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ELECTROSTATIC ACCELERATOR DIELECTRICS

A Workshop on Insulators and Conductors in Electrostatic Machines

C.M. COOKE

Massachusetts Institute of Technology
Cambridge, USA

May 1989

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C.M. Cooke is a consultant for the Vivitron project.

Electrostatic Accelerator Dielectrics

A Workshop on Insulators and Conductors in Electrostatic Machines

by

Chathan M.Cooke

Massachusetts Institute of Technology

High Voltage Research Laboratory

Cambridge, MA USA

1. INTRODUCTION

Our interest in high voltage insulation is centered on the fact that electrostatic accelerator performance is closely linked with our ability to sustain terminals at high voltage and to manage the energy flow when breakdowns do occur. There is substantial interest in ever higher voltages, now several tens of megavolts, provided the insulation can be achieved with reasonable reliability and cost. Such very high voltages necessitate large systems so that careful design is required to avoid excessive cost. The following descriptions are an introduction to stimulate discussion, they highlight the characteristics of insulation technology and design strategies for improved use. First, the basic geometry of the insulation in accelerators is considered. Then, there follows a more detailed description about each of the insulation regions. Finally, topics for discussion are given.

The hope for the workshop is to broaden our thinking about what limits insulation performance and to sharpen our focus on the more important areas of concern.

2. ACCELERATOR INSULATION STRUCTURE AND DIELECTRIC PERFORMANCE

2.1 Accelerator Insulation Structures

The whole purpose of the high voltage in an accelerator is to energize the acceleration tube. The inherently low electric stresses that can be sustained in the vacuum within the acceleration tubes sets the needed overall length of the column. Fortunately, the surrounding gas can readily tolerate the allowable tube stresses so that the radial terminal region often operates at two times and more the longitudinal column stress.

The basic insulation structure employed to sustain the high terminal voltages in an accelerator starts from an initial simple coaxial geometry. Breakdown in these systems has been found to occur according to the high field at the center conductor (ie. terminal) [1], see also the paper by T. Joy at this conference. This basic coaxial form has been modified in three different ways, each made to achieve certain enhancements. Figure 1 illustrates these four configurations:

1) coaxial,
2) bundled,
3) intershield, and
4) Vivitron design (= 'super-bundle')

The last is the recently employed new structure in the Vivitron, seen here in Strasbourg. It is composed of many discrete electrodes arranged in concentric circles. Because it contains characteristics of 2) and 3), it might be called a 'super-bundled' design. In the following section, each of the three modifications to the basic coaxial design are considered .

2.2 Comparison of Insulation Structures

i) The Bundle

The bundled structure, which divides the center conductor into several smaller spaced conductors, all at equipotential, has not been common in accelerators, but has been employed for high voltage, open-air power transmission lines. It successfully lowers wind load and creates a lower field compared to a single conductor with the same current carrying capacity. Some studies with the bundled geometry in compressed SF6 have been made at MIT. [2] They showed that the field was highest at the outer region of each of the conductors, Figure 2, and more importantly, that breakdown usually developed from this high field region in close accordance to the same field levels in the single conductor designs. Figure 3 shows the breakdown levels in two such systems, one twice the size of the other. Figure 4 is an open shutter photo of the some breakdowns in such a system.

One reason for considering the bundled geometry is the new low-field space created in the interior of the bundle. Solid supports which traverse the gas gap could penetrate this low-field region so as to enable the solid insulators to have extra length and therefore higher voltages. However, as seen in Figure 5, the solid dielectric usually distorts and acts to increase the local fields on the adjacent conductors. This is because the solid, with it's higher dielectric constant, forces the fields to penetrate further into the central region. The bundled design is thus expected to lower rather than increase the attainable voltage. Experimentally, breakdown is observed to originate in this locally higher field region, Figure 4.

ii) The Intershield

Another variation in structure is the intershield(s), ie. number (3) above. These extra electrodes divide the single coaxial gap into a series of coaxial gaps. and because the potential of the intershield is set resistively to a desired value, the maximum field for a fixed outer diameter and terminal voltage can be made lower than that in the simple single coaxial design. The penalty for this is more electrode area and a complexity for service access to the terminal. There is also a lower surge impedance, a topic for discussion later.

iii) The 'Super-bundle'

The Vivitron 'super-bundle' achieves a mix of the two ideas of bundles and intershields. With it, the intershield is replaced by several smaller discrete electrodes. Their potential is also set resistively so that the field is more uniform than the simple single coaxial gap. In a design like the Vivitron, the ratio of the field at the terminal to that at the tank is about 1.8 compared to a value of 2.7 in a coaxial gap.

iv) Generalization

In addition to the radial stresses, which are considered in the 4 major geometries, there are also the ends and hence edge effects to consider which concentrate the electric stress at the smaller radii of curvature. It is concluded however, for all cases radial or end region, that the dominant factor that determines the breakdown voltage is the electric stress in the gas. For insulation, SF6 gas is clearly superior to air or nitrogen, Figure 6, and as yet there has not been found a better practical substitute. One additional advantage of SF6, due to it's well defined discharge inception conditions, is the low incidence of spurious low voltage breakdowns.

2.3 Solid Insulators

The last component of the basic geometry in electrostatic accelerators is the solid dielectric support structures. The traditional approach has been to have the low electric stress column provide the mechanical support. More recently, with increased voltage and weight needs, there is a trend to introduce solid supports in the higher field radial gap region. The Vivitron structure is a clear example of this new direction. The report at this conference on a new NEC machine with extra support from insulators in the radial gap is another example.

Experience with insulators in high field radial gaps has shown that the electric stress at the insulator surface is also critical. The previous Figure 5 shows one example of a solid structure where breakdown voltage is reduced from that in the plain gas gap without the insulator when the insulator causes a redistribution of the stress so that it concentrates the field to local regions.

Alternately, a solid insulators configuration can be designed to redistribute the stress so that it lowers the field in the vicinity of the insulator. Figure 7 shows 2 post type insulators [2,3] in the radial gap of a bundled conductor geometry system. With the post design, the field in the radial gap is redistributed so that the maximum stress on the insulator surface is lower than that in the gas gap by itself. [4]

2.4 Defect Model for Dielectric Failure

Examination of the collected experience of many tests in various geometries and the theory of gas ionization, [2] leads to the conclusion that on the one hand, gas insulation will not breakdown when stresses are everywhere below a critical value; and on the other hand, will always breakdown at high stress. Figure 8 indicates this threshold concept. From a practical point of view however, systems do exhibit a transition region between these two limits of no breakdown and always breakdown. Among the factors which can cause a spreading of this transition region are:

electrode area
time at stress
pressure
geometry
trapped charges on insulators
particles
and other 'defects'.

3. TOPICS FOR DISCUSSION

A listing of potential subjects for discussion during the meeting is presented in Table I. In particular, each of the major areas of insulation is included, gas solid and vacuum. Furthermore, topics such as the belt, or charge transport system which can involve high fields are also of interest. And finally, it is appropriate to consider what are good methods to monitor the condition of the high voltage insulation as well as possible preventative maintenance.

4. SUMMARY

The gas gap insulation of the terminal voltage in electrostatic machines has been found to be sensitive to regions of high electric stress; however needed voltages can be obtained when there is careful attention to control stresses so that they remain below well defined limits. Four major design options exist for the radial gap structure, the latest being the 'super-bundle', Vivitron structure. In order to obtain satisfactory performance from solid support insulation attention is again focussed on the electric stress values and distribution. In fact, any structure or defect which enhances the local electric field in the gas is of concern for the voltage insulation. Among topics suggested for further discussion are concerns of damage from sparks, structures with radial support insulation, possible effects from charges on/in acceleration tube walls, charge transport belts / ladders, and improved monitoring of the insulation for signs of degradation or troubles.

Table I

Topics for Discussion

Workshop on Insulators and Conductors in Electrostatic Machines

1. Gas Dielectrics
    + Defect Model for Breakdown
        - No fundamental difference between large vs small size systems
        - Types of defects
        - Breakdown probabilities from the defect distribution
    + Can Damage by Breakdown Events be Estimated
        - The surge impedance idea, I=V/Zs
        - Has it been measured on full size machines
        - Does such damage limit performance
    + Are Spark Gaps really a Good/Useful Idea
        - If so, how to make spark gaps protective and not injurious
    + Any Successful Experience with Gases other than SF6
2. Solid Supports
    + Does solid support insulation lessen the stress attainable
    + Structures, besides Vivitron, with 'radial' solid supports
    + End effects and spark initiation
        - bundled, recessed, toroidal
    + Is Surface Flashover fundamentally different than the gas gap
3. Down the Tubes
    + Any observed beam charging of tube wall insulation
        - on surface
        - in volume
    + Any success with acceleration gaps not subdivided into small lengths
    + Surface treatments which improve tube performance?
    + Is there an optimum current to grade the tube potential?, What?
4. Belt / Ladder Charge Transport
    + Putting it On, Keeping it On
    + Taking it Off, Keeping it Off
5. Where's the Expert (system)
    + Operational Control / Conditioning
        - High Voltage
        - Beam
    + Maintenance
        - Monitoring vs Don't Touch It

Simple vs Complex Geometries

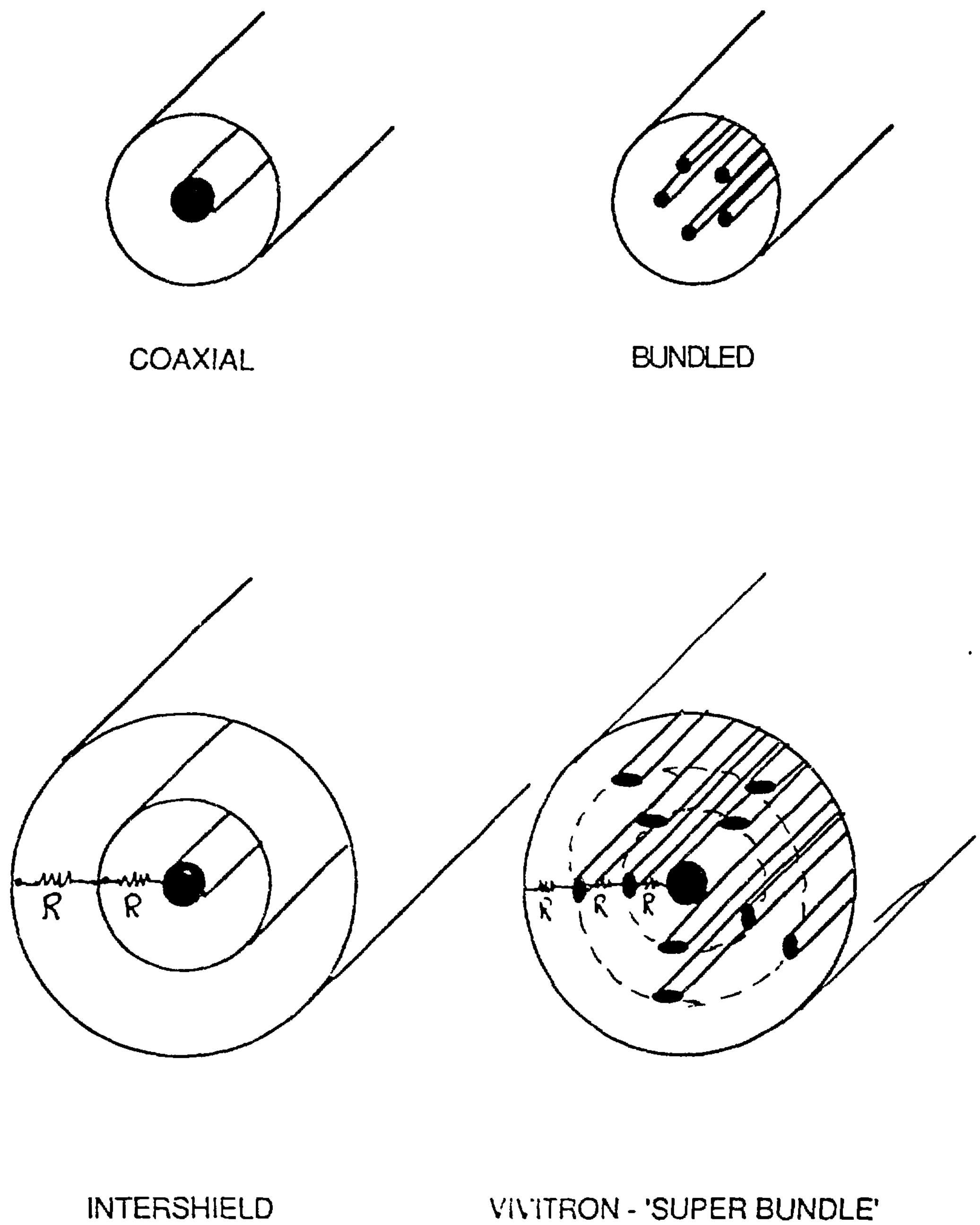


Figure 1

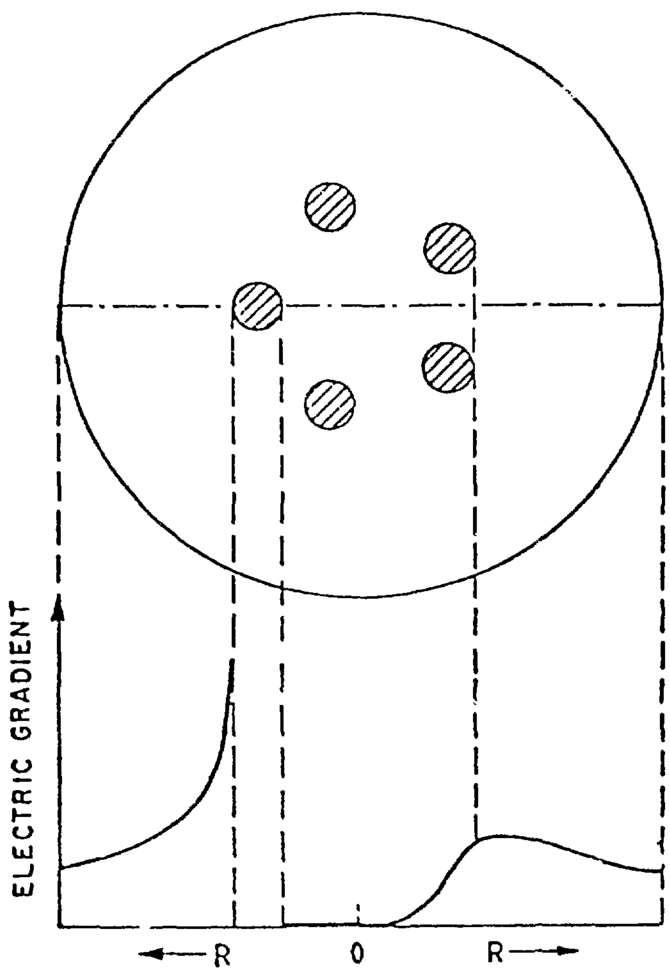


Figure 2

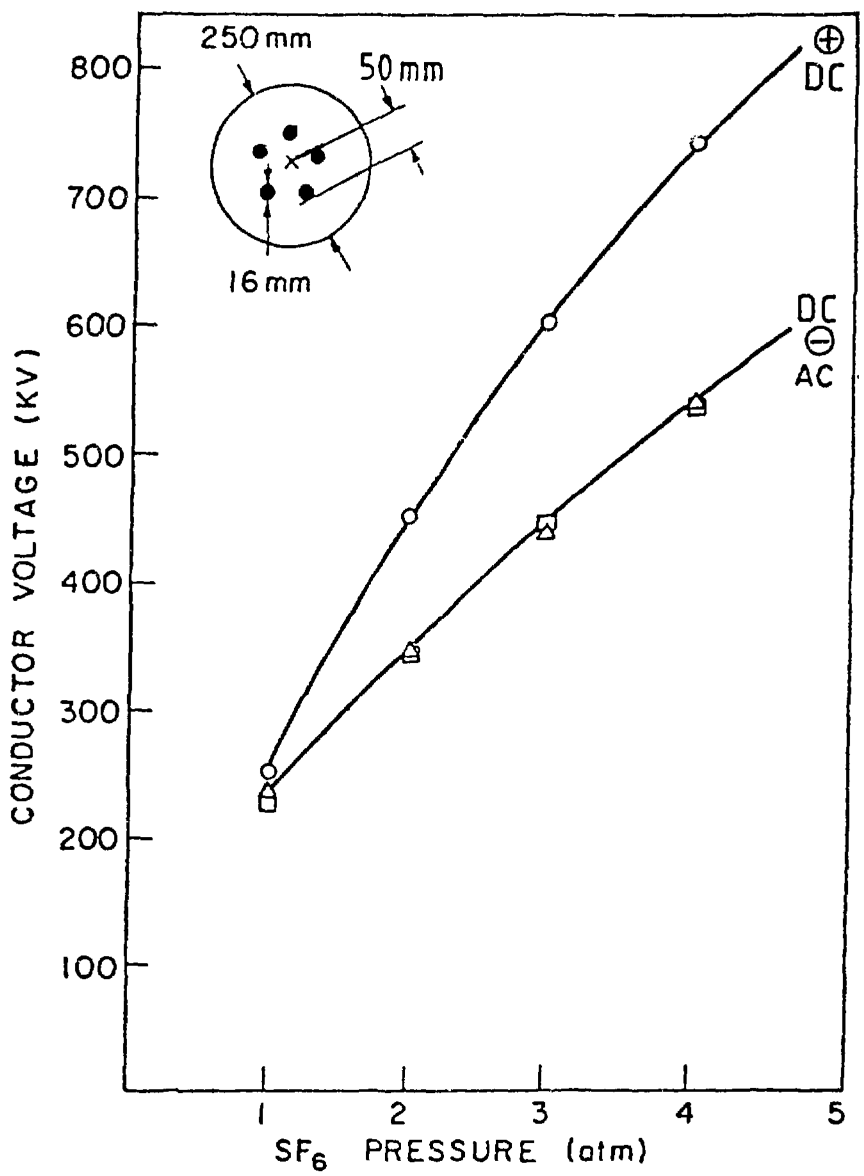
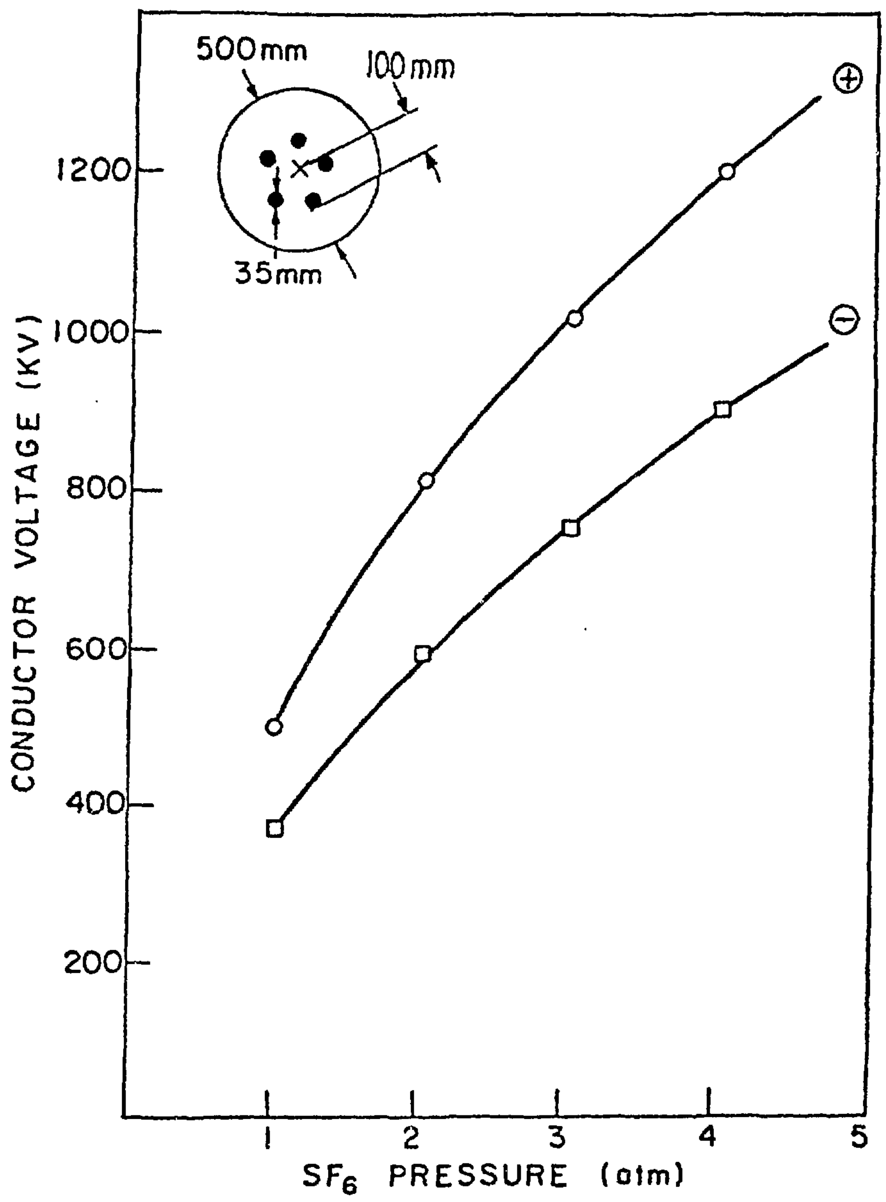

250 mm
50 mm
16 mm
800
700
600
500
400
300
200
100
CONDUCTOR VOLTAGE (KV)
⊕
DC
DC
⊖
AC
1
2
3
4
5
SF6 PRESSURE (atm)

Figure 3a



500mm
100mm
35mm
1200
1000
800
600
400
200
CONDUCTOR VOLTAGE (KV)
1
2
3
4
5
SF6 PRESSURE (atm)

Figure 3b

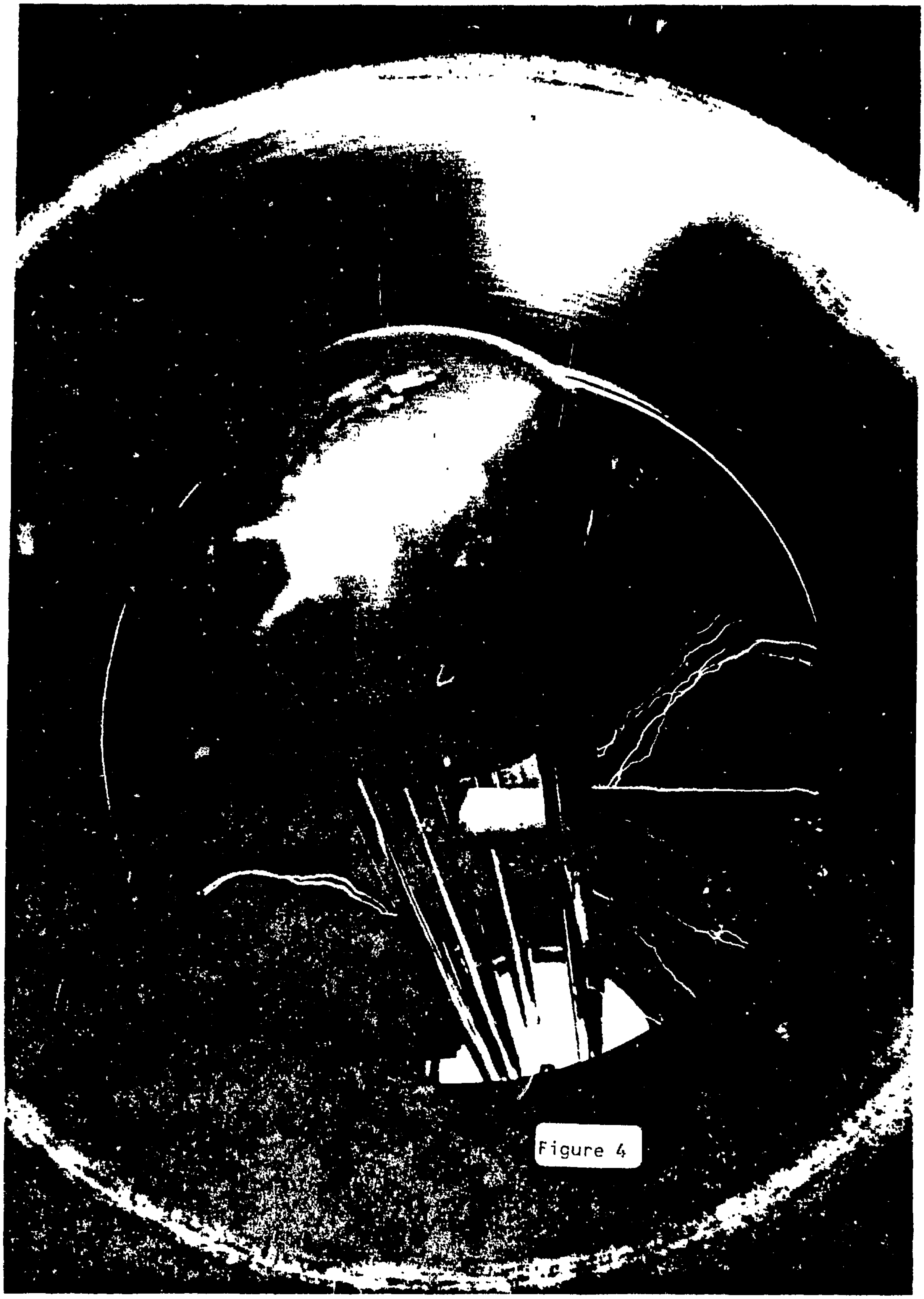
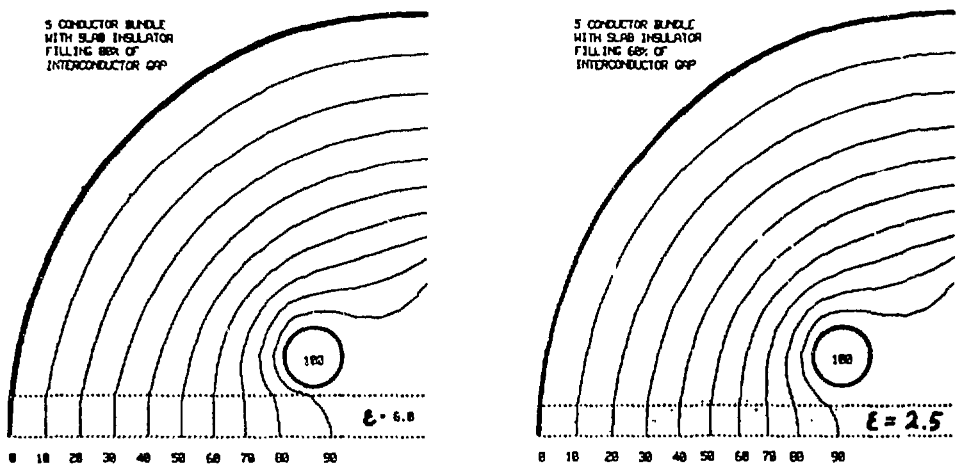
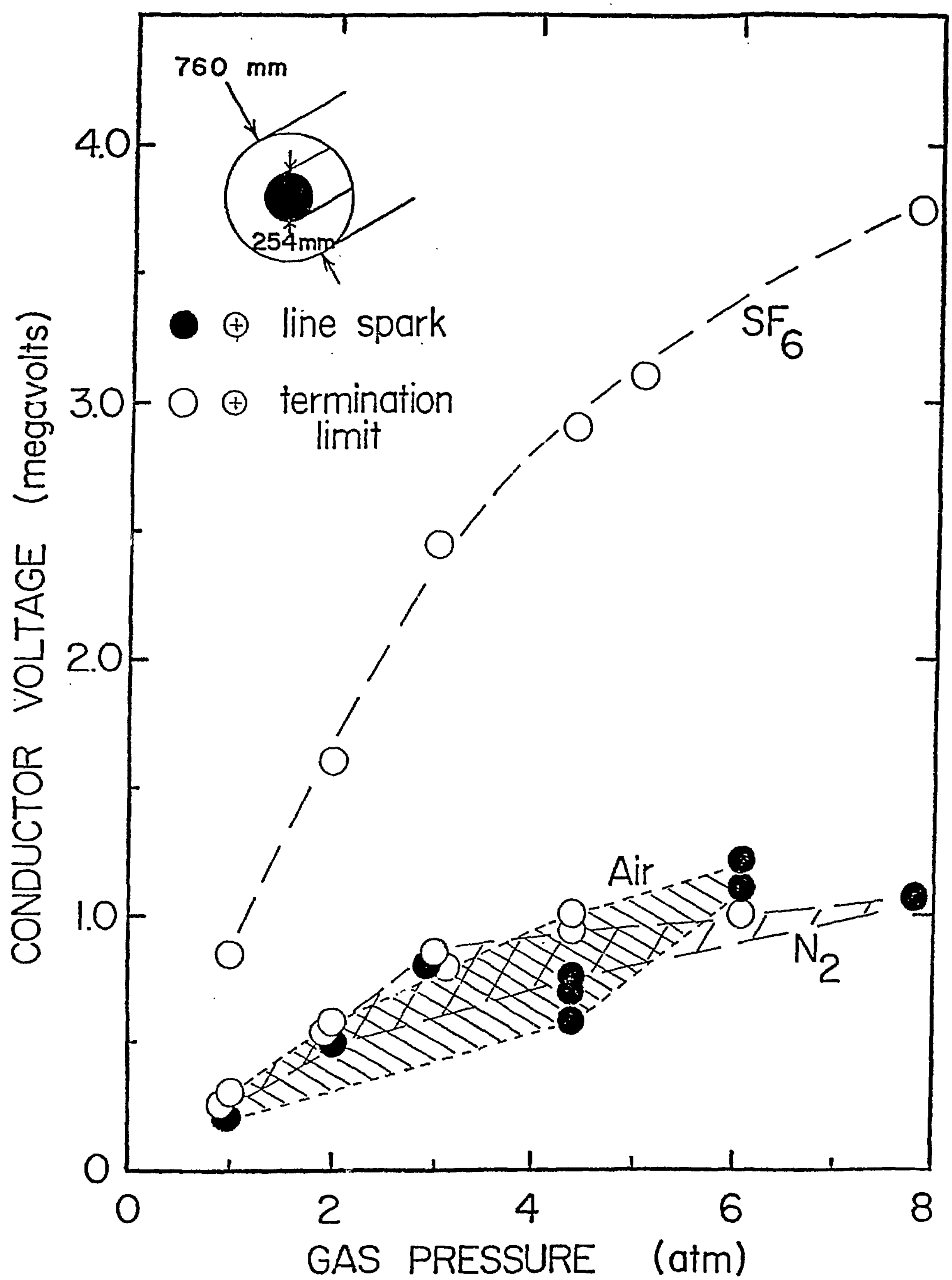


Figure 4



5 CONDUCTOR BUNDLE
WITH SLAB INSULATOR
FILLING 80% OF
INTERCONDUCTOR GAP
100
ε = 6.0
0 10 20 30 40 50 60 70 80 90
5 CONDUCTOR BUNDLE
WITH SLAB INSULATOR
FILLING 60% OF
INTERCONDUCTOR GAP
100
ε = 2.5
0 10 20 30 40 50 60 70 80 90

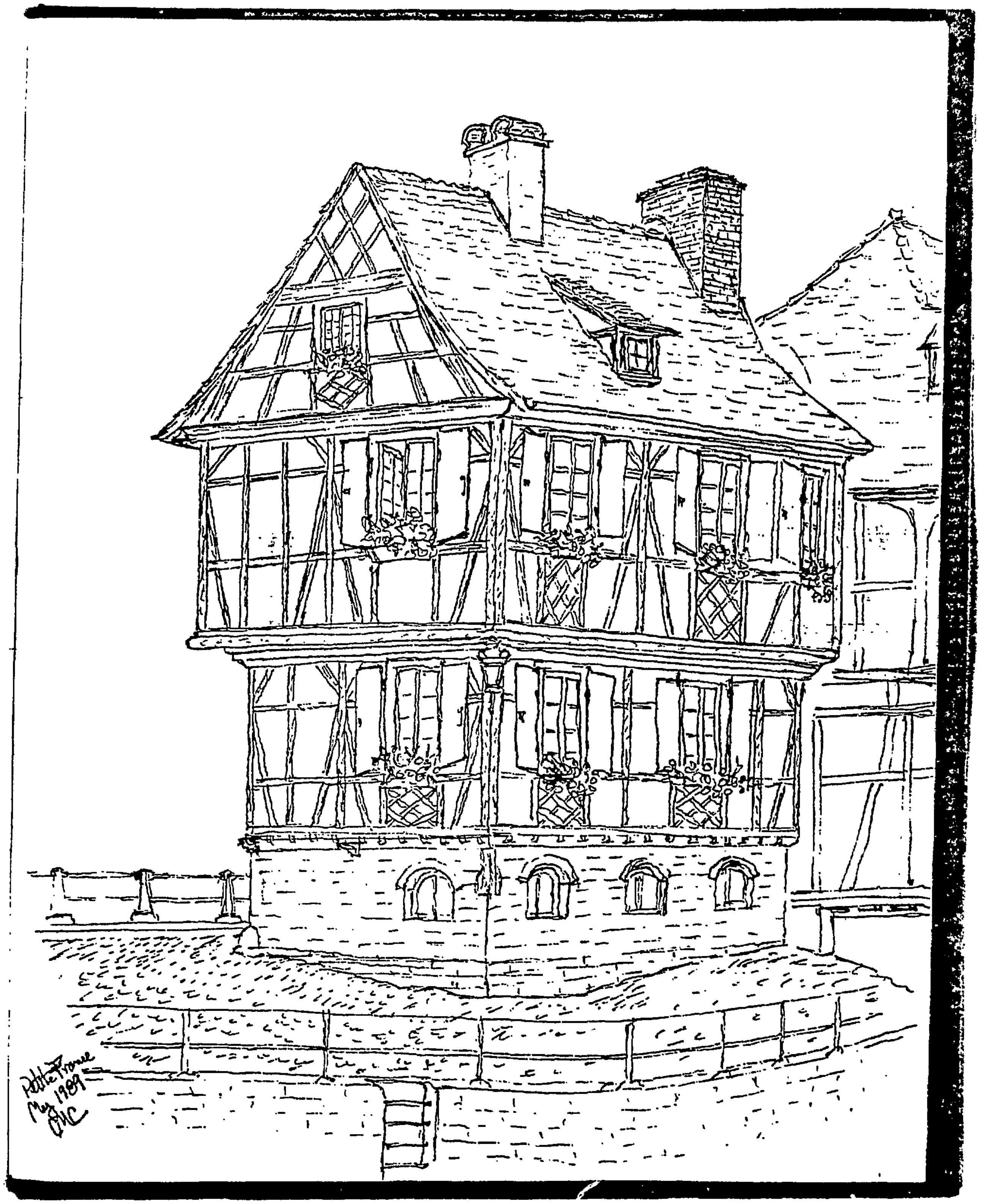
Figure 5



760 mm
254mm
line spark
termination limit
SF6
Air
N2
CONDUCTOR VOLTAGE (megavolts)
4.0
3.0
2.0
1.0
0
0
2
4
6
8
GAS PRESSURE (atm)

Figure 6

Figure 7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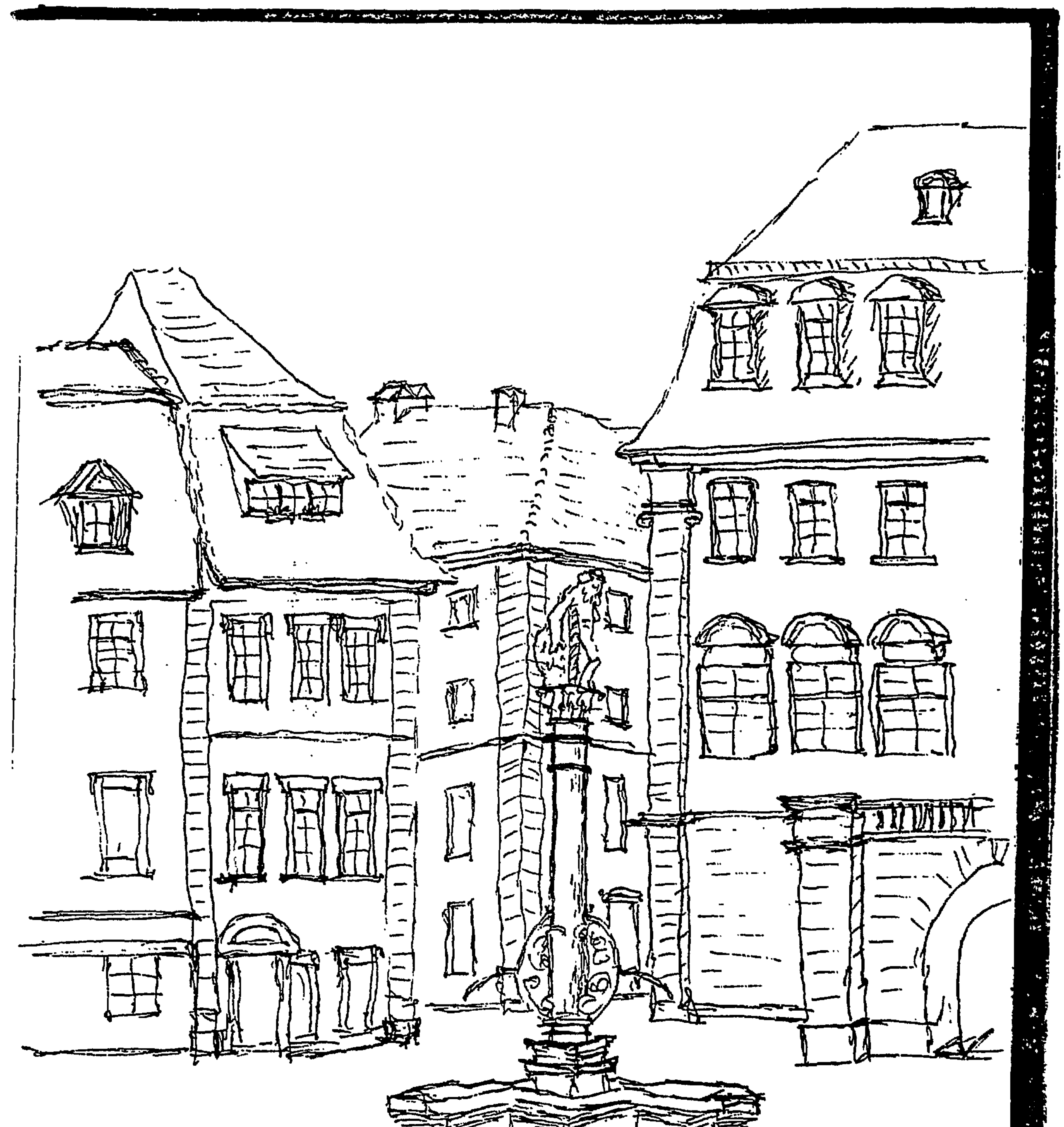
Heidelberg 1989
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