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Search for Monopoles Above the 15-Foot Bubble Chamber

(revised)

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ABSTRACT

Magnetic monopoles having energies less than about 40 TeV will be slowed to their terminal velocity by the earth's atmosphere. They may then be gathered by the fringing magnetic field of the 15-foot bubble chamber. We propose placing detectors of Lexan and nuclear emulsion on the floor of the E-202 box which is presently suspended from the roof above the bubble chamber. Such a system would be sensitive to monopole masses between 20 GeV and 50 TeV and to monopole charges between $\sim$0.7 and 10 hc/2e.

Although the experiment would run simultaneously with normal bubble chamber operation, it would require the construction of a scuttle in the portion of the roof above the E-202 box. In fair weather, the scuttle will be open permitting unimpeded entry of magnetic monopoles. In inclement weather, the scuttle will close automatically. An exposure of seven months (two long cooldowns) with the magnetic field on would lower the existing limit on in-flight detection of magnetic monopoles by a factor of 24.

Physics Justification

Let us, for the moment, assume that the event found recently in the upper atmosphere is really a magnetic monopole having twice the Dirac charge $\hbar c/2e$ and at least 600 times the proton mass.[1] Is there any way that such a monopole could have escaped detection in the other searches that have been completed in the last decade? In the following table we summarize the most sensitive of these searches:

authors	area x time product for one event (cm^2-sec)	limits (on energy of monopole when it enters earth's atmosphere).	technique
Kolm, Villa, and Odian (1971)[2]	$\gtrsim 5 \times 10^{17}$	$E \lesssim 10^{16}$ eV	monopoles trapped in iron spherules contained in sea sediment
Eberhard, Ross, Alvarez, and Watt (1971)[3]	$\gtrsim 5 \times 10^{17}$	$E \lesssim 10^{13}$ eV	monopoles trapped in magnetic crystals in lunar samples
Fleischer, Hart, Jacobs, Price, and Aumento (1969)[4]	$> 5 \times 10^{17}$	$E \lesssim 10^{16}$	monopoles trapped in sediment
Fleischer, Price and Woods (1969)[5]	$> 2 \times 10^{18}$	$E > 10^{14}$ eV	stored tracks in mica/and obsidian
Fleischer, Hart, Nichols, and Price (1971)[6]	$> 9 \times 10^{12}$	$E > 10^{14}$ eV	tracks in Lexan at sea level
Carithers, Stefanski, and Adair (1966)[7]	> 7 (2*) $\times 10^{13}$	$E < 10^{14}$ eV	north-seeking monopoles slowed in atmosphere and collected by the fringing field of the magnet for the 14-inch bubble chamber

*factor of two inserted since this experiment is sensitive only to poles of one sign.

Price, Shirk, Osborne, and Pinsky (1975)[1]	$\gtrsim 1 \times 10^{12}$	$E > 2 \times 10^{11}$ eV	balloon and Skylab flights

Four of these searches set upper limits approximately a million times more stringent than that suggested by the recent event. Further, these searches are complementary. The experiments of Kolm et al and Eberhard et al require that the monopole have sufficiently low energy that it can be stopped close to the surface of the earth (or moon). Conversely, the experiment of Fleischer et al[5] required that the monopole have sufficiently high energy to pass through naturally occurring mica or obsidian.

The latter experiment, however, was only marginally sensitive to monopoles bearing twice the Dirac charge. The former experiments assume that a monopole may be trapped in ferromagnetic material for geologically-long periods.

These trapping experiments contain a series of assumptions, each plausible but none proved. Specifically, the experiments assume that:

a) The monopole is stable for geologically-long periods.

b) The monopole is affected by the H rather than the B-field and hence can be trapped by induced "poles" in the ferromagnetic material.

c) Monopole diffusion due to abrasion of the trapping site by non-magnetic material is negligible.

Because the possibility exists that one or more of the assumptions are wrong, alternative types of experiments should be performed.

If the four most sensitive experiments are - for any reason - incapable of detecting monopoles, the next limiting experiment is that of Carithers et al. The upper limit set by this experiment is still a factor of about 35 more stringent than the rate suggested by the recent event. But 35 is a much smaller number than a million. We are thus led to the following working hypothesis:

i) Monopoles are produced in (or impact on) the upper atmosphere at a rate consistent with the upper limit set by Carithers et al.

ii) The monopoles have sufficiently low energy to be slowed to their terminal velocity by the earth's atmosphere (Energy $<$ 40 TeV for very heavy poles and $<10^{20}$ eV for poles of 10 GeV mass).[8]

iii) Once slowed, the monopoles drift along magnetic field lines towards the earth's surface (as in the original hypothesis of Malkus).[9]

iv) Monopoles which are drifting along field lines above the bubble chamber will be gathered in by the fringing field of the bubble chamber,[10] the polarity of the magnet being adjusted so as to attract north-seeking monopoles.

v) This magnetic field will accelerate monopoles to sufficiently high energies that they leave visible tracts in Lexan detectors and nuclear emulsions.

Since the 15-foot bubble chamber has a monopole-gathering power 30 times as great as that of the 14-inch chamber used by Carithers et al, a search at this installation should either find several monopoles or should be able to set stringent limits on their properties. The proposed experiment will be sensitive to a wider range of mass than the experiment of Carithers et al.

To be generally useful, such a search should cover a range of monopole masses and charges which includes, but is not limited to, the particular parameters of the event of Price et al. We propose to accomplish this search by exposing Lexan sheets and nuclear emulsions at a convenient location above the 15-foot bubble chamber.

Experimental Technique

Distinguishing a monopole from a fragmenting, heavy nucleus in the presence of the primary cosmic radiation is - as is now known - a difficult experimental problem. Fortunately, this problem is obviated at sea level by the observed absence of penetrating heavy nuclei.[6] We do not expect that the proximity of the accelerator will produce any such nuclei.[11]

Even if penetrating heavy nuclei (or other new particles) are found, however, the fringing field of the bubble chamber provides a mechanism for distinguishing slow, magnetically charged particles from electrically charged ones. The former will be accelerated along field lines, whereas the latter will not (see fig. 1).

A convincing demonstration of a moving monopole would require the presence of tracks along a consistent trajectory in at least two detectors. One layer of Lexan will be used for rapid scanning since, when completely etched through, an area may be scanned at the rate of 1 sq ft per minute. The emulsion will be used to determine the velocity of the particle. If the mass of the monopole is a TeV or greater, it would be accelerated only to small velocities ($0.01 \lesssim \beta \lesssim 0.5$) by the fringing field of the bubble chamber. At such speeds, emulsions provide unambiguous velocity measurements.

Consider a slowed monopole attracted by the fringing field. The descent of the monopole is controlled by the ionization loss in air (fig. 2) and by the energy gained from the fringing field (fig. 3). Using these two curves, one can readily determine the energy, velocity, and range in Lexan at any given altitude of a monopole of given charge and mass.

<u>Need for Scuttle in Existing Roof</u>

At the altitude of the roof, the range of a previously-slowed monopole would be approximately 20 mils of plastic. This distance is too short to permit reliable detection. However, the increasing fringing field in the next 10 feet accelerates the monopoles until they have a range of nearly 200 mils of plastic. We propose placing detectors of Lexan and nuclear emulsion at this lower altitude which is the bottom of the E-202 box. To permit the monopoles access to the bottom of the box, we will remove the decking of the roof immediately above the box.

A heavy roof scuttle will replace the removed decking. This scuttle will be controlled pneumatically thus permitting the roof to be sealed against inclement weather (see fig. 4).

The roof scuttle is to be manufactured by a commercial vendor who specializes in such work. The two leaves will cover an opening 13 ft. X 13 ft.; thus, when open each leaf will be 6½ ft. high X 13 ft. long. Each leaf is composed of a welded frame of 2 in. X 4 in. steel channel filled with fiberglass insulation and covered on both sides with aluminum sheeting. The leaves will be made to withstand a load of 30 pounds per square foot which corresponds to a wind load of 90 mph or a snowload of 60 inches. Opening and closing will be controlled by a total of four 6-in. diamater pneumatic pistons operating at a maximum pressure of 100 psi. For details of the scuttle, see fig. 5; its placement on the roof is shown in fig. 6. The view of the roof and open scuttle as seen from the south is shown in fig. 4.

The scuttle will close automatically when either precipitation or winds in excess of 50 mph are detected.

<u>Equipment costs</u>

pneumatically controlled roof scuttle	$ 11,000
rigging scuttle up to roof	1,500
welding scuttle to roof and installing weather-tight flashing	2,000
sealing top lip of box to roof	1,000
20 sheets of Lexan, each 12' X 12' X 0.010" (200 lb)	(500)
sheet of emulsion (100 micron thick X 12' X 12')	8,000
processing of nuclear emulsion	2,000
processing of Lexan	500
scanning microscopes	(8,000)
Lexan etching tank	(2,000)
TOTAL	$ 36,500
Less equipment already in hand (enc. in parentheses)	$ (10,500)
NET	$ 26,000

Timetable for Experiment

The timetable is severely constrained by the 6-8 week delivery time for the construction of the scuttle and by the need to install the scuttle by early October, 1976 so as to have it in place in time for the next cooldown. The experimenters have sufficient funds to build the scuttle and to make a weather-tight installation. They request that Fermilab support only the rigging of the scuttle on to the roof ($1,500). The Lexan detectors are in hand. The installation of the emulsions will be deferred until later when permitted by funds from Fermilab or the experimenters.

Appendix

Some useful formulas follow:

MONOPOLE FORMULAS

Energy Gain	$\frac{dE}{dx} = 20\ nH\ [\text{MeV/cm}]$, H in Kilogauss
Energy Loss (ionization)	$-\frac{dE}{dx} = 10\ n^2 \left[\frac{\text{GeV}}{\text{g/cm}^2}\right]$ (high energy limit)
Area x Time factor for consistency with Galactic Mag. field (of Age 200 M. yr.)	$= 10^{15}\ n\ [\text{cm}^2 \text{s}]$
Energy loss through atmosphere (vertical incidence)	$= 10^4\ n^2\ [\text{GeV}]$
Energy loss ratio: monopole/charged particle	$\frac{-(dE/dx)\text{mon}}{-(dE/dx)_{ze}} = \left[\frac{g\beta}{ze}\right] = 4.7\ 10^3 \left[\frac{\beta n}{z}\right]^2$

Footnotes

1. P. B. Price, E. K. Shirk, W. Z. Osborne, and L. S. Pinsky, Phys. Rev. Letts. 35, 487 (1975). P. B. Price, Bull. Am. Phys. Soc. 21, 61 (1976).

2. H. H. Kolm, F. Villa, and A. Odian, Phys. Rev. D 4, 1285 (1971).

3. P. H. Eberhard, R. R. Ross, L. W. Alvarez, R. D. Watt, Phys. Rev. D 4, 3260 (1971).

4. R. L. Fleischer, H. R. Hart, Jr., I. S. Jacobs, P. B. Price, W. M. Schwartz, and F. Aumento, Phys. Rev. 184, 1393 (1969).

5. R. L. Fleischer, P. B. Price, and R. T. Woods, Phys. Rev. 184, 1398 (1969).

6. R. L. Fleischer, H. R. Hart, Jr., G. E. Nichols, and P. B. Price, Phys. Rev. D 4, 24 (1971).

7. W. C. Carithers, R. Stefanski, and R. K. Adair, Phys. Rev. 149, 1070 (1966).

8. The detectors will, of course, be sensitive to penetrating monopoles of higher energies. The detectors, however, are only large enough to permit setting a limit on penetrating monopoles comparable to that of Ref. 6.

9. W. V. R. Malkus, Phys. Rev. 83, 899 (1951).

10. If the drift velocity is too low, a strong wind could blow the monopole away. We calculate that even with attached (paramegnetic) oxygen molecules a monopole in the earth's magnetic field should have a velocity of at least 50 m/s and so be impervious to anything less than a hurricane. (See N. A. Fuchs, "Mechanics of Aerosols", Pergammon, Lond., p. 29, 1964).

11. It is kinematically possible for a 300 GeV nucleus to emerge in the forward direction when a 400 GeV proton strikes a heavy target. However, such production is very strongly suppressed. A search for penetrating heavy ions near a primary target has been done already with negative results. (L. Lederman, private communication).

Figure Captions

Fig. 1. Trajectories of an n = 2 Monopole of Various Masses in Fringing Field of Bubble Chamber.

Fig. 2. Ionization Loss of an n = 2 Monopole in Air and Lexan.

Fig. 3. Magnetic Field vs. Altitude Above the Bubble Chamber.

Fig. 4. Elevation of Bubble Chamber Room Showing Detector Planes and Roof Scuttle. (view from south)

Fig. 5. Details of Roof Scuttle (drawing courtesy of Bilco Co.)

Fig. 6. Detail of Placement of Scuttle in Roof

Trajectories of Monopoles in Fringing Field

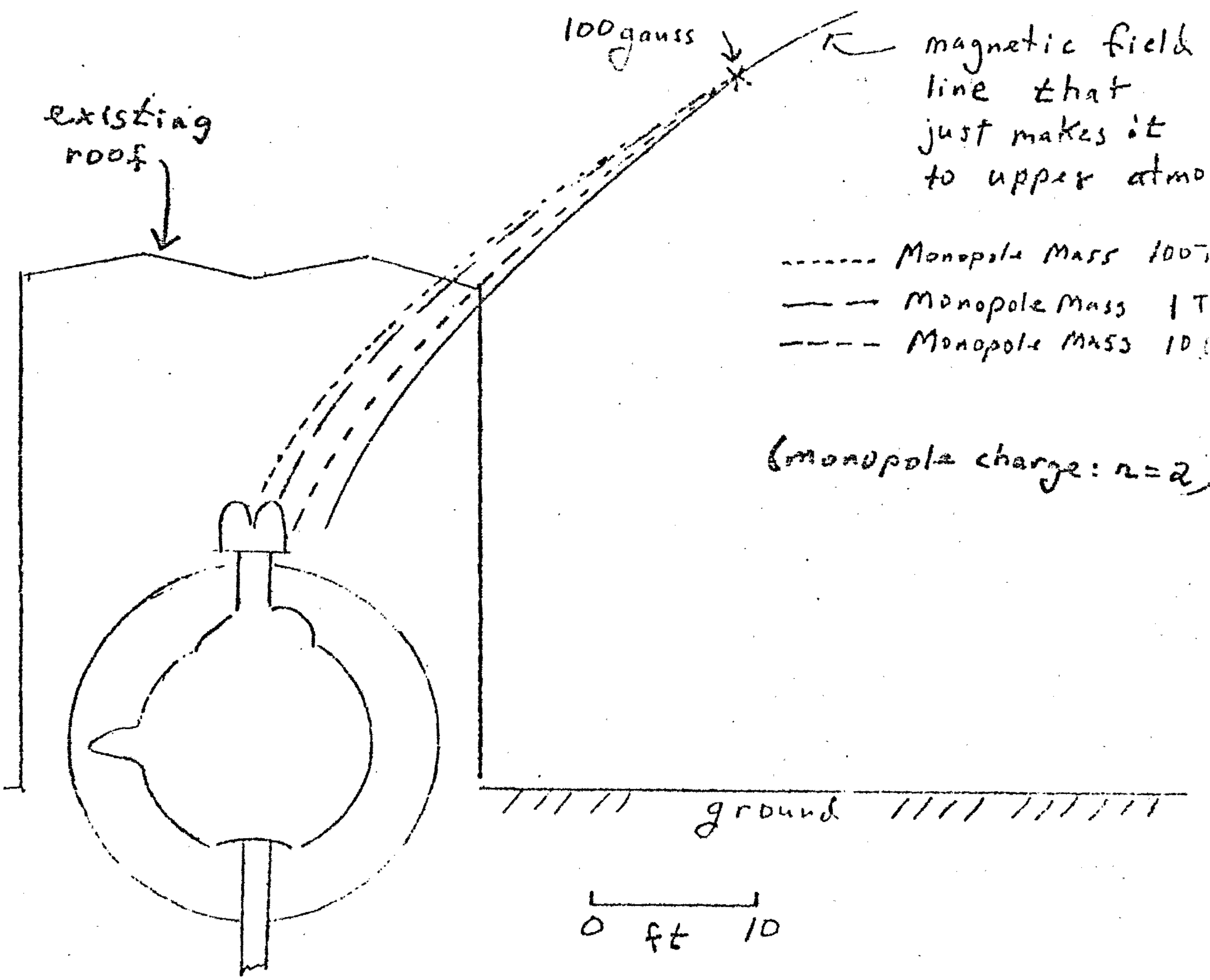
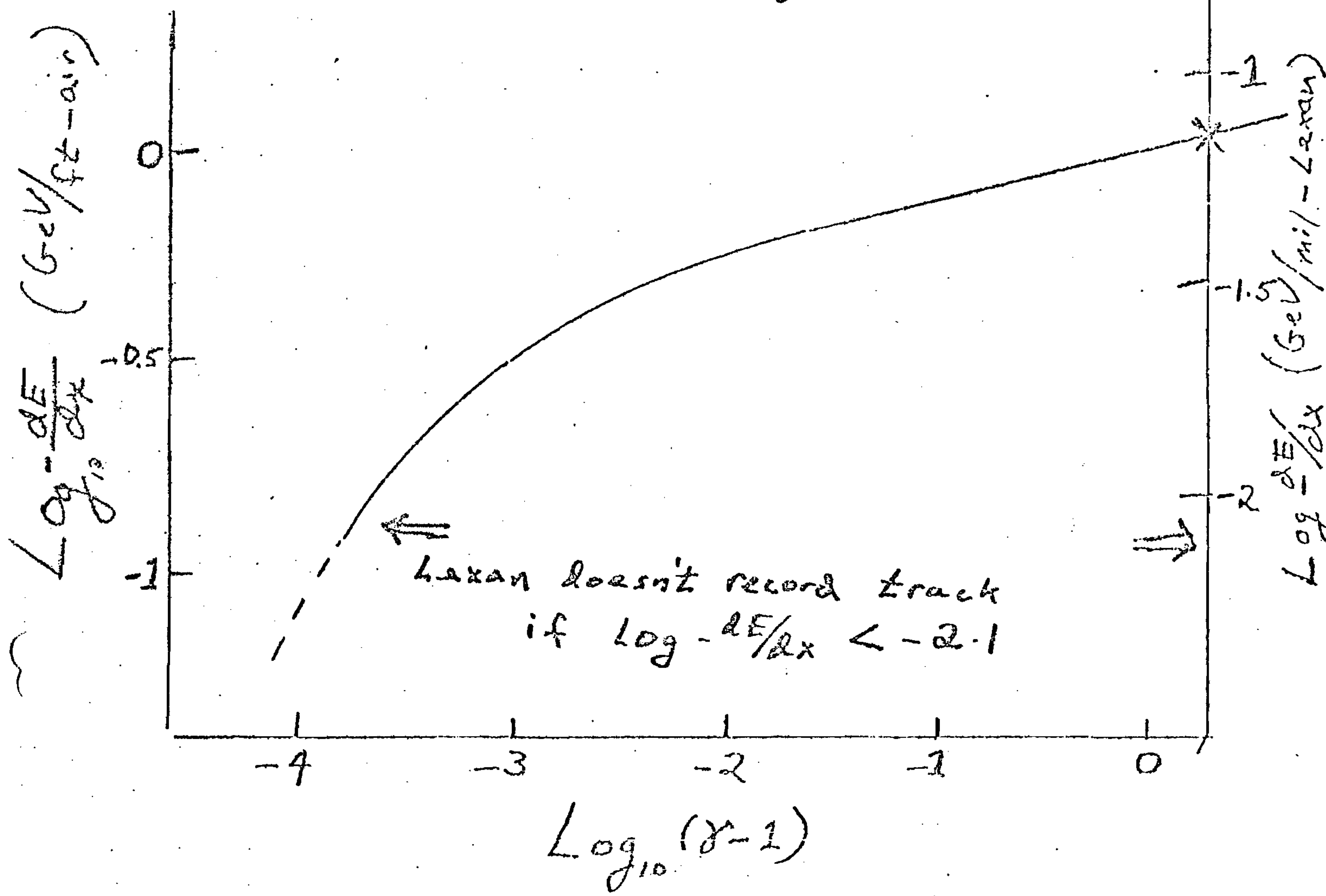


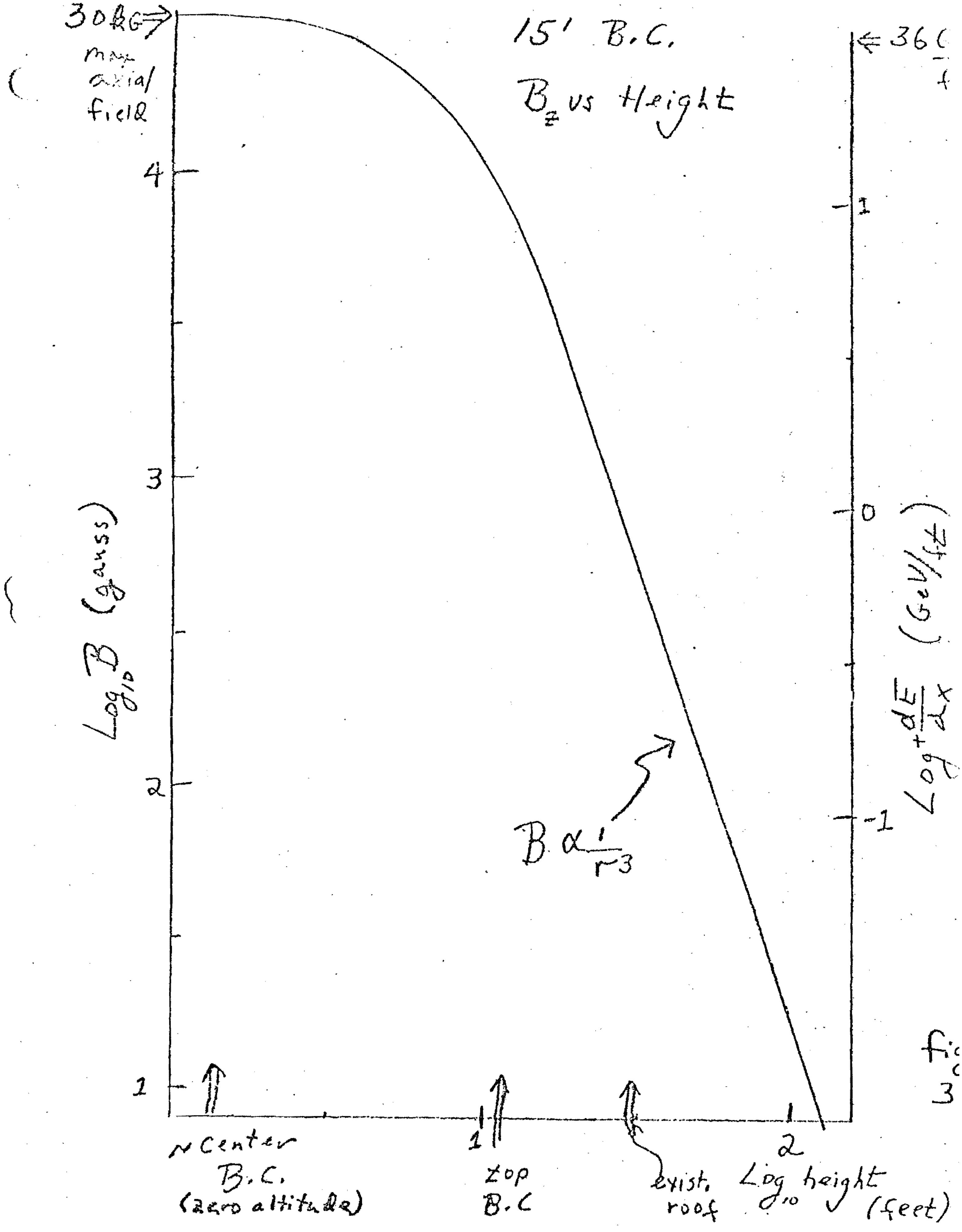
fig 1

Ionization Loss of
Schwinger Monopole
vs ($\gamma - 1$)

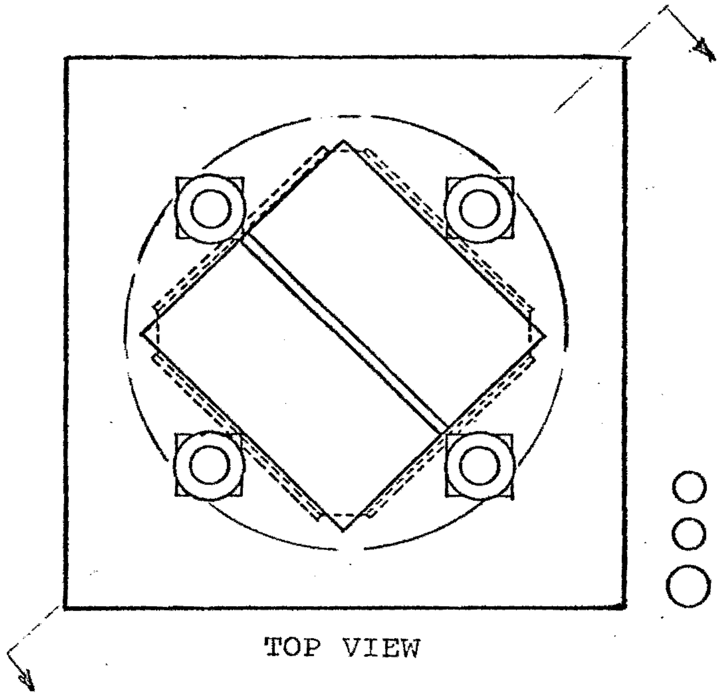


Point X gives "conventional" point equivalent to $(137)^2 \times$ ionization for minimum ionizing, singly charged electrical particle.

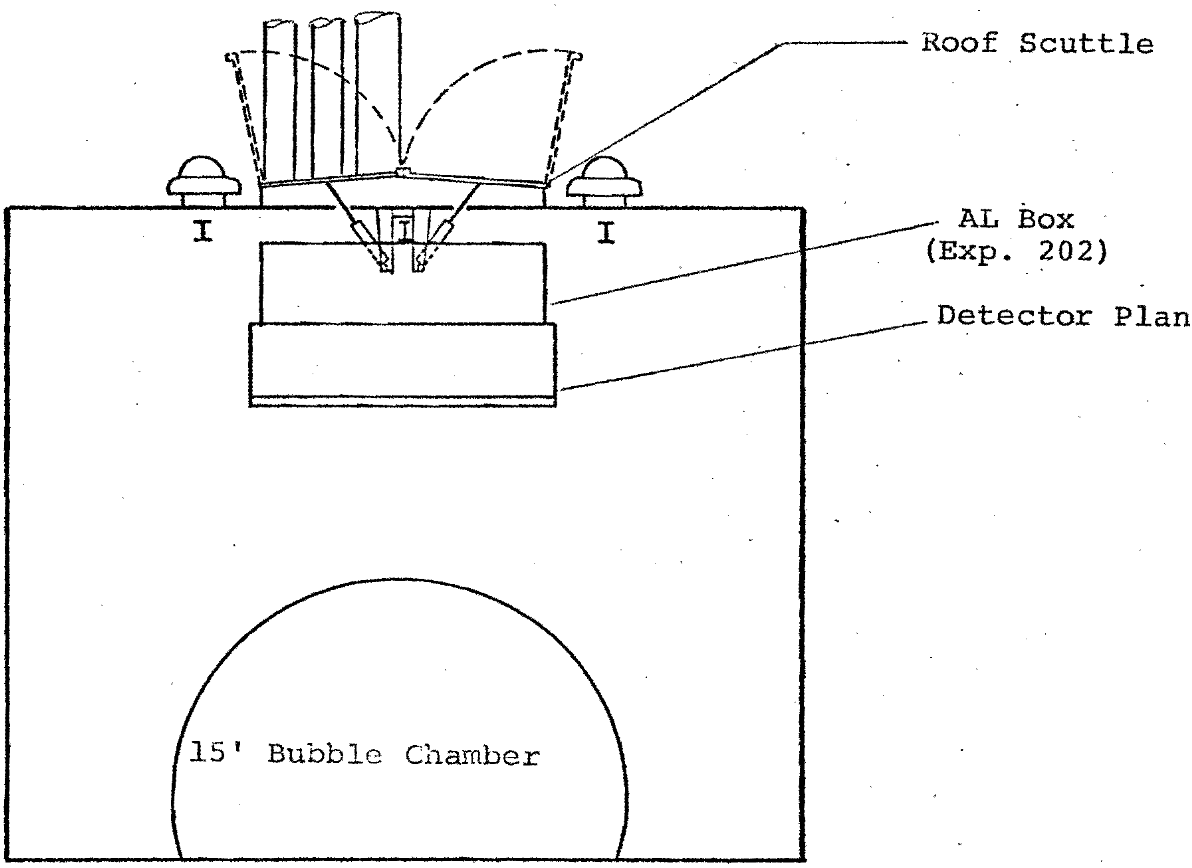
fig 2



30kG
max axial field
15' B.C.
B_z vs Height
4
3
2
1
Log10 B (gauss)
36
1
0
-1
Log dE/dx (GeV/ft)
B α 1/r3
center B.C. (zero altitude)
1
top B.C
exist. roof
2
Log10 height (feet)



TOP VIEW



VIEW FROM SOUTH

Figure 4

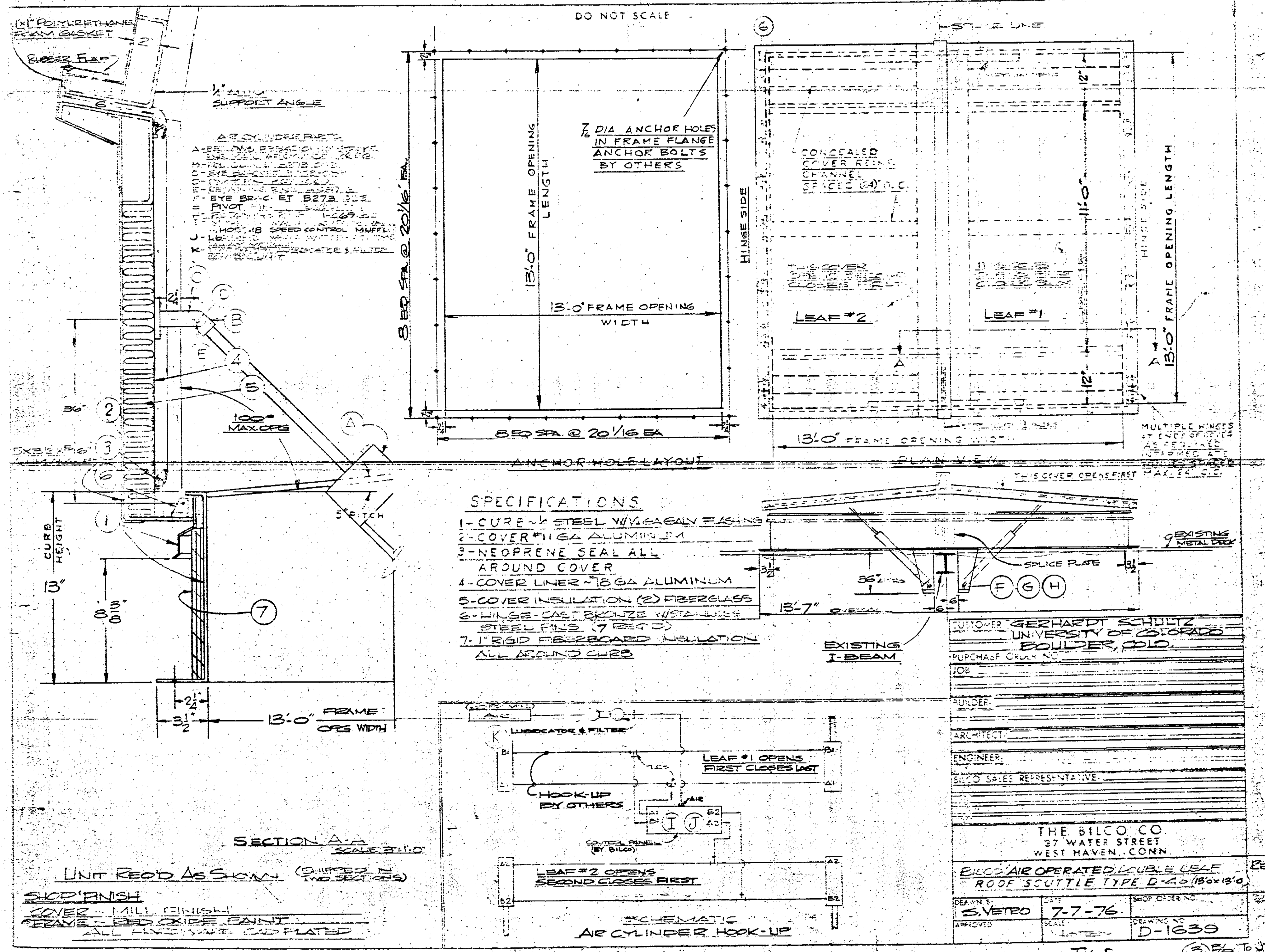
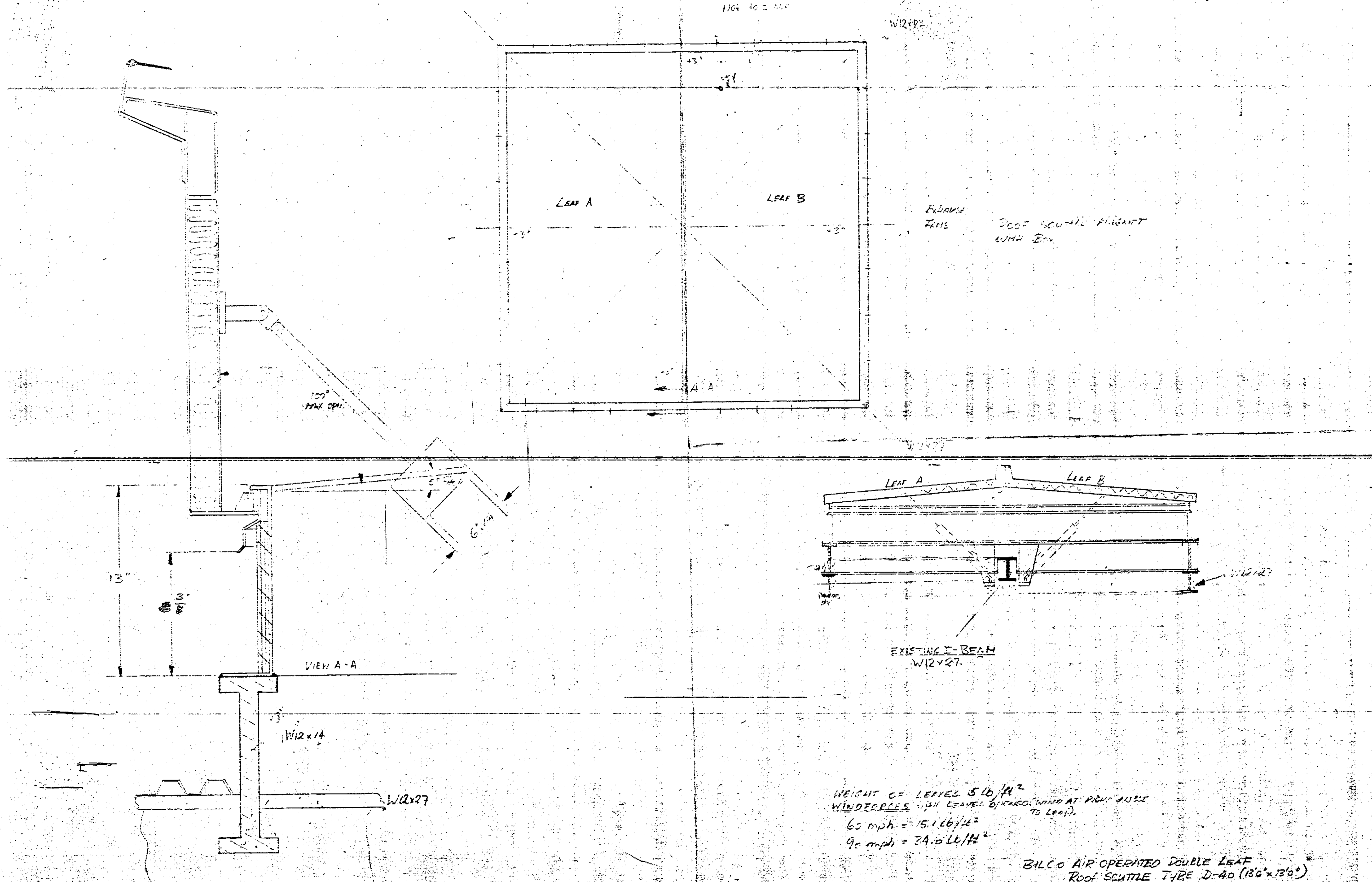

DO NOT SCALE
1x1" POLYURETHANE FOAM GASKET
RUBBER FLAP
1/4" ALUM SUPPORT ANGLE
AIR CYLINDER PARTS
7/16 DIA ANCHOR HOLES IN FRAME FLANGE ANCHOR BOLTS BY OTHERS
13'-0" FRAME OPENING LENGTH
13'-0" FRAME OPENING WIDTH
8 EQ SPA @ 20 1/16 EA
HINGE SIDE
ANCHOR HOLE LAYOUT
CONCEALED COVER REINF CHANNEL SPACED (24") O.C.
LEAF #2
LEAF #1
13'-0" FRAME OPENING WIDTH
13'-0" FRAME OPENING LENGTH
PLAN VIEW
MULTIPLE HINGES AT ENDS OF COVER AS REQUIRED
THIS COVER OPENS FIRST
100° MAX. OPG
5° PITCH
36"
CURB HEIGHT
13"
8 3/8"
2 1/4"
3 1/2"
13'-0" FRAME OPG WIDTH
SPECIFICATIONS
1- CURB ~ 1/4 STEEL W/16 GA GALV FLASHING
2- COVER #11 GA ALUMINUM
3- NEOPRENE SEAL ALL AROUND COVER
4- COVER LINER ~ 18 GA ALUMINUM
5- COVER INSULATION (2) FIBERGLASS
6- HINGE - CAST BRONZE W/STAINLESS STEEL PINS (7 REQ'D)
7- 1" RIGID FIBERBOARD INSULATION ALL AROUND CURB
EXISTING METAL DECK
SPLICE PLATE
13'-7" OVERALL
EXISTING I-BEAM
SECTION A-A
SCALE 3"=1'-0"
UNIT REQ'D AS SHOWN (SHIPPED IN TWO SECTIONS)
SHOP FINISH
COVER - MILL FINISH
FRAME - RED OXIDE PAINT
ALL HINGES ... CAD PLATED
AIR
LUBRICATOR & FILTER
LEAF #1 OPENS FIRST CLOSES LAST
HOOK-UP BY OTHERS
CONTROL PANEL (BY BILCO)
LEAF #2 OPENS SECOND CLOSES FIRST
SCHEMATIC AIR CYLINDER HOOK-UP
CUSTOMER GERHARDT SCHULTZ UNIVERSITY OF COLORADO BOULDER, COLO.
PURCHASE ORDER NO.
JOB
BUILDER
ARCHITECT
ENGINEER
BILCO SALES REPRESENTATIVE
THE BILCO CO. 37 WATER STREET WEST HAVEN, CONN.
BILCO AIR OPERATED DOUBLE LEAF ROOF SCUTTLE TYPE D-40 (13'0"x13'0")
REV.
DRAWN BY S. VETRO
DATE 7-7-76
SHOP ORDER NO.
APPROVED
SCALE
DRAWING NO. D-1639

FIG. 5



WEIGHT OF LEAVES 5 Lb/ft²
WINDFORCES WITH LEAVES OPENED (WIND AT RIGHT ANGLE TO LEAF)
60 mph = 15.1 Lb/ft²
90 mph = 34.0 Lb/ft²

BILCO AIR OPERATED DOUBLE LEAF
Roof SCUTTLE TYPE D-40 (13'0"x13'0")

7-18-76

FIG: 6