Smoke Control Basics

Recorded February 19, 1996

Chair:	James S. Buckley, P.E. Michaud, Cooley, Erickson
Presentation 1:	"Basic Approaches to Smoke Management" John Klote, Ph.D., P.E. NIST
Length:	30:35
Presentation 2:	"Considerations in the Application, Selection, and Specification of Fire Safety Related Dampers" Michael L. Wolf, Ph.D., P.E. Greenheck Fan Corporation
Length:	29:34
Presentation 3:	"Smoke Control Systems Damper Components Requirement" Francis J. McCabe, Ph.D., P.E. Prefco Products, Inc.
Length:	21:44
Presentation 4:	"Smoke Management System Design—Where to Start?" William A. Webb, Ph.D., P.E. Rolf Jensen & Associates, Inc.
Length:	30:35

The views of the speakers do not purport to reflect the position of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, nor does their presentation imply any recommendation or endorsement, thereof by the Society. This videotape was recorded at an ASHRAE seminar held in conjunction with the Society's 1996 Annual Meeting in Atlanta, Georgia.

NIST

Fundamentals of Smoke Control

February 1996

John H. Klote
National Institute of
Standards and Technology
Gaithersburg, MD

Acceptance Testing - The Major Smoke Control Problem?

Symptom Not the Problem

Some of the Problems:

- Lack of Planning
- Overly Complicated System
- Unrealistic Expectations

Mechanisms of Smoke Management

Compartmentation

Dilution

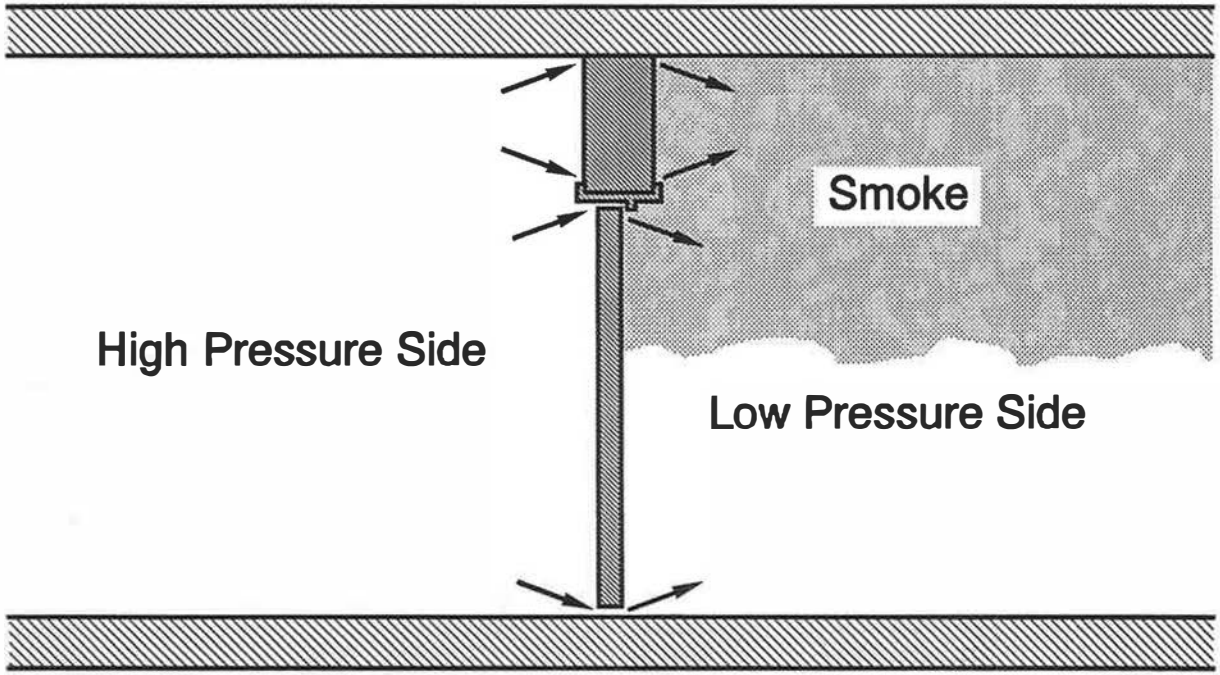
Air Flow

Pressurization

Buoyancy

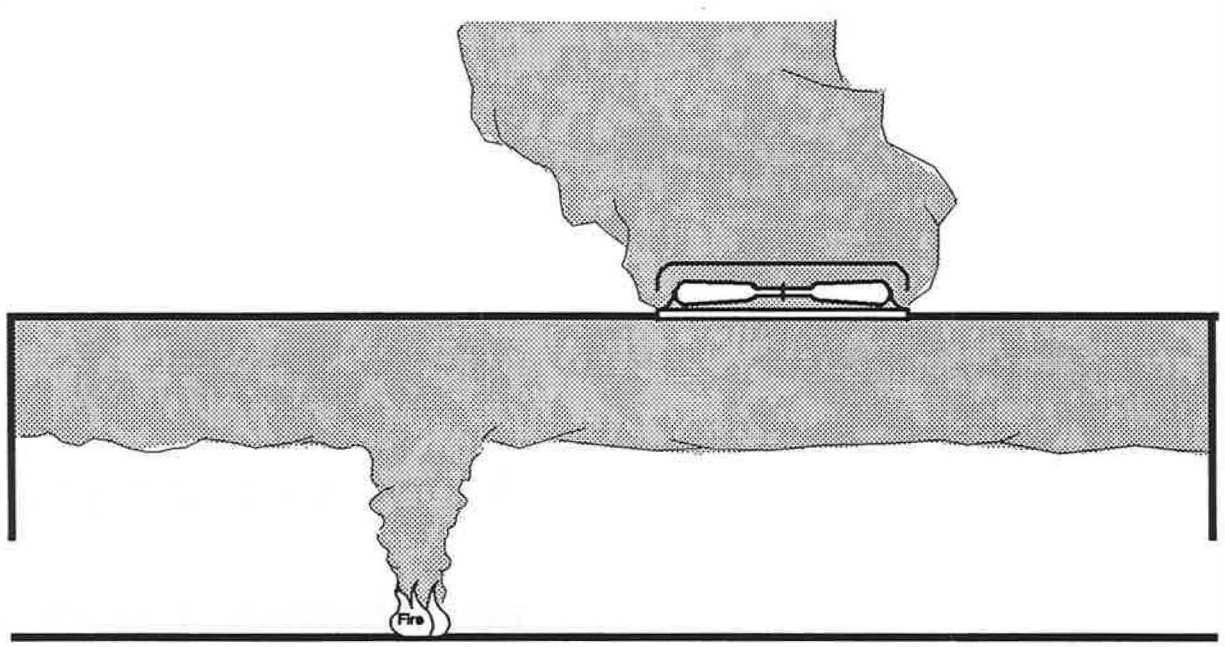
Pressurization

ΔP Across a Barrier
ASHRAE Smoke Manual & NFPA 92A



Buoyancy

Malls, Atria, Large Spaces



Some Smoke Control Systems

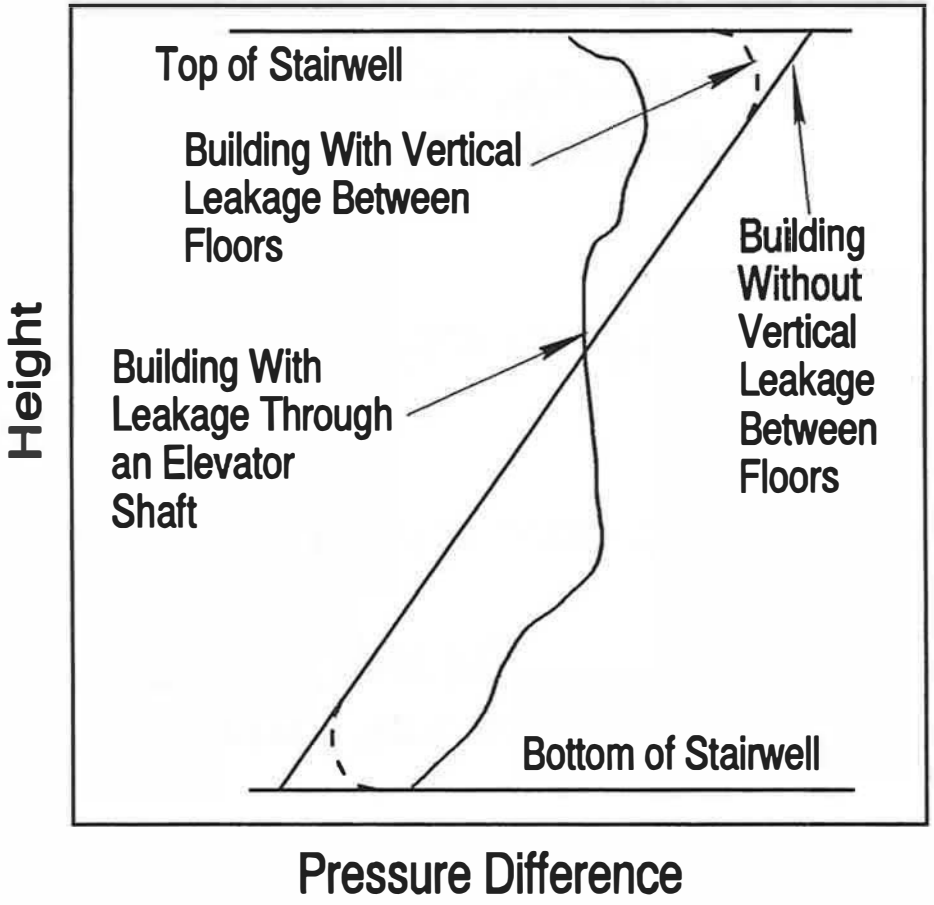
Stairwell Pressurization

Elevator Pressurization

Zoned Smoke Control

Atrium Exhaust (Really Smoke Management)

Stairwell Pressurization



Stairwell Pressurization

Pressurization Range:

Min ΔP - Control Smoke
Max ΔP - Door Opening

Major Problem: ΔP Fluctuations due to Open Doors

Several System Approaches (ASHRAE Manual)

Computer Analysis
ASCOS (ASHRAE Manual)
CONTAM (George Walton)

Elevator Smoke Control

NIST/NRCC Joint Project:

Smoke Control for Fire Evacuation of the Disabled (U.S. Part Funded by V A)

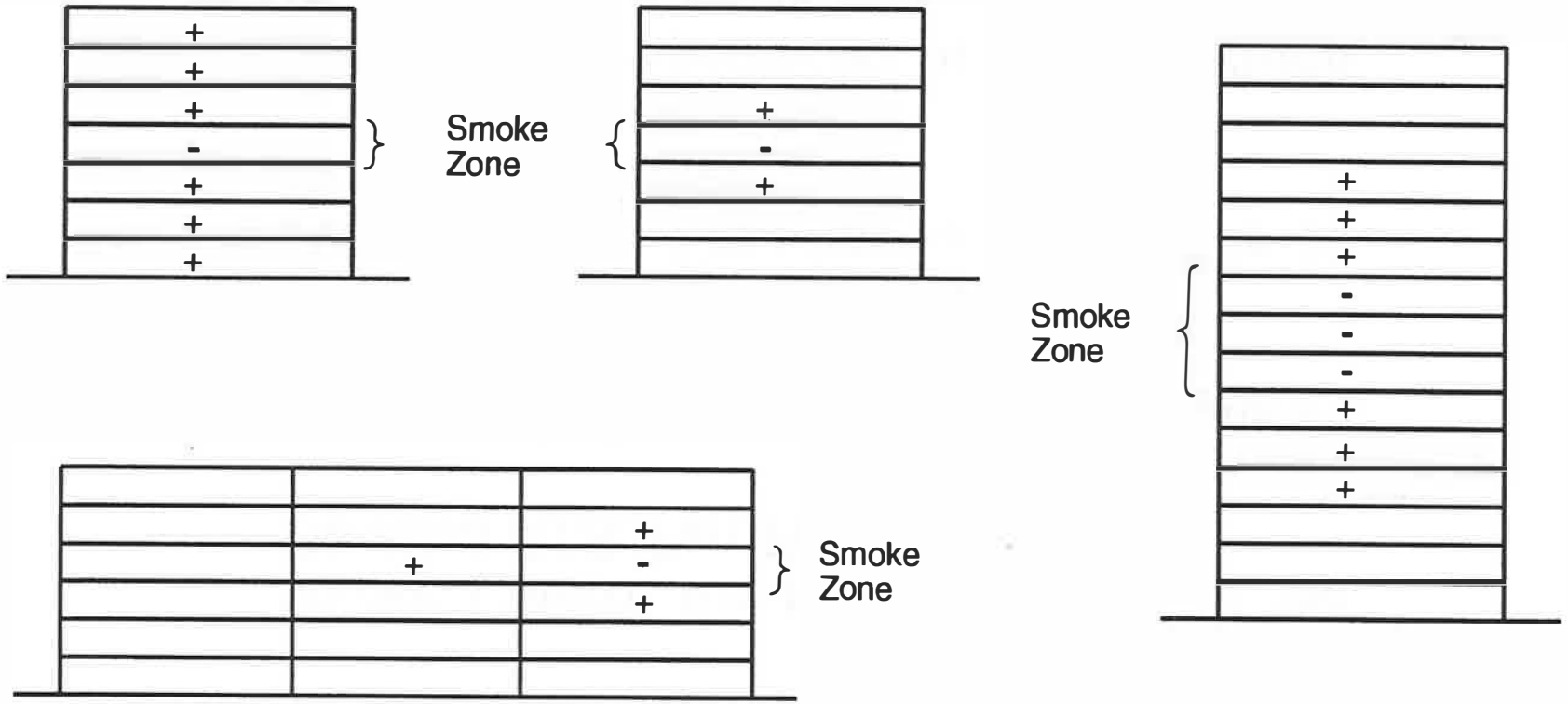
Conceptual Studies of Elevator Smoke Control Systems

Full-Scale Fire Experiments at NRCC's 10 Story Fire Research Tower

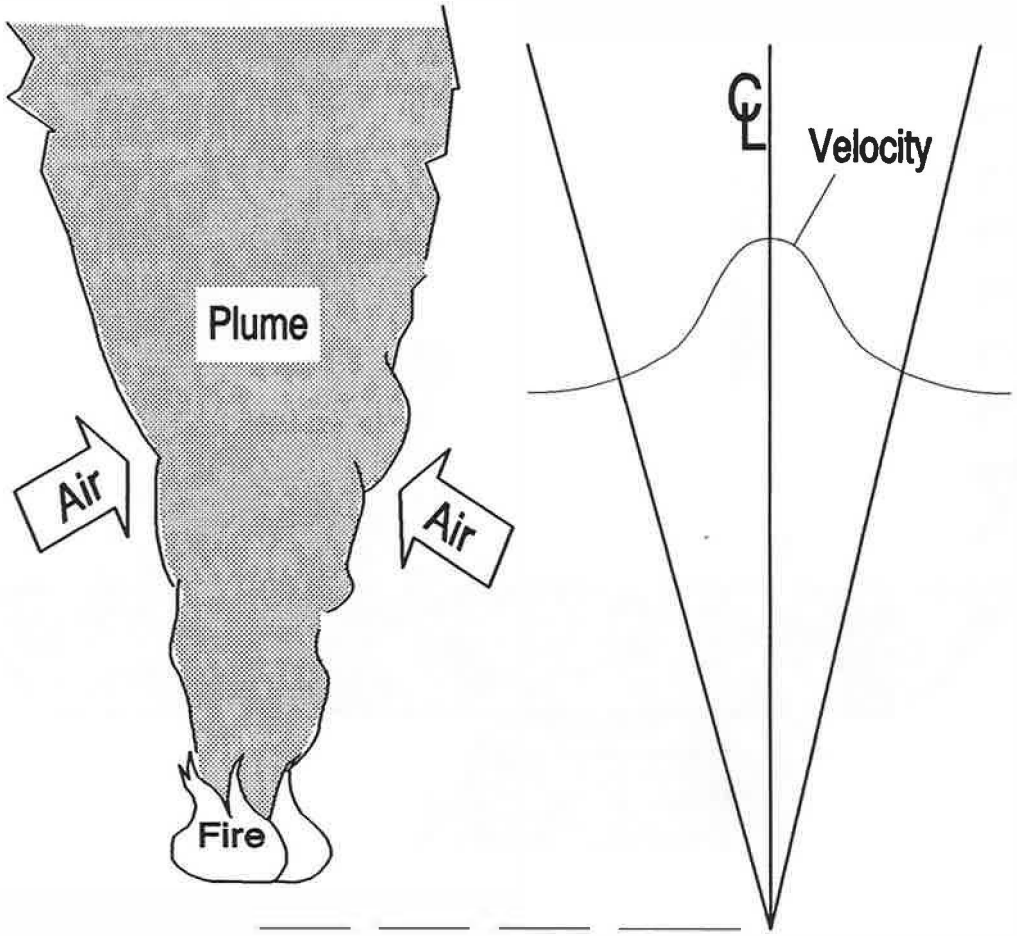
Analysis and Experiments of Elevator Piston Effect

Design Information: ASHRAE Manual

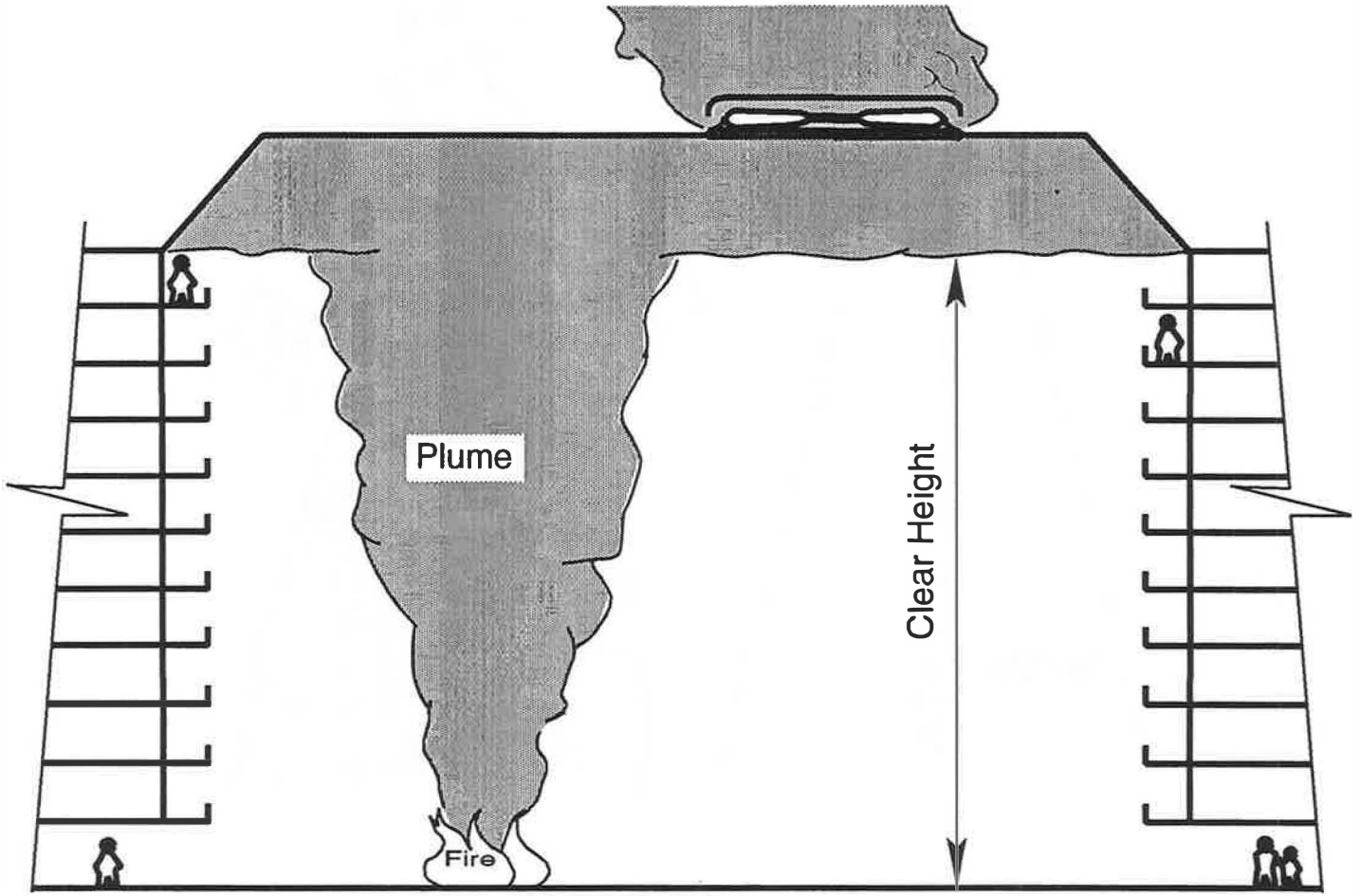
Zoned Smoke Control



Atrium Smoke Control



Atrium Smoke Control



Summary

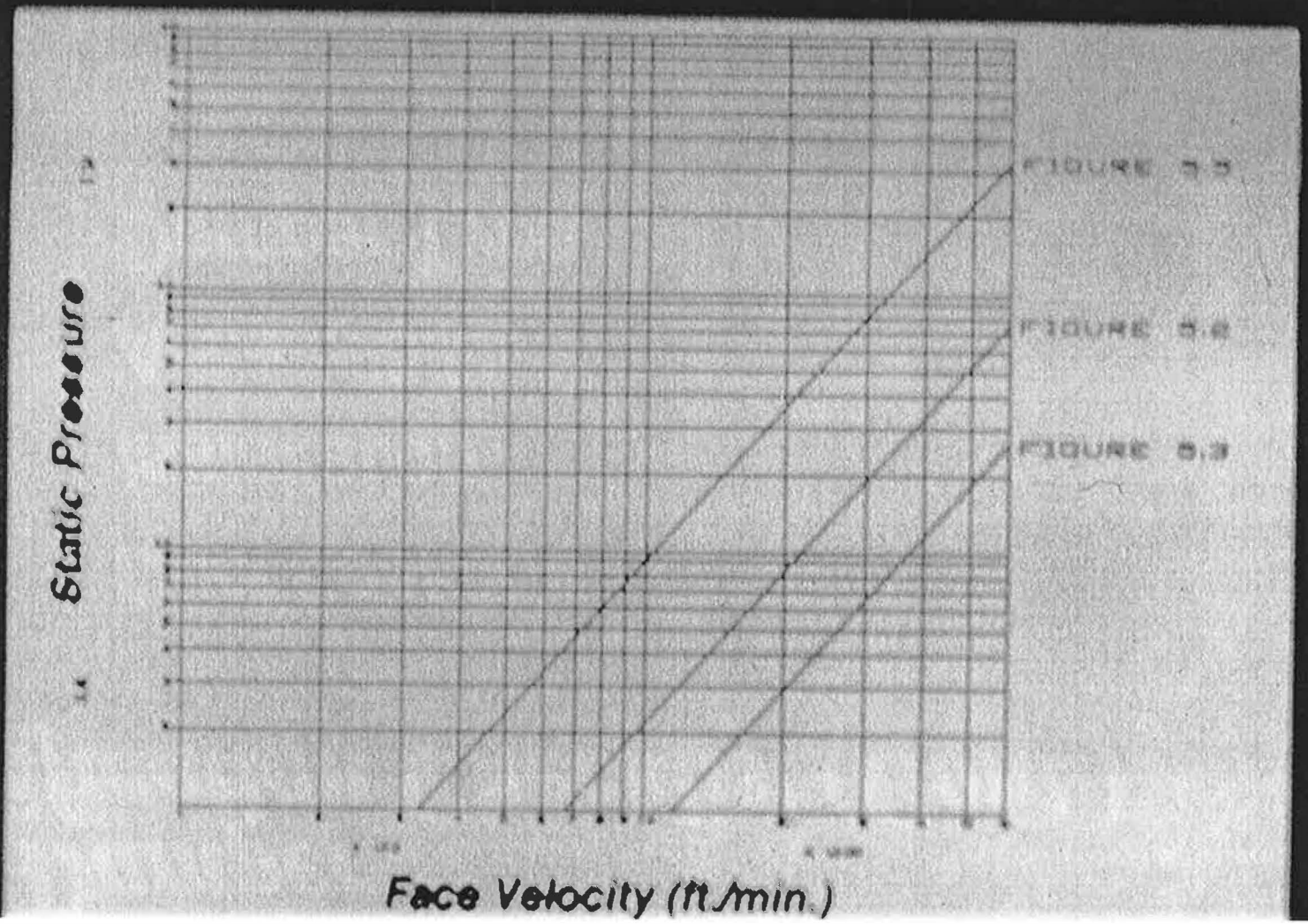
Mechanisms of Smoke Management
- Compartmentation
- Dilution
- Air Flow
- Pressurization
- Buoyancy

Smoke Control Systems
- Stairwell Pressurization
- Elevator Pressurization
- Zoned Smoke Control
- Atrium Exhaust (Really Smoke Management)

Operational Rating

Each smoke damper shall be equipped with an actuator having an operational airflow rating of at least 110% of the maximum design airflow at its installed location. The operational pressure rating for each damper shall be a minimum of 8 in. w.g. Operational airflow ratings shall be for airflow in both directions through the damper.

Pressure Drop Graph



Fire Damper Specification Checklist (Cont.)

- Duct Leakage
- Installation
- Accessibility
- Damper Type

Smoke Damper Specification Checklist

- NFPA 92A&B/UL555S Classified
- Leakage Classification
- Elevated Temperature Rating
- Operational Airflow Rating
- Pressure Loss
- Installation
- Accessibility
- Duct Leakage
- Actuator

Leakage Classification

Smoke dampers shall be UL labeled with a **Class I** leakage rating. (maximum leakage of 4 cfm per sq. ft. @ 1 in. w.g. and 8 cfm per sq. ft. @ 4 in. w.g.)

OR

Smoke dampers shall be UL labeled with a **Class II** leakage rating (maximum leakage of 10 cfm per sq. ft. @ 1 in. w.g. and 20 cfm per sq. ft. @ 4 in. w.g.)

OR

Smoke dampers shall be UL labeled with a **Class III** leakage rating (maximum leakage of 40 cfm per sq. ft. @ 1 in. w.g. and 80 cfm per sq. ft. @ 4 in. w.g.)

Elevated Temperature Rating

Smoke Dampers dampers shall be UL labeled with a Temperature Degradation/Cycling rating of _____ (usually 250 °F, 350 °F or 450 °F).

Closure Temperature

Each fire damper shall be equipped with a **heat responsive device** (e.g. fusible link) which has been tested and **approved for use with the damper** assembly in accordance with UL Standard 555. The heat responsive device shall have a **temperature rating** of _____ (usually 165°F or 212°F)

System Rating

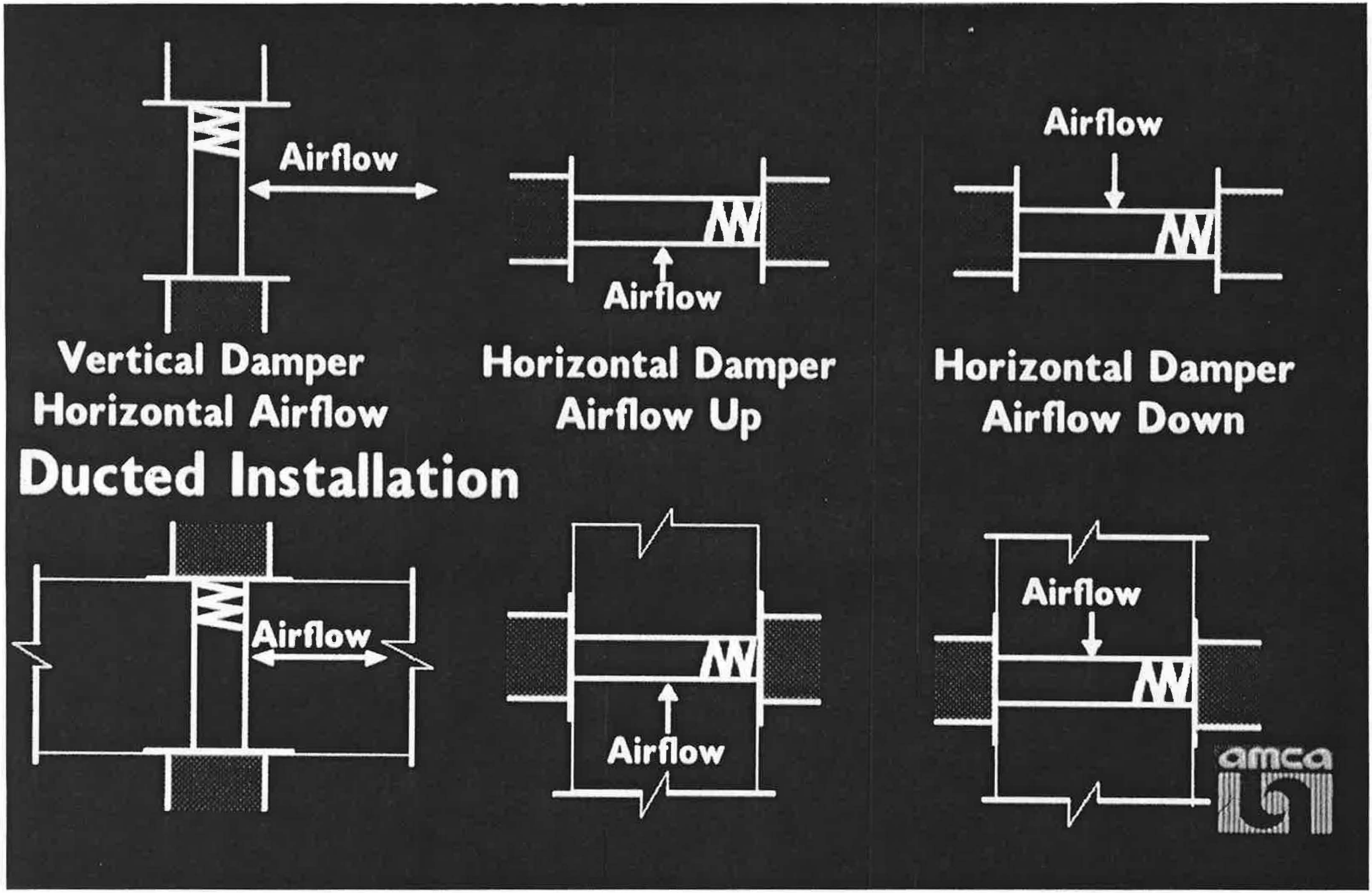
Fire dampers shall be UL labeled for use in **static** systems.

OR

Fire dampers shall be UL labeled for use in **dynamic** systems.

System Rating (Cont.)

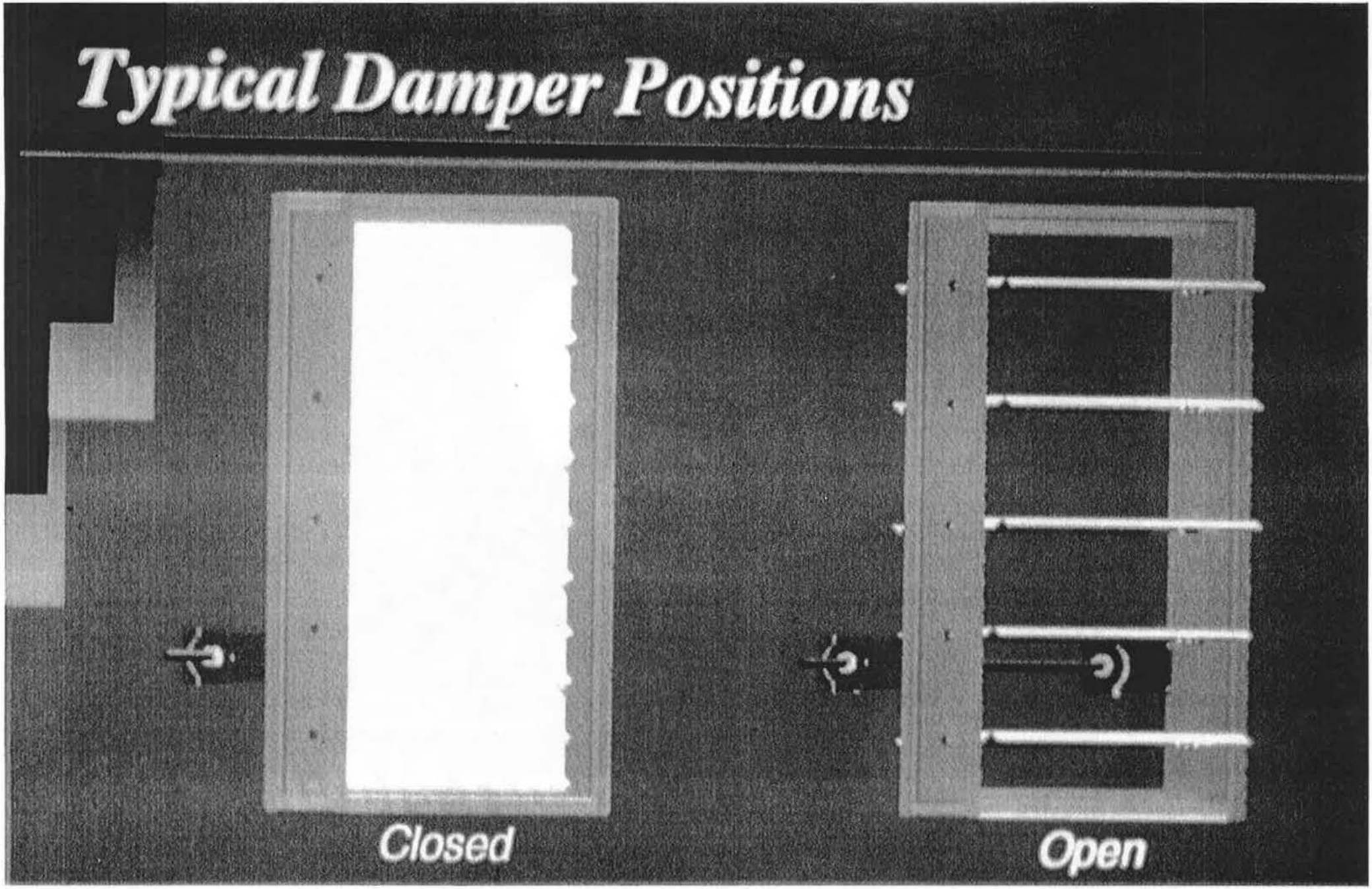
The dynamic closure rating for each damper shall be at least **110%** of the maximum **design airflow** at its installed location. The dynamic closure pressure rating for each damper shall be a minimum of **8 in. w.g.** Ratings shall be for airflow in either direction through the damper.


Airflow
Airflow
Airflow
Vertical Damper
Horizontal Airflow
Horizontal Damper
Airflow Up
Horizontal Damper
Airflow Down
Ducted Installation
Airflow
Airflow
Airflow
amca

Pressure Loss

Manufacturer's submittal information shall include a **graphical representation** of duct velocity vs. pressure drop across the damper. The graphical representation shall include data for a 12x12 damper, 24x24 damper, and 36x36 damper tested in accordance with the latest edition of **AMCA Standard 500** and shall include data for test figures, **5.2, 5.3, and 5.5.**

Mr. Simple Damper Man


Typical Damper Positions
Closed
Open

Fire Damper Specification Checklist

- NFPA 90A/UL555 Classified
- Hourly Fire Rating
- System Rating
- Closure Temperature
- Pressure Loss
- Duct Leakage
- Installation
- Accessibility
- Damper Type

NFPA 90A/UL555 Classified

All fire dampers shall meet the requirements of NFPA 90A and shall be tested, rated and **labeled** in accordance with the latest edition of UL Standard 555. The contractor shall submit the manufacturer's data sheets and **installation instructions** detailing compliance with these specifications.

Hourly Fire Rating

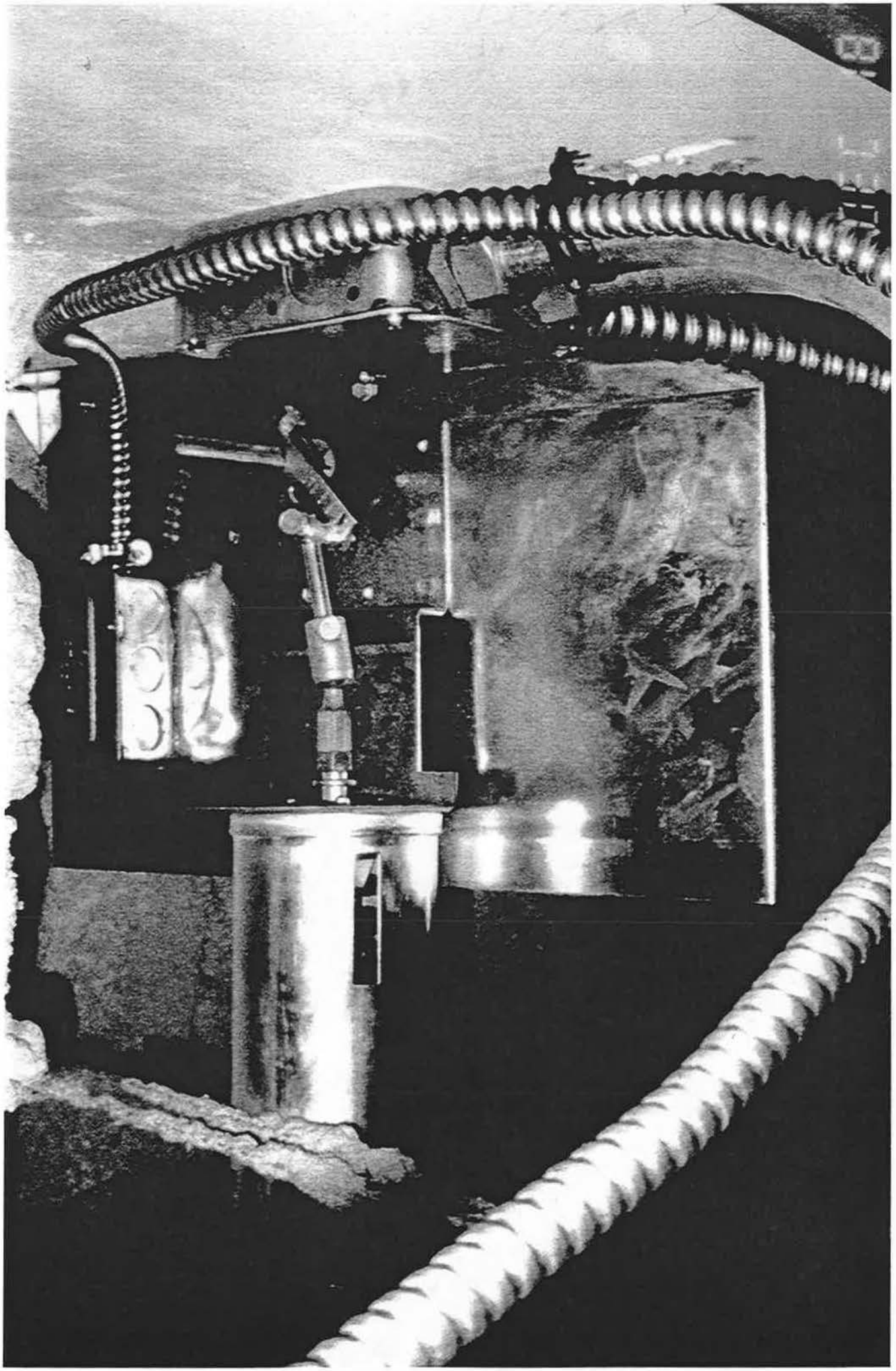
Fire dampers shall be UL labeled with a 1-1/2 hour fire rating.

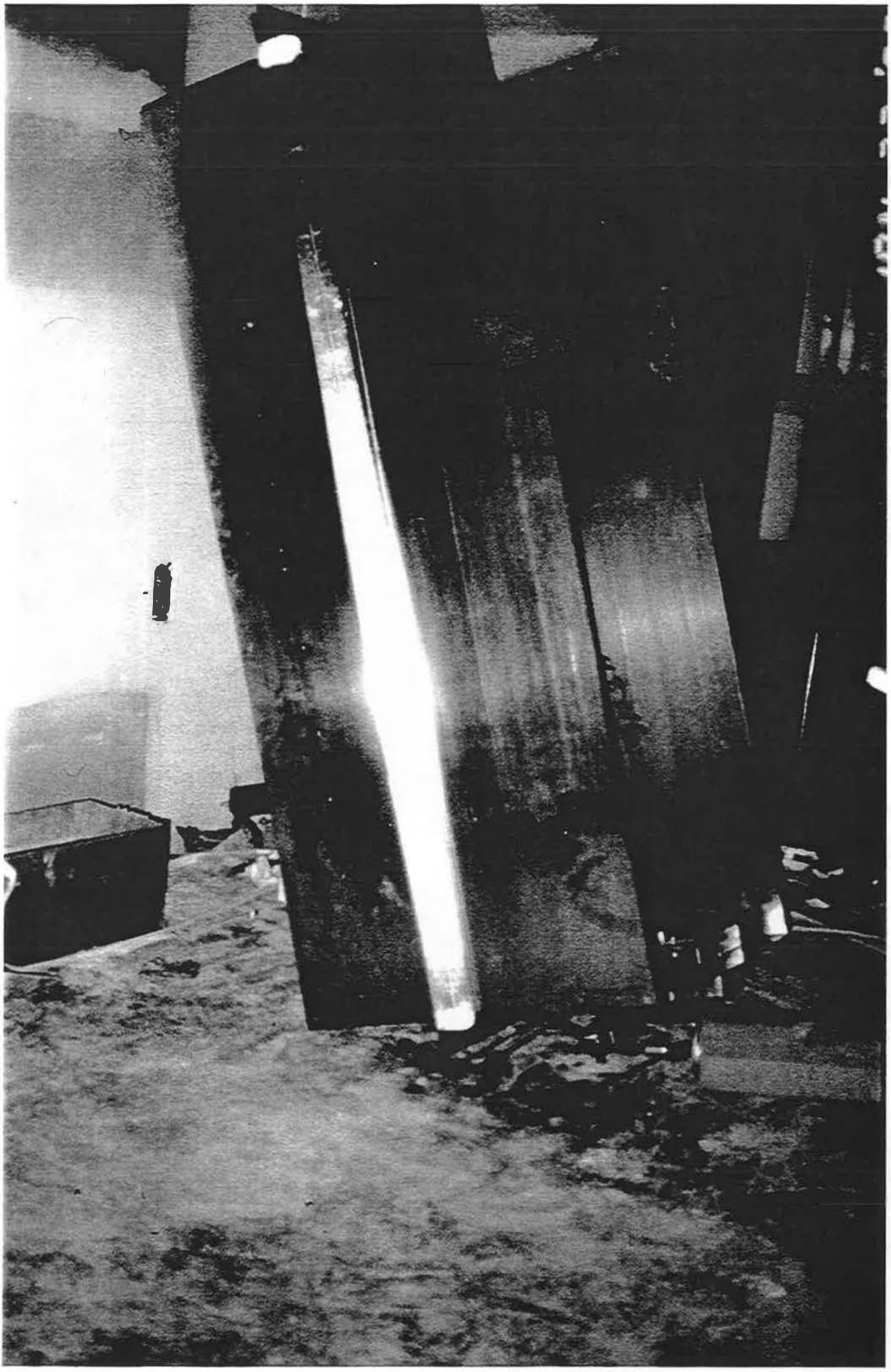
OR

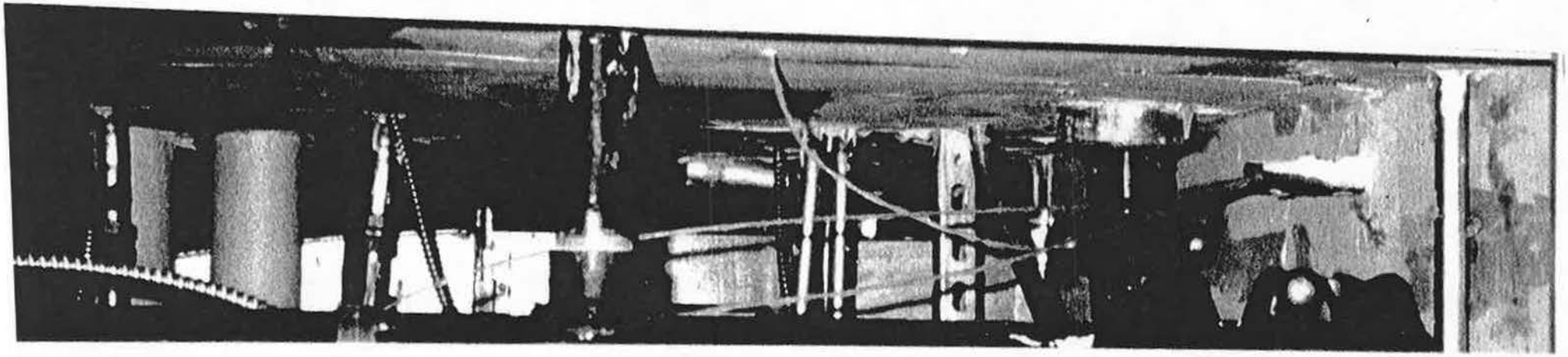
Fire dampers shall be UL labeled with a 3 hour fire rating.

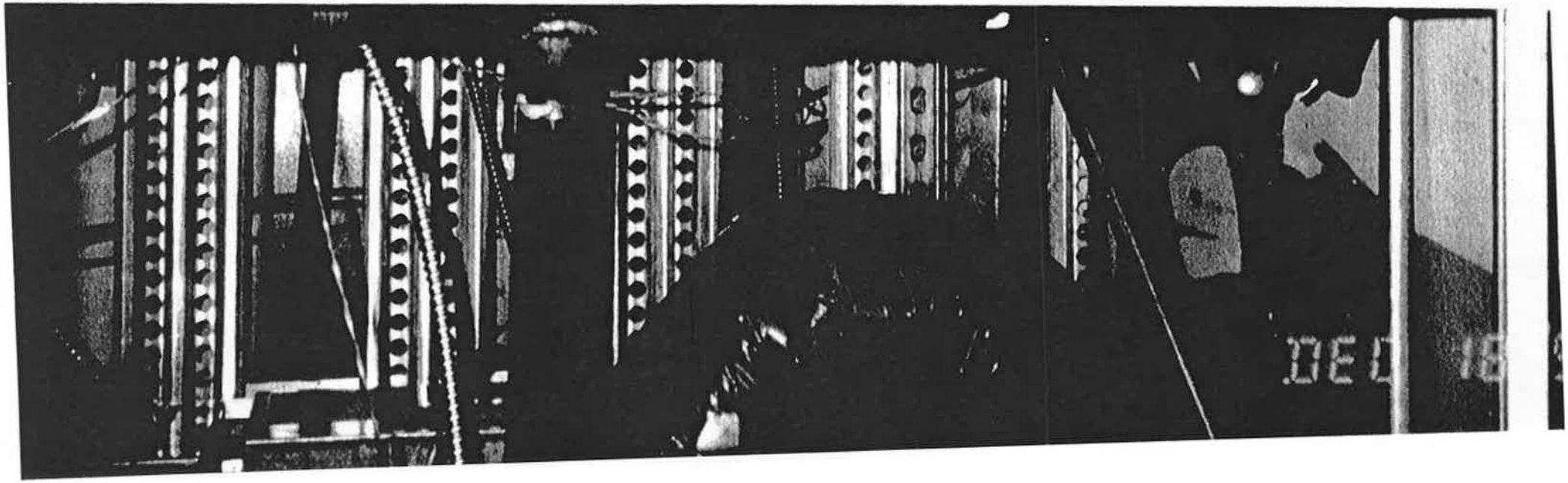
Actuators

Actuators shall be factory installed. Manufacturer's submittal data shall indicate actuator space requirements around the damper.





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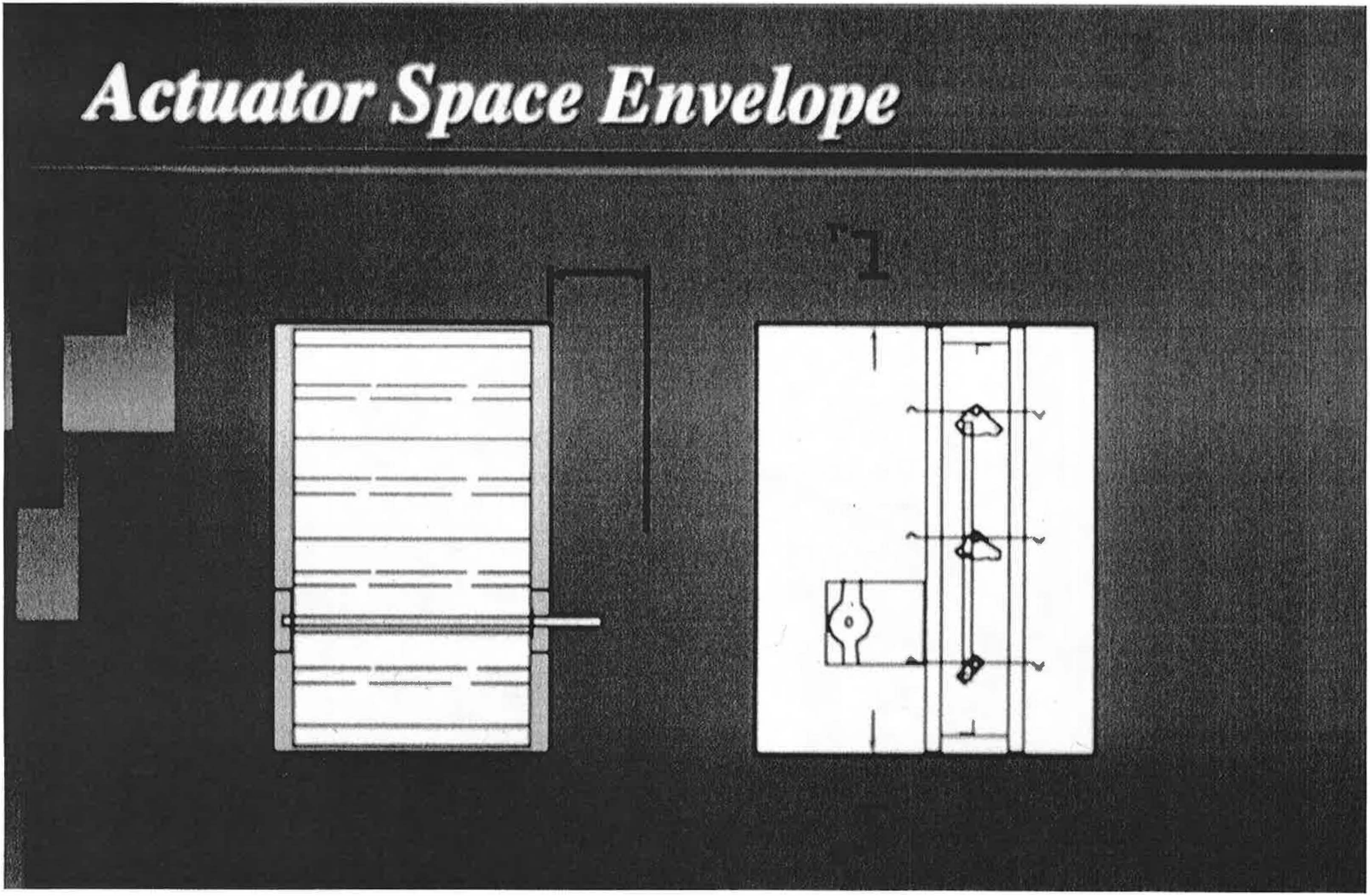
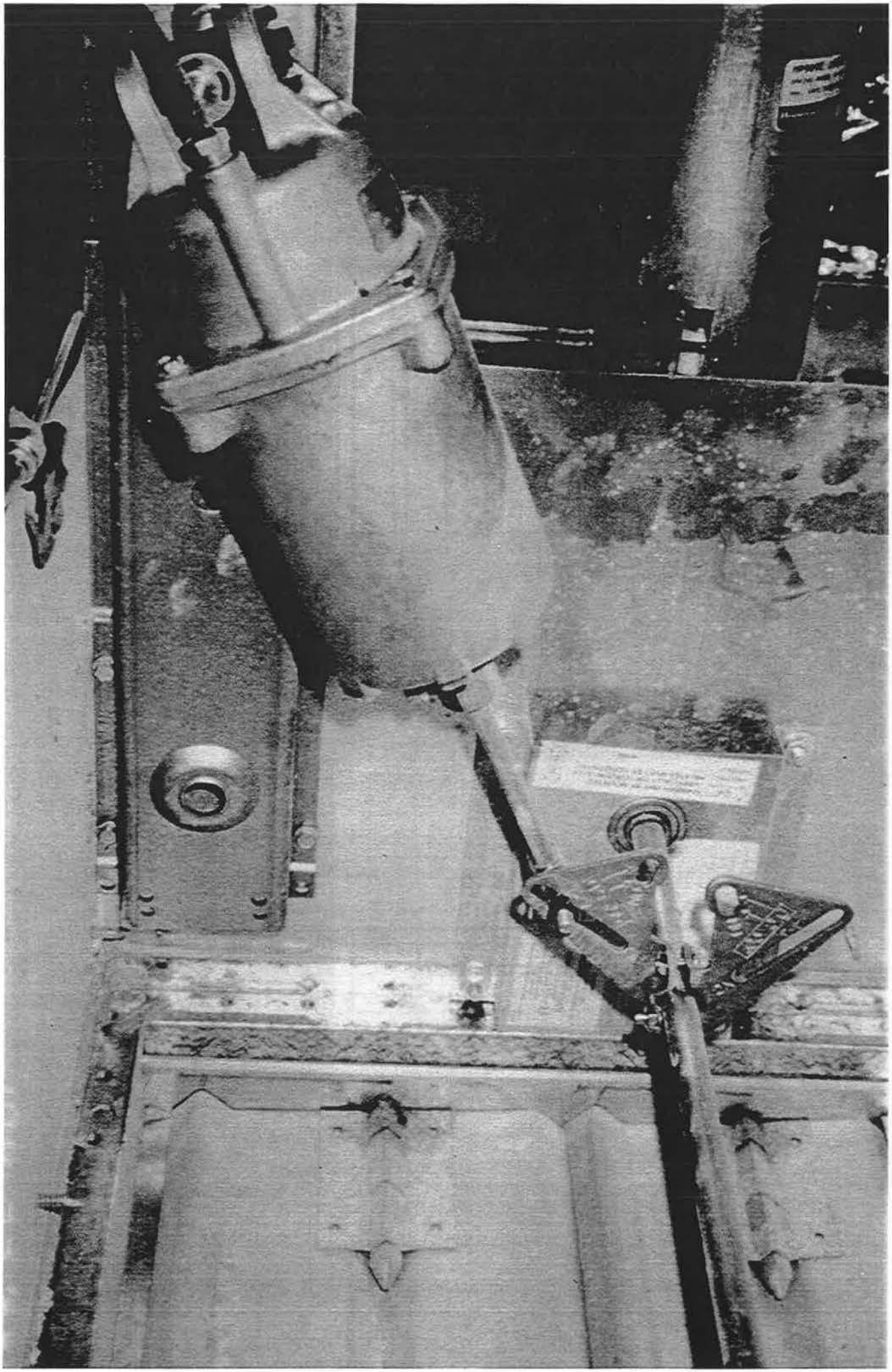
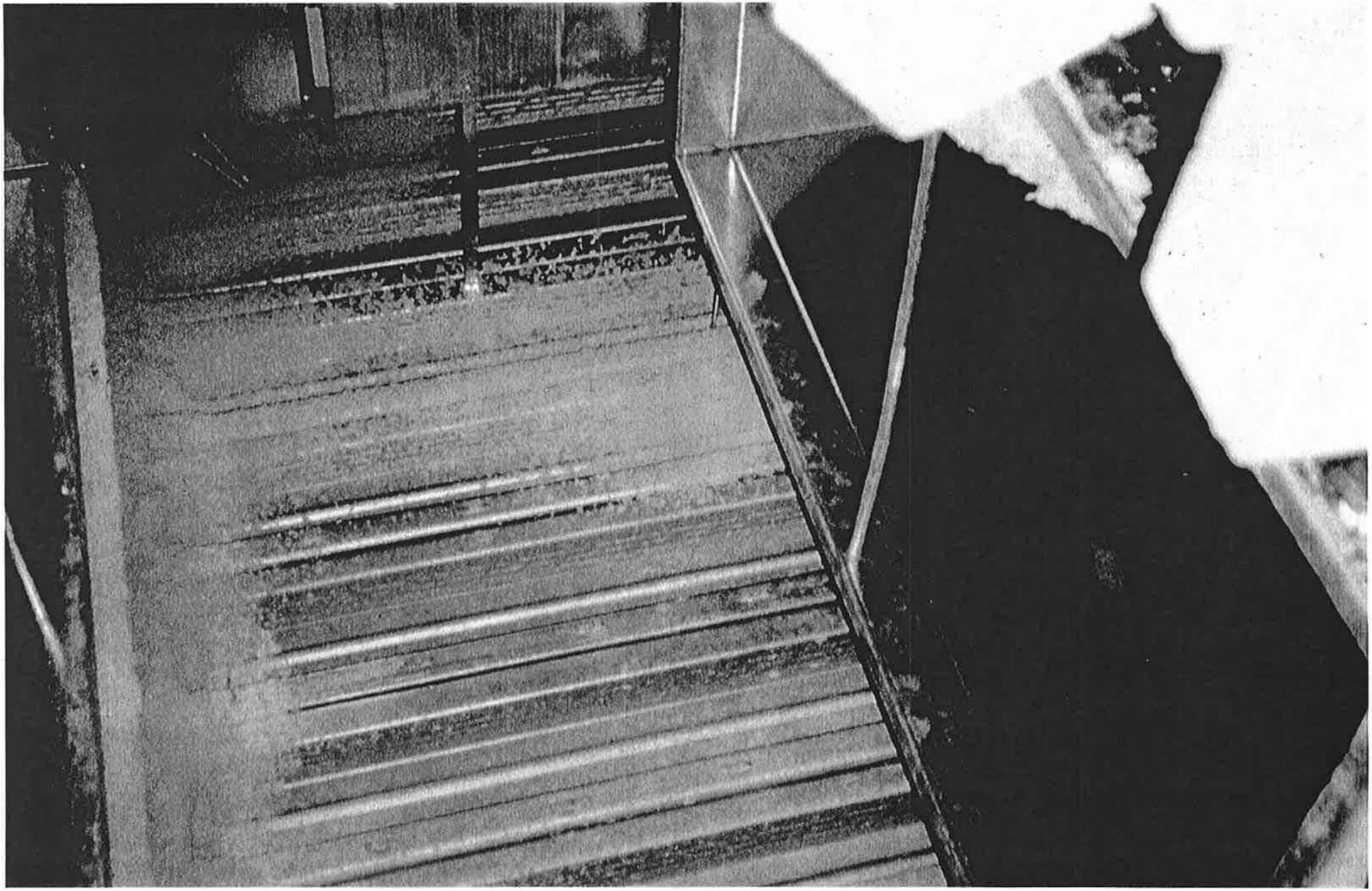
Damper Application Issues

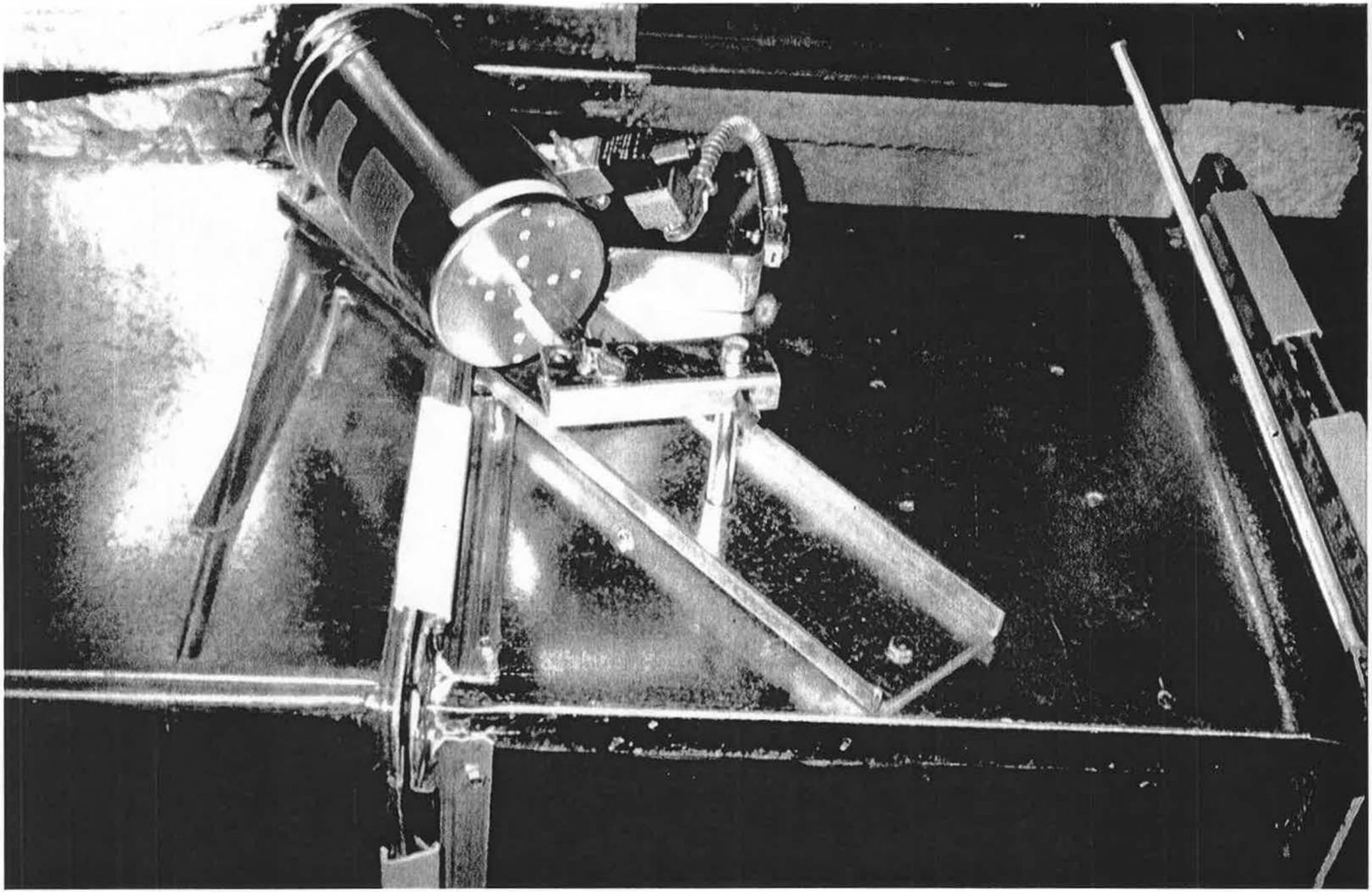
- Fire Damper Specification Checklist
- Smoke Damper Specification Checklist
- Installation Guidelines

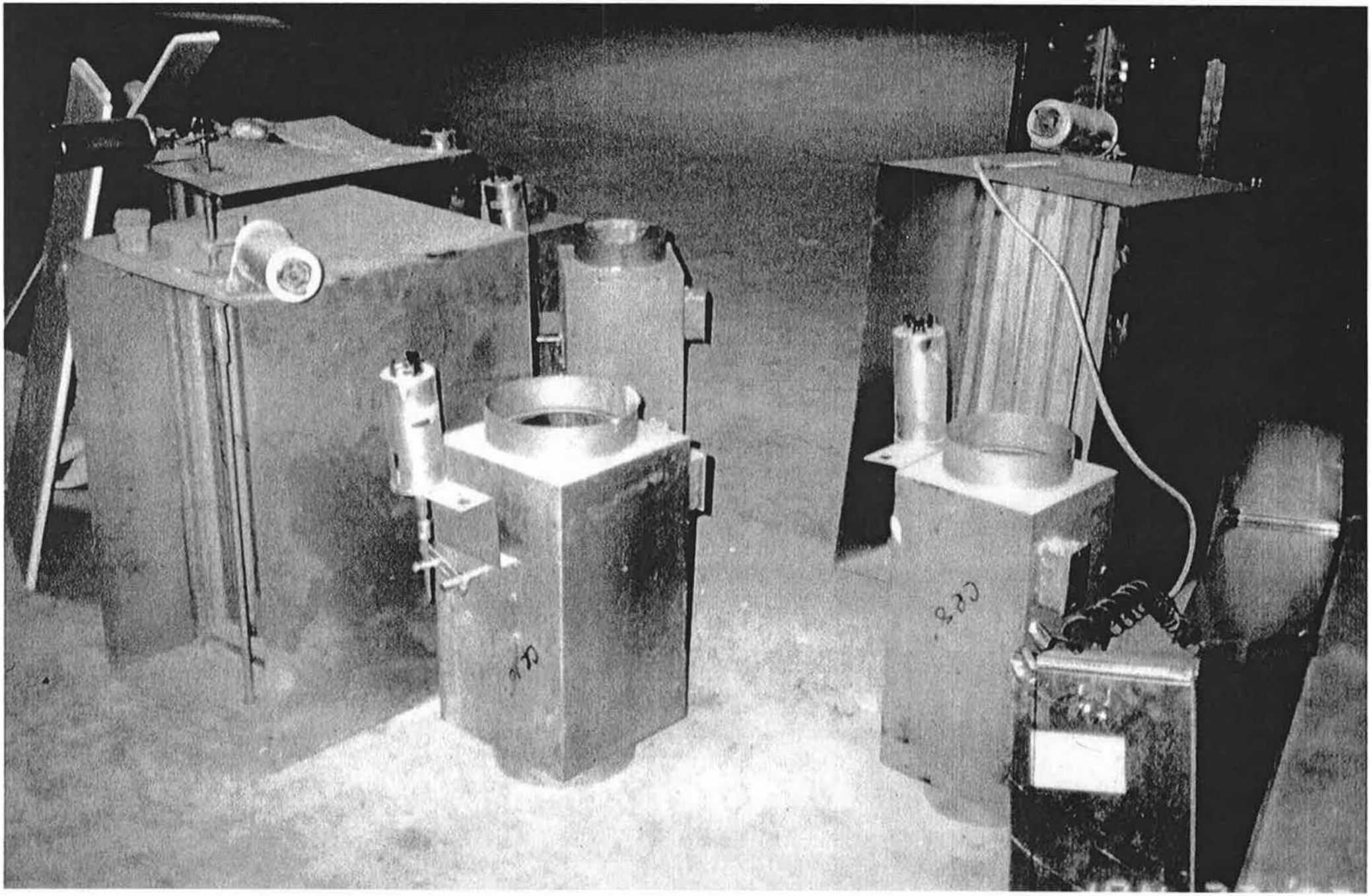
Actuator Space Envelope











Installation Guidelines

- Handling (prior to installation)
- Installation
- Testing

Smoke Control Systems Damper Components (1)

1. PRESSURIZATION - In order of pressure gradients (from negative fire zone):

a. Occupied zones (lowest positive (+) pressure)

b. "Sandwich" areas around fire zone (+),

c. Escape routes (corridors (++), vestibules (+++), stairwells (++++) -- higher as you go out),

c. "Sandwich" areas around fire zones (+), and

d. Refuge areas, disabled persons safety spaces; fire fighters control and staging areas... etc..(++++)

Smoke Control Systems Damper Components (2)

2. Low temperature **PURGING** - while components such as dampers, fans, and detectors still work (at least up to 450°F); in zones that received smoke input in the incipeint stages of the fire prior to the establishment of pressurization differentials -- or as a stand alone mode; e.g., for atria smoke control +.

Smoke Control Systems Damper Components (3)

3. EXHAUST - De-pressurizing the fire zone is as critical as lowering fire temperatures in guaranteeing the success of the "pressure sandwich" and escape route pressurization systems. Some smoke may also be removed. (See ASHRAE Paper No. 3427 (RP559).

In transitioning from 'active' smoke control modes the return or exhaust damper(s) must never close without causing or having the fire room supply dampers closure also -- smoke spread would result.

Smoke Control Systems Damper Components (4)

4. CONTAINMENT - The last stand where the smoke control system damper components that are in the fire barriers around the fire zones are closed to maintain barrier ('passive') integrity, just before their operating ratings (temperature limits) are reached.

This is also a critical fire control (barrier) mode. ('Passive') positive fire pressure is contained by the now passive (no mechanical) fire energy.

Smoke Control Systems Damper Components (5)

5. Smoke PURGING after the fire on a components survivability basis. This is a very slow smoke clearing operation that would have little relativity to pressure dynamics -- dampers would be full open and fans to 100%.

Smoke Control Systems Damper Components (6)

N.B. No fire room return or exhaust damper should close (on elevated temperature) without signaling closure of the fire room supply damper -- or smoke would be spread by positive pressure in the fire room, the initial fire damper operation concept is a critically wrong action as the return/exhaust damper is certianly going to close first if it is fitted with a fire damper heat responsive device.

Smoke Control Systems Damper Components (8)

GENERAL DAMPER OPERATING TEMPERATURES PER SYSTEMS MODES (& STATUS)

Ambient (active)	**Pressurization& Purge**
Low Temp. (Ambient - 450°F)(active)	**Exhaust & Pressurization**
Medium Temp. (450°F - 850°F)	**(Passive) Smoke (& Fire) Containment**
High Temp. (850°F - 2000°F)	**Fire Containment (& Smoke Per ISO)**

The damper designer/Manufacturers goal would be that one combination air/smoke/fire damper design would handle all the above performance parameters in all of the systems modes of operation.

Smoke Control Systems Damper Components (7)

General Damper Design Criteria as to Smoke Systems Requirements:

A) Ambient - 450°F 'active' smoke system modes operation/actuation (fans, & etc., on) cycling capability.

B) 450°F - 850°F 'passive' smoke & fire containment.

C) To 2000°F fire barrier (tighter seals to meet ISO (Internaltional) Standards).

D) 8" W.G. (ambient) systems supply pressures & 4" systems return pressures cycling & leakage tests.

E) (Pressurization) leakage rates (ambient) of 170 CFM/FT² supplies, and 120 CFM/FT² returns -- Class IV.

F) 32" W.G. transient pressure closure (rapid) possiblity -- or 'spike' precluded by 3 second minimum closure.

G) 2000-5000 FPM system ambient flows.

H) 3000-7000 FPM heat expanded flows.

I) .5" W.G. sprinklered & unsprinklered fire room ('passive') pressure.

J) 28 CFM/FT², Class III 'passive' leakage.

K) 1/16"/FT at full fire heated blade expansion - while maintaining leakage rated performances to 'active' and passive requirements.

L) 15 second closure and 90 second opening cycle time.

M) 25 LB.IN./FT² operating torque.

N) G90 corrosion resistance (or other specific atmosphere) exposure & cycling.

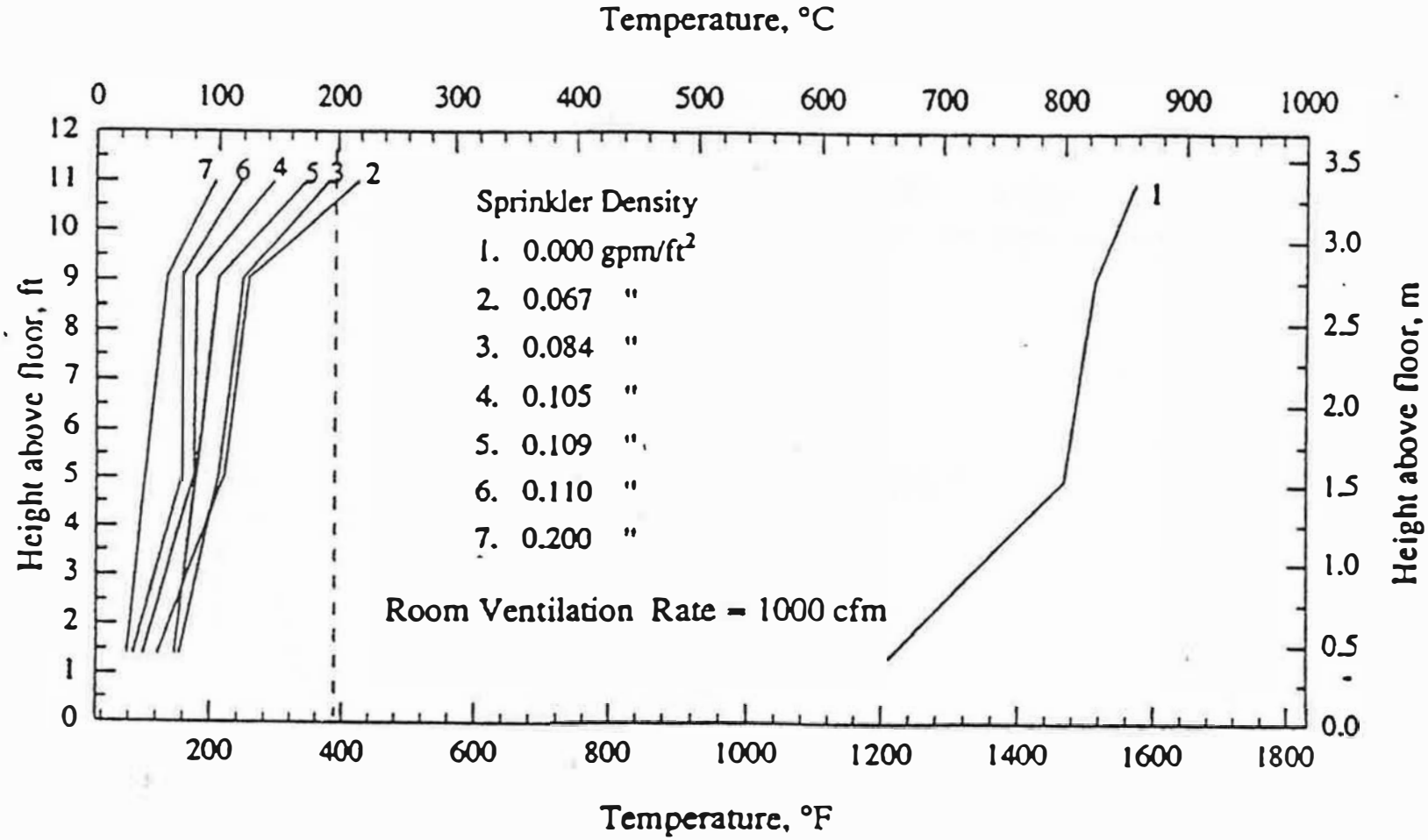


Figure 6 *Temperature profiles at north thermocouple tree in the one-story test room for different spray application rates, for ventilation rate of 1,000 cfm (0.42 m^3/s).*

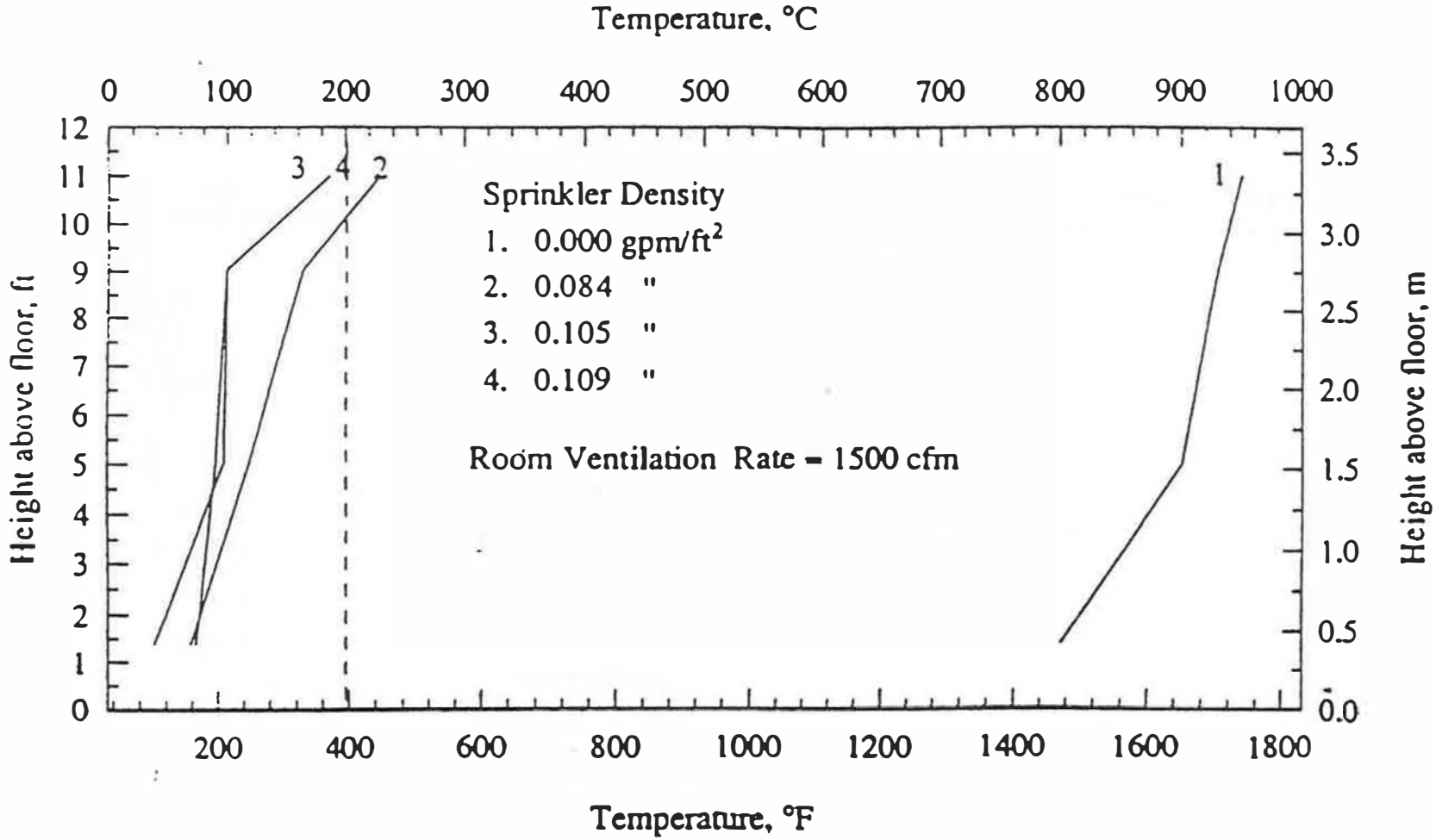


Figure 7 *Temperature profiles at north thermocouple tree in the one-story test room for different spray application rates, for ventilation rate of 1,500 cfm (0.63 m^3/s).*

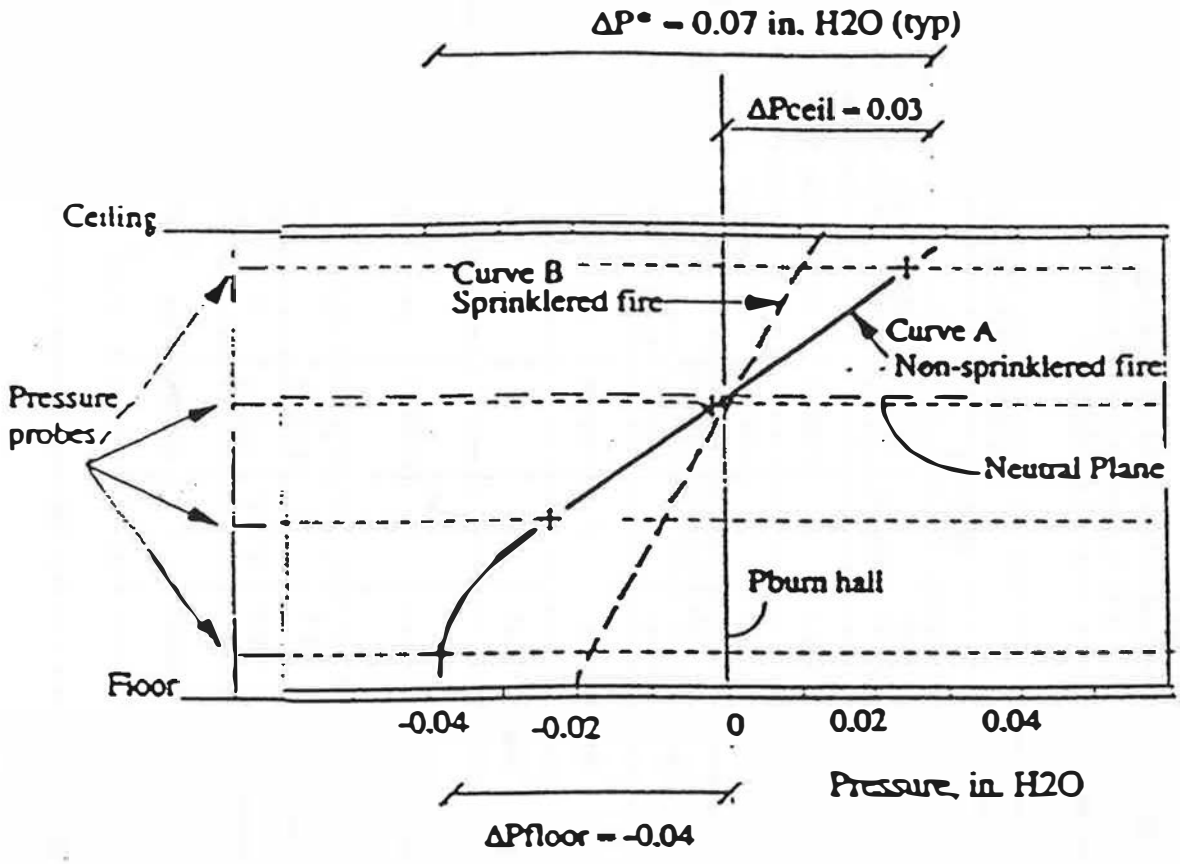


Figure 8 *Typical pressure profiles in the one-story test room for a sprinklered and a nonsprinklered fire.*

TABLE 1
SMOKE SYSTEMS FUNCTIONS WITH DAMPER POSITIONS AND REQUIRMENTS
VIS-A-VIS Amb. - 450° Active, 450° - 850° Passive (to 2000° Fire under ISO)
(Needs full development by ASHRAE TG5.SMC)

SMOKE SYSTEMS FUNCTIONS / SITUATION (See Figure 1)					DAMPER POSITION			DAMPER PERFORMANCE REQUIREMENTS								
								SUPPLY				EXHAUST Note (1)				
FUNCTION	ZONE	PHASE	CONTROL	ZONE TEMP-ERATURE	SUPPLY	DEDICATED VENT NOTE (2)	EXHAUST	TEMP-ERATURE	SYSTEM PRESSURE	VELOCITY/ LEAKAGE AT DAMPER	LEAKAGE PRESSURE	TEMP-ERATURE	SYSTEM PRESSURE	VELOCITY/ LEAKAGE Note (3)	LEAKAGE PRESSURE Note (4)	TRANSIENT PRESSURE 32° Pos.
PRESSURIZATION (FULL BUILDING)	"A" (Non-Fire No Smoke)	-	Automatic	Ambient	Open	Closed	Closed	Ambient	8"	2-5000FPM	N/A	Ambient	-3"	2/ 120CFM/FT²	4"	DATA
PRESSURIZATION (SANDWICH ONLY)	"A" (Non-Fire No Smoke)	Adj. to C1 & C2	Automatic with Fire Fighter Supervision	Ambient to 450°F	Open	Closed	Closed	Ambient	8"	2-5000FPM	N/A	450°F	-2"	3/ 120CFM/FT²	4"	
PRESSURIZATION (STAIRWELL)	"A" (Non-Fire No Smoke)	-	Automatic	Ambient	Open with pressure set	Controlled to set pressure	Closed	PRESSURE SET OPTIONAL				PRESSURE RELEASE OPTIONAL				DEVELOPMENT
								Ambient	0.8"	1-5000FPM	Set .04-0.45	Ambient	Set .04-0.45	Set .04-.45"	N/A	
PURGE (AIR CHANGES)	"B" (Non-Fire With Smoke)	-	Fire Fighter Control - Maintain Positive Pressure	Ambient to 450°F	Open	Open	Open	Ambient	8"	2-5000FPM	N/A	450°F	-3"	3-7000FPM	N/A	
EXHAUST	"A" (Non-Fire No Smoke)	C1	Automatic with Fire Fighter Supervision	Ambient to 450°F	Closed Note (2)	Open	Open	Ambient	-3"		4"	450°F	-2"	3-7000FPM	N/A	
PURGE (AIR CHANGES) NOTE (3)	"C"Fire Zone	C1	Before 450°F (Automatic and/or with Fire Fighter Supervision-Maintain Negative Pressure	Ambient to 450°F	Open	Open	Open	Ambient	8"	2-5000FPM	N/A	450°F	-2"	3-7000FPM	N/A	
CONTAINMENT NOTES (5) & (6)	"C"Fire Zone	C2	Automatic	450°F to 2000°F	Closed	Closed (or Open By Fire or Supervision)	Closed	450°F	8"	170/ 28CFM/FT²	8"	450°F	-2"	3/ 120CFM/FT²	4"	-GOING
								2000°F	0.2" or .03"	/ 12CFM/FT²	.5"	850°F (or 2000°F ISO)		1/ 200CFM/FT²	.5"	
PURGE (RE-OPEN FOR AIR CHANGES) NOTE (7)	"C"Fire Zone	C3	Under 150°F (Fire Fighter Supervision Recommended	Below 150°F	Open	Open	Open	Ambient	8"	2-5000FPM	N/A	Ambient	-3"	2-5000FPM	N/A	Note (8)

NOTES:
(1) Some codes require that supply air continues to flow into the fire zone, for cooling, during the exhaust mode (Max. 50% of exhaust ambient volume capabilities essential to maintain negative pressure in the fire zone).
(2) Venting is a design alternate covered by NFPA 92A & 204M.
(3) The test leakage rates based on ambient Class III 1" @ 40CFM/FT² as converted from (elevated) temperature & .5 pressure requirements and Class IV (or greater for ambient pressurization) 8" & 4" supply and return requirements).
(4) The main leakage requirement is when pressurization is lost and the damper must act as part of the physical baarrier system around the fire zone for containment. This function could be called 'passive' (leakage) smoke control; and leakage tested to 450°F (min), (0.2" W.G. unsprinklered and .03 sprinklered fire room conditions) @ 0.5" W.G.
(5) It is probable that, with most sprinklers & fire fighter suppression the only damper position change will be automatic closure for containment from the initial fire and smoke locations damper settings.
(6) Closure for containment must have synchronous closure of supply with return damper while pressurization is 'active' to avoid accidental smoke spread.
(7) This re-open function is on an assumed component survivability basis.
(8) Transient pressures may be eliminated as a problem by requiring a minimum closure time of 3 seconds.
(9) Damper operating times need development as to system modes need with economics considered.

SMOKE MANAGEMENT SYSTEM DESIGN - WHERE TO START

by

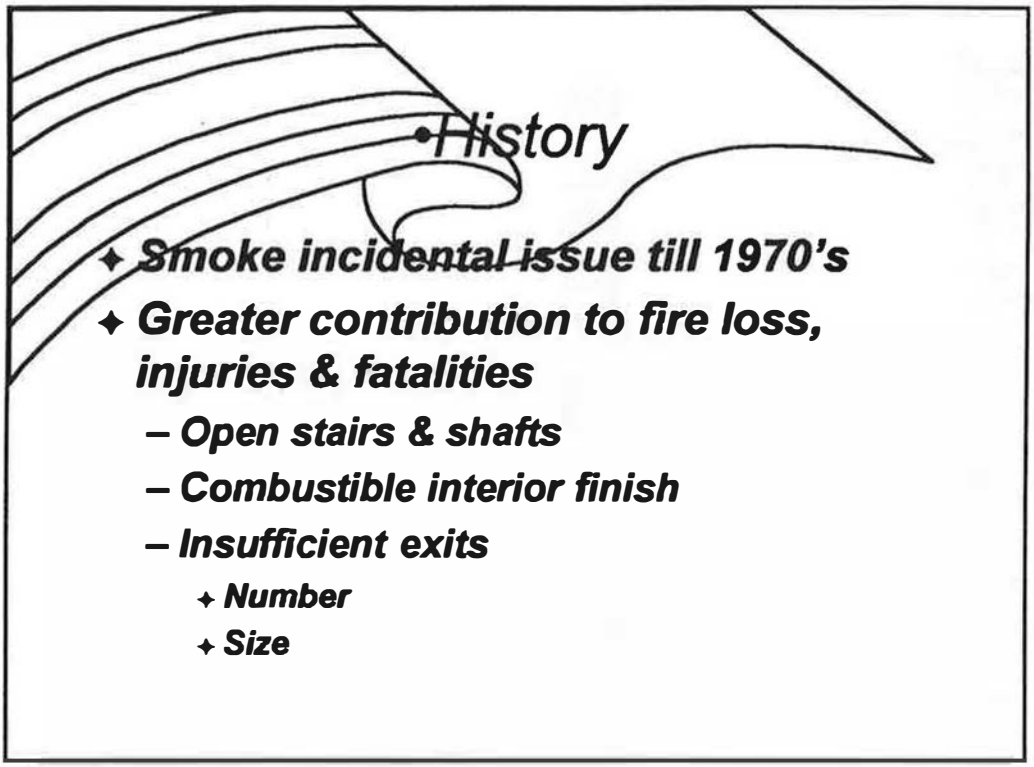
William A Webb, PE

Rolf Jensen & Associates, Inc.

Atlanta - Feb 19, 1996

History

- ***Smoke incidental issue till 1970's***
- ***Greater contribution to fire loss, injuries & fatalities***
  - ***Open stairs & shafts***
  - ***Combustible interior finish***
  - ***Insufficient exits***
    - ***Number***
    - ***Size***



Development of codes

Save the city-prevent conflagration

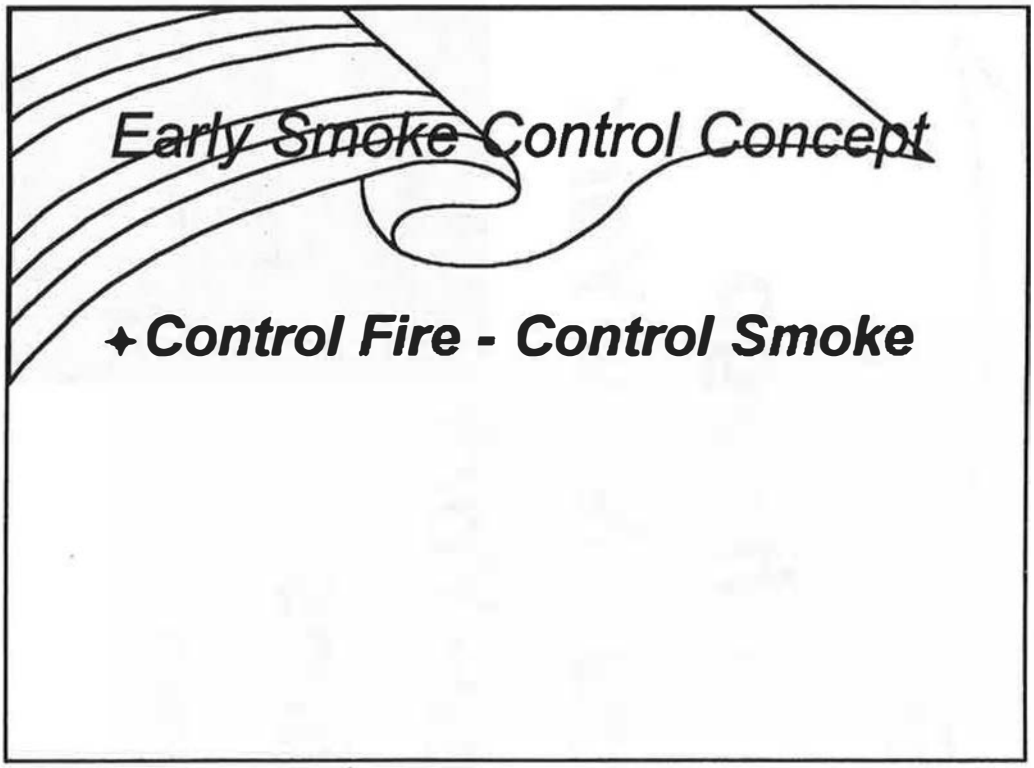
Save the building

Save the floor

Save the life

Smoke not an issue till set goal to save the floor

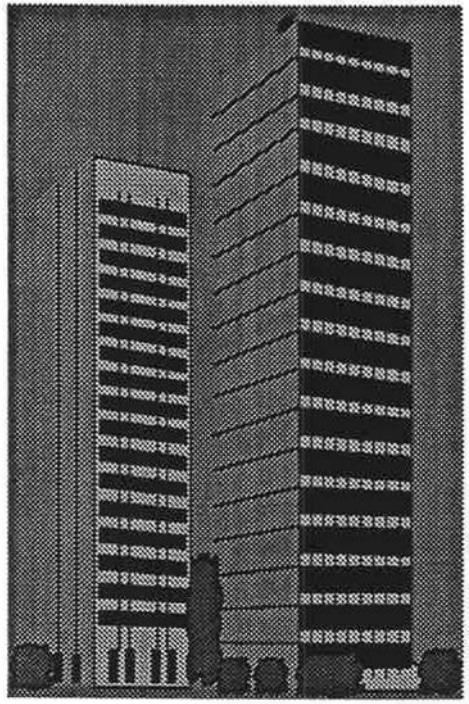
- ***Control Fire - Control Smoke***



Many still advocate this as the most effective strategy

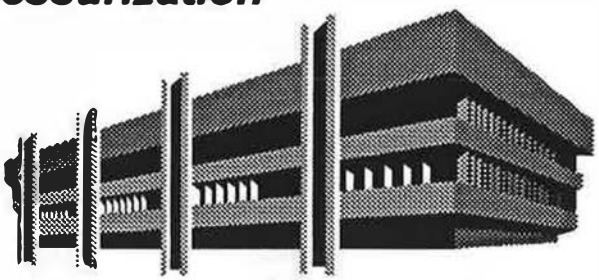
What Changed in the 1970's - Hi Rise

- ***Hawthorne House - Chicago***
- ***One New York Plaza - New York***
- ***919 Third Ave - New York***
- ***1969 - 10 Hi-Rise fires***
- ***1970 - 9 Hi-Rise fires***



What Were the Results

- NYC LL5 - 1973
- Smoke control concepts proliferated in codes
  - Stair pressurization
  - Malls
  - Atria



LL5 had many features in addition to smoke control.

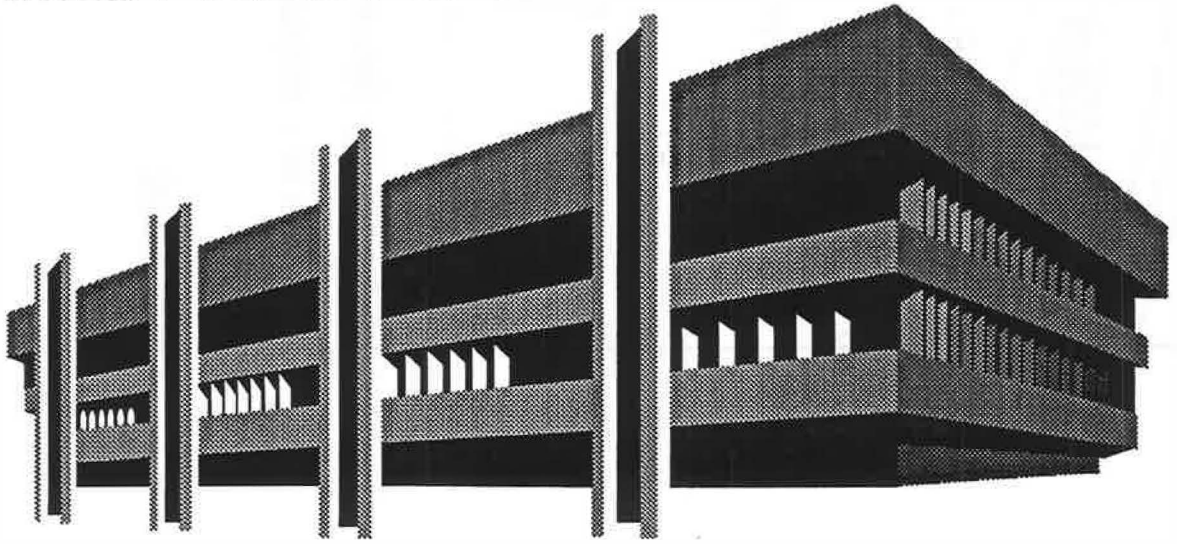
Sprinklers or compartmentation

New	Existing
Smokeshaft	Smokeshaft
	or
	Pressurized stair

No smokeshaft, pressurized stair or compartmentation w/AS

What Were the Results

- ***NYC LL5 - 1973***
- ***Smoke control concepts proliferated in codes***
  - ***Stair pressurization***
  - ***Malls***
  - ***Atria***



Early Smoke Control Concepts

- ***Shutdown HVAC***
- ***Vent thru panels or windows or shafts***
- ***Stair pressurization - LL5 tests***
- ***Pressure sandwich***
- ***Exhaust - air change rate***

Exhaust - Air Change Rate

- ***Sprinklers for fire control***
- ***Maximum use of normal HVAC***

ASHRAE Smoke Control Manual

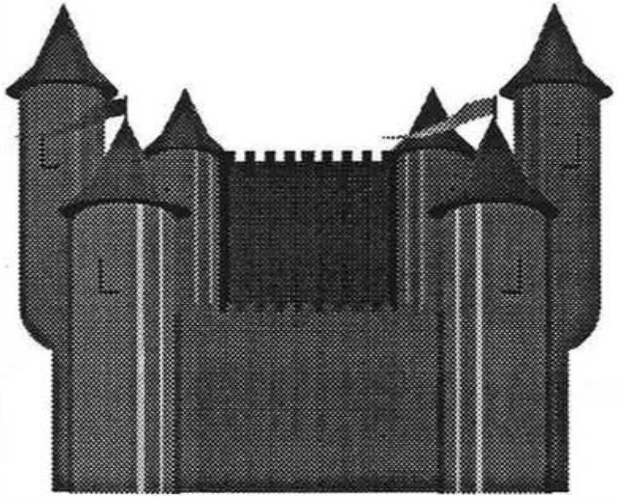
- ***Stair pressurization***
- ***Zoned smoke control***
- ***ASCOS***

Recent Developments

- ***NFPA Smoke Management Systems Committee***
  - ***NFPA 92A - Recommended Practice for Smoke-Control Systems***
  - ***NFPA 92B - Guide for Smoke management Systems in Malls, Atria, and Large Areas***
- ***ASHRAE/SFPE Design of Smoke Management Systems***

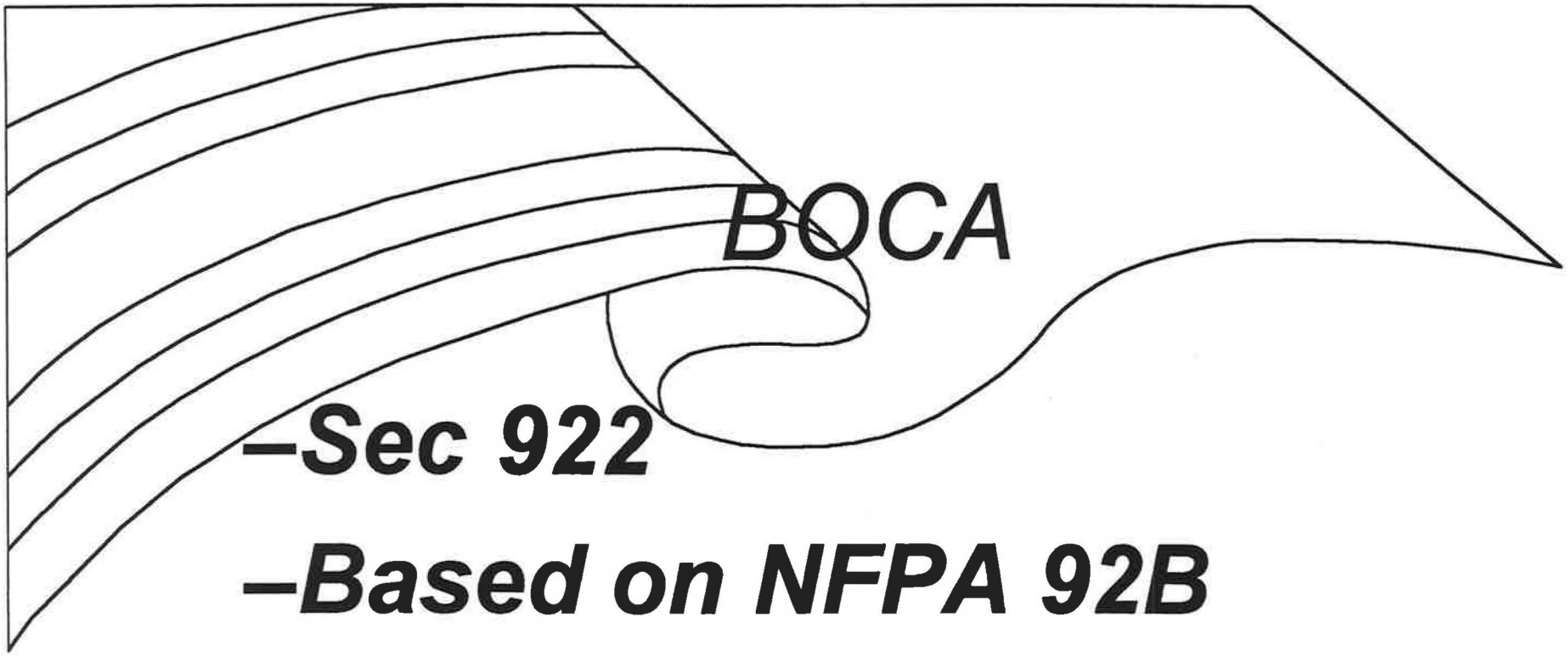
Codes

- ***Smoke management in 3 general areas***
  - ***Stair pressurization/smokeproof towers***
  - ***Hi-Rise***
  - ***Large areas***
    - ***Malls***
    - ***Stadia***
    - ***Atria***



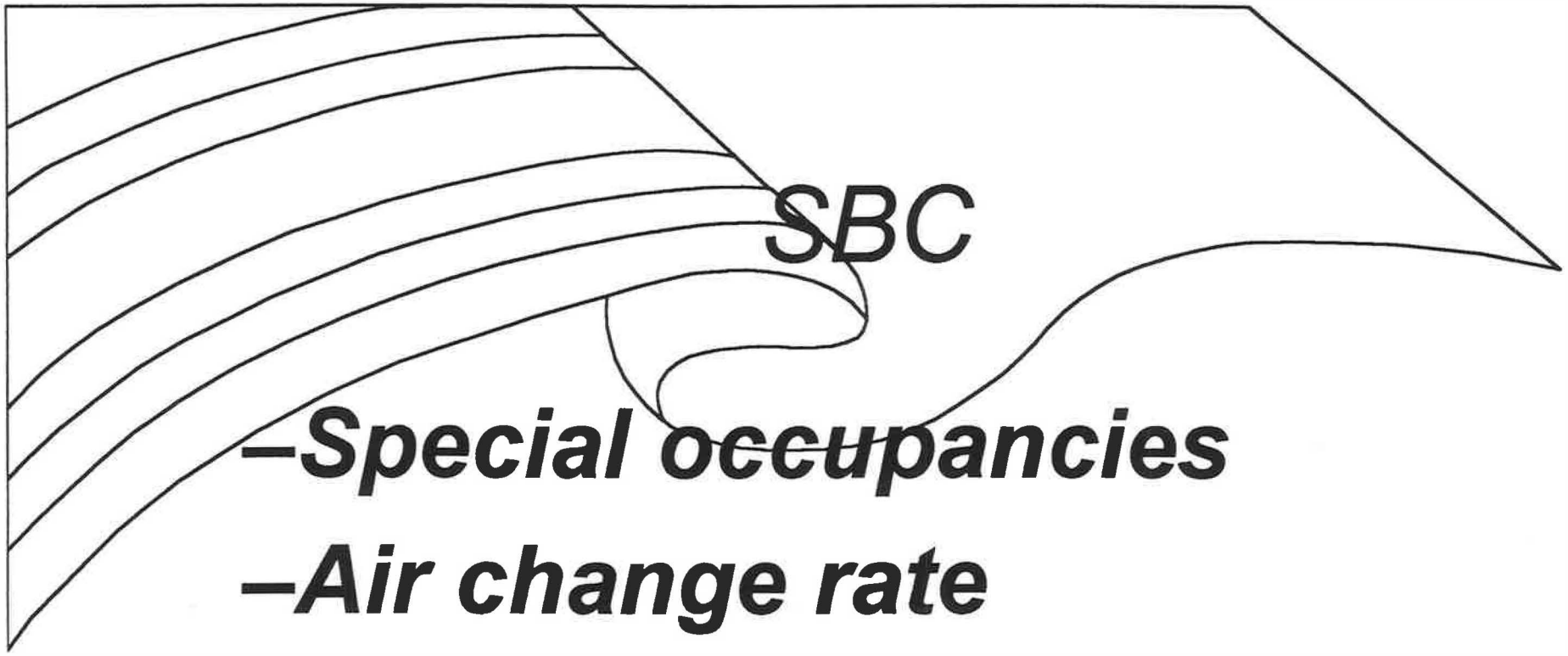
Model Codes

- ***BOCA***
- ***SBC***
- ***UBC***



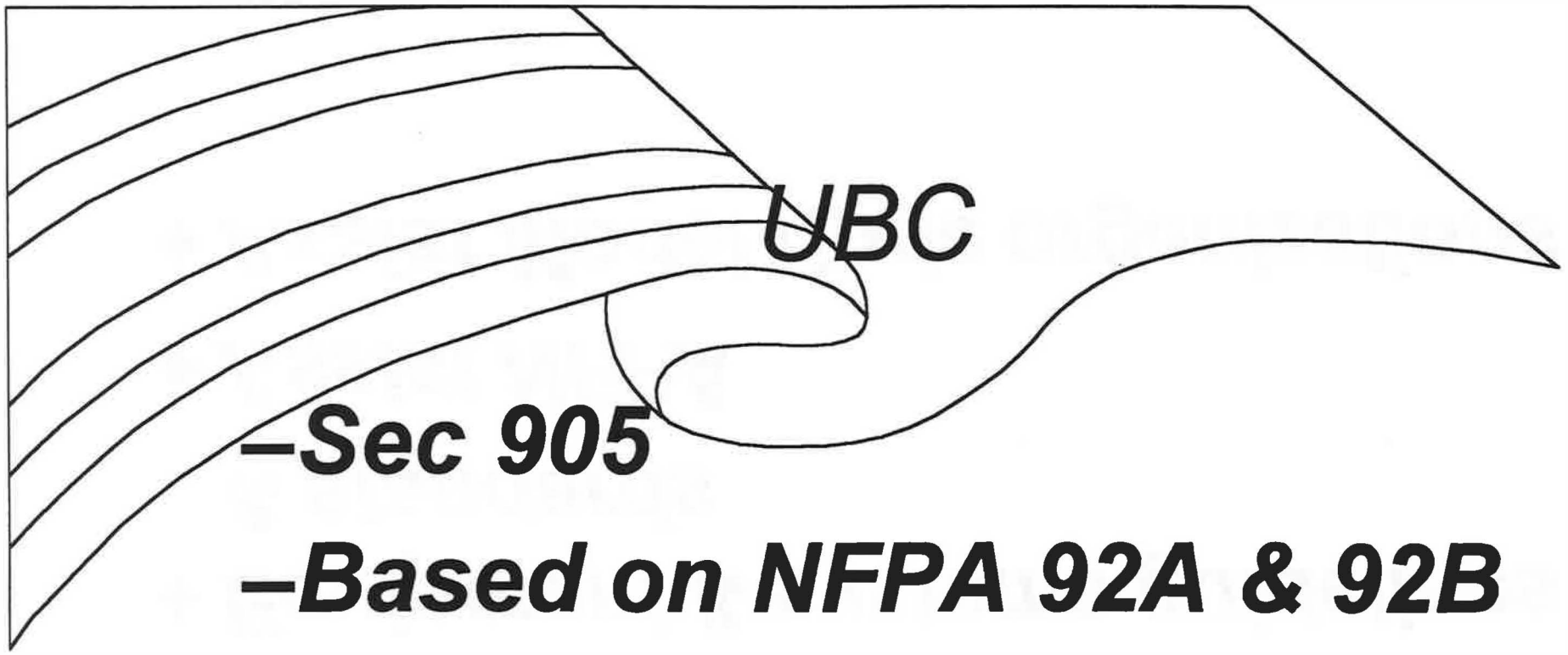
–Sec 922

–Based on NFPA 92B



–Special occupancies

–Air change rate



- ***Sec 905***
- ***Based on NFPA 92A & 92B***
- ***Based on ASHRAE Guideline 5, Commissioning Smoke Management Systems***

ASHRAE's Role

- ***Scientific basis***
- ***Research***
- ***Equipment & systems guidelines & standards***
- ***Assist NFPA***
- ***Assist Model Code organizations***

Smoke Control System:

- Engineered System
- Mechanical Fans
- Airflow
- Pressure Differences
- Across Barriers

Smoke Management System:

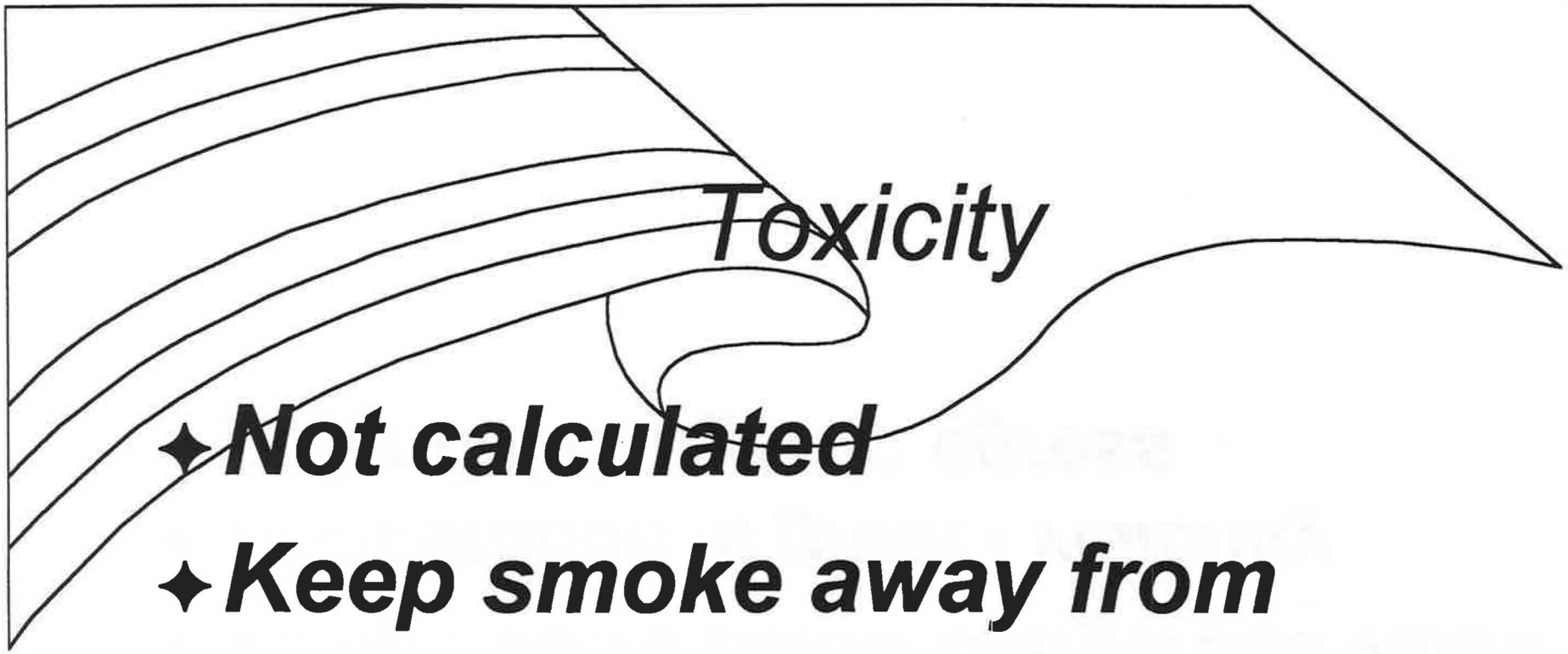
- Engineered System
- Modify Smoke Movement

Smoke Control - What & When

- ***Stair pressurization***
- ***Compartmented spaces***

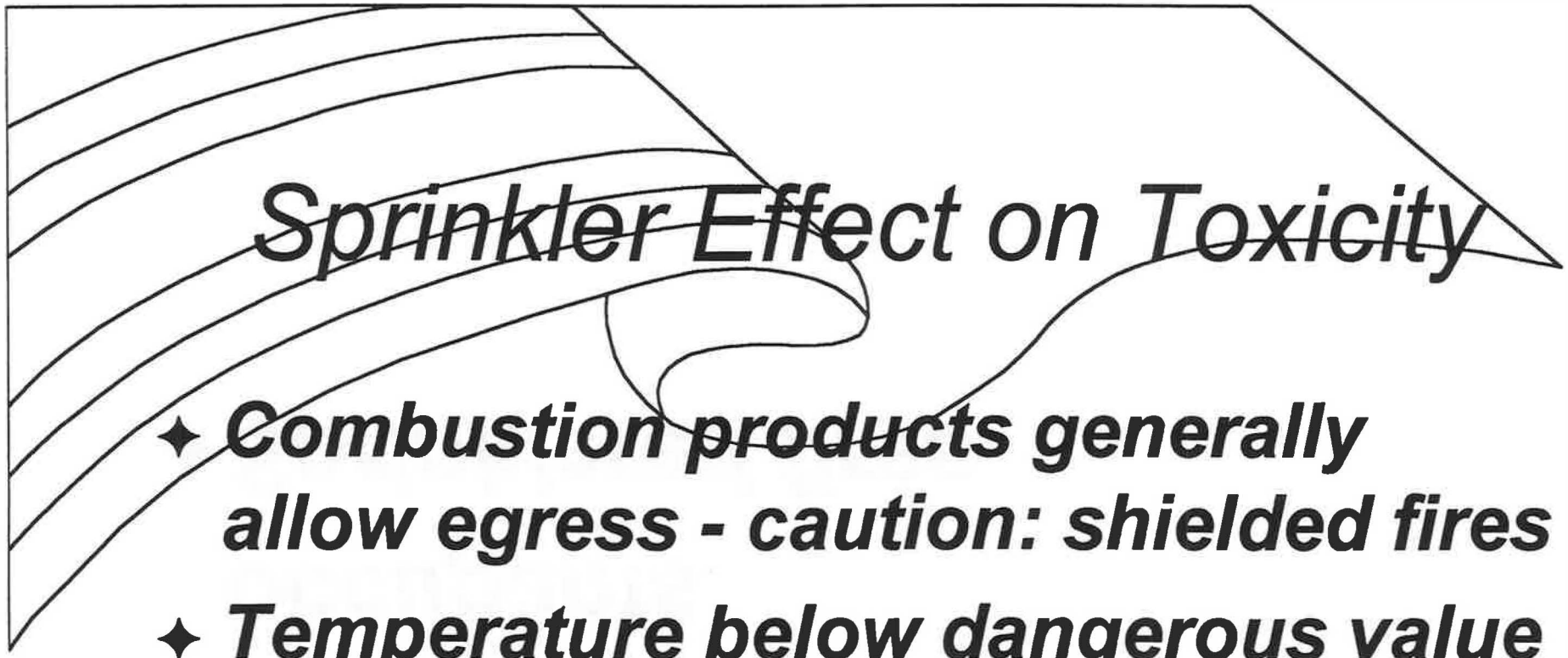
Smoke Management - What & When

- ***Atria***
- ***Large undivided areas***
- ***Plume height most significant factor***



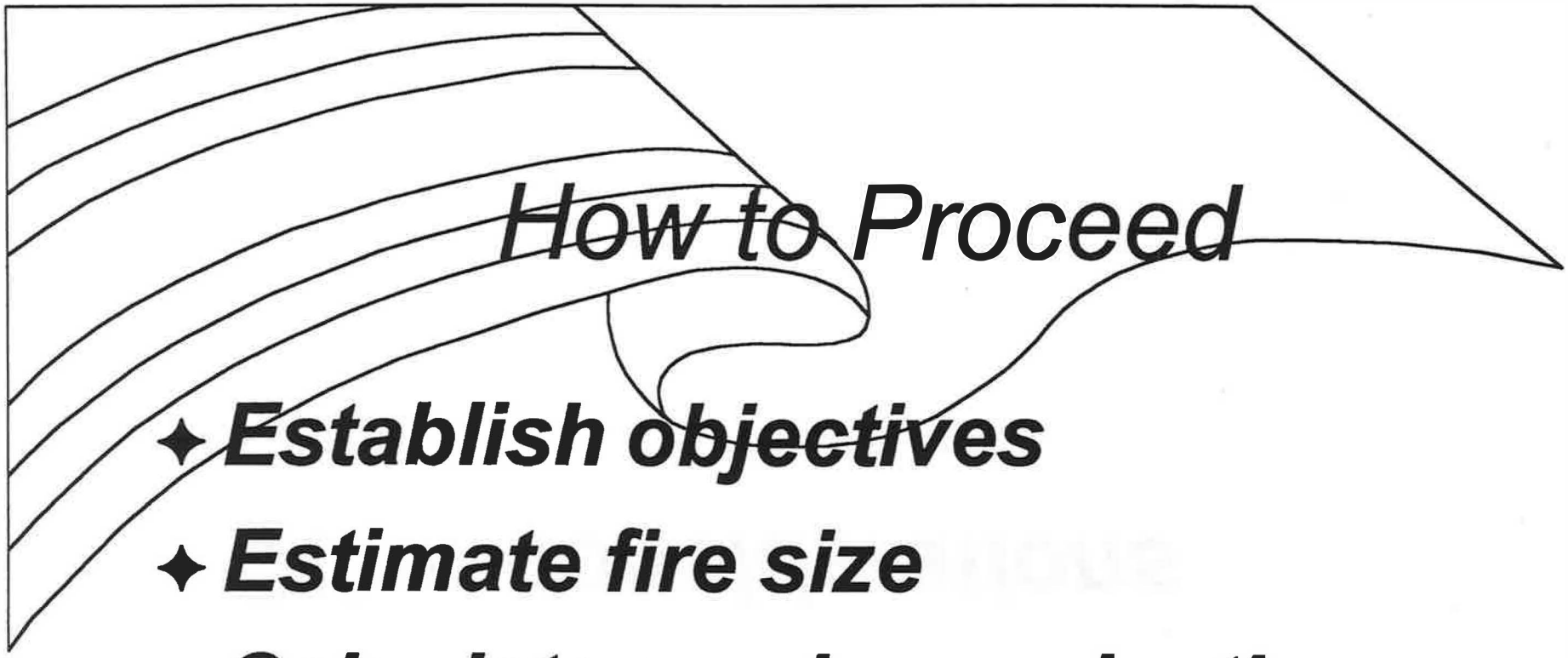
Toxicity

- ***Not calculated***
- ***Keep smoke away from occupants***
- ***Sprinklered fires***



Sprinkler Effect on Toxicity

- ***Combustion products generally allow egress - caution: shielded fires***
- ***Temperature below dangerous value***
- ***Obscuration is great - visibility potential danger to egress***



How to Proceed

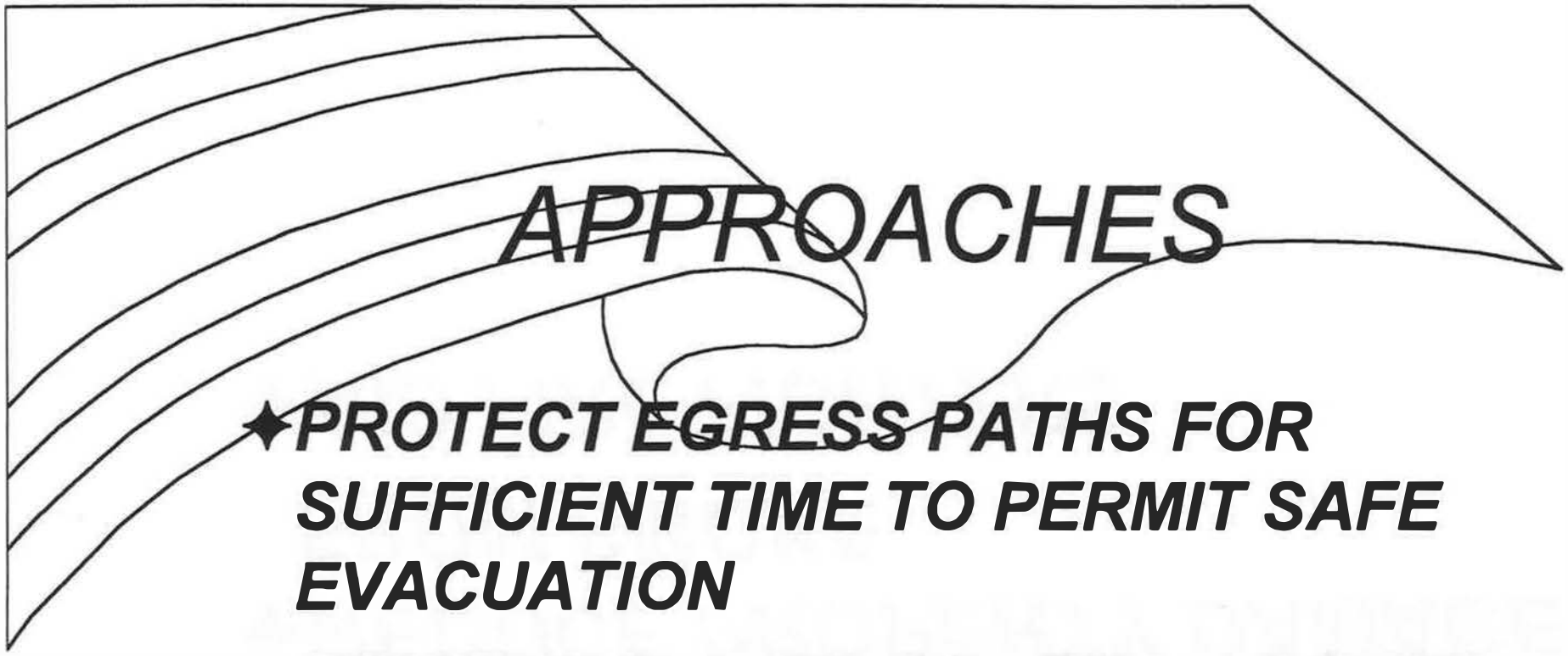
- ***Establish objectives***
- ***Estimate fire size***
- ***Calculate smoke production***
- ***Document calculations & design***

DESIGN OBJECTIVES

- ***Goals***
- ***Approaches***
- ***Other considerations***

GOALS

- ***REDUCE DEATH AND INJURY FROM SMOKE***
- ***REDUCE PROPERTY DAMAGE FROM SMOKE***
- ***AID FIRE FIGHTERS***



APPROACHES

- ***PROTECT EGRESS PATHS FOR SUFFICIENT TIME TO PERMIT SAFE EVACUATION***
- ***CONFINE SMOKE TO AREA OF ORIGIN***
- ***MAINTAIN SMOKE LAYER AT A HEIGHT TO PERMIT FIRE FIGHTERS ACCESS TO REACH SEAT OF THE FIRE***

OTHER CONSIDERATIONS

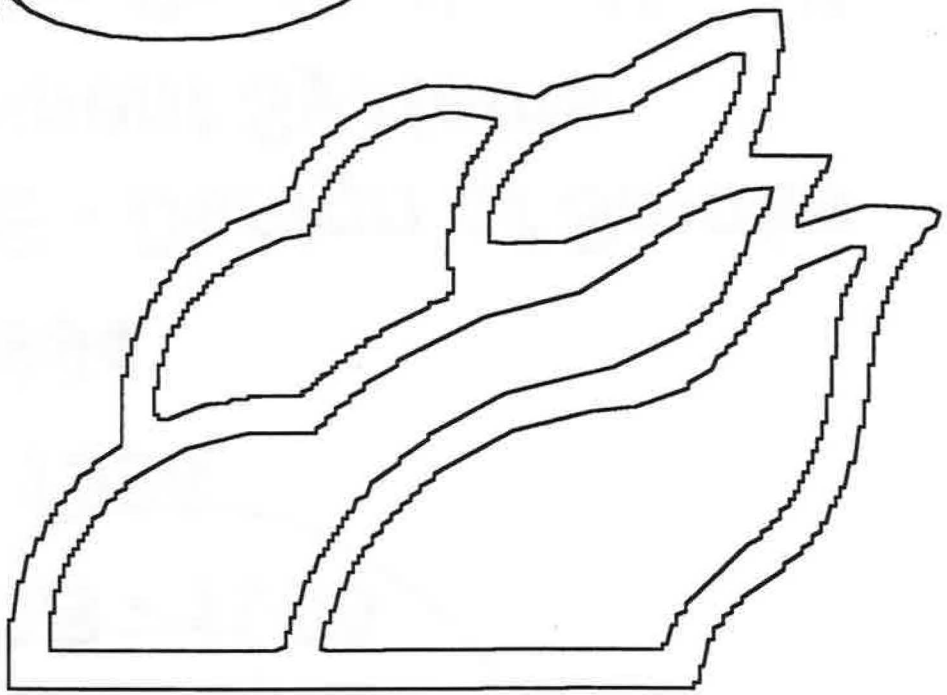
- ***MINIMIZE COST BY USING NORMAL HVAC***
- ***MAINTAIN SYSTEM SIMPLICITY TO IMPROVE RELIABILITY***

HEAT RELEASE RATES- STEADY FIRES

- 5000 Btu/s or
- OFFICES :25Btu/ft^2-s
- MERCANTILE & RESIDENTIAL :50 Btu/ft^{2}s

T^2 Fires - Unsteady Fire

- *Ultra-Fast*
- *Fast*
- *Medium*
- *Slow*

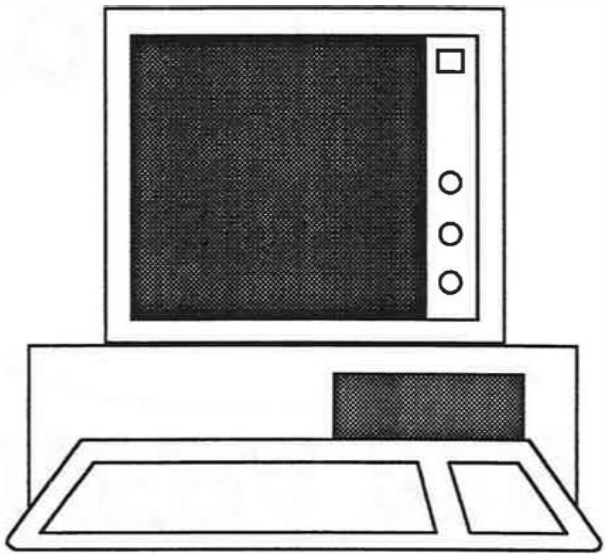


Smoke Production

- ***NFPA 92B - 1995***
- ***BOCA - 1996***
- ***UBC - 1994***
- ***ASHRAE - Design of Smoke Management Systems***
- ***NFPA Fire Protection Handbook - 17th Ed.***
- ***SFPE Handbook of Fire Protection Engineering - 2nd Ed.***

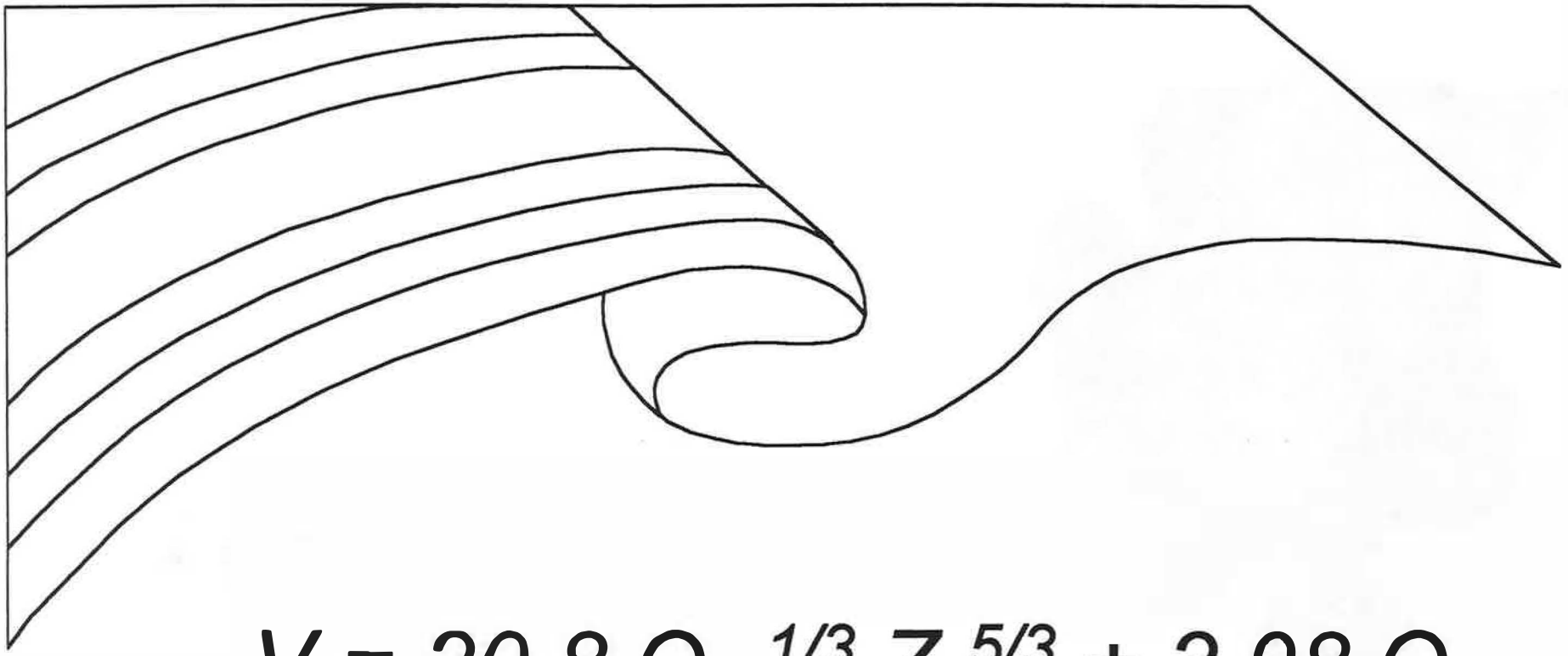
Computer Programs

- *FPETool - v 3.2 - NIST*
- *ASMET - v1.0 - NIST*
- *CONTAM 95 - NIST*
- *FMD - ASHRAE*



BOCA Adaptation of NFPA 92B

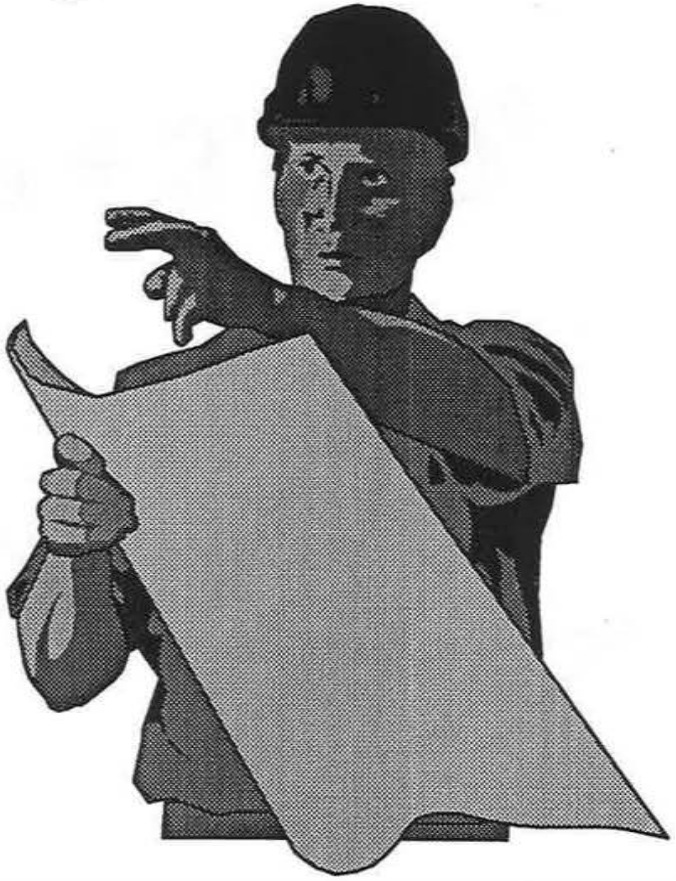
$$Z = 0.67H - 0.28H \ln \left[\frac{tQ^{1/3} H^{2/3}}{A} \right]$$



$$V = 20.8\ Q_c^{\,1/3}\ Z^{\,5/3} + 3.98\ Q_c$$

Document

- ASHRAE Guideline 5
- NFPA 92A & B
- UBC



Conclusion

- ***Research & improved SW & HW***
- ***Beware - Fire is unpredictable.***
  - ***Calculations are only as good as the underlying research.***
  - ***Experience & judgement still needed***