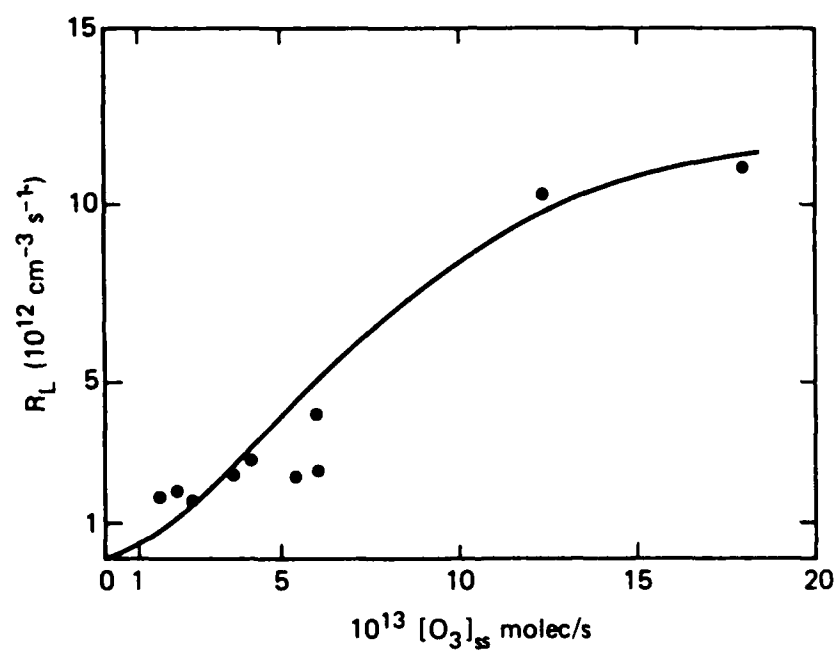
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JA-7873-66



JA-7873-69

PROPOSED MODELING STUDIES ON REMOVAL BY CLOUD PROCESS
OF MASSIVE EMISSIONS OF PARTICLES

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ABSTRACT

In general, atmospheric aerosols originate by several processes: (1) condensation and sublimation of vapors and the formation of smokes in combustion, (2) reactions among trace gases, (3) mechanical disruption and dispersal of matter at the earth's surface as mineral dusts, and (4) coagulation of nuclei to produce larger particles of mixed constitution. The particles participate actively during cloud formation either as cloud condensation nuclei or ice-forming nuclei, or passively by being removed by cloud droplets and raindrops through processes of collision and coalescence. The evolution of dust and smoke particles is additionally controlled by dynamic processes such as transport, turbulent mixing and deposition. These natural processes of aerosol evolution would be greatly affected if extraordinary amounts of dust and smoke particles were injected into the atmosphere by blasts or large fires.

The scavenging efficiency for aerosols produced by blasts and fires can be examined in numerical simulations which describe coagulation processes involving aerosols, cloud droplets and raindrops. The investigation of the evolution

within clouds of dust and smoke particles of very high concentrations is important for clear understanding of the resulting global budget of aerosols and for better assessment of the potential climatic impact. The collision efficiency between particles can be formulated from a combination of theoretical analyses and available experimental data. A numerical module for wet removal can be used to evaluate scavenging efficiency, modification of cloud properties, and applicability of cloud microphysics parameterizations currently in use.

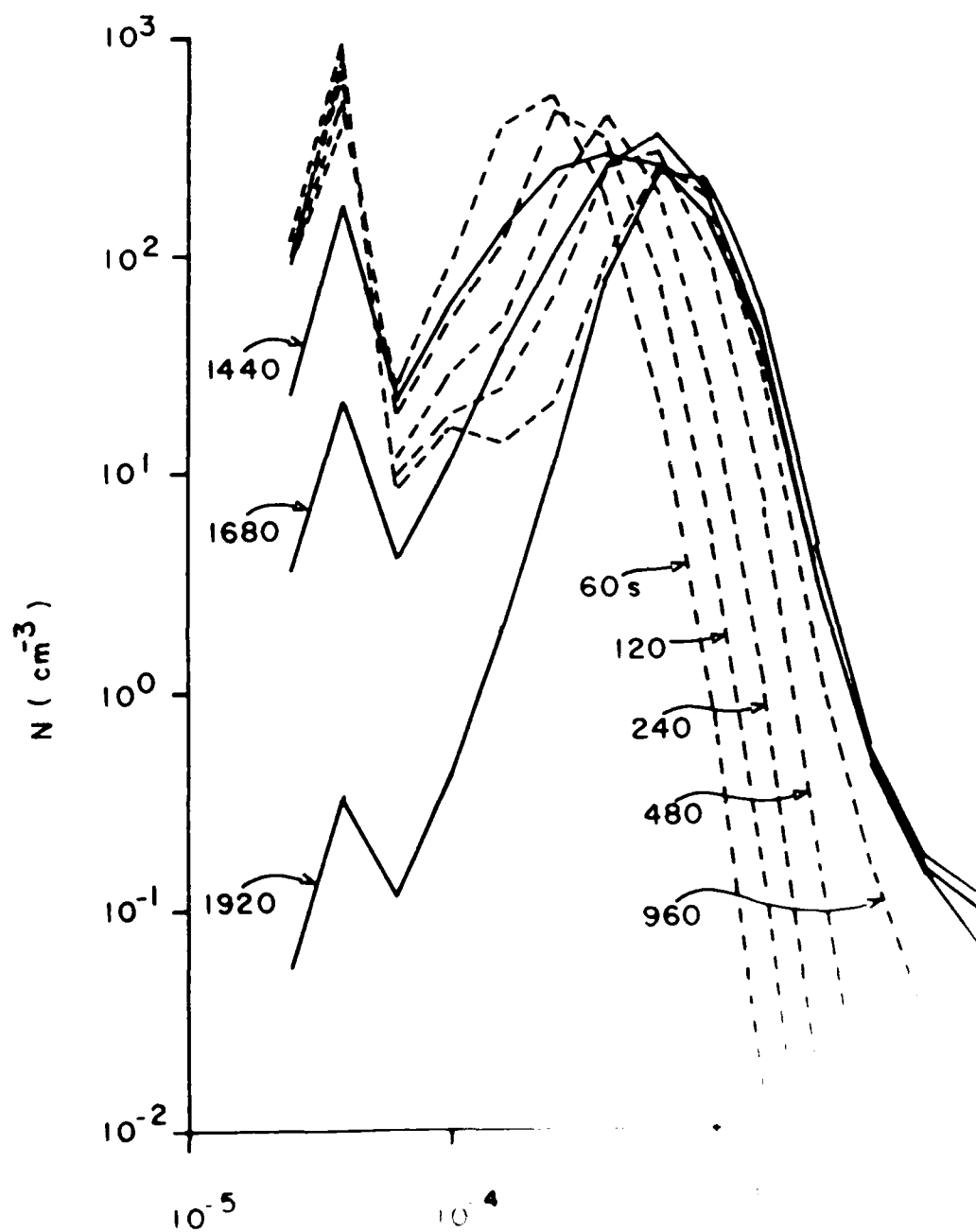
A cloud model originally developed at Argonne to study cloud microphysics parameterizations has been modified to examine the behavior of submicron aerosols in clouds. Lagrangian computations following a rising parcel of air were made in order to understand and identify mechanisms that control the fate of smoke and dust particles in clouds. The air parcel was assumed to be saturated initially and to contain aerosols of high number density (1650 cm^{-3}). Some portion of the aerosols in the parcel could be activated to form cloud droplets and the rest could remain inactivated due mainly to the Kelvin effect. Thereafter, the spectrum was allowed to evolve and form raindrops. The model treated particle sizes ranging from $0.04 \mu\text{m}$ to $164 \mu\text{m}$ in radius.

Computations have been made for 40 min of simulated time. The spectral evolution and the role of each microphysical mechanism in the spectral evolution are presented in Figs. 1 and

2, respectively. Figure 1 shows that the spectrum evolves quickly during the first five minutes of cloud development due mainly to condensation, which affects the growth of particle sizes approximately up to the mode radius near $10\text{ }\mu\text{m}$. The spectral evolution starts to produce raindrops, associated with sizes greater than about $50\text{ }\mu\text{m}$ in radius, after 10 min of simulated time. The submicron size particles are not removed or activated until simulated time exceeds 20 min, but thereafter they are quickly scavenged as the cloud starts to accumulate drops greater than about $100\text{ }\mu\text{m}$ in radius. In Fig. 2, we see clearly that the combined processes of condensation and coagulation can remove submicron particles much more effectively than either process alone. We also found that the removal of submicron particles is augmented if precipitation is included.

Figure 1. Number distributions of aerosols, cloud droplets and raindrops after various periods of simulation.

Figure 2. The role of cloud microphysical processes of condensation and coagulation in the spectral evolution of particles.



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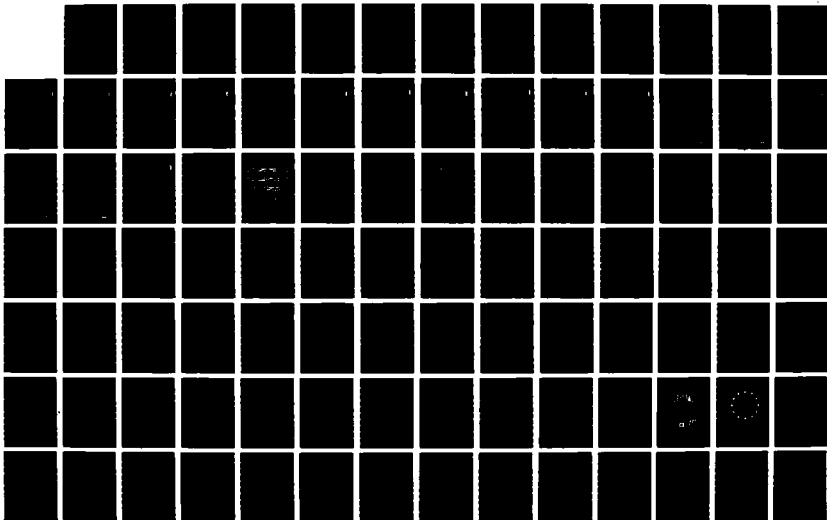
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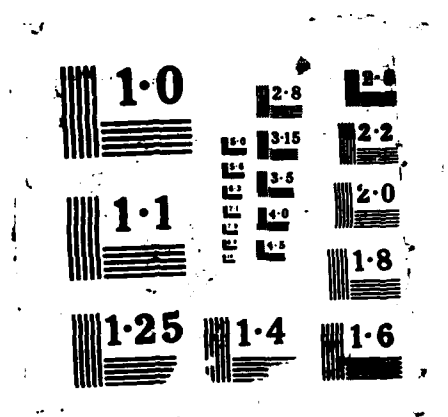
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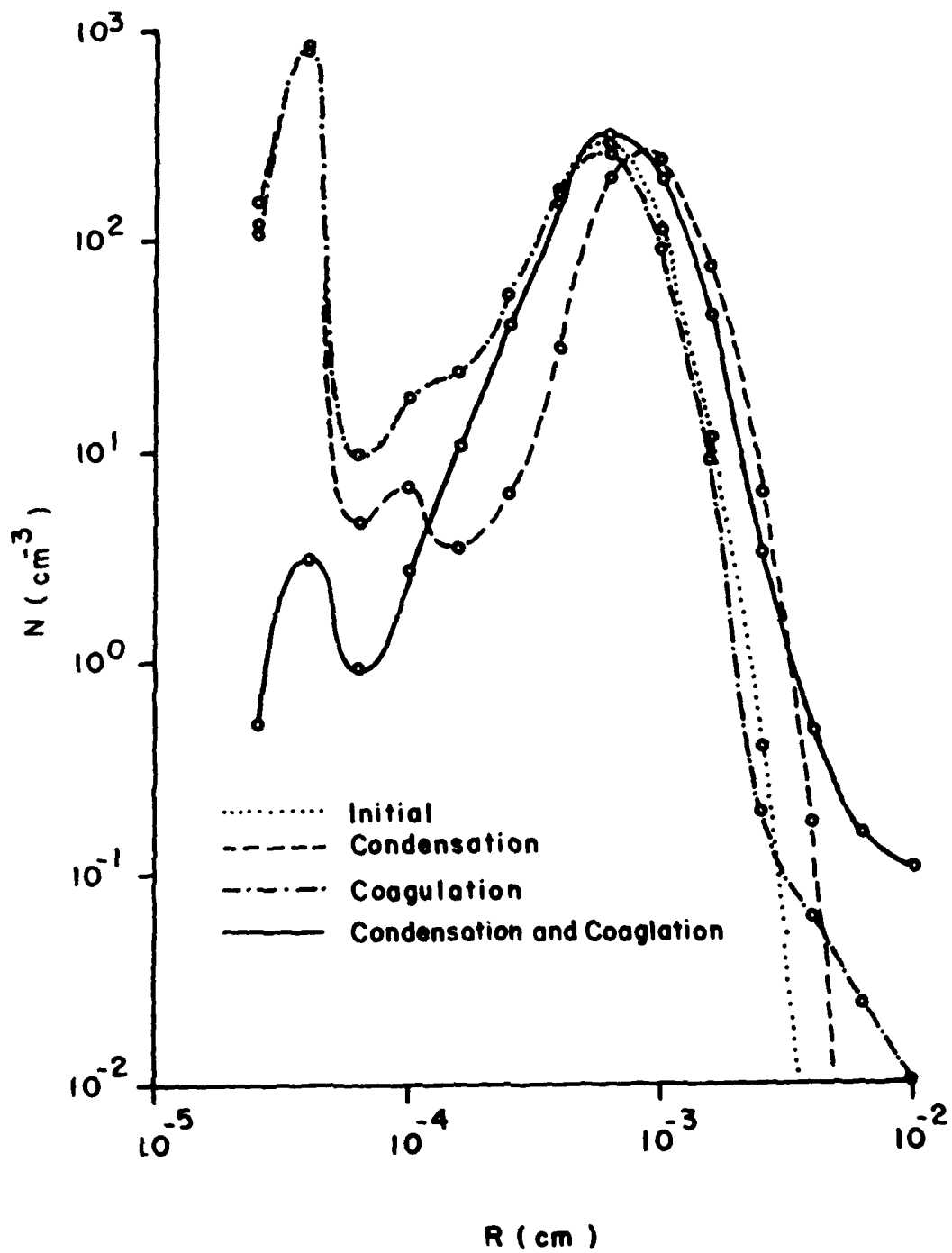
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**The University of Missouri-Rolla Cloud Simulation
Chambers**

**Daniel R. White
Donald E. Hagan
John C. Carstens**

**Graduate Center for Cloud Physics Research
University of Missouri-Rolla**

THE UMR CLOUD SIMULATION CHAMBERS

The UMR cloud simulation program is based on two cooled-wall expansion chambers designed to produce uniform cooling comparable to that produced in cloud updrafts. The smaller chamber, called Proto II, is currently producing cloud, and the larger--more sophisticated--Romulus chamber is scheduled for completion in the summer of 1985.

These chambers feature thermoelectric modules to cool the walls at the same rates as the expansion cools the gas. Thermal wall effects are thus effectively removed and a closed parcel thermodynamic environment similar to that found in the core of a convective cloud in the absence of turbulent mixing can be simulated.

After a sample of moist aerosol-laden air has been introduced into the chamber, the sensitive volume undergoes a controlled expansion which cools the gas and produces the increased relative humidity required for cloud formation. The chamber's initial condition can be set at any desired state of relative humidity less than 100%. The cooling capability is sufficient to allow ice nucleation and crystal growth studies to be carried out.

The creation of a viable cloud simulation program has necessitated developmental work on a broad front so that the required science and technology would come together to support the experimental effort at about the same time. Much of this effort has gone into the development of the following peripheral and supporting equipment:

1. Air preconditioning system for drying and filtering large volumes of air (see Fig. A2) for flushing the chamber and for use by aerosol generation equipment.
2. Precision saturator columns and thermal regulation columns for relative humidity (see Fig. A3).
3. A variety of aerosol generation techniques have been developed for the production of artificial nuclei. Much effort has gone into characterizing aerosols and rendering them monodispersed. Natural nuclei can be employed.
4. Precision continuous flow thermal diffusion chamber (CFDs) for characterizing the critical activation supersaturation spectrum of the condensation nuclei have been developed. Three vertical plate CFDs are currently operational. Three vertical plate CFDs are currently under construction. These will operate simultaneously, two in the CFD mode and one in the isothermal mode, to cover the entire CCN spectrum with high resolution and will provide automatic data acquisition in a format for immediate assimilation by the simulation chamber minicomputer system to aid in establishing last minute parameters for experiment control.
5. Optical and electrical aerosol characterization equipment for measuring the size distribution of both wet and dry aerosol particles. A GE CNC counter and a UMR Aitken nucleus counter are also available for measuring total particle concentrations and sensing the Aitken nuclei content of sample air. This makes possible scavenging experiments.

6. Laser light scattering equipment enables one to determine the Mie scattering intensity at one angle. The total attenuation of a light beam (from a light emitting diode operating at a different wavelength from the argon ion laser) is also measured with a precision of three parts in 10^4 . A photograph is also taken with flash illumination in order to verify the droplet concentration at specified intervals. These optical systems are described in more detail in Appendix C.
7. The digital data acquisition and control system is built around a NOVA 840 and a NOVA 3 minicomputer. When both are operational, a greater real time computational capacity is available for experiments. State-of-the-art techniques are employed extensively through the system, particularly in the measurement and control of temperature and pressure.
8. A wide variety of simulation chamber control options have been developed. These can be readily configured to best suit the demands of individual experiments. It is possible to run various microphysical models in real time on one of the minicomputers and use the output in the control of the chamber or to compare with the output of the various optical sensors. In this area we envision a continuous evolution of capability as new experiments are developed.

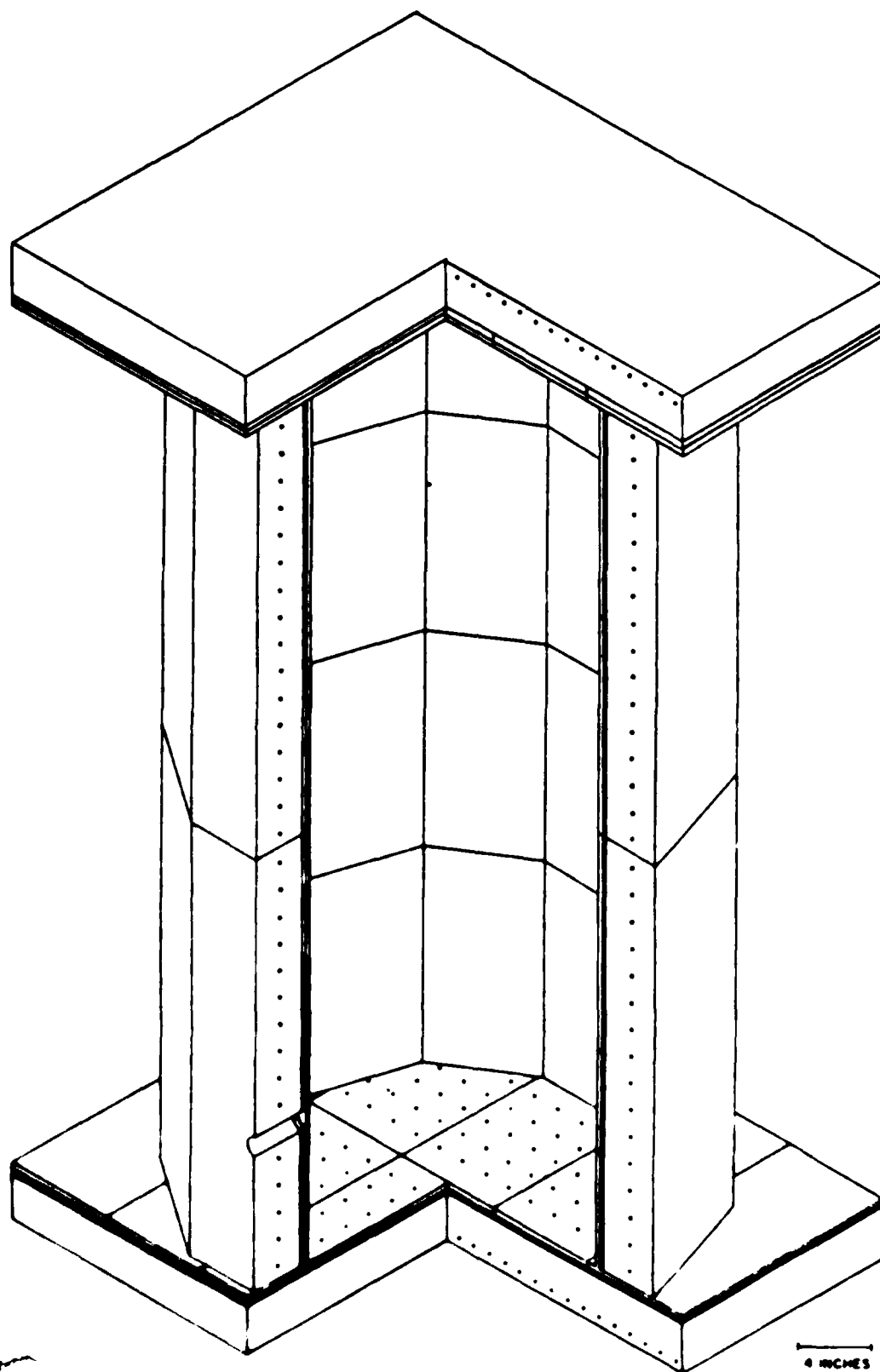


Fig. A1 Protective Cloud Simulation Chamber

UMR CLOUD SIMULATION FACILITY

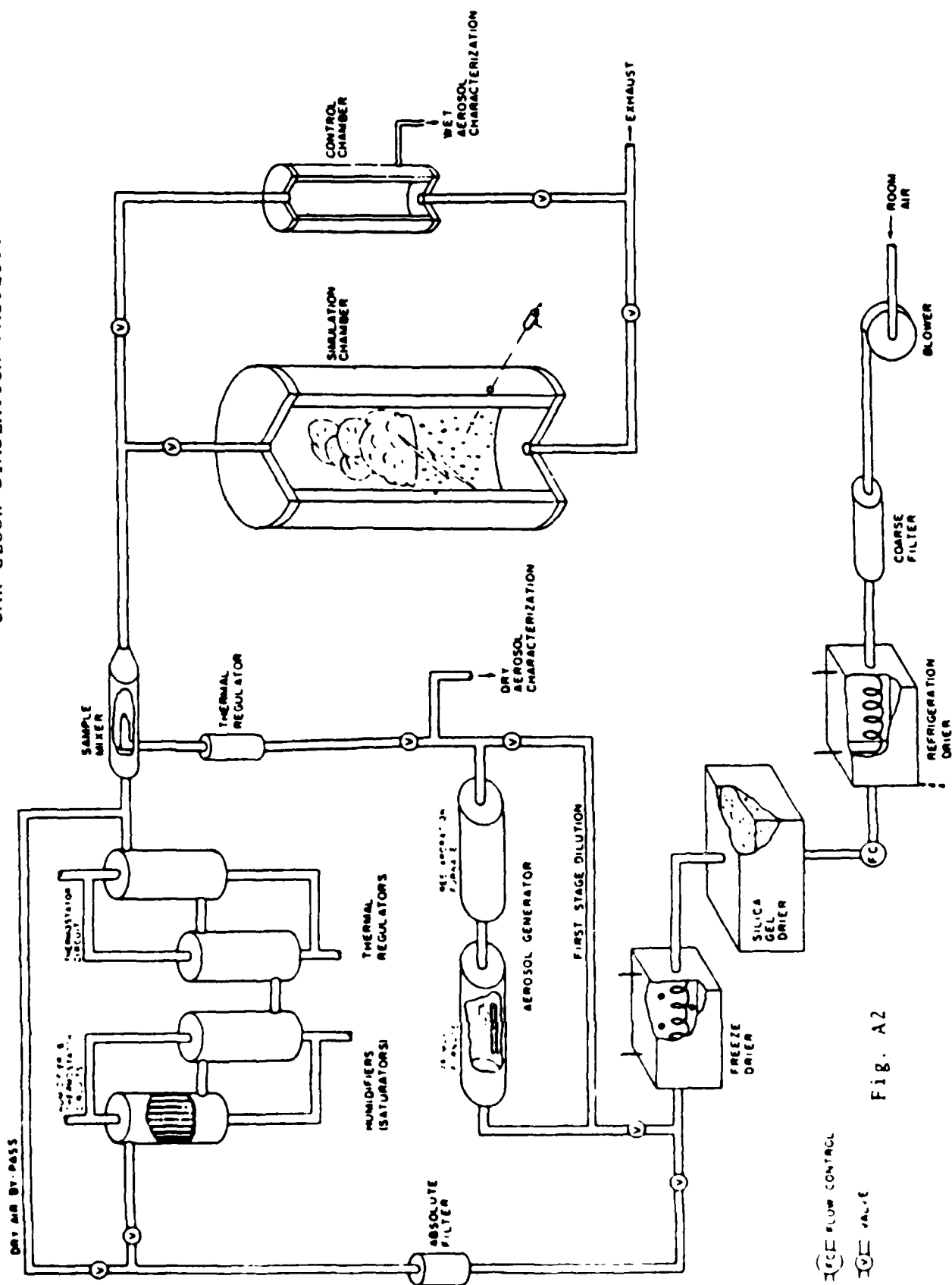


Fig. A2

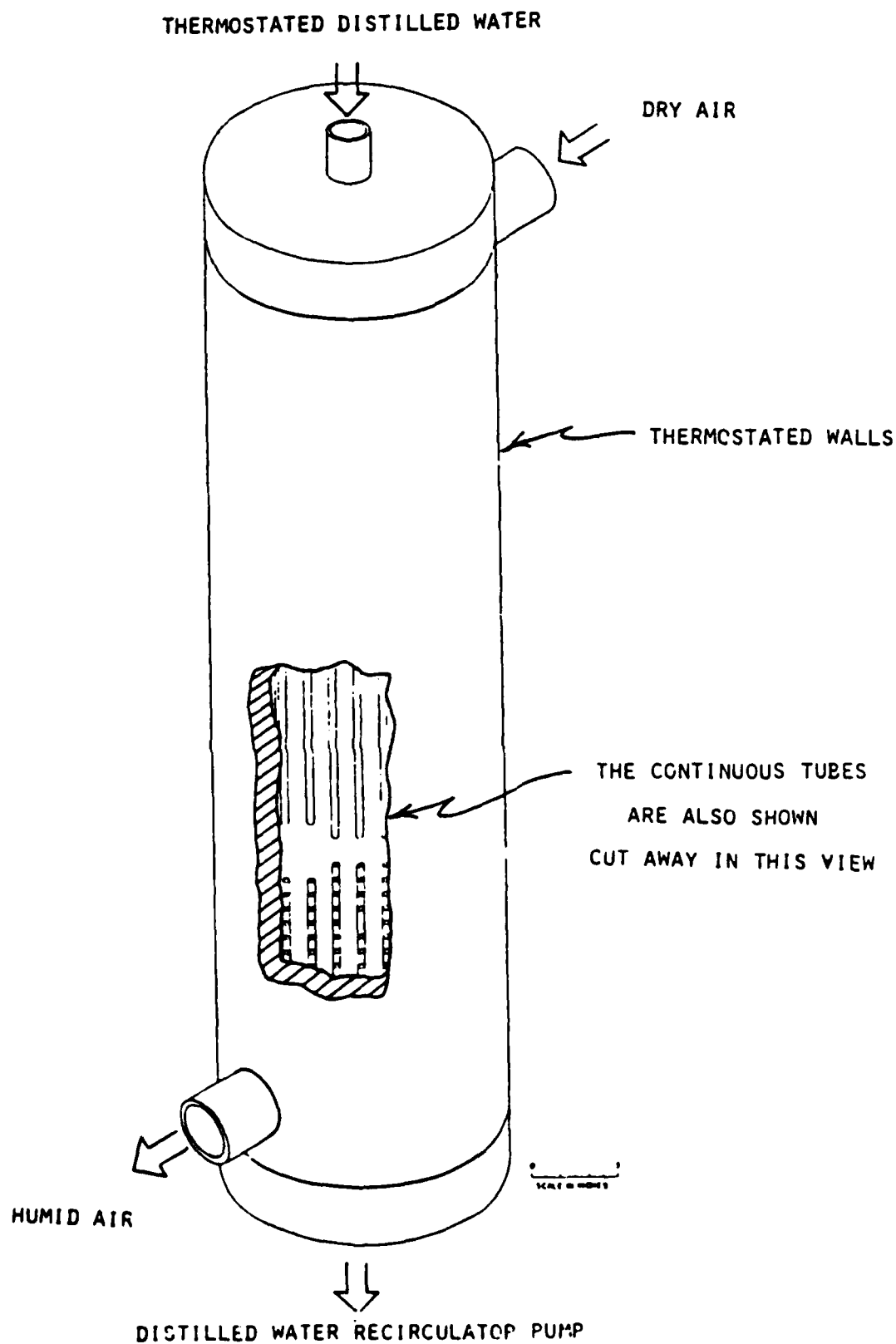


Fig. A3 Humidifier

TABLE I
PROTO II CHAMBER SPECIFICATIONS

Temperature	Prototype Chamber
Range	40° to -40°C
Control	
Holding: At fixed temperature	
RMS deviation from	
spatial average, 40 sensors	0.030°C
Cooling Mode: Maximum rate, at least	10°C/min.
Wall temperature lag	
from control point	0.01°C/(°C/min.)*
RMS deviation from	
spatial average	0.080°C @ 6°C/min. 0.040°C @ 3°C/min.
Wall Measurement Precision	<u>+0.002°C</u>
Pressure	
Reference pressure absolute accuracy	<u>+0.01%</u> , dead weight pressure gauge
Dynamic sensor range	0 to 100 Torr differential
Resolution	<u>+0.05 Torr</u>
Control:	
Holding: Standard deviation (time)	0.5 Torr
Expansion: Maximum rate	3.9 Torr/sec 12 (C/min. wet adiabatic)
Offset from command valve	0.5 Torr
Standard deviation with (time)	0.36 Torr
Wall Cooling Method	Thermoelectric modules plus fluid heat exchange in heat sink
Volume	48 cm dia x 61 cm ht OR 48 cm dia x 122 cm ht

*Cooling Rate

SECTION 2
PLUME DYNAMICS AND CLOUD PHYSICS

Scavenging of submicron aerosols by clouds.

R.F.Pueschel, NASA Ames Research Center, Moffett Field, CA 94040.

Scavenging by clouds and precipitation is the most effective mechanism by which aerosols are removed from the atmosphere. Data on the relationships between aerosol and cloud spectra and concentrations before, during and after cloud formation show the extent and time scales with which the aerosol-cloud interaction occurs. Specifically, the following results will be discussed:

(1) The accumulation mode, the longest lived portion of the atmospheric aerosol, provides the cloud condensation nuclei around which drops form. Particles as small as $0.1 \mu\text{m}$ diameter are ingested into cloud drops during the cloud's formation; the nucleation scavenging of submicron particles is the more efficient the larger their size.

(2) In polluted airmasses, there are more submicron particles removed from the aerosol than there are cloud drops formed. This is different from clean air situations where a 1:1 relationship between the loss of submicron particles and the formation of cloud drops exists. Thus, in polluted air a mechanism in addition to nucleation scavenging has to be invoked to account for the aerosol losses. Stephan flow, a hydrodynamical movement of a vapor-gas mixture normal to the surface of a condensing liquid, to compensate for gas diffusion away from the surface, is a possible explanation.

(3) Nucleation scavenging during cloud formation is 180 times faster than is in-cloud attachment of the residual aerosol after the cloud has formed.

***THE ROLE OF BUOYANCY INDUCED TURBULENCE
IN SCAVENGING PARTICULATES FROM
LARGE SCALE FIRES***

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Presented at the Global Effects Program Technical Meeting,
February 25 - 27, 1986
NASA - Ames Research Center
Moffet Field, CA

TOPICS

- Area of Interest
- Problem Definition
- Objective
- Method of Approach
- Summary

AREA OF INTEREST

- Uncertainty in Predicting Amount and Structure of Soot and other Particulates Reaching High Altitudes
- Scavenging and Coagulation can have a Strong Effect

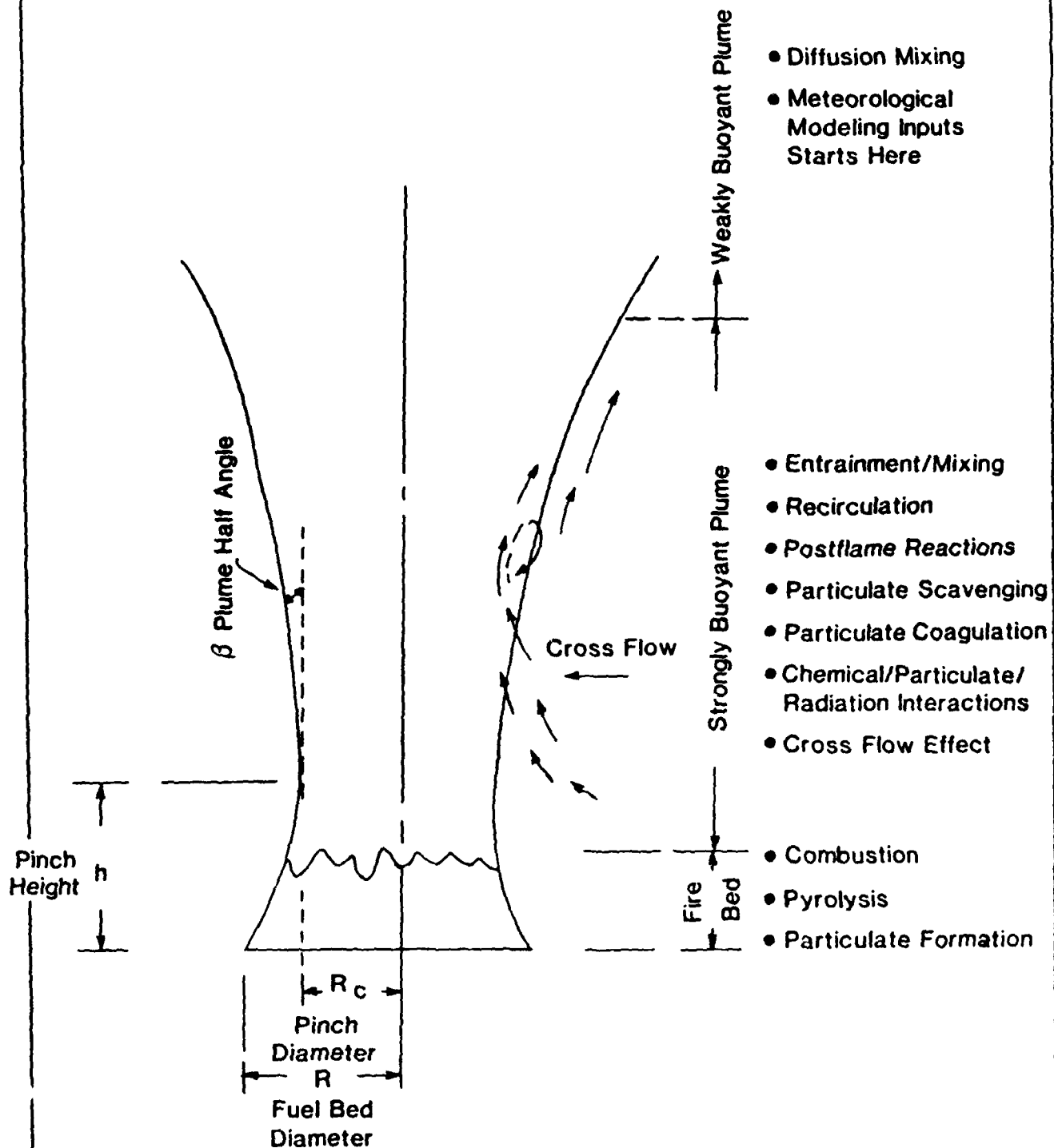
PROBLEM DEFINITION

- Local Plume Properties are Required
- Spatial and Temporal Variations in Temperature, Concentration and Velocity are Important in Plume Flow Fields
- Properties Depend upon Mixing Rates which, in Turn, Depend Upon Buoyancy-Induced Turbulence and Entrainment Rates

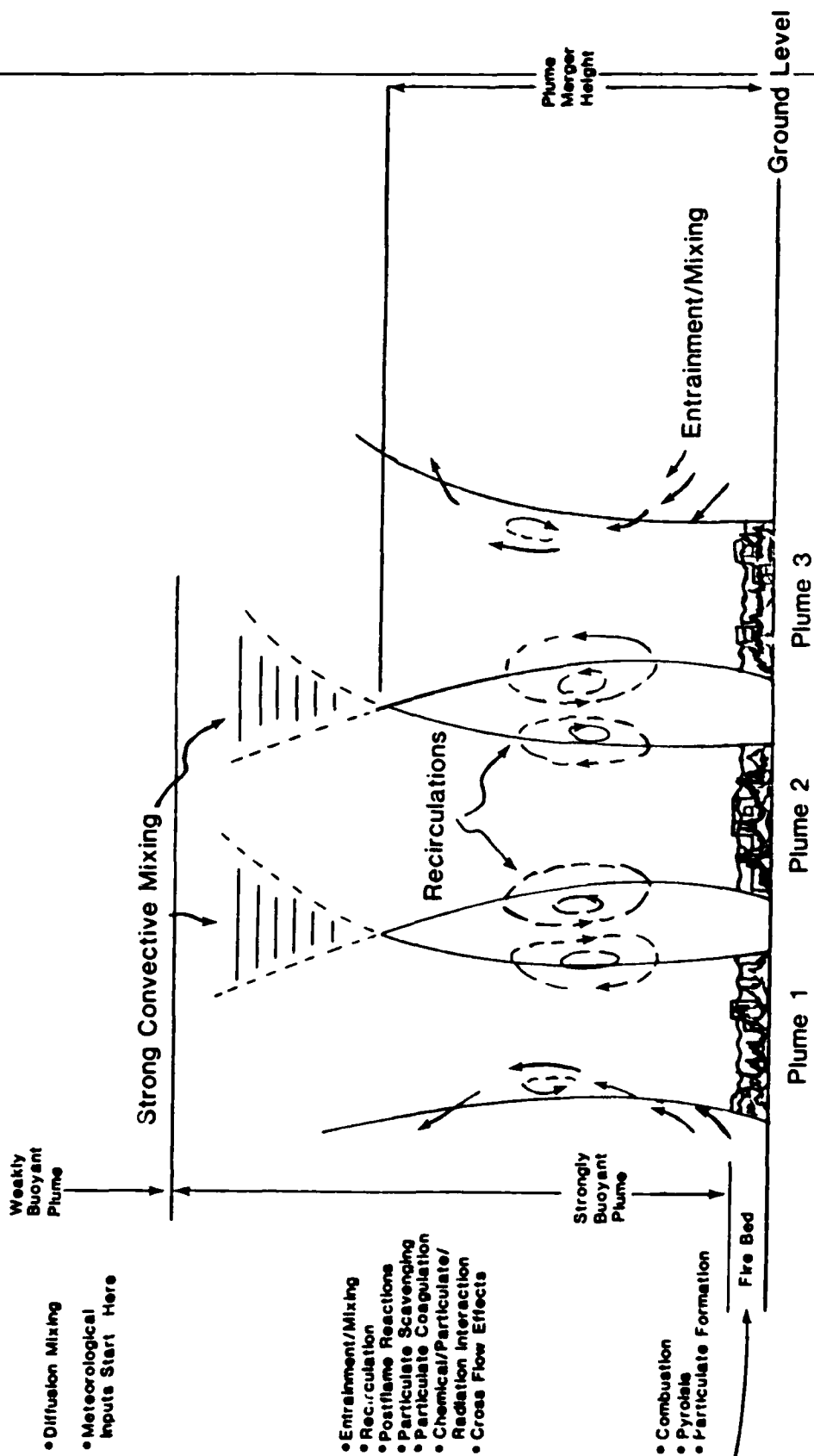
OBJECTIVES

- To Describe Local Properties in the Near and Intermediate Plume Flow Fields with Emphasis on Buoyancy – Induced Turbulence and Entrainment Processes

SAIC



Single Plume Characteristic Regions



Interacting Plume Phenomena.

SAL

SUMMARY OF OBSERVATIONS

- Complex Interplay of Time Dependent Entrainment and Mixing Processes
- Combustion Completion and Secondary Rate Processes are Relatively Slow and therefore are Non - Equilibrium Processes
- Mass Fire is Likely Comprised of Small Multiple Fire Plumes Interacting with One Another , Merging to Form a Single Large Scale Plume

SAT

METHOD OF APPROACH

- Single Plume Modeling
 - Axisymmetric
 - Steady
 - Transient
- Multiple Plume Modeling
 - 3-D
 - Steady
 - Transient
- Plume Structure
 - Local Properties
 - Scaling

SAL

PRELIMINARY RESULTS ON TURBULENT PLUMES

- Buoyancy Induced Mean Flow Acceleration
- Buoyancy Induced Turbulence

SAIL

BUOYANCY GENERATED TURBULENCE

$$\underbrace{\frac{\partial k}{\partial \tau} + u_j \frac{\partial k}{\partial x_j}}_{\text{rate of change}} = \underbrace{- \frac{\partial}{\partial x_j} \left[u_j \left(\frac{u_i u_i}{2} + \frac{p}{\rho} \right) - \nu \frac{\partial k}{\partial x_j} \right]}_{\text{diffusive transport}}$$

$$\underbrace{- \overline{u_i u_j} \frac{\partial u_i}{\partial x_j}}_{\text{production by shear}} = \underbrace{- \beta g_i \overline{u_i T}}_{\text{production by buoyancy forces}} - \underbrace{\nu \frac{\partial u_i}{\partial x_j} \frac{\partial u_i}{\partial x_j}}_{\text{dissipation}}$$

where,

$$k = \frac{1}{2} \overline{u_i u_i}$$

SAIC

$k-\epsilon-q$ TURBULENCE MODEL

1. TURBULENT KINETIC ENERGY

$$\rho u \frac{\partial k}{\partial x} + \rho v \frac{\partial k}{\partial r} = \frac{1}{r} \frac{\partial}{\partial r} \left(r \mu_T \frac{\partial k}{\partial r} \right) + \mu_T \left(\frac{\partial u}{\partial r} \right)^2 - \rho \epsilon + \rho g \frac{\beta}{2} (ak)^2$$

2. TKE DISSIPATION RATE

$$\rho u \frac{\partial \epsilon}{\partial x} + \rho v \frac{\partial \epsilon}{\partial r} = \frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\mu_T}{Pr_\epsilon} \frac{\partial \epsilon}{\partial r} \right) + 1.44 \frac{\epsilon}{k} \mu_T \left(\frac{\partial k}{\partial r} \right)^2 - 1.92 \frac{\rho \epsilon^2}{k} + \rho g \beta \epsilon \left(\frac{q}{k} \right)^2$$

3. TEMPERATURE $[q \equiv (T')^2]^{1/2}$

$$\rho u \frac{\partial q}{\partial x} + \rho v \frac{\partial q}{\partial r} = \frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\mu_T}{Pr_q} \frac{\partial q}{\partial r} \right) + 2.7 \mu_T \left(\frac{\partial T}{\partial r} \right)^2 - 1.8 \frac{\rho \epsilon}{k} q - 2k \left(\frac{\partial q}{\partial r} \right)^2$$

$$Pr_k = 0.6$$

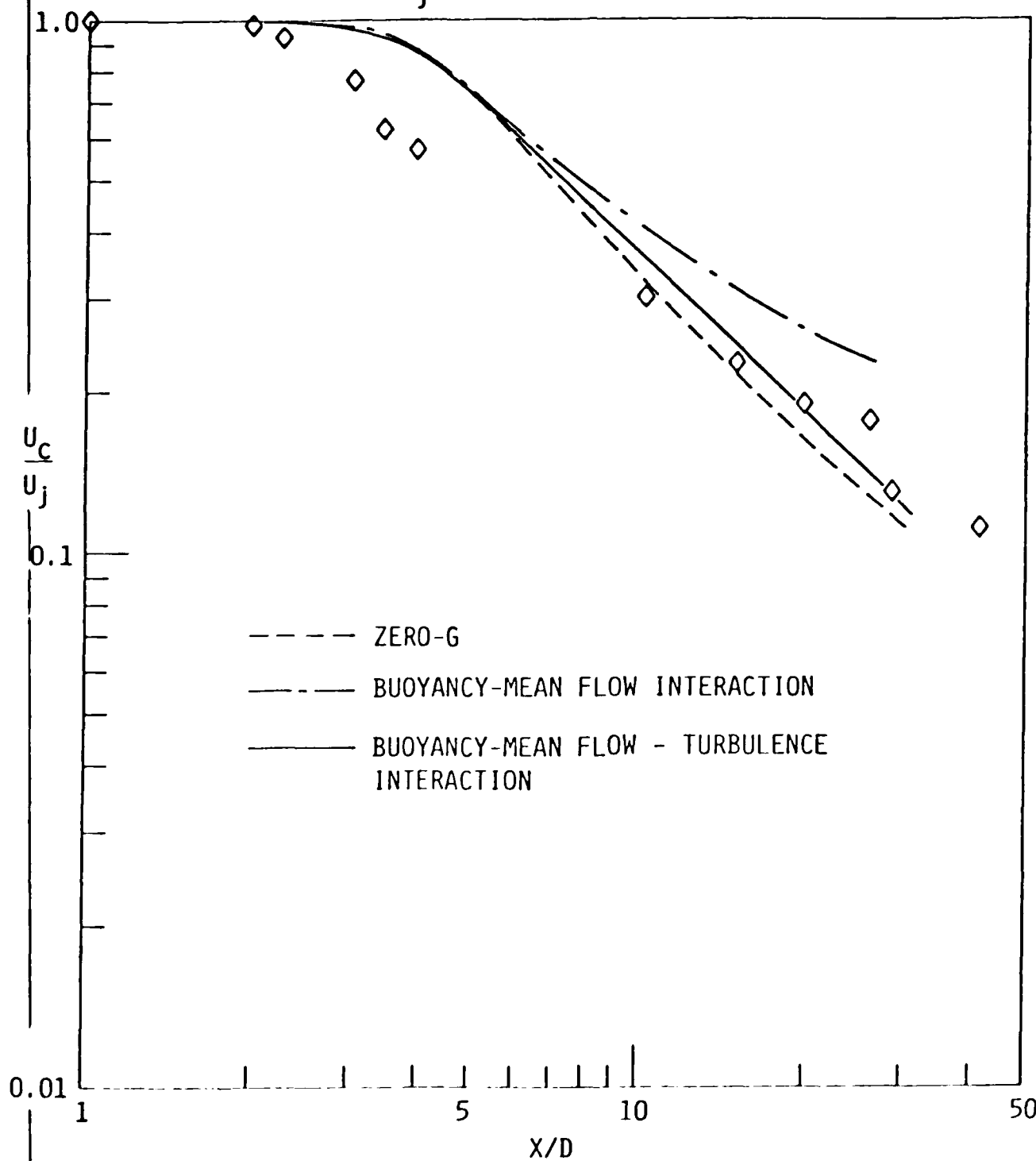
$$Pr = 0.6$$

$$Pr_q = 0.7$$

$$\mu_T = 0.09 \rho \frac{k^2}{\epsilon}$$

EFFECT OF MODELING ASSUMPTIONS ON PREDICTION OF CENTERLINE VELOCITY, HOT BUOYANT JET

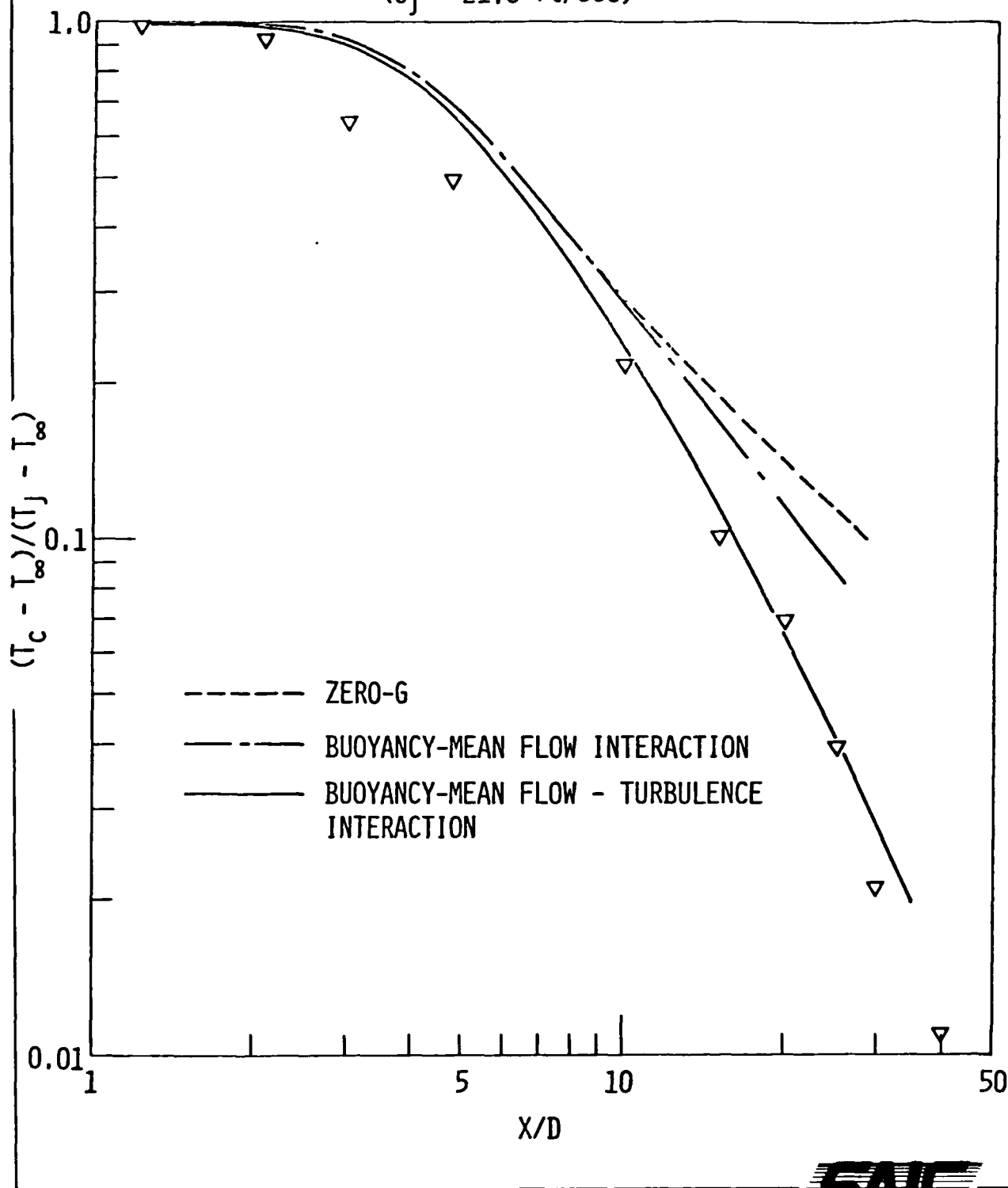
($U_j = 21.6$ ft/sec)

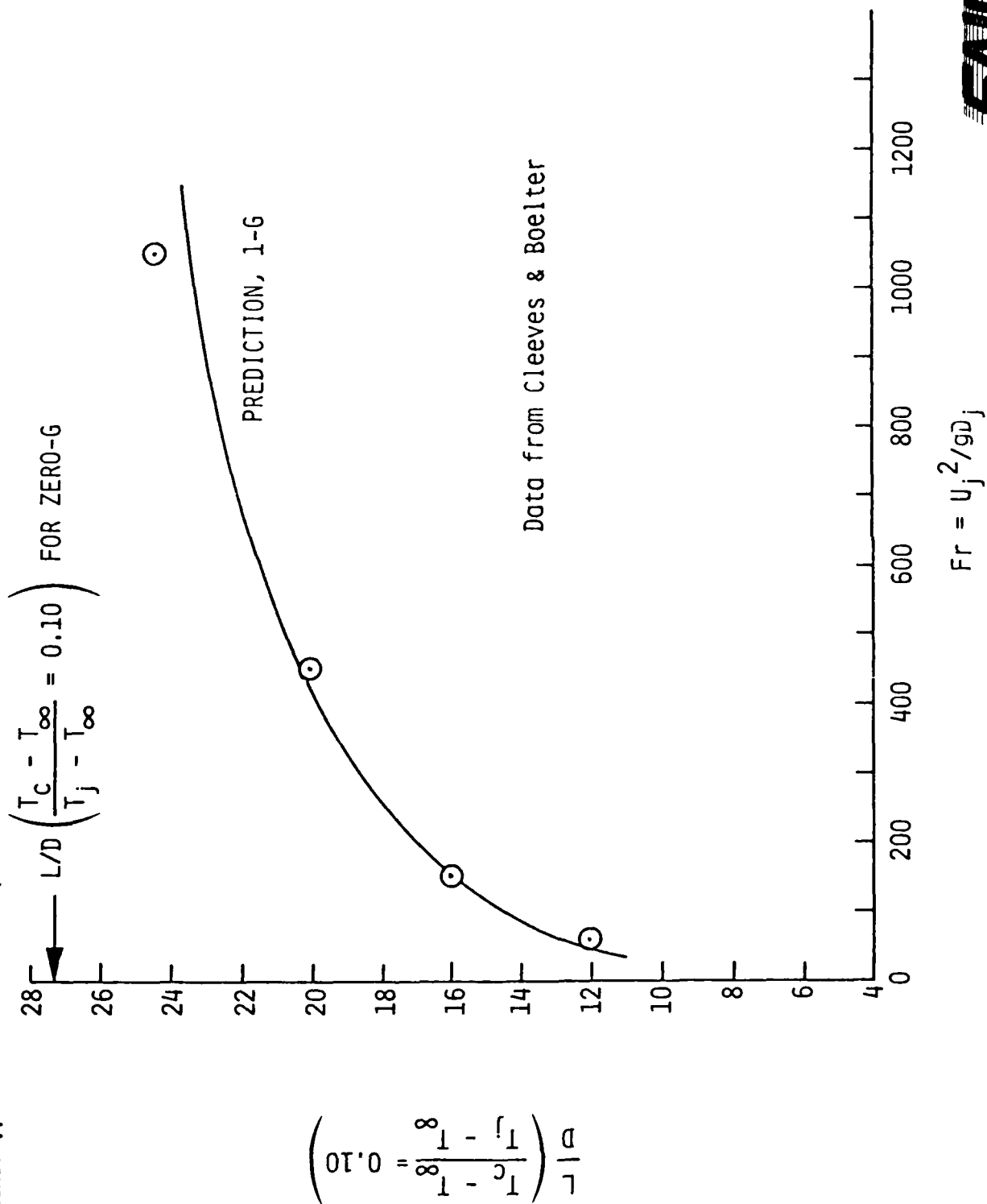


SAIC

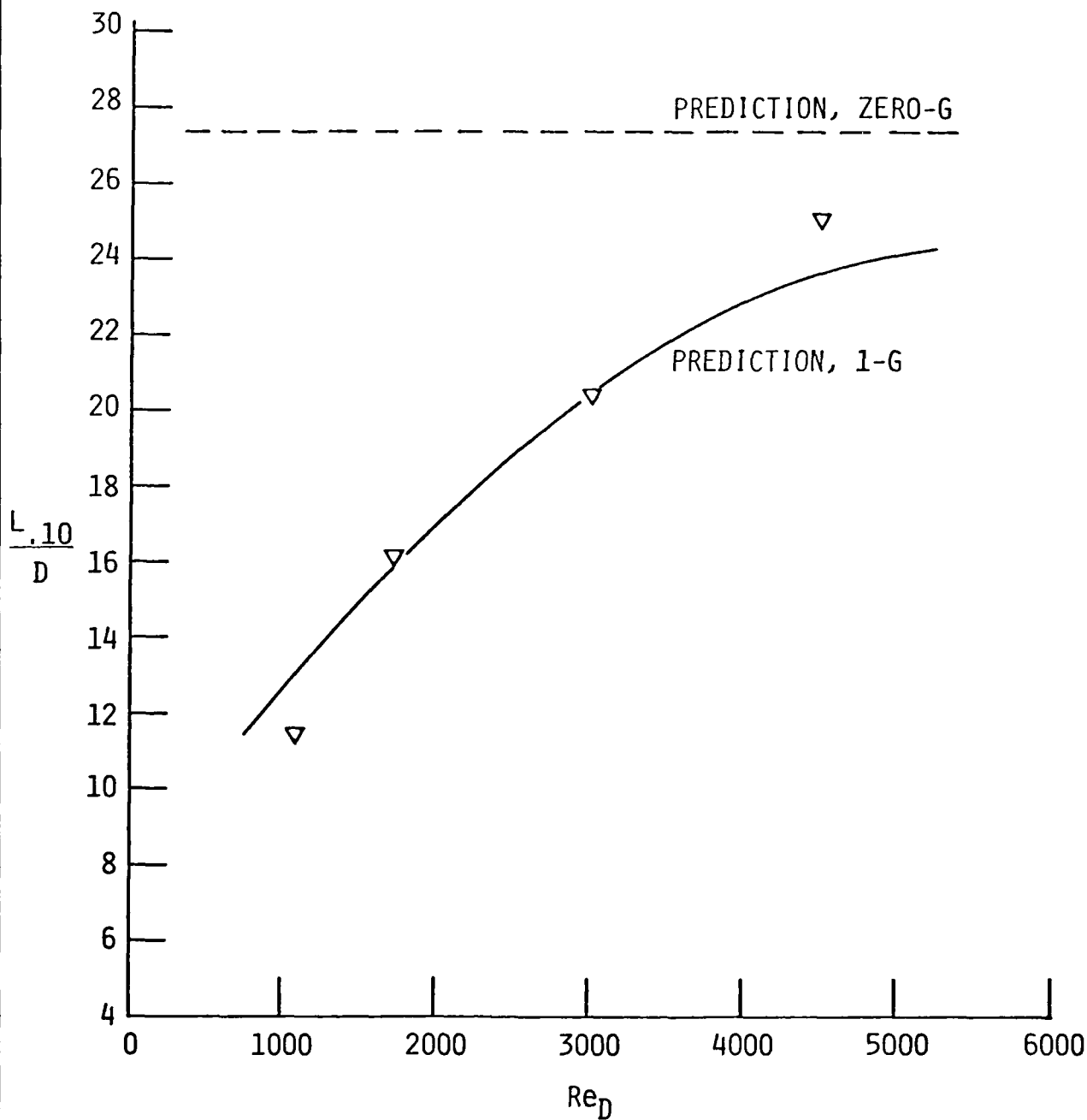
EFFECT OF MODELING ASSUMPTIONS ON PREDICTION OF
CENTERLINE TEMPERATURE, HOT BUOYANT JET

($U_j = 21.6$ ft/sec)

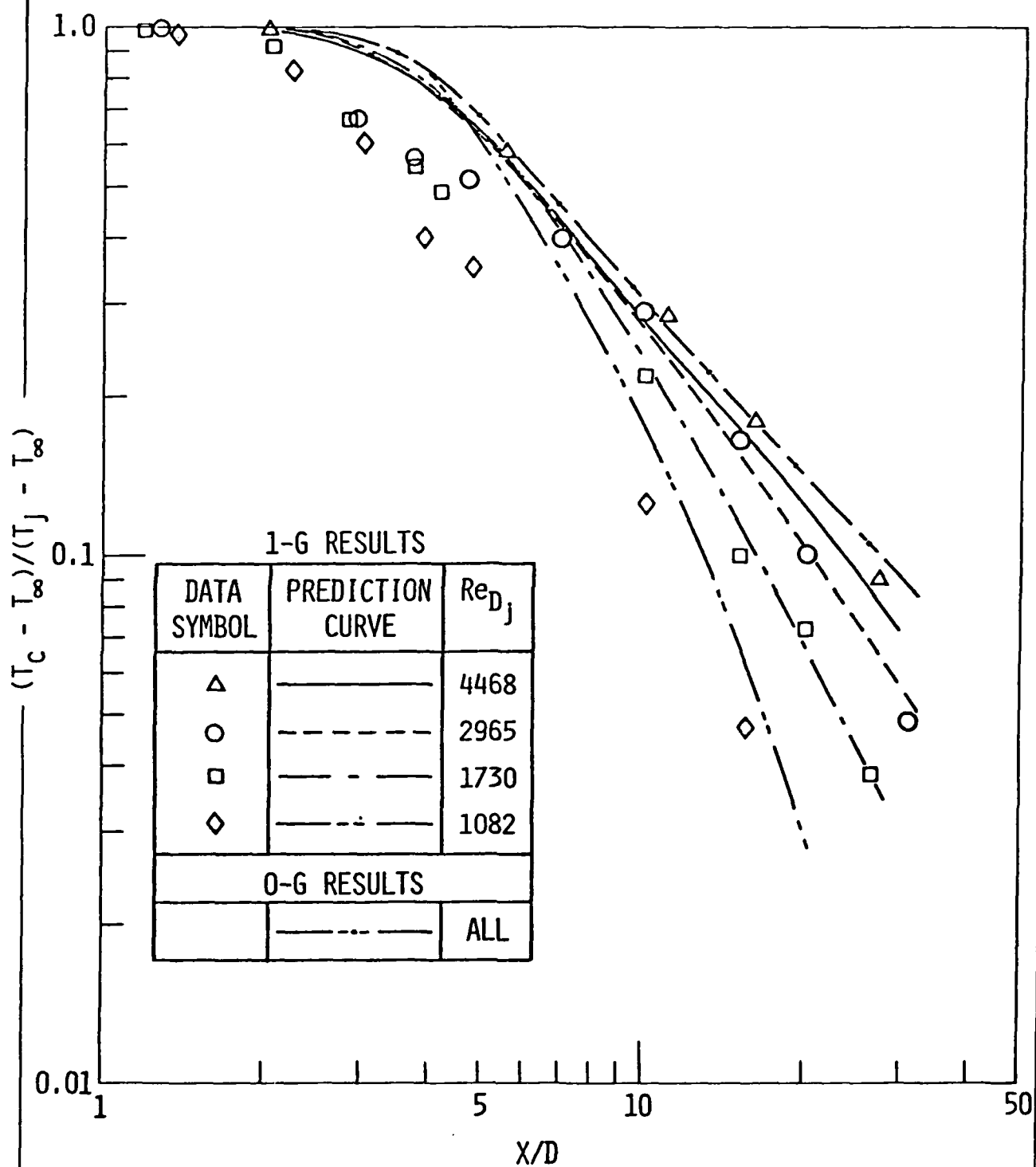




COMPARISON OF PREDICTED AND MEASURED BUOYANT PLUME LENGTHS



SAIC



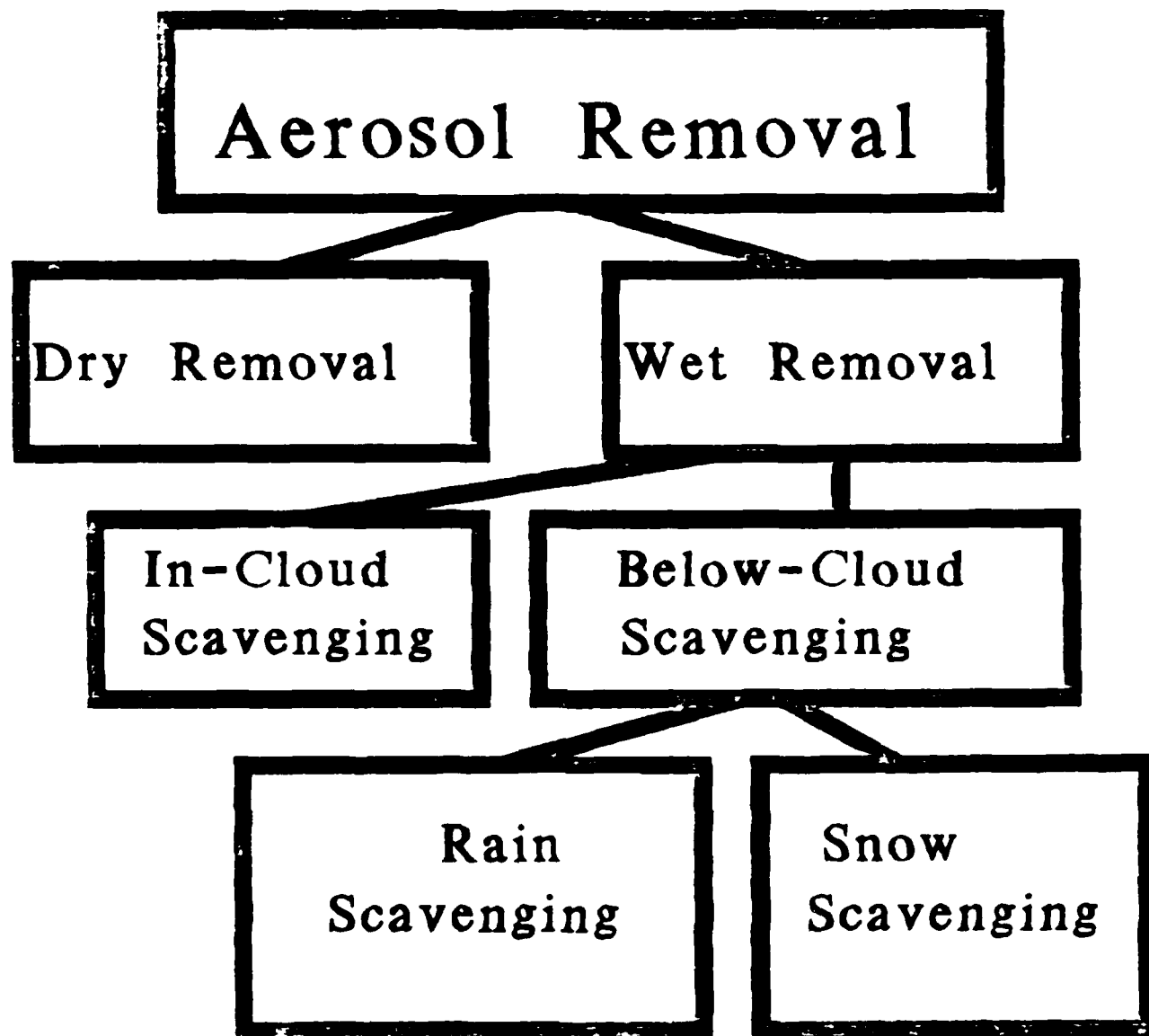
SUMMARY OF REQUIREMENTS

- Modeling
 - Application of Existing Multidimensional Analyses and Computer Codes Developed through the Incorporation of Appropriate Buoyancy-Induced Turbulence and Entrainment Submodels
 - Axisymmetric
 - 3-D
 - Chemical and Physical Processes
- Data
 - Laboratory Scales (cms)
 - Intermediate Scale (meters)
 - Large Scale (up to 100 meter)
- Various Programs of Differing Levels can be Defined to Address
 - Scaling
 - Multiple Plume Interactions
 - Fuel Effects



On the Scavenging of Aerosol Particles by Snow Crystals

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Previous Research In Precipitation Scavenging

1. Rain Scavenging

Wang, P.K., and H.R. Pruppacher, 1977b

"An experimental determination of the efficiency with which aerosol particles are collected by water drops in subsaturated air"

J. Atmos. Sci., 34, 1664-1669.

Wang, P.K., S.N. Grover, and H.R. Pruppacher, 1978

"On the effect of electric charges on the scavenging of aerosol particles by clouds and small raindrops"

J. Atmos. Sci., 35, 1735-1743.

Wang, P.K., 1979a

"Particular solutions to the steady-state diffusion equation and their application to aerosol scavenging problems"

Pap. Meteor. Res. (Taipei), 2, 37-42.

Wang, P.K., and H.R. Pruppacher, 1980a

"The effect of an external electric field on the scavenging of aerosol particles by cloud and small raindrops"

J. Coll. Interf. Sci., 75, 286-297.

Walcek, C., P.K. Wang, J.H. Topalian, S.K. Mitra, and H.R. Pruppacher, 1981

"An experimental test of a theoretical model designed to determinate the rate at which freely falling water drops scavenge SO₂ in air"

J. Atmos. Sci., 38, 871-876.

Wang, P. K., 1983b

"Collection of aerosol particles by a conducting sphere in an external electric field-continuum regime approximation"

J. Coll. Interf. Sci., 94, 301-318.

2. Snow Scavenging

Wang, P. K., and H. R. Pruppacher, 1980b

"On the efficiency with which aerosol particles of radius less than 1 micron are collected by columnar ice crystals"

Pure Appl. Geophys., 118, 1090-1108.

Martin, J.J., P.K. Wang, and H.R. Pruppacher, 1980a

"On the efficiency with which aerosol particles of radius larger than

Pure Appl. Geophys., 118, 1109-1129.

2. Snow Scavenging (cont'd)

Martin, J.J., P.K. Wang, and H.R. Pruppacher, 1980b
"A theoretical determination of the efficiency with which aerosol particles are collected by simple ice plates"
J. Atmos. Sci., 37, 1628-1638.

Martin, J.J., P.K. Wang, and H.R. Pruppacher, 1980c
"A theoretical study of the effect of electric charges on the efficiency with which aerosol particles are collected by ice crystal plates"
J. Coll. Interf. Sci., 78, 44-56.

Wang, P.K., and S.M. Denzer, 1983
"Mathematical description of the shape of plane hexagonal snow crystals"
J. Atmos. Sci., 40, 1024-1028.

Wang, P. K., 1983a
"On the definition of collision efficiency of atmospheric particles"
J. Atmos. Sci., 40, 1051-1052.

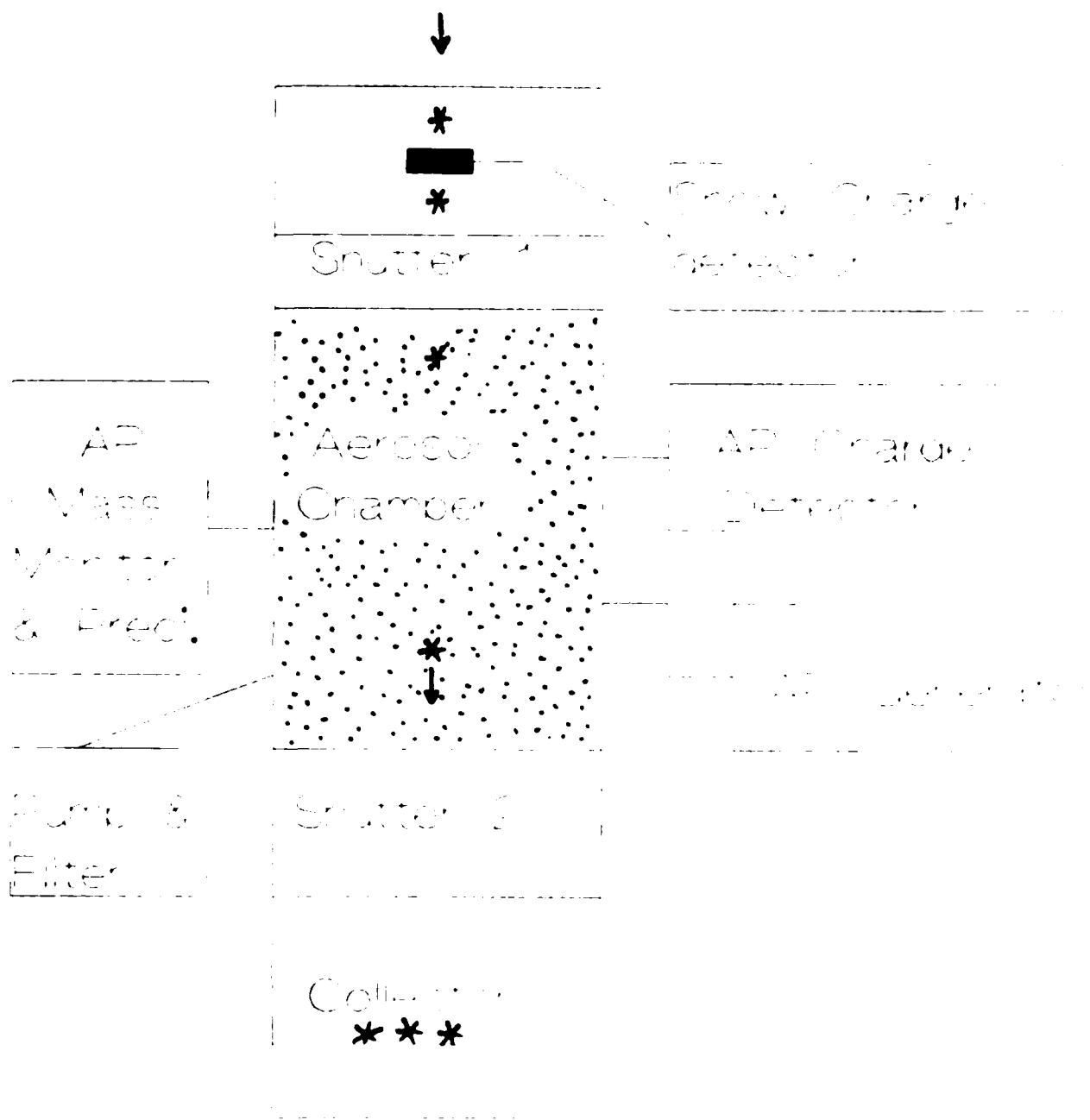
Wang, P.K., 1985
" A potential and stream function analysis of two-dimensional steady state convective diffusion equations involving Laplace fields"
Int. J. Heat Mass Transfer, 28, 1089-1095.

Wang, P. K., C. H. Chuang, and N. L. Miller, 1985
" Electrostatic, temperature, and vapor density fields surrounding stationary columnar ice crystals"
J. Atmos. Sci., 42, 2371-2379.

Wang, P. K., 1985
"A convective diffusion model for the scavenging of submicron aerosol particles by snow crystals of arbitrary shapes"
accepted by J. de Rech. Atmos.

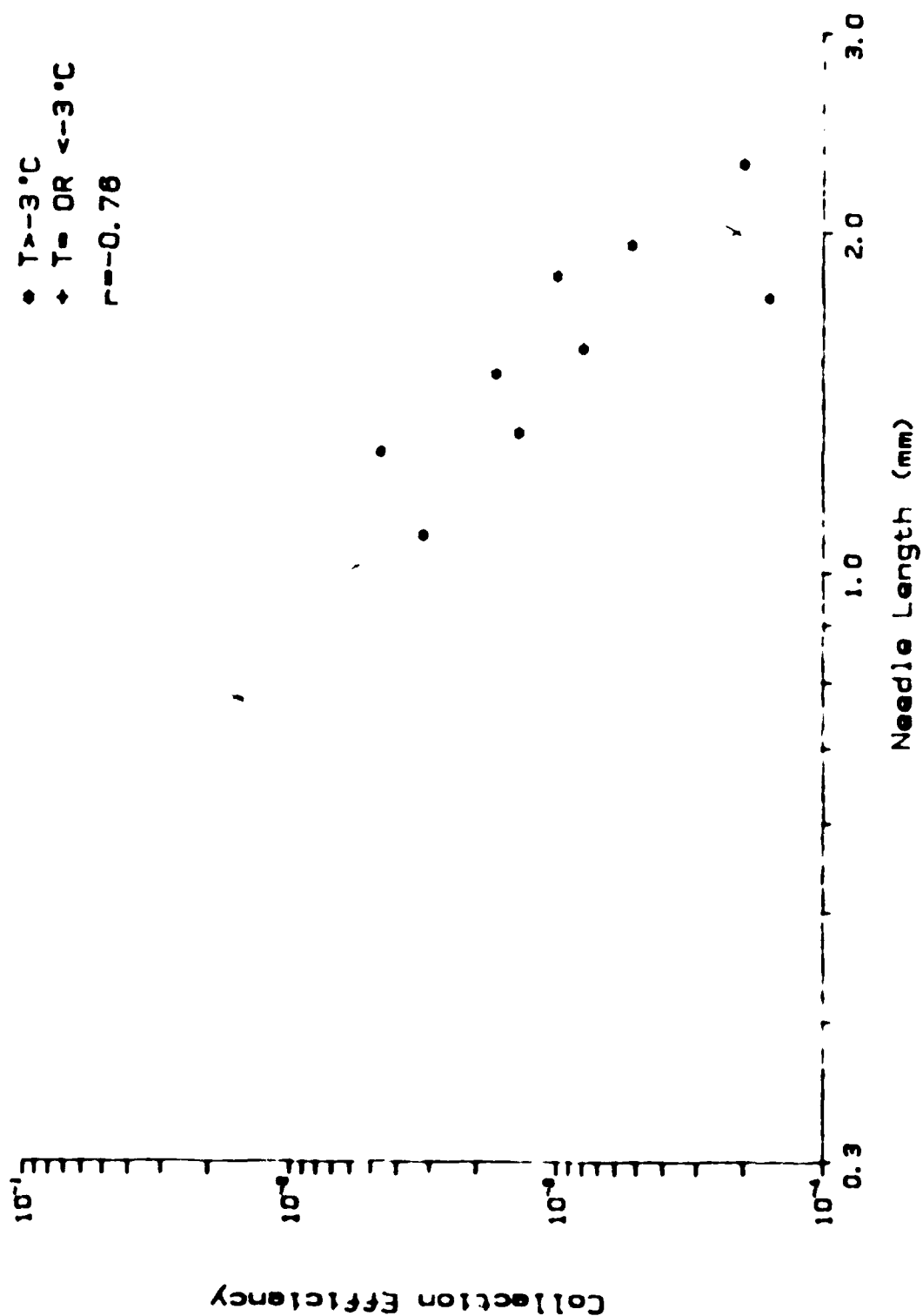
Wang, P. K., 1985
" Brownian diffusion of charged fine particles surrounding a conducting cylinder in the presence of an external electric field"
accepted by J. Aerosol Sci.

Wang, P. K., and D. Sauter
" Experimental measurements of the snow scavenging efficiencies of aerosol particles "
(to be submitted to J. Atmos. Sci.)



Snow-AP Snowfalling Filter

NEEDLES



STELLAR CRYSTALS

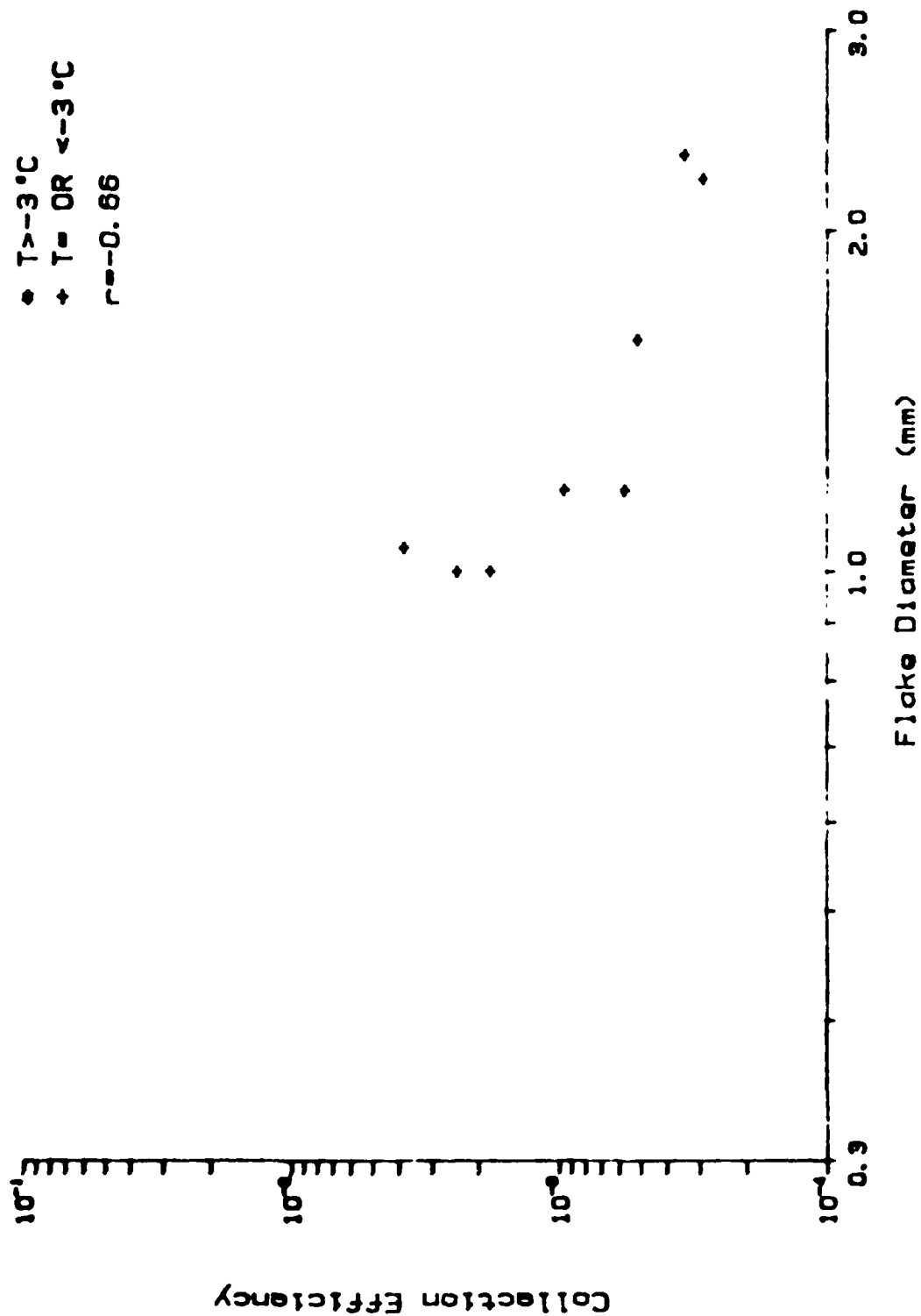


Fig 4.11

HEXAGONAL PLATES

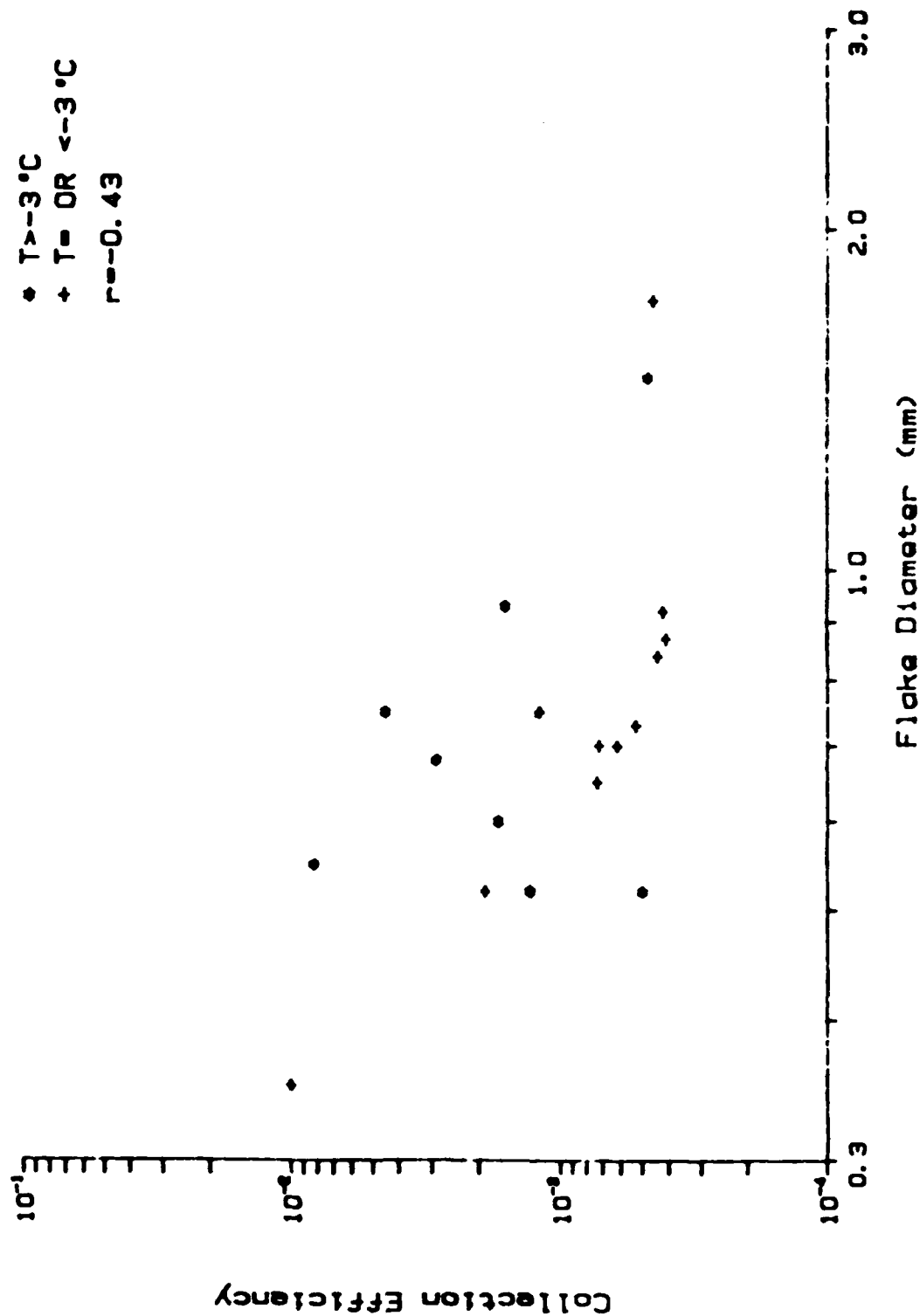


Fig 4.21

BROAD BRANCHED CRYSTALS

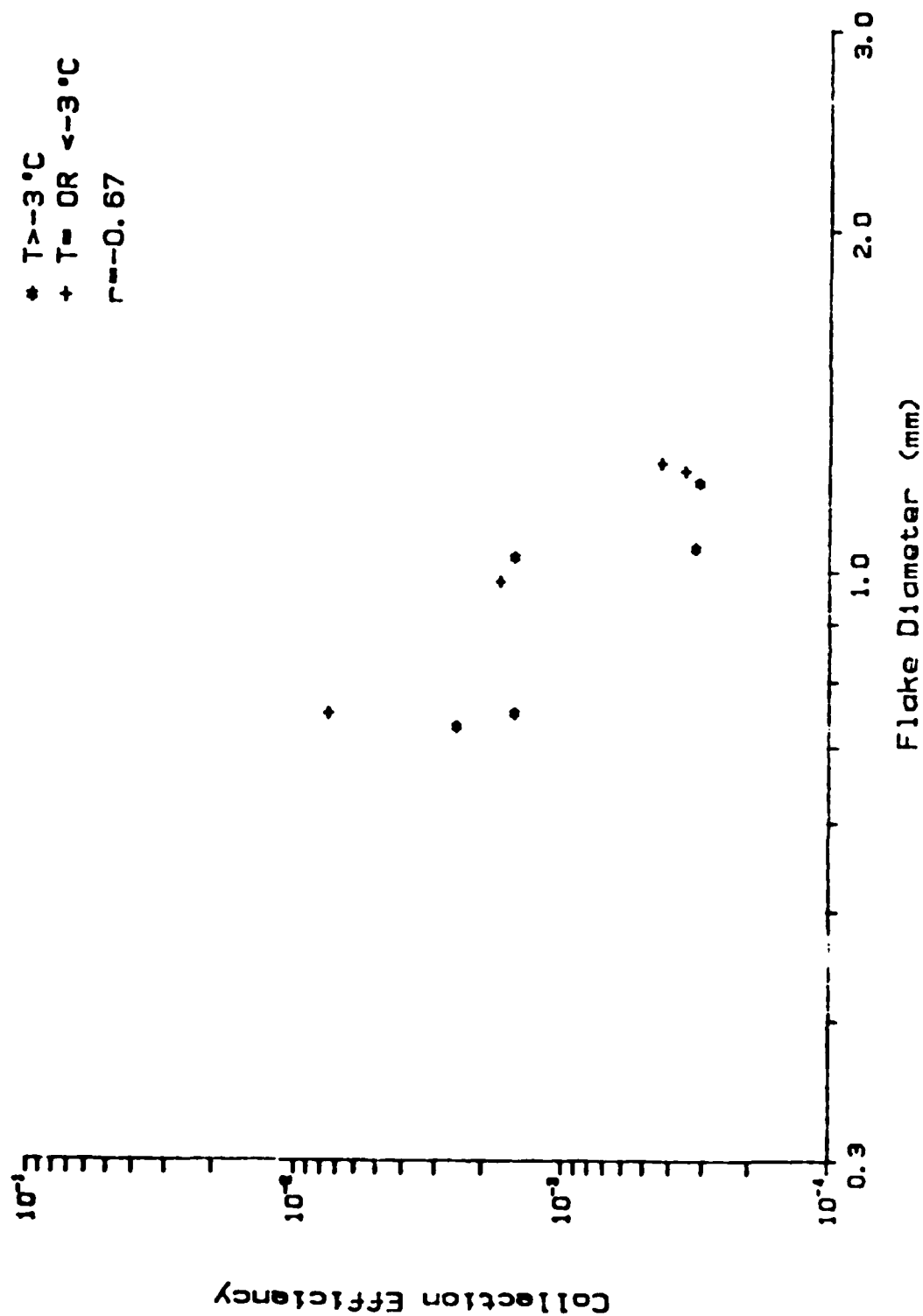


Fig 4.16
126

ALL PLATELIKE FLAKES

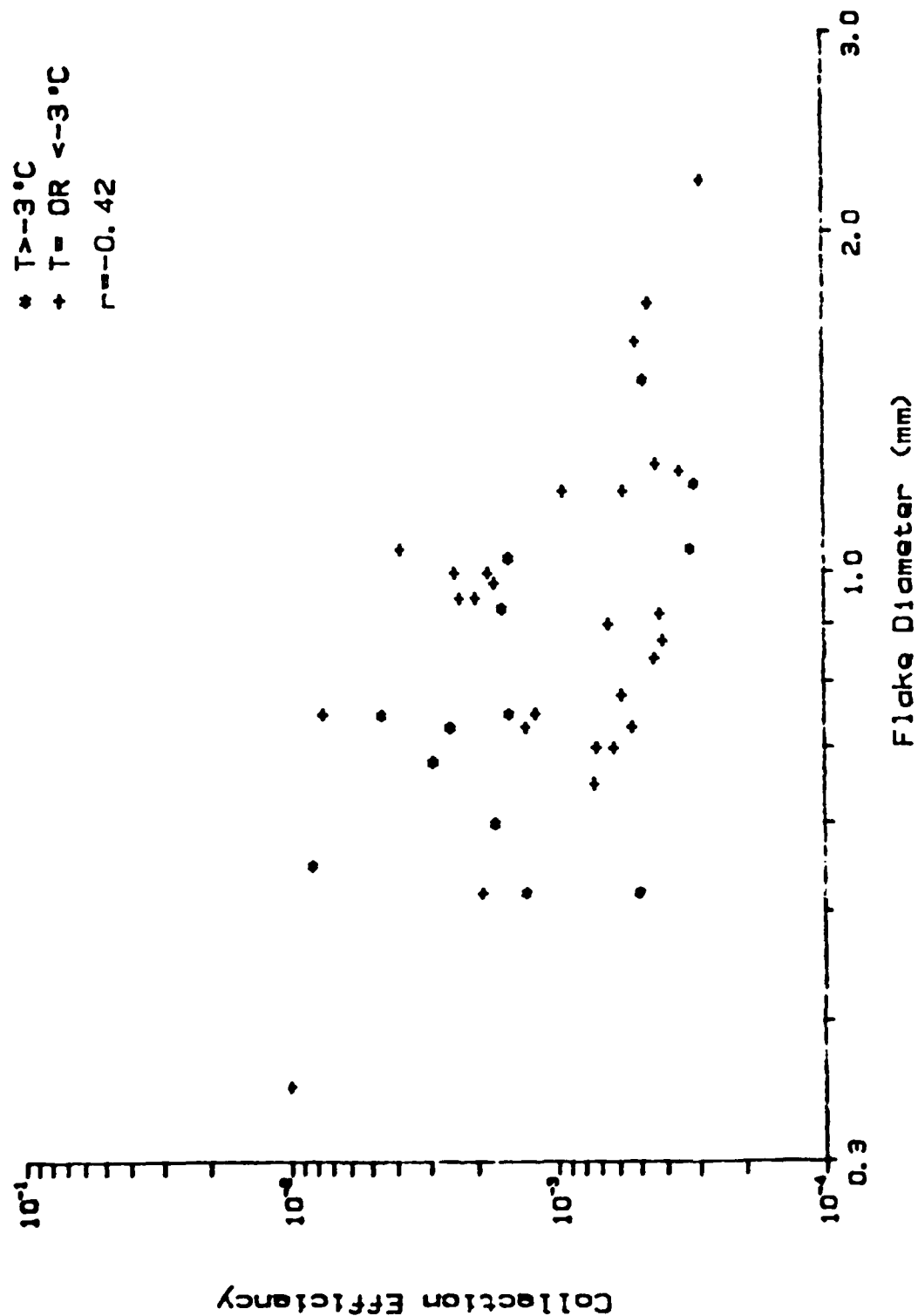


Fig 4.1
127

NEEDLES

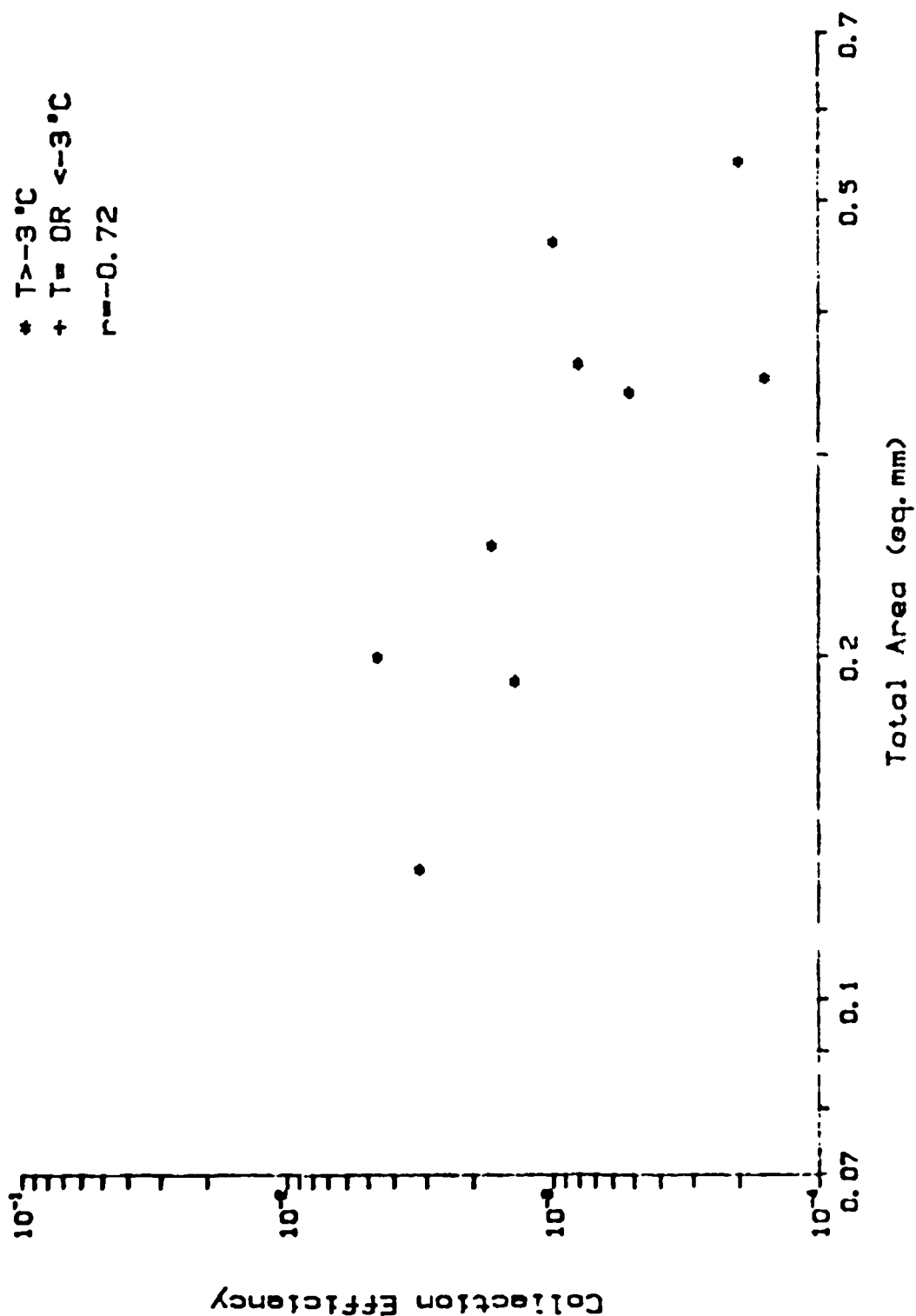


Fig. 4.9

STELLAR CRYSTALS

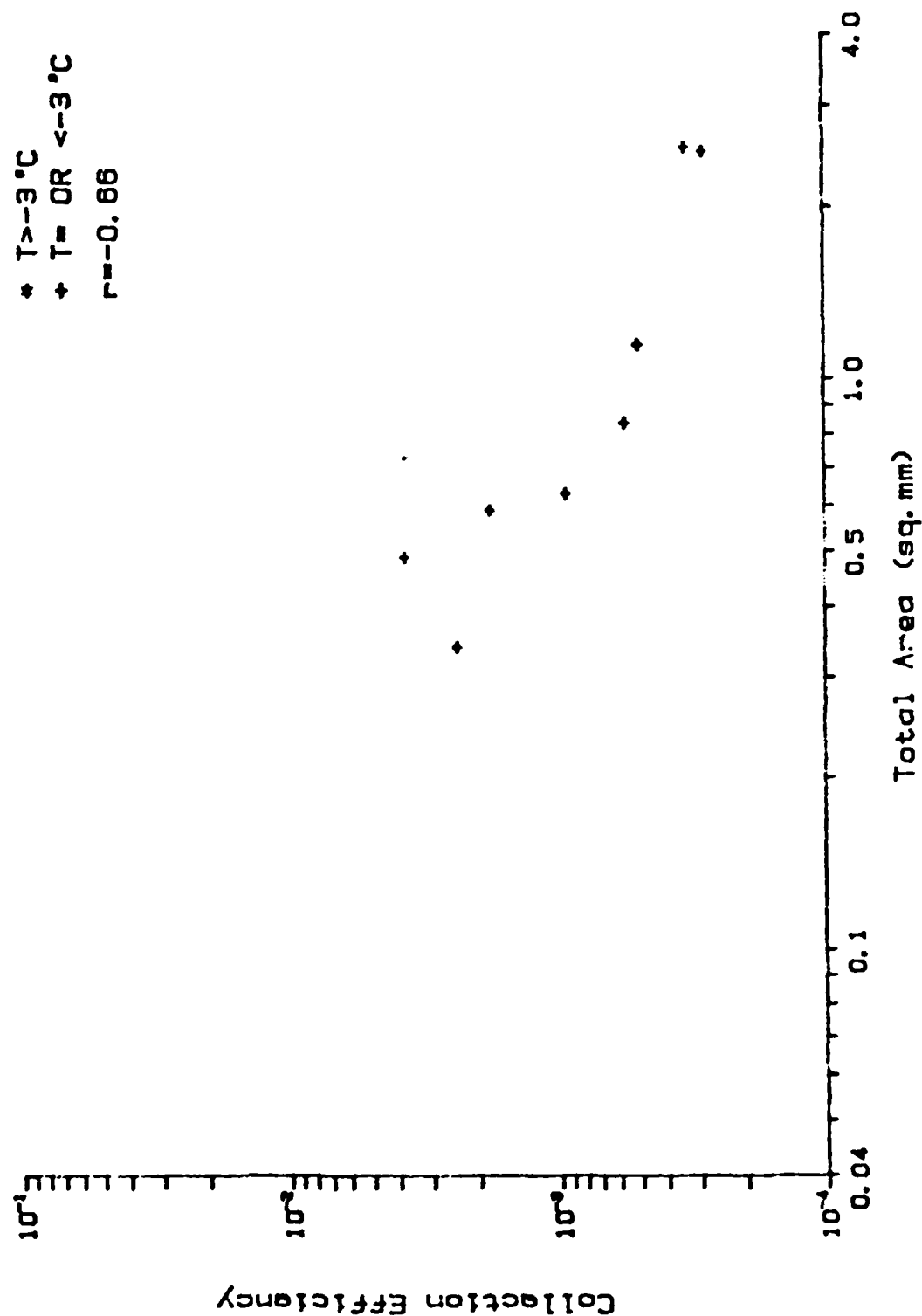


Fig 4.14

HEXAGONAL PLATES

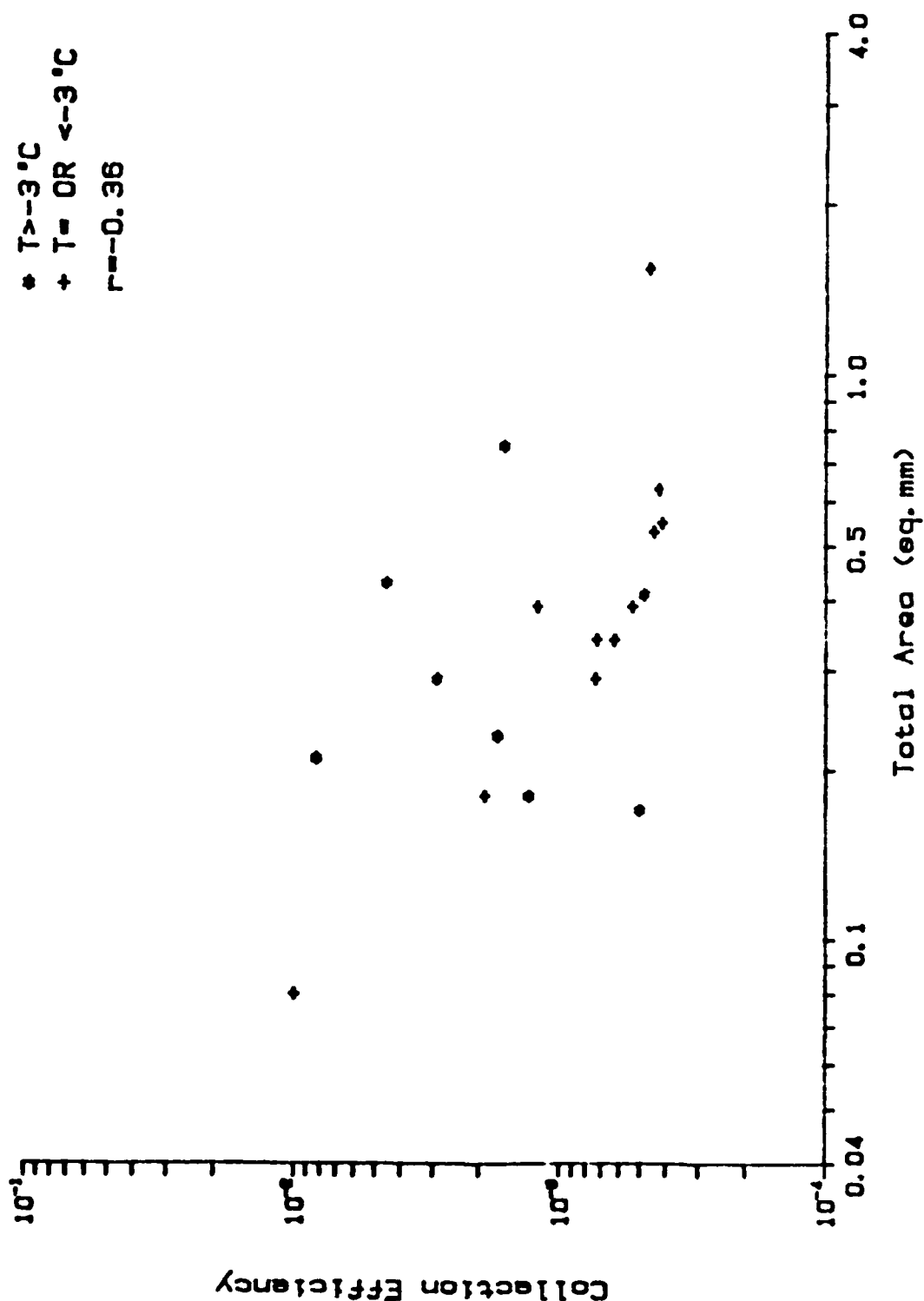


Fig 4.24

BROAD BRANCHED CRYSTALS

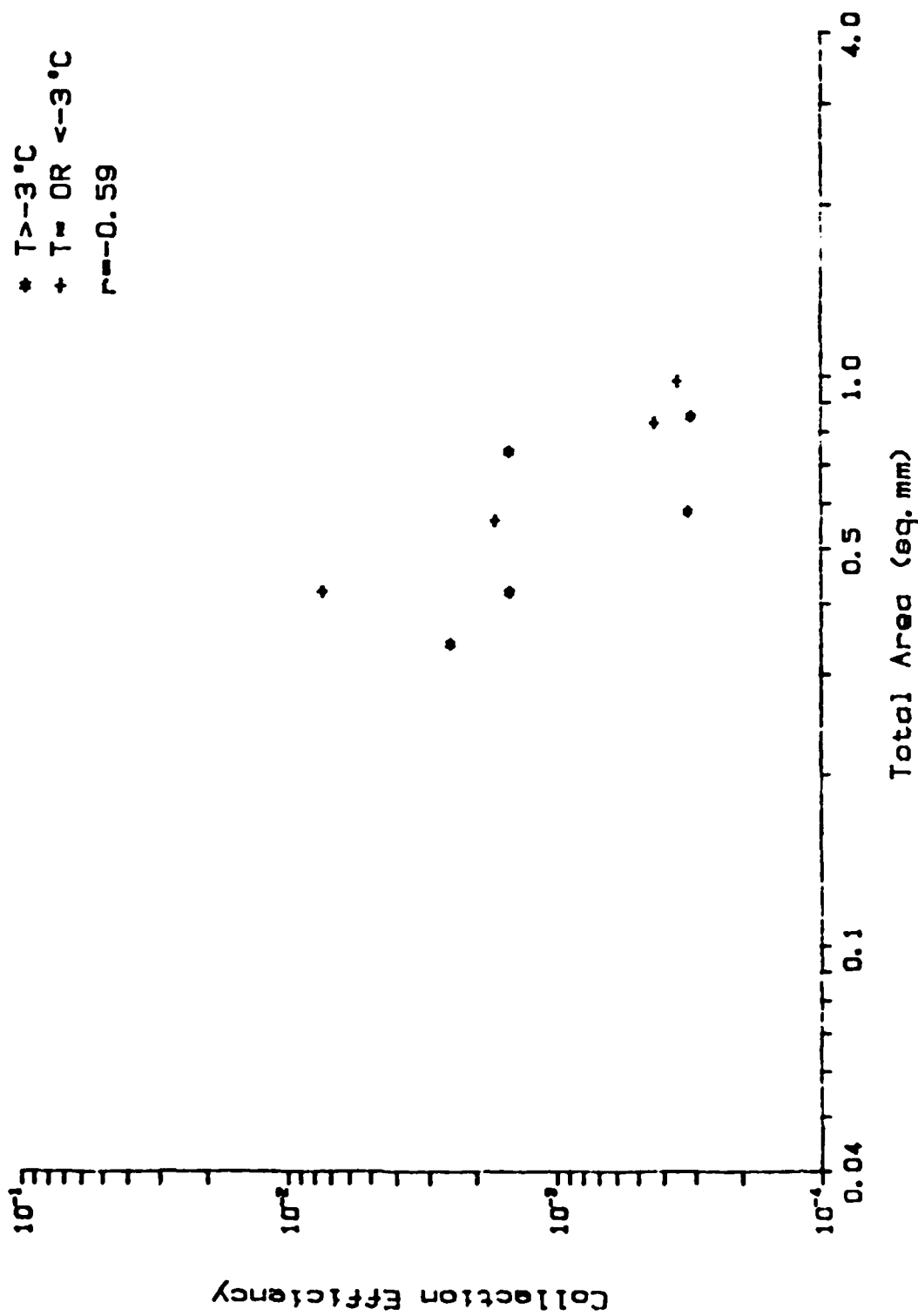


Fig 4.19

ALL PLATELIKE FLAKES

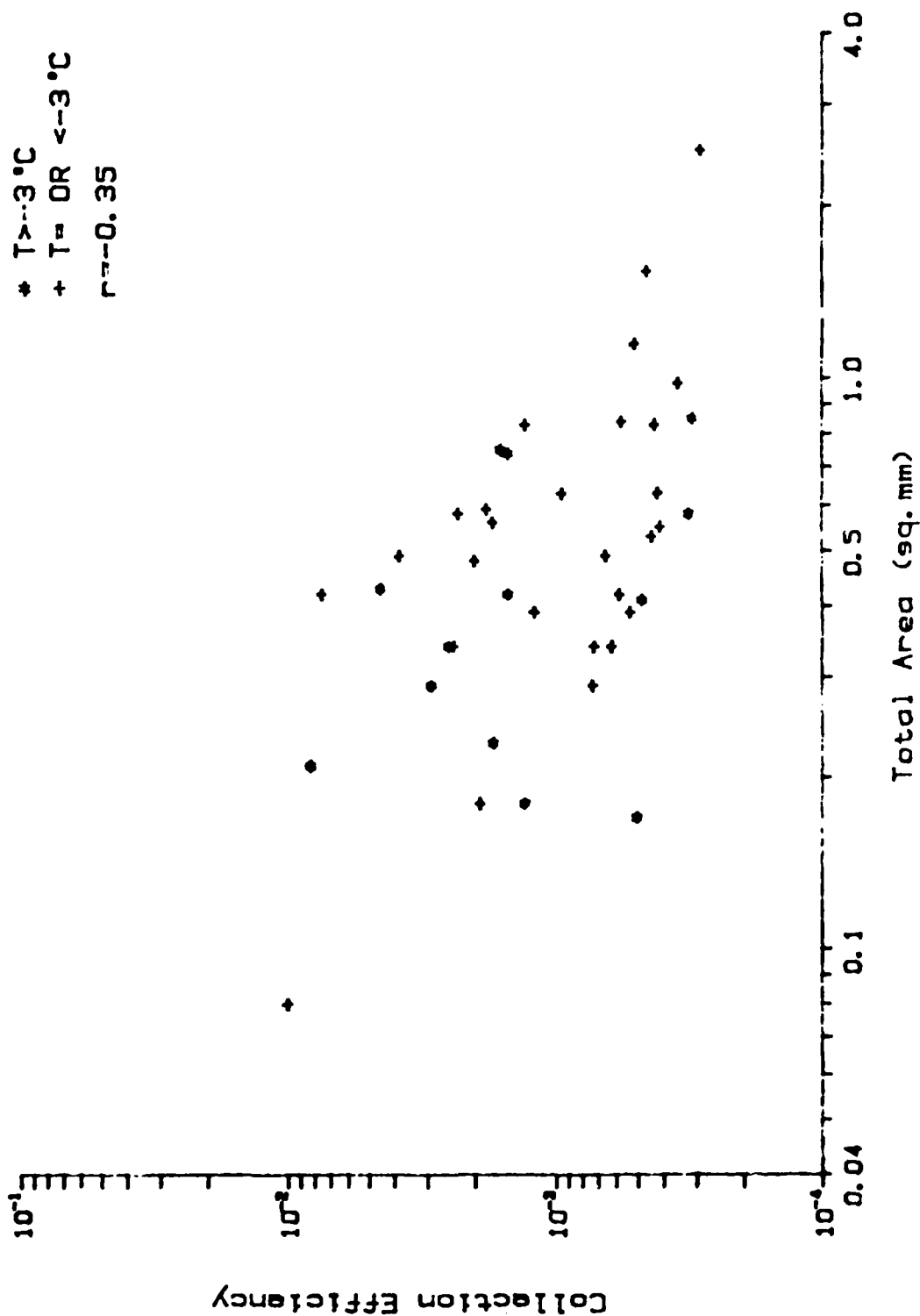


Fig 4.4

Theoretical Consideration

Basically a convective diffusion problem

The mechanisms involved are:

1. Inertial impaction
2. Brownian diffusion
3. Thermophoresis
4. Diffusiophoresis
5. Electric forces
 - Static charges
 - Extrenal electric field
6. Turbulence

Models:

1. Trajectory Model – Brownian diffusion not treated
valid for particle radius > 0.5 micron.
2. Flux Model – inertial impaction not treated
valid for particle radius ≤ 0.5 micron.

Flux Model: (Good for $r \leq 0.5 \mu\text{m}$)

④

Convective Diffusion Equation (CDE)

$$D \nabla^2 n - B \vec{F} \cdot \nabla n = 0 \quad \dots (1)$$

Ventilation-Enhanced CDE

$$\bar{f}_p D \nabla^2 n - B \sum \bar{f}_i \vec{F}_i \cdot \nabla n = 0 \quad \dots (2)$$

where $\bar{f}_i$'s are overall ventilation factors.

$$\text{B.C.} \quad \begin{cases} n = 0 & \text{at } \phi = \phi_0 \text{ (Surface)} \\ n = n_\infty & \text{at } R \rightarrow \infty \end{cases} \quad \dots (3)$$

where ϕ is the force potential.

Solution of (2) :

$$n = n_\infty \left[e^{\frac{B}{D \bar{f}_p} (\phi - \phi_0)} - 1 \right] / \left(e^{\frac{B \phi_0}{D \bar{f}_p}} - 1 \right) \quad \dots (4)$$

⑤

Resulting collection kernel :

$$K = -\frac{1}{n_\infty} \frac{\partial N}{\partial t} = -\frac{1}{n_\infty} \oint (\pi B \vec{F} - D \vec{f}_p \cdot \nabla n) \cdot d\vec{S}$$

$$= \frac{B}{e \frac{D \vec{f}_p}{\phi} - 1} \oint \vec{F} \cdot d\vec{S} \quad (\vec{F} = \sum_i \vec{f}_i \vec{F}_i) \quad \dots (5)$$

Collection Efficiency

$$E = \frac{K}{K^*} \quad \dots \dots (6)$$

Consider the following external forces :

$$\vec{F} = \vec{F}_e + \vec{F}_{th} + \vec{F}_{df} \quad \dots \dots (7)$$

$\vec{F}_e$: Electric force , $\vec{F}_{th}$: Thermophoretic force

$\vec{F}_{df}$: Diffusiophoretic force.

⑥

Applying electrostatic theory,

$$\oint \vec{F}_e \cdot d\vec{S} = 4\pi C_f (V_s - V_\infty) = 4\pi Q_f$$

$$\oint \vec{F}_{th} \cdot d\vec{S} = 4\pi c \bar{f}_h \bar{x}_{th} (T_s - T_\infty)$$

$$\oint \vec{F}_{df} \cdot d\vec{S} = 4\pi c \bar{f}_h \bar{x}_{df} (\rho_{v,s} - \rho_{v,\infty})$$

V : Electric potential, T : Temp., ρ_v : Vapor density

C : Capacitance (different for different shapes + sizes)

$$\bar{x}_{th} = \frac{12 \pi \eta_a r (k_a + 2.5 k_p N_{kn}) k_a}{5(1 + 3 N_{kn}) (k_p + 2 k_a + 5 k_p N_{kn}) P}$$

$$\bar{x}_{df} = \frac{6 \pi \eta_a r (0.74 D_v M_a)}{(1 + \alpha N_{kn}) M_w \rho_a}$$

(7)

Therefore the collection kernel is

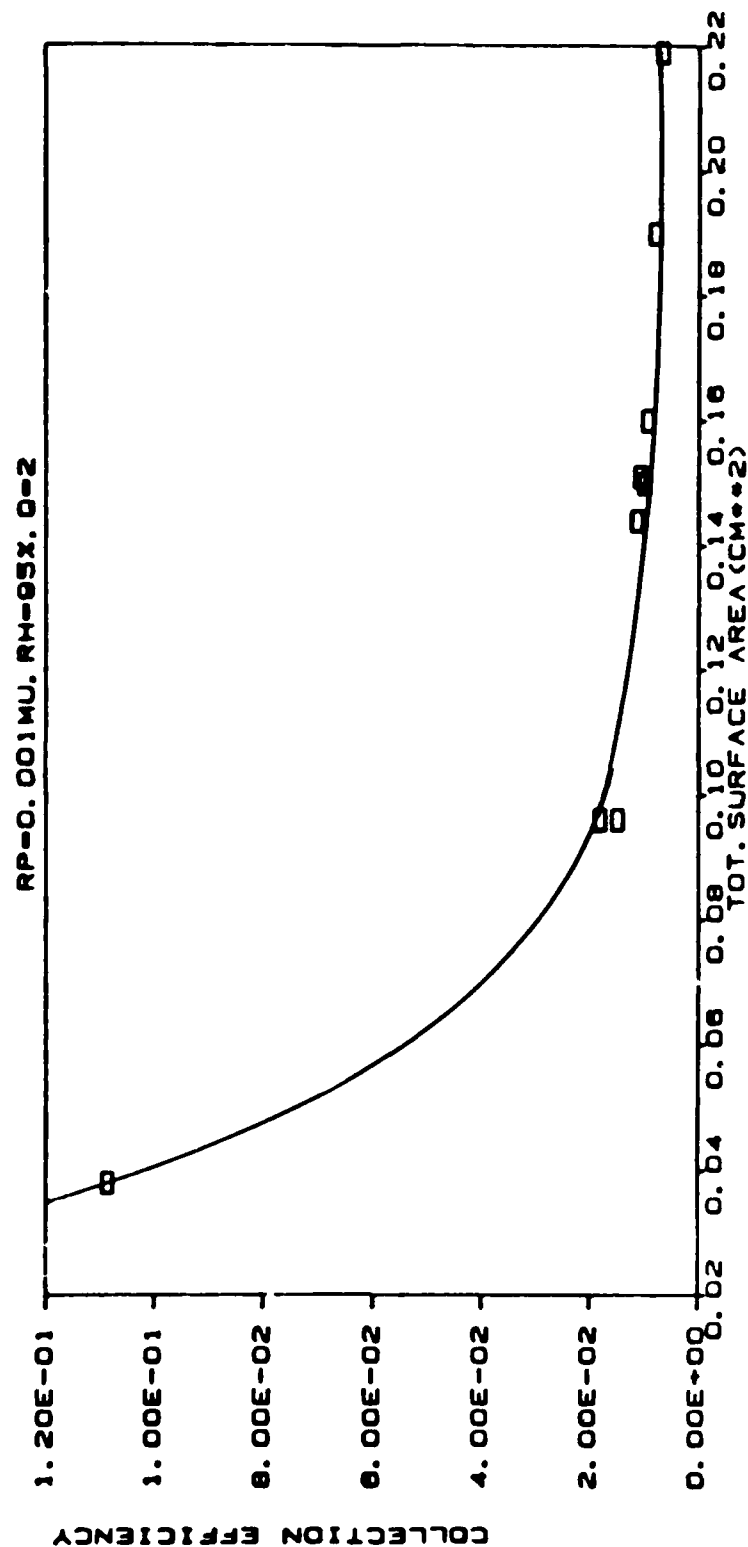
$$K = - \frac{4\pi B [\alpha_f + C \bar{f}_h \bar{z}_{th} (T_s - T_\infty) + C \bar{f}_h \bar{z}_{df} (p_{v,s} - p_{v,\infty})]}{e^{\frac{B}{D_f} \phi} - 1}$$

$$= - \frac{4\pi B \phi_0 C}{e^{\frac{B}{D_f} \phi_0} - 1}$$

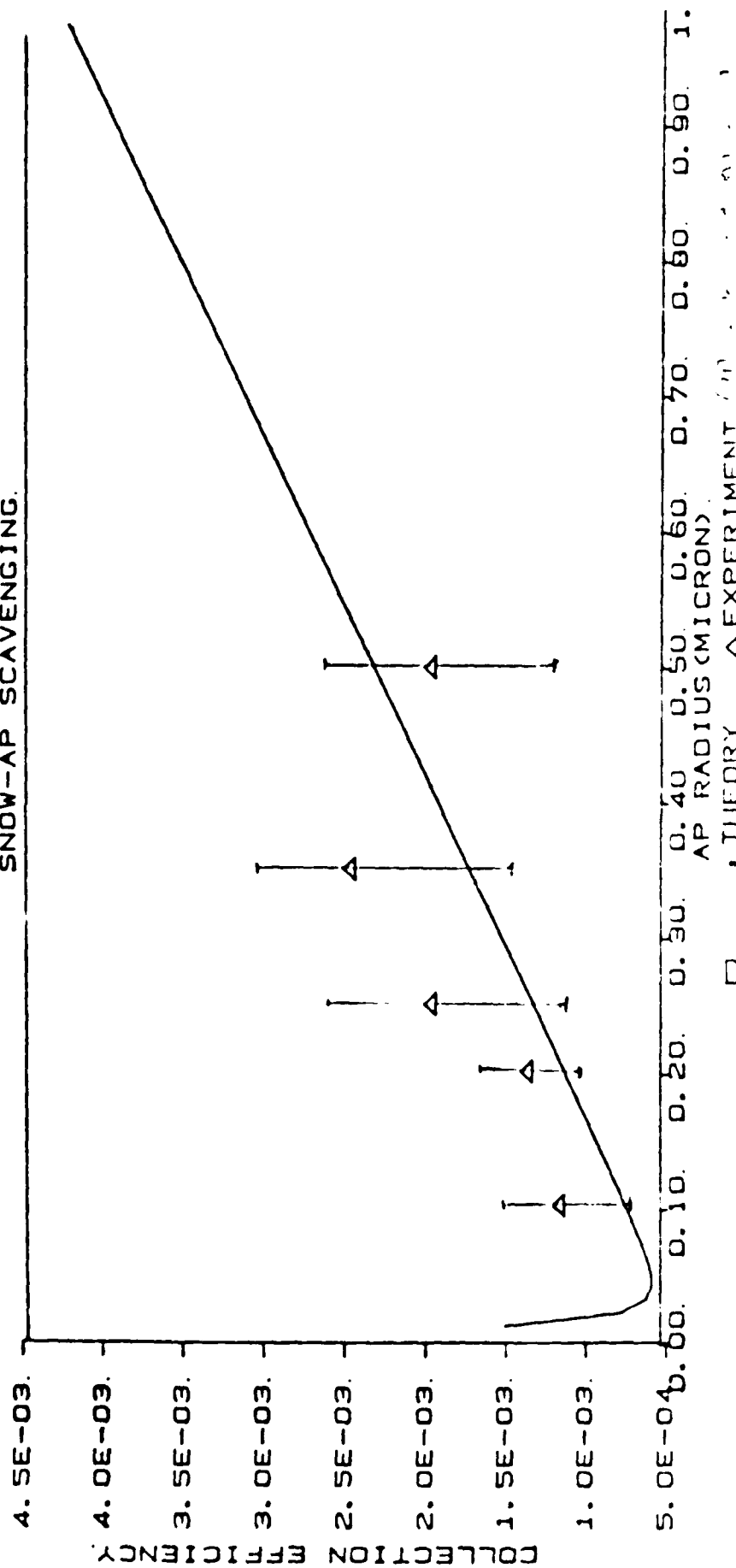
For sphere : $C = a$ (radius)

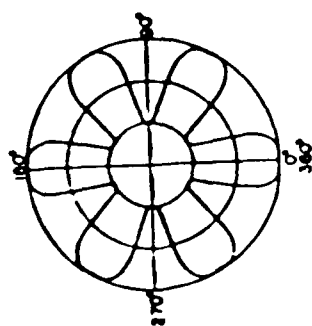
For complicated shapes such as snow flakes,

C can be measured experimentally.

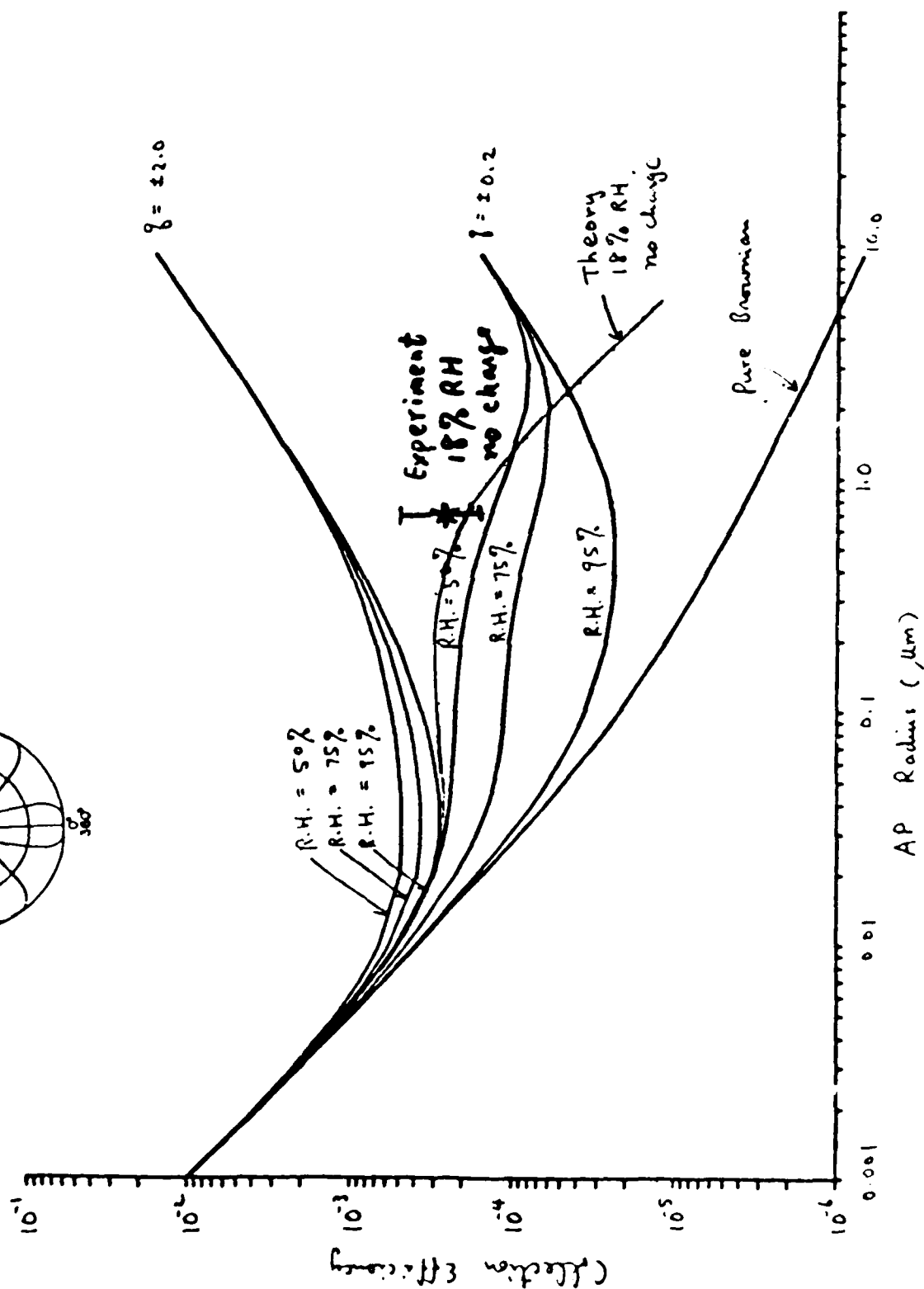


SNOW-AP SCAVENGING.





Max. Dimension = 0.2 cm



CLOUD MODEL SENSITIVITY STUDIES
ON THE VERTICAL PENETRATION OF SOOT

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Air Force Geophysics Lab.
AFGL/LYC
Hanscom AFB, MA
(617) 861-2948

OVERVIEW

- Review 3-D cloud model results
 - dependence of upward soot penetration on atmospheric conditions
- Offers hope for simple parameterization of vertical soot profiles
- Atmospheric stability indices - distributions
 - by season
 - by region
- Sample procedure: how distribution approach might be used to estimate amount of soot initially entering stratosphere

- Forest fire (and other) smoke plume heights - sensitive to atmospheric stability, moisture content, in addition to fire intensity - (NRC, '85)
- If urban fires have larger heat fluxes (10x), are those larger fires also sensitive to atmospheric structure?
- 3-D numerical cloud simulations indicate that they are.

3-D Cloud Model Simulations

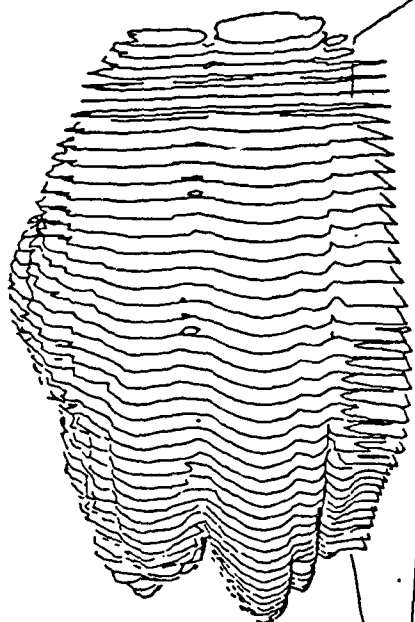
- standard atmosphere + moisture, winds
- to 30 min (60 min w/ reduced heat flux)
- cloud microphysics (cloud, rain, ice, "snow", graupel/hail)
- soot tracer

see descriptions by Tripoli & Cotton

SAMPLE OUTPUT

- 3-D pictures
- 2-D cross sections
- numerical output fields

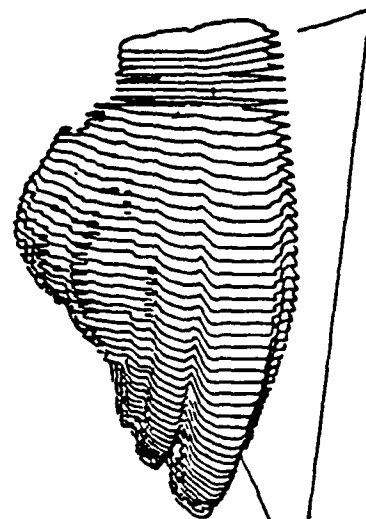
MOIST



DRY

(3)
TIME = 1800. SECONDS

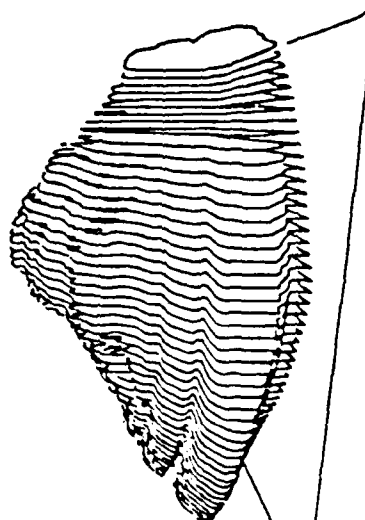
SHORE

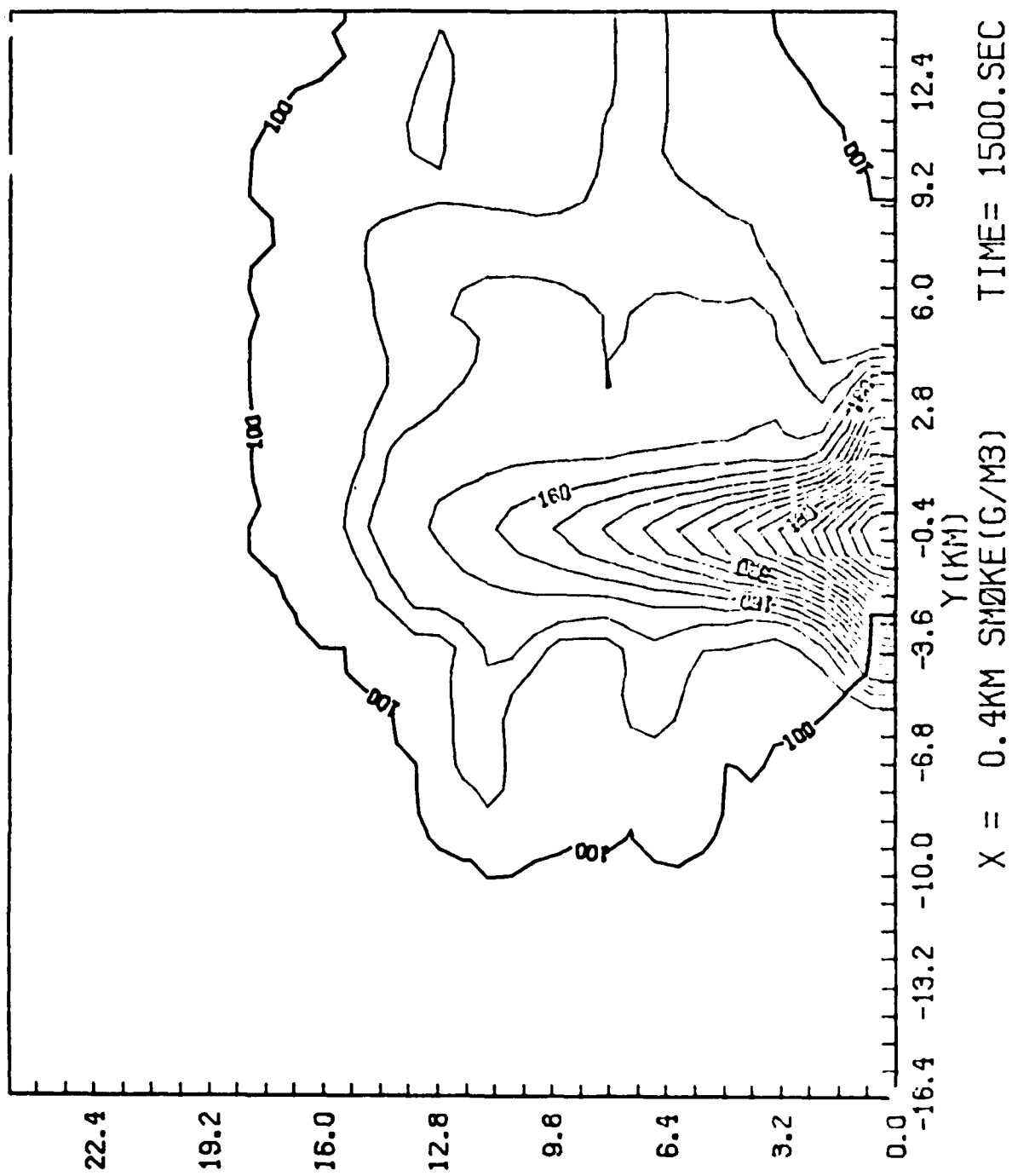


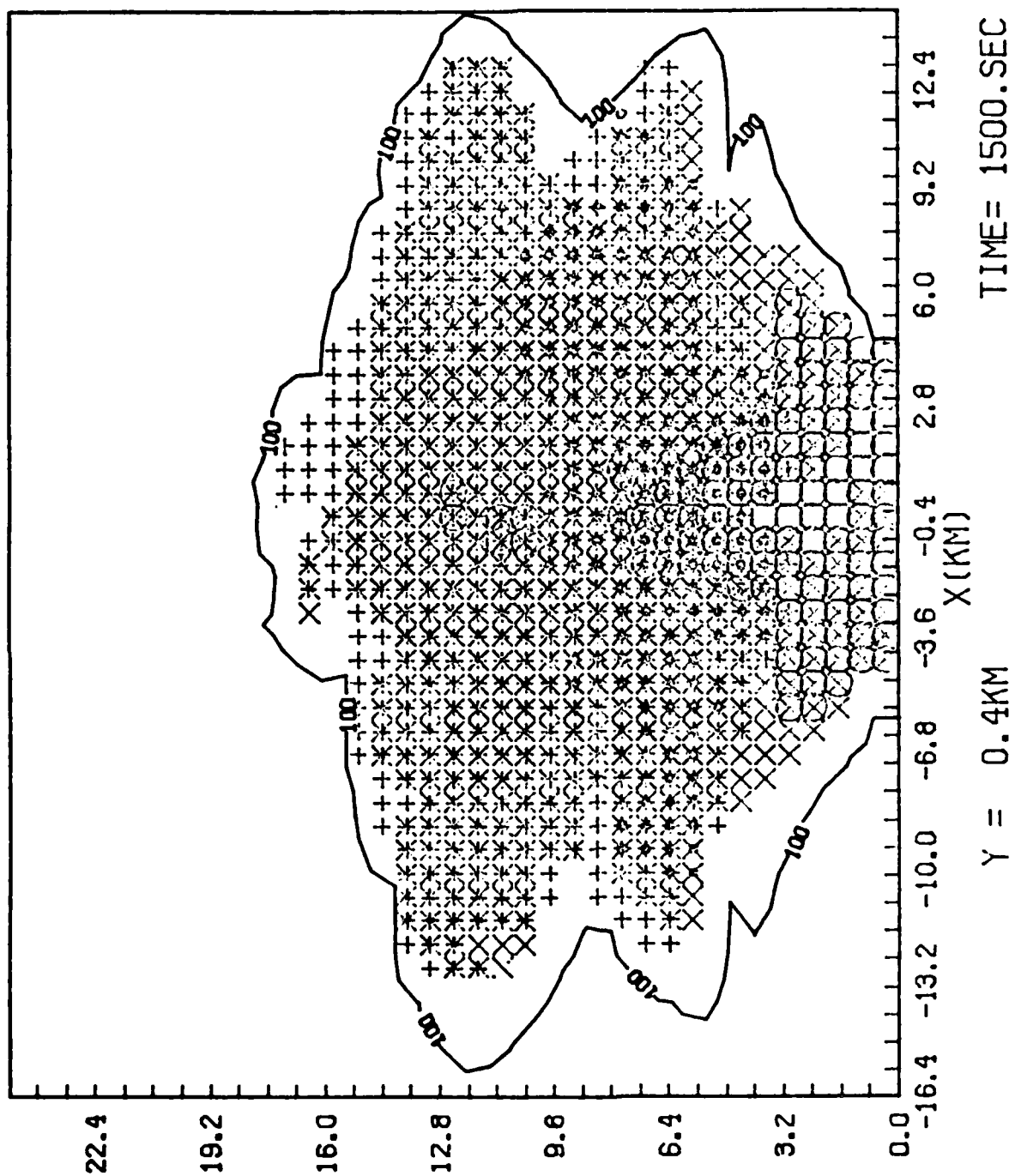
DRY
ATMOSPHERE

(3)
TIME = 1800. SECONDS

SHORE







SUMMARY OF MODEL-RUN COMPARISONS

Stability

unstable (Cotton & Tripoli): 44% into stratosphere
stable (std. atmos): 22% " "

Moisture (std atmos)

with 40-50% RH in troposphere: 22% into stratosp
with 0 moisture < 1% " "

Heat flux (std atmos)

100% - smoke penetrated to 14 km.
10% - no smoke above 6 km.

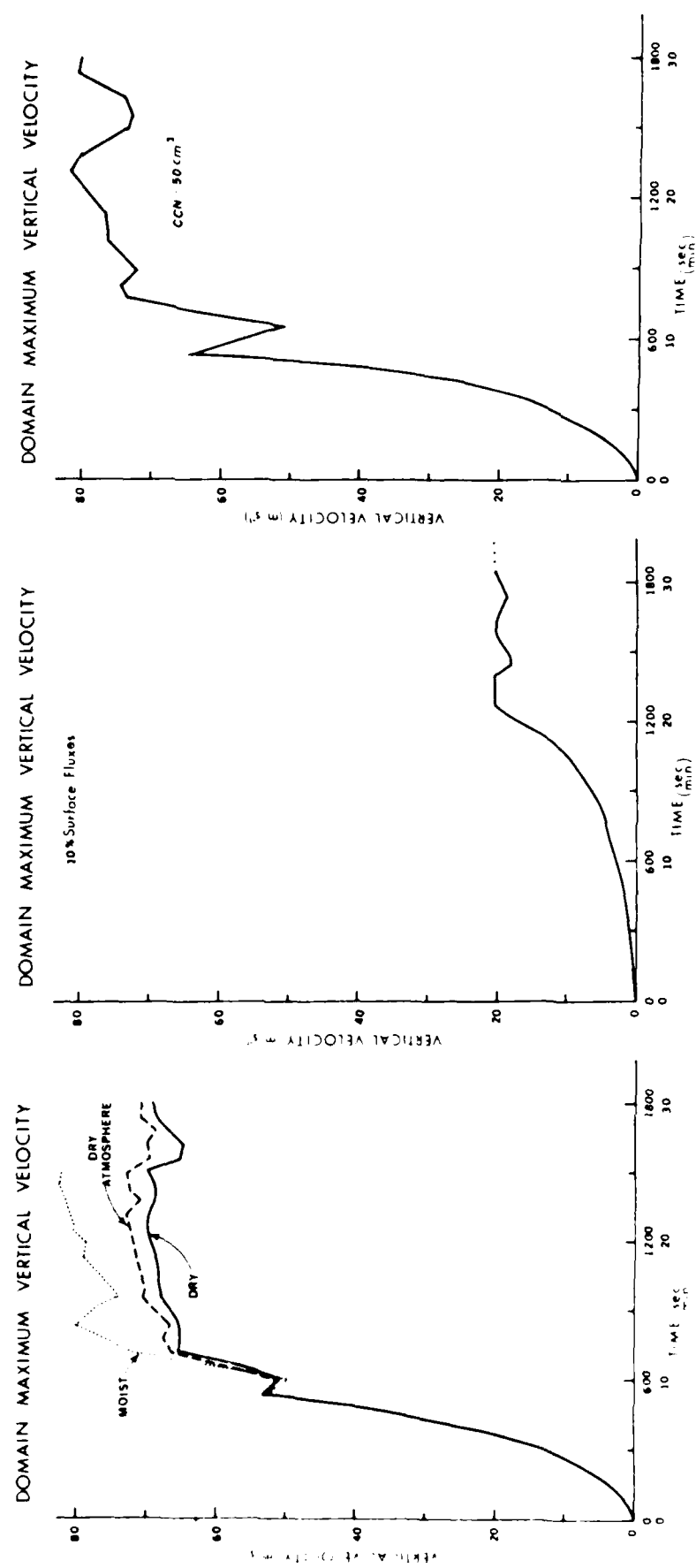
Large heat-flux fires - sensitive to atmosphere

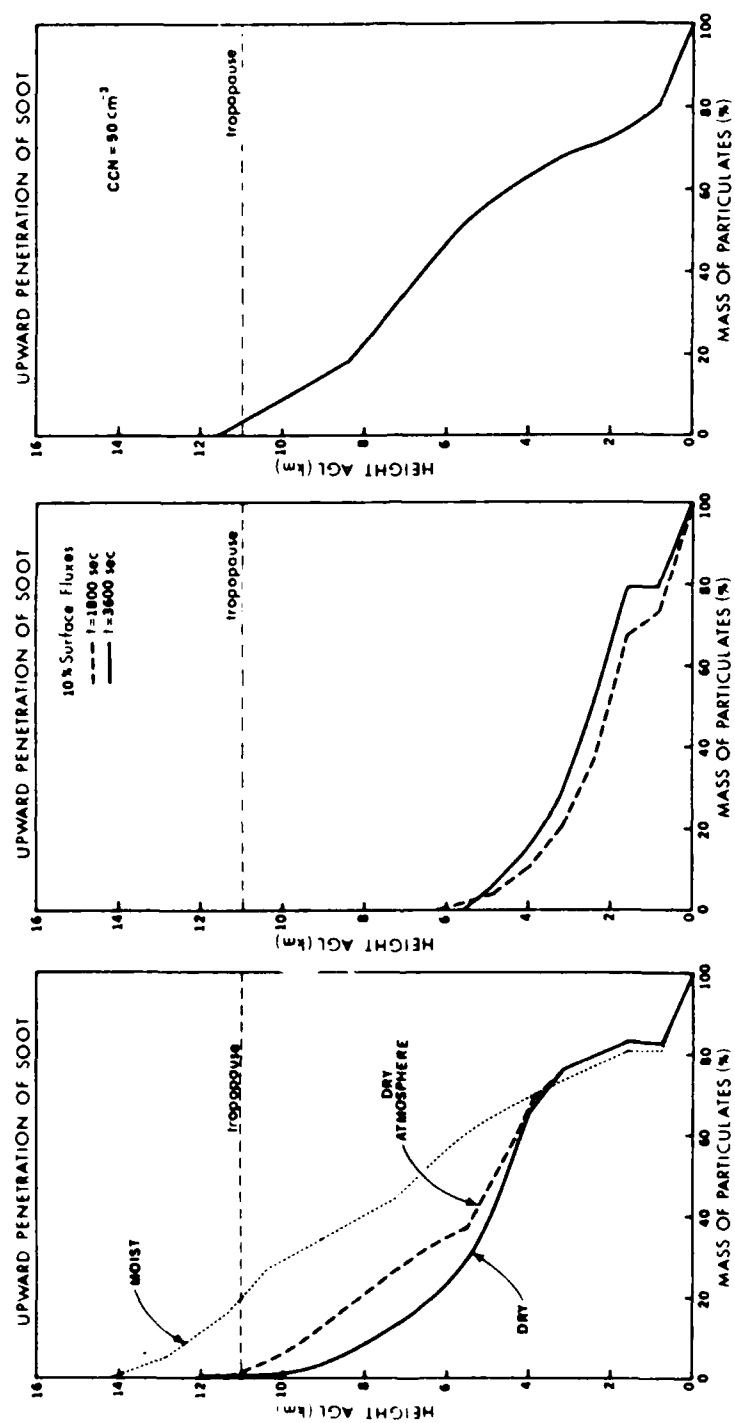
MODEL - RUN COMPARISONS

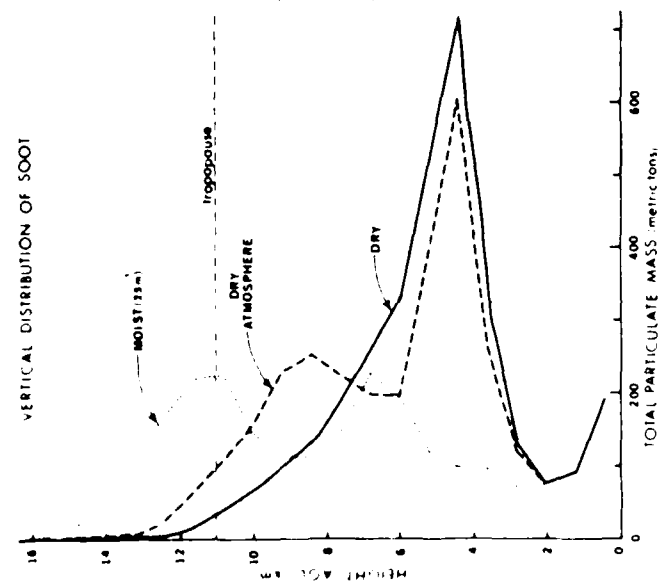
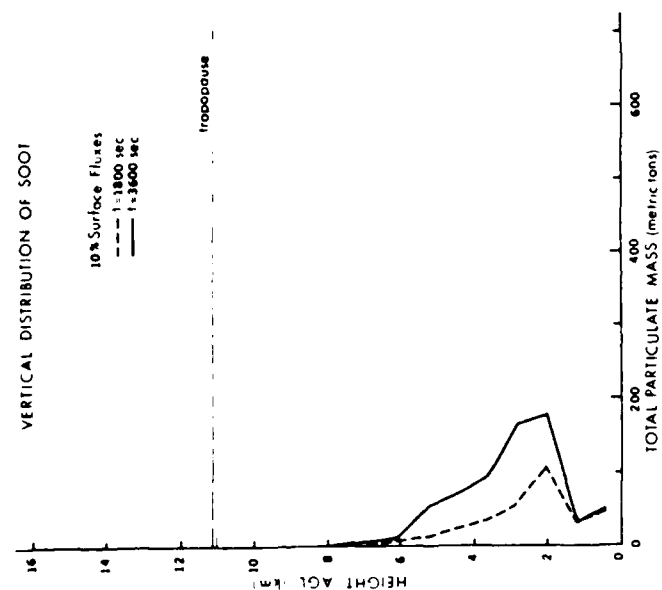
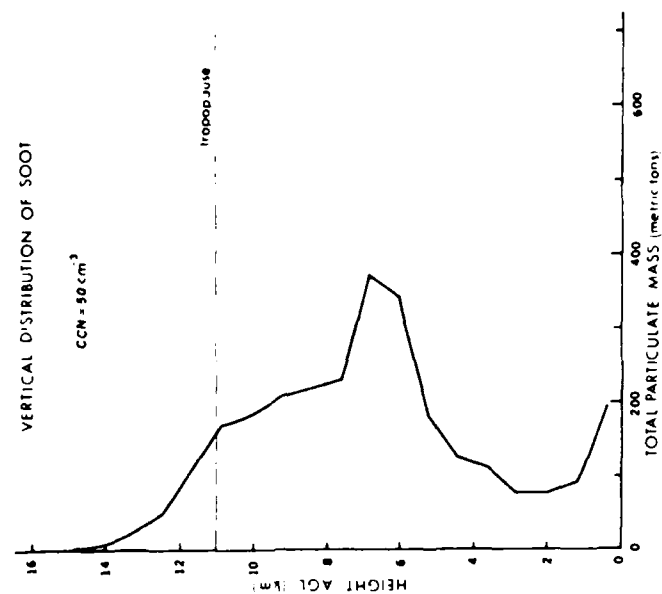
One more issue - CCN concentrations
5000 cm^{-3} 22% into stratosphere
50 cm^{-3} 11% into stratosphere
(attempt to represent some large nuclei)

less latent heat of fusion

but with the phoretic effects modeled,
< 2% scavenging in both cases



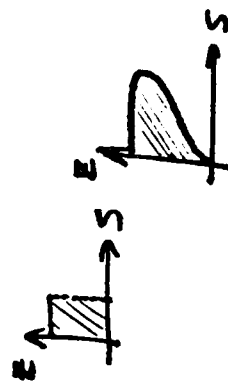




PARAMETERIZATION OF VERTICAL INJECTION PROFILE

Previous results suggest that vertical injection profiles can be parameterized in terms of some stability (etc.) parameter as input into larger-scale models. Need

- profile shape
uniform



detrainment curve

- height of plume

fire heat flux
atmospheric stability
atmospheric moisture
(low-level, precipitable water)
wind profile
tropopause height (normalize?)
etc.

VARIABILITY OF STABILITY INDICES BY SEASON, BY REGION

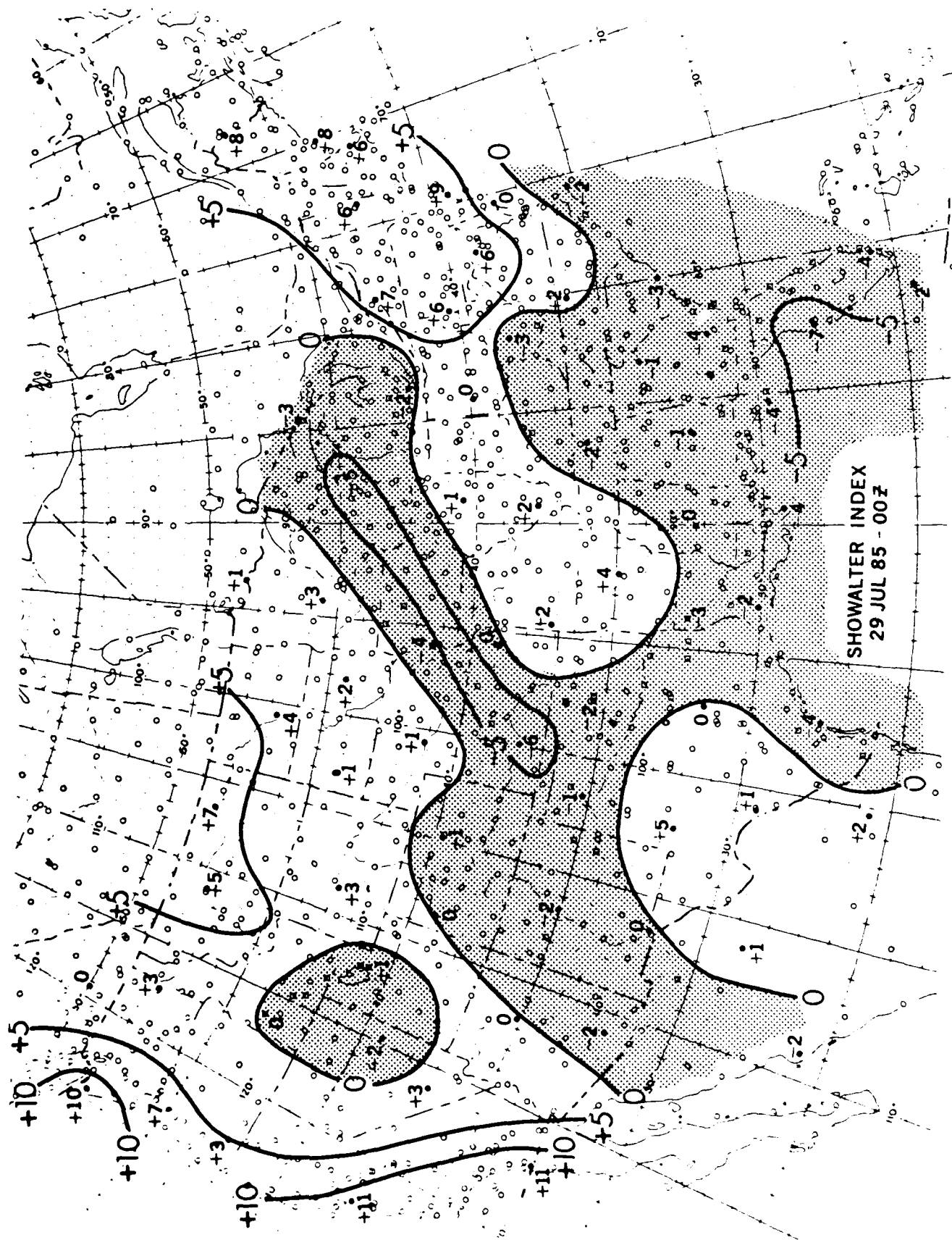
Analog of the desired parameter

Stability Indices, e.g.

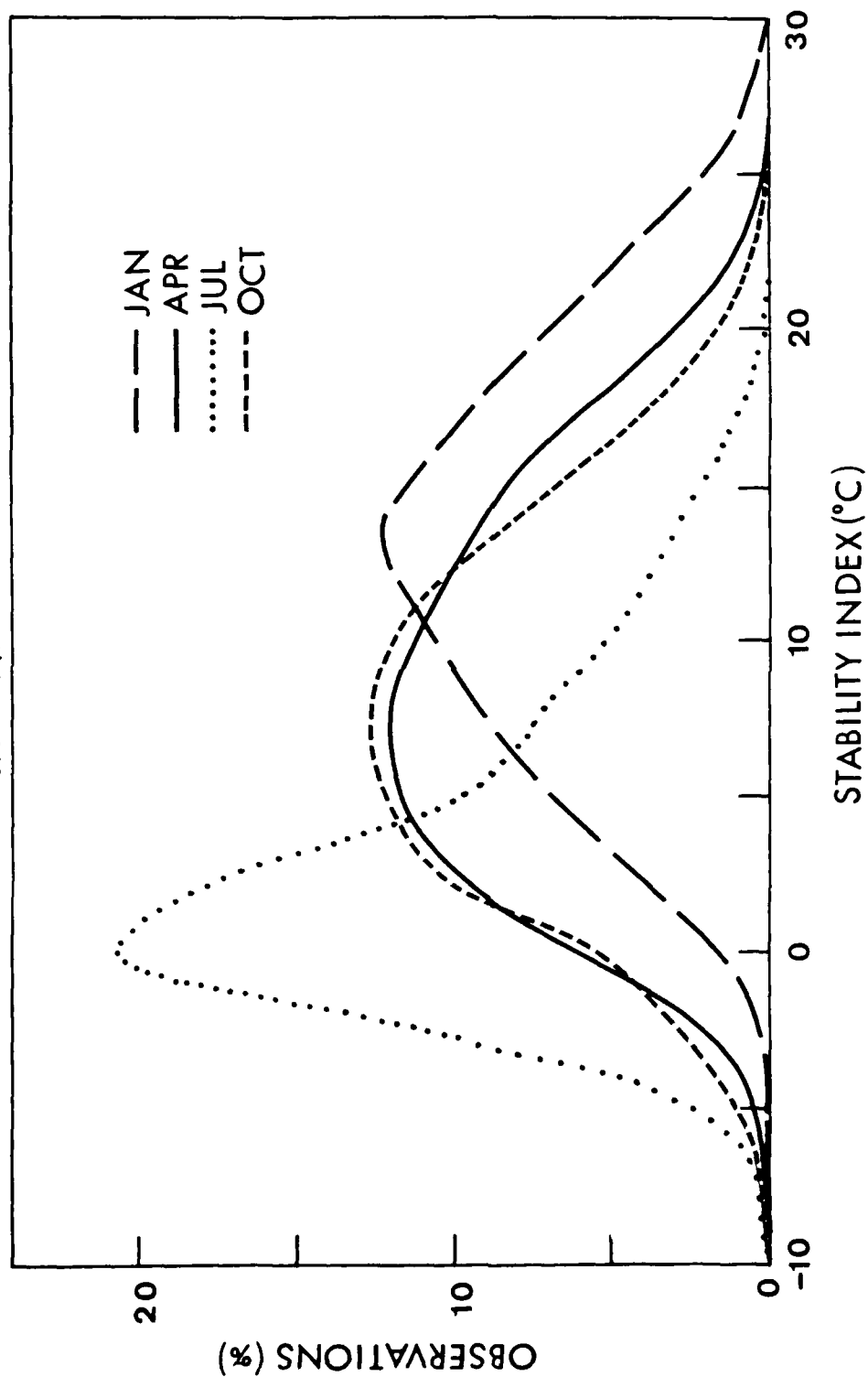
- simple: Showalter Stability Index (SSI)
850mb tmp, humidity; 500mb tmp.
- complex: SWEAT Severe Weather Threat Index
mixture of tmp, moisture, wind shear values
at various levels

Both compiled by U.S. Air Force's Environmental
Technical Applications Center (ETAC)

12-year period ('73-'84)
~ 8,000 obs per month (12-yr sample)

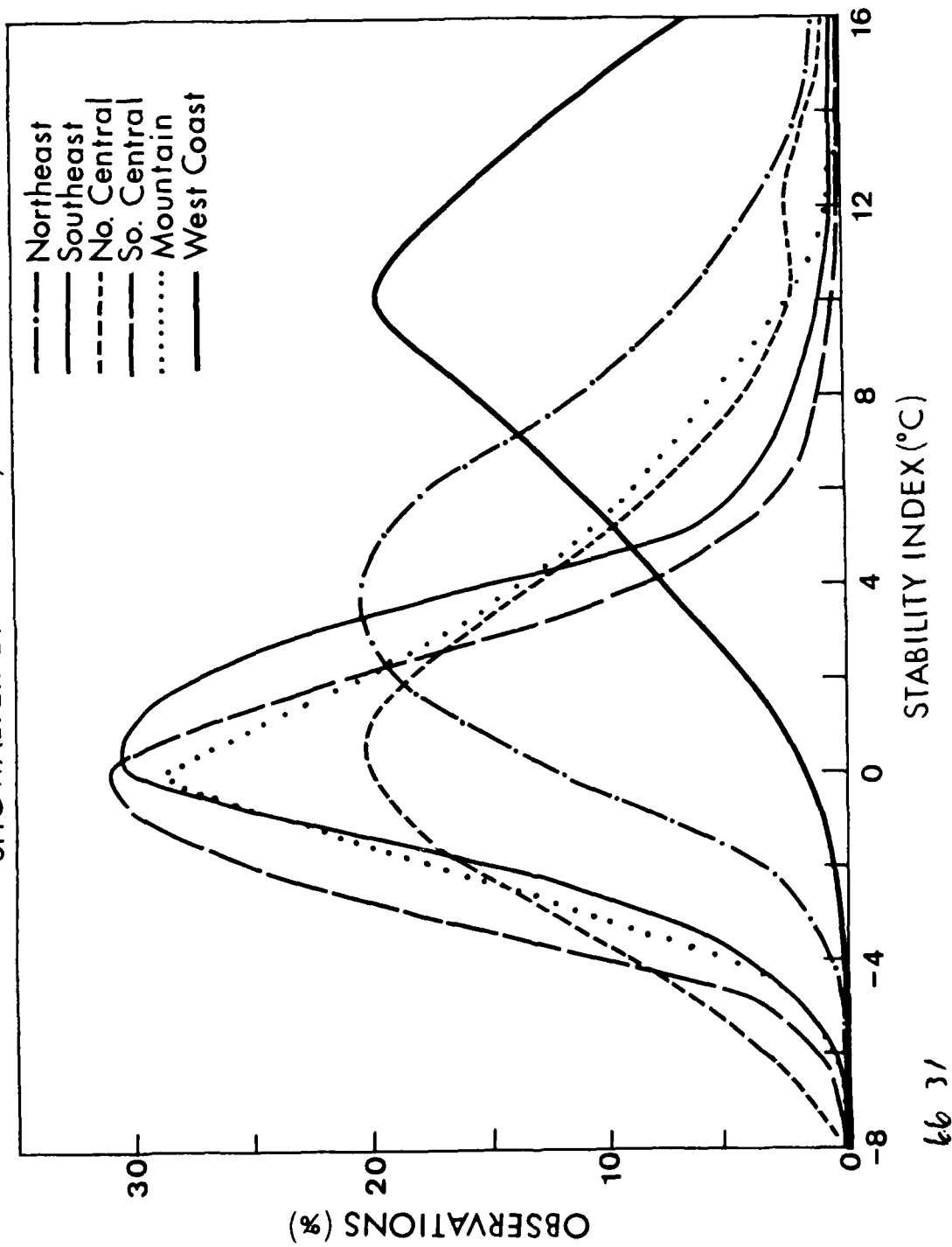


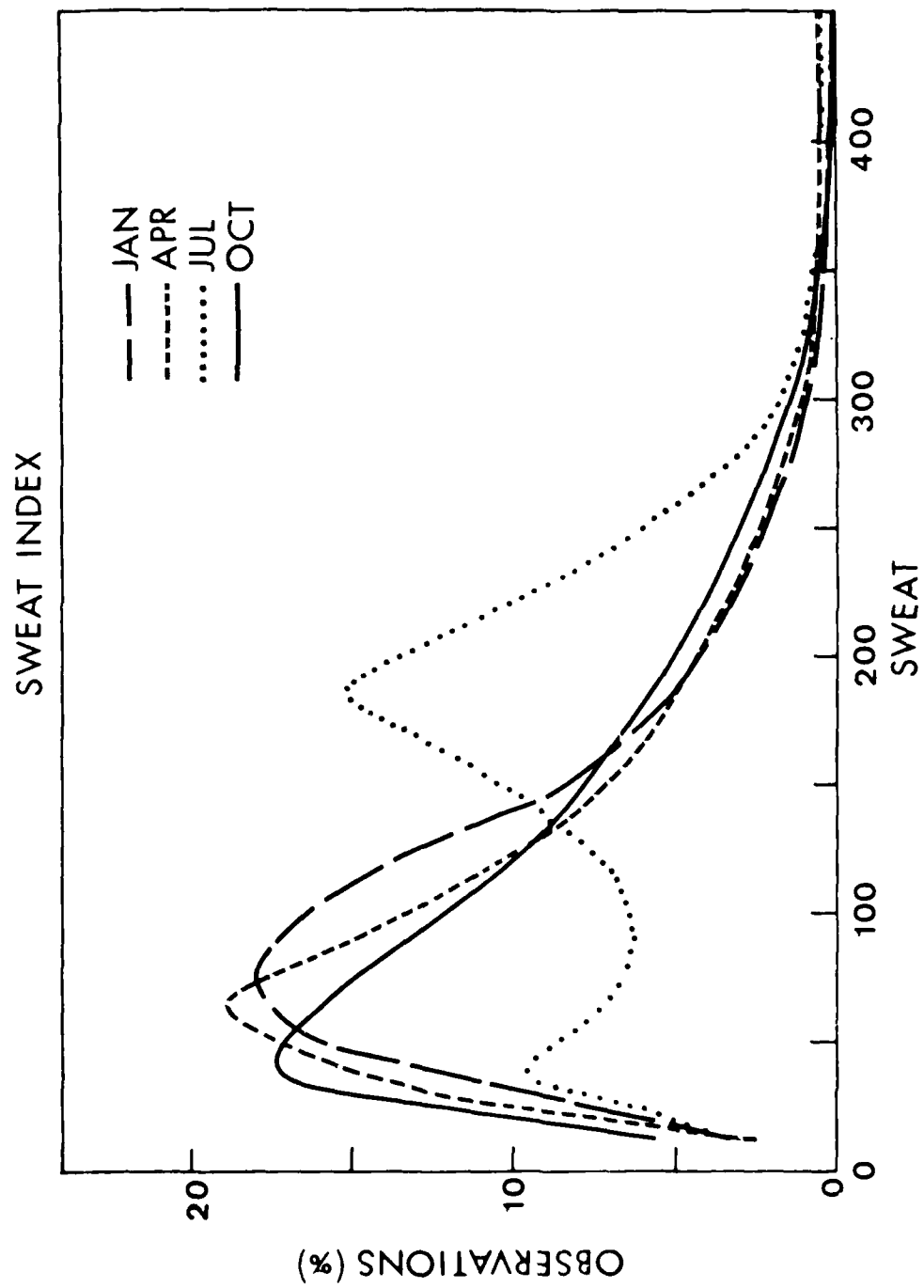
SHOWALTER



66-32

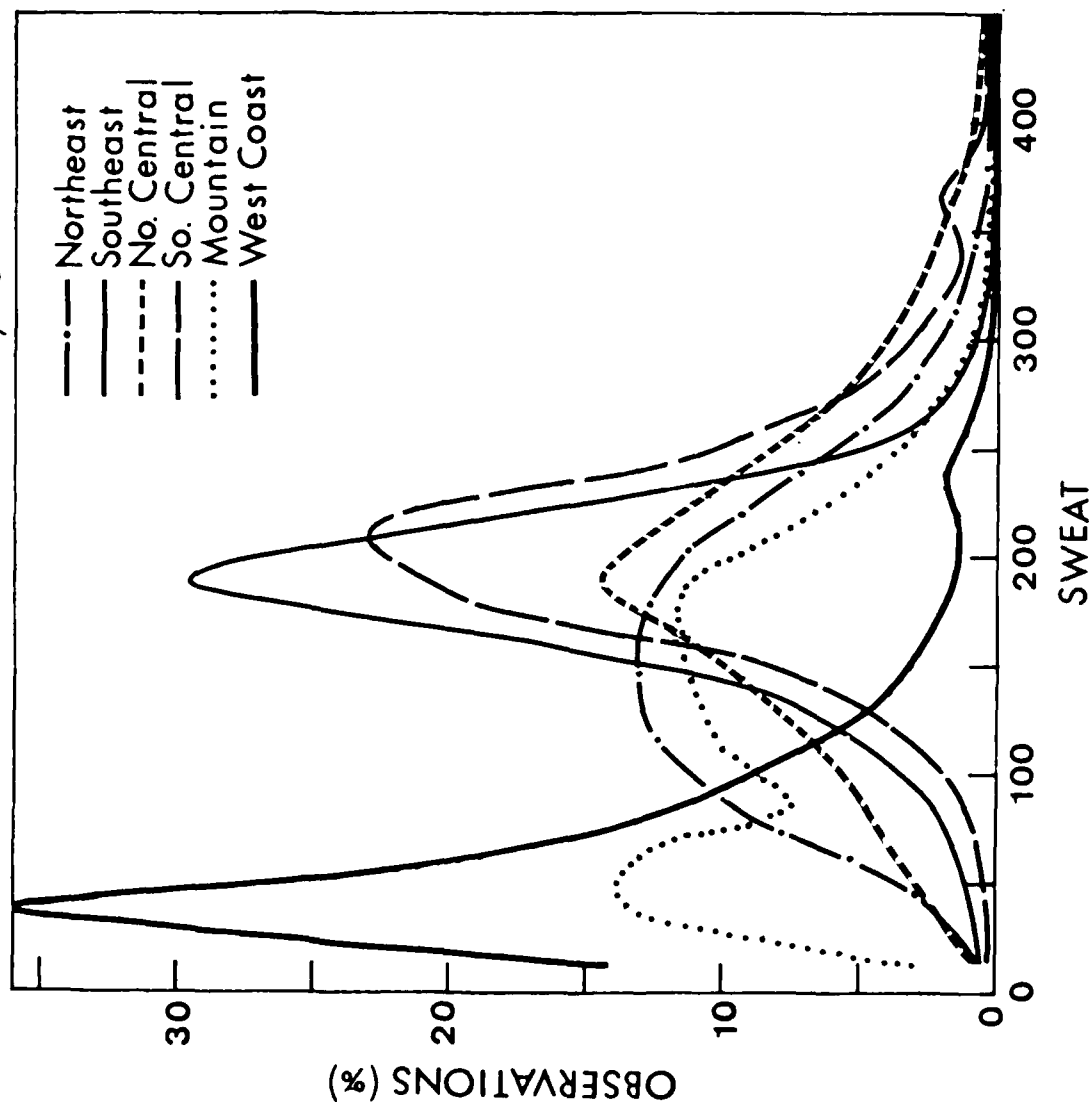
SHOWALTER BY REGION, JULY





66-29

SWEAT BY REGION, JULY



66-30

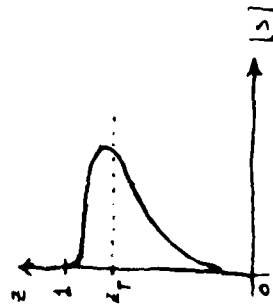
APPROACH: CRUDE EXAMPLE (using SSI)

Assume vertical smoke distribution can be described by

$$p(z) = 30(z^4 - z^5) \quad 0 \leq z \leq 1 \quad \sim B(s, z)$$

cumulative distribution

$$S(z) = \begin{cases} 0 & z \leq 0 \\ 6z^5 - 5z^6 & 0 < z < 1 \\ 1 & z \geq 1 \end{cases}$$



If z_T is taken to be the tropopause height, then

$S(z_T)$ represents the amount of smoke in troposphere

$1 - S(z_T)$ " " amount of smoke in stratosphere

DISTRIBUTION APPROACH

Where does tropopause fall in the distribution of smoke?

(2.)

$$\text{let } z_T = z_T(SSI)$$

$$\text{e.g. } z_T = 0.9 + SSI/50$$

Then:

SSI	z_T	$S_Z(z_T)$	$1 - S_Z(z_T)$
+5	1.00	1.00	0.0
0	0.9	0.89	0.11
-5	0.8	0.66	0.34

Now use observed SSI distributions to estimate stratospheric injection ~~of~~ of smoke.

RESULTS: STRATOSPHERIC SMOKE INJECTION

	<u>% of soot</u>	<u>T_g (NRC)</u>	<u>Optical Depth 1/2 hemisphere</u>
JULY	7.5	11.3	0.5
JAN	0.6	0.9	0.04

STABILITY DISTRIBUTION APPROACH

- ① Vertical soot profile - determine
here - assumed a B detrainment-like profile
- ② Relate stability (etc.) parameter to level of
tropopause in this distribution
here - simple linear $z_T = 0.9 + \frac{SSI}{50}$
- ③a Climatological: use observed stability-parameter
distributions to determine amount of soot at
levels of interest
e.g. above tropopause
- ③b Model input (larger-scale): use model-derived
values to calculate stability (etc.) parameter, then
obtain geometric altitudes by multiplying distribution
heights by $\frac{z_{tropopause}}{z_T}$

SUMMARY

- Vertical soot profile, max. heights related to fire, atmosphere properties
- Should be able to determine a parameter which takes all these effects into account (?)
- How would such a parameter behave
 - Clues from stability indices - by season, region
- How could such a parameter be used to estimate vertical smoke profile info?

Crude example using SSI,
assuming B dist'n of smoke in vertical
Estimated 7.5% of smoke would enter stratosphere
in July case. Corresponds to optical depth of 0.5
using NRC baseline data.

WHY BOTHER?

Framework, guidance in interpreting cloud observations and cloud model results.

Use model, obs:

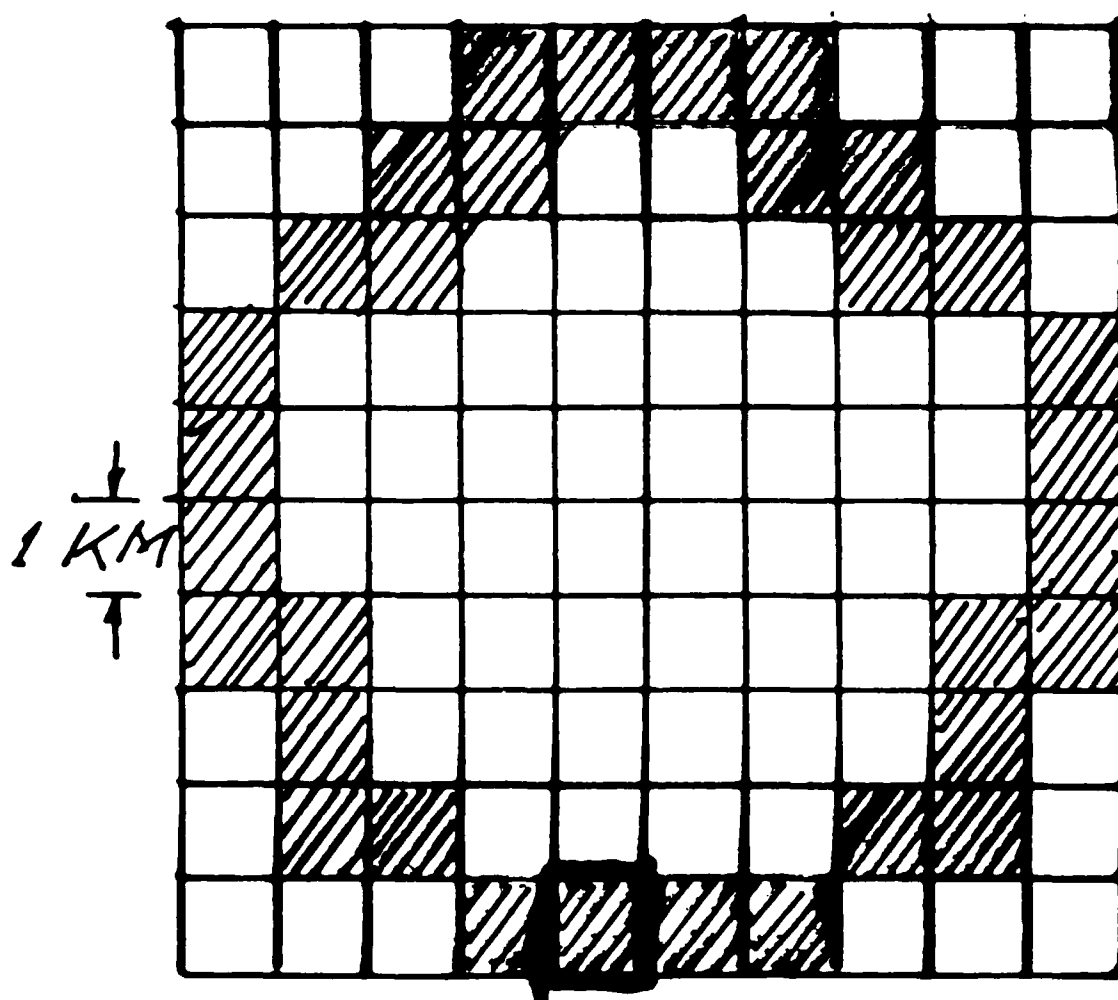
- to find a suitable parameter
- to find an appropriate vertical soot profile
- to relate the two
- to evaluate the scheme.

Then use a lot of data to determine distributions of the parameter.

MULTIPLE PLUME FLOW FIELDS

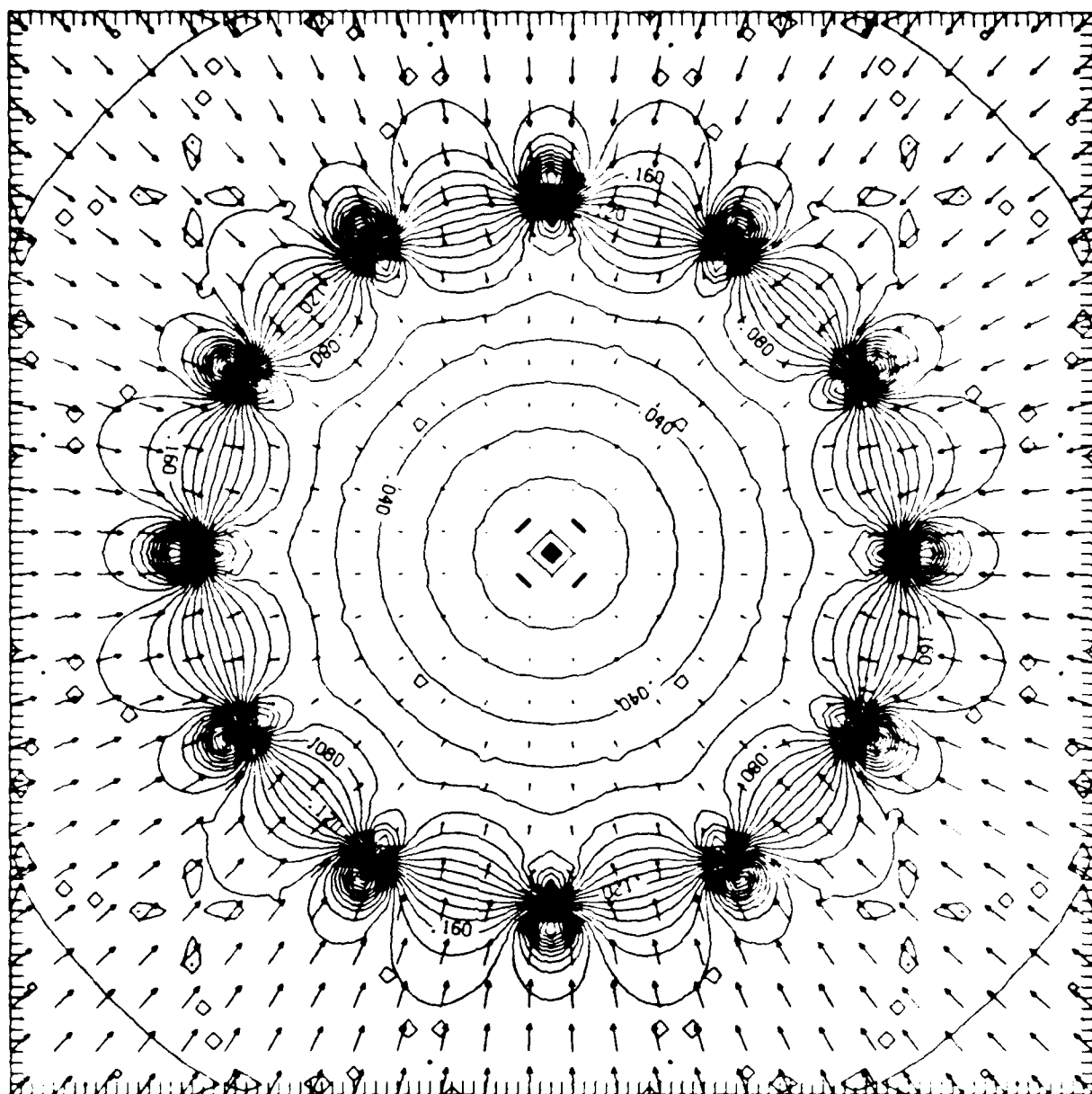
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GAITHERSBURG, MD. 20899

MASS FIRE BURN GEOMETRY



CROSS HATCH INDICATES
BURNING AREA AT 1 KM
RESOLUTION

CENTER FROM 0 19 29000 CENTER INTERVAL OF .10000E-01 P11.3.31: 1.7592
 2827.00
 MAXIMUM VECTOR



VELOCITY DECOMPOSITION

$$\vec{u} = \nabla \phi + \vec{V}$$

$$\phi = \sum_i \phi_i$$

$$\vec{V} = \sum_i \vec{V}_i$$

$$\nabla^2 \phi_i = \frac{\gamma-1}{\gamma P_0} Q_i$$

$$\nabla \cdot \vec{V}_i = 0$$

$$\nabla \times \vec{V}_i = \vec{\omega}_i$$

NOTE THAT ALTHOUGH EACH COMPONENT OF THE FLOW IS AXIALLY SYMMETRIC WITH RESPECT TO A LOCAL ORIGIN, THE NET RESULTANT FLOW IS THREE DIMENSIONAL.

ROLE OF KINEMATICS

CONSERVATION OF MASS & ENERGY
TOGETHER WITH PERFECT GAS LAW
YIELD

$$\nabla \cdot \vec{U} = \frac{\gamma - 1}{\gamma P_0} \sum_i Q_i$$

Q_i = LOCAL HEAT RELEASE RATE
IN "i"TH PLUME

P_0 = AMBIENT PRESSURE

γ = SPECIFIC HEAT RATIO

THE VORTICITY FIELD $\vec{\omega}$ IS DEFINED
IN TERMS OF THE VELOCITY $\vec{U}$ BY

$$\nabla \times \vec{U} = \vec{\omega}$$

GIVEN A REPRESENTATION FOR
 Q_i AND $\vec{\omega}$, THE VELOCITY FIELD
IS DETERMINED UNIQUELY EVERY-
WHERE

REPRESENTATION OF $\vec{\omega}$

VORTICITY PRIMARILY IN PLUMES

$$\vec{\omega} = \sum_i \vec{\omega}_i$$

$\vec{\omega}_i$ = VORTICITY OF i "TH PLUME

EACH PLUME IS AXIALLY SYMMETRIC

$$\vec{\omega}_i \cong \omega_{\theta} \hat{\theta}_i$$

$\hat{\theta}_i$ = UNIT VECTOR IN LOCAL AZIMUTHAL DIRECTION

$$\omega_{\theta} \cong \frac{\partial u_z}{\partial r}$$

$$= - \frac{2U_0(z)}{R(z)} (r/R) \exp\{- (r/R)^2\}$$

$U_0(z)$ = CENTRLINE VELOCITY OF PLUME

$R(z)$ = LOCAL PLUME WIDTH

SCALING LAWS

$$D^* = \{Q_0 / \rho_0 c_p T_0 \sqrt{g}\}^{2/5}$$

$$\vec{u} = (g D^*)^{1/2} \vec{u}^*(r^*, z^*)$$

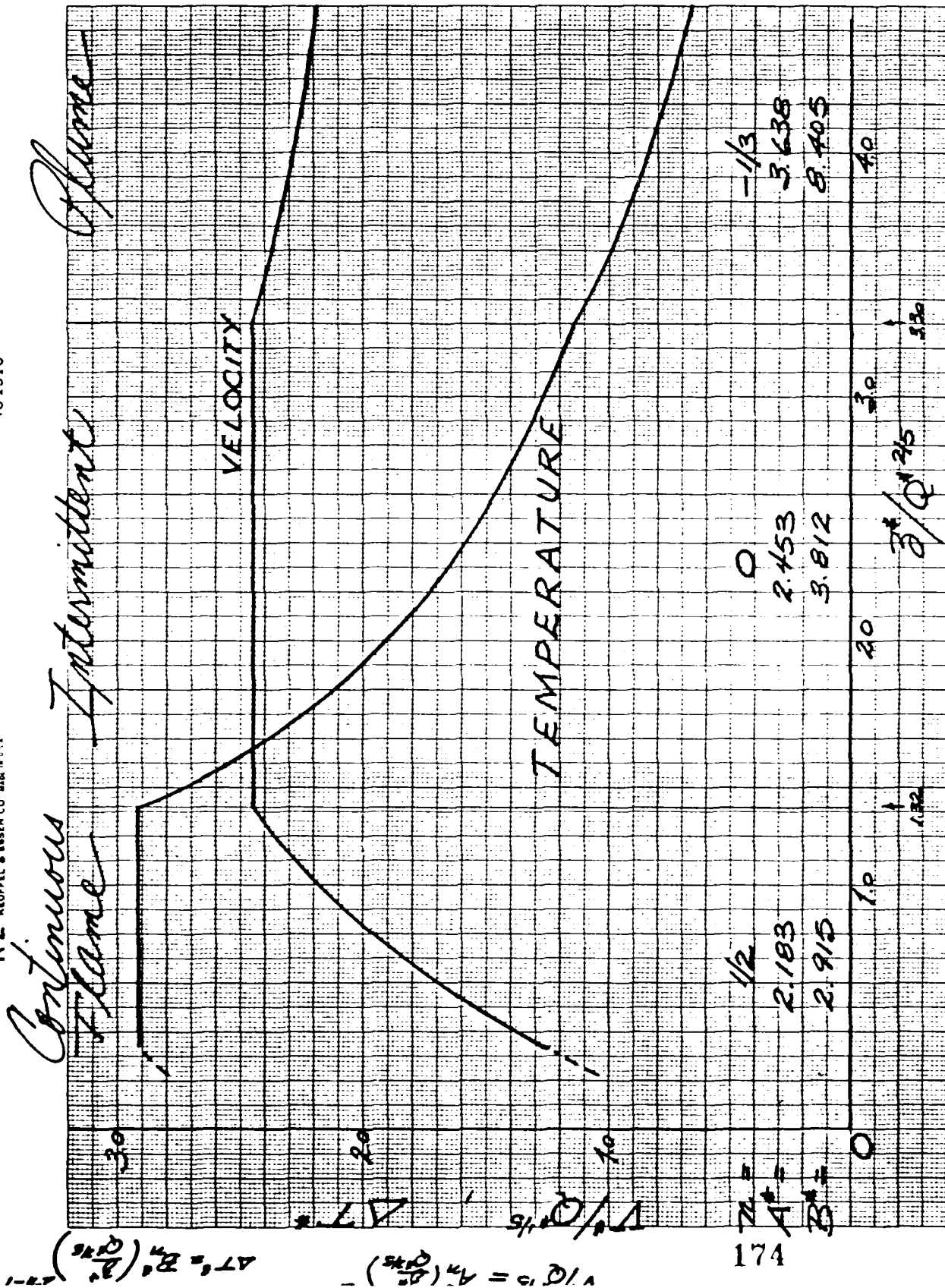
$$r^* = r / D^* \quad ; \quad z^* = z / D^*$$

$$\omega_\phi = (g / D^*)^{1/2} \omega^*(r^*, z^*)$$

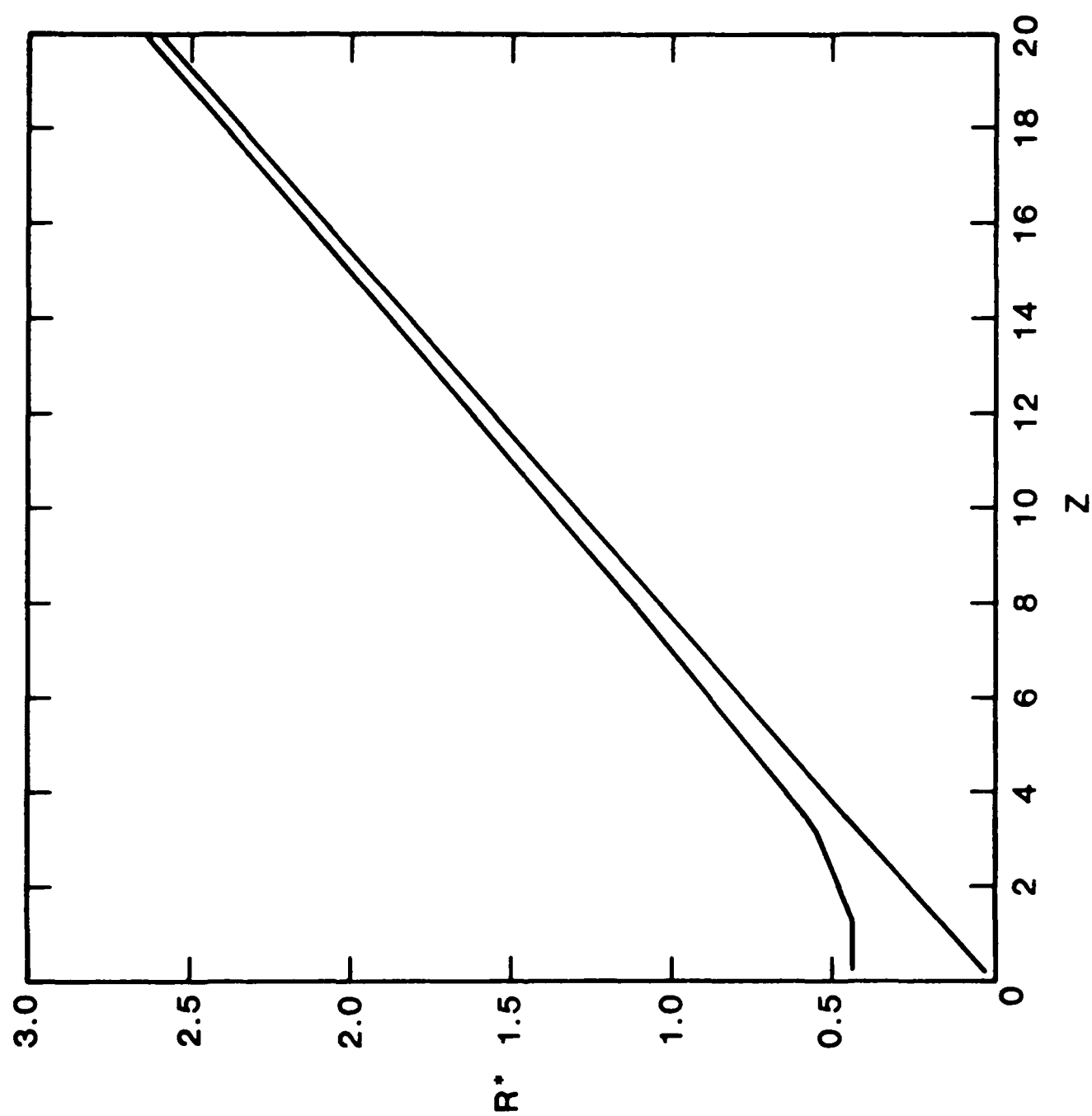
$$\phi = (g D^*)^{1/2} D^* \bar{\phi}^*(r^*, z^*)$$

$$\psi = (g D^*)^{1/2} D^* \bar{\psi}^*(r^*, z^*)$$

THIS SCALING LEADS TO A
"UNIVERSAL" FLOW FIELD WHICH
DEPENDS ONLY ON THE RADIATED
FRACTION OF THE CHEMICAL HEAT
RELEASE

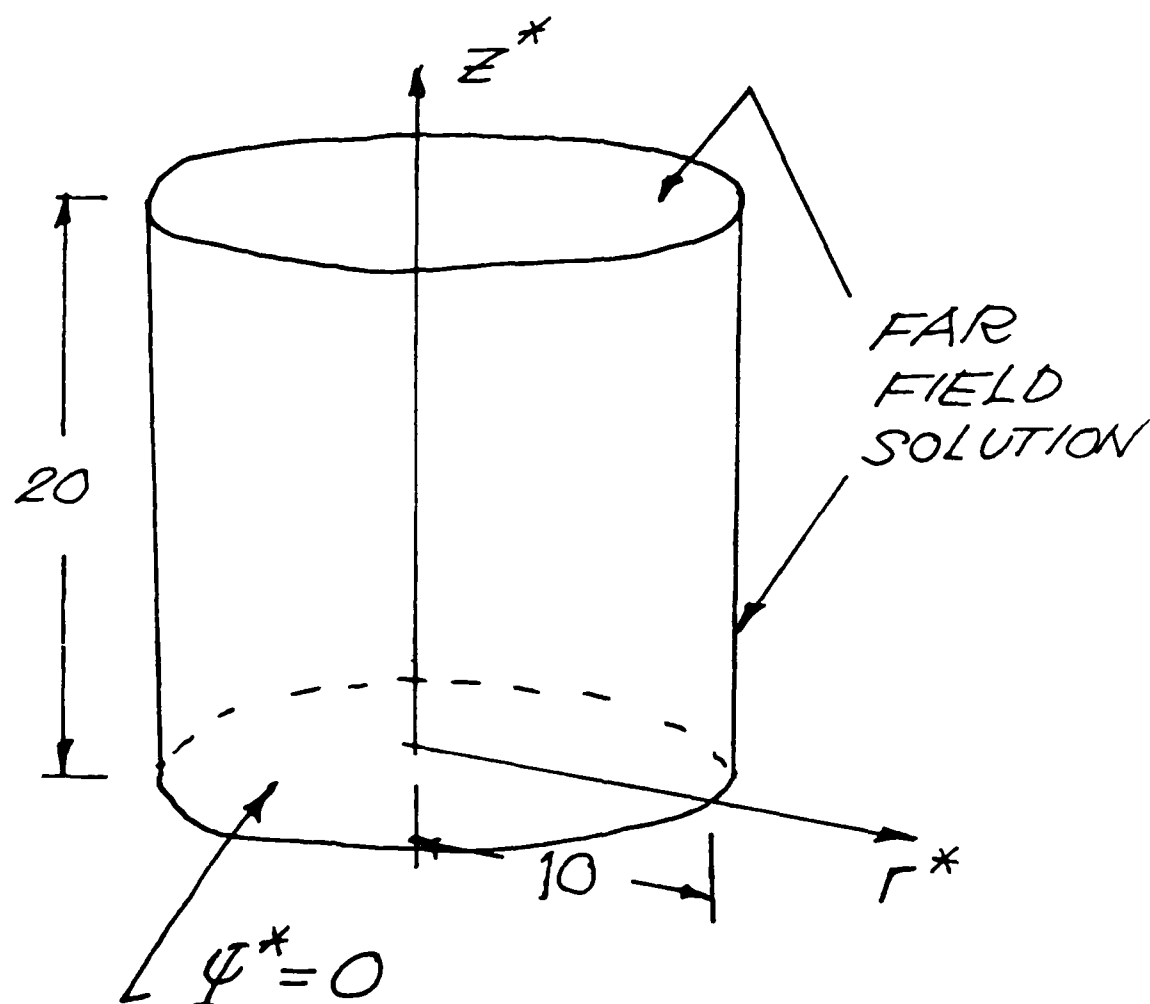


$$Z^* = \partial D; Q^* = Q / \rho C_p T_\infty \sqrt{g D^3}; V^* = V / \sqrt{g D}; \Delta T^* = \Delta T / T_\infty$$



VECTOR POTENTIAL EQ.

$$\frac{\partial^2 \Psi^*}{\partial z^{*2}} + \frac{\partial^2 \Psi^*}{\partial r^{*2}} - \frac{1}{r^*} \frac{\partial \Psi^*}{\partial r^*} = -r^* \omega^*$$



POINT SOURCE PLUME

$$\psi^* = \rho^{5/3} F(\mu)$$

$$\omega^* = \rho^{-4/3} \Omega(\mu)$$

$$\rho^2 = r^2 + z^2$$

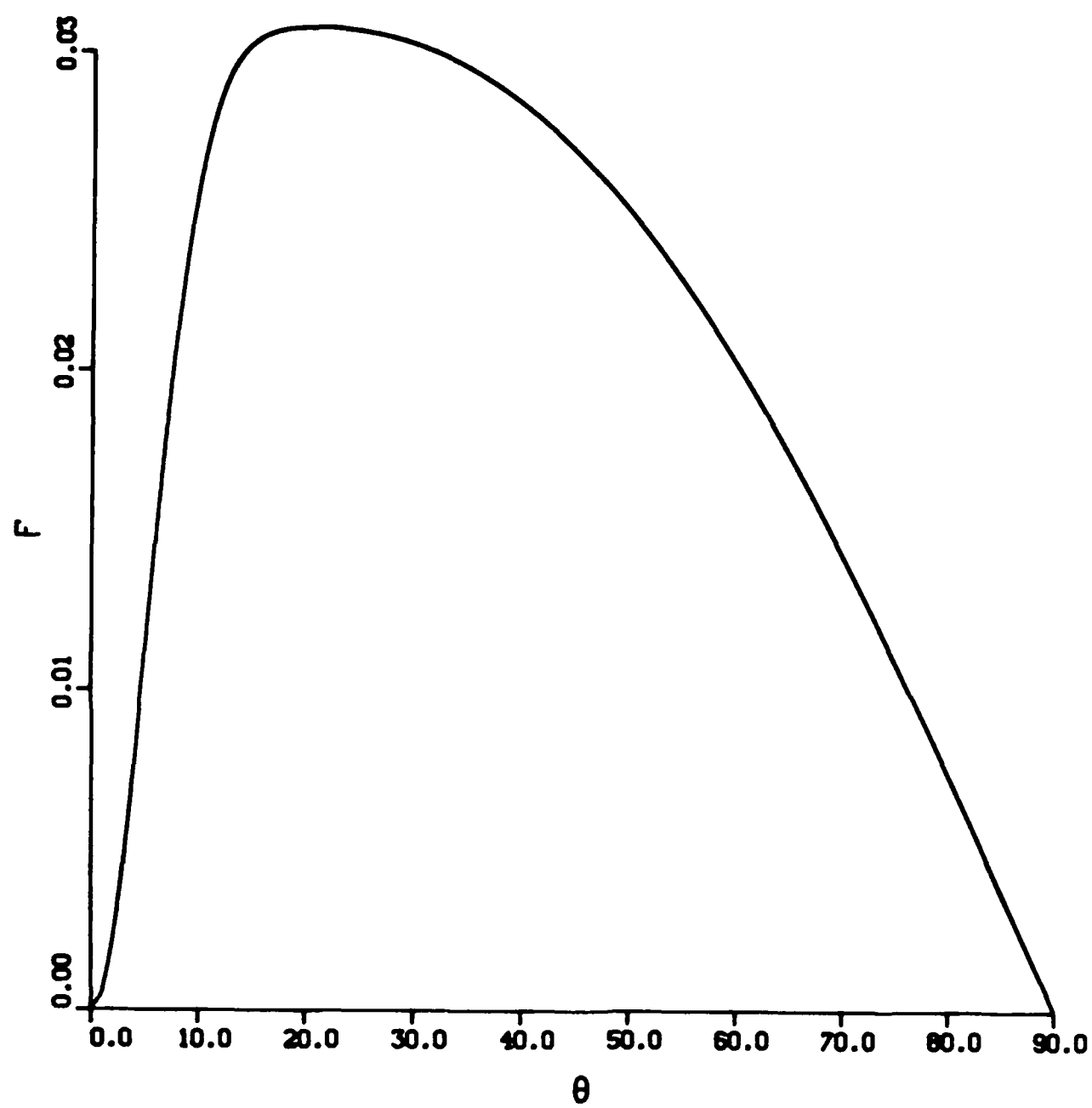
$$\mu = \cos \theta$$

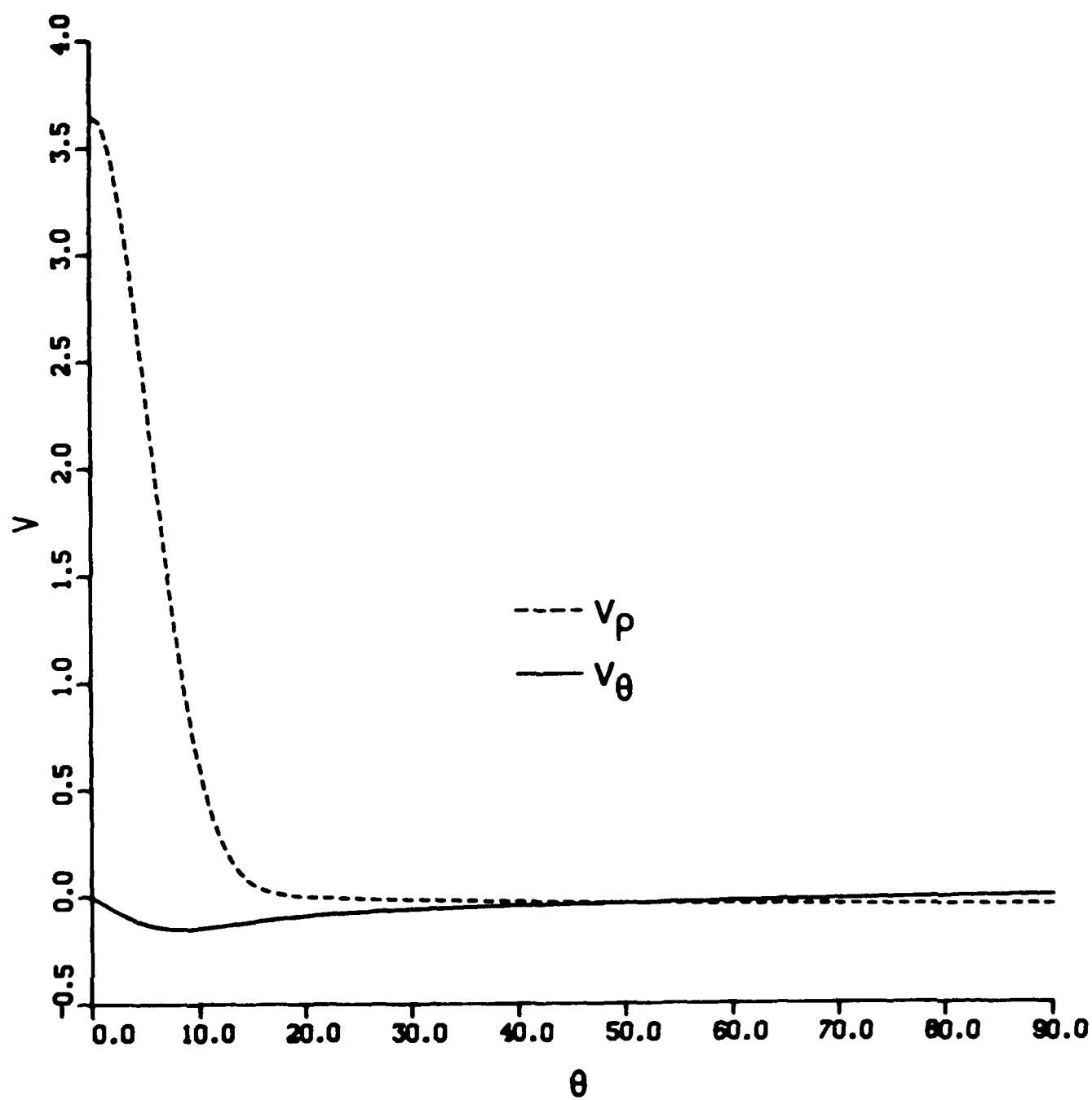
$$\frac{d^2 F}{d\mu^2} + \frac{10}{9(1-\mu^2)} F = -\frac{\Omega(\mu)}{\sqrt{1-\mu^2}}$$

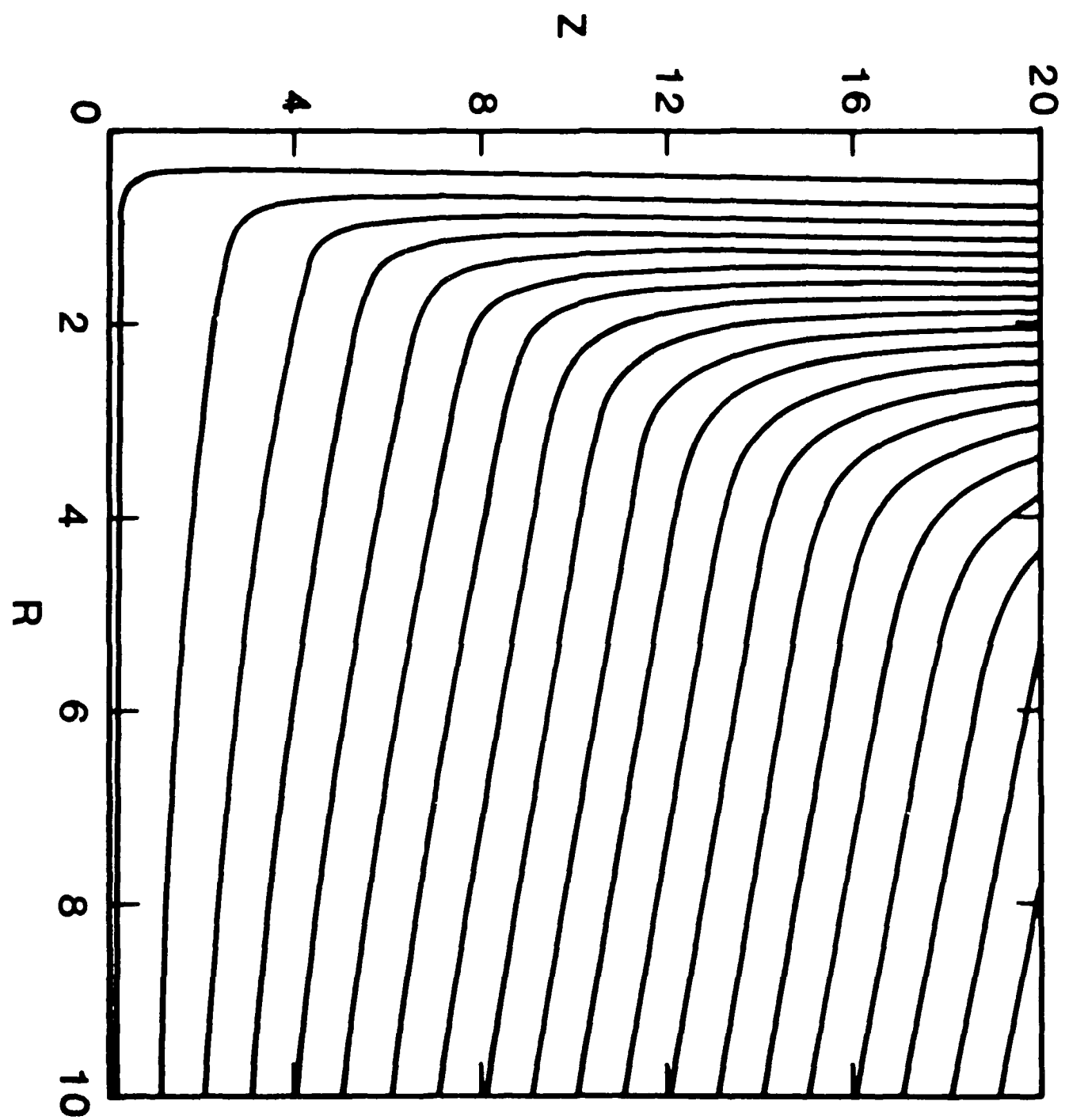
$$r = \rho \sin \theta \quad ; \quad z = \rho \cos \theta$$

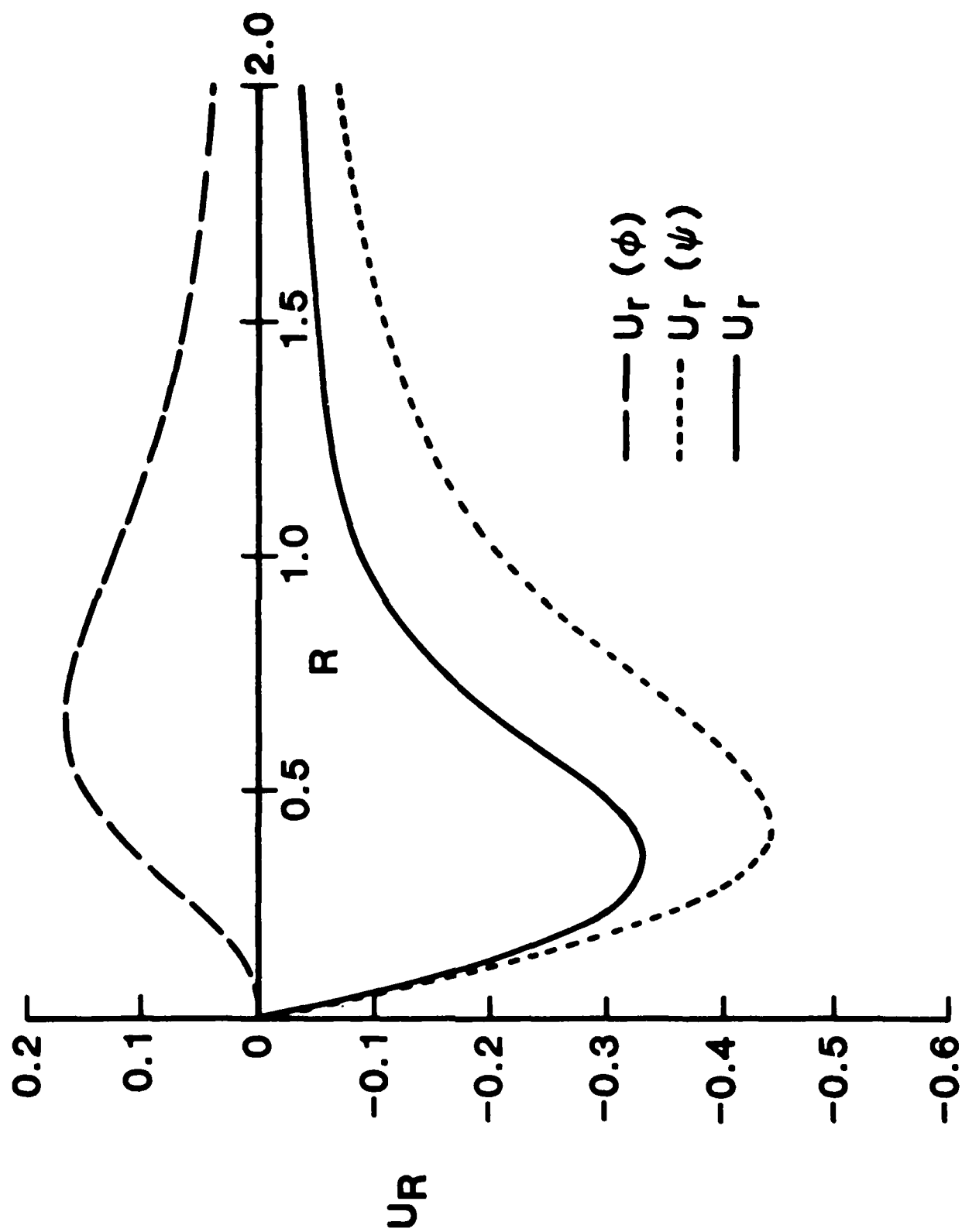
$$F(0) = F(1) = 0$$

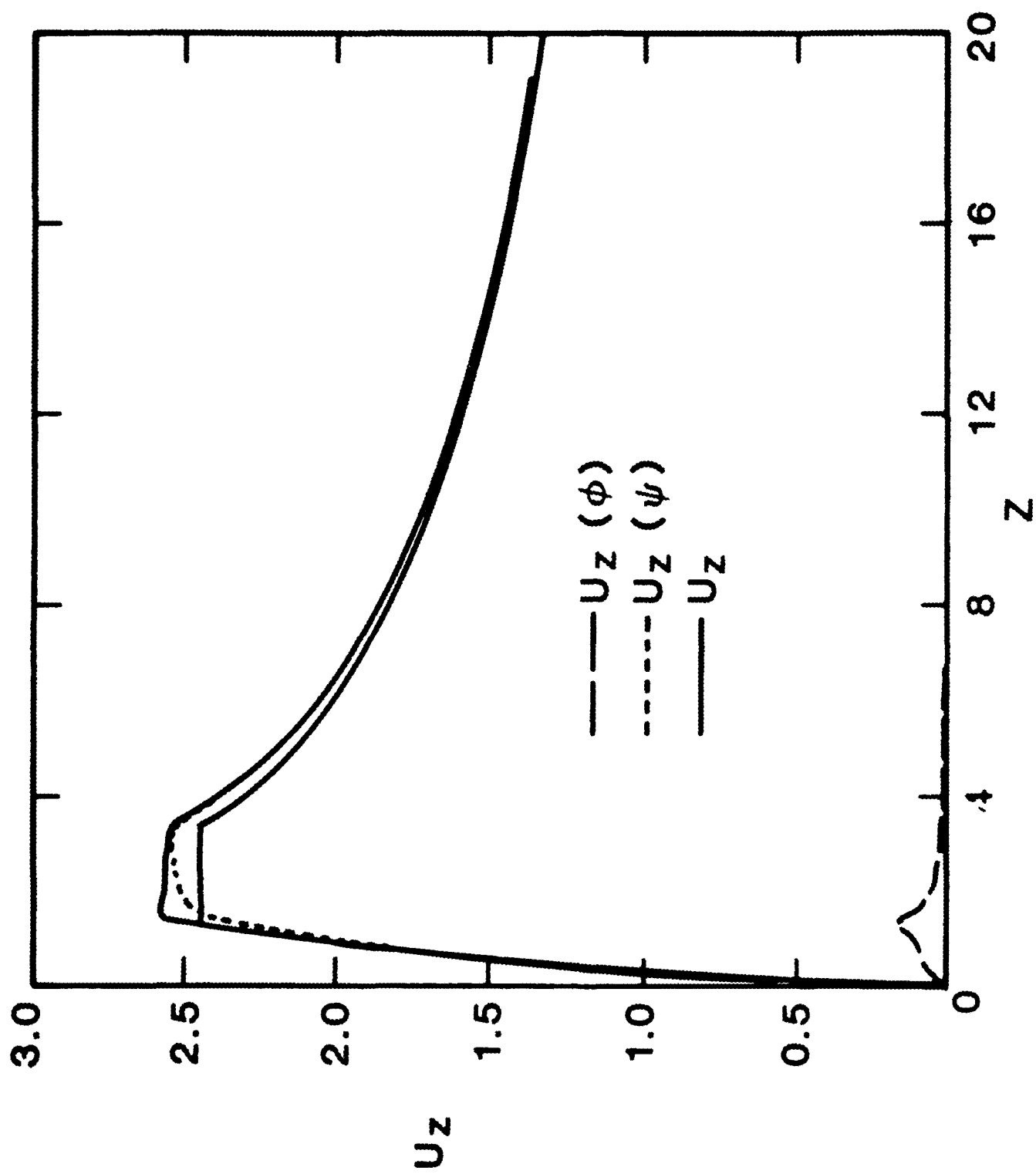
THE SOLUTION TO THIS PROBLEM
GENERATES THE FAR FIELD FOR
EACH PLUME

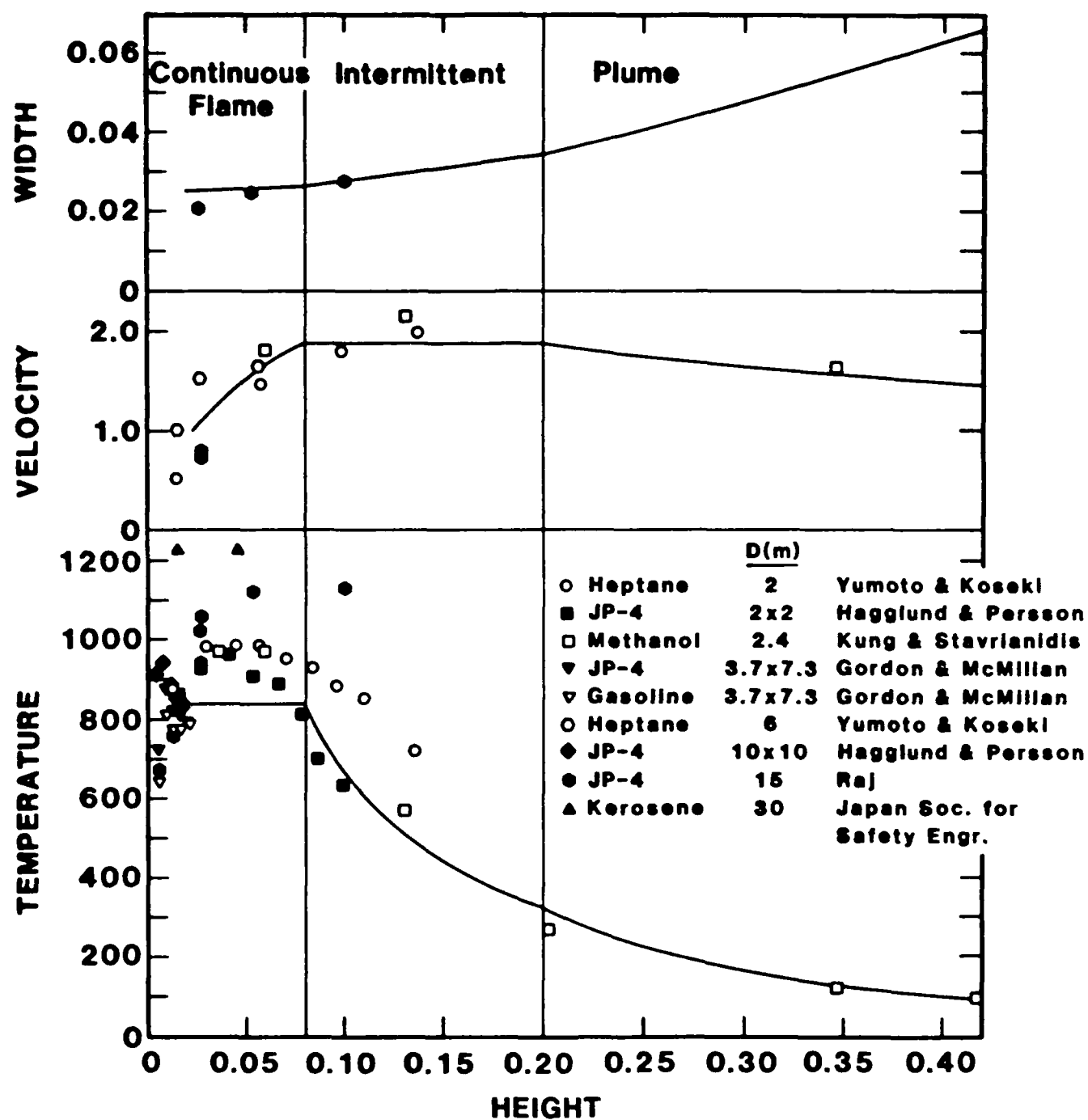


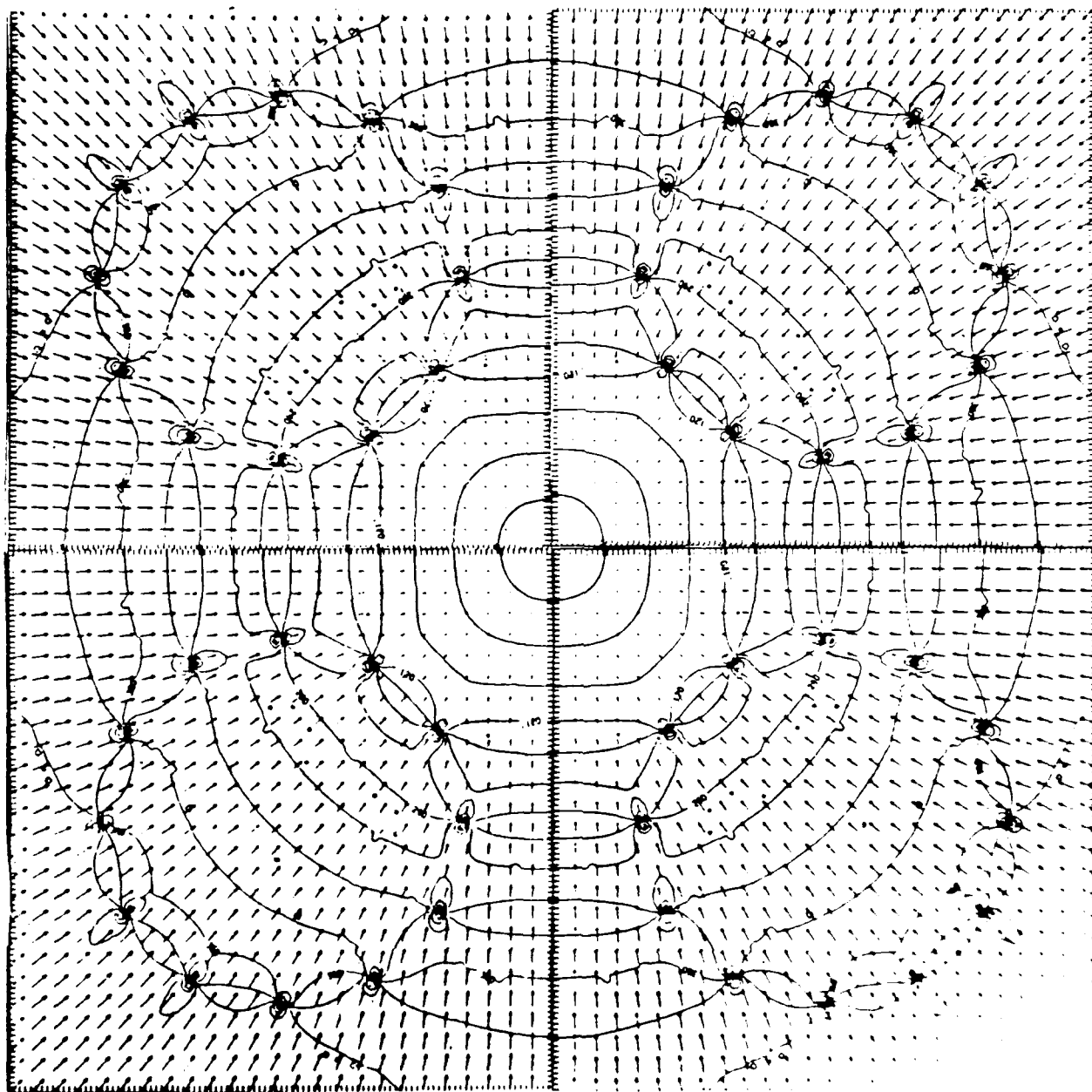












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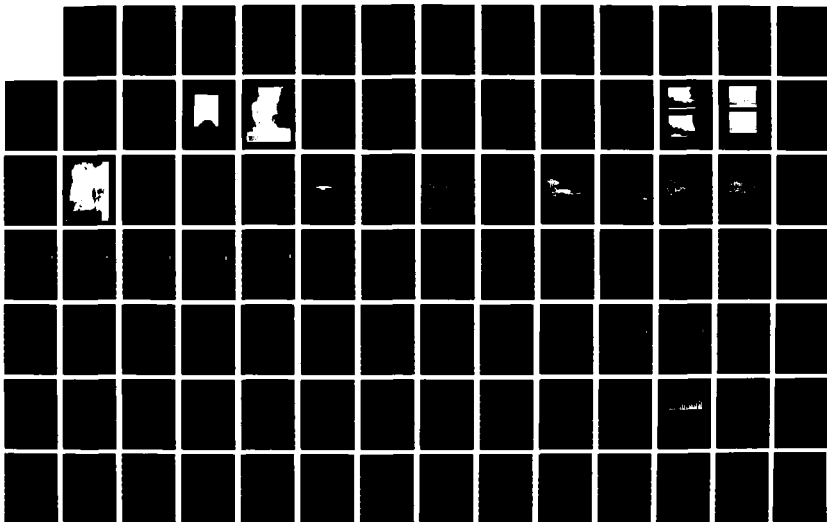
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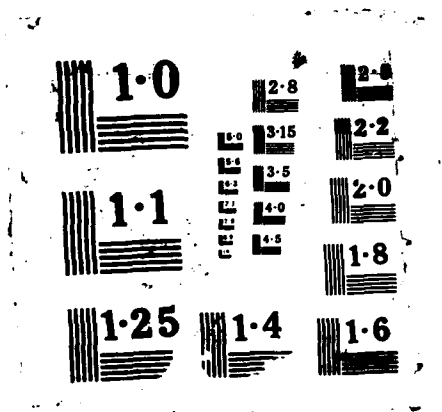
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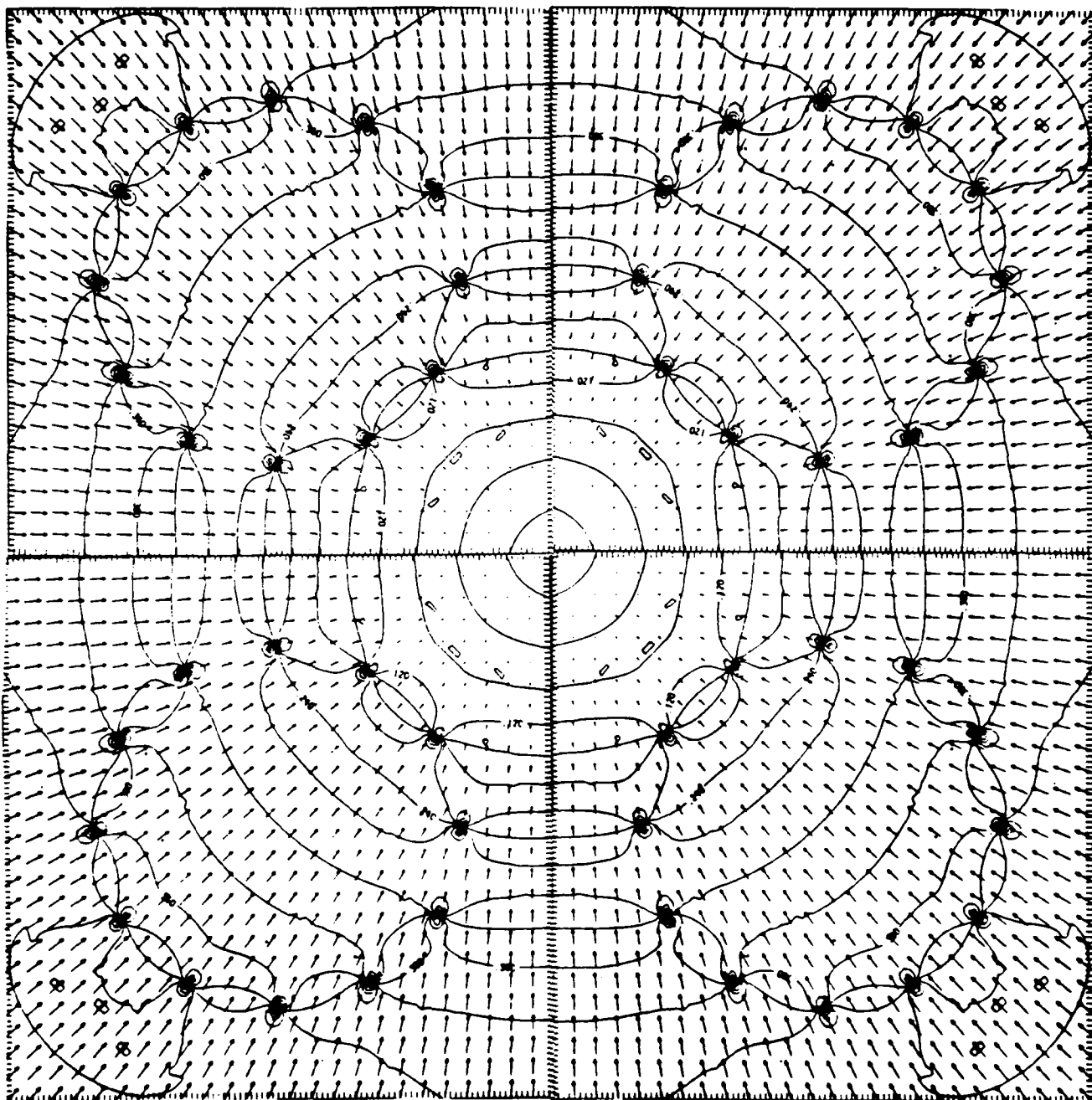
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CAPABILITIES

- 1) VERY GENERAL FIRE PLANFORM
- 2) PERMITS MODELING FROM
ESTABLISHED DATABASE
- 3) RANDOM AS WELL AS DETERMINISTIC
INPUT IN SIZE AND LOCATION
- 4) HIGH SPATIAL RESOLUTION FOR
MODEST COMPUTER RESOURCES

PHYSICAL SIMULATION OF
LARGE-AREA FIRE PLUMES*

by

M. Poreh, J. E. Cermak and J. A. Peterka

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CSU Project 2-95660

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March 1986

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Center, California.

PHYSICAL SIMULATION OF LARGE-AREA FIRE PLUMES

by

M. Poreh, J. E. Cermak and J. A. Peterka

ABSTRACT

The dynamics of large-area fire plumes has been investigated by physical simulation using small-scale models. The models use heat or helium to generate the buoyancy flux. They neglect the radiative heat transfer and assume a relatively shallow combustion layer, an assumption which is found to be consistent with the measurements in the model, but maintain the correct dimensionless parameters which determine the dynamics of the plume outside the combustion layer.

Four regions of distinct flow characteristics have been identified. A combustion layer whose height is small compared to the horizontal dimension of the fire. A radial convective boundary layer, where radially-inward induced winds carry the rising plume toward the center. A central core and a convective plume above it, which rises to large heights.

Vigorous mixing with the ambient air occurs in the radial convective boundary layer, where the hot burned fuel rises in the form of thermals. Such thermals are formed for both continuous combustion layers and for large fires which are made of many distinct, close, small fires. It is found that these two cases produce similar plumes.

The simulations show that the plume above the burning area contracts considerably as it rises, and that the upper convective plume behaves as a weak plume with a virtual origin below the

surface, at z/R of the order of -1.5 . The subsequent plume rise in an upper stably-stratified atmosphere would thus be much smaller than that of a plume originating from a point source at the ground, with the same buoyancy flux.

The simulations also show that the induced radial velocities of a large-area fire in a calm neutral atmosphere are not as large as those estimated by previous numerical and analytical models. In addition, the study suggests that the kinetics of a single fire, which is surrounded by numerous other fires would not be much different from that of an individual fire in a calm atmosphere, as oxygen depletion is found to decrease with the size of the fire.

SUMMARY OF THE PRESENTATION

Simulation Rationale

- The simulation is based on the conventional approach to fluid modelling. All the important dimensionless parameters and boundary conditions must be the same in the model and prototype ($\pi_m = \pi_p$).
- The Reynolds number in the model cannot be matched with that of the prototype. However, it is shown to be large, so that 'Reynolds number independence' is expected.
- The models neglect radiative effects.
- It is assumed that the relative thickness of the combustion layer (CL) in large-area fires is small compared to the size of the fire. Thus, the model simulates the flow above the relatively shallow CL.
- The flow above the CL is assumed to be governed by
 - σ - The buoyancy flux per unit area produced in the CL, which is proportional to the burning ratio (J/sec) [σ]
 $= L^2/T^3$.
 - R - The size (radius) of the (assumed circular) CL.
 - π_i - Dimensionless boundary conditions describing the ambient wind, ambient circulation and atmospheric stratification.

The presentation focuses on Large Area Fires (LAF) in a calm, neutrally stratified atmosphere. It has been shown, however, that the physical simulation can include the effects of ambient stratification and circulation (Poreh et al., 1986).

The above assumptions imply that the velocity field $u(\vec{x})$ and the effective gravitational field $g'(\vec{x}) = g\Delta\rho(x)/\rho_a$ are given by

$$\frac{u(\vec{x})}{(\sigma R)^{1/3}} = f(\vec{x}/R) \quad (1)$$

and

$$\frac{g'(\vec{x})}{\sigma^{2/3} R^{-1/3}} = g(\vec{x}/R) \quad (2)$$

Buoyancy flux in the models have been generated by:

- (1) Heat flux, as suggested by R. R. Long.
- (2) Flow of lighter-than-air gas (helium) from a porous circular plate.

It is noted that the value of $\Delta\rho/\rho_a$ of helium is approximately equal to that of burned fuel at stoichiometric proportions (BFSP). Namely, ideal burning of the fuel without mixing with surplus air. Thus, the model simulates an area source of buoyancy produced by a flux of BFSP before it mixes with additional air.

Theoretical considerations and previous experience suggest that $\Delta\rho/\rho_a$ of the buoyant gases at the source need not be the same in the model and the prototype, unless a strong whirl is expected. This assumption is confirmed by the experimental results (Fig. 6). The value of $\Delta\rho/\rho_a$ in one of the model ($R = 50$ cm) was matched with the expected value in a $R = 2$ km urban fire.

Experimental Configuration (Figure 1)

- Two circular helium models with $R = 27$ cm and $R = 50$ cm were used.
- A two-dimensional area source (2 m x 2 m) was placed in a 2 m wide test section of a wind tunnel.

Summary of the Experimental Results

- The shape of the plume based on flow visualization and helium concentration measurements is shown in Figures 2 and 3. Considerable necking of the plume is observed, similar to the necking of a 14 acre fire in Project Flambeau (Figure 4).
- Four regions of distinct flow were identified (Figure 3):
 - (1) A relatively shallow CL.
 - (2) A radial convective boundary layer.
 - (3) A central core.
 - (4) A convective plume. The convective plume which can be described as a plume from a virtual point source at approximately $z_v = -1.5 R$.

The assumption of a relatively small thickness of the combustion layer is based on the flame height correlation of Thomas (1963) shown in Figure 5. The value of $m''/(\rho_0 \sqrt{gD})$ for large urban fires is expected to be of the order of 10^{-5} , so that the ratio of the flame height to the size of the fuel bed (L/D) is expected to be, according to this correlation, of the order of 10^{-2} .

The model does not have a CL. However, a 'pseudo combustion layer' (PCL) has been defined by the height where the injected helium mixes with 6 times air by mass. This is the order of the observed mixing at the edge of turbulent combustion layers. The thickness of this PCL in the model was smaller than 1 mm, as shown in Figure 6. This figure, which shows the value of the dimensionless gravity coefficient $g'(z)$ in the two circular models also confirms the validity of Eq. 2. Near the ground; however, the value of g' may be affected by its initial value at the source.

Since g' is proportional to $\Delta\rho/\rho_a$, which is approximately proportional to $\Delta T/T_a$, the order of magnitude of $\Delta T/T_a$ in large-area fires was estimated (Figure 7).

The conclusion that $\Delta T/T_a$ in the fire plume decreases with the size of the fire appears surprising, but it is a direct consequence of Eq. 2. One may also conclude that the average oxygen depletion in large-area fire plumes is smaller than in small-area fires. This conclusion does not imply that large oxygen depletion cannot exist within individual fires burning within a LAF.

Induced Radial Velocities

The induced radially-inward velocities at the edge of the fire were found to be

$$U_R = k(\sigma R)^{1/3}$$

where $k = 0.24 - 0.5$, much smaller than in numerical models and in reports on large-area fires. (It should be stressed that the

above estimate is for fires in a calm, dry, neutrally stratified atmosphere.)

Figure 8 compares the shape of the radial velocity profile for a point source of buoyancy (a) and for an area source of buoyancy (b), which can be described, at $z > R$, as a convective plume from a virtual source at z_v . The figure demonstrates why, for the same buoyancy flux, the induced radial velocities increase when z_v is decreased. The conclusion is that area sources produce large inward-radial velocities which depend on the effective necking of the plume.

Estimated Plume Rise in a Stably-Stratified Atmosphere

Briggs equation or the analysis of Morton, Turner and Taylor are for a buoyant plume from a point source. The initial mixing in the radial convective boundary layer (CBL) of an area source would decrease the final plume rise.

Figure 9 shows a rough estimate of the plume rise for an area source with a given total buoyancy flux as a function of the position of the virtual origin. The estimate is based on the assumption that the behavior of the plume at $z > 0$ may be calculated using the width of the virtual plume at $z = 0$. The data is for a buoyancy flux produced by a 100 km^2 fire.

The average plume rise for $z_v = 0$ is identical with the estimate given in the NCR report (1985, p. 74). One clearly sees from Figure 10 that the plume rise is reduced drastically with the lowering of the virtual origin. At $z_v/R = -1.5$ one gets an average plume rise of the order of 5 km.

This drastic reduction is initially surprising. However, if one examines the theoretical solution of Morton et al. for the loss of buoyancy flux from a point source with height (Figure 10), which shows that most of the buoyancy flux is lost when the plume achieves a large width, the reason for the large difference in plume rise between point sources and area sources becomes clear.

It is interesting to note that while lowering of z_v decreases the plume rise, it increases the induced radial velocities.

The Nature of the Radial Convective Boundary Layer (CBL)

The CBL is the largest region above the combustion layer. Our study indicates that it is very similar to atmospheric CBL:

- The Monin-Obukhov length is very small $L/R = O(10^{-4})$.
- The effect of the horizontal shear is small and the induced horizontal velocities do not cause mixing.
- Buoyancy flux is in the form of thermals with large upward velocities, $w_z > U_R$.
- To satisfy continuity fresh cool air descends to the ground between the thermals (or the individual fire plumes).
- Rapid dilution of individual fire plumes is expected.

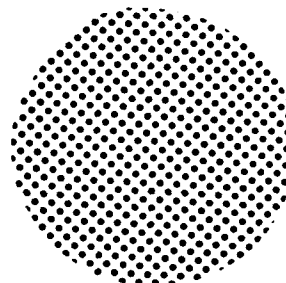
The flow visualization in Figure 11 shows the radial CBL in the two-dimensional fire model. Figure 12 shows, as well, a smoke filament introduced outside the fire.

Figure 13 shows smoke filaments introduced from outside the fire as they enter the CBL. A rapid descent of the fresh air is

observed, as in cases of fumigation. The same pattern was observed in the circular models and in Project Flambeau. Many numerical and analytical models neglect this unique form of mixing.

The Effect of Urban Streets

The effect was simulated by covering the porous source with perforated plates. The porosity of the plates was 12 percent and 30 percent. The gross plume shape appeared in the flow visualization to be unchanged.



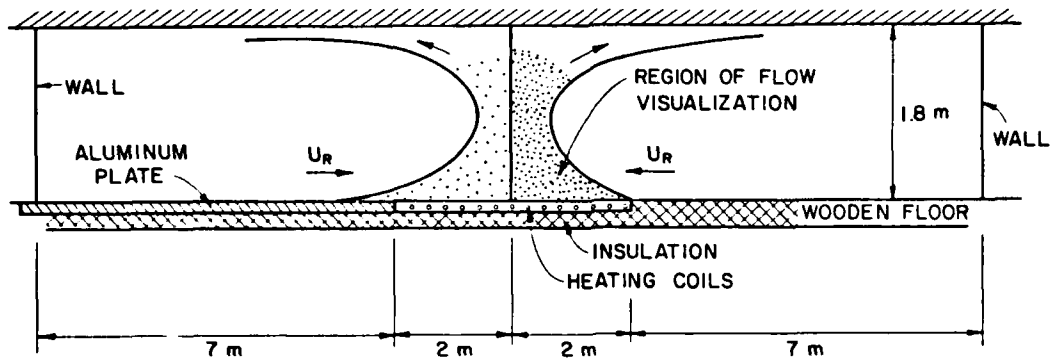
Conclusions

- Physical models can simulate important features of large area fire plumes.
- The rise, in a stably stratified atmosphere, of a plume with a given buoyancy flux decreases with the area of the source.
- Area sources of buoyancy induce larger radial, inward, ground-level velocities than point sources, but the magnitude of these velocities is not as high as previously reported.
- The interaction between simultaneously burning fires over a large area is not expected to be large. This conclusion is based on two observations: the average oxygen depletion in plumes of LAF is not expected to be large. The upward velocities of the individual plumes

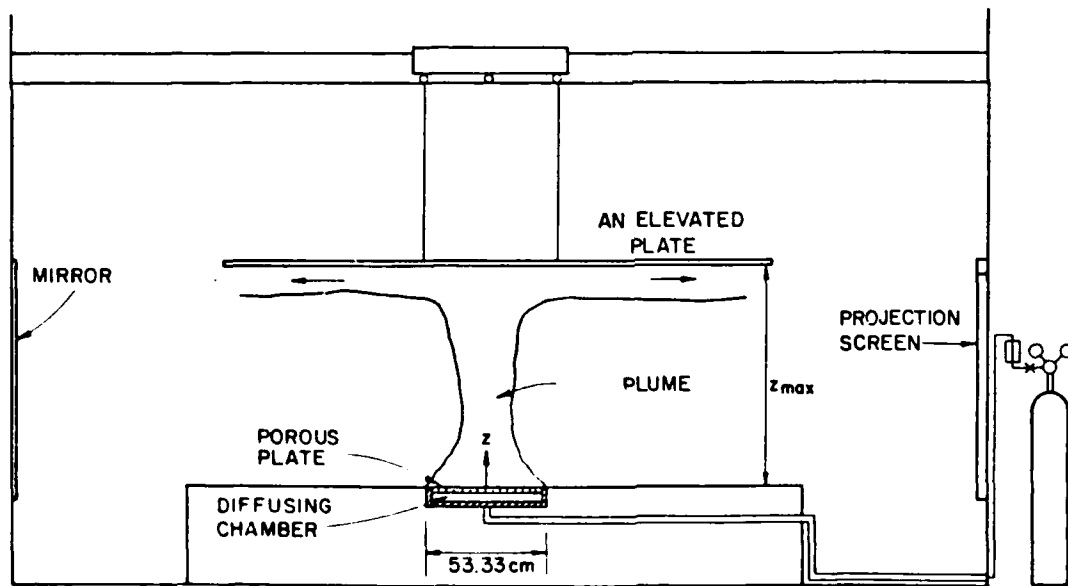
within a LAF are expected to be larger than the induced horizontal velocities.

Proposed Future Simulations

- Measure, in small-scale models, the instantaneous temperature (oxygen depletion) LAF and in an individual fire surrounded by other fires.
- Study the detailed effect of streets and noncombustible areas on the flow and temperature field of a LAF.
- Study the behavior of LAF plumes in a stably stratified atmosphere.
- Study the merger of fire plumes from close area fires.



The two-dimensional fire model in the Meteorological Wind Tunnel.



The circular fire model.

Figure 1. Schematic description of the experimental configurations.

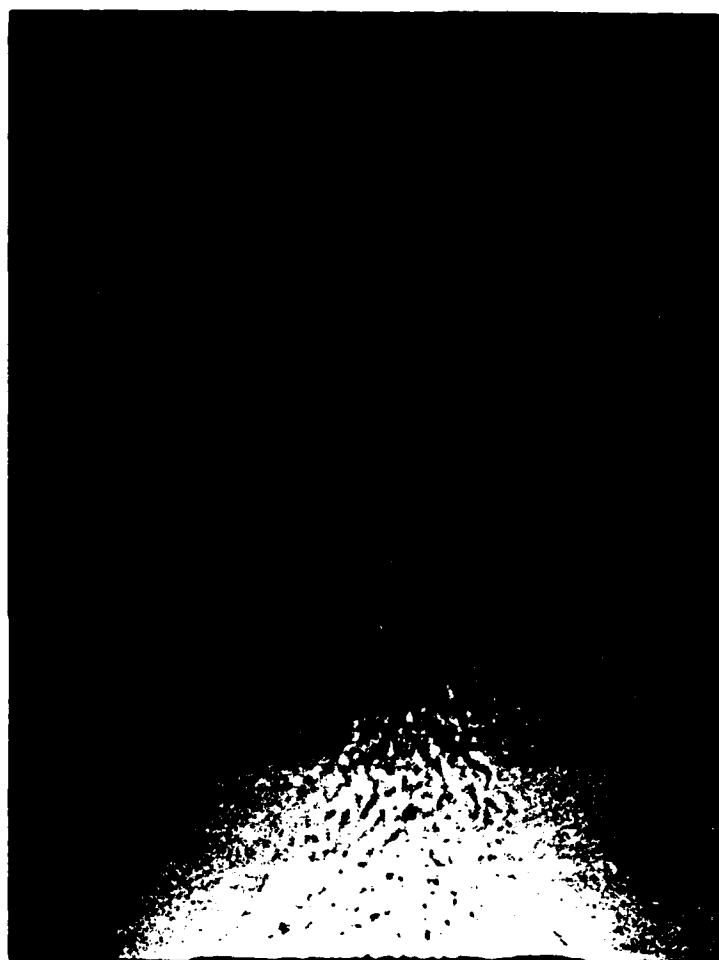


Figure 3. A photograph of the plume shadowgraph.



Figure 4. A 15-acre fire in the Flambeau Project. Trees in foreground are 12 ft high.

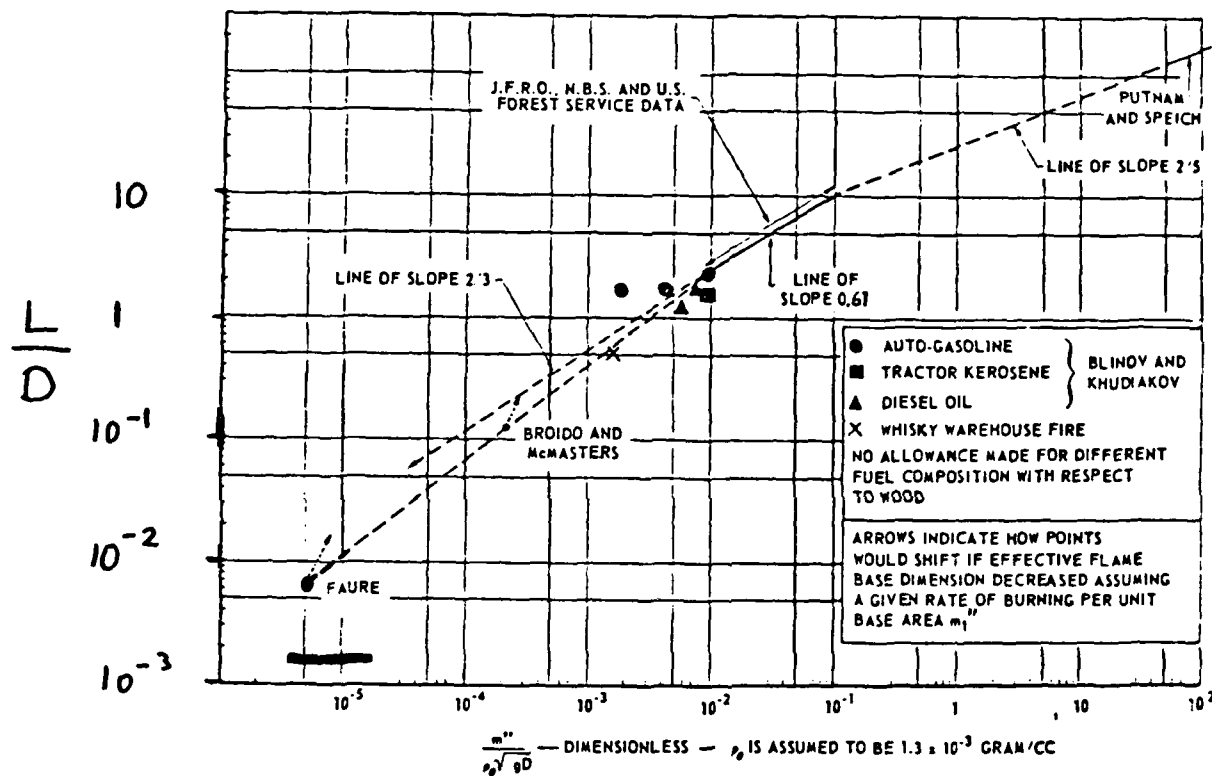


FIG. 4. Flame height correlation.

Figure 5. Flame height correlation according to P.H. Thomas (1963).

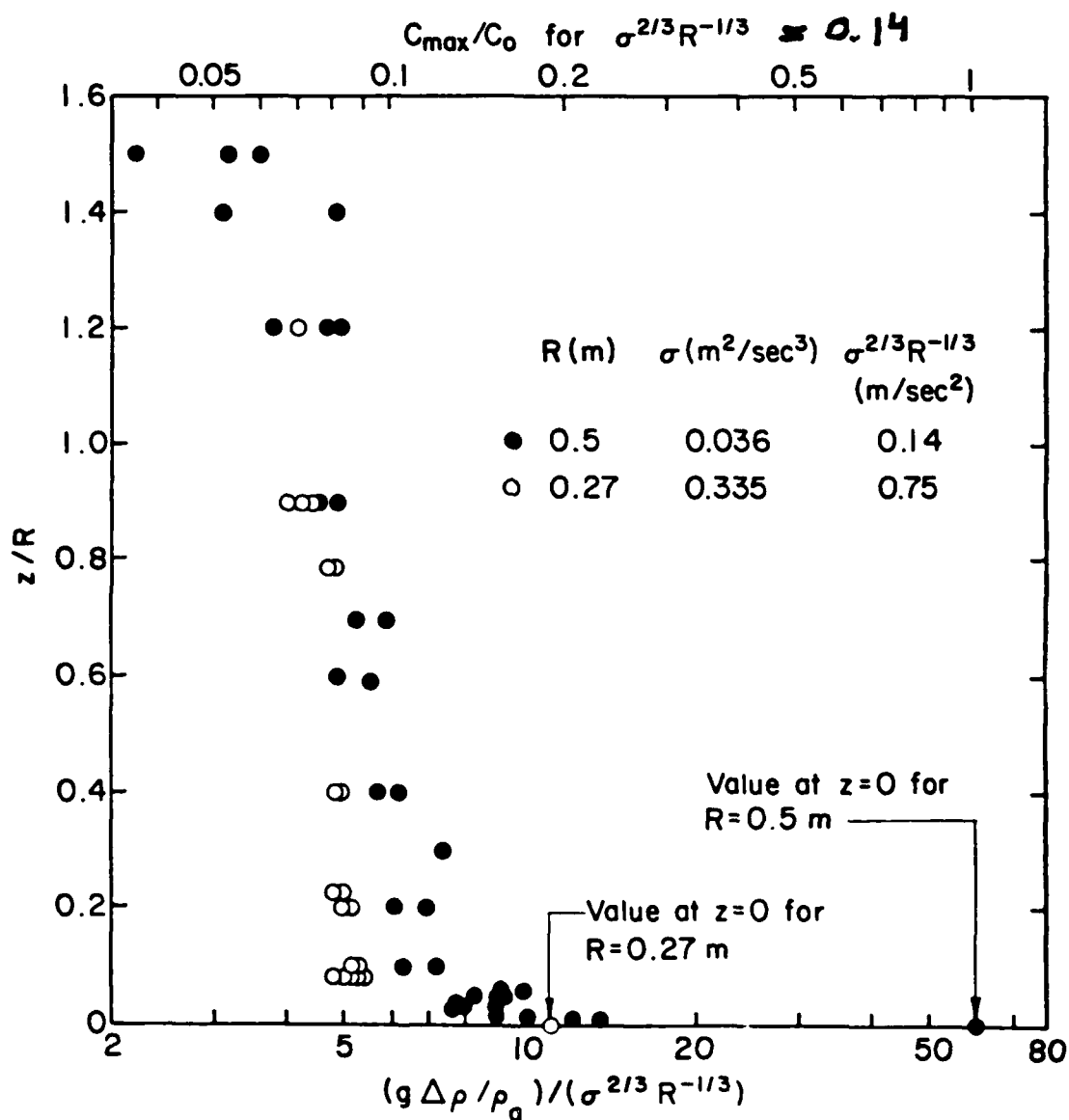


Figure 6. Measured dimensionless buoyancy parameter at the center of the plume in two physical models.

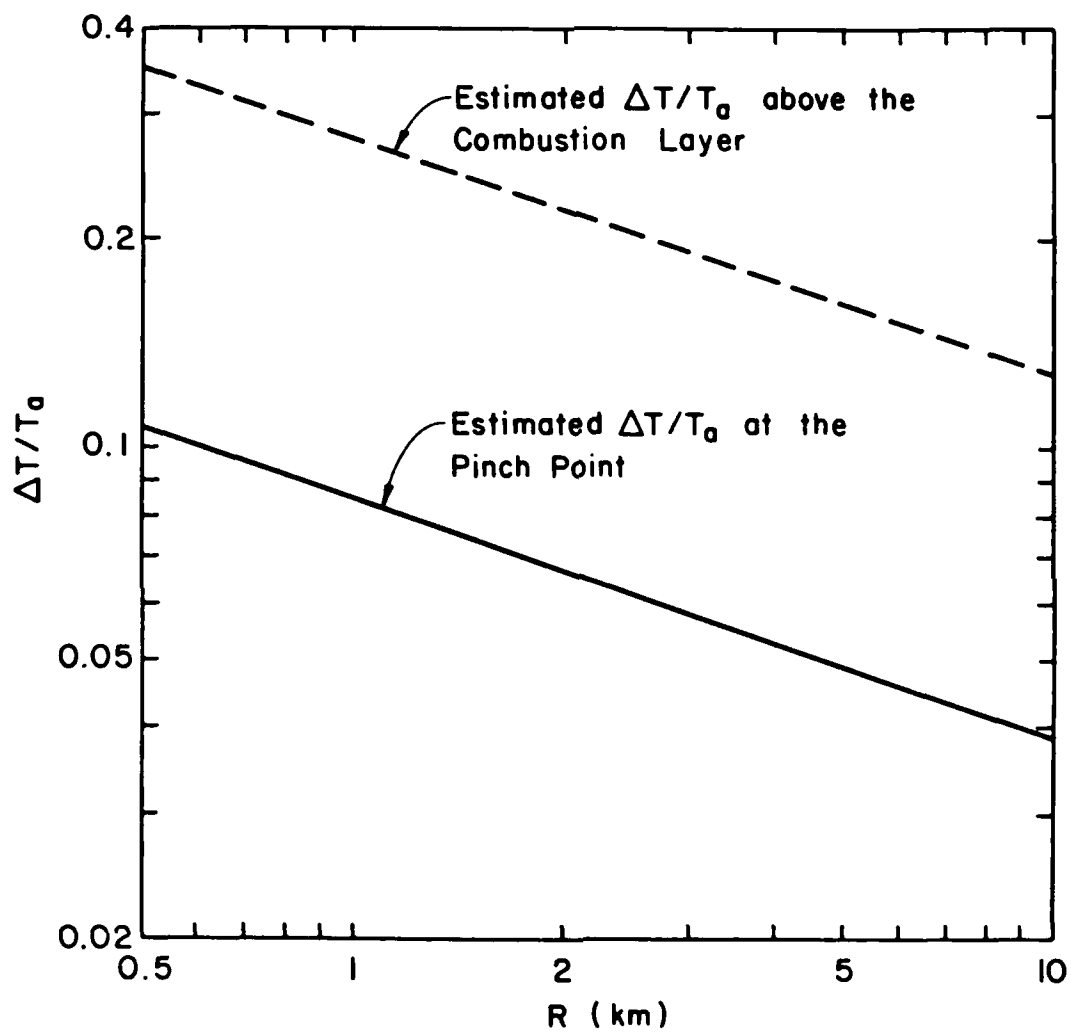


Figure 7. Estimated increase of plume temperatures for different size fires.

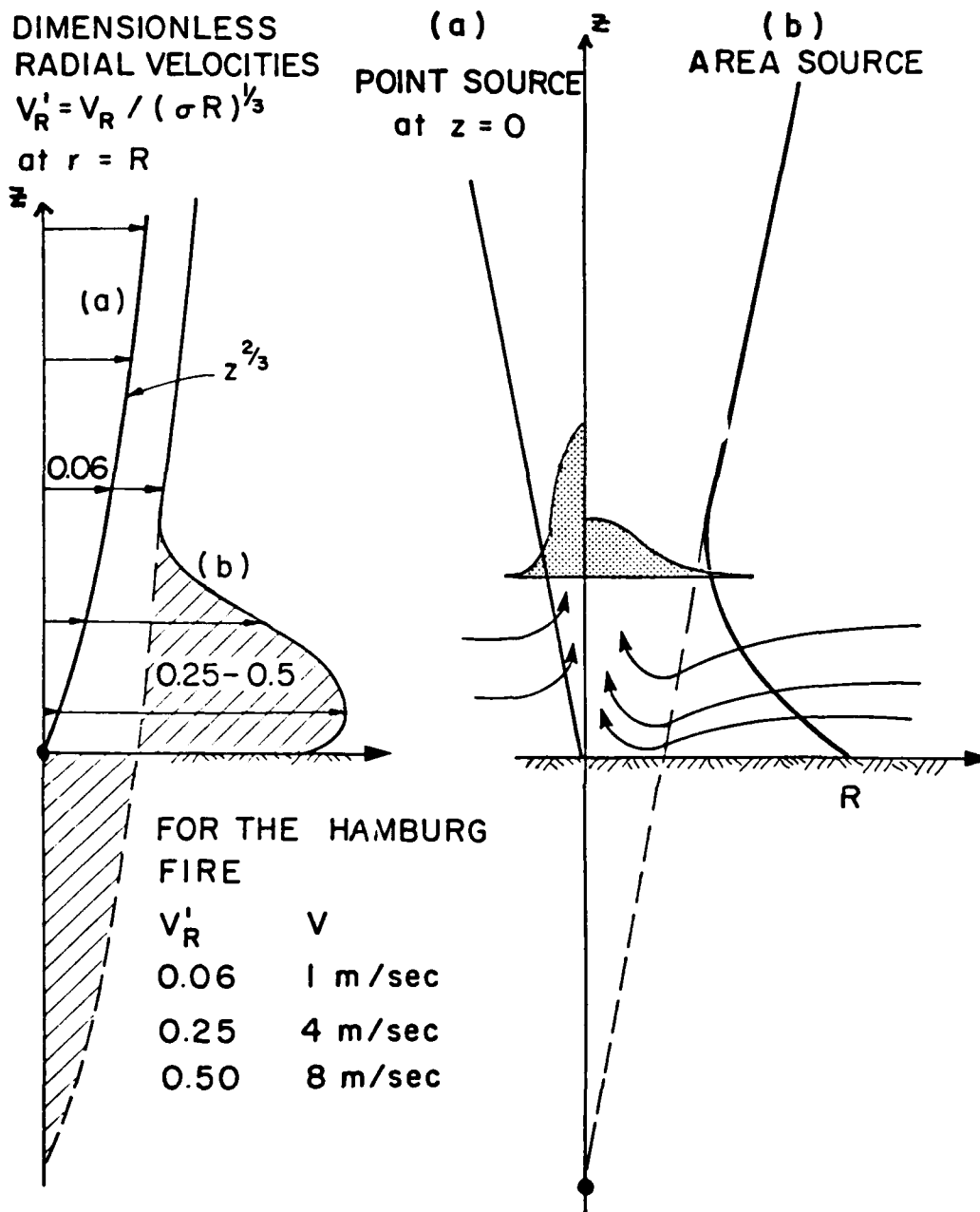


Figure 8. Schematic description of induced radial velocities for a point source (a) and an area source (b). (The correlation between the dimensionless velocities and expected velocities for the Hamberg Fire are shown in the figure).

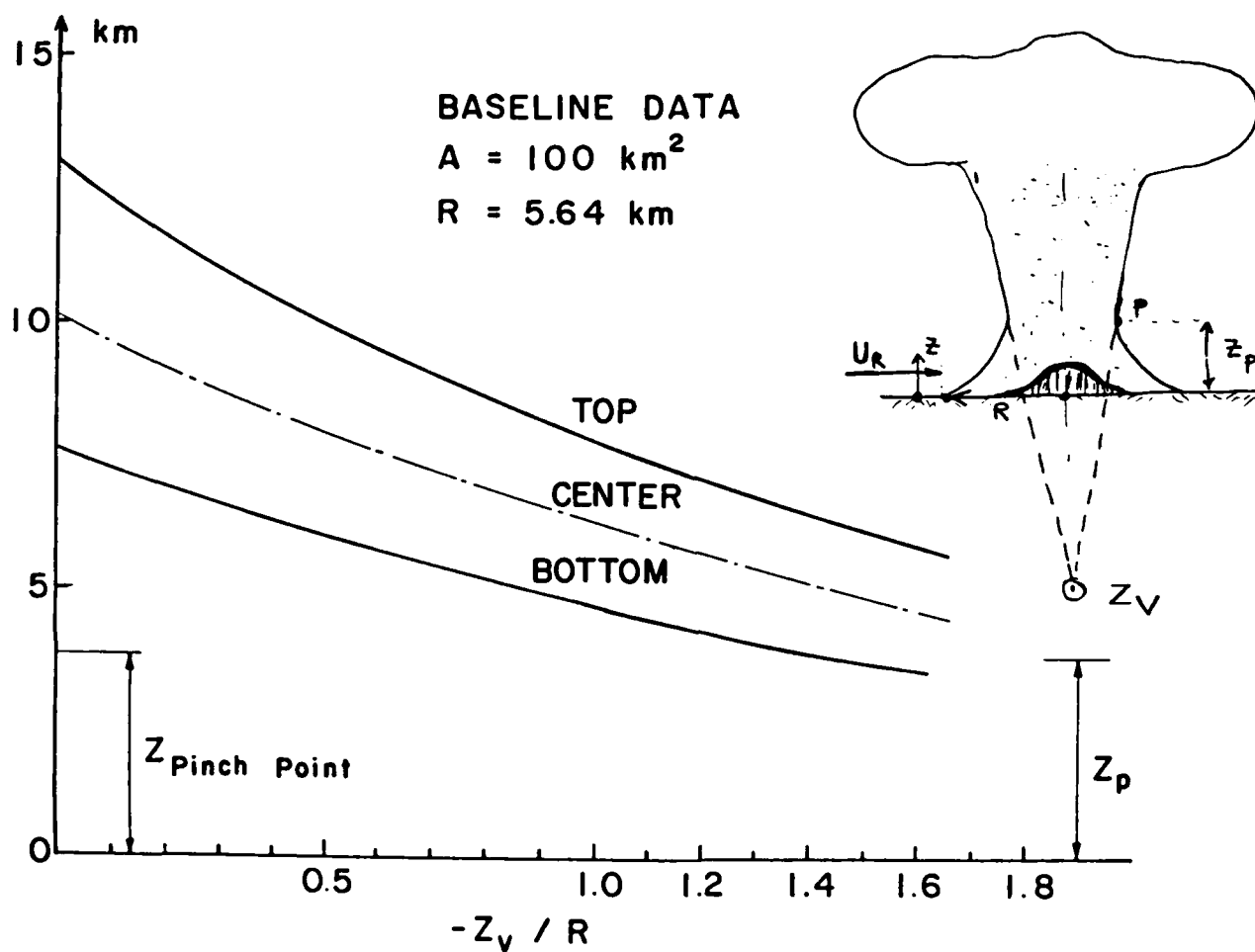


Figure 9. Estimate plume rise for a 100 km fire in a stably stratified atmosphere as a function of the position of the virtual source.

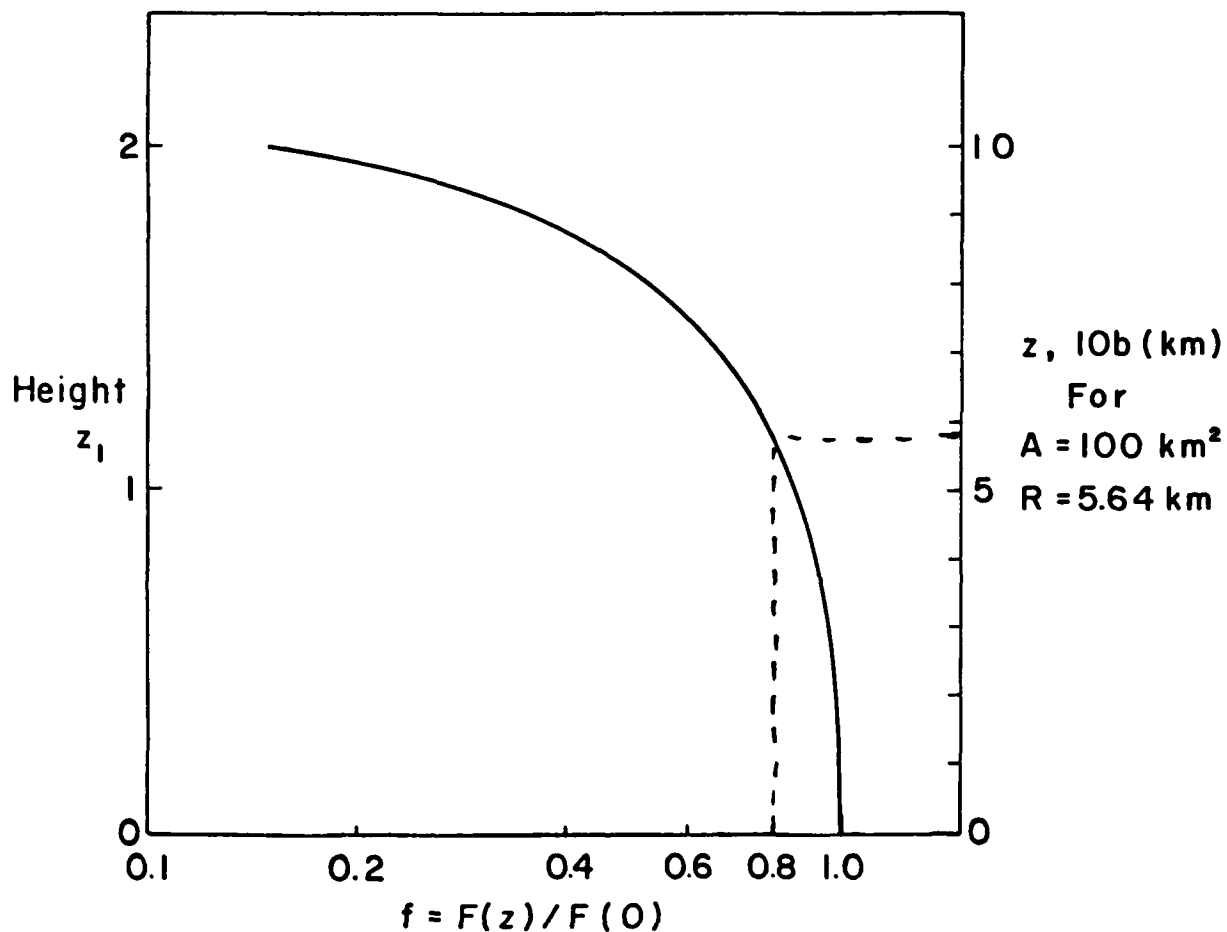


Figure 10. The relative reduction of buoyancy flux F with the height z in a stably stratified atmosphere according to Morton et al. (1956). (Note that most buoyancy flux disappears at large heights after the plume has increased its width.)

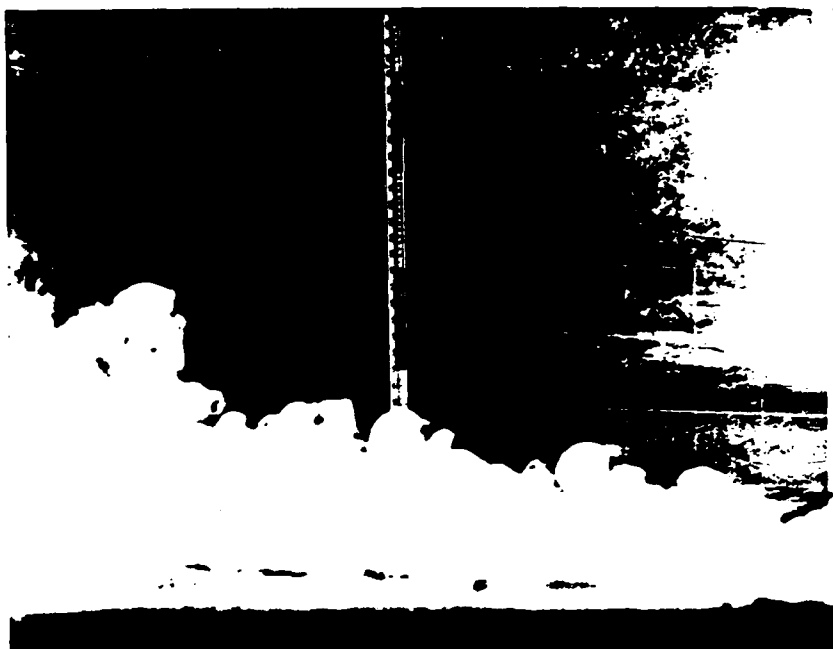


Figure 11. Photographs of the outer developing CBL in the two-dimensional fire model.



Figure 12. Photographs of the CBL in the two-dimensional fire model together with a smoke filament released above the layer.

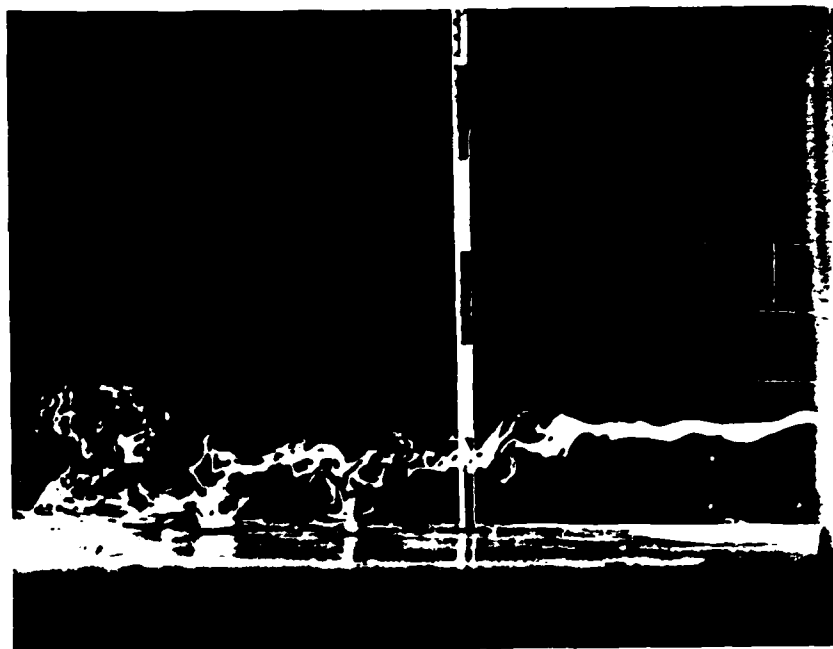


Figure 13. Photographs of smoke filaments released above the CBL in the two-dimensional fire model. (Note the rapid decent of the filaments in the CBL.)

**SMOKE PLUMES
FROM LARGE AREA FIRES**

A. KARAGOZIAN,

D. REMETCH

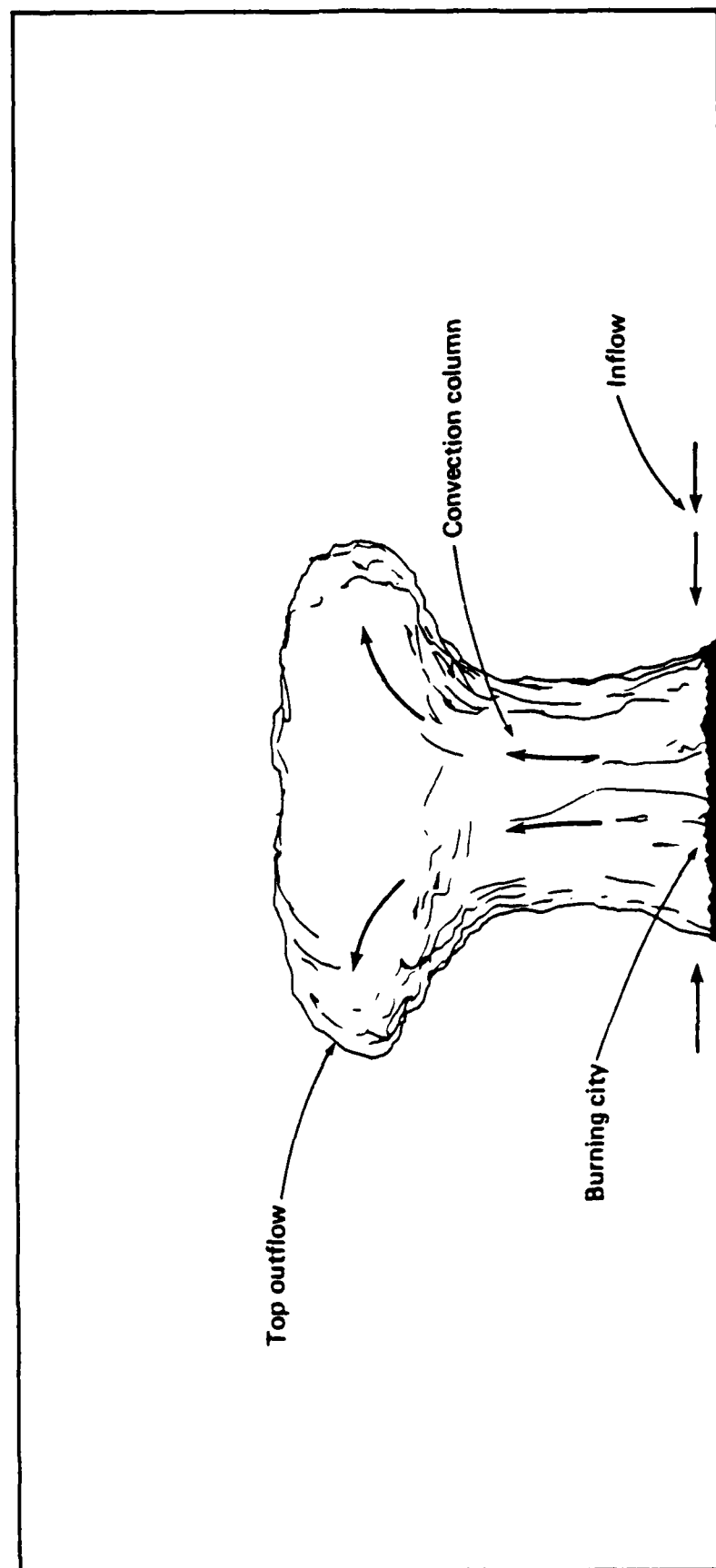
R. D. SMALL

GLOBAL EFFECTS PROGRAM MEETING

February 26-27, 1986

**PSR
F.T.N**

LARGE AREA FIRE IN THE ATMOSPHERE



HYDROCODE APPROXIMATION OF LARGE SMOKE PLUMES

- VARIABLES

- FIRE SIZE AND INTENSITY; BURNING TIME
- ATMOSPHERE TEMPERATURE PROFILE
- INVERSION HEIGHT
- HUMIDITY PROFILE

- MODELING ASSUMPTIONS

- HEAT RELEASE
- TURBULENCE
- TWO-DIMENSIONAL/AXISYMMETRIC
- RESOLUTION
- CITY STRUCTURE

- VALIDATION

- FLAMBEAU
- METEOTRON
- CHAPLEAU

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FLAMBEAU FIRE 460-7-66

- DATA

- 30 ACRE TEST SITE
- 240 15 m X 15 m FUEL PILES,
- 7.5 m AISLES
- 330 m CROSS SECTION
- 40,000 LB/PILE - MIXED JUNIPER AND PINON
- HEAT RELEASE MEASURED
- VELOCITIES MEASURED

- SIMULATION

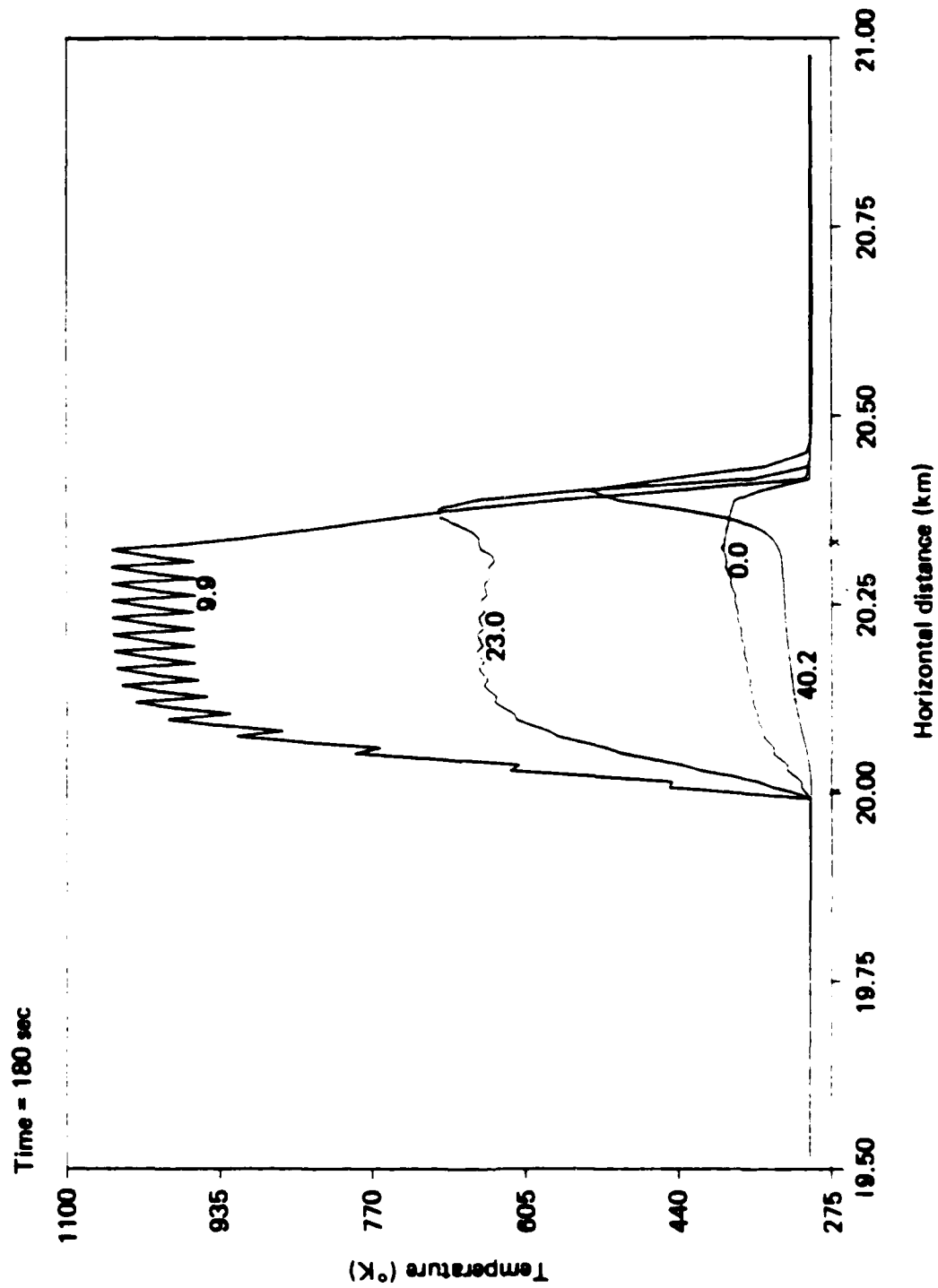
- MEASURED HEAT RELEASE USED
- TWO-DIMENSIONAL WITH AMBIENT WIND
- FUEL BED - AISLES MODELED

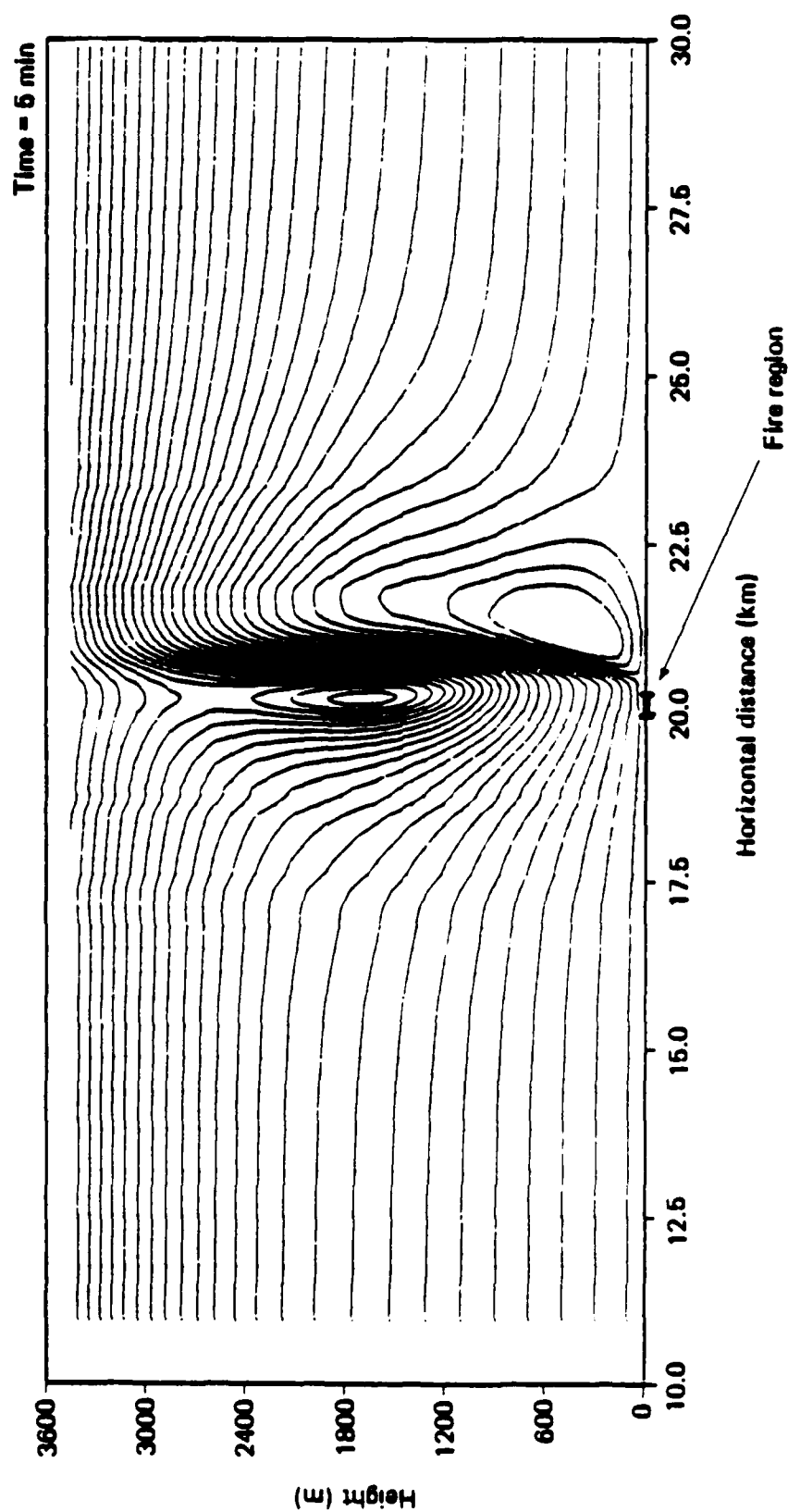
- RESULTS

- MERGING OF PLUMES CALCULATED
- PLUME RISE IN CROSSWIND
- FAIR AGREEMENT WITH MEASURED VELOCITIES

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TEMPERATURE AT CONSTANT HEIGHTS





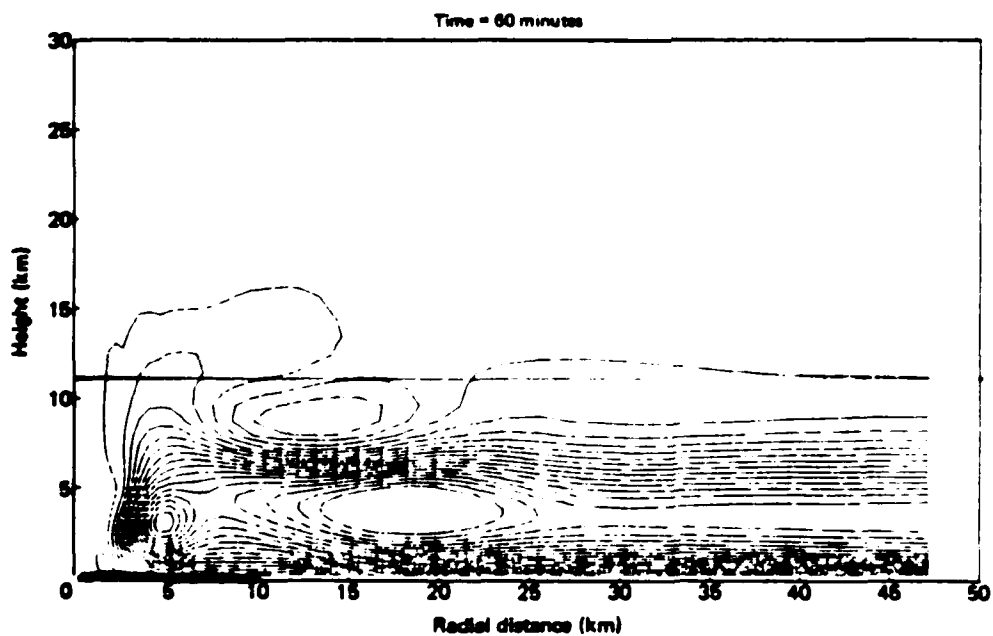
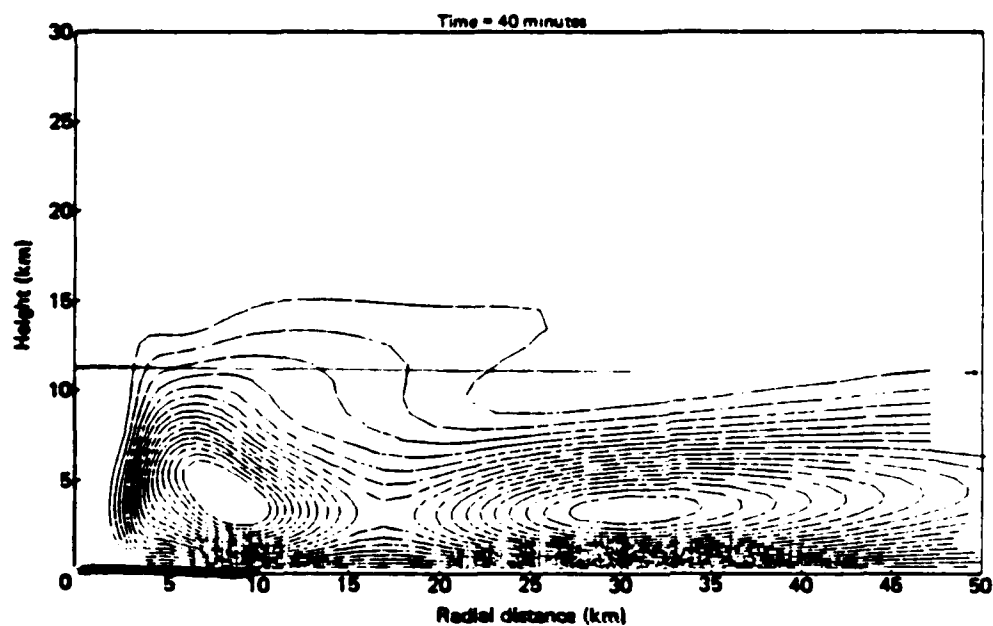
Streamlines: Flambeau fire 460-7-66.

EXAMPLE CASES

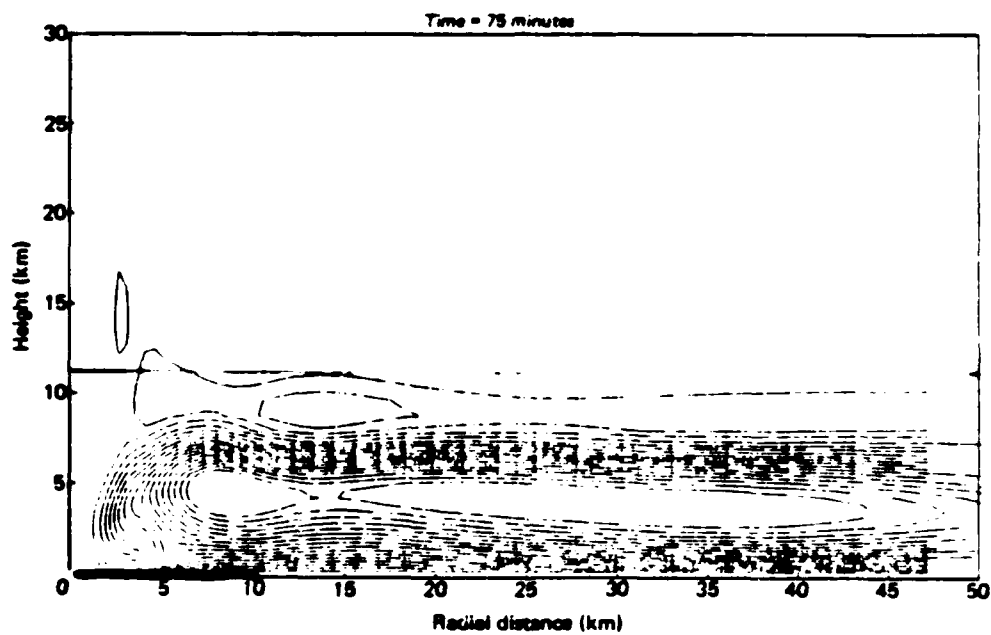
- FIRE RADIUS 10 km
- FIRE ZONE HEIGHT 100 m
- HEAT RELEASE RATES $1 \text{ kW/m}^3 + 2.5 \text{ kW/m}^3$
- FUEL CONSUMPTION $2 \text{ g/cm}^2/\text{hr}$
- SMOKE EMISSION FACTOR 3 PERCENT
- RELATIVE HUMIDITY RATIOS 0, 0.5, 0.77
- U.S. STANDARD ATMOSPHERE TEMPERATURE PROFILE
- TROPOPAUSE AT 11 km

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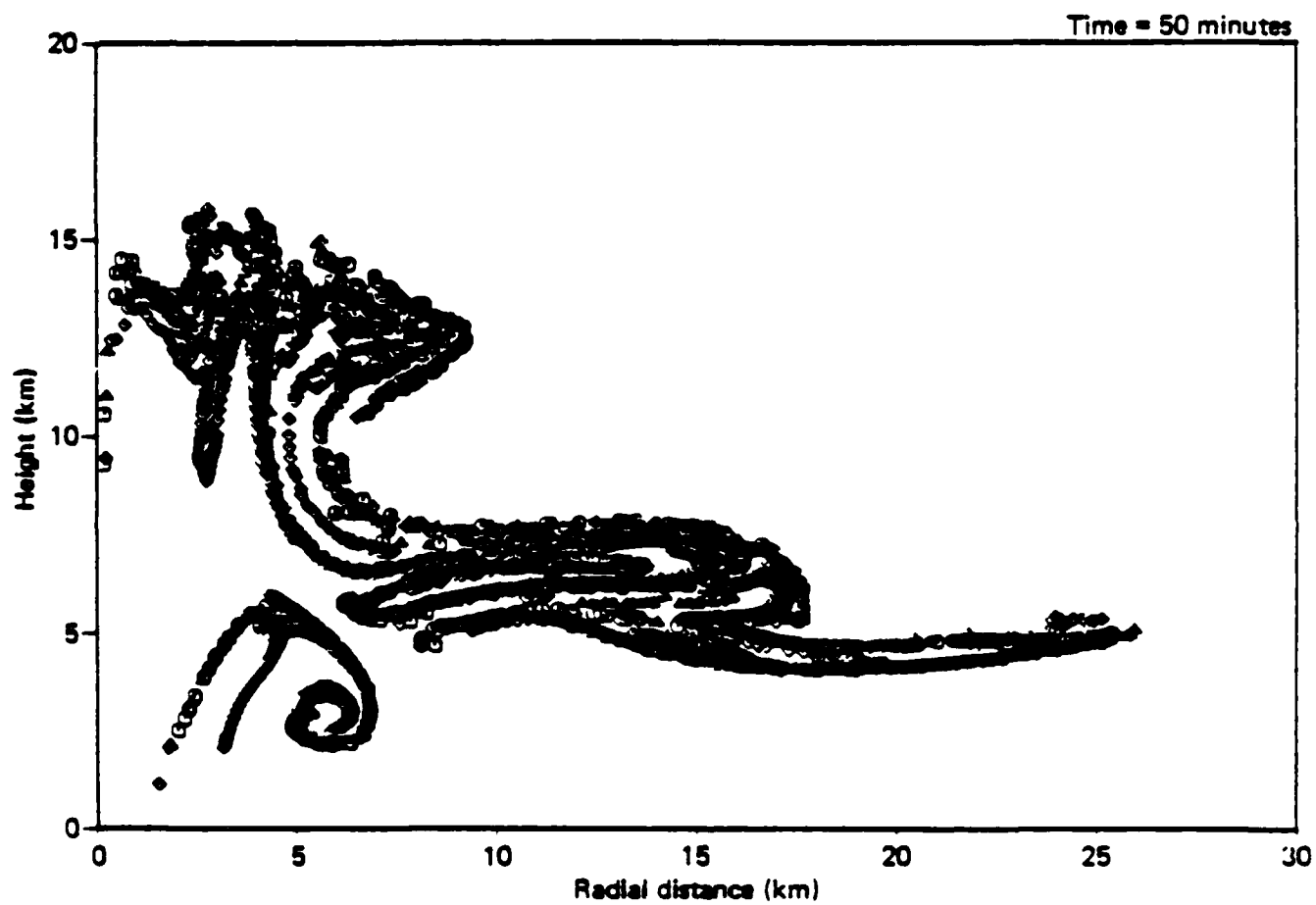
1 KW/M3 LARGE AREA FIRE: U. S. STANDARD ATMOSPHERE



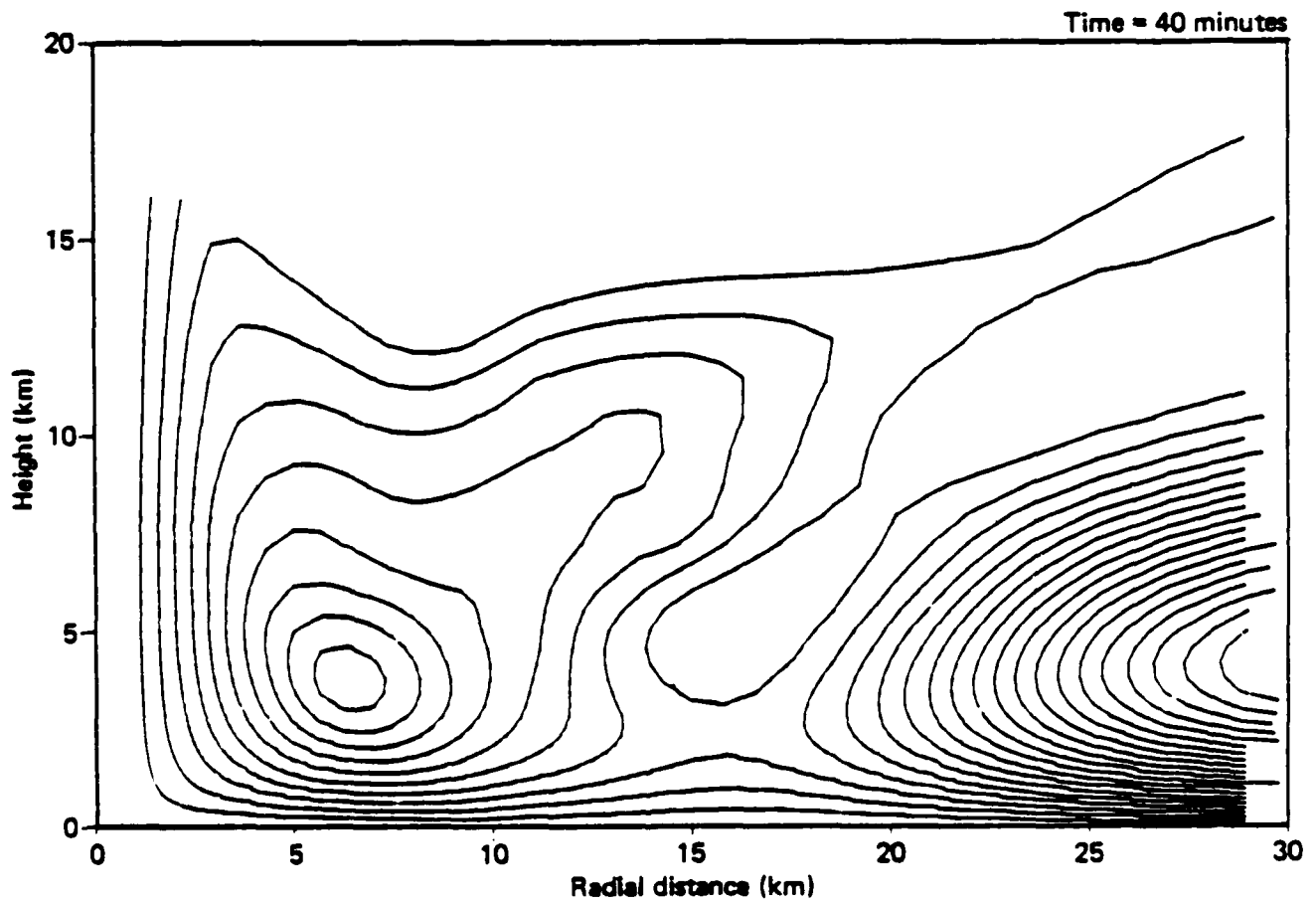
1 KW/M3 LARGE AREA FIRE: U. S. STANDARD ATMOSPHERE



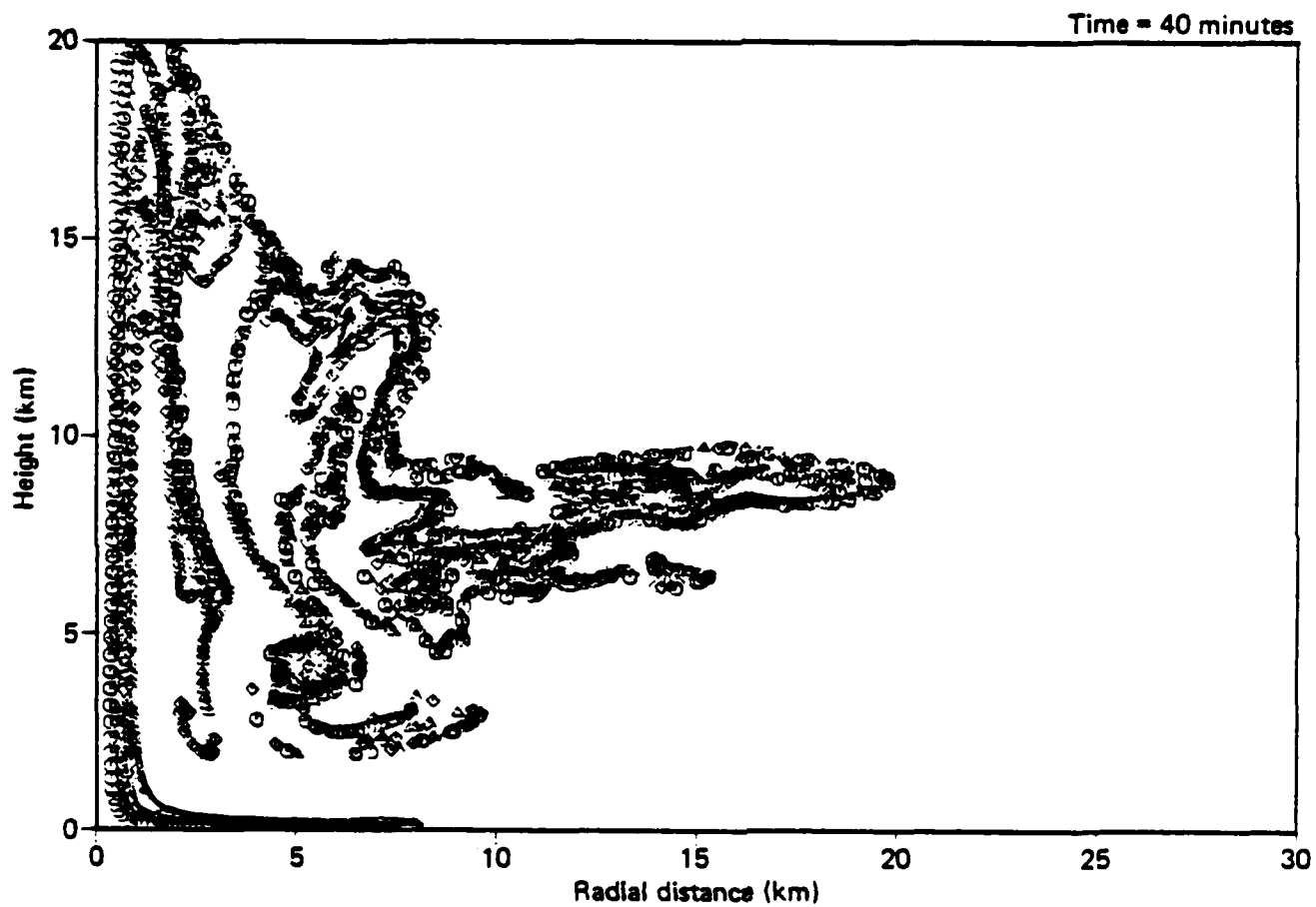
Smoke tracers: 10-km radius area fire; $Q = 1\text{ kW/m}^3$; $\phi_0 = 0$.



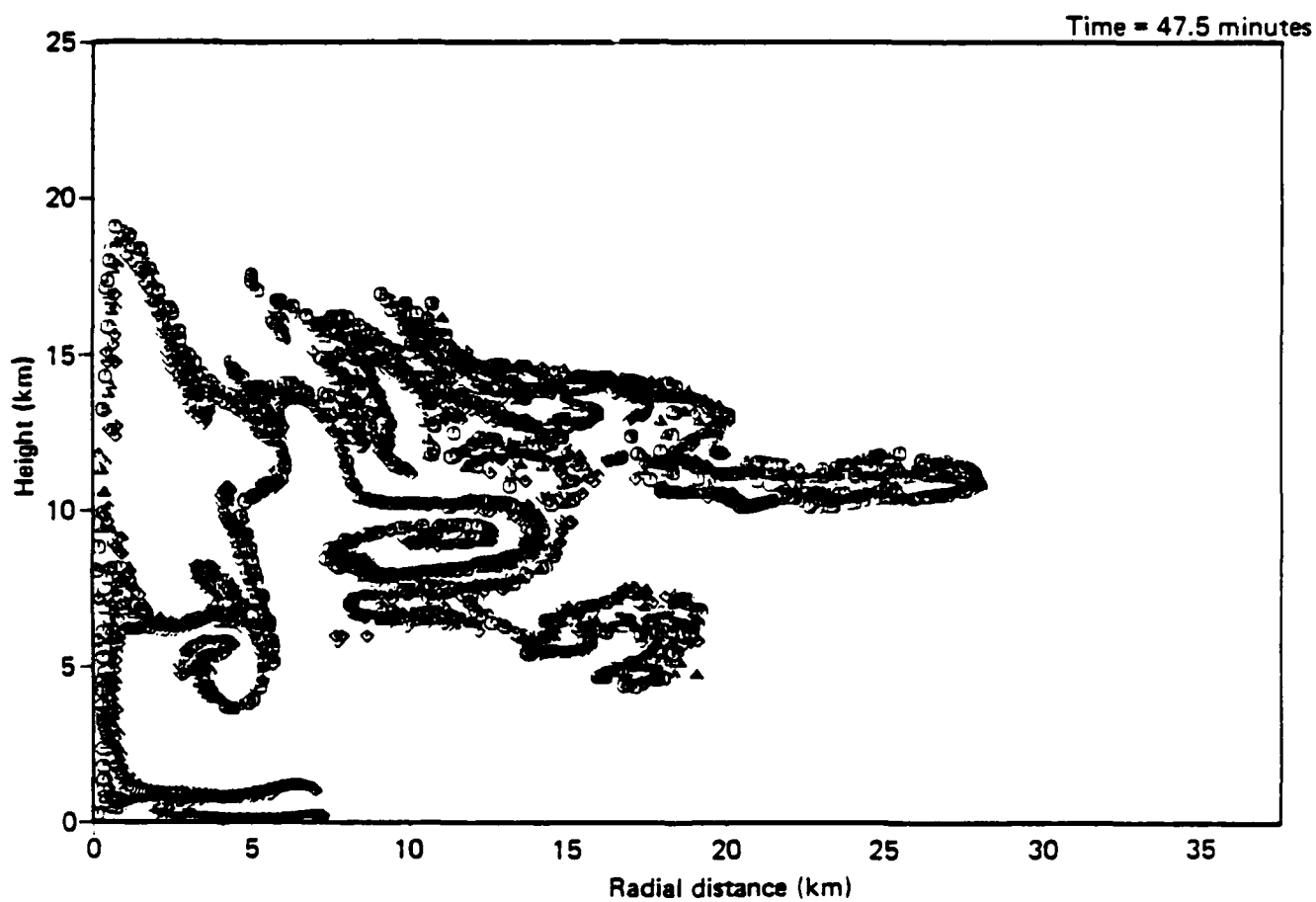
Streamlines: 10-km radius area fire; $Q = 1 \text{ kW/m}^3$; $\phi_0 = 0.77$.



Smoke tracers: 10-km radius area fire; $Q = 1 \text{ kW/m}^3$; $\phi_0 = 0.77$.



Smoke tracers: 10-km radius area fire; $Q = 2.5 \text{ kW/m}^3$; $\phi_0 = 0.77$.



CONCLUSIONS

- ATMOSPHERIC GRADIENTS CONTROL PLUME RISE
- MODERATE ENERGY PLUMES CONTAINED BY TROPOPAUSE
- MOISTURE INFLUENCES SMOKE CLOUD HEIGHT
- BETTER RESOLUTION OF CITY REQUIRED
- NEW HEAT RELEASE MODEL NEEDED
- LOWER HEAT RELEASE SIMULATIONS NEEDED

PSR
F.T.N

TROPOPAUSE RESPONSE TO LARGE AREA FIRES

DAVID P BACON

**SCIENCE APPLICATIONS
INTERNATION CORPORATION**

FEBRUARY 26, 1986

**PRESENTED AT THE DNA GLOBAL EFFECTS
PROGRAM MEETING AT NASA/AMES**

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The Terminal Area Simulation System (TASS)

Equations for:

Momentum
Pressure
Potential Temperature
Water Vapor
Cloud Water
Cloud Ice
Rain
Snow
Hail
Smoke (Massless Tracer)
Dust (Massive Tracer)

Turbulence:

Smagorinsky - shear
- stratification

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Parameterizations:

**Rain drop initiation
Rain drop growth
Evaporation of rain
Freezing of supercooled cloud water and rain
Initiation of cloud ice
Ice growth
Cloud ice becomes hail
Deposition and sublimination of hail
and cloud ice
Hail growth
Shedding of unfrozen water
Initiation of snow
Snow growth
Melting of hydrometeors**

Additional Diagnostics:

**Radar reflectivity
Hydrometeor concentrations**

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Boundary Conditions:

Surface - Nonslip velocity
- Continuous thermodynamics
- Time-dependent heat source

Axial - Symmetric

Lateral - Open boundary

Top - Zero vertical velocity
- Other variables continuous

Initial Conditions:

Ambient atmosphere initialized by
temperature and dewpoint sounding.

Fireball modelled by a "Thermal Bubble" - a
hemispherical region of overtemperature
(1 MT Nuclear - 675 KT Thermal)

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WOOD: 8500-9000 BTU/lb

8600 BTU/lb ~ 20 MJ/kg

2 % SMOKE EMISSION FACTOR = 20 g/kg

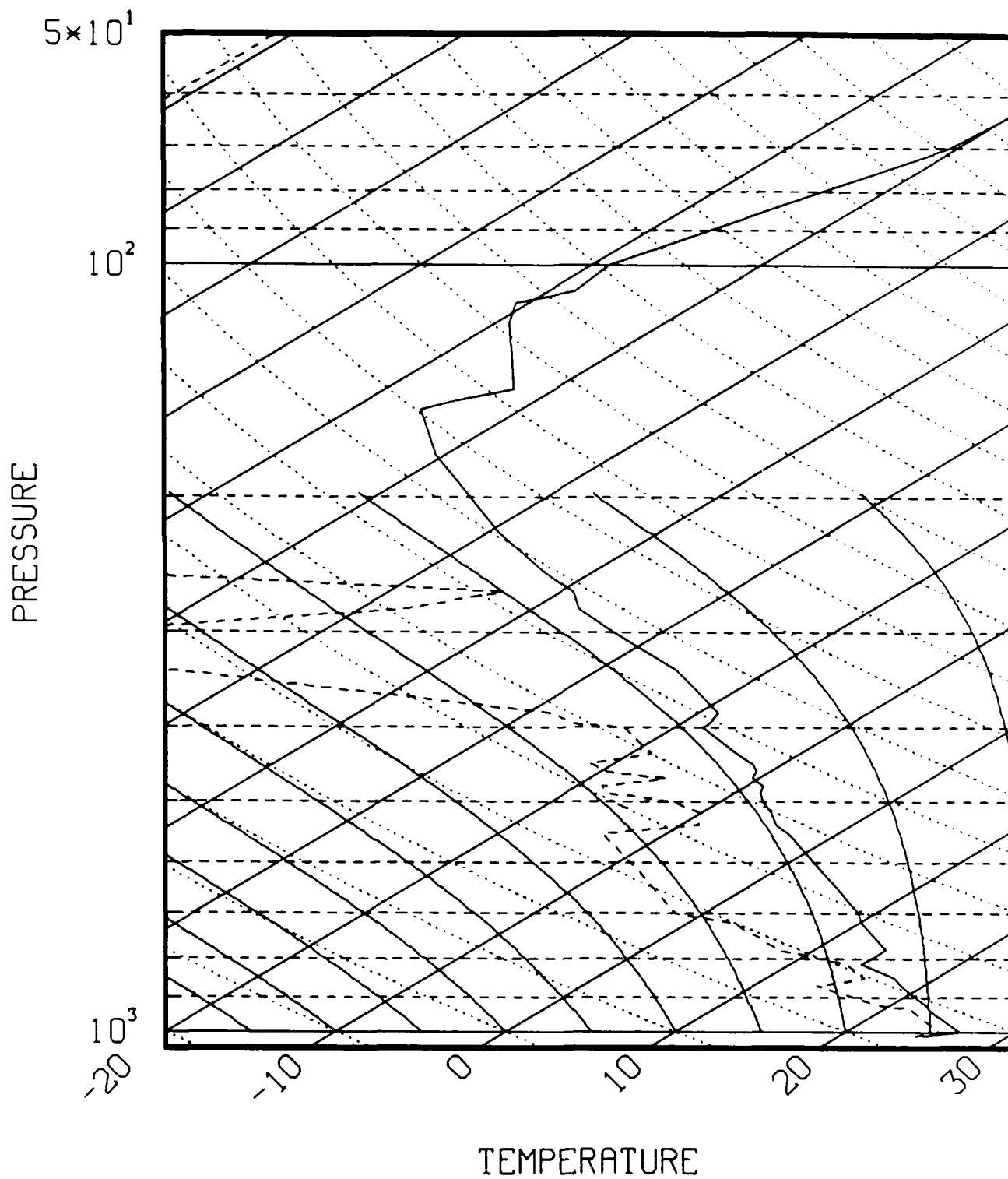
SMOKE EMISSION = 1 g/MJ

FIRE INTENSITY: UNIFORM OVER 10 km RADIUS

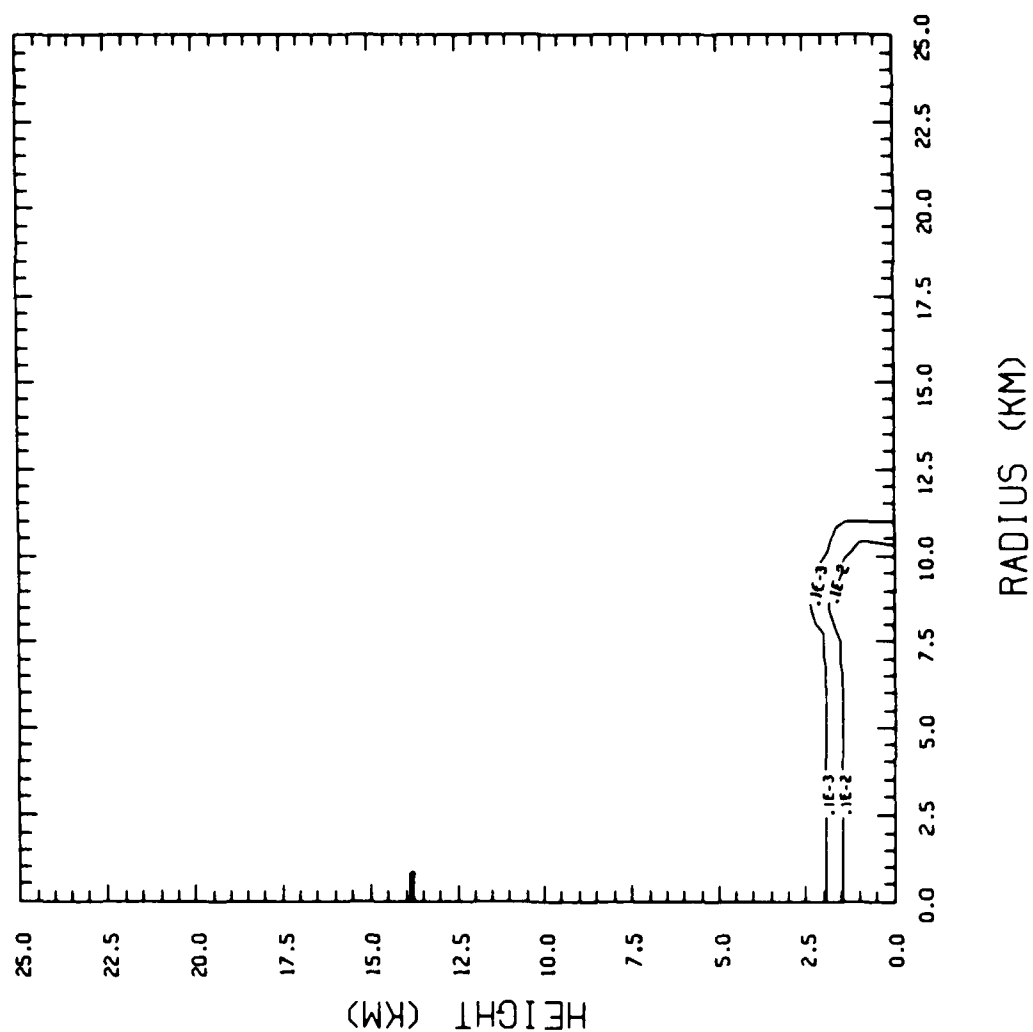
45 min LINEAR RISE
60 min @ 50 kW/m²
45 min LINEAR DECAY

TOTAL HEAT INPUT ~ 10¹⁷ J
TOTAL SMOKE INPUT ~ 10¹¹ g

LCH DATA @ 2400Z 4-10-79

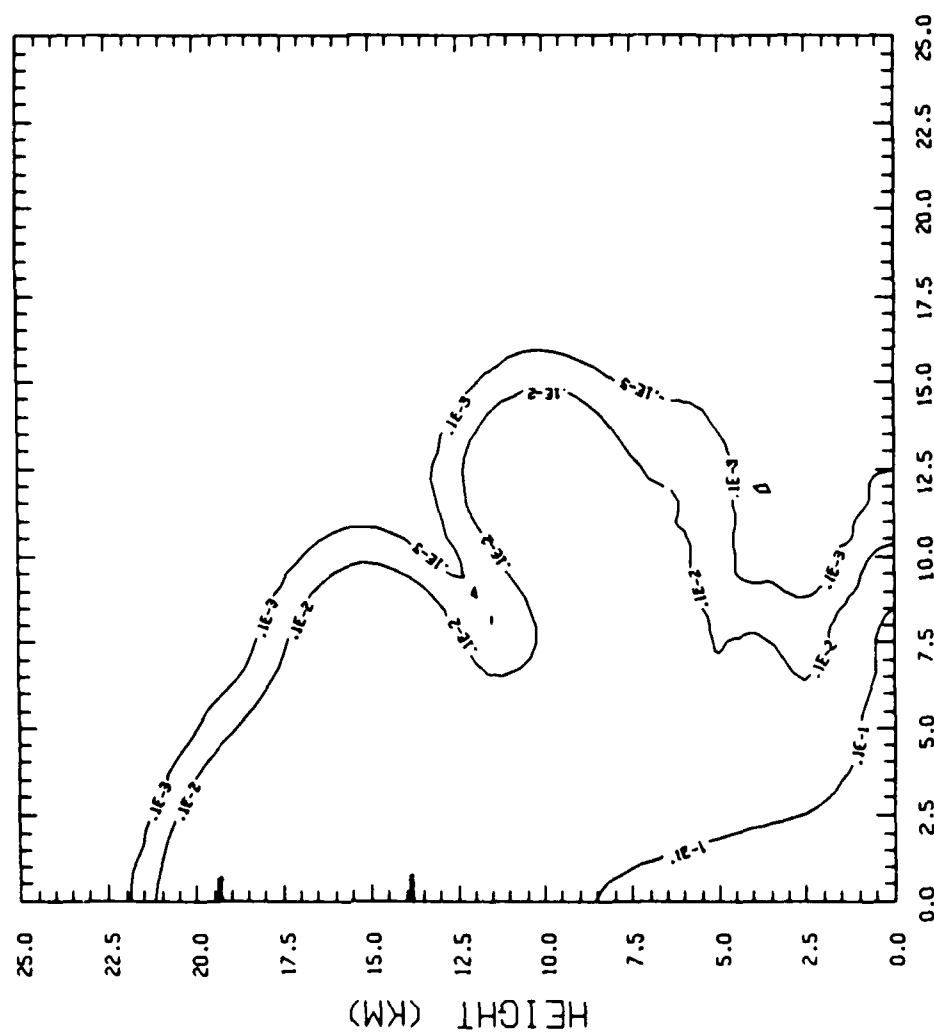


SMK 2.5 HR--50 KW/M**2 @ LCH TIME= 15.1



CONTOUR FROM .10000E-03 TO 10.000
(USER'S LEVELS)

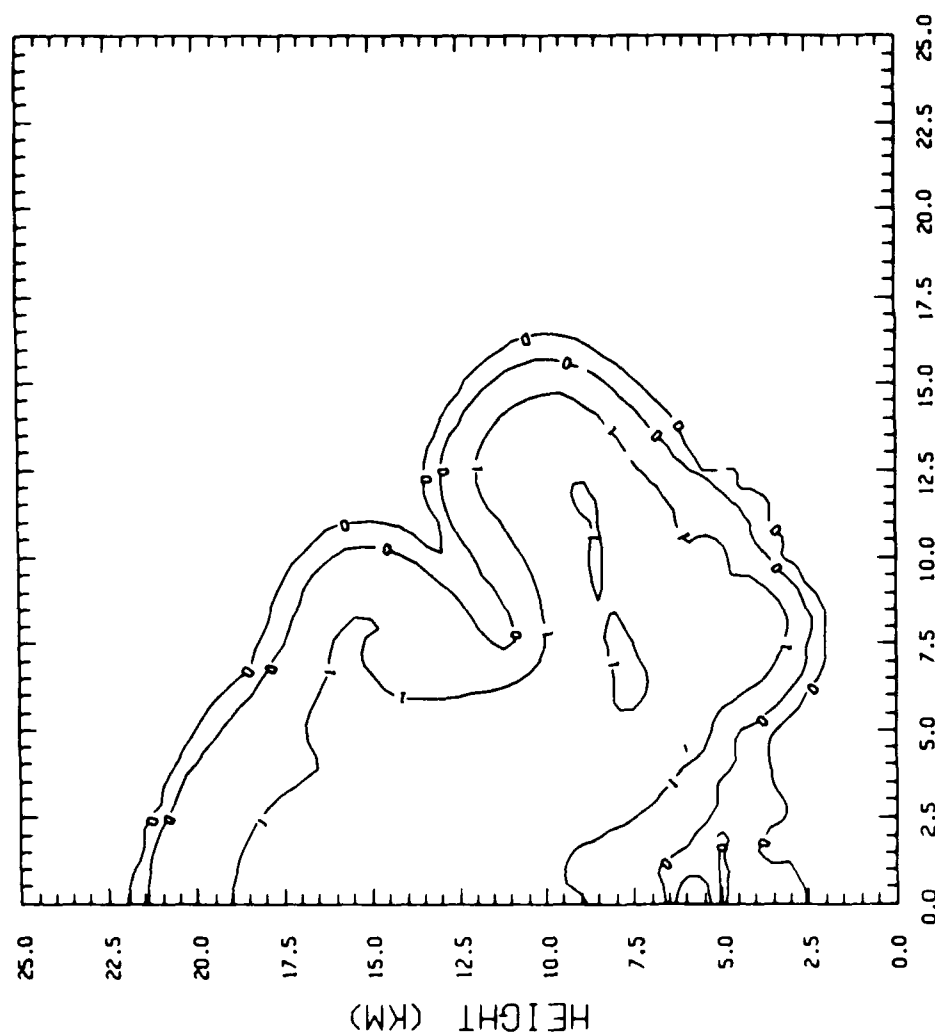
SMK 2.5 HR--50 KW/M**2 • LCH TIME= 45.0



RADIUS (KM)

CONTOUR FROM .10000E-03 TO 10.000
(USER'S LEVELS)

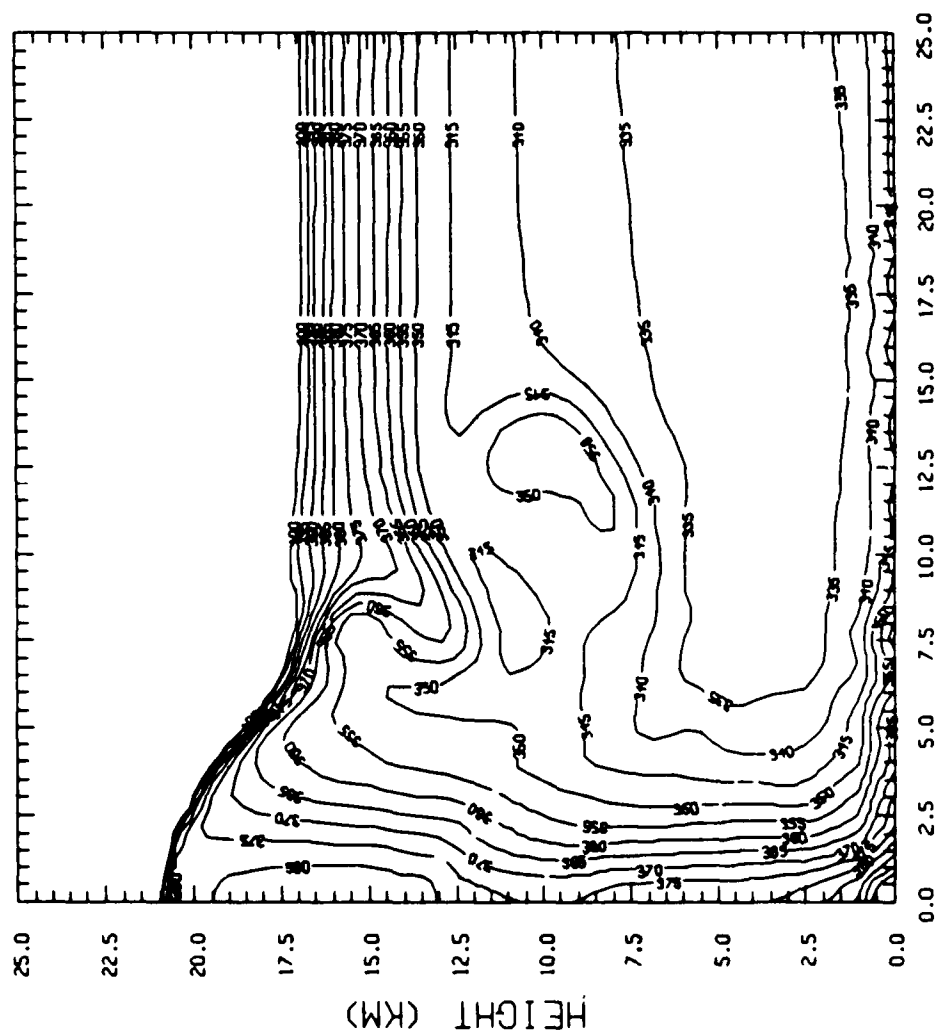
TPW 50 KW/M**2 FIRE • LCH TIME= 45.0



RADIUS (KM)

CONTOUR FROM .10000E-01 TO 1.0000
(USER'S LEVELS)

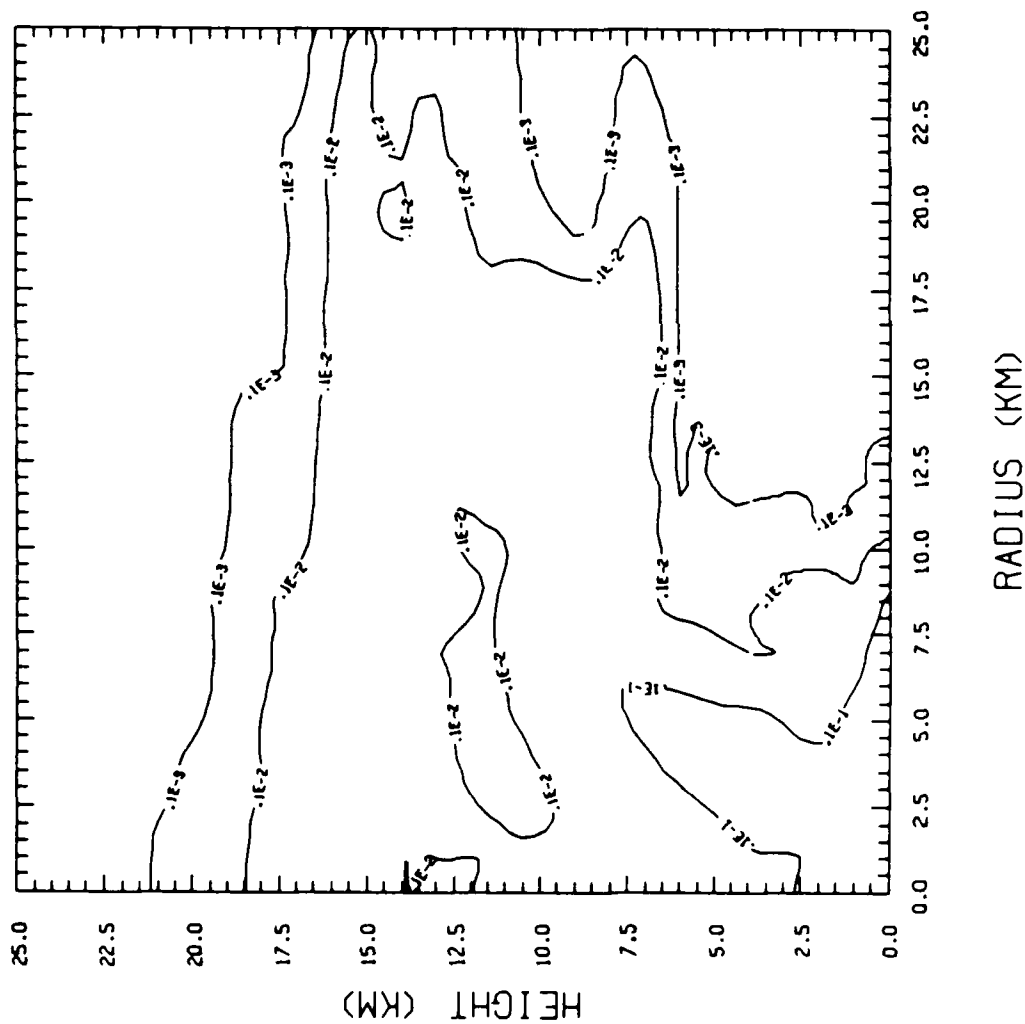
EPOT 2.5 HR--50 KW/M**2 @ LCH TIME= 45.0



RADIUS (KM)

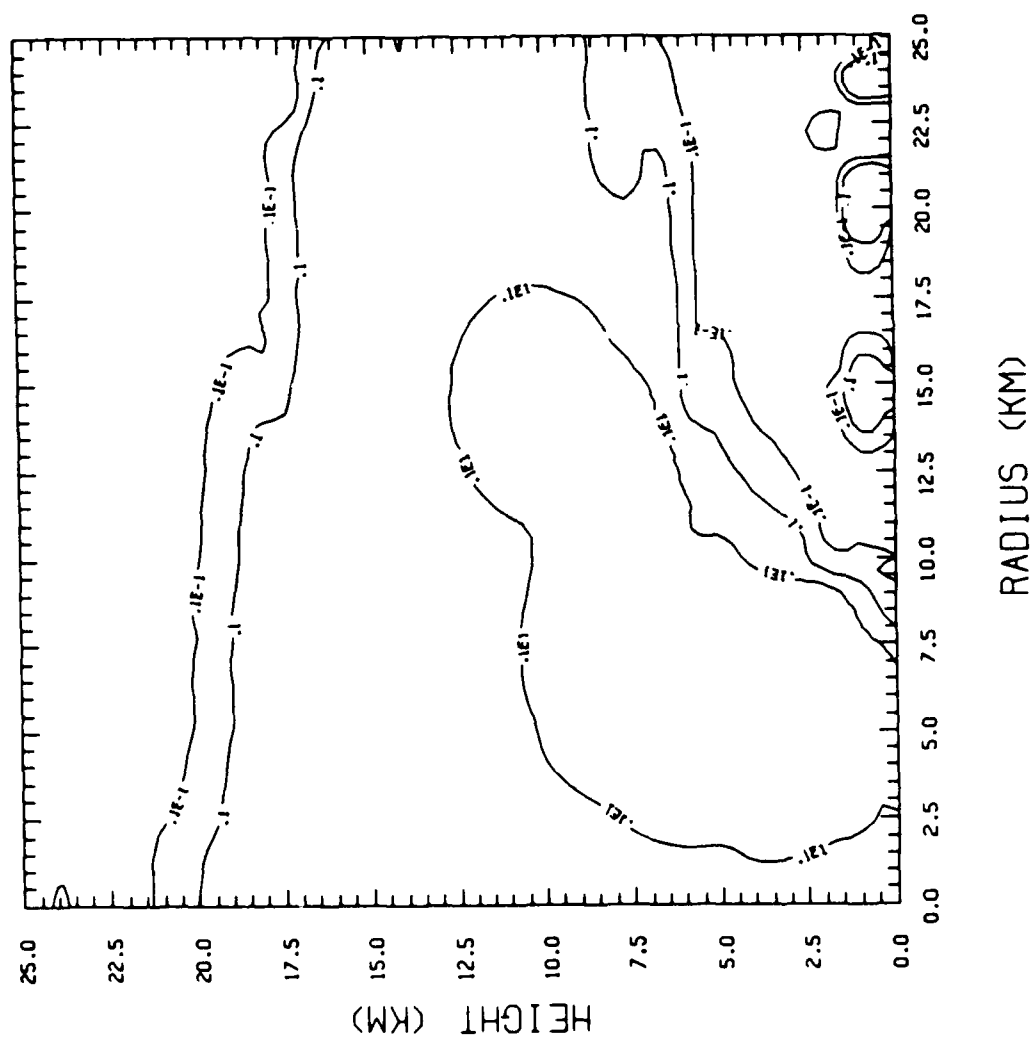
CONTOUR FROM 335.00 TO 400.00
(USER'S LEVELS)

SMK 2.5 HR--50 KW/M**2 • LCH TIME= 90.0



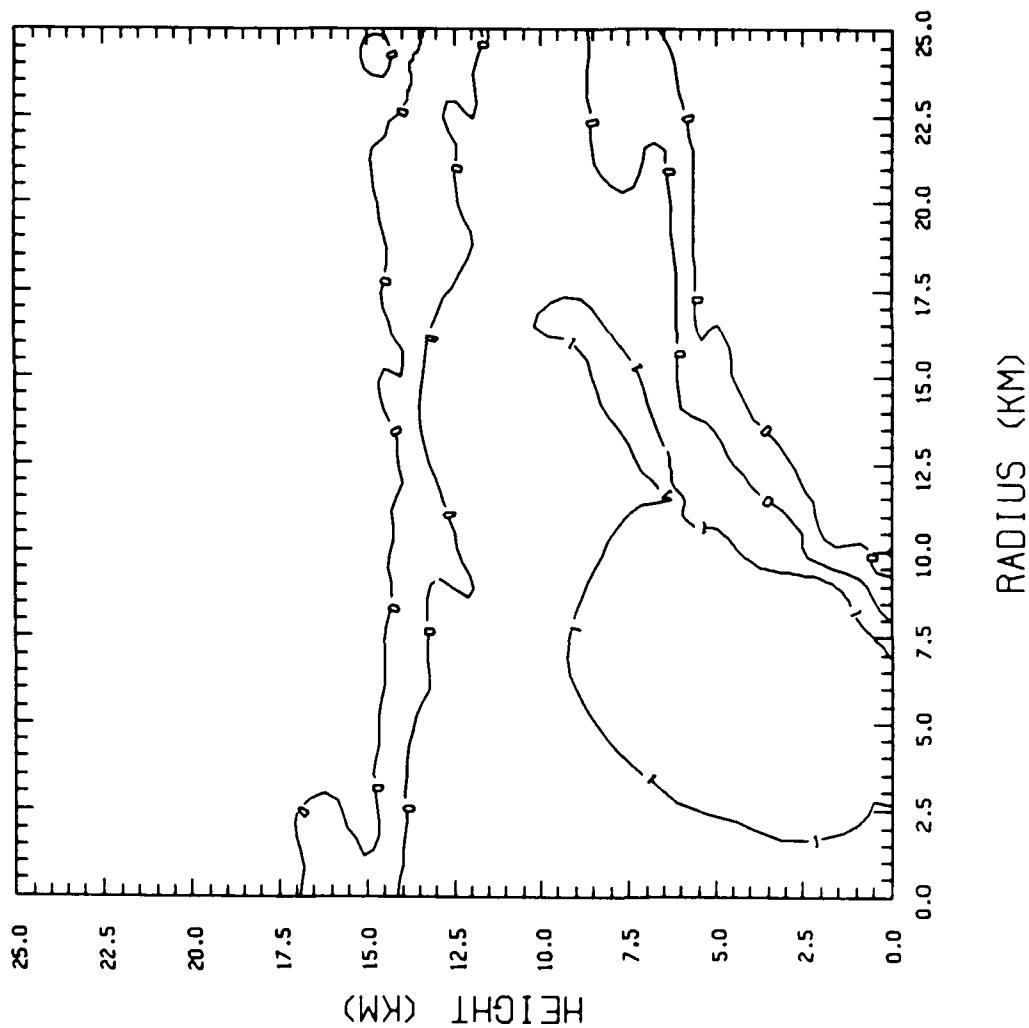
CONTOUR FROM .10000E-03 TO 10.000
(USER'S LEVELS)

```
TCW      2.5 HR--50 KW/M**2  @ LCH
TIME= 90.0
```



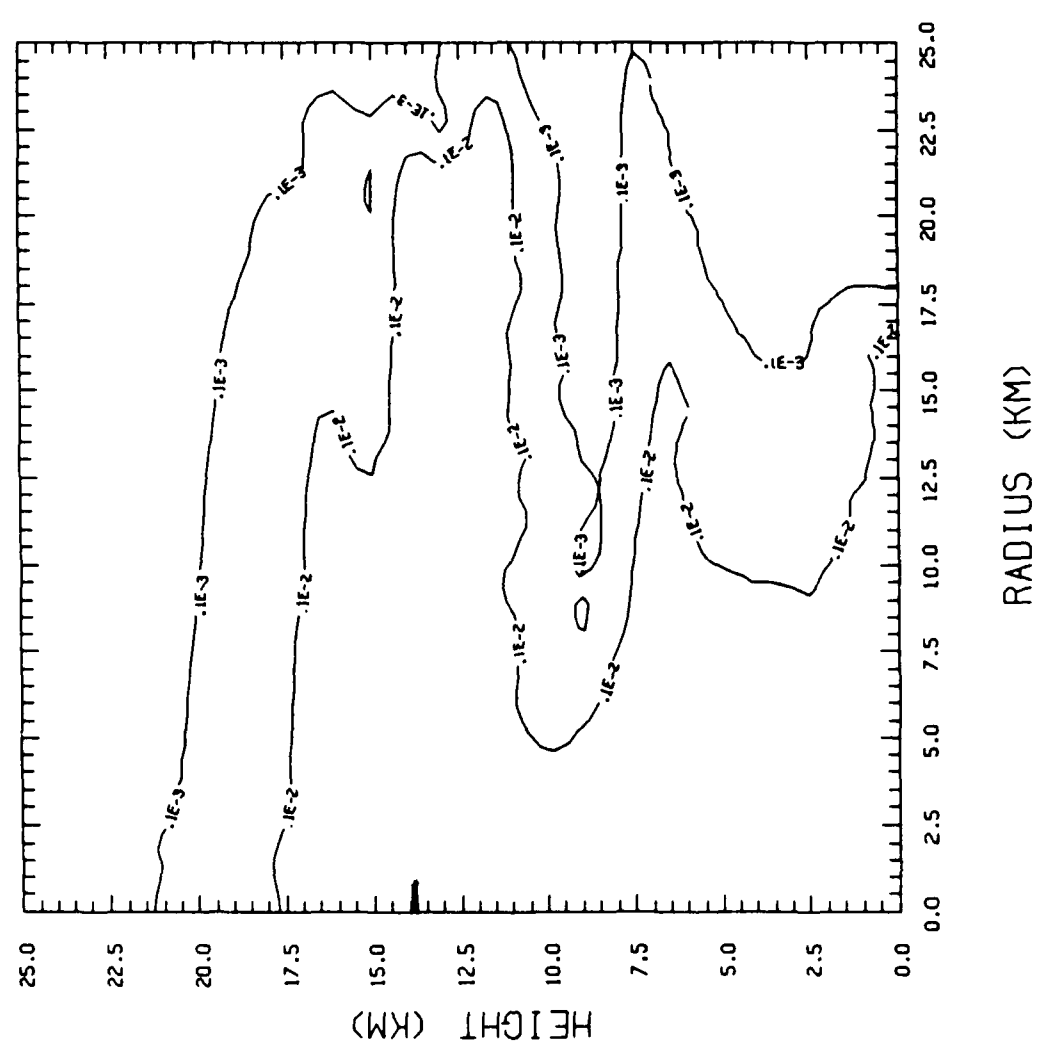
CONTOUR FROM .1000E-01 TO 10.000
(USER'S LEVELS)

TPW 50 KW/M**2 FIRE • LCH TIME= 90.0



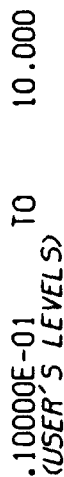
CONTOUR FROM .10000E-01 TO 1.0000
(USER'S LEVELS)

SMK 2.5 HR--50 KW/M**2 @ LCH TIME=180.0

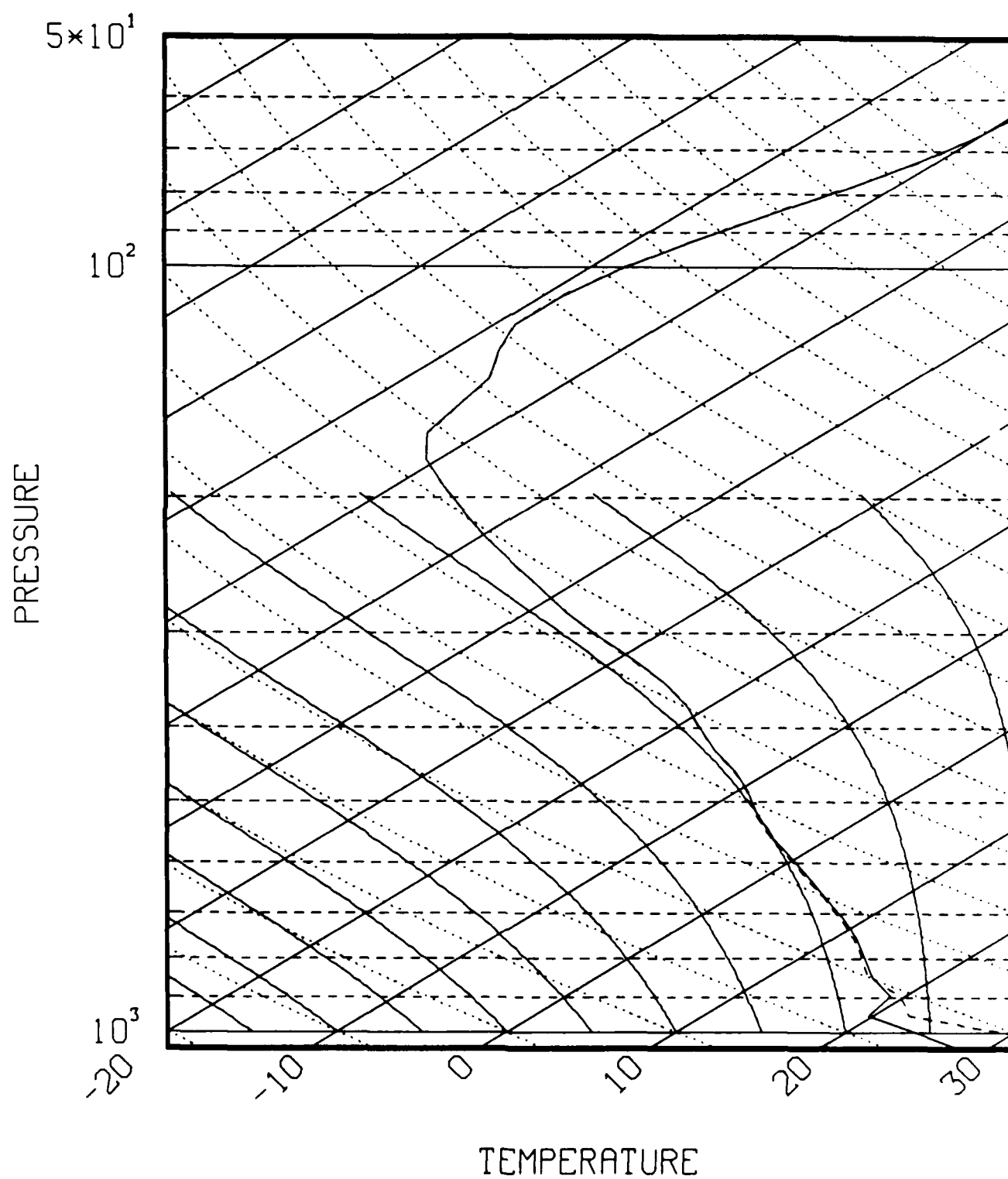


CONTOUR FROM .10000E-03 TO 10.000
(USER'S LEVELS)

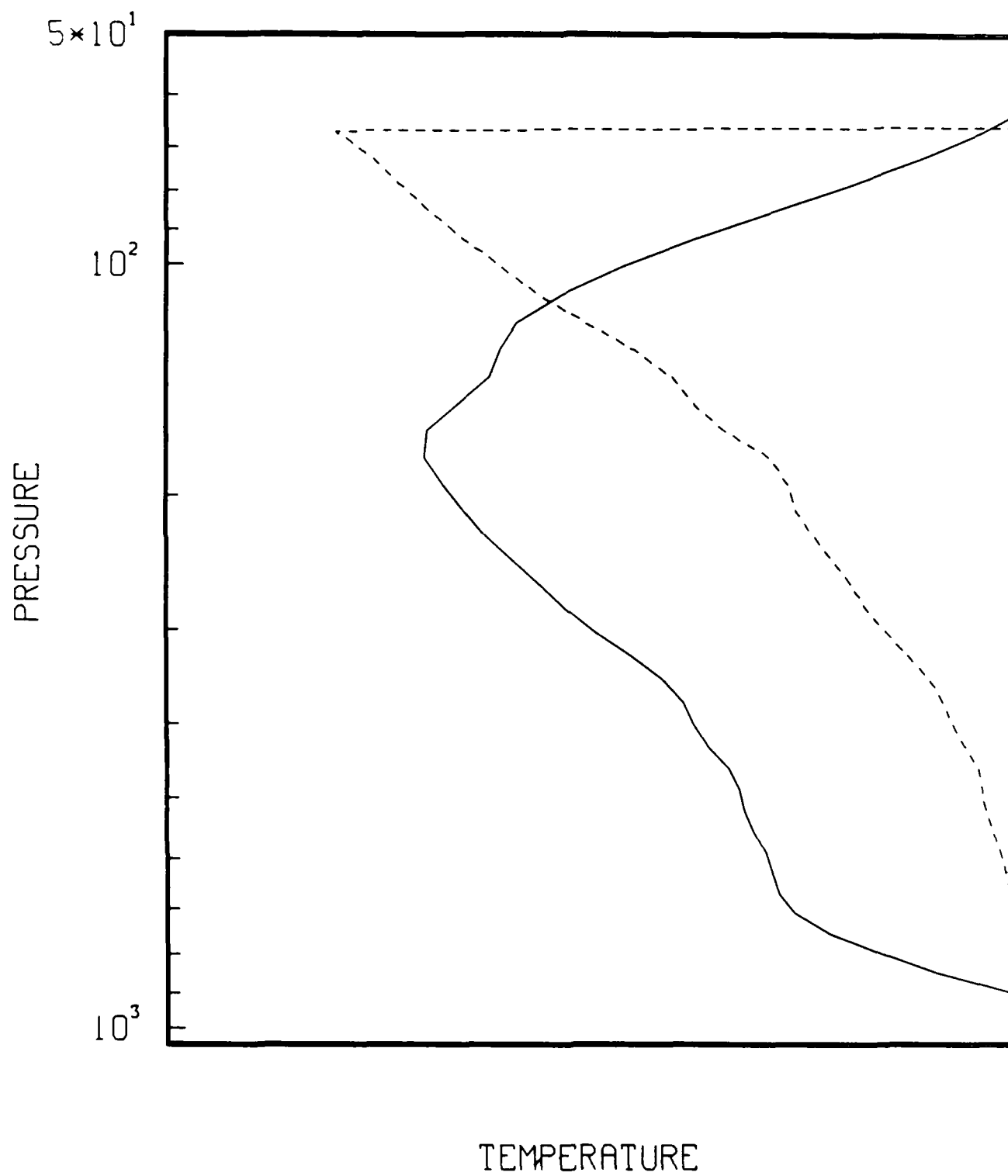
ICM



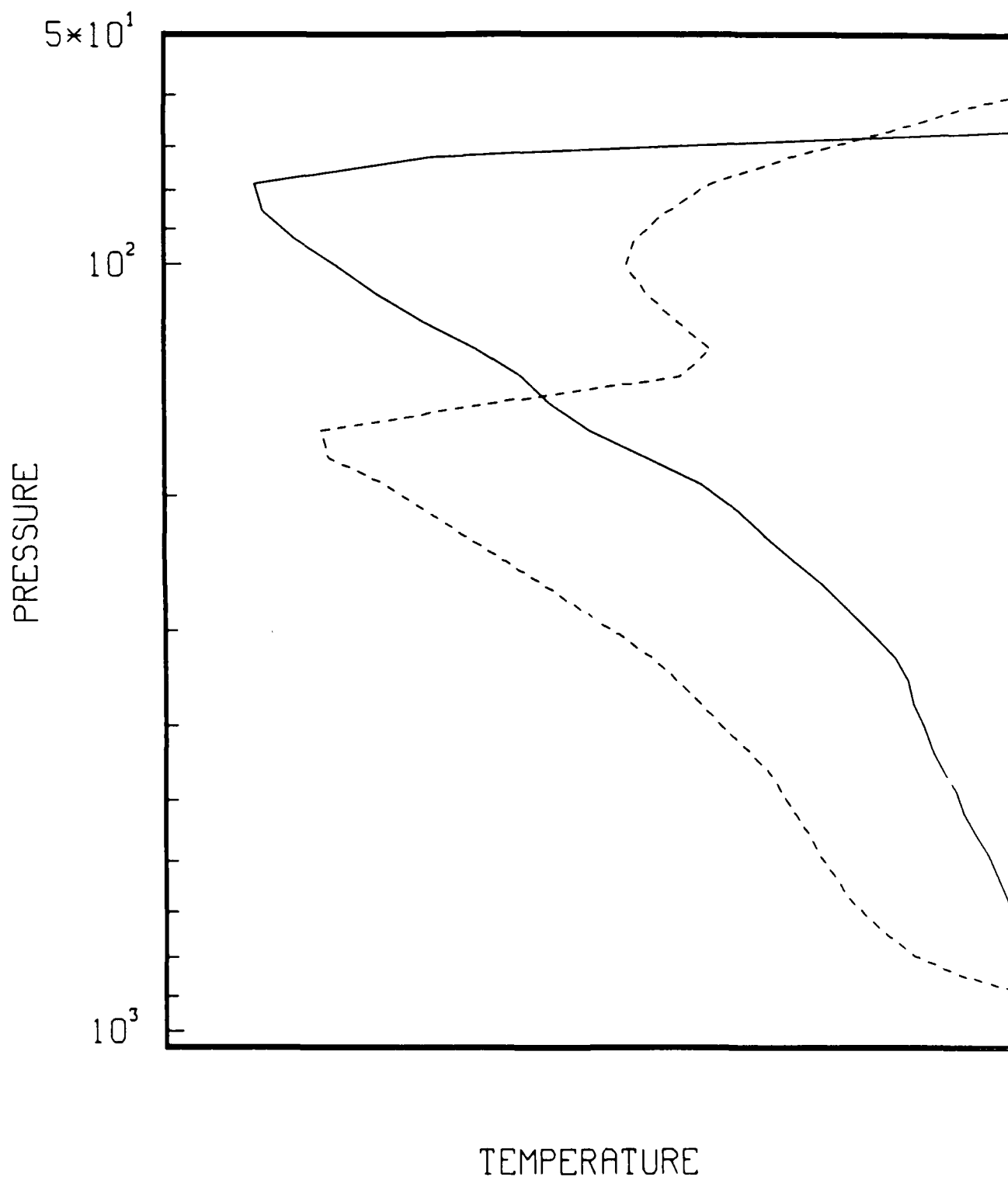
ANALYZED LCH DATA @ 0 & 15 MIN



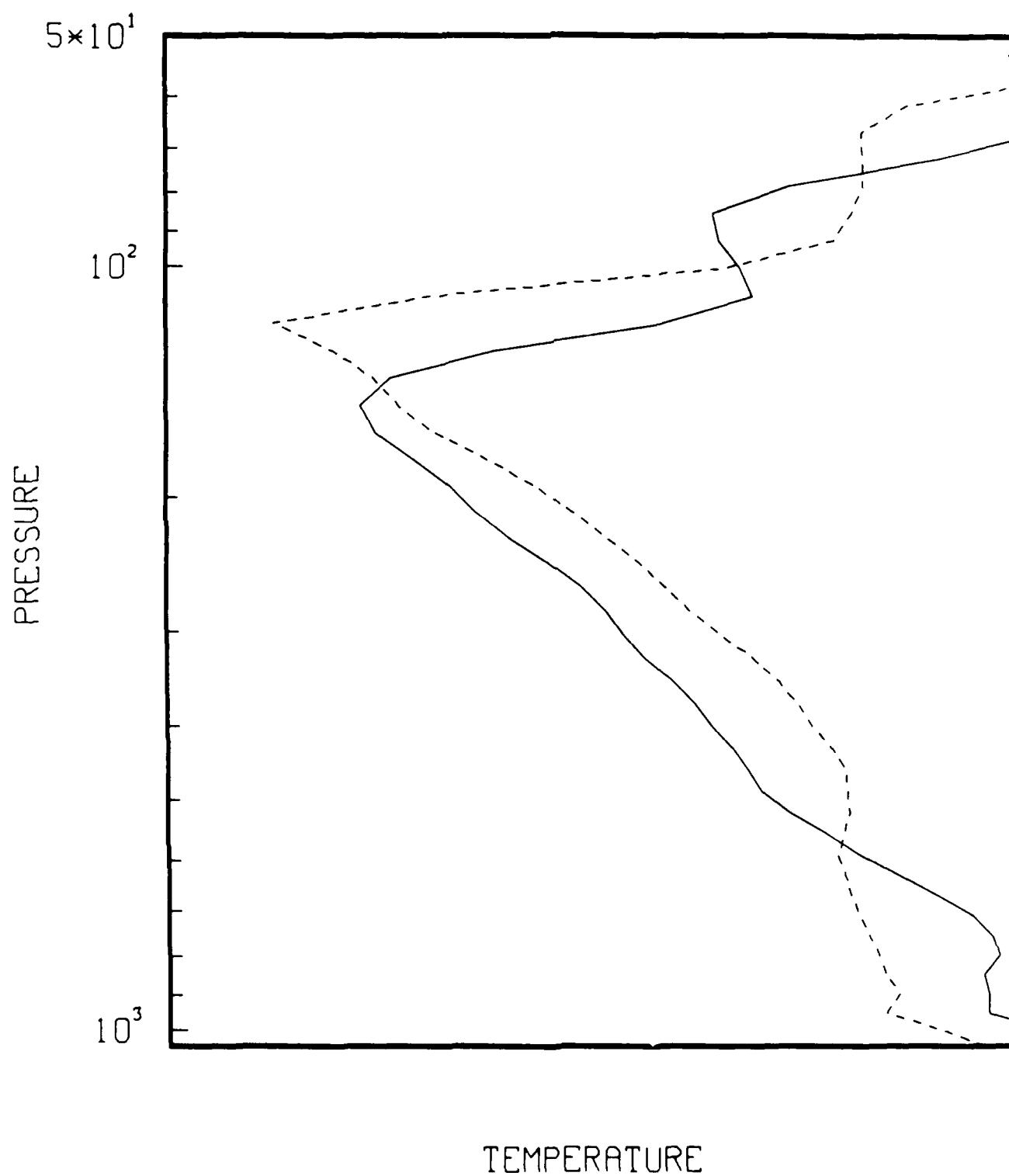
ANALYZED LCH DATA @ 30 & 45 MIN



ANALYZED LCH DATA @ 60 & 90 MIN

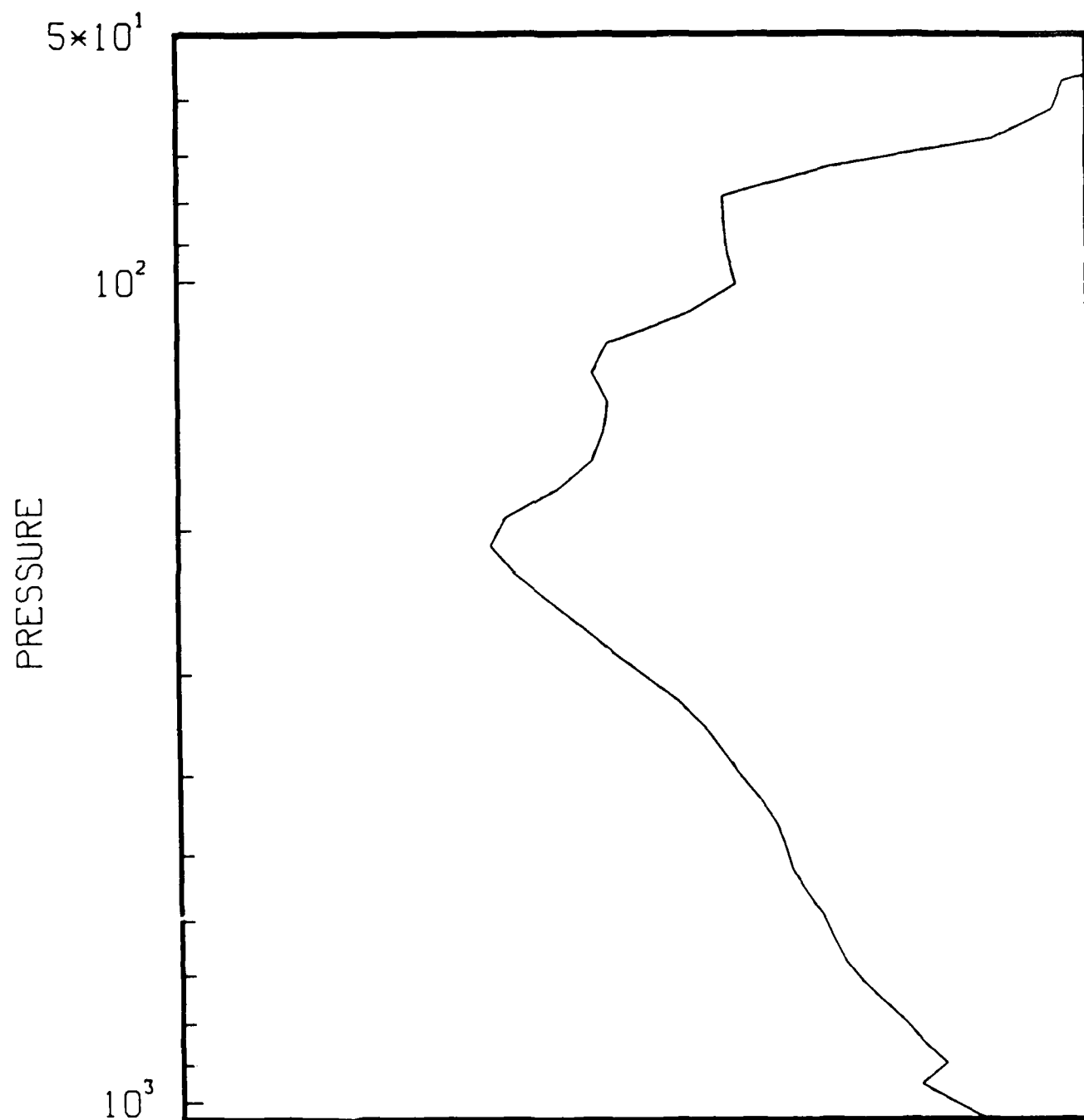


ANALYZED LCH DATA @ 120 & 150 MIN

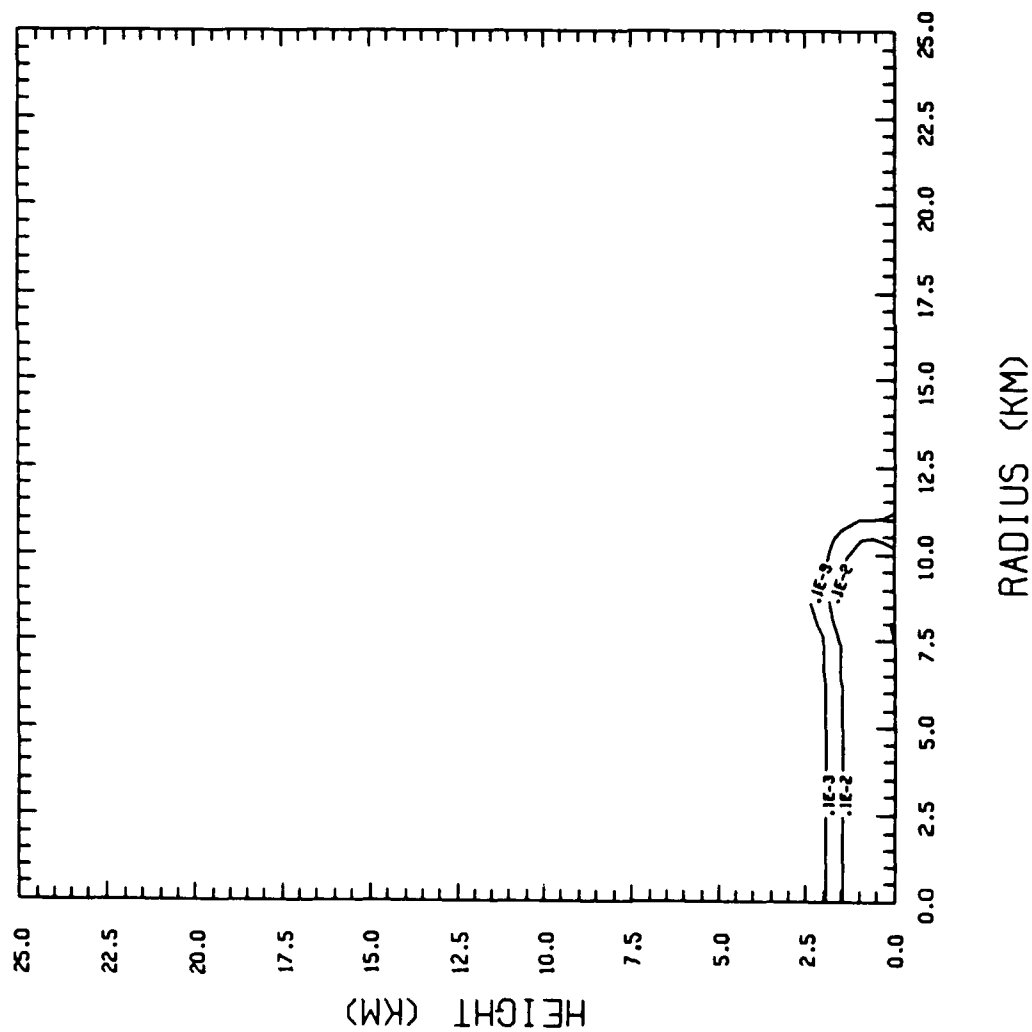


ANALYZED LCH DATA @

180 MIN

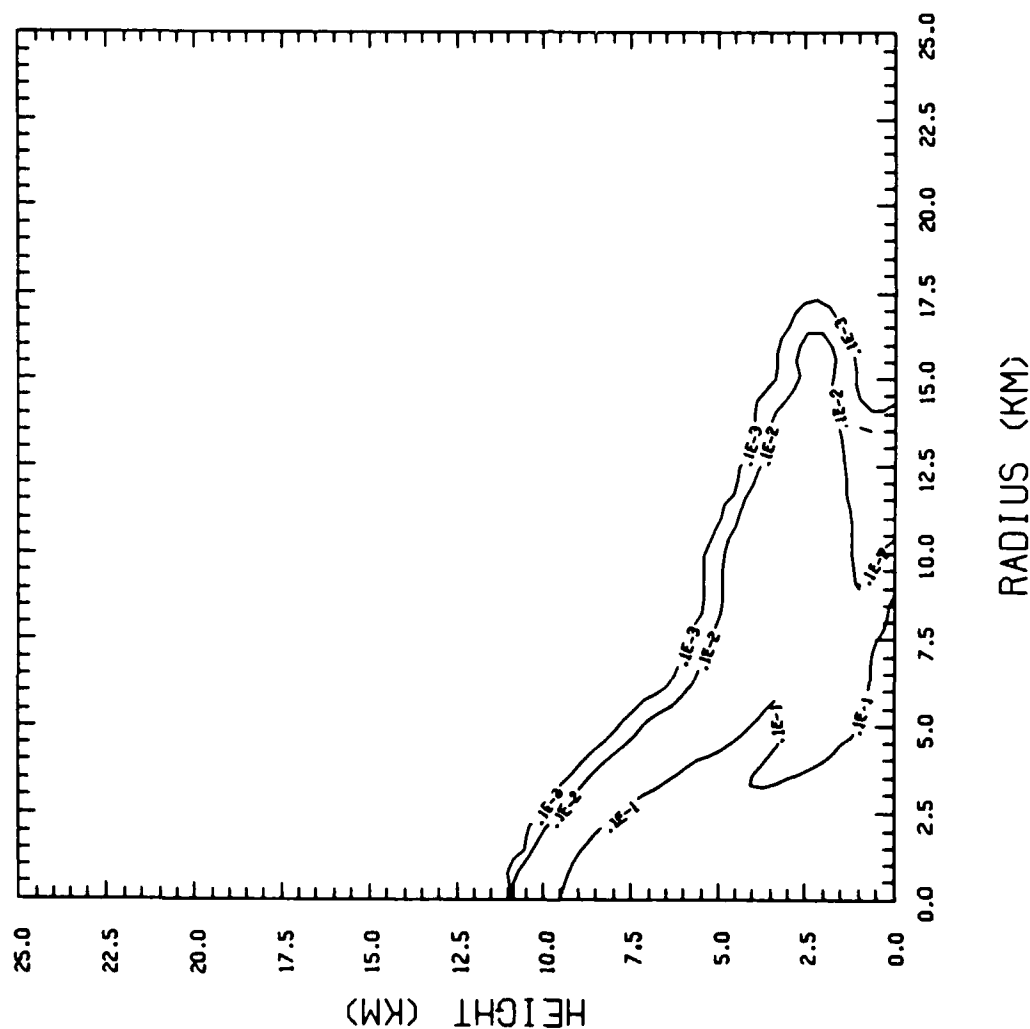


SMK 50 KW/M**2 FIRE • LCH-DRY TIME= 15.1



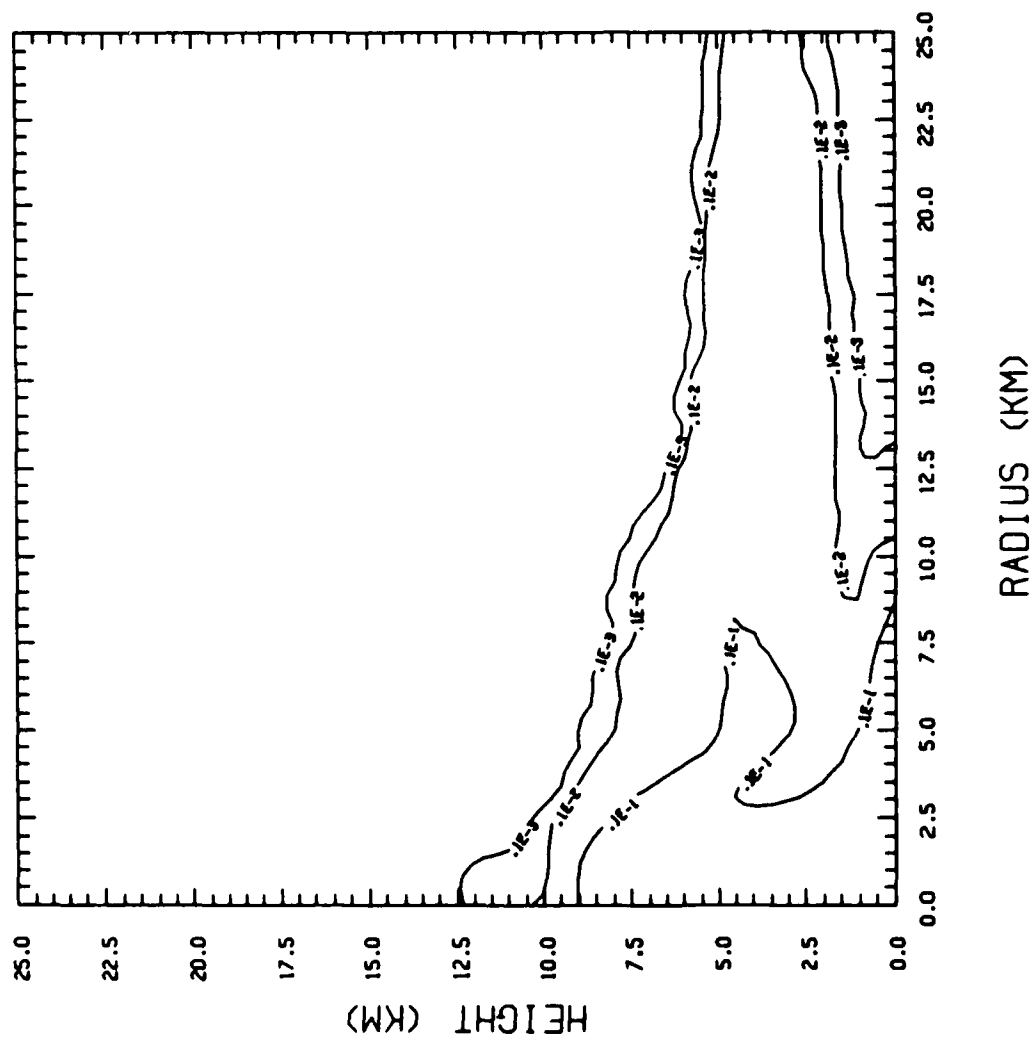
CONTOUR FROM .10000E-03 TO 10.000
(USER'S LEVELS)

SMK 50 KW/M**2 FIRE • LCH-DRY TIME= 45.0



CONTOUR FROM .10000E-03 TO 10.000
(USER'S LEVELS)

SMK 50 KW/M**2 FIRE • LCH-DRY TIME= 90.0



CONTOUR FROM .10000E-03 TO 10.000
(USER'S LEVELS)

CONCLUSIONS:

- WITHOUT THE PRESENCE OF WATER, THE SMOKE CANNOT STABILIZE ABOVE THE TROPOPAUSE.
- WITHIN MOISTURE PRESENT, THERE IS $O(10^{-3})$ TIMES MORE CONDENSATE THAN SMOKE AND $O(10^{-2})$ TIMES MORE PRECIPITATION. EARLY TIME SCAVENGING MUST BE CONSIDERED.
- SMOKE CAN BE INJECTED INTO THE "STRATOSPHERE", BUT ONLY ALONG WITH WATER WHICH WILL AFFECT ITS RESIDENCE TIME.

NEXT EFFORTS :

- ADD SOUTH DAKOTA SCHOOL OF MINES
SCAVENGING MODEL TO TASS.
- ADD DIAGNOSTICS FOR OPTICAL DEPTH
AND TOTAL SMOKE ABOVE A GIVEN
ALTITUDE v. ALTITUDE.

SAIC

Science Applications International Corporation

The Numerical Simulation of Smoke Plume Dynamics in Intense Fires



Michael M. Bradley

Lawrence Livermore National Laboratory

The numerical model



- Two-dimensional
- Time-dependent
- Nonhydrostatic
- Compressible
- Eulerian
- Terrain-following coordinate system
- Cloud and rain parameterization
- Dynamic equations are fully nonlinear
- Flux form of substance transport equations
(using fourth-order spatial differencing)

Benchmark Case



- U.S. standard spring-fall atmosphere
- No background wind
- Ambient moisture only – none from fire
- Smoke is passive tracer

Vertical Smoke Distributions After 1 hr

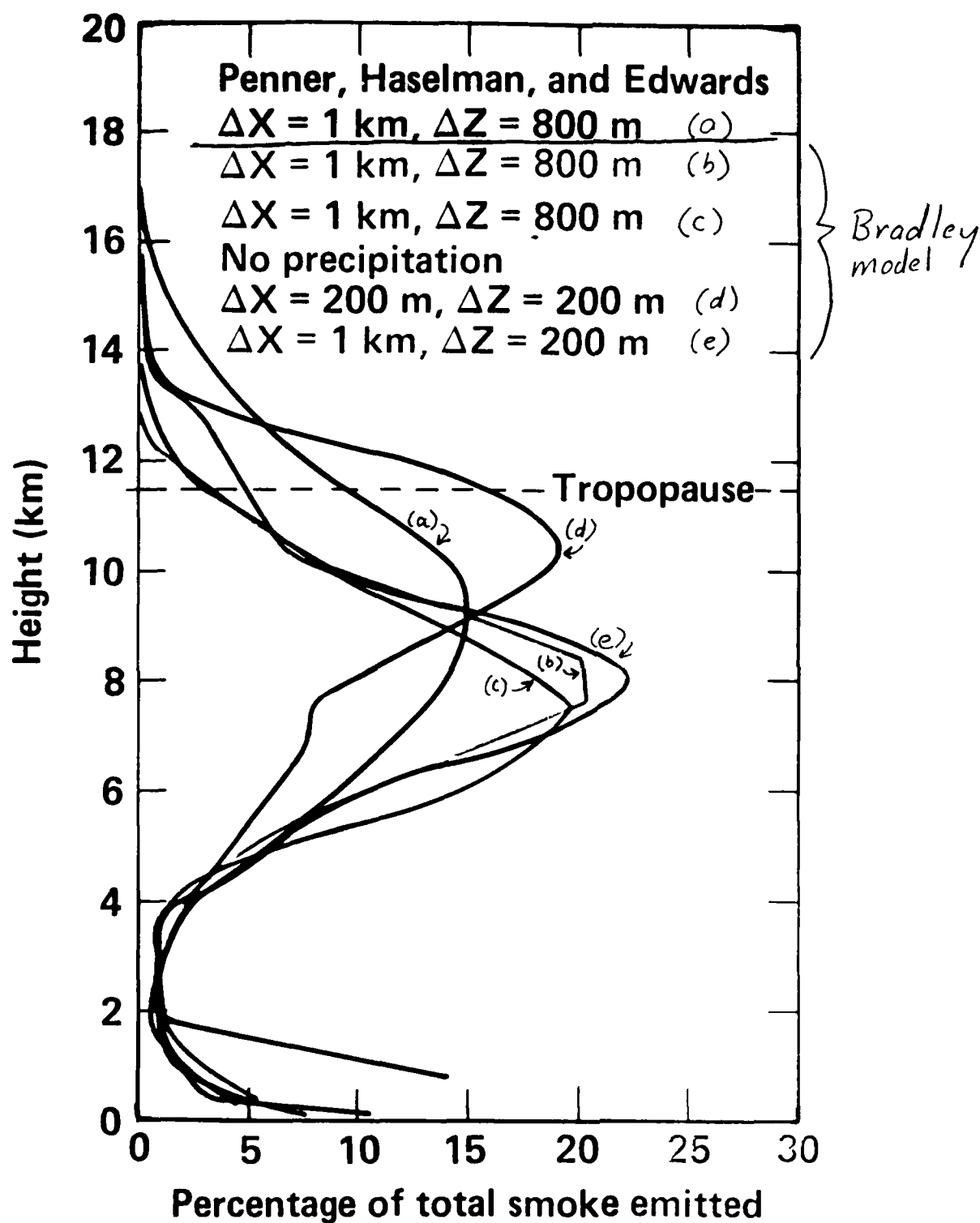


Figure 1 Normalized smoke profiles for intense fire (89 W m^{-2}) with no wind and ambient moisture only.

$\Delta x = \Delta z = 200 \text{ m}$
time = 1 hr
Bradley model

U.S. Standard spring-fall atmosphere
No ambient wind
Moisture - ambient only
 89 kW/m^2 heat source

integrated smoke distribution *

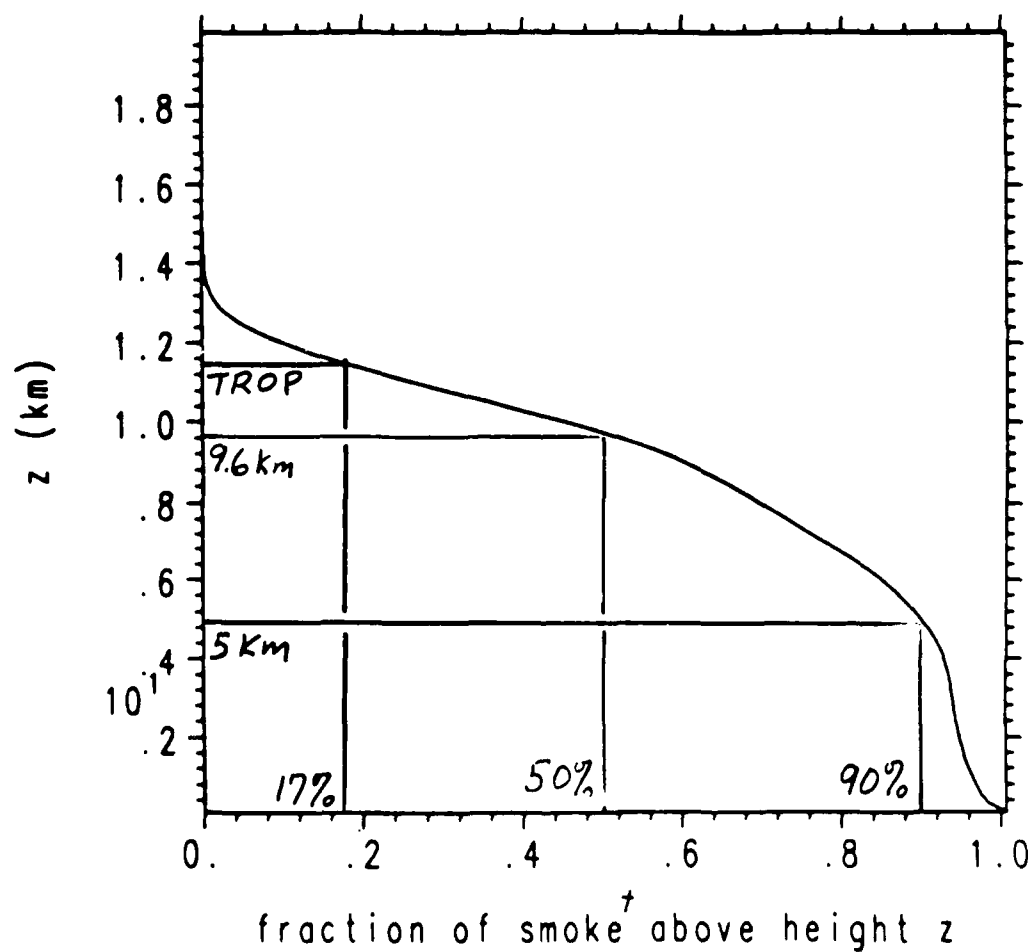


Figure 2

* Top-downward integration of curve (d) on Figure 1.

† Fraction of smoke emitted from source. Conservation is good to within less than $\frac{1}{2}\%$.

A Note on Linearization

Model uses this equations:

$$\partial u / \partial t = -c_p \Theta_m \frac{\partial \pi}{\partial x} + \dots$$

where:

$$\Theta_m = \Theta (1 + .61 q_v) (1 - q_c - q_r - q_s)$$

$$\Theta = \bar{\Theta}(z) + \Theta' \quad q_v = \bar{q}_v(z) + q_v'$$

Some models linearize this to:

$$\partial u / \partial t = -c_p \bar{\Theta}_v \frac{\partial \pi}{\partial x} + \dots$$

where:

$$\bar{\Theta}_v = \bar{\Theta}(z) (1 + .61 \bar{q}_v(z))$$

At least for the benchmark case, there was no significant difference in the vertical smoke profile using the linearized form.

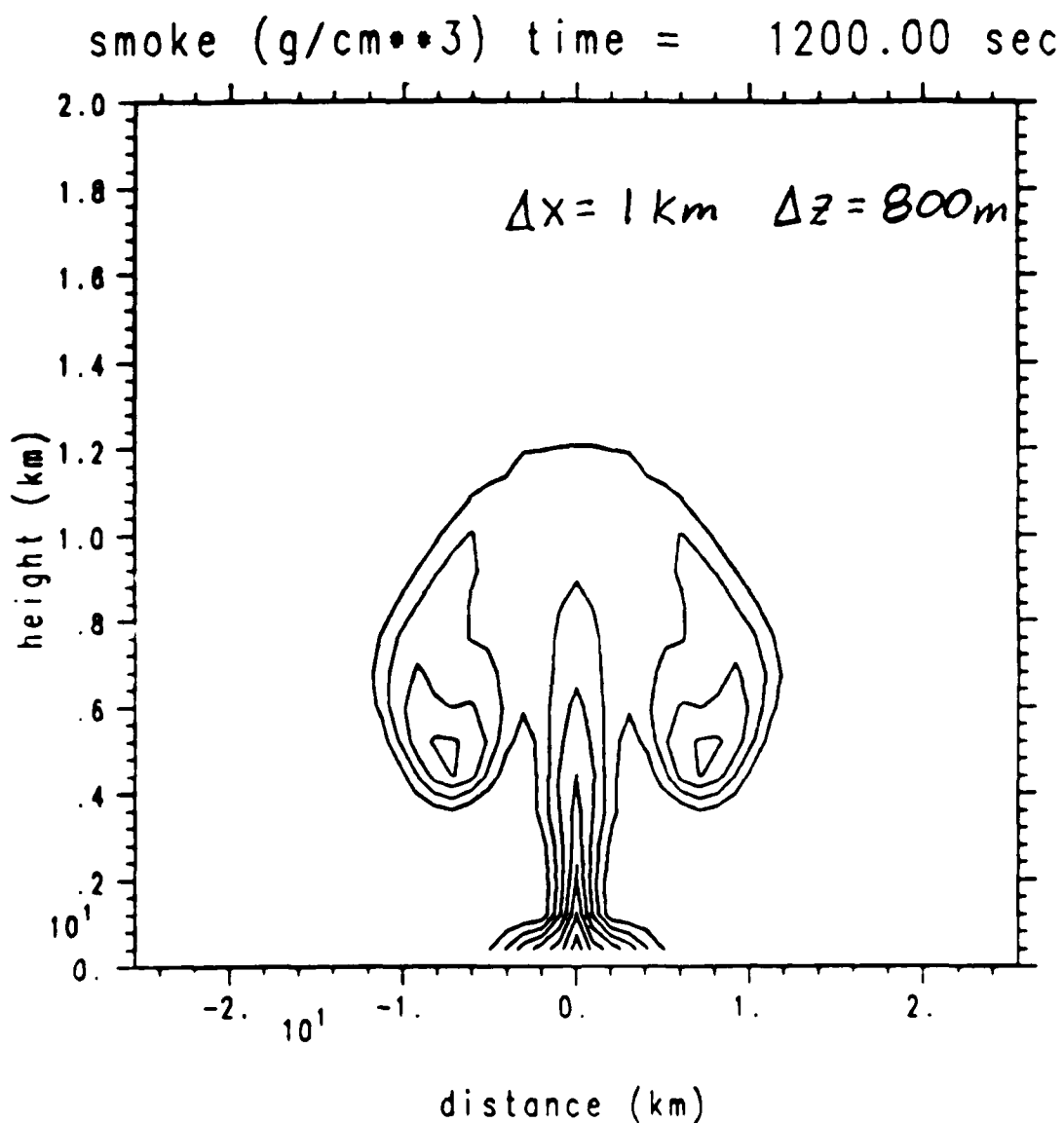


Figure 3. Smoke density contours for low resolution ($\Delta x = 1000 \text{ m}$, $\Delta z = 800 \text{ m}$) simulation. Contour interval is $5 \times 10^{-10} \text{ g cm}^{-3}$. Compare with Figure 4 and curve (b) in Figure 1.

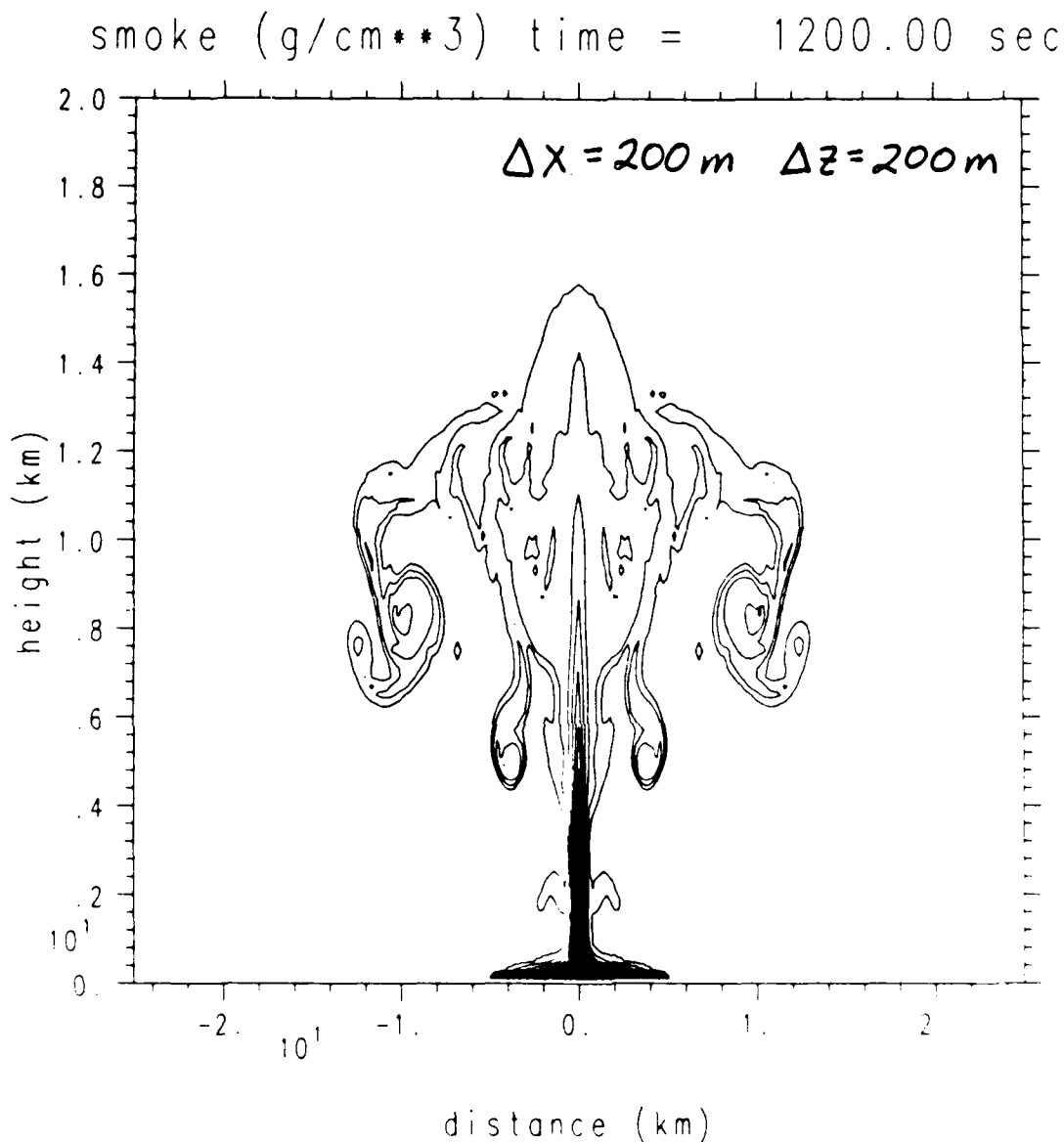


Figure 4. Smoke density contours for high resolution ($200\text{m} \times 200\text{m}$) simulation. Contour interval is $5 \times 10^{-10} \text{ g cm}^{-3}$. In addition to exhibiting fine structure, the smoke plume rises higher than in the low resolution simulation. Smoke distribution is shown in Figure 1, curve (d) (at 1 hr).

Sources of Differences



- Equations
- Numerical methods
- Resolution, especially horizontal
- Turbulence parameterizations
- Atmospheric soundings

Future Research



- **Condensation scavenging parameterization**
- **Interface with sophisticated condensation nucleation model**
- **Three-dimensional model**

SECTION 3
MESOSCALE MODELING

**REGIONAL-SCALE INTERACTIONS
BETWEEN ATMOSPHERIC
DYNAMICS AND AEROSOLS**

Douglas L. Westphal

*The Pennsylvania State Univ.,
Department of Meteorology,
Univ. Park, PA 16802*

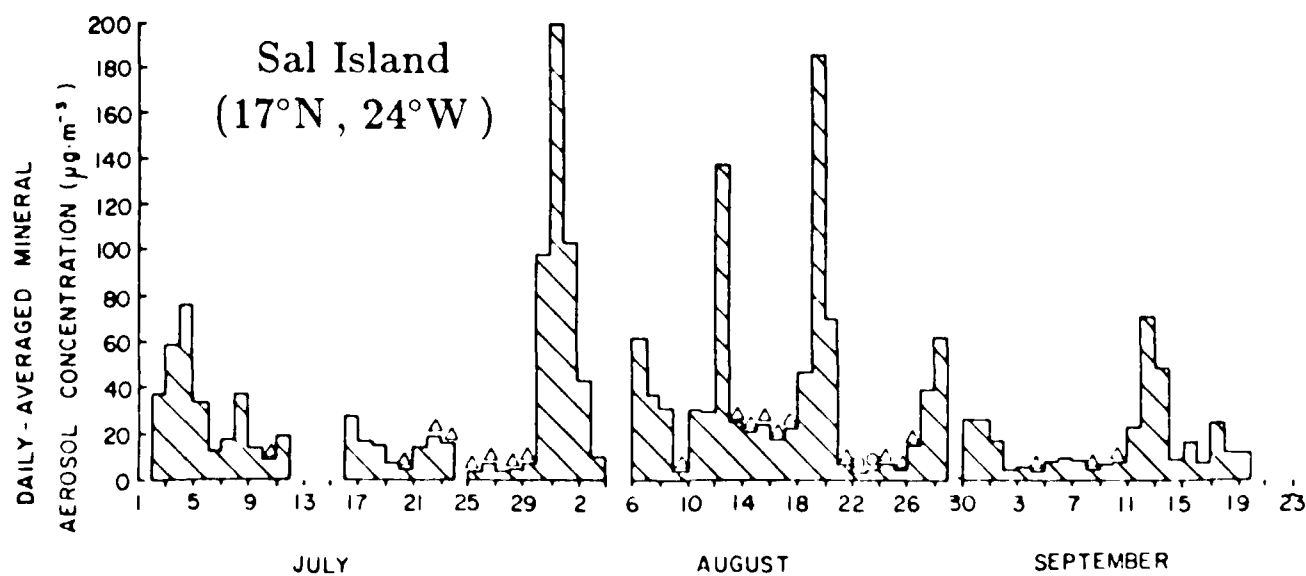
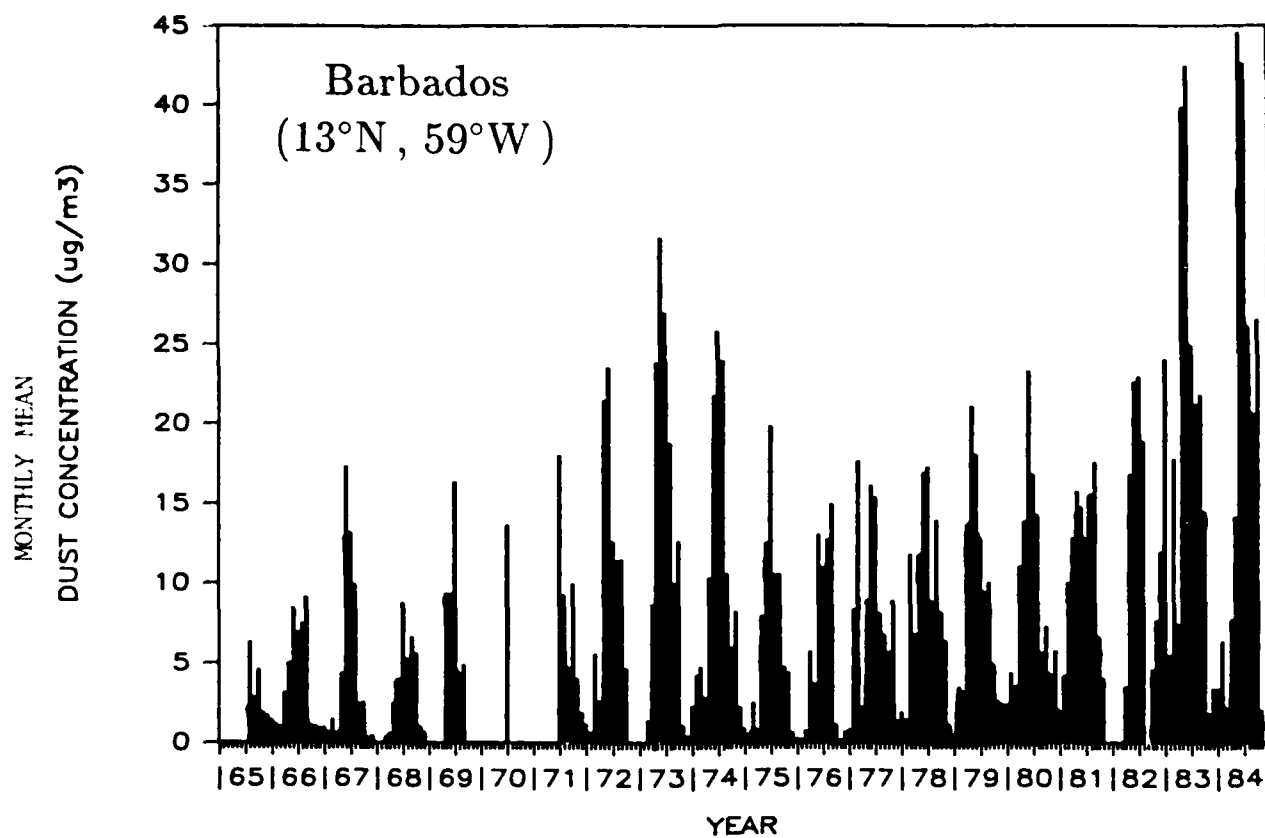
and

Owen B. Toon

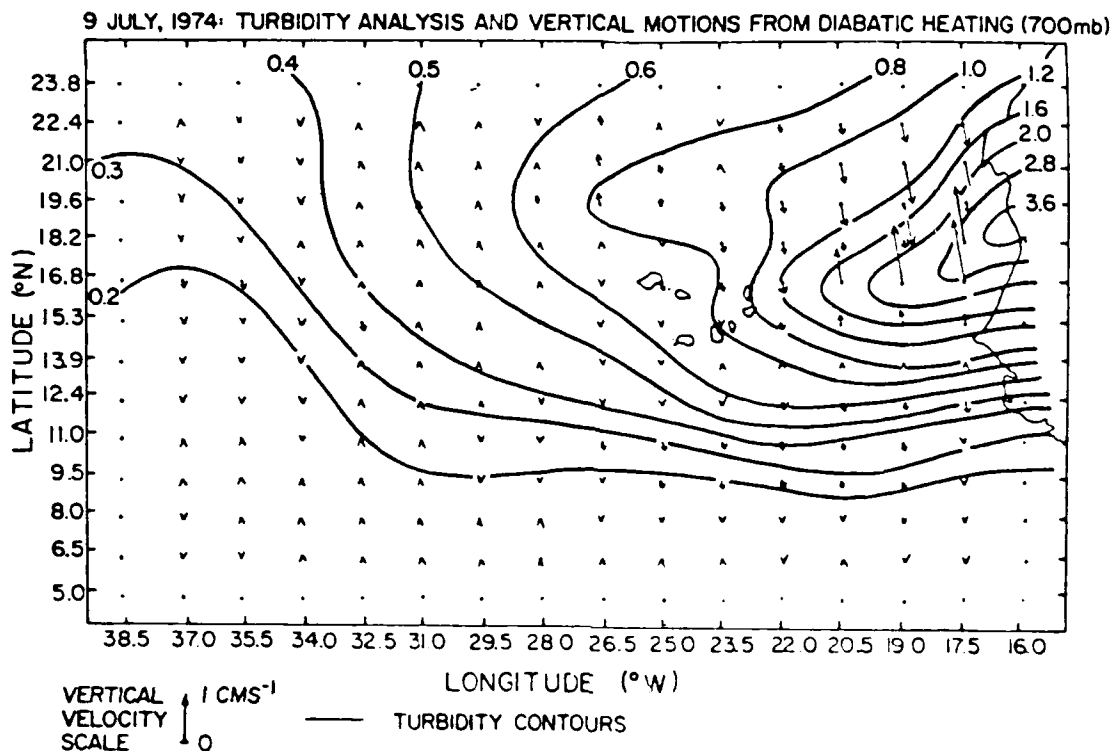
*NASA Ames Research Center,
Space Sciences Division,
Moffett Field, CA 94035*

NUCLEAR WINTER: MESOSCALE TOPICS

- Vertical lofting of aerosol by the fire and cloud
- Coagulation and wet removal in the convective plume
- Dynamical perturbation by the fire and cloud
- Self-generated bouyancy of soot clouds;
cloud formation in bouyant soot clouds;
cycling of soot through cloud droplets
- Spread of individual plumes;
formation of larger, "GCM-scale" clouds
- Influence of diurnal radiative forcing on the
response of the atmosphere
- Influence of geographical location and season
on the above items



1974



Turbidity isopleths determined from satellite irradiances and diagnosed 700 mb vertical motions associated with radiative heating of dust for 1200 GMT, July 9, 1974 (Karyampudi, 1979).

NUMERICAL MODELS

Atmospheric — Penn State/NCAR Limited-Area Model

- Primitive equations, hydrostatic
- Predicted ground temperature
- Subgrid-scale vertical fluxes
- Precipitation: Large-scale and subgrid-scale (cumulus) precipitation

Aerosol — Ames Research Center's Aerosol Model

- Continuity equation for each size aerosol and each type of aerosol
- Dry and wet removal
- Coagulation
- Condensation
- Surface or gridpoint source, or initial cloud
- Radiation

SCAVENGING PARAMETERIZATION

Scavenging rate Λ in (s^{-1}) is given by

$$\begin{aligned}\Lambda &= 4.2 \times 10^{-4} E R^{0.79} & R^{0.63} &\leq 7000/EH \\ \Lambda &= 3R^{0.16}/H & R^{0.63} &> 7000/EH\end{aligned}$$

where:

E is the collection efficiency, 0.83

H the depth of the precipitating cloud (m)

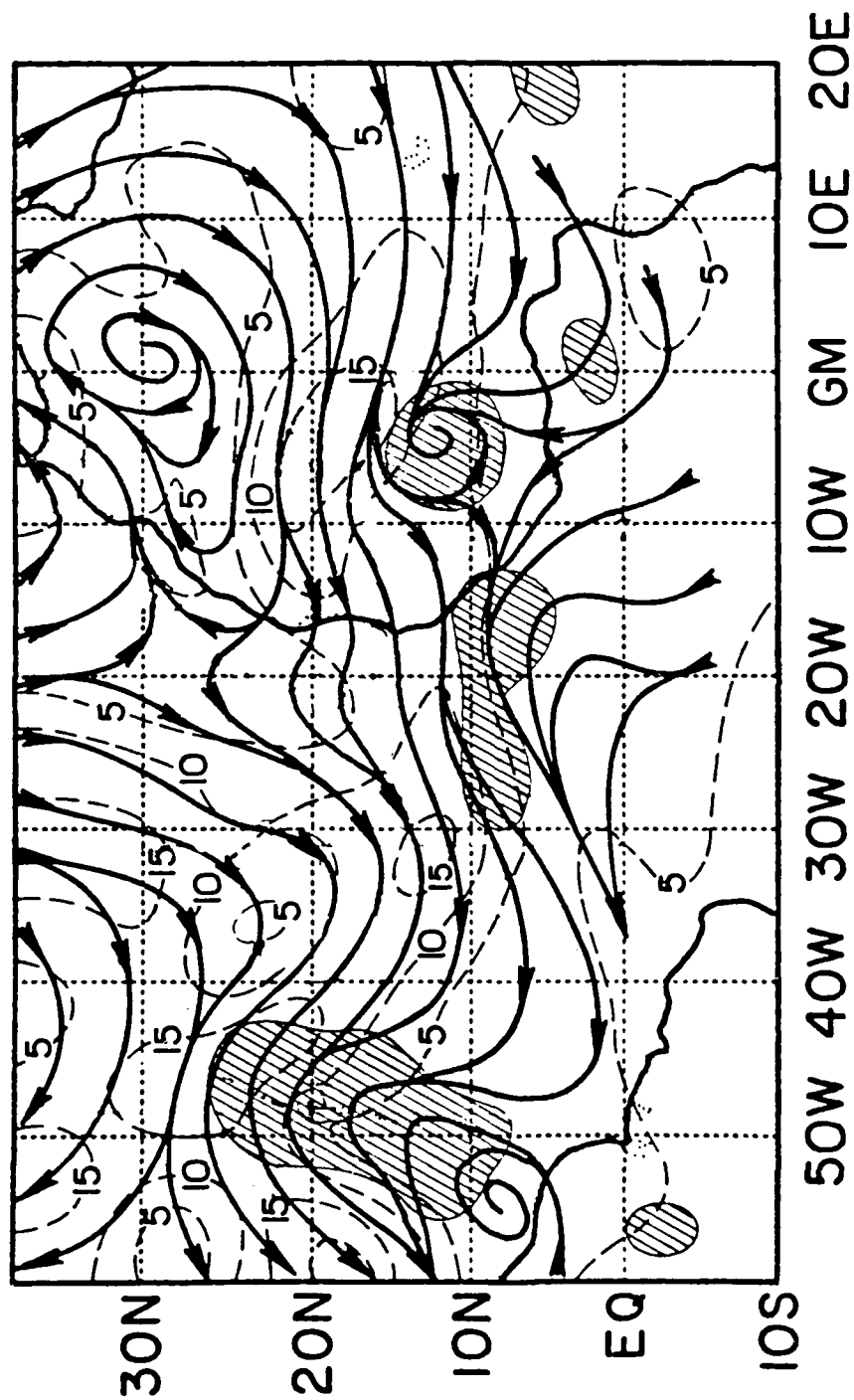
R the rainfall rate ($mm\ hr^{-1}$)

- Marshall-Palmer droplet size distribution assumed
- No dependence on aerosol size
- Non-convective rainfall R_n is due to supersaturation in the grid box
- Convective rainfall R_c and the fraction a_p covered by convection are determined by a cumulus cloud parameterization

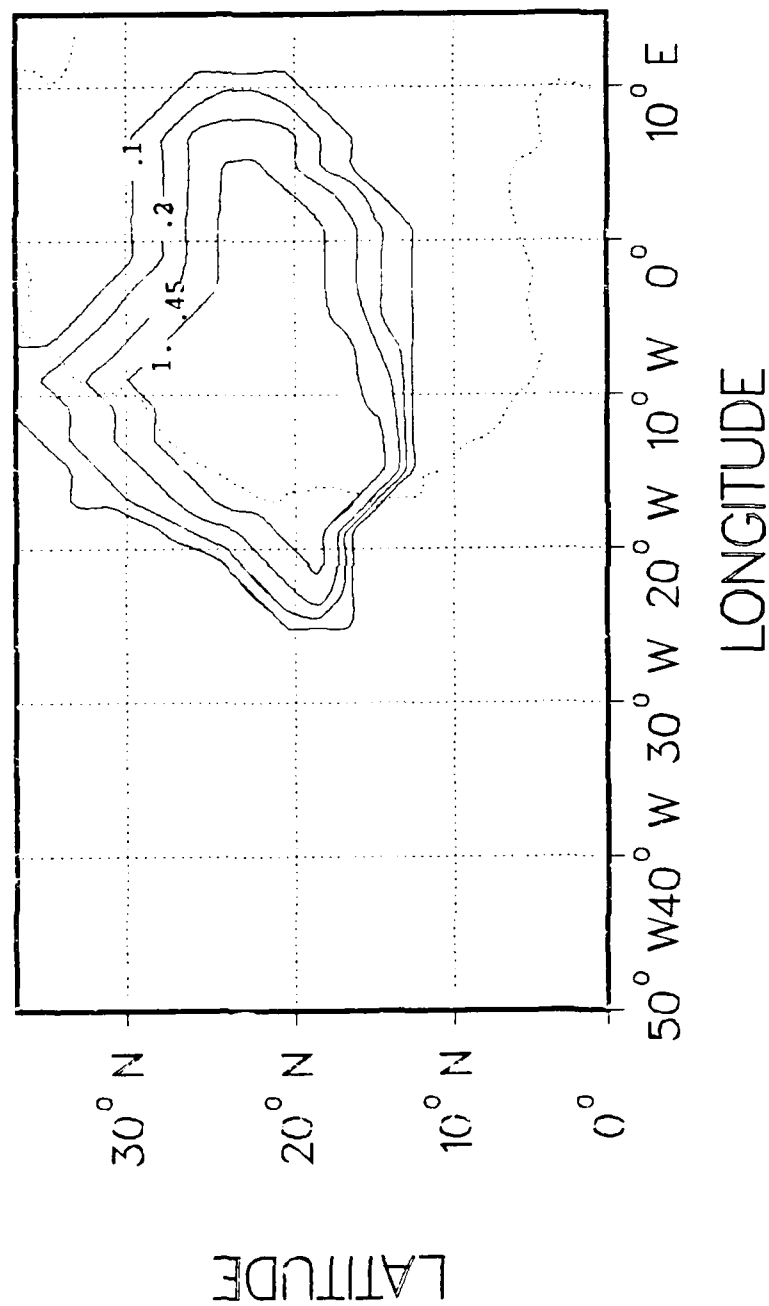
The total scavenging rate for a grid box is

$$\Lambda = (1 - a_p)\Lambda(R_n) + a_p\Lambda(R_n + R_c)$$

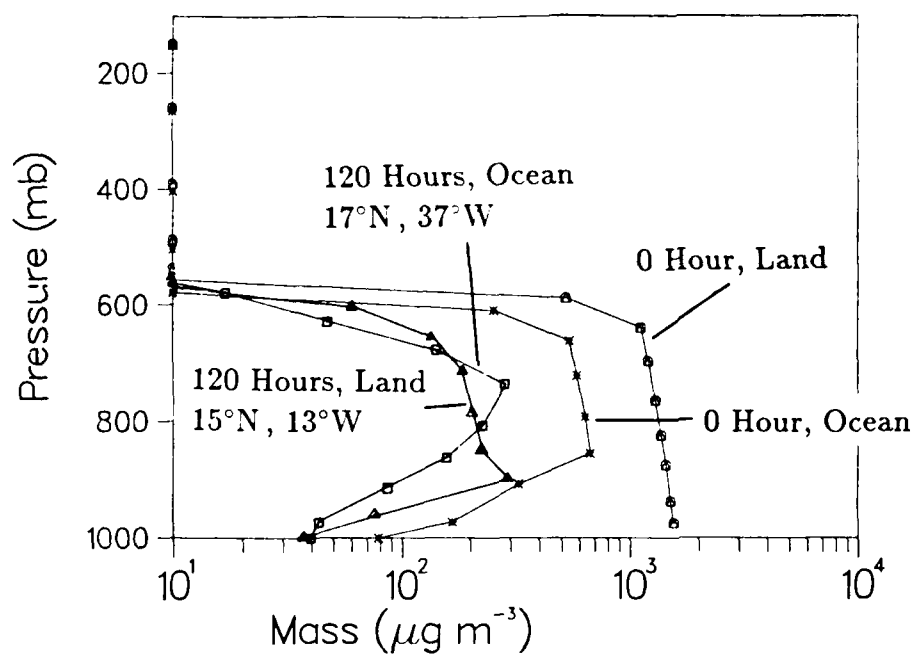
120 hr. simulated 700 mb streamlines (solid), isotachs (dashed, in ms^{-1}), and areas of precipitation (cross-hatched).



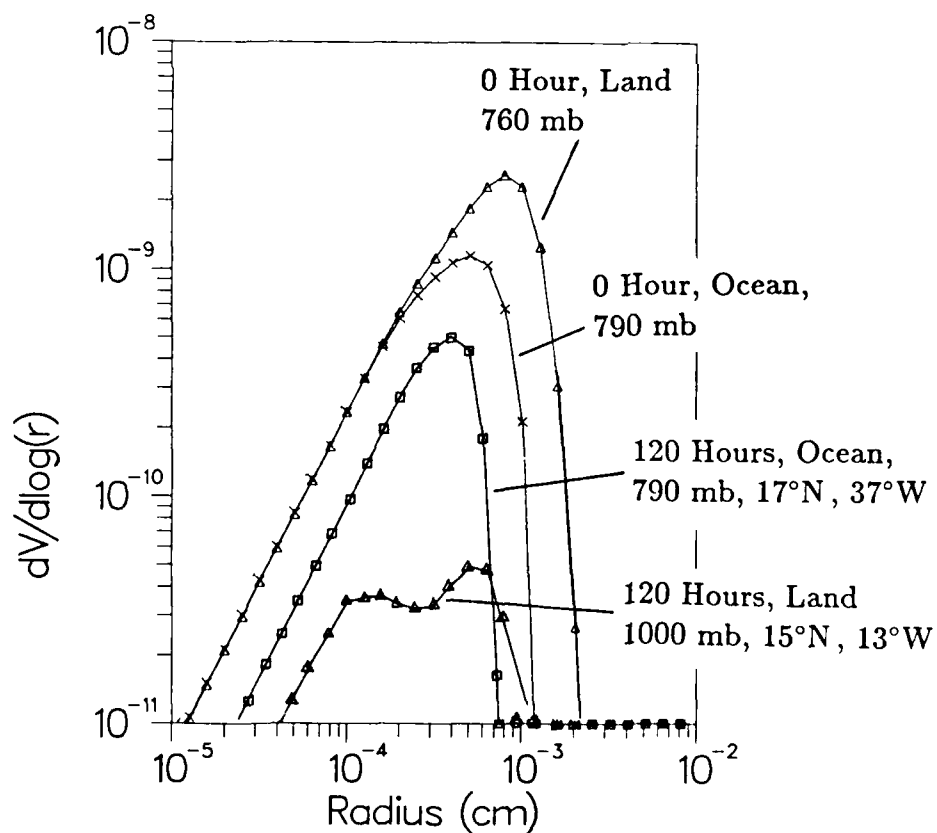
0 hr. Optical Depth, 23 Mt



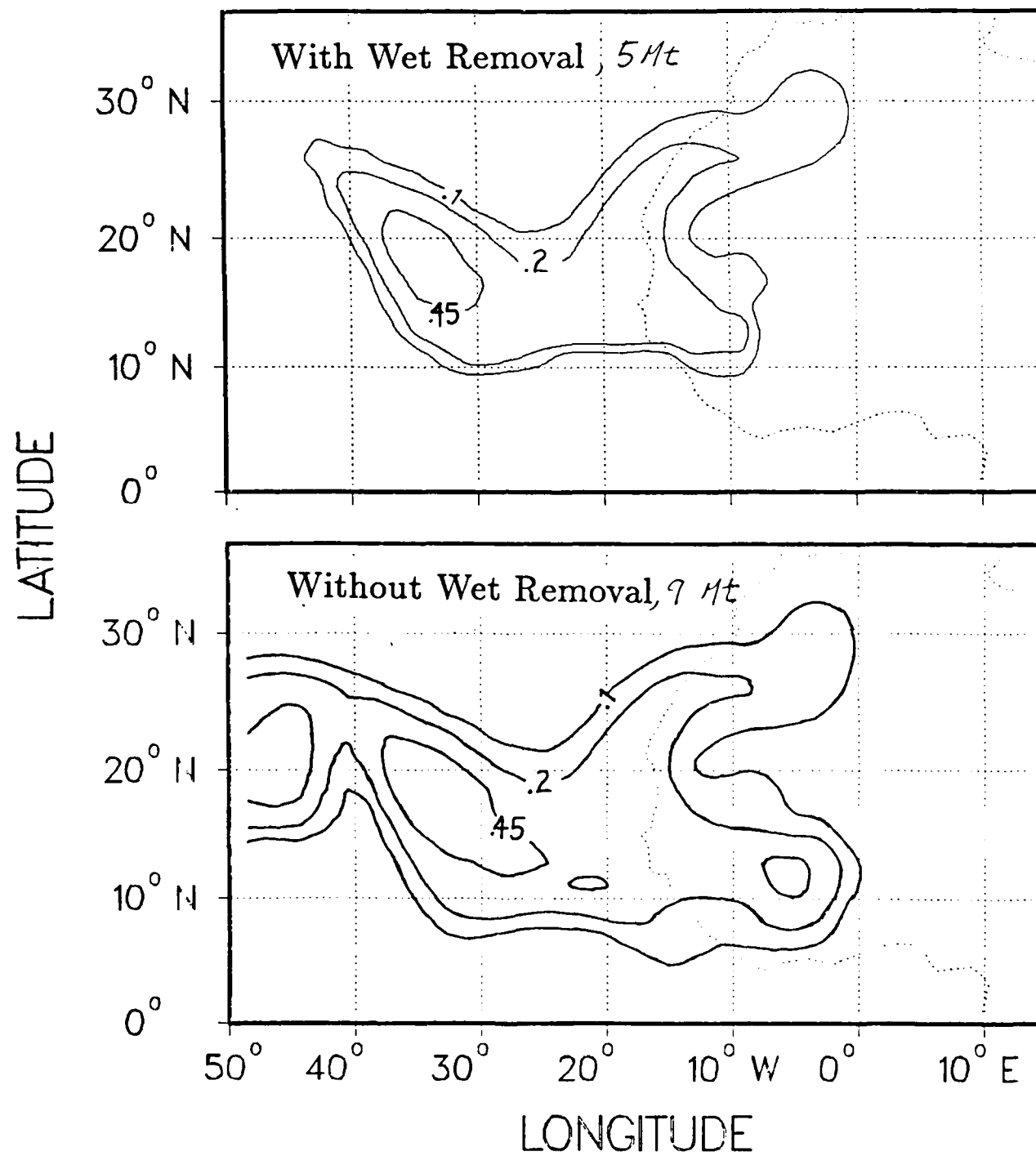
Vertical Profiles of Mass Concentration ($\mu\text{g m}^{-3}$)



Size Distributions by Volume



120.1 Hours
Optical Depth



FUTURE WORK

- Include radiative heating in the Saharan dust simulations
- Conduct tests to determine the resolution requirements of soot cloud modeling
- Use a non-hydrostatic model to develop an input dataset of the initial spatial and size distribution of a soot cloud
- Carry out experiments that address the outstanding problems of nuclear winter

Algorithms for Computations of Aerosol Physics
and Radiative Transfer

Owen B. Toon
NASA Ames Research Center
Space Sciences Division
Moffett Field, CA 94035

Overview of Ames Program

I Develop Natural Analogs to Nuclear Winter

A. Saharan Dust Storms

B. Volcanic Clouds

II Determine Fuel Loading

III Develop Algorithms for Aerosol Physics

IV Perform Regional Scale Modeling

Algorithms for Aerosol Physics

I Aerosol Microphysics and Transport

II Radiative Transfer in Aerosols

III Interactions Between Aerosols and Clouds

Aerosol Microphysics and Transport

I General Properties

**A. In Arbitrary Coordinates So Can Be Used
In A Variety of Dynamical Models**

B. Description in Preparation

II Transport

A Timesplit So Can Be Used in 1,2,or 3-D Models

**B. Finite Elements in Horizontal, Curve Fitting
Scheme in Vertical. Exactly Conserve Mass,Have
Little Numerical Diffusion,No Negative Numbers,
Numerically Efficient**

III Microphysics

A. Resolves Size Distribution

**B. Includes:Sedimentation, Coagulation,Multiple
Aerosol Constituents,Condensational Growth,
Gases**

$$\begin{aligned}
 \frac{\partial C}{\partial t} z + \nabla_z \cdot C_z V_z + \frac{\partial}{\partial z} (W_z + V_{fall}) C_z - \nabla_z \cdot S^{KH} \nabla C_z / S \\
 - \frac{\partial}{\partial z} S^{K_z} \frac{\partial}{\partial z} (C / S) = (\rho - L)
 \end{aligned}
 \tag{2}$$

$$\begin{aligned}
 \frac{\partial C}{\partial t} + \frac{\partial UC}{\partial \bar{x}_1} + \frac{\partial VC}{\partial \bar{x}_2} + \frac{\partial WC}{\partial \bar{x}_3} - \frac{\partial}{\partial \bar{x}_1} S^* K_1 \frac{\partial}{\partial \bar{x}_1} C / S^* \\
 - \frac{\partial}{\partial \bar{x}_2} S^{*K_2} \frac{\partial}{\partial \bar{x}_2} C / S^* - \frac{\partial}{\partial \bar{x}_3} S^* K_3 \frac{\partial}{\partial \bar{x}_3} C / S^* = (\rho - L) V_m H_{m1} H_{m2}
 \end{aligned}
 \tag{1}$$

$$\begin{aligned}
 \frac{\partial C_z}{\partial t} + \nabla_z \cdot C_z V_z + \frac{\partial}{\partial z} (W_z + V_{fall}) C_z - \nabla_z \cdot S^{KH} \nabla C_z / S \\
 - \frac{\partial}{\partial z} S^{K_z} \frac{\partial}{\partial z} (C / S) = (\rho - L)
 \end{aligned}
 \quad (2)$$

$$\begin{aligned}
 \frac{\partial C}{\partial t} + \frac{\partial UC}{\partial \bar{x}_1} + \frac{\partial VC}{\partial \bar{x}_2} + \frac{\partial WC}{\partial \bar{x}_3} - \frac{\partial}{\partial \bar{x}_1} S^* K_1 \frac{\partial C}{\partial \bar{x}_1} S^* \\
 - \frac{\partial}{\partial \bar{x}_2} S^{*K_2} \frac{\partial C}{\partial \bar{x}_2} S^* - \frac{\partial}{\partial \bar{x}_3} S^{*K_3} \frac{\partial C}{\partial \bar{x}_3} S^* = (P-L) V_m H_{m1} H_{m2}
 \end{aligned}
 \quad (1)$$

TABLE 1

Conversion scaling factors for various coordinate systems

Coordinate Systems	H_{m1}	H_{m2}	H_{m3}	ds_1	ds_2	V_m	ds_3
Spherical Coordinates	$\sin \bar{\theta}$	1	a	$d\lambda$	$d\bar{\theta}$		
Mercator	$\frac{\cos \phi}{\cos \phi_0}$	$\frac{\cos \phi}{\cos \phi_0}$	1	dx	dy		
Polar Stereographic	$\left(\frac{1+\sin \phi}{2}\right)^{-1}$	$\left(\frac{1+\sin \phi}{2}\right)^{-1}$	1	dx	dy		
Lambert Conformal	$\frac{(1+\sin \phi) \cos \phi_n}{(1+\sin \phi_0) \cos \phi_0}$	$\frac{(1+\sin \phi) \cos \phi_n}{(1+\sin \phi_0) \cos \phi_0}$	1	dx	dy		
Rectangular	1	1	1	dx	dy	1	dz
Pressure						$1/g$	dp
Sigma = $\frac{P - P_{top}}{P_{b\bar{t}m} - P_{top}}$						P^*/g	dσ
Log Pressure $Z = H \ln (P/P_{sfc})$						T/T_0	dz

$$U = U_c/H_{m1} \quad V = V_c/H_{m2} \quad W = ds_3/dt + V_{fall} V_m^{-1} \quad C = C_z V_m \text{ area } H_{m1} H_{m2}$$

$$K_{x1} = 1/H_{m1}^2 K \quad K_{x2} = 1/H_{m2}^2 K \quad K_{x3} = V_m^{-2} K_z$$

$$S^* = S V_m H_{m1} H_{m2} \quad dx_1 = H_{m3} ds_1^2 \quad dx_2 = H_{m3} ds_2 \quad dx_3 = ds_3$$

$\bar{\theta}$ = colatitude

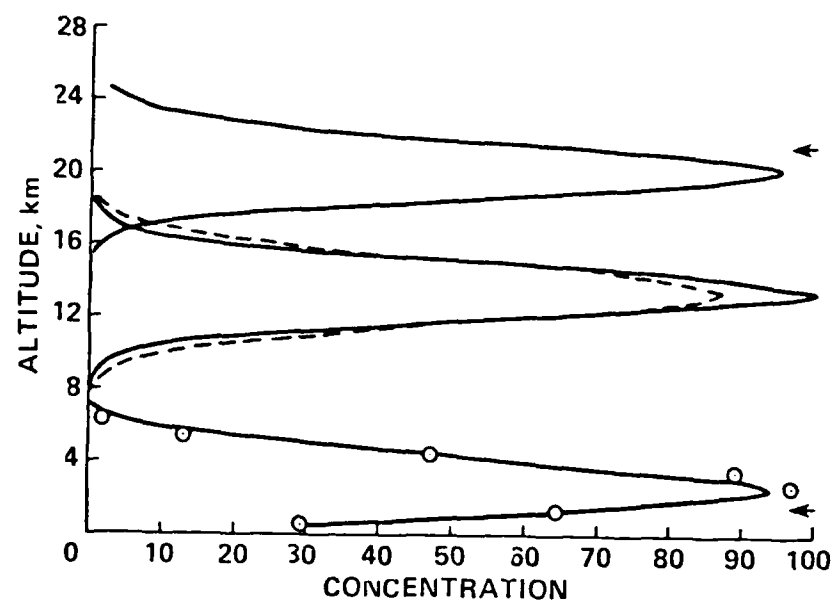
ϕ = latitude ϕ_0 = latitude at which projection is true

λ = longitude n = constant which can be adjusted to make

a = radius of Earth (the projection true at a second latitude ϕ_1)

$$S = \text{air density} \quad n = (k(k-1))^{-1} \quad k = \ln \left(\frac{\cos \phi_0}{\cos \phi_1} \right) \div \ln \left(\frac{\tan(\pi/4 - \phi_0/2)}{\tan(\pi/4 - \phi_1/2)} \right)$$

$$g = \text{gravitational acceleration} \quad H = \text{Scale height} = RT_0/g$$



AD-A105 150

TECHNICAL PAPERS PRESENTED AT THE DEFENSE NUCLEAR
AGENCY GLOBAL EFFECTS R. (U) DOD NUCLEAR INFORMATION
AND ANALYSIS CENTER SANTA BARBARA CA. 15 MAY 86

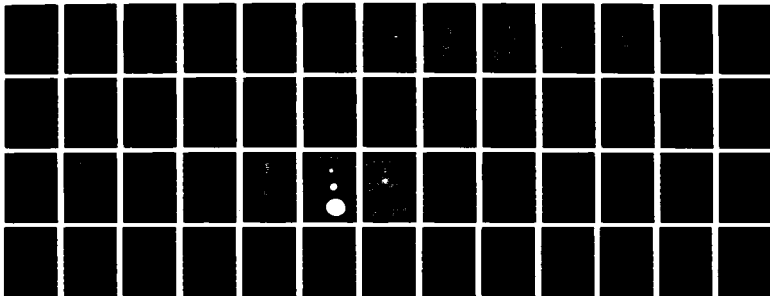
4/4

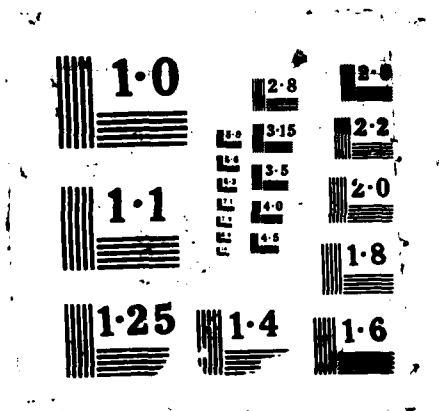
UNCLASSIFIED

DASIAC-TN-86-29-VOL-2 DNA001-82-C-0274

F/G 15/6.4

NL





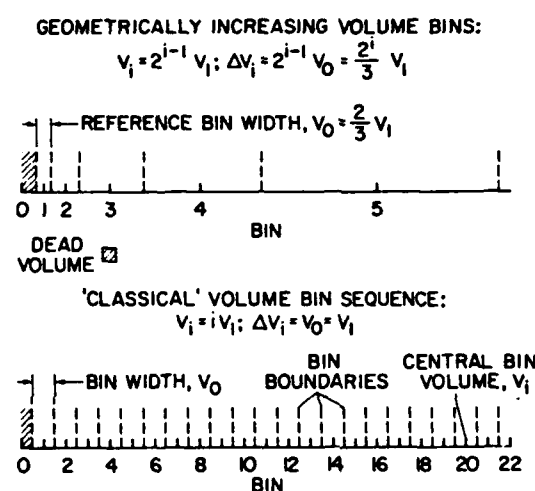


Figure 7.- Aerosol particle volume bin structures for numerical models.

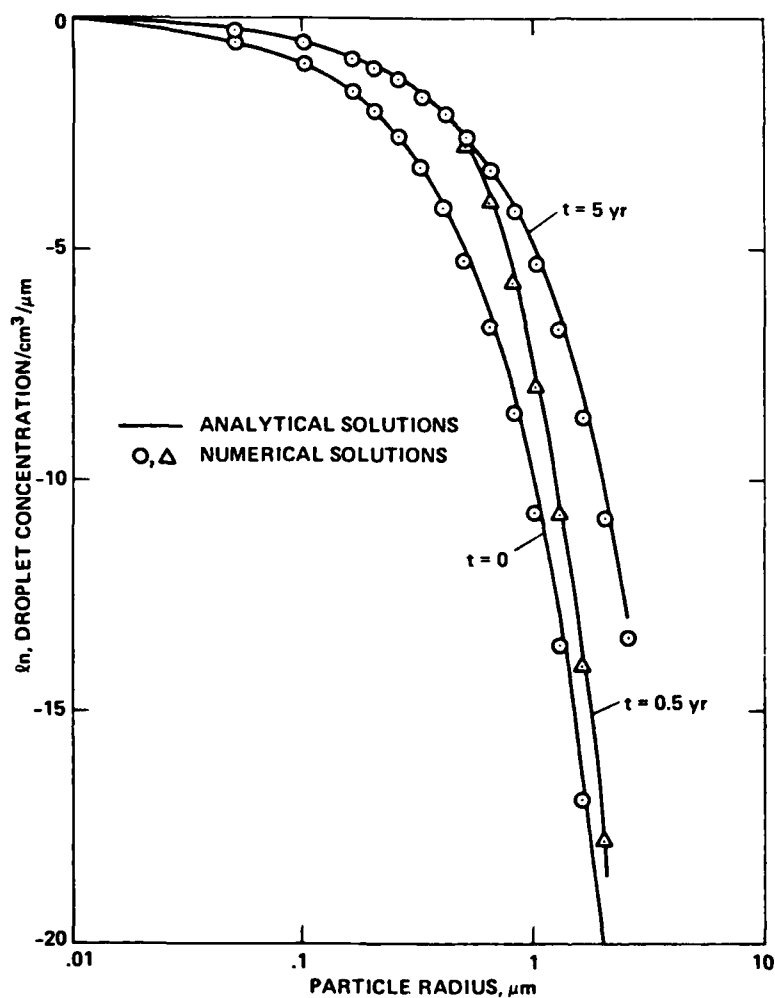


Figure 8.- Aerosol droplet growth. The evolution of a droplet size distribution following a change in the droplet growth rate is shown. Both analytical and numerical solutions are given. The conditions for the calculation are described in the text.

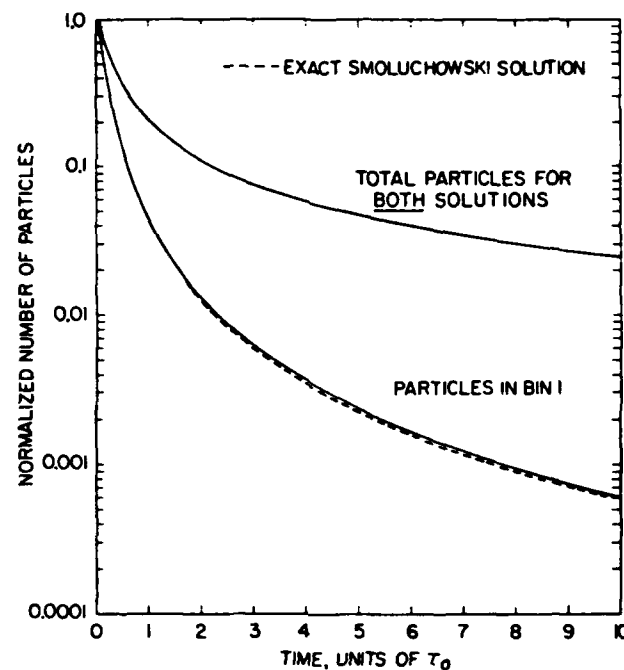


Figure 9.- Aerosol coagulation. Calculated transient decay curves are shown for the number of particles in the smallest model size bin, and for the total number of particles of all sizes, when one particle is initially placed in the smallest model bin. Time is measured relative to the characteristic coagulation time, τ_0 . The exact solutions of Smoluchowski are shown for comparison.

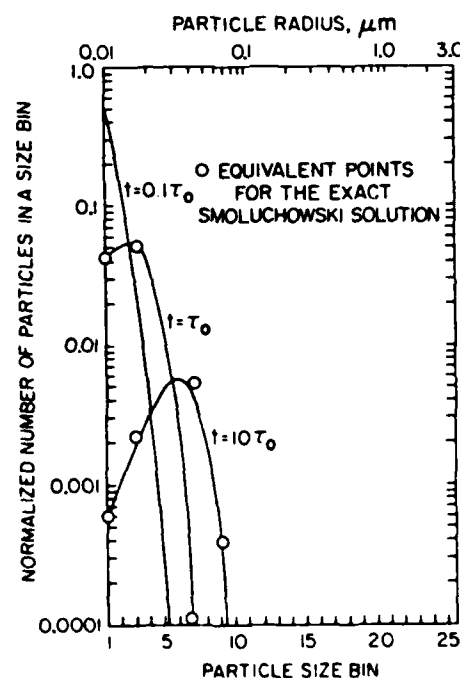


Figure 10.- The development of an aerosol size spectrum by coagulation. The conditions for the calculation are the same as for figure 9.

Radiative Transfer

I Solar Wavelengths

Use Two-Stream Approximation for Scattering with Tridiagonal Solver. Numerically Efficient, Accurate to 10% or Better for Heating Rates.

II Infrared Wavelengths

Use Two Stream Source Function Technique for Scattering. Numerically Efficient, Exact in Limit of No Scattering, 10% Accuracy with Scattering.

III Status

A. Algorithms Developed and Checked for Speed and Accuracy

B. Absorption Coefficients Under Development Based on McClatchey tape.

$$\mu \frac{\partial I_\nu}{\partial \tau}(\tau_\nu, \mu, \phi) = I_\nu(\tau_\nu, \mu, \phi) - S_\nu(\tau_\nu, \mu, \phi) - \frac{\omega_{0\nu}}{4\pi} \int_0^\pi \int_0^{2\pi} P_\nu(\mu, \mu', \phi, \phi') I_\nu(\nu, \mu', \phi') d\mu' d\phi'. \quad (1)$$

$$\frac{\partial F_n^+}{\partial \tau_n} = \gamma_{1n} F_n^+ - \gamma_{2n} F_n^- - S_{+n} \quad (10)$$

$$\frac{\partial F_n^-}{\partial \tau_n} = \gamma_{2n} F_n^+ - \gamma_{1n} F_n^- - S_{-n} \quad (11)$$

$$F_n^+ = k_{1n} \exp(\lambda_n \tau) + \Gamma_n k_{2n} \exp(-\lambda_n \tau) + C_n^+(\tau) \quad (18)$$

$$F_n^- = \Gamma_n k_{1n} \exp(\lambda_n \tau) + k_{2n} \exp(-\lambda_n \tau) + C_n^-(\tau). \quad (19)$$

Mesoscale Modeling of Coastal Flows
During Periods of
Extended Solar Obscuration

by

Charles R. Molenkamp



Basic Question:

If a layer of smoke obscures the ground, will a temperature difference develop between land and sea that could modify the flow field so that the likelihood of precipitation would be increased?

Preliminary Answer:

Not in the first few days after solar obscuration.

Approach:

**Numerical Simulation Using the Colorado State University
Mesoscale Model (Pielke, et. al)**

- CSU Mesoscale Model

- **Hydrostatic incompressible flow**
- **Radiational and surface heat budget**
- **Surface flux, planetary boundary, and synoptic layers**
- **Vertical diffusion depends on atmospheric stability**

Procedure:

Run CSU Mesoscale Model

- 4 hour initialization
- 24 hour normal diurnal cycle starting at dawn (05:18)
- 48 hours with no solar incident radiation

Initial Conditions

- West Coast with 5 m/s synoptic flow from West
- Sounding for the Oregon Coast on 23 Aug 72
- Sea Surface Temperature is 289 K

CSU Mesoscale Model -- Radiation Calculation

- Solar flux absorbed in the atmosphere by water vapor
- Longwave flux divergence includes absorption, emission by water vapor and CO₂
- Surface temperature calculated by a heat balance equation
 - incoming solar radiation
 - incoming longwave radiation
 - latent heat flux
 - sensible heat flux
 - soil heat flux
 - outgoing surface longwave radiation

MODIFICATIONS TO THE CSU MESOSCALE MODEL

● CLOUDS

- When the atmosphere is saturated any excess water vapor is assumed to exist as cloud water (fog)**
- Evaporative heating/cooling changes temperature**

● RADIATION (Long Wave)

MODIFICATIONS TO THE CSU MESOSCALE MODEL

• CLOUDS

• RADIATION (Long Wave)

- New model for clear air long wave radiation

The new version calculates fluxes at each level

The old version assumed for each level that the

entire atmosphere had the temperature of that level

- Effect of clouds on long wave radiation

The upward and downward flux out of each cloudy layer is given by:

$$F_{out} = (1 - \epsilon) F_{in} + \epsilon \sigma T^4$$

where ϵ is the emissivity of the layer

and T is the temperature at the outgoing edge of the layer

2 Runs of the Model

- **OLD**

- no clouds
- old radiation parameterization

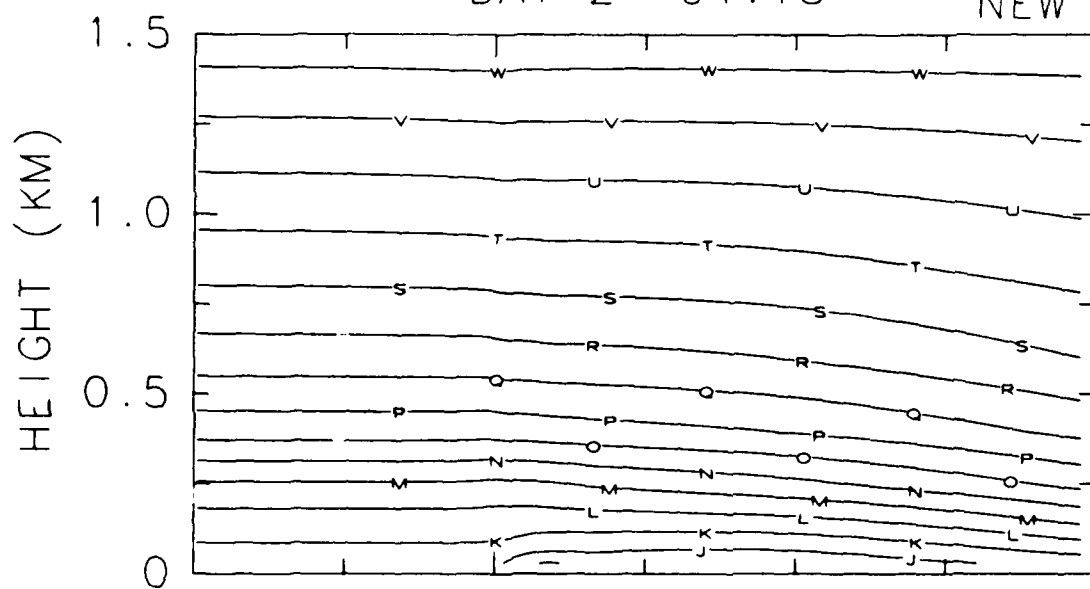
- **NEW**

- clouds where atmosphere is saturated
- new radiation parameterization, including the effect of clouds

POTENTIAL TEMPERATURE

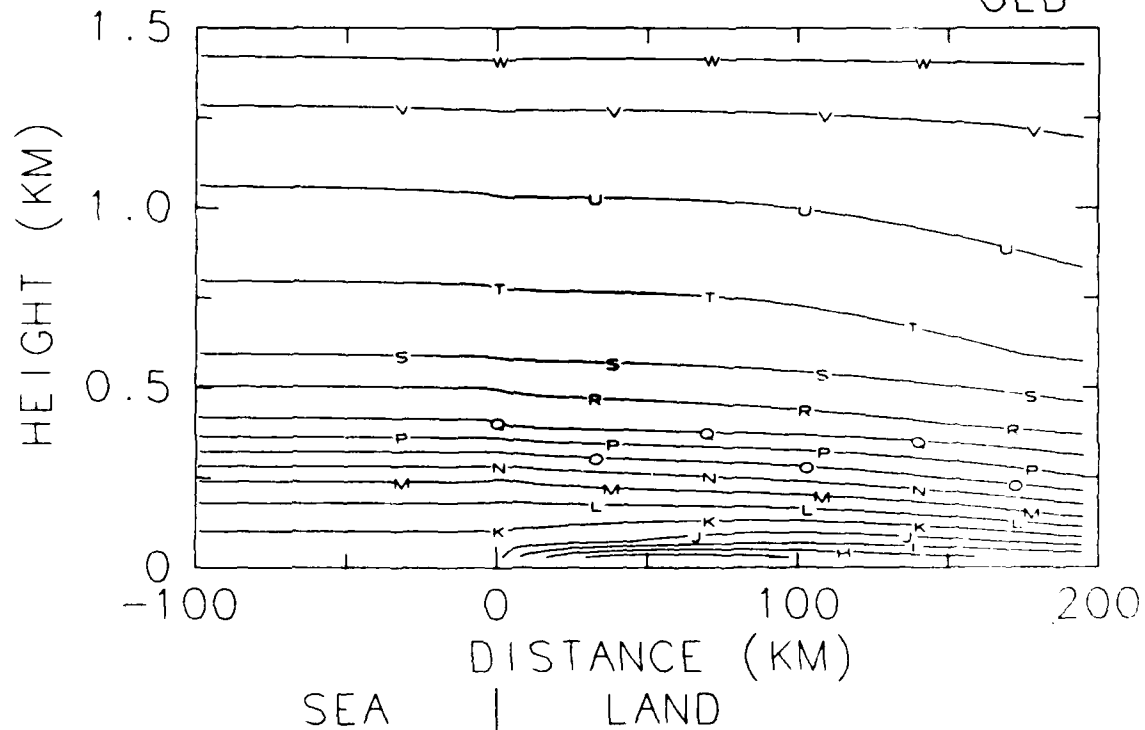
DAY 2 04:18

NEW



W = 300
V = 299
U = 298
T = 297
S = 296
R = 295
Q = 294
P = 293
O = 292
N = 291
M = 290
L = 289
K = 288
J = 287
I = 286
H = 285
G = 284
F = 283
E = 282
D = 281
C = 280
B = 279
A = 278

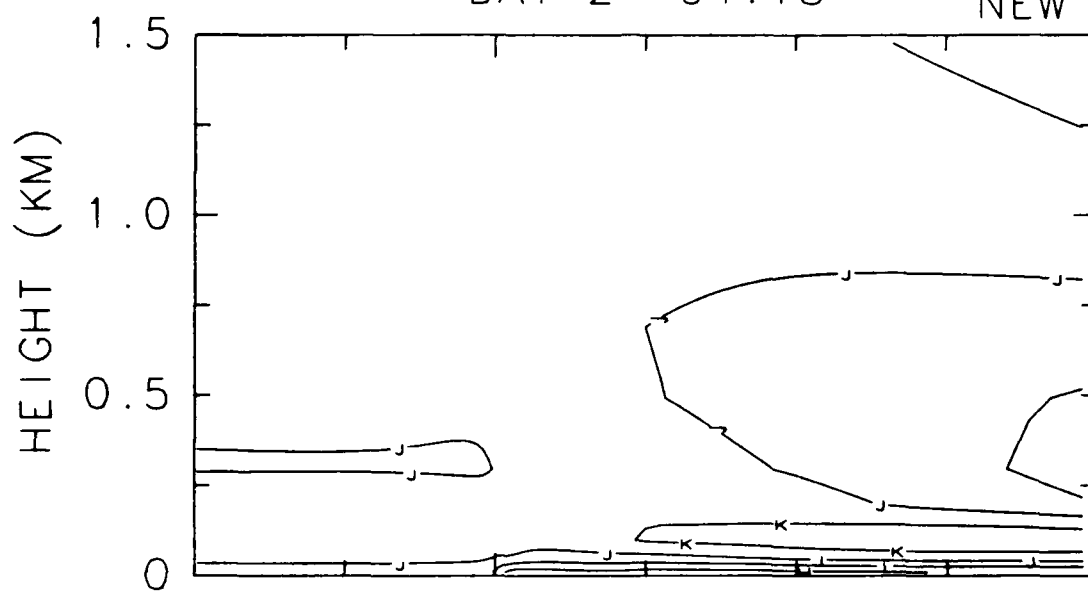
OLD



EAST-WEST VELOCITY (M/S)

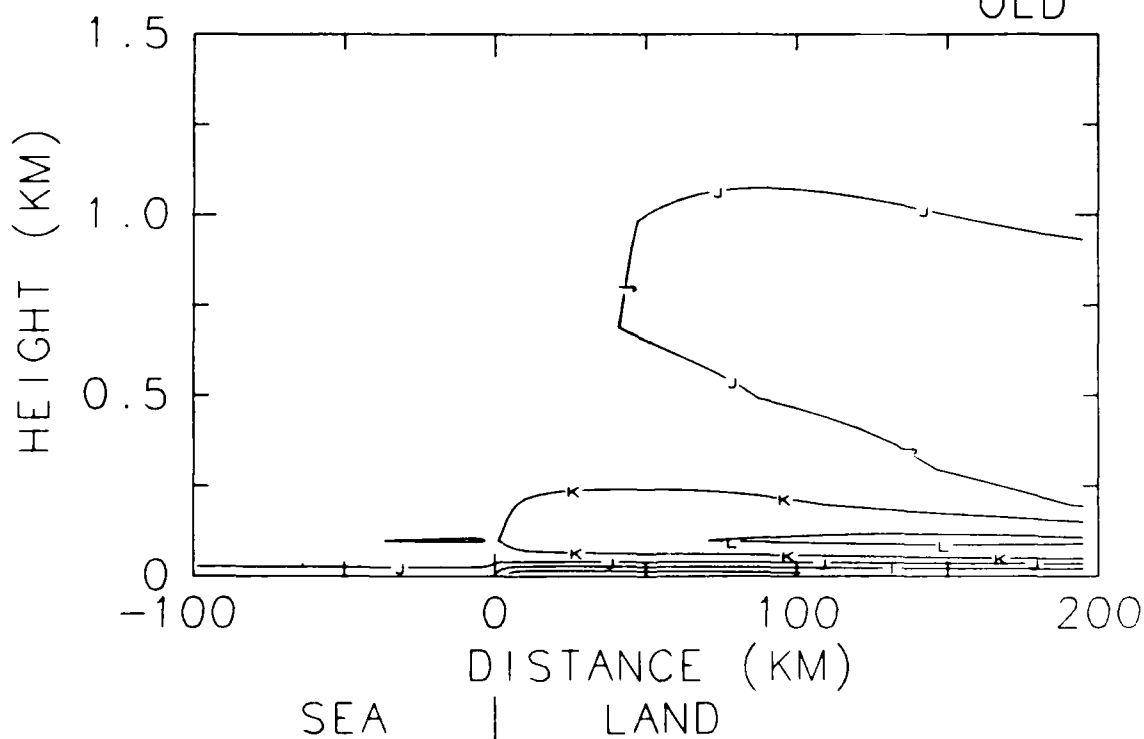
DAY 2 04:18

NEW



F = 0
G = 1
H = 2
I = 3
J = 4
K = 5
L = 6

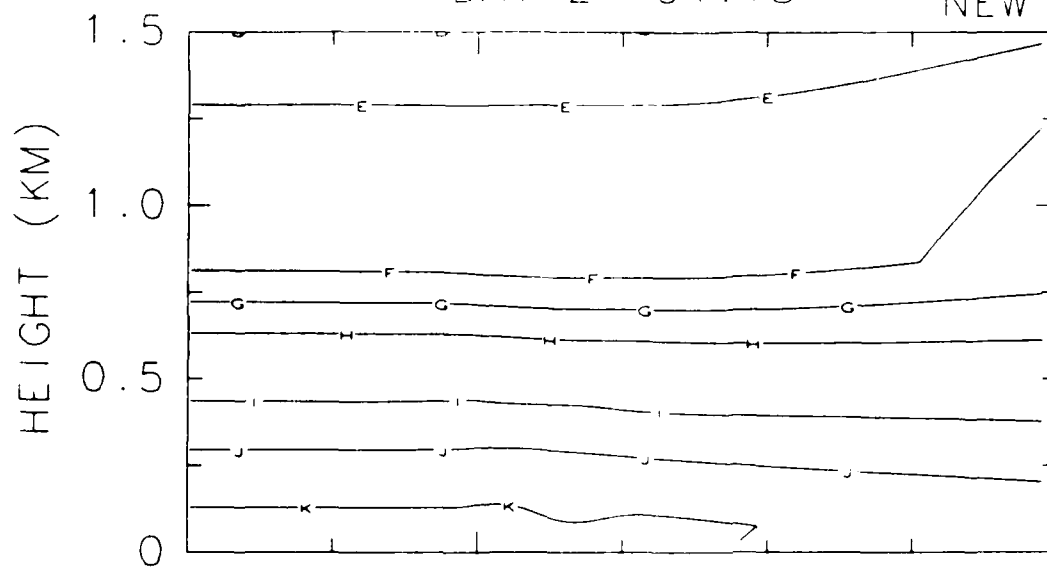
OLD



SPECIFIC HUMIDITY (G/G)

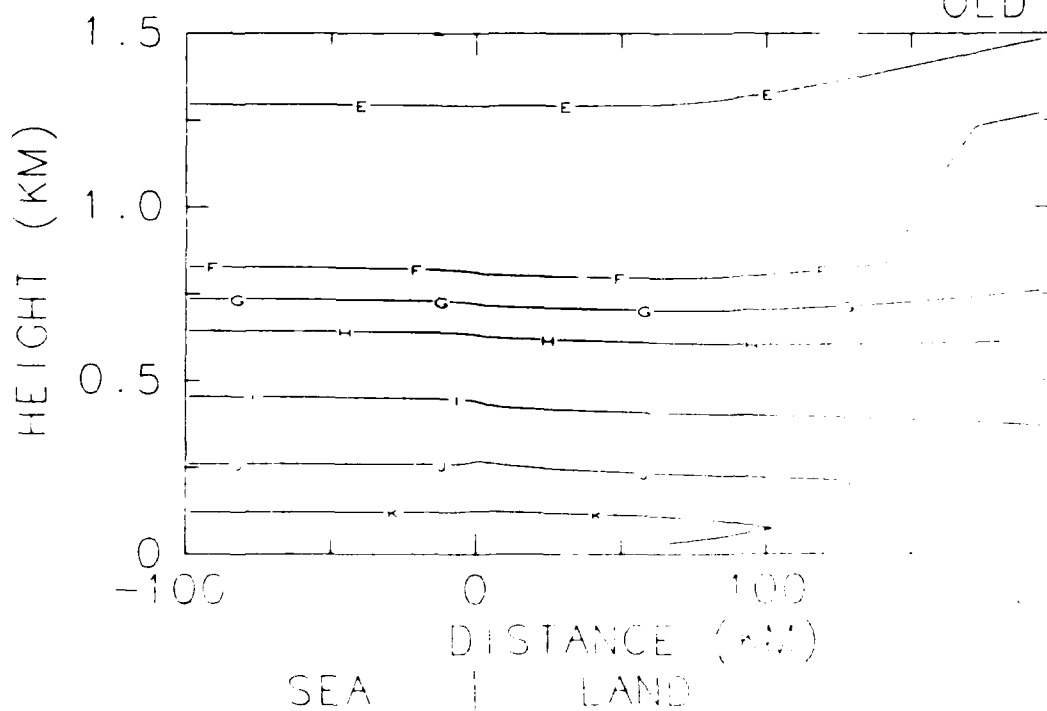
DAY 2 04:18

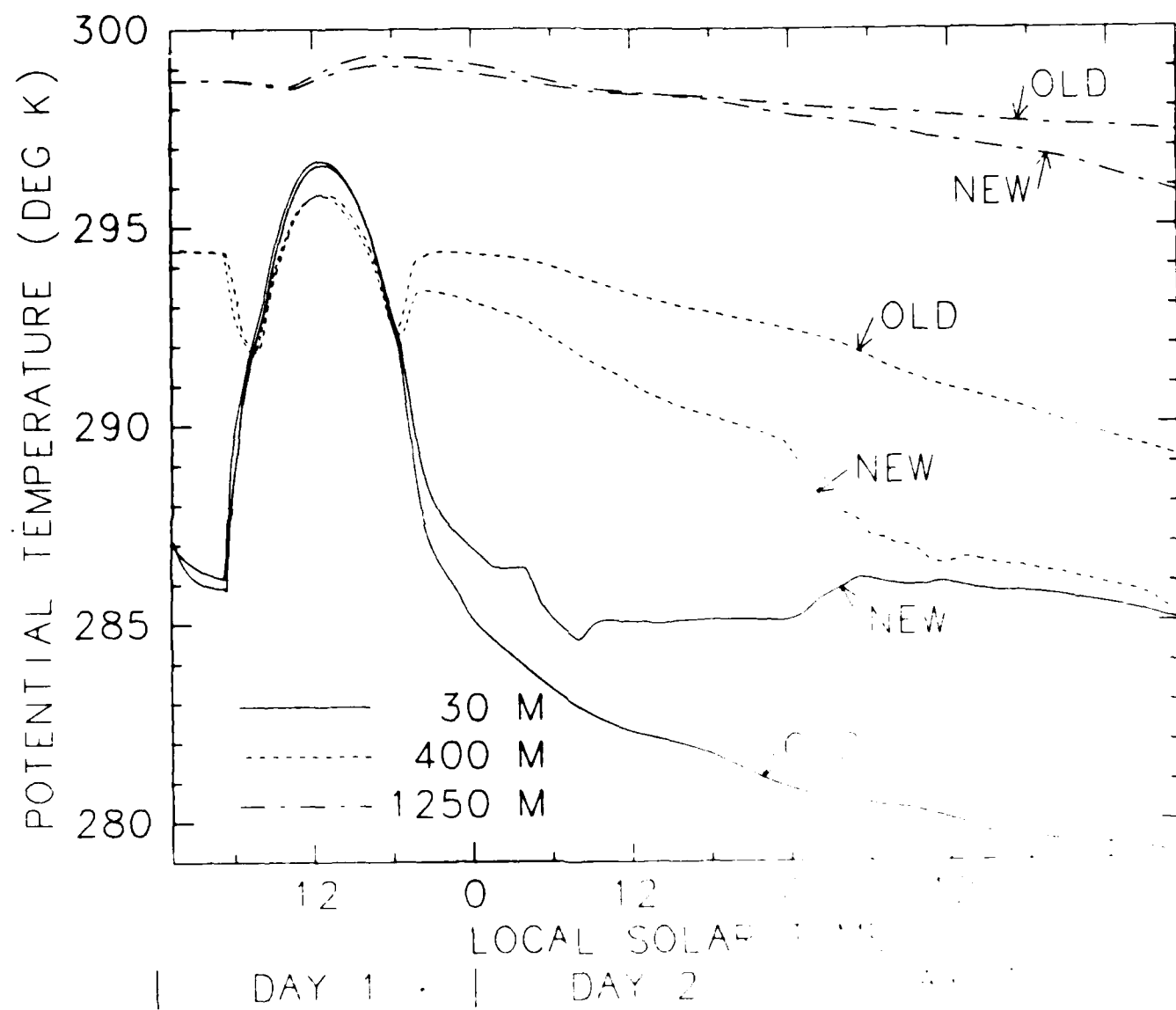
NEW



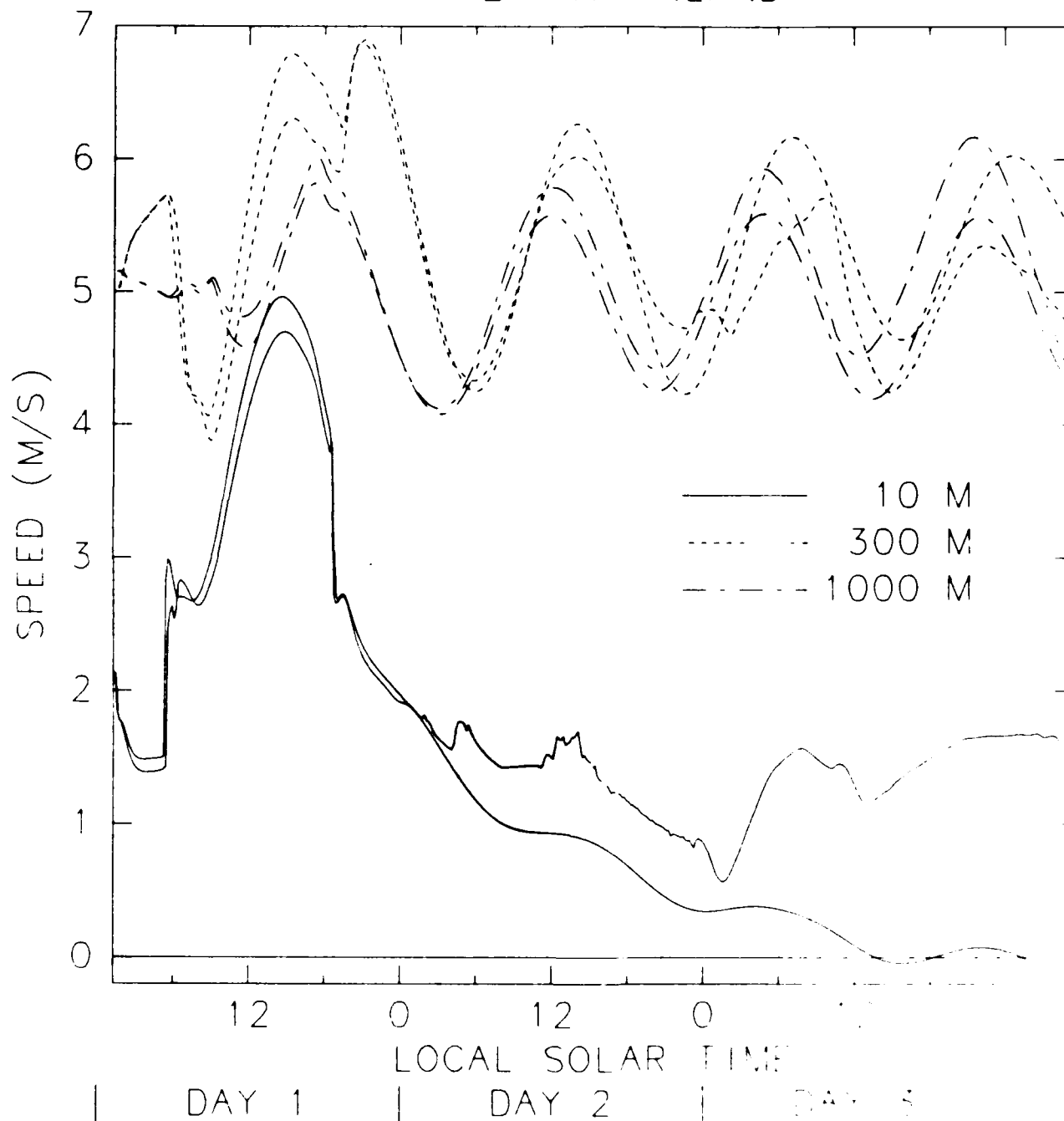
K = 0.010
J = 0.009
I = 0.008
H = 0.007
G = 0.006
F = 0.005
E = 0.004
D = 0.003

OLD





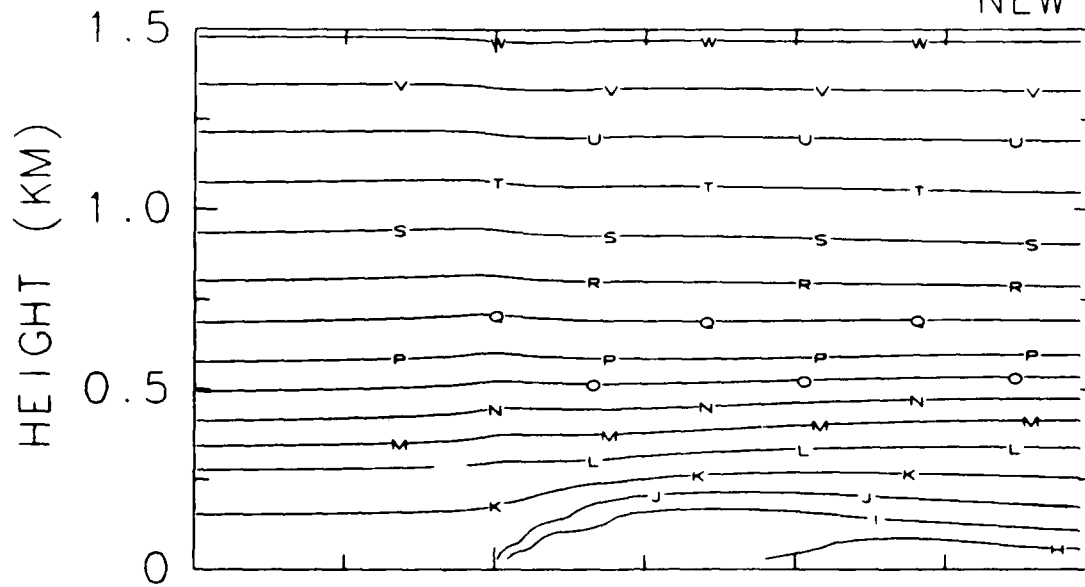
WIND NORMAL TO COASTLINE
AT 27 KM INLAND



POTENTIAL TEMPERATURE

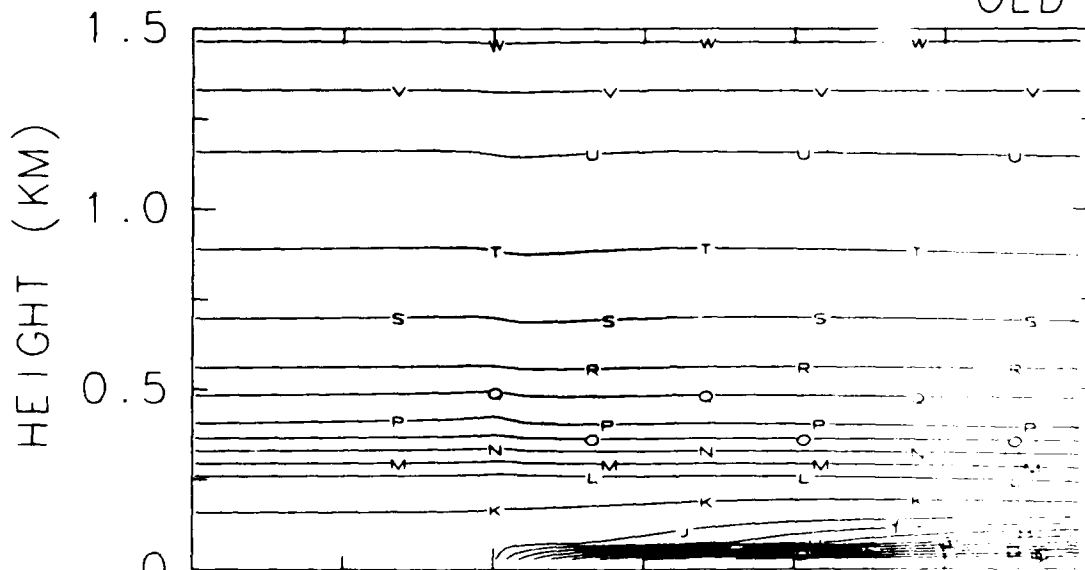
DAY 2 17:18

NEW



W =	300
V =	299
U =	298
T =	297
S =	296
R =	295
Q =	294
P =	293
O =	292
N =	291
M =	290
L =	289
K =	288
J =	287
I =	286
H =	285
G =	284
F =	283
E =	282
D =	281
C =	280
B =	279
A =	278

OLD



-100

0

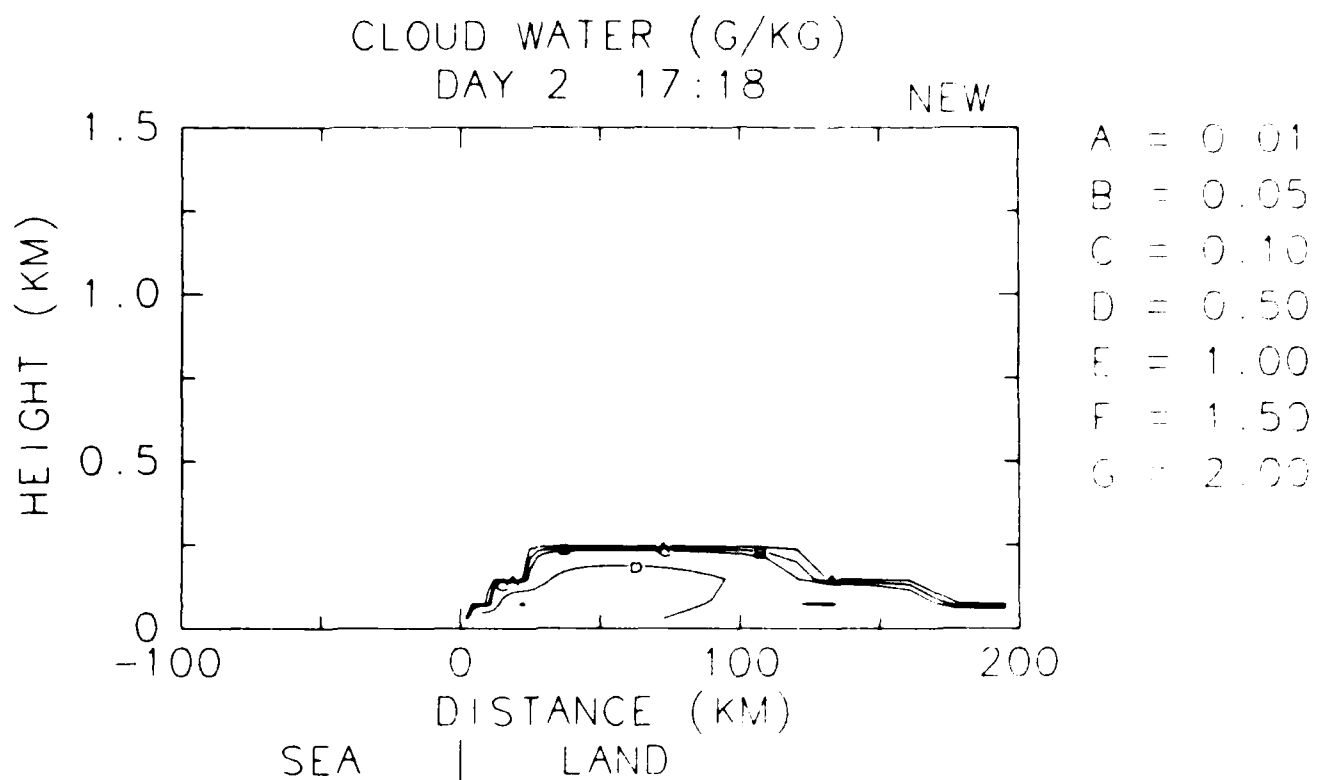
100

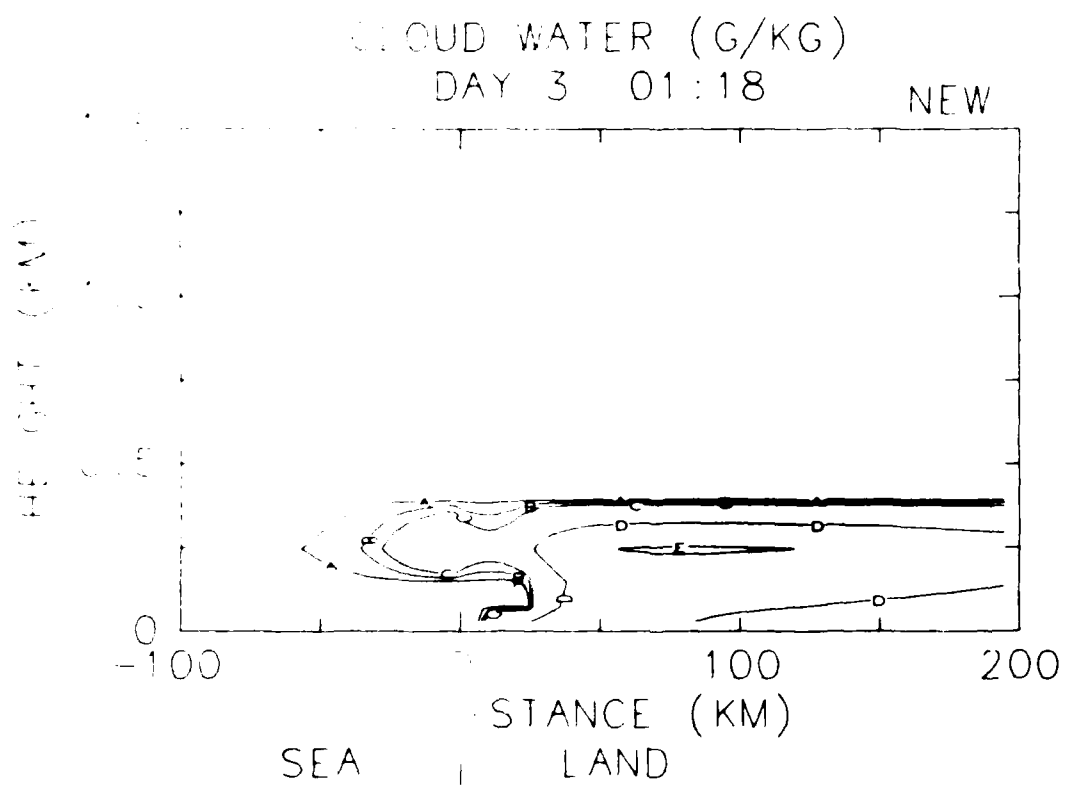
200

DISTANCE (KM)

SEA

| LAND

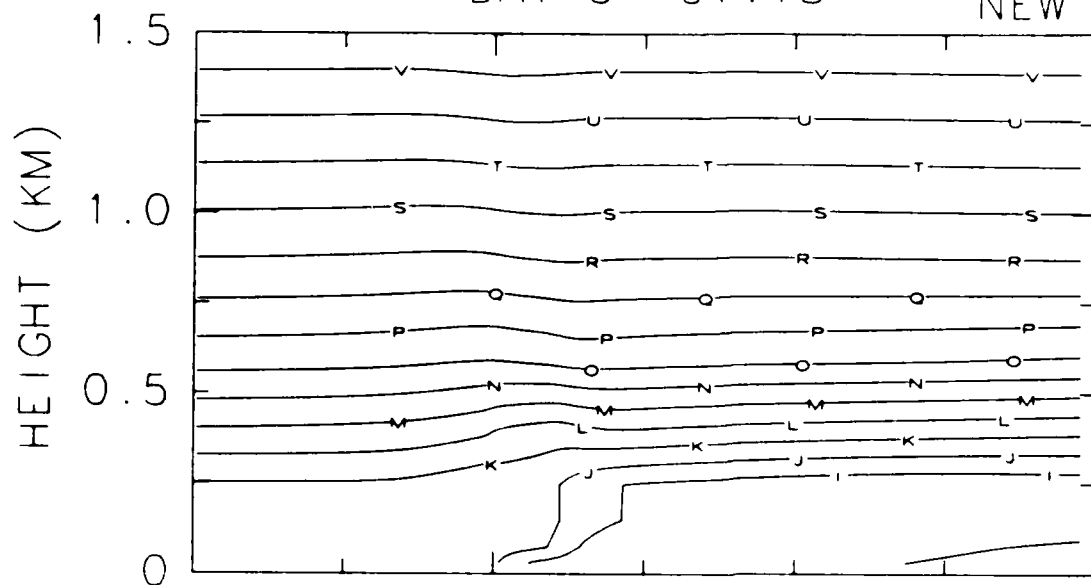




POTENTIAL TEMPERATURE

DAY 3 01:18

NEW



W = 300

V = 299

U = 298

T = 297

S = 296

R = 295

Q = 294

P = 293

O = 292

N = 291

M = 290

L = 289

K = 288

J = 287

I = 286

H = 285

G = 284

F = 283

E = 282

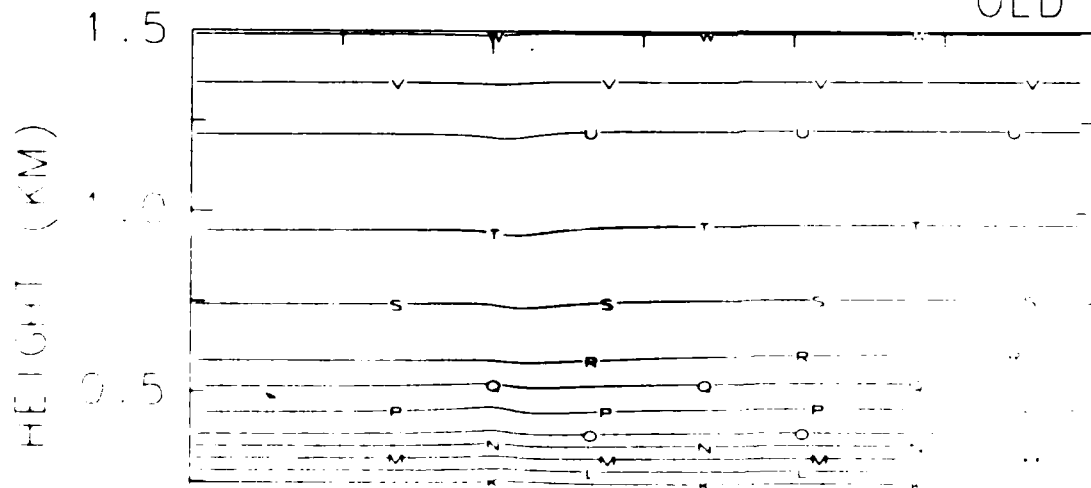
D = 281

C = 280

B = 279

A = 278

OLD



-100

0

100

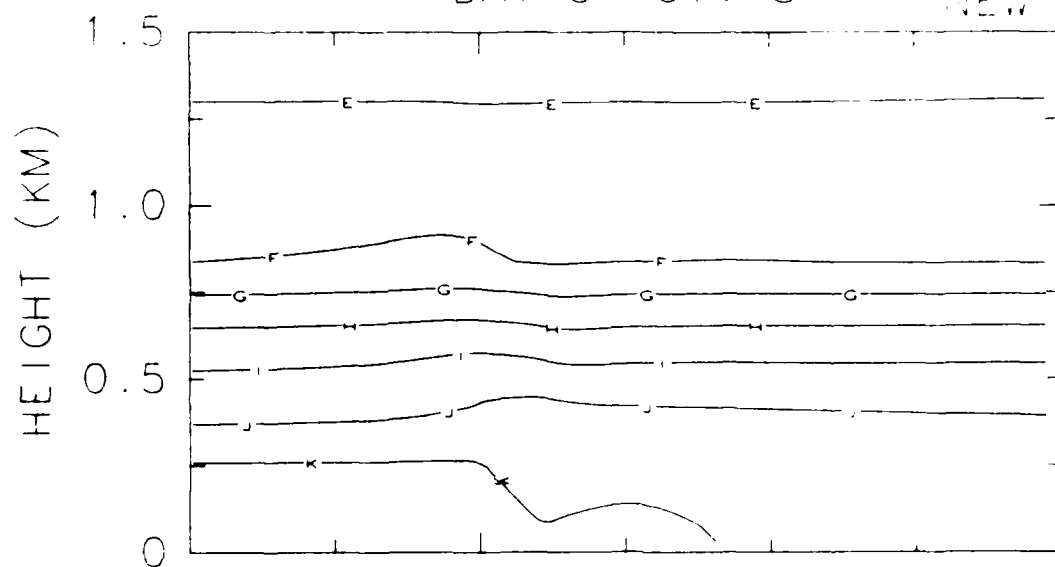
DISTANCE (KM)

SEA

LAND

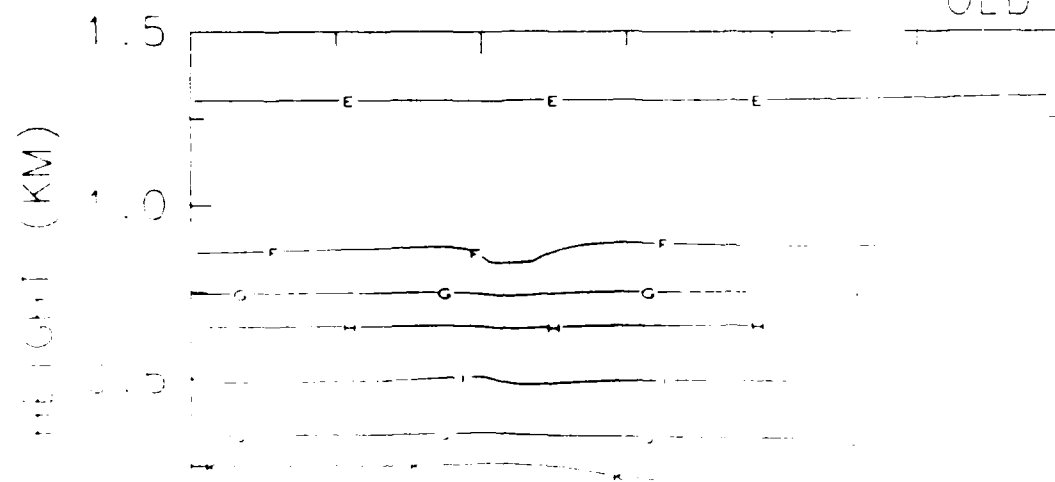
SPECIFIC HUMIDITY (G/G) DAY 3 01:18

NEW



A = 0.010
B = 0.010
C = 0.010
D = 0.010
E = 0.008
F = 0.005
G = 0.004
H = 0.003

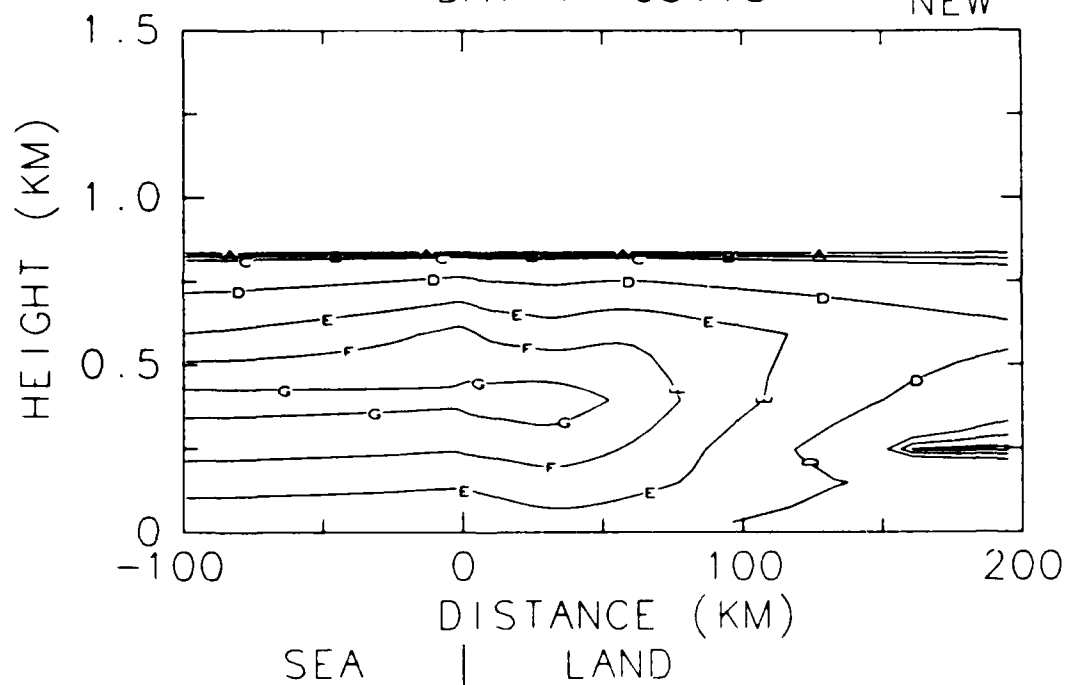
OLD



CLOUD WATER (G/KG)

DAY 4 05:18

NEW



A = 0.01

B = 0.05

C = 0.10

D = 0.50

E = 1.00

F = 1.50

G = 2.00

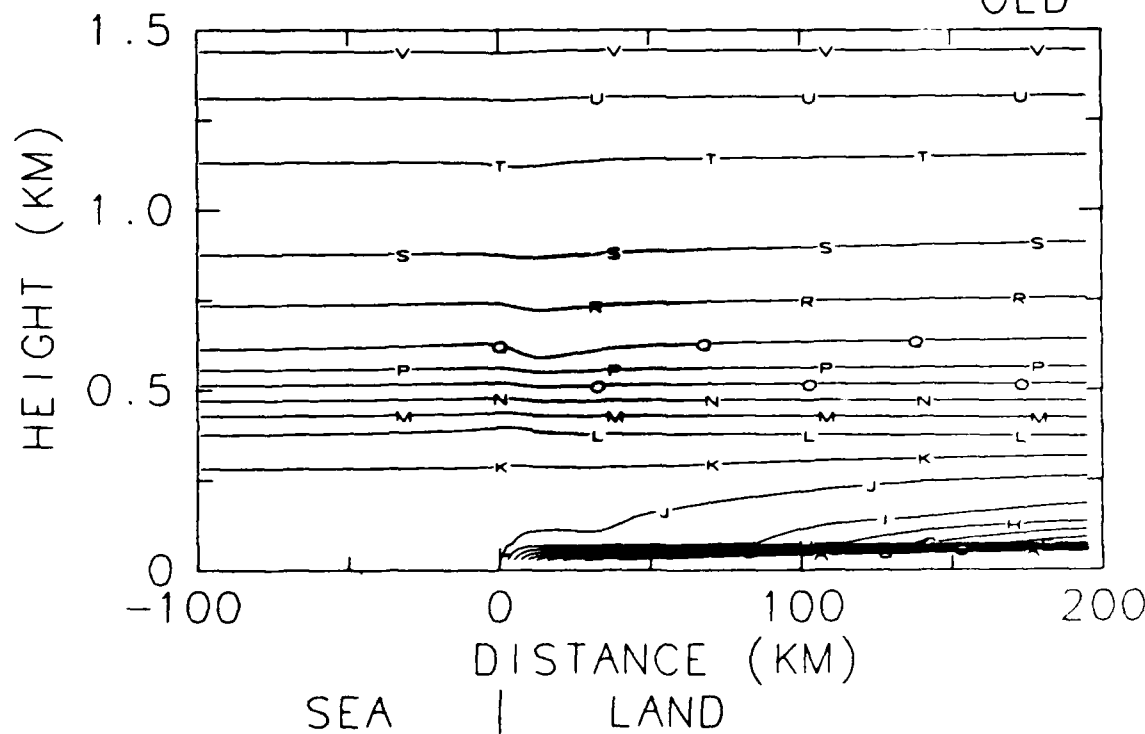
POTENTIAL TEMPERATURE DAY 4 05:18

NEW



W = 300
V = 299
U = 298
T = 297
S = 296
R = 295
Q = 294
P = 293
O = 292
N = 291
M = 290
L = 289
K = 288
J = 287
I = 286
H = 285
G = 284
F = 283
E = 282
D = 281
C = 280
B = 279
A = 278

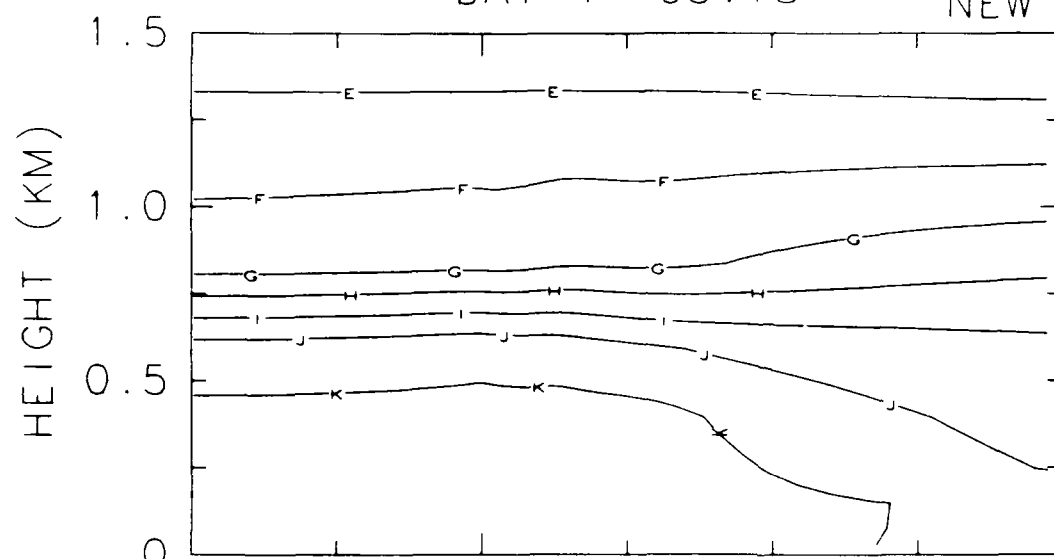
OLD



SPECIFIC HUMIDITY (G/G)

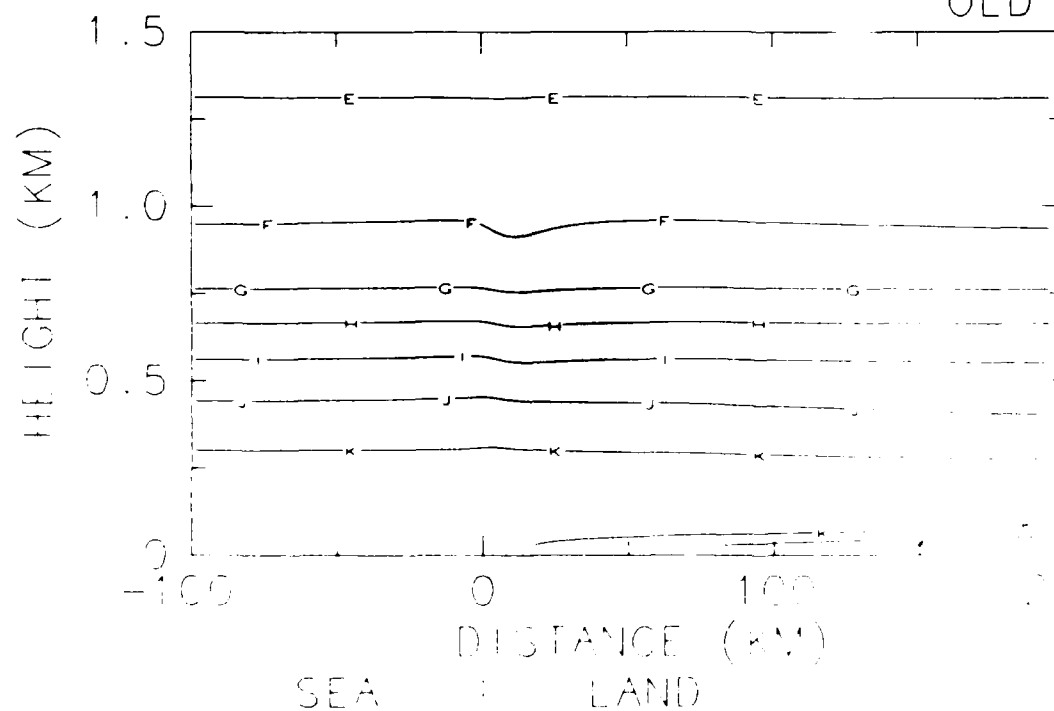
DAY 4 05:18

NEW



K = 0.010
J = 0.009
I = 0.008
H = 0.007
G = 0.006
F = 0.005
E = 0.004
D = 0.003

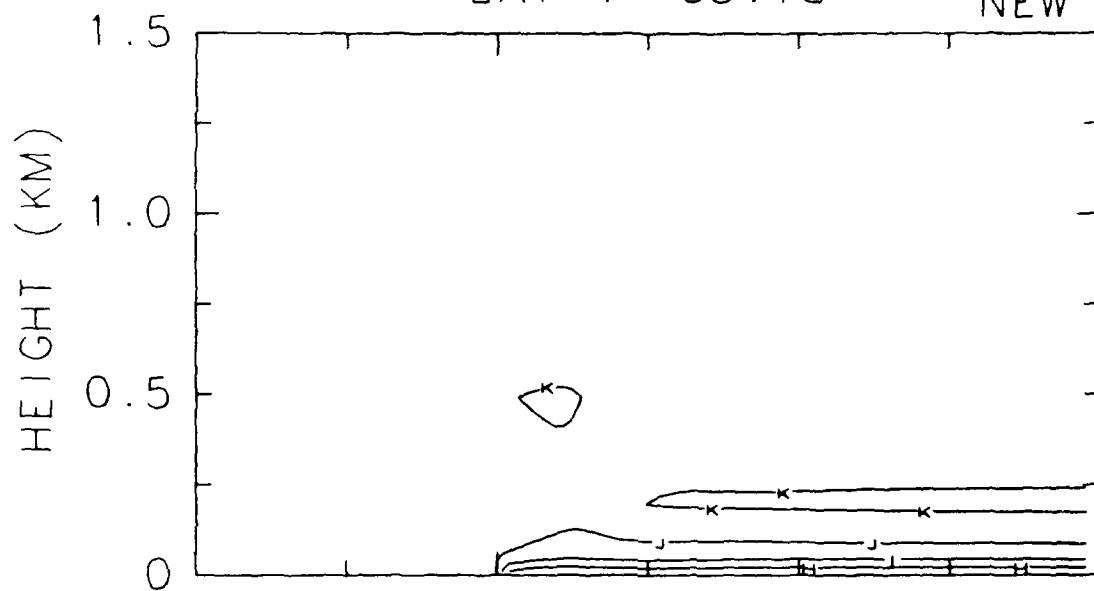
OLD



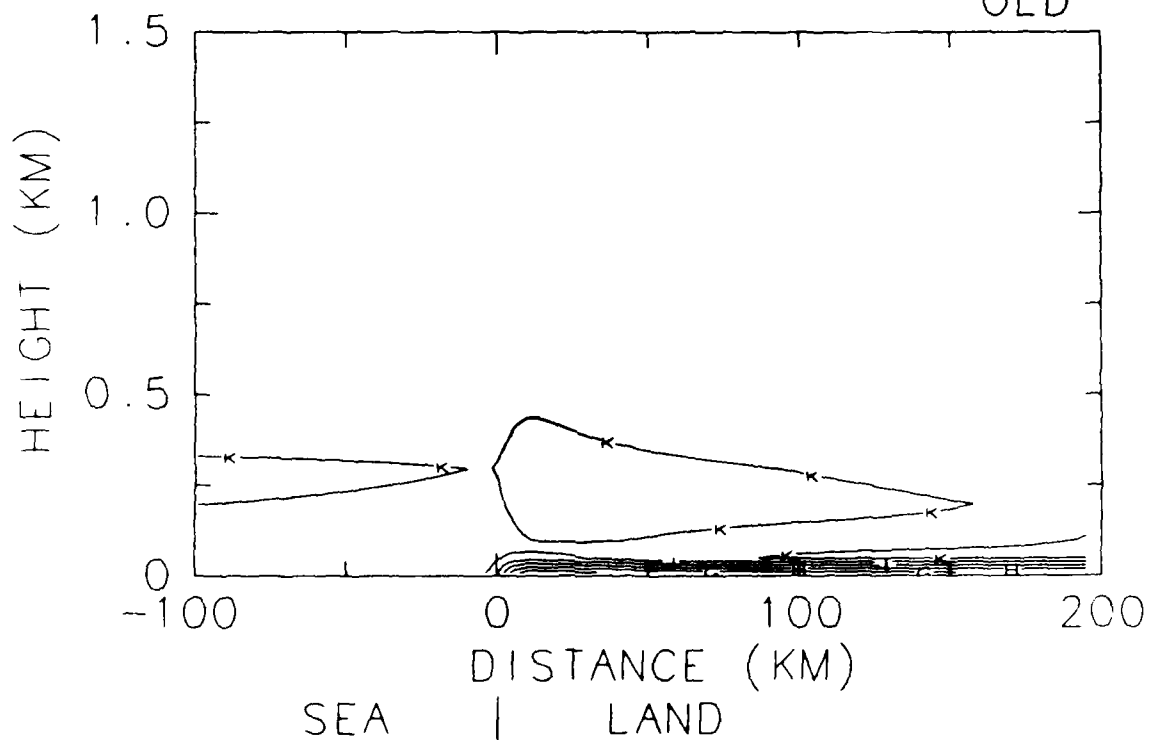
EAST-WEST VELOCITY (M/S)

DAY 4 05:18

NEW



OLD



● **OLD**

- + Very Cold Layer Forms over Land
- + Cold Layer is Very Thin
- + No Significant Perturbation above 200 M
- + No Significant Vertical Motion

● **NEW**

- + Fog Forms over Land at Dawn and Thickens with Time
- + Fog Forms over Ocean about 20 Hours Later
 - Vertical Mixing of Moisture from Sea
 - Radiative Cooling Aloft
- + Fog over Land and Sea Up to 800 M in 2 1/2 Days
- + Fog Eliminates Land/Sea Surface Temperature Contrast
- + No Significant Vertical Motion

*A Numerical Simulation
of
The Possible Effects of
Nucleation Scavenging
on
Plume Injection*

*by
Greg Tripoli
Chang Chen
William Cotton*

R. A. M. S.

Regional Atmospheric Modeling System

Time dependent P.D.E. for

$\vec{V}$ (u, v, w) (velocity)

P (pressure)

Θ (potential temperature)

$\vec{q}$
 $\vec{q}_v$
 $\vec{q}_c$
 $\vec{q}_r$
 $\vec{q}_i$
 $\vec{q}_g$
 $\vec{q}_a$

mixing ratio ($\frac{\text{grams water}}{\text{grams air}}$)

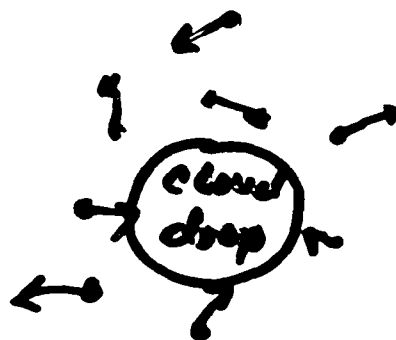
for

vapor, cloud, rain, crystals,
graupel, aggregates

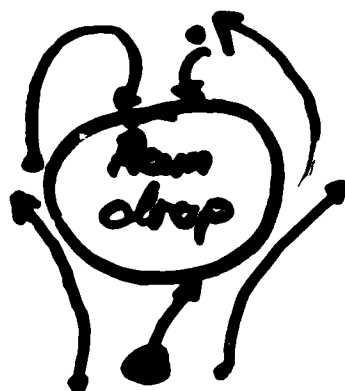
Phoretic Scavenging



Brownian Scavenging



Hydronamic Capture



Electric Effects



Nucleation Scavenging

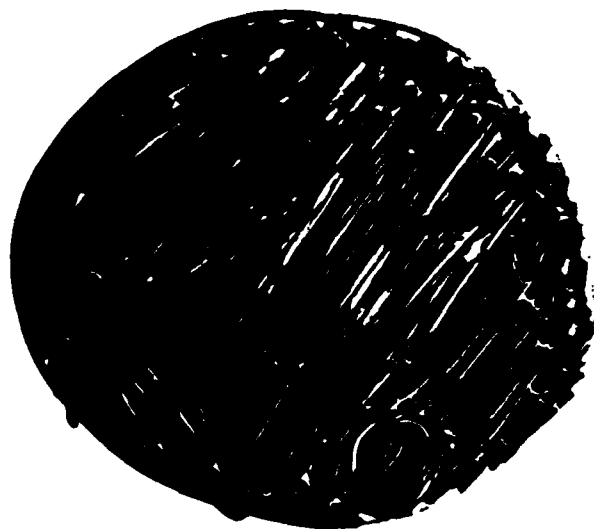
A



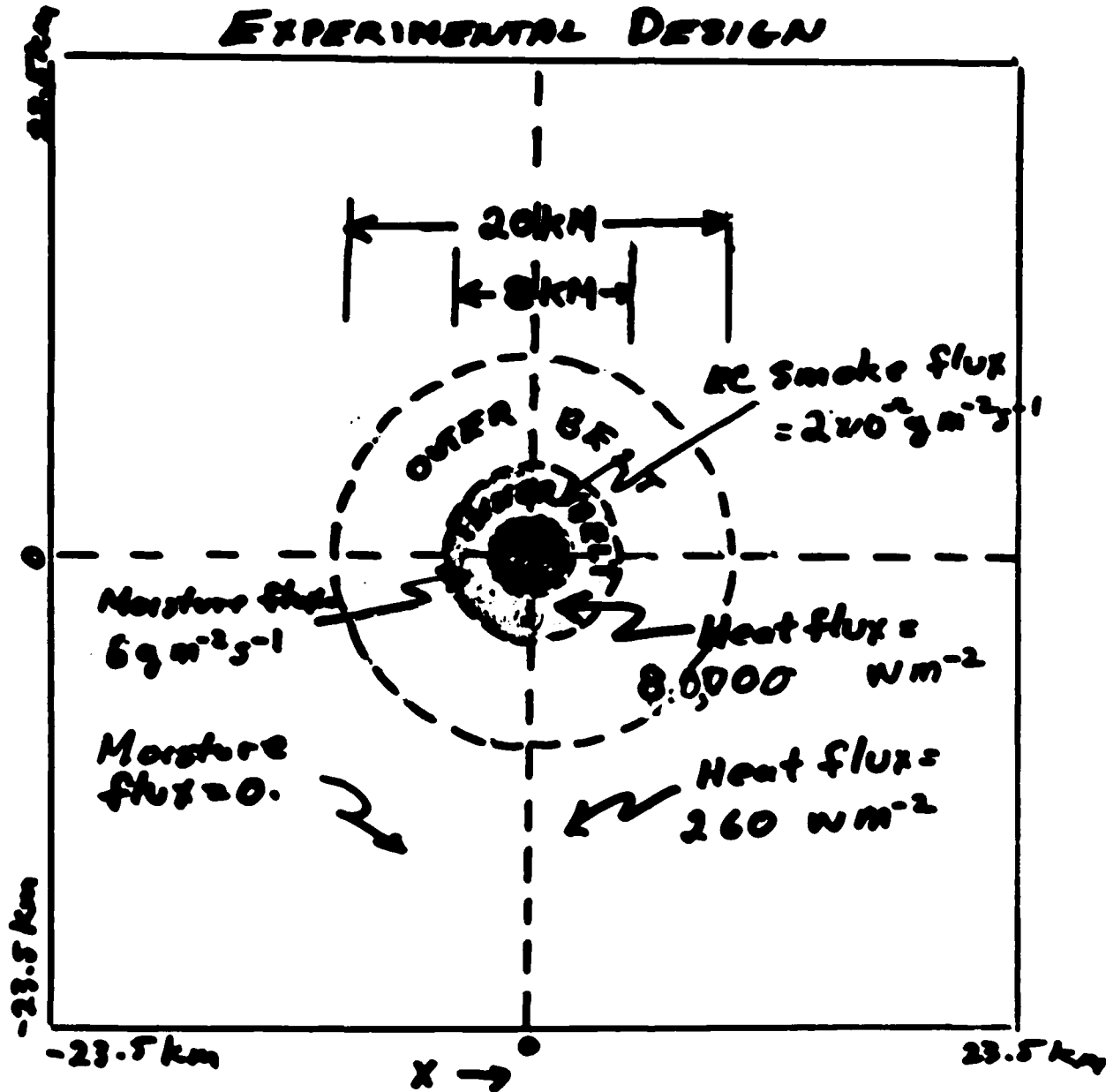
B



C



EXPERIMENTAL DESIGN



$$\begin{aligned}\Delta X &= 1 \text{ km} \\ \Delta Y &= 1 \text{ km} \\ \Delta Z &= .75 \text{ km}\end{aligned}$$

EC Produced is
20% of smoke which is
1% of fuel
(Croteau, et al, 1989, for wood)

Assumptions:

1. Homogeneous fuel density of 110 kg m^{-2} (10% water content) within inner belt.
2. Neglect fire in outer belt.
3. City center same as inner belt

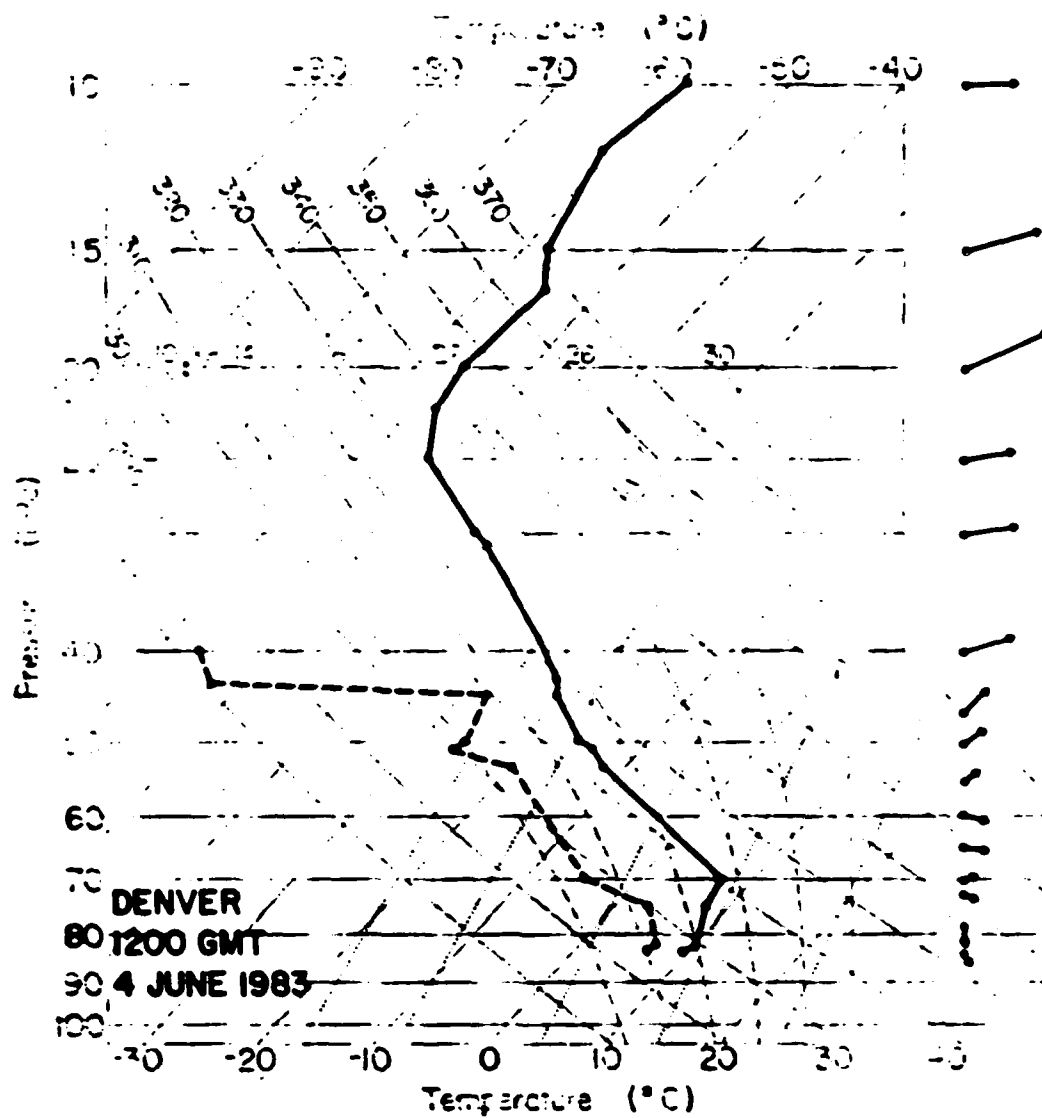


Figure 3

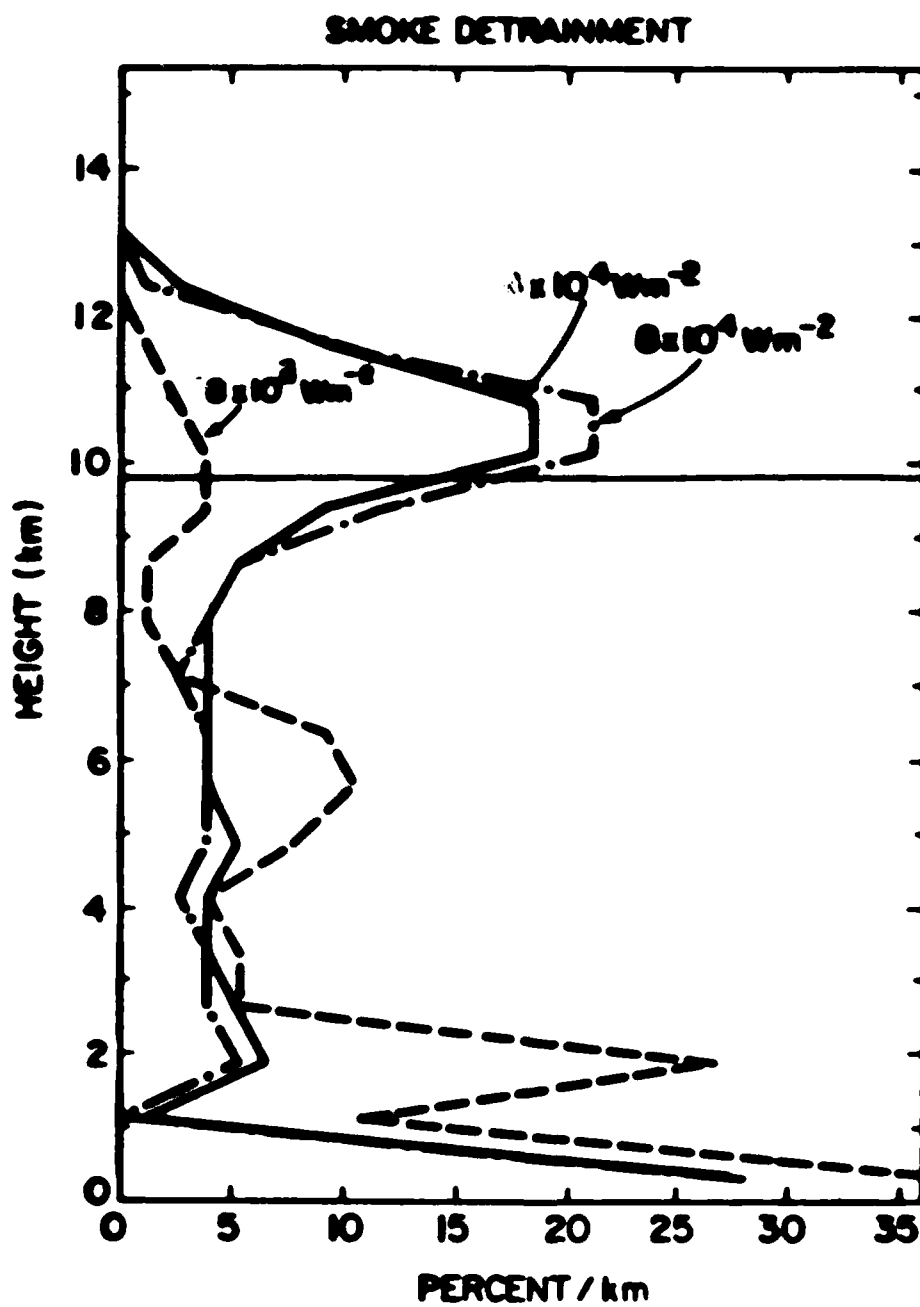


Figure 4

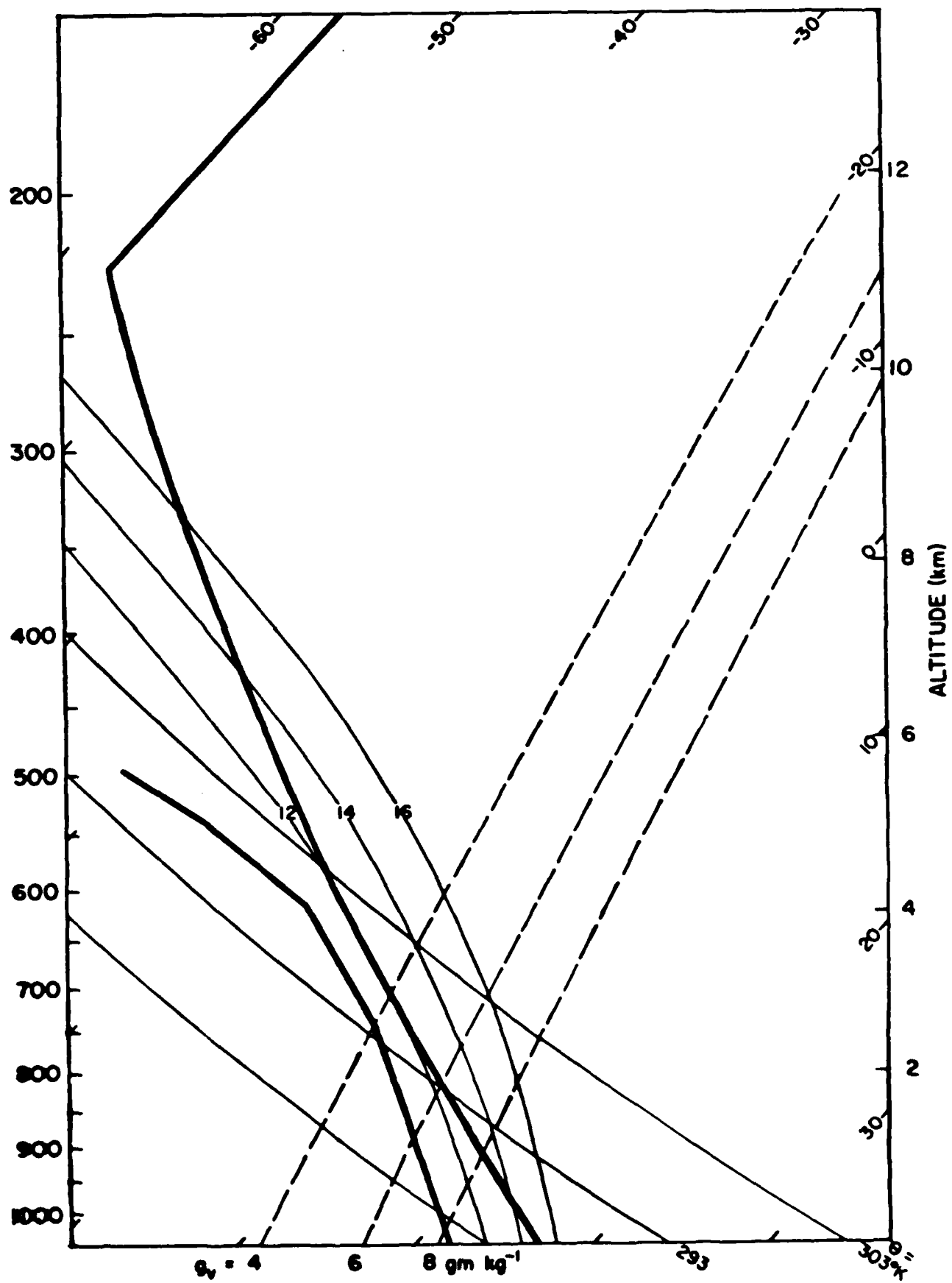
DESIGN OF EXPERIMENT
TO TEST EFFECTIVENESS OF
NUCLEATION SCAVENGING

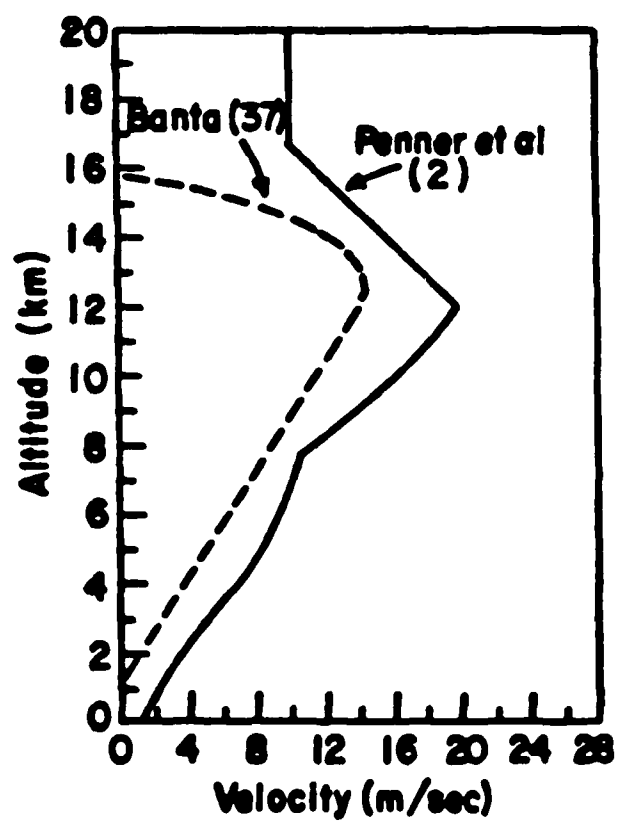
- 1) Use conservative standard spring/fall atmosphere, wind as Penner et al. (1985)
- 2) Use Penner et al. (1985) high intensity case (low intensity case results trivial since deep cloud never forms)
- 3) Use Cotton (1985) phoretic/Brownian scavenging model.
- 4) Nucleation scavenging:

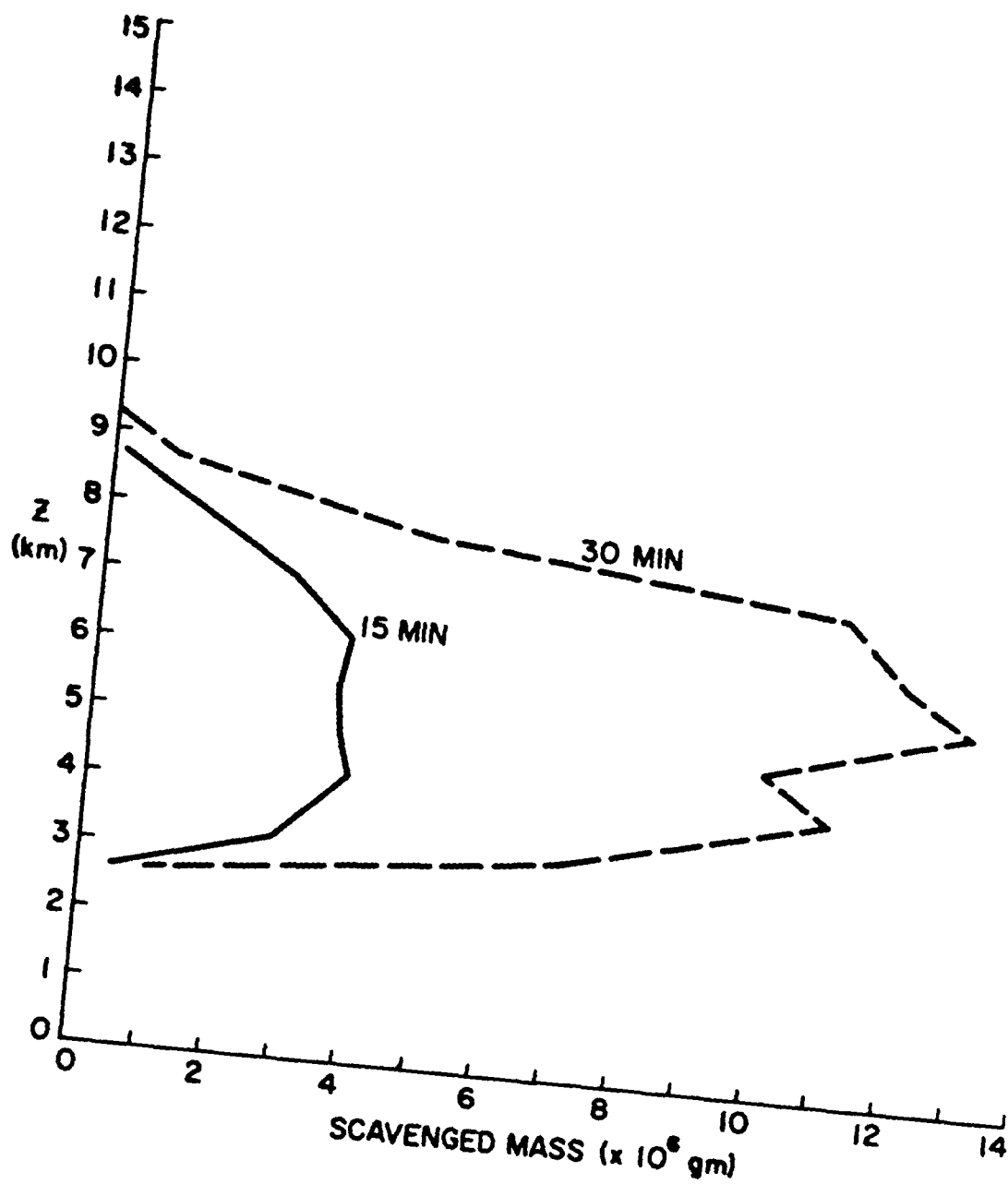
$$S_N = -\frac{C_{Lcr} + C_{cl} + C_{cg} + C_{ca}}{r_c} r_{EC}$$

INHERENT ASSUMPTIONS FOR NUCLEATION SCAVENGING

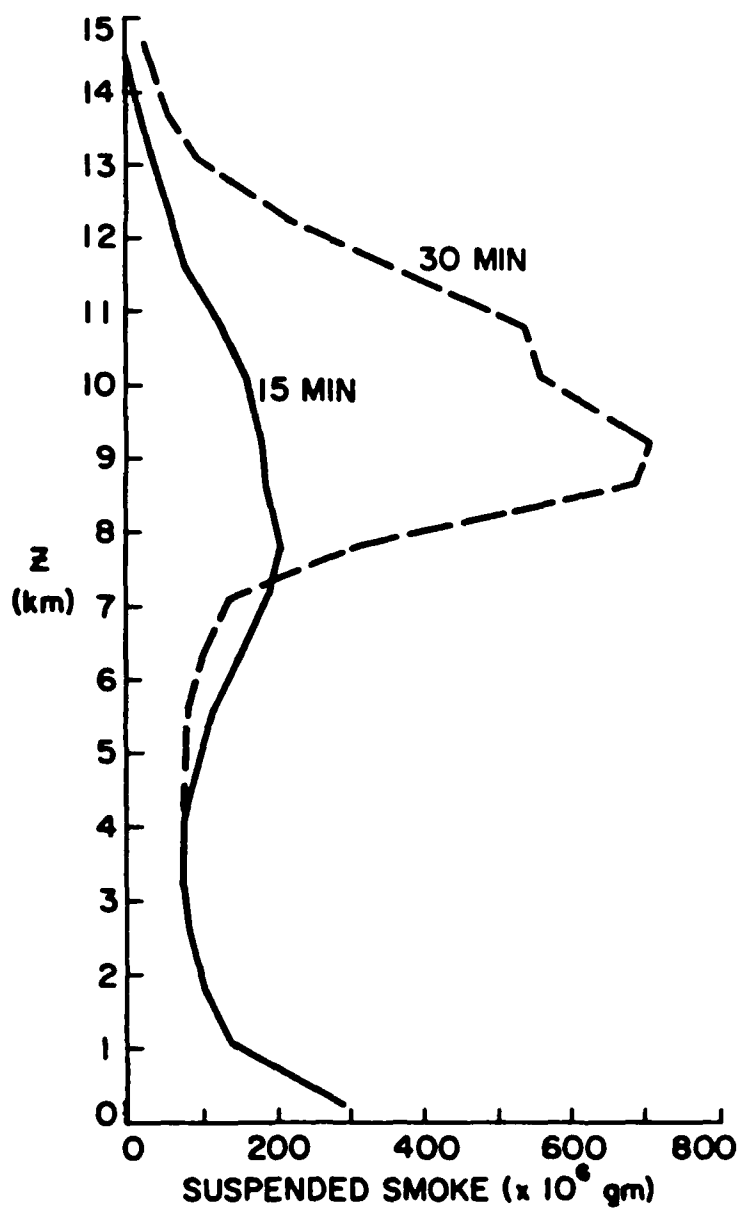
- 1) All smoke particles will nucleate.
- 2) Smoke collected onto precipitation particle will be lost from system, even if precipitation re-evaporates. (We assume many will be combined to make large precipitating smoke particle).
- 3) Collection efficiency of cloud droplets unity despite smaller size.







(No Nucleation Scavenging)



(No Nucleation Scavenging)

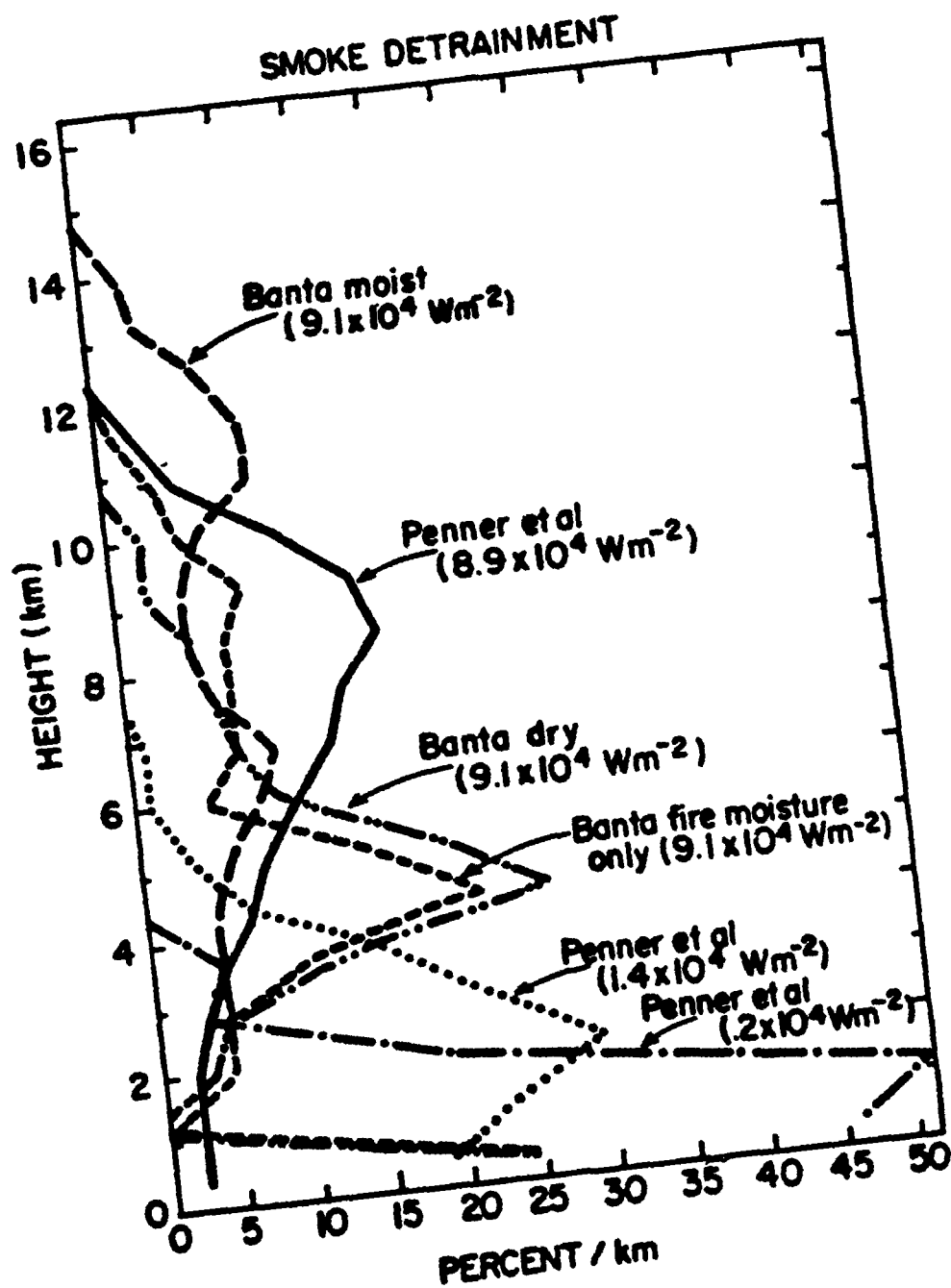
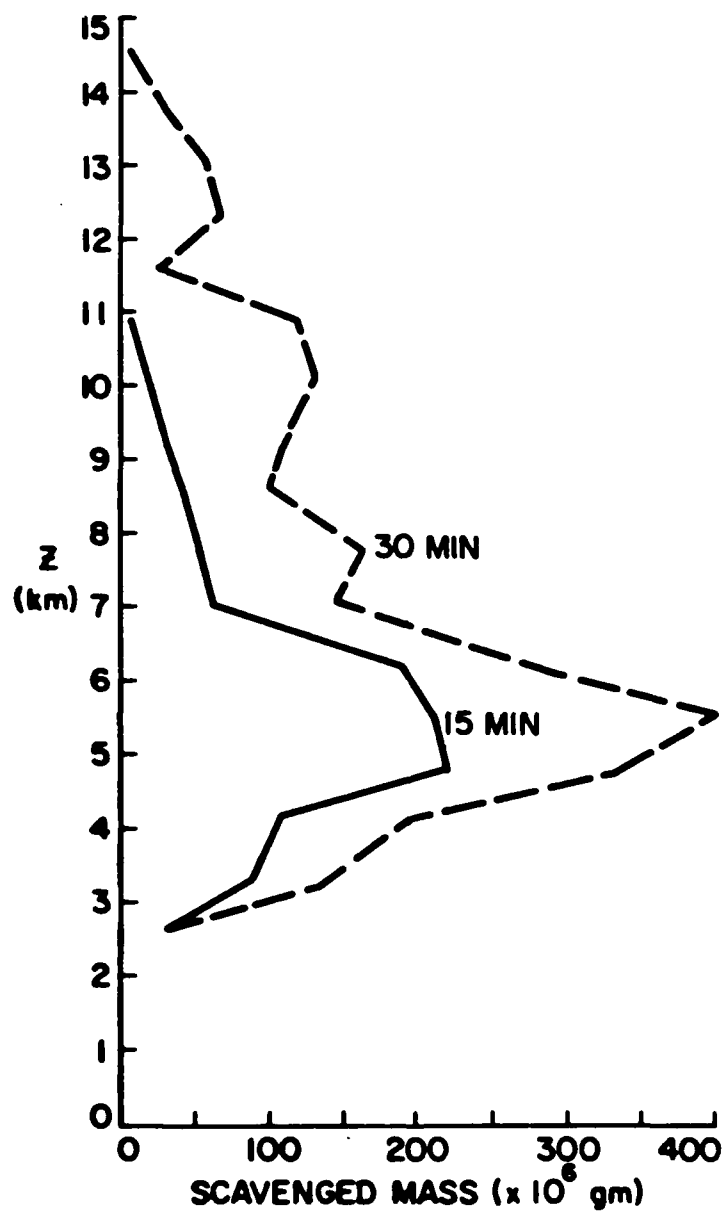
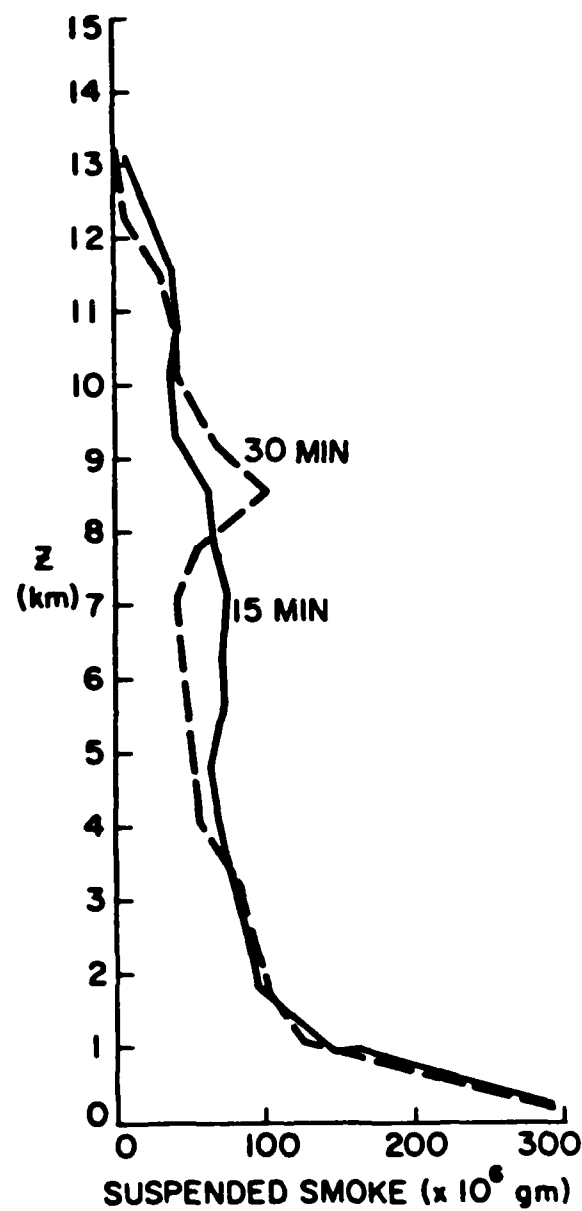


Figure 10

(Results of other investigators)



Nucleation Scavenging



Nucleation Scavenging

CONCLUSIONS ABOUT SCAVENGING

- A. Nucleation scavenging might remove up to 80% of smoke if effective.
- B. Phoretic scavenging is of minor importance.
- C. There are some major uncertainties:
 - 1) How effective is smoke as a cloud condensation nuclei?
 - 2) Will the very large numbers of CCN render the accretion of cloud droplets by precipitation particles ineffective (1 g/kg cloud ~ 1 micron cloud drops).
 - 3) How much larger will the smoke particles captured by precipitation be?

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