Fermilab

F.Kircher:er
2/12/79

TEST OF LQT-1

LQT-1 is the first 10" long trim quadrupole. It was tested on February 8 in Lab 5 (helium bath).

I. TRAINING

The coil has shown training although we tried to reduce it by pulsing a small current during cooldown.

Quench #	I Quench (A)	dI/dt (A/sec)
1	52	10
2	54	10
3	60	2
4	65	1
5	68	1
6	70	1
7	71	1
8	74	1
9	75	1
10	80	10
11	85	1
12	86	2
13	89	10
14	90	10

The maximum current reached (90A) is about 75% of the critical current along the load line (see Fig. 1).

The coil did not show any degradation when ramped between 1A/sec and 40A/sec.

II.-1. INTEGRAL STRENGTH

Its value vs. the current is lower than expected:

Current (A)	$\int B_{quad} dl$ at 1" (kg inch)	Transfer Function (kg inch/A)
25.1	19.4	0.773
38.1	29.7	0.769
50.0	38.5	0.767
62.9	47.1	0.748
74.8	53.7	0.718

Cont'd.

With the present design, a current of 71A is needed to get the nominal value of 52 kg inch. The deduced magnetic length from these results is 7.4 inches (at 50A). The reason for getting a shorter magnetic length than expected is the random winding which does not enable to get the theoretical shape of the body as the number of turns increases.

Without changing the body design the following total length of the coil can be deduced to reach the nominal value of 52 kg inch:

11.2" for a current of 60A.

12.6" for a current of 50A.

II.-2. FIELD HOMOGENEITY

Value of $\frac{\int B_N dl}{\int B_{quad} dl}$ at 1" for 50A and 75A:

N	50A	75A
Sextupole	3.0 E-3	3.6 E-3
Octopole	2.1 E-3	2.2 E-3
Decapole	3 E-4	4. E-4
12 Pole	5.6 E-3	7.0 E-3
20 Pole	2 E-4	2. E-4

The integral field and the magnetic homogeneity show some iron saturation effects.

III. PROTECTION

The effect of the voltage threshold and the value of the dump resistance on the current decay after a quench were studied:

τ is such as $I(\tau) = \frac{I_{max}}{e}$

$\bar{R}_i$ is such as $\tau = \frac{L}{R_d + R_i}$ (L = 250mH)

$\int I^2 dt = I^2_{max} \frac{\tau}{2}$

All the quenches were around 90A (W_s #1kJ)

Cont'd.

R Dump (Ω)	Threshold (V)	τ (m sec)	$\bar{R_i}$ (Ω)	$\int I^2 dt$ (A^2 sec)
0.4	0.35	140	1.4	540
0.4	3.5	160	1.2	610
0.2	0.35	150	1.5	570
0.2	3.5	140	1.8	540
0.1	0.35	140	1.7	540
0.1	3.5	140	1.7	540
0.	0.35	140	1.8	540
0.	3.5	140	1.8	540

The results show that:

- the coil is self-protected and does not need any dump resistance.
- the voltage threshold can be put at a high level.
- the maximum temperature during a quench is around 50K.

IV. CONCLUSIONS OF THE TEST

- Training still to improve.
- Which way to be chosen to reach the nominal strength?
- Is magnetic homogeneity good enough?
- Take into account the results about protection for actual scheme.

FK:er
cc: D.Edwards
H.Edwards
W.B.Fowler
G.R.Kalbfleisch
M.B.Leininger
A.V.Tollestrup
R.Yarema

TEST OF LQT-1

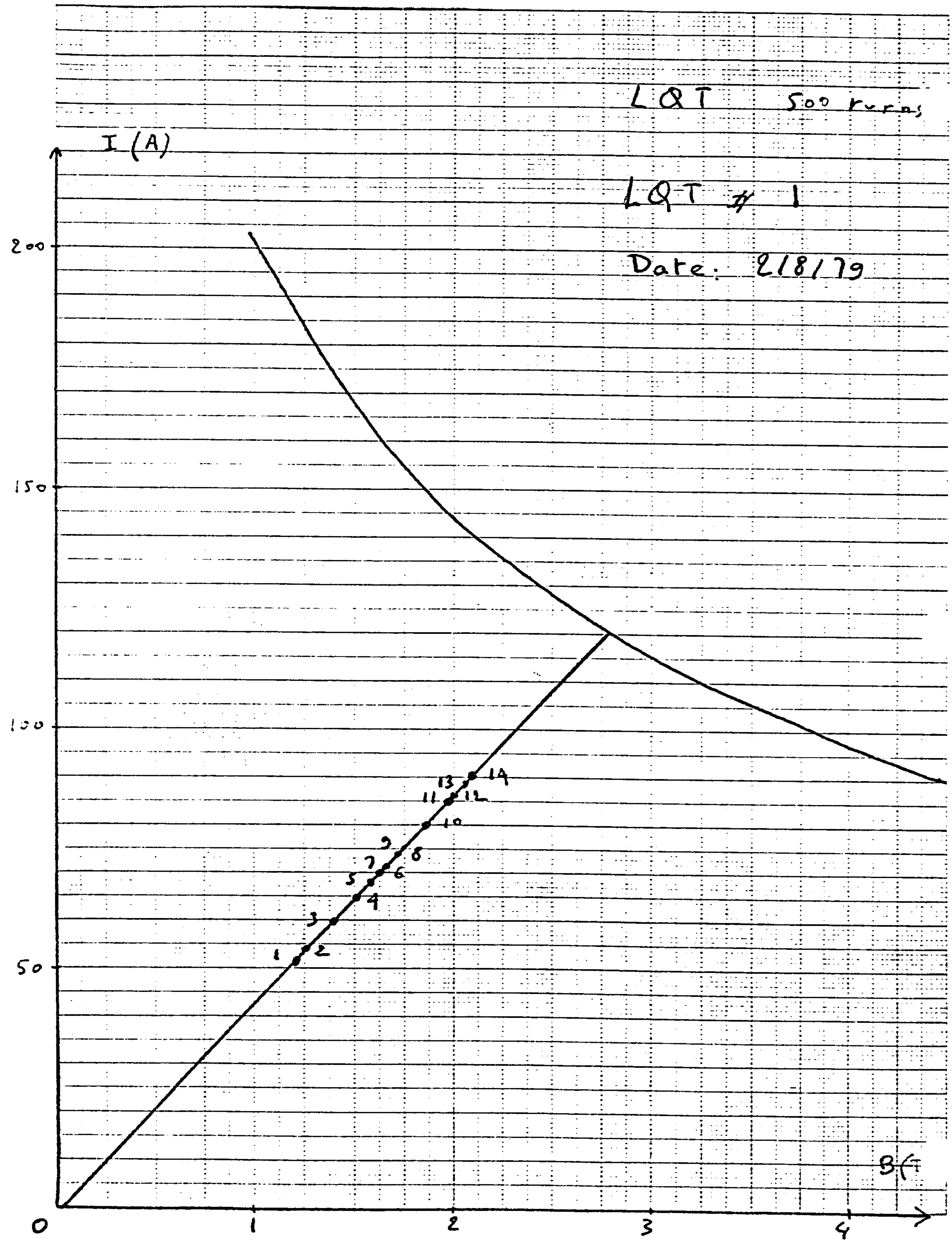


Figure 1.

SUPPLEMENT (addition)

Figures S22 through S25 show energy density distributions in the Doubler magnet coils due to scattering from a beam scraper at a medium straight section. The iron beam scraper with an aperture of 4.5 cm(horizontal) by 2 cm(vertical) and 2 m in length is placed 12 m upstream of the Doubler magnets. The incident proton energy is 1000 GeV. The beam strikes an inside edge of the scraper with an incident angle of 0 mrad. The ϕ angle is π in Figures S22, S23, and S24 and 0 in Figure S25. In Figure S22 beam collimator and vacuum chamber plug are not present. The vacuum chamber radius is 3.68 to 3.81 cm. The vacuum chamber plug with a 5 cm(H) by 3 cm(V) aperture is added in Figure S23. In Figures S24 and S25 a 2 m long iron collimator with a 5 cm(H) by 3 cm(V) aperture is placed immediately upstream of the Doubler magnets. The plug and collimator reduce the peak energy density to about 6×10^{-3} GeV/(cm^3.interacting proton) from 4×10^{-2} GeV/(cm^3.interacting proton).

Figures S26 through S33 show energy density distributions due to scattering from the extraction wire septum for various configurations of the beam bump arrangement at the long straight section. Four B-2 type bending magnets are used for the beam bump of 3 mrad as shown in Figure 6. The incident proton energy is 1000 GeV. A string of four quadrupole magnets which are to be placed upstream of the dipole string are omitted in the present study. Figure S26 is essentially the same as Figure 3 in which beam bump, vacuum chamber plug and collimator are not present. A small discrepancy at the upstream end is due to different binnings in the two cases.

Table II summarizes the conditions and peak energy densities.

Table II. Peak energy densities due to scattering from the extraction electrostatic wire septum for various configurations shown in Figures S26 through S33.

Figure	Plug	Beam Bump	Collimator	Peak Energy Density GeV/(cm^3. incid.prot. First	Second
S26	No	No	No	4×10^{-3}	2×10^{-3}
S27	Yes	No	Yes	9×10^{-4}	6×10^{-4}
S28	No	4M, H-In	-	-	9×10^{-4}
S29	No	3M, H-In	-	-	4×10^{-4}
S30	Yes	3M, H-In	-	2×10^{-4}	5×10^{-5}
S31	Yes	3M, H-Out	-	2×10^{-4}	$6 \times 10^{-}$
S32	No	3M, V	-	-	8×10^{-5}
S33	Yes	3M, V	-	5×10^{-5}	4×10^{-5}

The 2 m long iron collimator with an aperture of 5 cm(H) by 3 cm(V) is used only in Figure S27. The vacuum chamber plug is made of iron and has an aperture of 5 cm(H) by 3 cm(V). The beam bumps, 4M and 3M correspond to the arrangements in which the electrostatic wire septum is placed upstream and downstream of the first bump magnet, respectively. The H-In and H-Out are the horizontal inward and outward bumps and the V is the vertical beam bump. The horizontal inward bump arrangement is slightly better than the horizontal outward bump when the vacuum chamber plug is not used, but they are essentially the same when the plug is used. In general, the vertical bump gives much lower peak energy density in the Doubler magnet coils than the horizontal bump because the narrow vertical aperture of the bump magnets is more efficient to absorb off-momentum secondary particles scattered from septum wires.

The peak energy density of 5×10^{-5} GeV/(cm^3.incident proton) achieved by the vertical bump (Figure S33) gives the limits for extraction due to scattering from the electrostatic wire septum of 4.5×10^{14} protons/sec for slow extraction and 1.2×10^{14} protons/pulse of 1 msec. The extraction inefficiency was assumed to be 2.5 %, i.e. 2.5 % of protons strike septum wires.

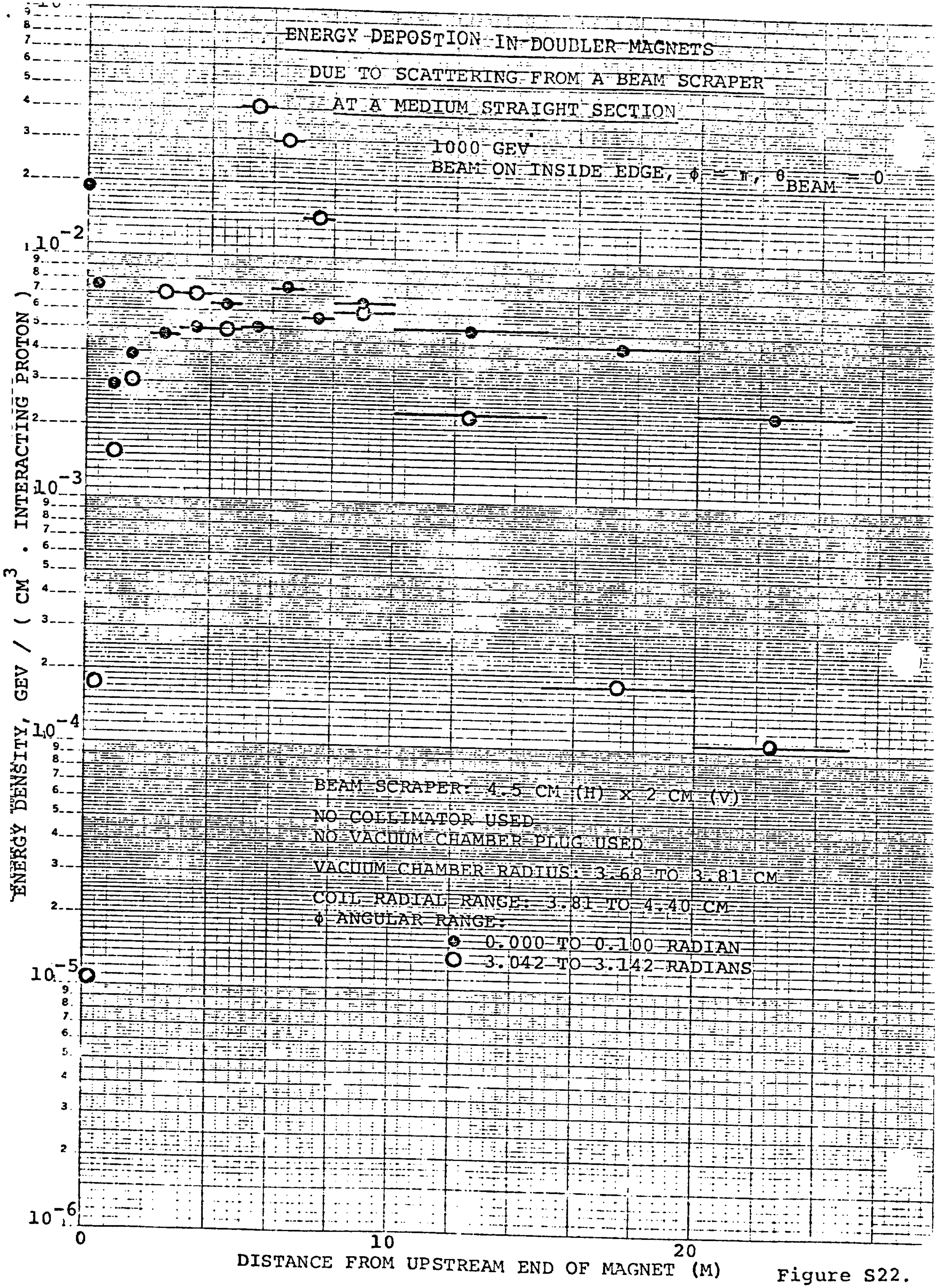

ENERGY DEPOSTION IN DOUBLER MAGNETS
DUE TO SCATTERING FROM A BEAM SCRAPER
AT A MEDIUM STRAIGHT SECTION
1000 GEV
BEAM ON INSIDE EDGE, φ = π, θ BEAM = 0
BEAM SCRAPER: 4.5 CM (H) x 2 CM (V)
NO COLLIMATOR USED
NO VACUUM CHAMBER PLUG USED
VACUUM CHAMBER RADIUS: 3.68 TO 3.81 CM
COIL RADIAL RANGE: 3.81 TO 4.40 CM
φ ANGULAR RANGE:
0.000 TO 0.100 RADIAN
3.042 TO 3.142 RADIANS
ENERGY DENSITY, GEV / (CM3 . INTERACTING PROTON)
DISTANCE FROM UPSTREAM END OF MAGNET (M)
0
10
20
10-2
10-3
10-4
10-5
10-6

Figure S22.

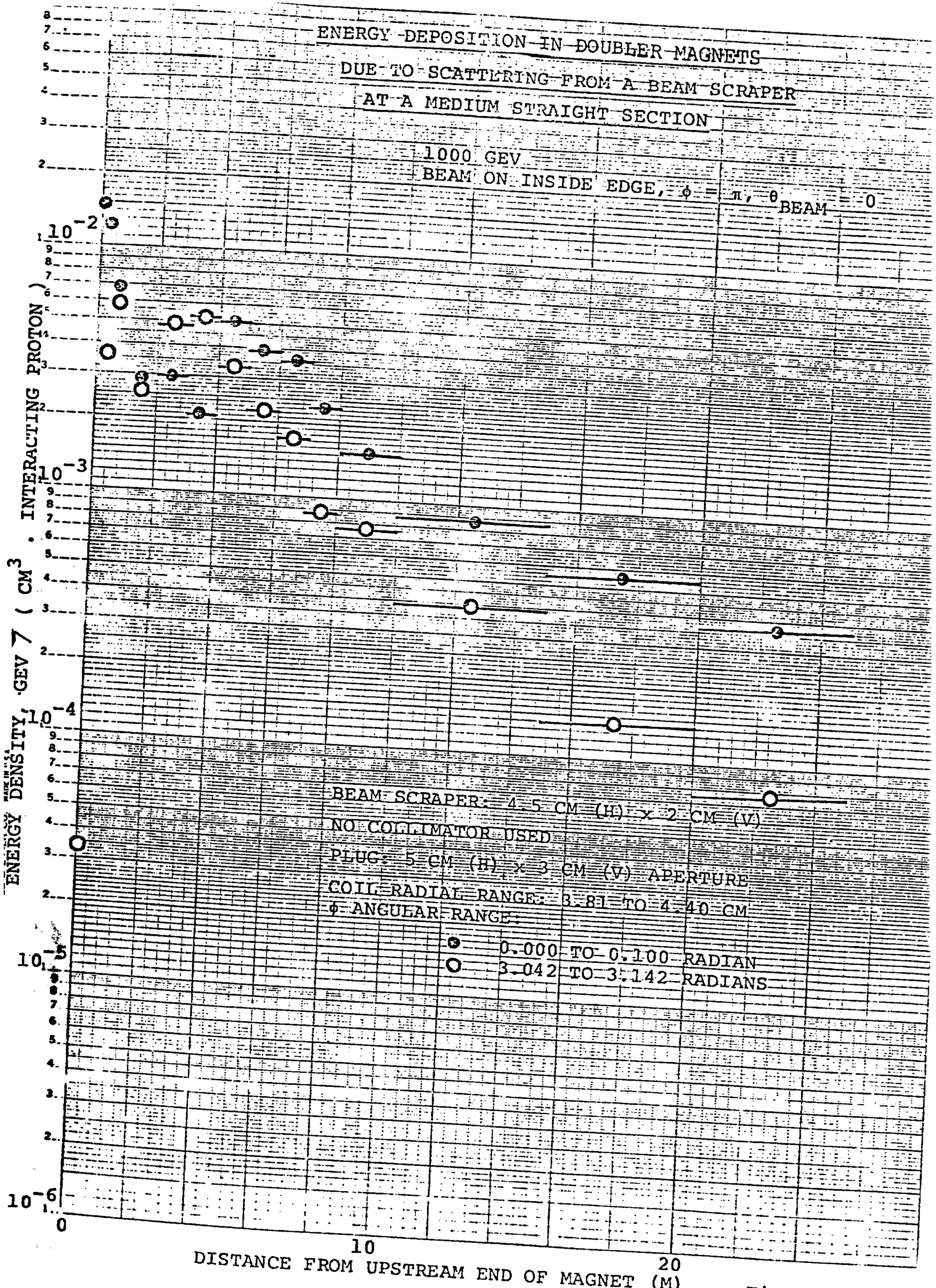

ENERGY DEPOSITION IN DOUBLER MAGNETS
DUE TO SCATTERING FROM A BEAM SCRAPER
AT A MEDIUM STRAIGHT SECTION
1000 GEV
BEAM ON INSIDE EDGE, $\phi = \pi$, $\theta_{BEAM} = 0$
BEAM SCRAPER: 4.5 CM (H) x 2 CM (V)
NO COLLIMATOR USED
PLUG: 5 CM (H) x 3 CM (V) APERTURE
COIL RADIAL RANGE: 3.81 TO 4.40 CM
ϕ ANGULAR RANGE:
0.000 TO 0.100 RADIAN
3.042 TO 3.142 RADIANS
ENERGY DENSITY, GEV / (CM^3 . INTERACTING PROTON)
DISTANCE FROM UPSTREAM END OF MAGNET (M)
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0
10
20

Figure S23.

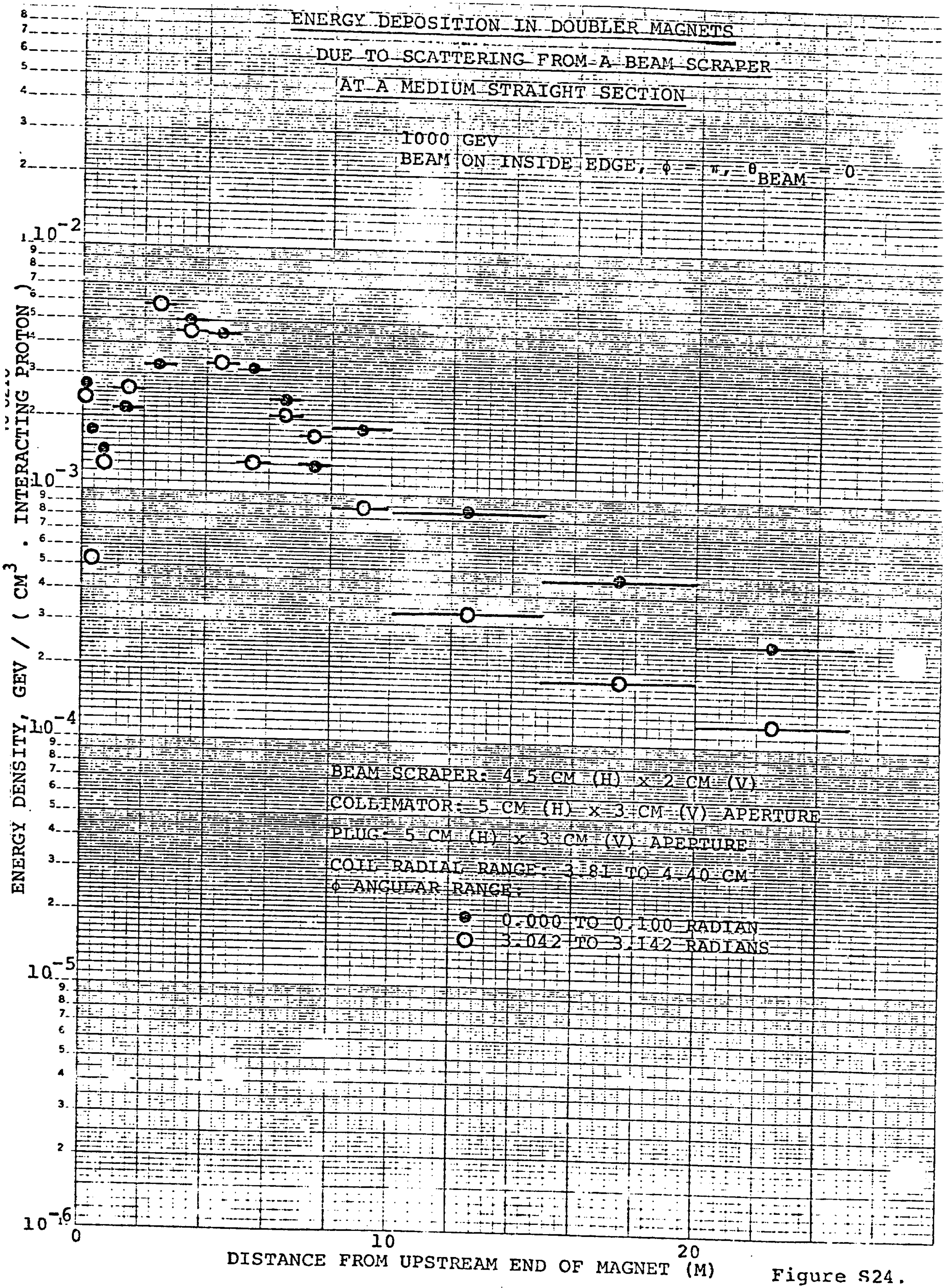
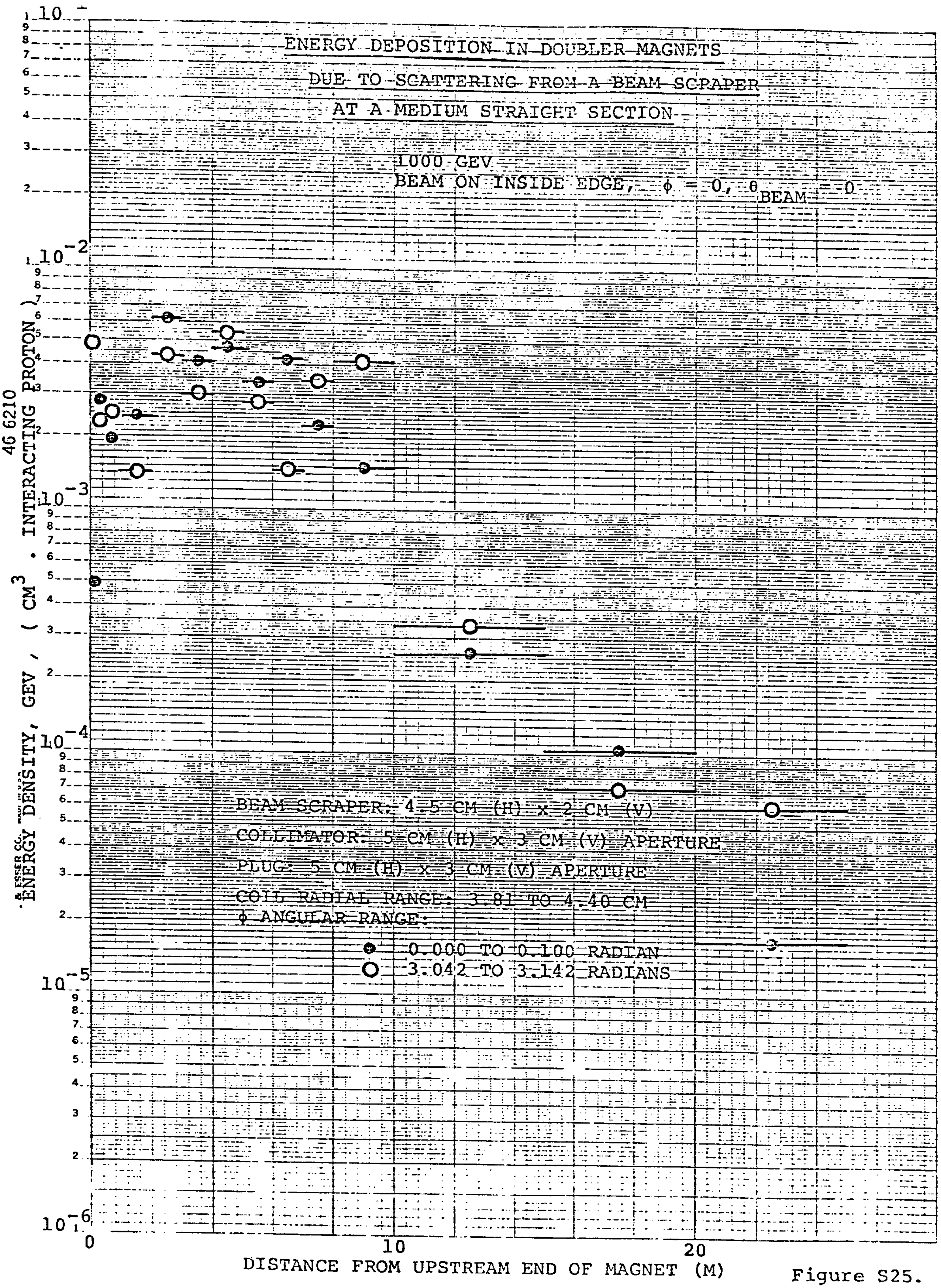
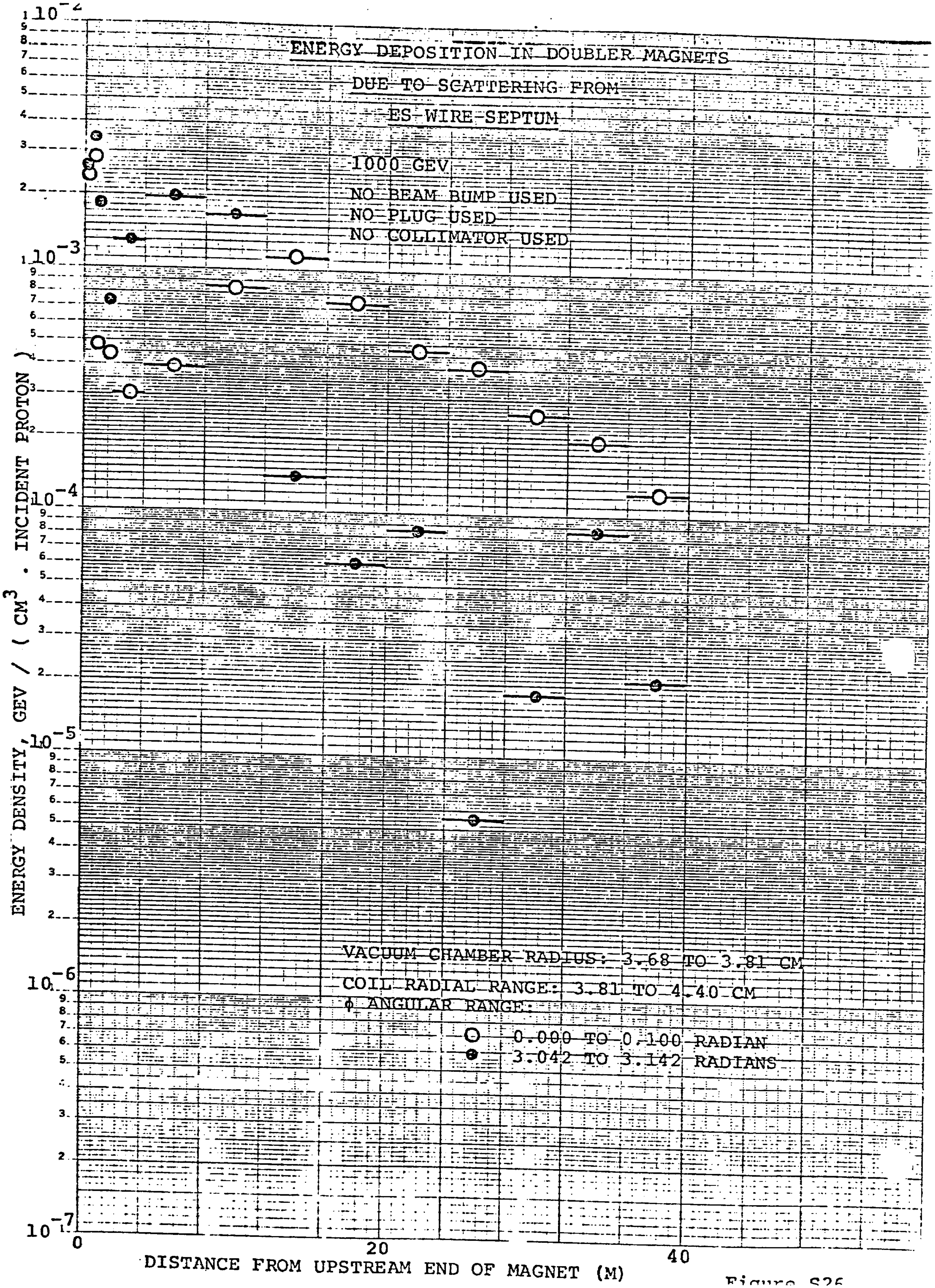

ENERGY DEPOSITION IN DOUBLER MAGNETS
DUE TO SCATTERING FROM A BEAM SCRAPER
AT A MEDIUM STRAIGHT SECTION
1000 GEV
BEAM ON INSIDE EDGE, $\phi = \pi$, $\theta_{BEAM} = 0$
BEAM SCRAPER: 4.5 CM (H) x 2 CM (V)
COLLIMATOR: 5 CM (H) x 3 CM (V) APERTURE
PLUG: 5 CM (H) x 3 CM (V) APERTURE
COIL RADIAL RANGE: 3.81 TO 4.40 CM
ϕ ANGULAR RANGE:
0.000 TO 0.100 RADIAN
3.042 TO 3.142 RADIANS
ENERGY DENSITY, GEV / (CM^3 . INTERACTING PROTON)
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0
10
20
DISTANCE FROM UPSTREAM END OF MAGNET (M)

Figure S24.


ENERGY DEPOSITION IN DOUBLER MAGNETS
DUE TO SCATTERING FROM A BEAM SCRAPER
AT A MEDIUM STRAIGHT SECTION
1000 GEV
BEAM ON INSIDE EDGE, ϕ = 0, θ_{BEAM} = 0
BEAM SCRAPER: 4.5 CM (H) x 2 CM (V)
COLLIMATOR: 5 CM (H) x 3 CM (V) APERTURE
PLUG: 5 CM (H) x 3 CM (V) APERTURE
COIL RADIAL RANGE: 3.81 TO 4.40 CM
ϕ ANGULAR RANGE:
0.000 TO 0.100 RADIAN
3.042 TO 3.142 RADIANS
ENERGY DENSITY, GEV / (CM^3 · INTERACTING PROTON)
DISTANCE FROM UPSTREAM END OF MAGNET (M)
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0
10
20
46 6210
Figure S25.


ENERGY DEPOSITION IN DOUBLER MAGNETS
DUE TO SCATTERING FROM
ES WIRE SEPTUM
1000 GEV
NO BEAM BUMP USED
NO PLUG USED
NO COLLIMATOR USED
VACUUM CHAMBER RADIUS: 3.68 TO 3.81 CM
COIL RADIAL RANGE: 3.81 TO 4.40 CM
φ ANGULAR RANGE:
0.000 TO 0.100 RADIAN
3.042 TO 3.142 RADIANS
ENERGY DENSITY, GEV / (CM3 . INCIDENT PROTON)
DISTANCE FROM UPSTREAM END OF MAGNET (M)
0
20
40
Figure S26

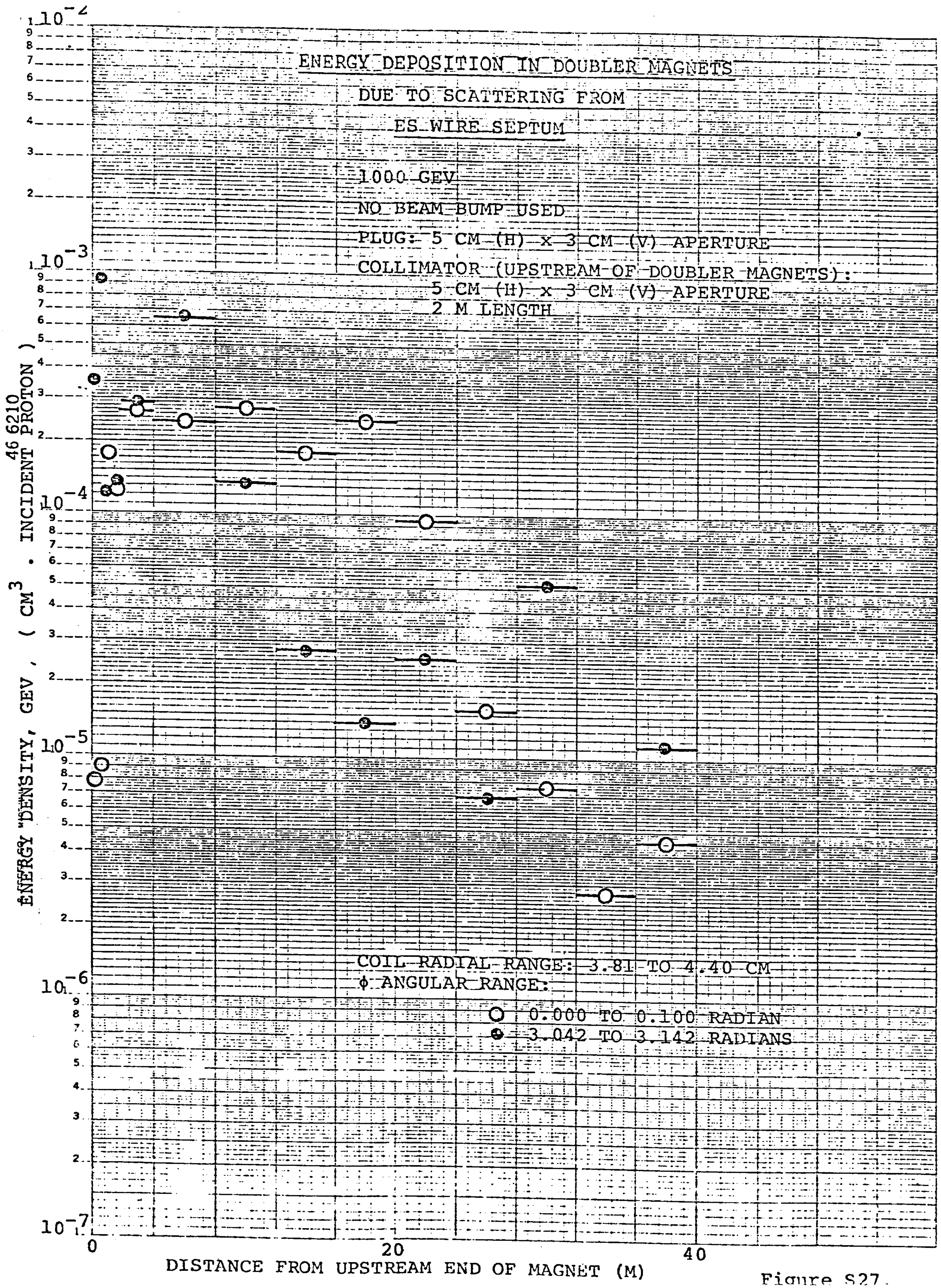

ENERGY DEPOSITION IN DOUBLER MAGNETS
DUE TO SCATTERING FROM
ES WIRE SEPTUM
1000 GEV
NO BEAM BUMP USED
PLUG: 5 CM (H) x 3 CM (V) APERTURE
COLLIMATOR (UPSTREAM OF DOUBLER MAGNETS):
5 CM (H) x 3 CM (V) APERTURE
2 M LENGTH
COIL RADIAL RANGE: 3.81 TO 4.40 CM
ϕ ANGULAR RANGE:
0.000 TO 0.100 RADIAN
3.042 TO 3.142 RADIANS
ENERGY DENSITY, GEV / (CM3 . INCIDENT PROTON)
46 6210
DISTANCE FROM UPSTREAM END OF MAGNET (M)
0
20
40

Figure S27.

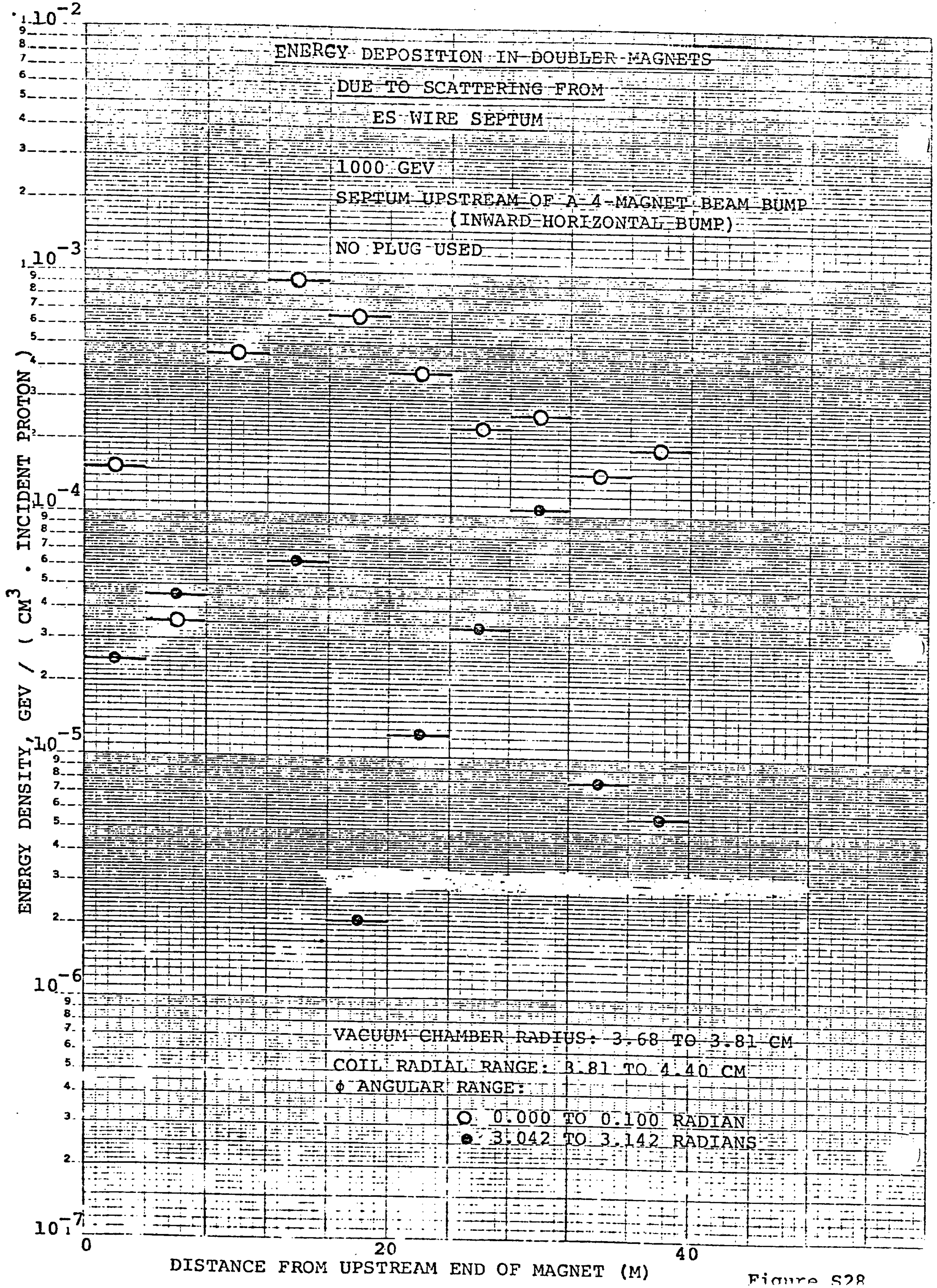

ENERGY DEPOSITION IN DOUBLER MAGNETS
DUE TO SCATTERING FROM
ES WIRE SEPTUM
1000 GEV
SEPTUM UPSTREAM OF A 4-MAGNET BEAM BUMP
(INWARD-HORIZONTAL BUMP)
NO PLUG USED
VACUUM CHAMBER RADIUS: 3.68 TO 3.81 CM
COIL RADIAL RANGE: 3.81 TO 4.40 CM
ϕ ANGULAR RANGE:
0.000 TO 0.100 RADIAN
3.042 TO 3.142 RADIANS
ENERGY DENSITY, GEV / (CM3 . INCIDENT PROTON)
DISTANCE FROM UPSTREAM END OF MAGNET (M)
0
20
40

Figure S28

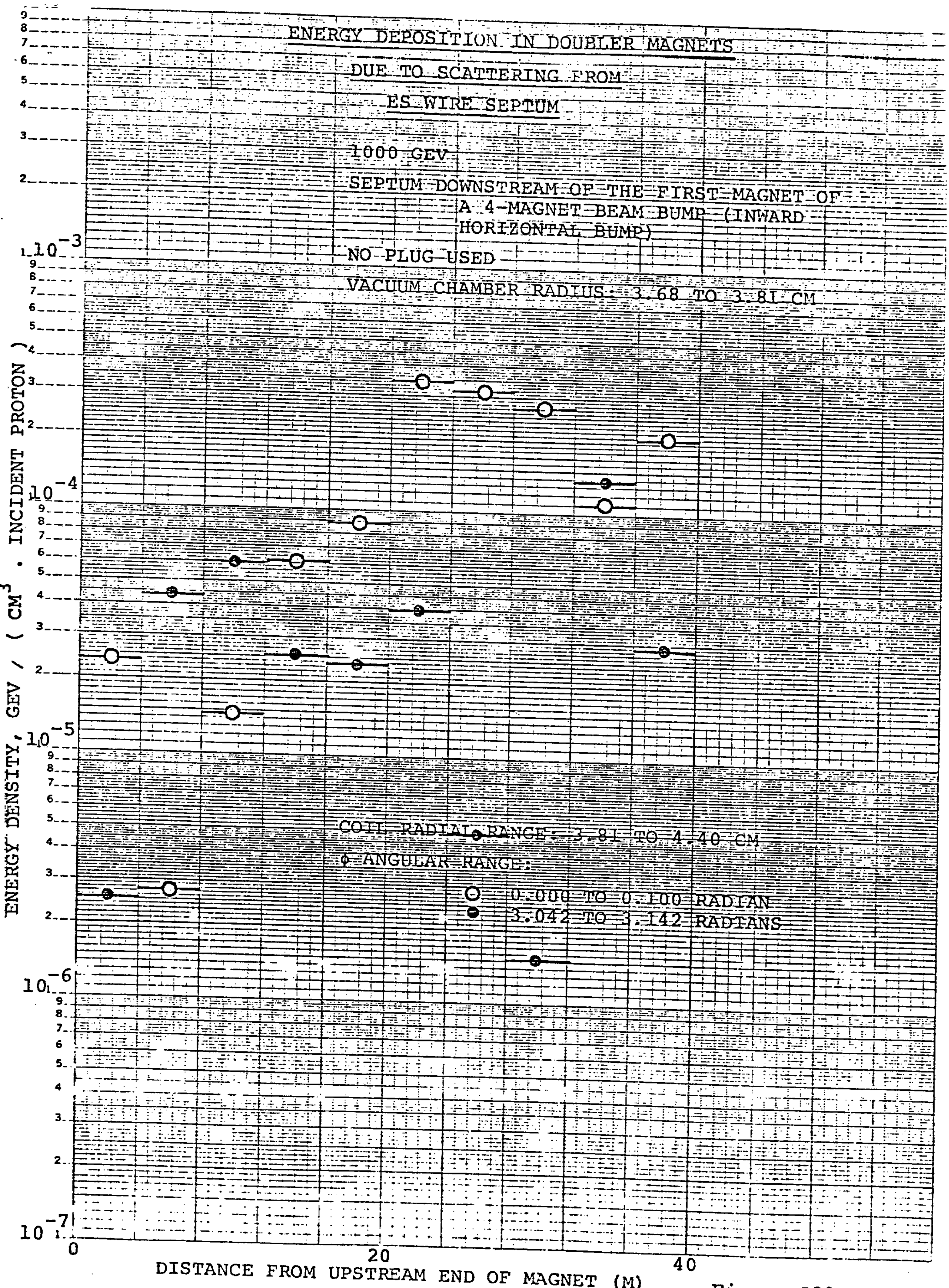
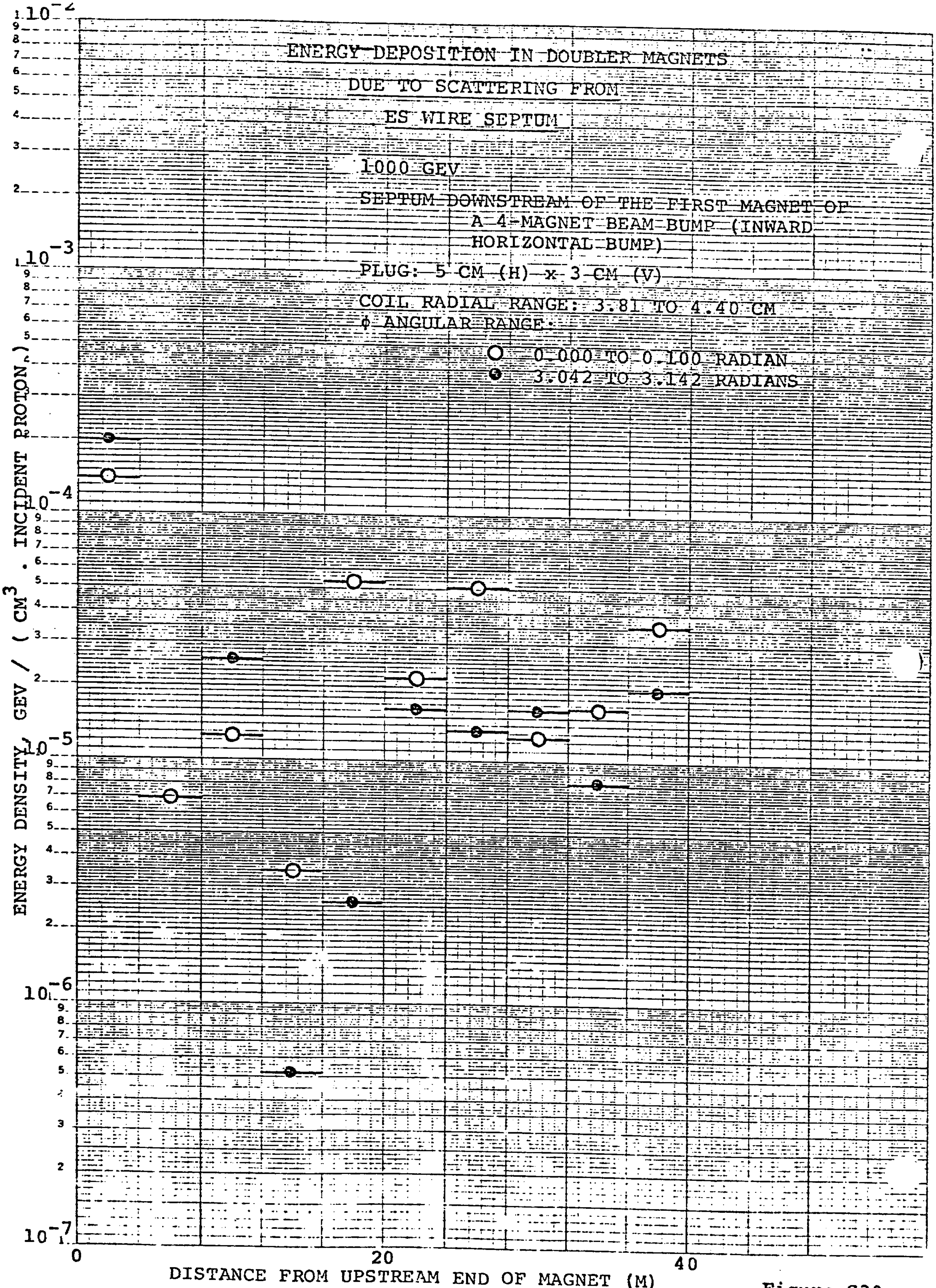
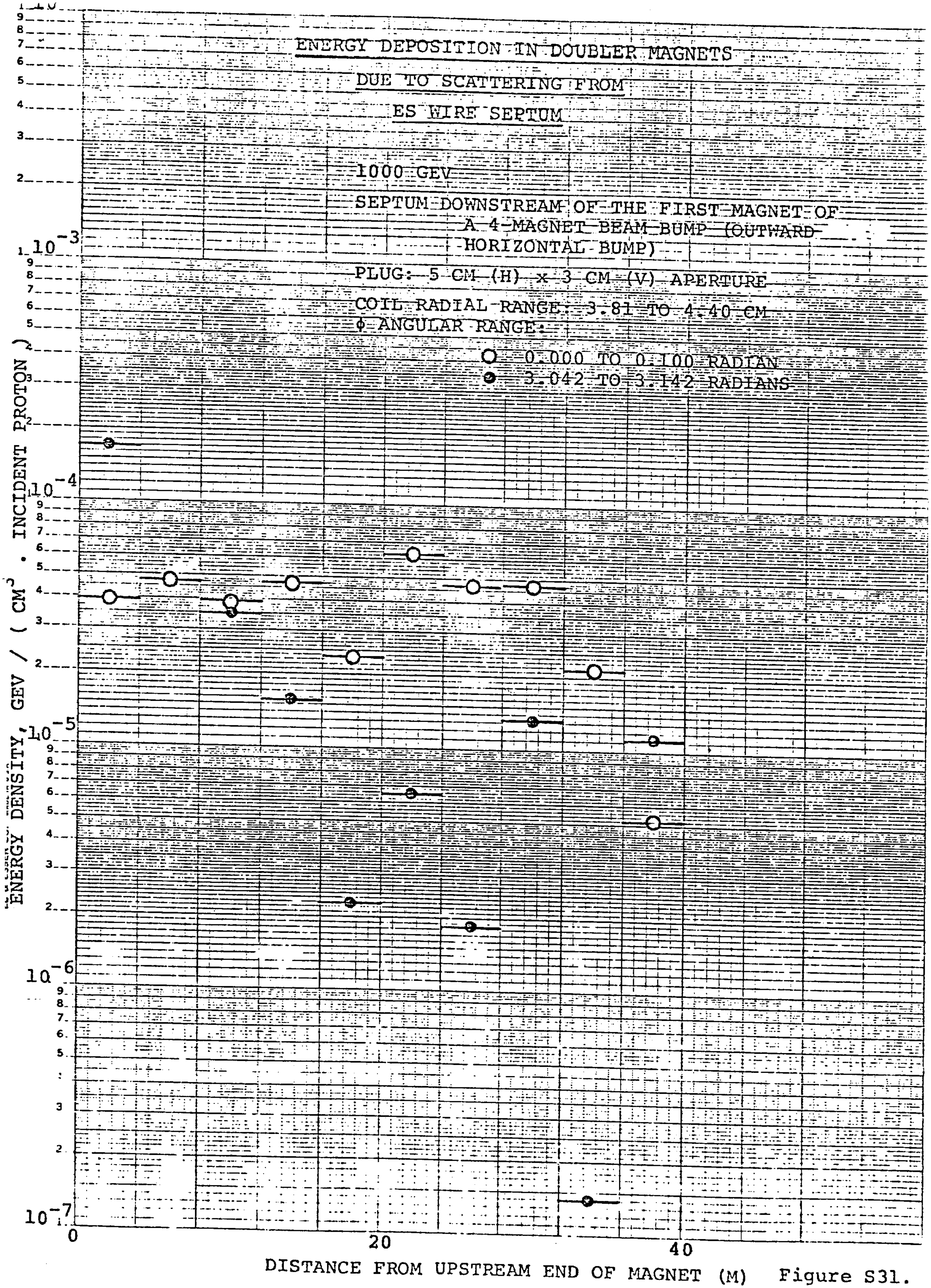

ENERGY DEPOSITION IN DOUBLER MAGNETS
DUE TO SCATTERING FROM
ES WIRE SEPTUM
1000 GEV
SEPTUM DOWNSTREAM OF THE FIRST MAGNET OF A 4-MAGNET BEAM BUMP (INWARD HORIZONTAL BUMP)
NO PLUG USED
VACUUM CHAMBER RADIUS: 3.68 TO 3.81 CM
COIL RADIAL RANGE: 3.81 TO 4.40 CM
φ ANGULAR RANGE:
0.000 TO 0.100 RADIAN
3.042 TO 3.142 RADIANS
ENERGY DENSITY, GEV / (CM3 . INCIDENT PROTON)
DISTANCE FROM UPSTREAM END OF MAGNET (M)
10-3
10-4
10-5
10-6
10-7
0
20
40

Figure S29.



ENERGY DEPOSITION IN DOUBLER MAGNETS
DUE TO SCATTERING FROM
ES WIRE SEPTUM
1000 GEV
SEPTUM DOWNSTREAM OF THE FIRST MAGNET OF A 4-MAGNET BEAM BUMP (INWARD HORIZONTAL BUMP)
PLUG: 5 CM (H) x 3 CM (V)
COIL RADIAL RANGE: 3.81 TO 4.40 CM
φ ANGULAR RANGE:
0.000 TO 0.100 RADIAN
3.042 TO 3.142 RADIANS
ENERGY DENSITY, GEV / (CM3 . INCIDENT PROTON)
DISTANCE FROM UPSTREAM END OF MAGNET (M)
10-2
10-3
10-4
10-5
10-6
10-7
0
20
40

Figure S30.


ENERGY DEPOSITION IN DOUBLER MAGNETS
DUE TO SCATTERING FROM
ES WIRE SEPTUM
1000 GEV
SEPTUM DOWNSTREAM OF THE FIRST MAGNET OF A 4-MAGNET BEAM BUMP (OUTWARD HORIZONTAL BUMP)
PLUG: 5 CM (H) x 3 CM (V) APERTURE
COIL RADIAL RANGE: 3.81 TO 4.40 CM
ϕ ANGULAR RANGE:
0.000 TO 0.100 RADIAN
3.042 TO 3.142 RADIANS
ENERGY DENSITY, GEV / (CM³ . INCIDENT PROTON)
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
0
20
40
DISTANCE FROM UPSTREAM END OF MAGNET (M)
Figure S31.

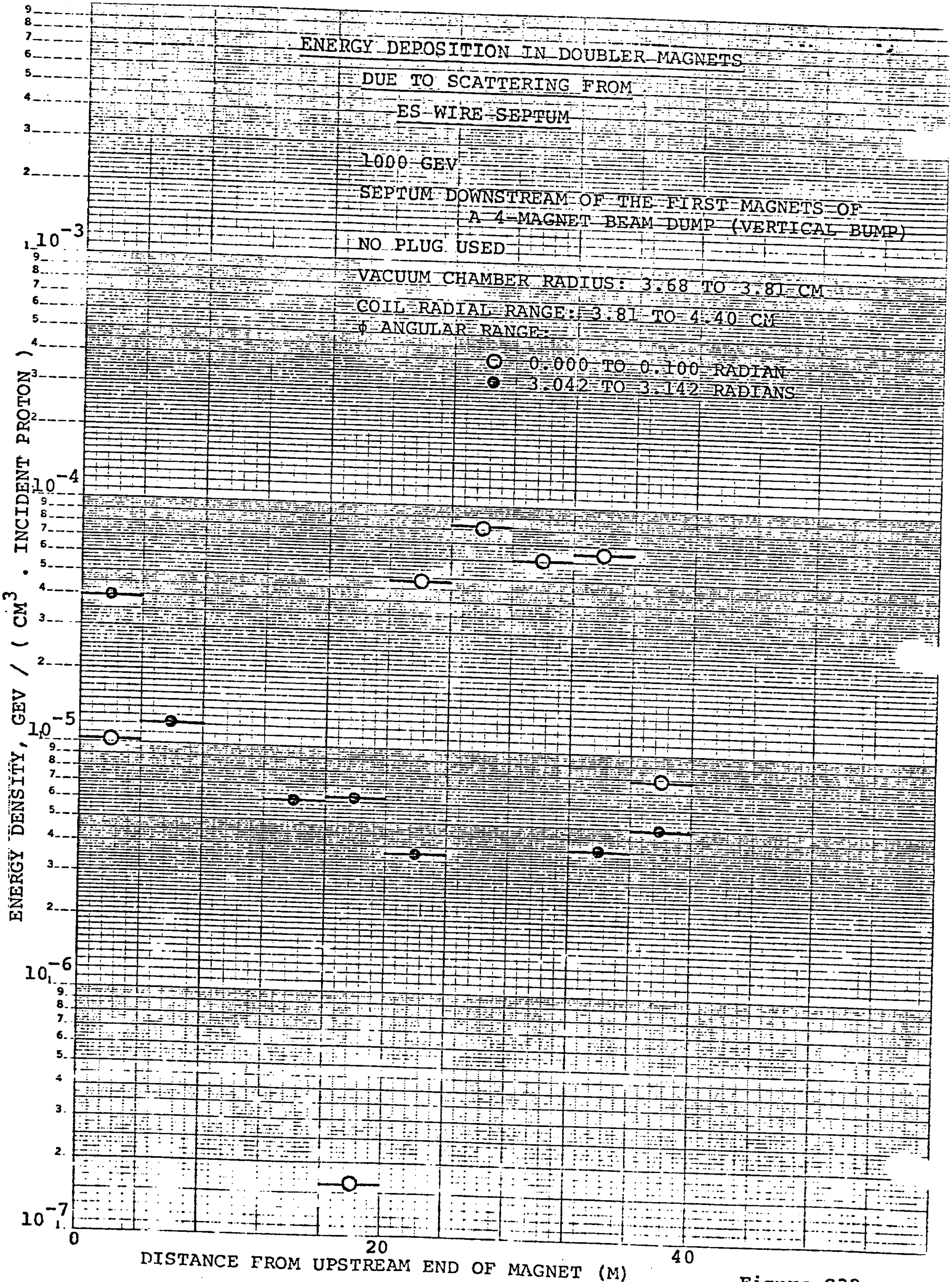

ENERGY DEPOSITION IN DOUBLER MAGNETS
DUE TO SCATTERING FROM
ES WIRE SEPTUM
1000 GEV
SEPTUM DOWNSTREAM OF THE FIRST MAGNETS OF
A 4-MAGNET BEAM DUMP (VERTICAL BUMP)
NO PLUG USED
VACUUM CHAMBER RADIUS: 3.68 TO 3.81 CM
COIL RADIAL RANGE: 3.81 TO 4.40 CM
φ ANGULAR RANGE:
0.000 TO 0.100 RADIAN
3.042 TO 3.142 RADIANS
ENERGY DENSITY, GEV / (CM3 . INCIDENT PROTON)
10-3
10-4
10-5
10-6
10-7
0
20
40
DISTANCE FROM UPSTREAM END OF MAGNET (M)

Figure S32.

October 16, 1978

R. Dixon/dmt

XVI. 1000 GEV SWITCHYARD UPGRADE

I. Introduction

Over the next 2 years the switchyard will be upgraded to deliver 1000 GeV proton beams to all three Experimental Areas. This report will discuss the schedule and the details for initially attaining this objective. Extraction from the Tevatron will be only briefly mentioned as a starting point for the switchyard discussion because many of the details are undetermined at this time. Also, to be discussed are the additional beam splitting stations being planned for the neutrino and meson beam lines.

Figure 1 gives the overall layout of the switchyard and should be used for the locations of the various enclosures and manholes in the following discussion. The major change necessary for achieving 1000 GeV in the switchyard is the replacement of the conventional EPB dipoles, making up the major horizontal bends in the proton and meson beam lines with superconducting Energy Doubler/Saver magnets. Vertical bending magnets and all quadrupoles will remain conventional in the initial upgrade. Under this plan the neutrino beam line will contain no superconducting devices.

The most significant modification to the neutrino beam will be the addition of a separate muon beam. This will be done by splitting the neutrino beam downstream of the present meson split resulting in a new beam line that will be targeted independently to the east of the present neutrino target area. The new muon beam line will require one set of superconducting dipoles.

The other split to be added in the switchyard will occur in the meson beam line. The first step will be a two-way split initiated in the F1 manhole by one electrostatic septum. This split will only be functional up to 450 GeV, howevever, future plans call for an eventual upgrading to a three-way split that will be operable at 1000 GeV.

II. Extraction

The details of extraction from the Tevatron are currently being worked on by Helen Edwards and Mike Harrison and will not be discussed in detail here. A significant change being considered would move the extraction septa to either D0 or F0 to alleviate the beam loss problem in the Transfer Hall. Also, in the present thinking the extraction Lambertsons and the extraction channel will be located directly beneath their main ring counterparts. Instead of bending the proton beam down at the Lambertsons and away from the accelerator in the extraction channel, the extracted Tevatron beam will be bent up at the Lambertsons (Fig. 2). In order to bring the beam to the present switchyard elevation in the center of the Transfer Hall extension a 5 mr bend is required. This can be accomplished with six extraction Lambertsons placed below the present main ring Lambertsons. The extraction channel will require 4 C-magnets and 14 H-magnets rather than two and seven presently in use. No vertical bending magnet will be required in the Tevatron extraction channel. The first vertical bend occurs at MVT90 which is used to adjust the proton split ratio. Quadrupoles MQ90 and MQ91 will be moved downstream of the splitting station into the transfer hall extension to make room for the additional magnets required in the extraction channel.

Also, required in the transfer hall extension is a switching magnet that will cancel the 5 mr vertical rise of the Tevatron beam and correct the 1 mr horizontal angle placing the beam into the present switchyard channel. This magnetic switch is conceivably a 22-foot Doubler magnet or two conventional main ring dipoles.

III. Proton Beam Line

The first modification that must be made to the proton beam line occurs at the electrostatic septa for the proton split. In order to maintain the present beam separation at the proton Lambertsons the number of septa must be increased from three to six with the three additional septa reaching into the transfer hall extension (Fig. 2). There is adequate space for the septa, MQ90, MQ91, and 2 twenty-foot dipoles which make up the magnetic switch mentioned above.

The Tevatron beam joins present switchyard beam line in the transfer hall extension just upstream of the proton Lambertsons, MH300, therefore a new set of Lambertsons is not required. However, it is necessary to achieve a 6.5 mr bend in the Lambertsons at 1000 GeV. This can be done by adding 2 more Lambertsons downstream of the present set of 5 and by running all of them at approximately 2000 amps instead of the 1200 amps they run at now. The beam line correction for moving the bend center downstream is made at the right bends. The use of more Lambertsons at less current is ruled out by the maximum beam separation permissable within the magnets, however there is an alternative. The number of Lambertsons can remain at 5 with the addition of 5 downstream H-magnets. This requires a total current of only 1000 amps through the Lambertsons and H-mangets. Again movement of the bend center must be accounted for downstream.

The right bends begin in Enclosure B and continue into Enclosure D. They account for a total horizontal bend of 77 mrads which can easily be made using 11 Doubler magnets running at 35 KG. These magnets replace 16 EPB dipoles in Enclosure B and 18 EPB dipoles in Enclosure D. The 11 superconducting magnets will be placed in 2 continuous sections, 5 in Enclosure B and 6 in Enclosure D. Twenty-two foot Doubler magnets can be put into Enclosure B through the transfer hall, however an access shaft must be constructed at the downstream end of Enclosure D to admit Doubler magnets. One such shaft has already been constructed in the meson beam line and will be described in the meson section.

Quadrupoles which are now interspersed in the two bend sections will be moved to either end of the string to minimize the complications arising from breaking the superconducting string. MQ301 is moved downtream 80 feet to the end of the first section and MQ304 is moved downstream 30 feet to the end of the second bend section.

Other changes necessary in the proton beam line will be to increase the number of conventional quadrupoles and trim magnets to provide additional focusing and bending power at 1000 GeV. There will be adequate room for this change everywhere except at MQ302. At that location an additional five-foot quadrupole can be added to achieve the required focusing. It will be necessary to move MQ310 and MQ311 130 feet upstream in order to make room for the additional splitting septa, trims and vertical bending magnets in Enclosure E (Fig. 3), which will be required to maintain the three-way split. Five additional septa will be required as well as 3 additional B1 magnets for the vertical bends, MV310. The space for these changes is obtained by moving beam line elements into the drift space at the upstream end of Enclosure E. Enclosure H modifications are being designed by the Proton Department and the details can be found in Reference 1. Table I is a summary of the additional proton beam line elements required to reach 1000 GeV.

IV. Neutrino Beam Line

Necessary modifications to the neutrino beam line are detailed in TM-796. Those details will be briefly reviewed here. The primary change is the addition of a muon beam line which will necessitate a new splitting station beginning just downstream of the meson split. To accommodate this split a new enclosure must be added along side the upstream end of Enclosure C (Fig. 4). The new enclosure will house 60 feet of electrostatic septum which will introduce a .22 mrad horizontal deflection between the NO beam and the new muon beam, MU0. Five 10-foot Lambertson magnets for the split will be placed in the G1 manhole and the existing G1 quadrupole doublet and drift space will be removed. At this point the MU0 beam is bent down 2.7 mrad.

move MQ310 and MQ311 130 feet upstream in order to make room for the additional splitting septa, trims and vertical bending magnets in Enclosure E (Fig. 3), which will be required to maintain the three-way split. Five additional septa will be required as well as 3 additional B1 magnets for the vertical bends, MV310. The space for these changes is obtained by moving beam line elements into the drift space at the upstream end of Enclosure E. Enclosure H modifications are being designed by the Proton Department and the details can be found in Reference 1. Table I is a summary of the additional proton beam line elements required to reach 1000 GeV.

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The vertical bend, MV100, will be made with 70 feet of main ring B2-type magnets running at 16 KG. These magnets will be located upstream of the new splitting station with the bend center moved approximately 10 feet from its present location.

The beams enter the G2 manhole with the MU0 beam coming in 17.8 inches below the N0 beam line and 2.44 inches to the east. At this point an 8.55 mr downward bend and a 33.5 mrad bend to the east is introduced in MU0. This can be done with four 22-foot Doubler magnets running at 43 kG. Accommodation of this bend requires lengthening of the G2 manhole by about 100 feet to the north. The MU0 and the N0 beams pass through quadrupole doublets in G2 which are each made up of 4 3Q120's.

From G2 the MU0 beam drifts to a target located approximately half way between Neuhall and the target service building. A buried beam pipe along side the neutrino berm and possibly 1 quad enclosure will deliver the beam from G2 to Muhall. The details of this transport will be described in a subsequent report by the Neutrino Department.

The G3 manhole will contain a quadrupole doublet for the N0 beam as well as some horizontal trim magnets (EPB dipoles) which coupled with some additional EPB dipoles located in G2 will correct for the .11 mrad horizontal angle introduced at the electrostatic septa. The electrostatic septa now present in G3 and used for the N7 split will be removed as the N7 bypass line will be discontinued.

Neuhall will contain the downstream string of B2 dipoles which form the second half of the MV100 vertical bend as well as the pre-target triplet which is made up of six 3Q120's. Room is also available for a set of trim magnets which will be necessary for targeting the beam. Table II summarizes the beam line elements required for the neutrino line upgrade.

V. Meson Beam Line

The meson beam line begins with the electrostatic septa located in the downstream end of Enclosure B. The number of these septa must be increased from three to six to attain adequate beam separation at the meson Lambertsons which are located 280' downstream at the beginning of Enclosure C (Fig. 4). This can be done by placing three additional septa downstream of the three existing septa. At 1000 GeV these septa will impart a .14 mrad deflection between the neutrino beam and the meson beam which will result in a .4" separation at the meson Lambertsons.

As at the proton split, the Lambertsons will be followed by 5 C- or H-magnets to provide an 11 mrad bend. The two EPB dipoles, MH201-1 and MH201-2 will be left in their present positions to serve as horizontal trims, and to allow 400-GeV beam to be delivered to the Meson Area through a superconducting left bend without the addition of the C-magnets following the Lambertsons. The left bends begin at the location of MH201-3 with a ten magnet continuous string that ends at MH202-4. MQ201 is placed immediately downstream of the superconducting string and will be made up of two 3Q120's (Fig. 4). MQ202 also moves downstream about 40 feet and becomes two 3Q120's. MQ203 retains it's present position but becomes two 3Q120's instead of one (Fig. 5). MQ204 must be moved upstream 40 feet to allow the second string of superconducting Doubler magnets to begin at the present location of MH203-4 (Fig. 5). This string consists of eleven Doubler magnets which ends at MH203-25 leaving adequate space to increase the number of magnets in the upstream MV204 vertical bend string from 4 to 8. Quads MQ205 and MQ206 remain at their positions before and after MV204, however it is not necessary to double their lengths.

In order to put the 22-foot Doubler magnets into Enclosure C it was necessary to construct an access shaft. The shaft is located about 20-feet downstream of MQ203 and comes directly into the top of the switchyard tunnel. The dimensions of the shaft are 14' x 5' which means that the magnets must be suspended at approximately 45 degrees to be placed in the tunnel. This method has been successfully tested and two Doubler Magnets have already been placed in the tunnel.

The 22 Doubler magnets must make a 9° horizontal bend. This is done by running them at 37 kG for 1000-GeV beam or at 15 kG for 400-GeV beam. Both sections of the bend will be powered in series.

A two-way split[3] in the meson beam line begins in the F1 manhole with two electrostatic septa which give a 45 μrad deflection between the two beams. The two quadrupoles MQ-210 and MQ211 will remain in F1 along with the septa. Three Lambertson magnets for the split will be located 1000 feet downstream of the septum in the F3 manhole. The two quadrupoles MQ230 and MQ231 presently located in F3 will be removed as well as MQ220 and MQ221 located in the F2 manhole. Initially the split will be constructed to operate at 400 GeV only. During this period there will be only one electrostatic septum in F1 and 2 Lambertson magnets in F3.

The two independent beam lines will enter Meshall separated horizontally by 16 inches which will allow ample room for the placement of two sets of magnets side-by-side. The two beam lines will each be similar to the present beam line which consists of the top half of the vertical bend, MV204, and a focusing triplett. To accommodate the large horizontal separation of the two beams before they reach Meshall a 48" pipe will be installed between the F3 manhole and Meshall.

The construction required to attain 1000 GeV includes the lengthening of the F1 manhole by about 30 feet to make room for additional quadrupoles to supplement MQ210 and MQ211. It will also be necessary to extend Meshall upstream by 75 feet to accommodate the vertical bends which will remain conventional.

Further details of the splitting modifications can be found in Reference 3, and the additional beam line elements required are summarized in Table III.

VI. Cryogenic Components for the Switchyard

Liquid helium for the right and left bends will be supplied by the Switchyard satellite refrigerator located in the Switchyard Service Building. The subcooled liquid will be transported to the dipoles through coaxial transfer lines which also return the two-phase helium, carries liquid nitrogen for the shield, and contains the superconducting leads. The transfer lines enter the tunnel through an existing penetration in the floor of the Switchyard Service Building. The entry point is in the crossover tunnel at the G1 manhole.

The left bend transfer line enters Enclosure C and splits at a Tee box to serve both the upstream and downstream bend sections. The right bends will be serviced through the bypass tunnel at the downstream end of Enclosure D. The longest path for the left bends is 250 feet to the upstream section. The right bends will require approximately 600 feet of transfer line if they are serviced entirely from the Switchyard Service Building. An alternative that would save two to three hundred feet would be to cool the upstream bend section using a refrigerator located near the end of the transfer gallery. One hundred and fifty feet of the transfer line to the left bends area is presently under construction in order to carry out a test of two Doubler magnets in the meson beam line.

VII. *Schedule for Switchyard Upgrade*

Current plans call for the switchyard upgrade to begin immediately. The first step will occur during mesopause and will entail replacing the fifty-six EPB dipoles that make up the left bends with twenty-two Energy Doubler/Saver magnets as described above. Work is underway now to install two Doubler magnets in the meson beam line in the drift space in Enclosure C. These magnets are to be run with opposing fields so as not to disturb Meson Laboratory operations between June and August 15, the scheduled shutdown date for the Meson Lab.

Upon successful completion of the two magnet test replacement of the left bends will begin during the August 15, to October first shutdown. All magnets should be installed and ready for operation by January, 1979, when the Meson Laboratory is scheduled to resume operation. As pointed out above, additional C-magnets, doubling of quadrupoles and electrostatic septa will not be necessary at this time. These changes can be made one step at a time over the next two years.

Also to be done during mesopause is the installation of the two-way split. This work will be carried out simultaneously with the left bends project.

Neutrino beam line modifications will begin during the Summer of 1979 with the construction of the new enclosure to house the electrostatic septa for the muon split and the lengthening of the G2 manhole for the horizontal bend in MUO. The neutrino upgrade will be completed in Fiscal Year 1979.

Proton beam line upgrade will be done in 1980 with replacement of the right bends and modifications to the proton splitting station being the major tasks.

A summary of the construction necessary to reach 1000 GeV is shown in Table IV. Also to be found in Table IV are the construction items necessitated by the additional splitting stations in m lines.

References

1. B. Cox, P. Garbincius, J. Lach, T. Murphy, K. Stanfield; Proton Laboratory 1 TeV Upgrade; March, 1978.

2. R. Evans, T. Kirk, TM-796; May, 1978.

3. A. Jonckheere, Meson Primary Proton Beam Targeting Upgrade; March, 1978.

TABLE I - Additional Elements Required for
1000 GeV Proton Beam Line

Electrostatic Septa

PSEP4-6	Additional for Proton/Neutrino Split
ES10 C&D	Additional for Proton 3-way Split
ES11 C&D&E	Additional for Proton 3-way Split

Total = 8

Doubler Magnets

MH302-1-5	Right Bends
MH303-1-6	Right Bends

Total = 11

Quadrupoles

MQ300B-305B	Additional Focusing
MQ310B-311B	Additional Focusing

Total = 8

EPB Dipoles

MHT-1-2	Additional Horizontal Trimming

Total = 2

Main Ring B1 Dipoles (10 foot)

MV310-4-6	Vertical Bends

Total = 3

40" Trims

MVT301B	Additional Vertical Trimming
MHT305B	Additional Horizontal Trimming
MVT308B	3-way Split Adjustment
MVT310C&D	3-way Split Adjustment
MVT311C&D	3-way Split Adjustment
MHT310	Additional Horizontal Trims

Total = 8

H-Magnets

MH300-6-10	Additional Proton/Neutrino Split

Total = 5

TABLE II - Additional Elements Required for
1000 GeV Neutrino Beam Line

Electrostatic Septa

MUSEP1-6	Muon Split
Total = 6	

Lambertson Magnets

MH400-1-5	Muon Split
Total = 5	

Doubler Magnets

MH401-1-4	Muon Horizontal/Vertical Bend
Total = 4	

Quadrupoles

MQ100B	Additional Focusing
MQ101B	Additional Focusing
Total = 2	

Main Ring B2 Magnets (10 foot)

MV100-1-7	Vertical Bends
MV140-1-7	Vertical Bends
Total = 14	

EPB Dipoles

MVT105	Muon Split Adjust
Total = 1	

40" Trims

MVT100B-103B	Additional for Meson/Neutrino Split
Total = 4	

TABLE III - Additional Elements Required for Meson Beam Line

Doubler Magnets

MH202-1-10	(Left Bends)
MH203-1-12	(Left Bends)

Total = 22

Electrostatic Septa

MSEP4-6	(Meson/Neutrino Split)
ES210-1-2	(Meson Split)

Total = 5

Quadrupoles

MQ201-4B	(Additional Focusing)
MQ252-8	(Additional Beam Line)
MQ262-8	(Additional Beam Line)

Total = 17

Deleted Quadrupoles

MQ220
MQ221
MQ230
MQ231

Total = 4
Net Quadrupoles Increase = 13

40" Trims

MVT201	Additional Vertical Correction
MVT202	Meson Split Adjustment
MHT204	Additional Horizontal Correction
MVT210, 211	Meson Split Adjustment
MVT230, 231	Meson Split Adjustment
MHT250	Additional Horizontal Trim
MHT260	Additional Horizontal Trim

Total = 9

EPB Dipoles

MHT201-1-2	Additional Horizontal Trim
MV204-5-8	Additional Vertical Bends
MV240-5-8	Additional Vertical Bends
MV250-5-8	Additional Vertical Bends

Total = 14

C-Magnets

MH300-6-10	Meson/Neutrino Split Magnets

Lambertson Magnets

MH330-1-3	Meson Split

TABLE IV - Summary of Required Switchyard Construction

Proton Area

1)	Access Shaft - Enclosure D	For installating Doubler magnets.

Neutrino Area

1) New enclosure along side C to house electrostatic septa for muon split.

2) Extend G2 manhole 100 feet to north to house horizontal bends for muon split.

Meson Area

1) Access shaft in Enclosure C for installing Doubler magnets.

2) Extend Meshall south by 75 feet to accommodate 3-way split.

3) Install 48" pipe between F3 and Meshall for 3-way split.

4) Lengthen F1 by 30' to accommodate quadrupoles and electrostatic septa for 3-way split.

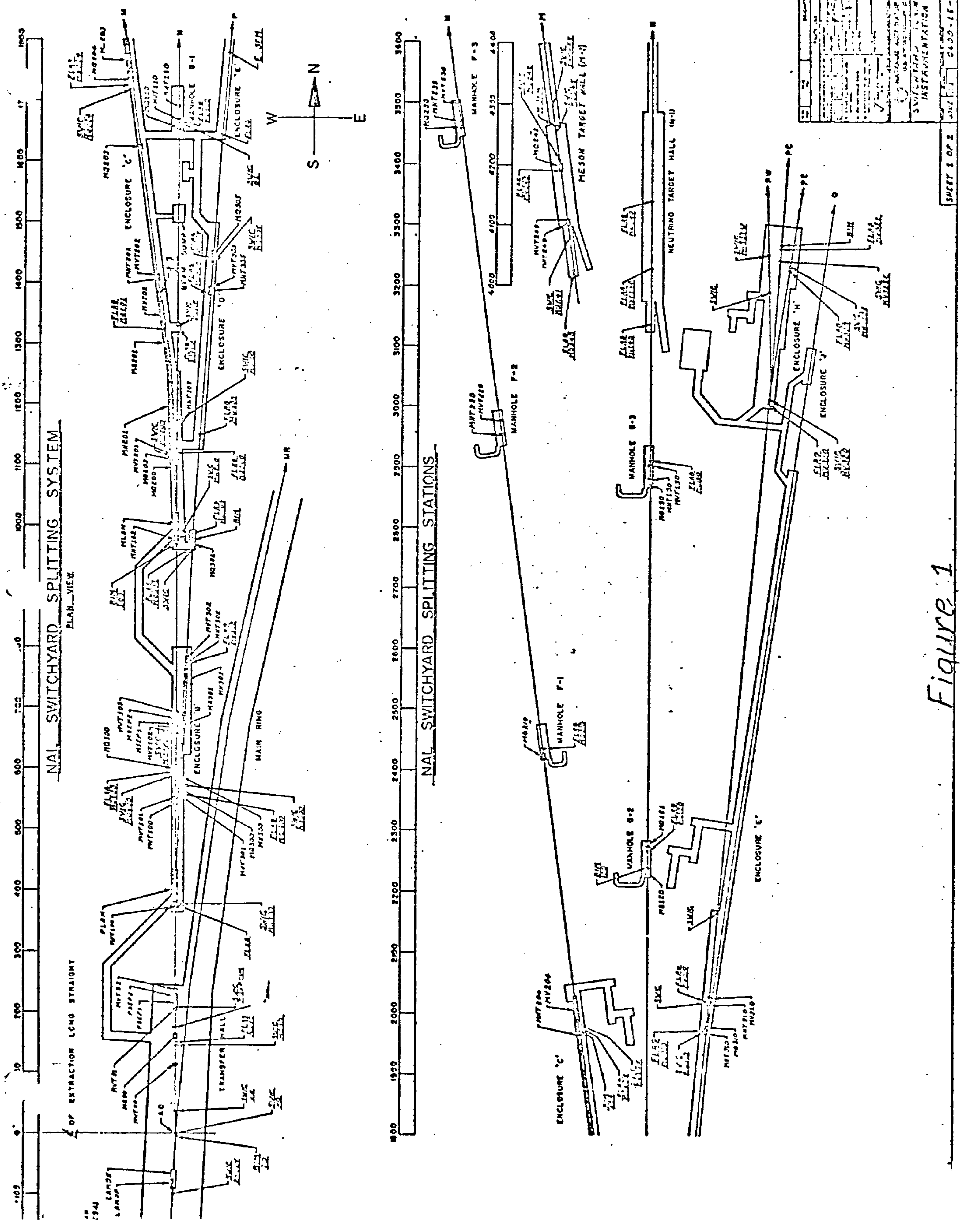
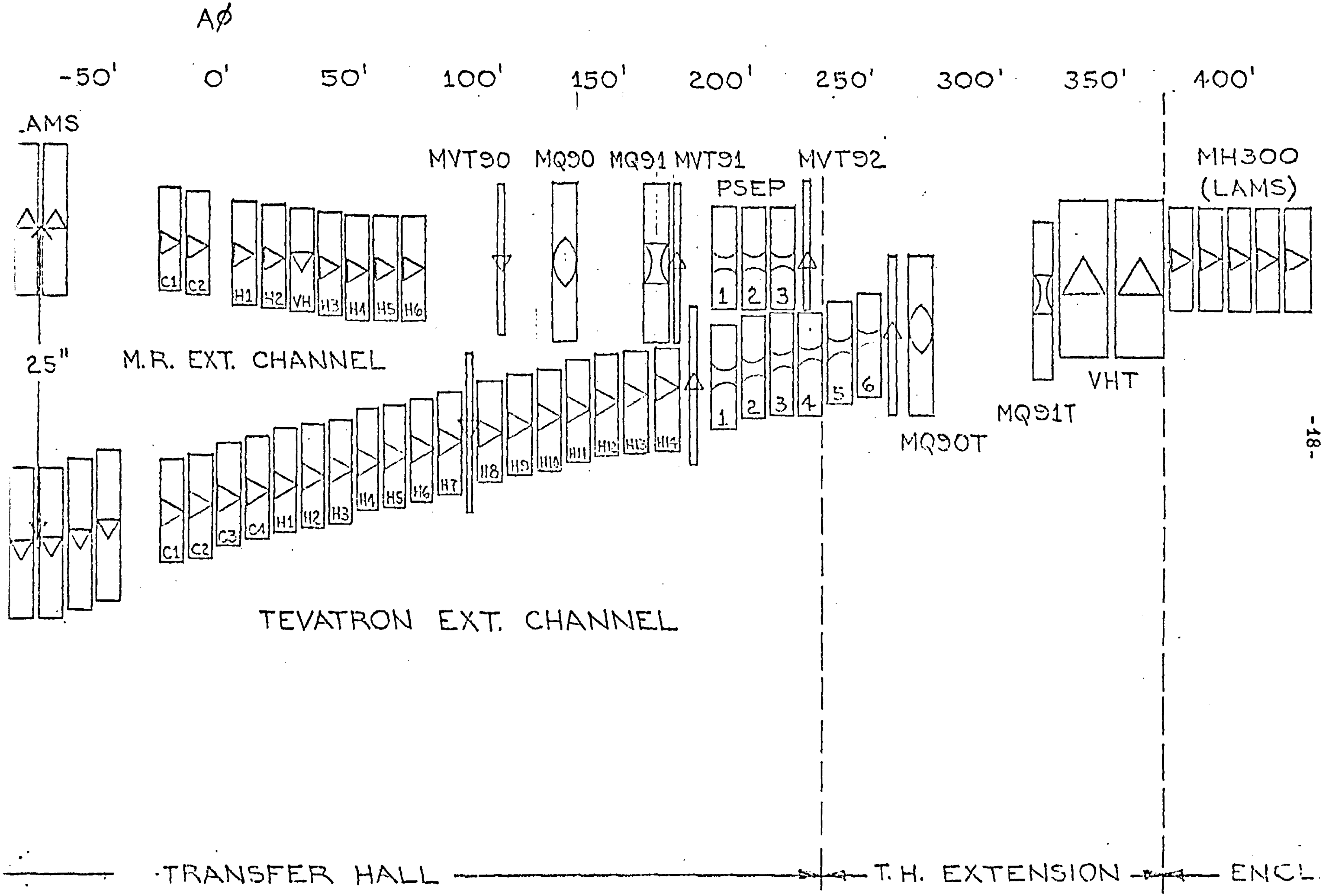

NAL SWITCHYARD SPLITTING SYSTEM
PLAN VIEW
NAL SWITCHYARD SPLITTING STATIONS

Figure 1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(LAMS)
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C2
H1
H2
VH
H3
H4
H5
H6
25"
M.R. EXT. CHANNEL
C3
C4
H7
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H9
H10
H11
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H13
H14
1
2
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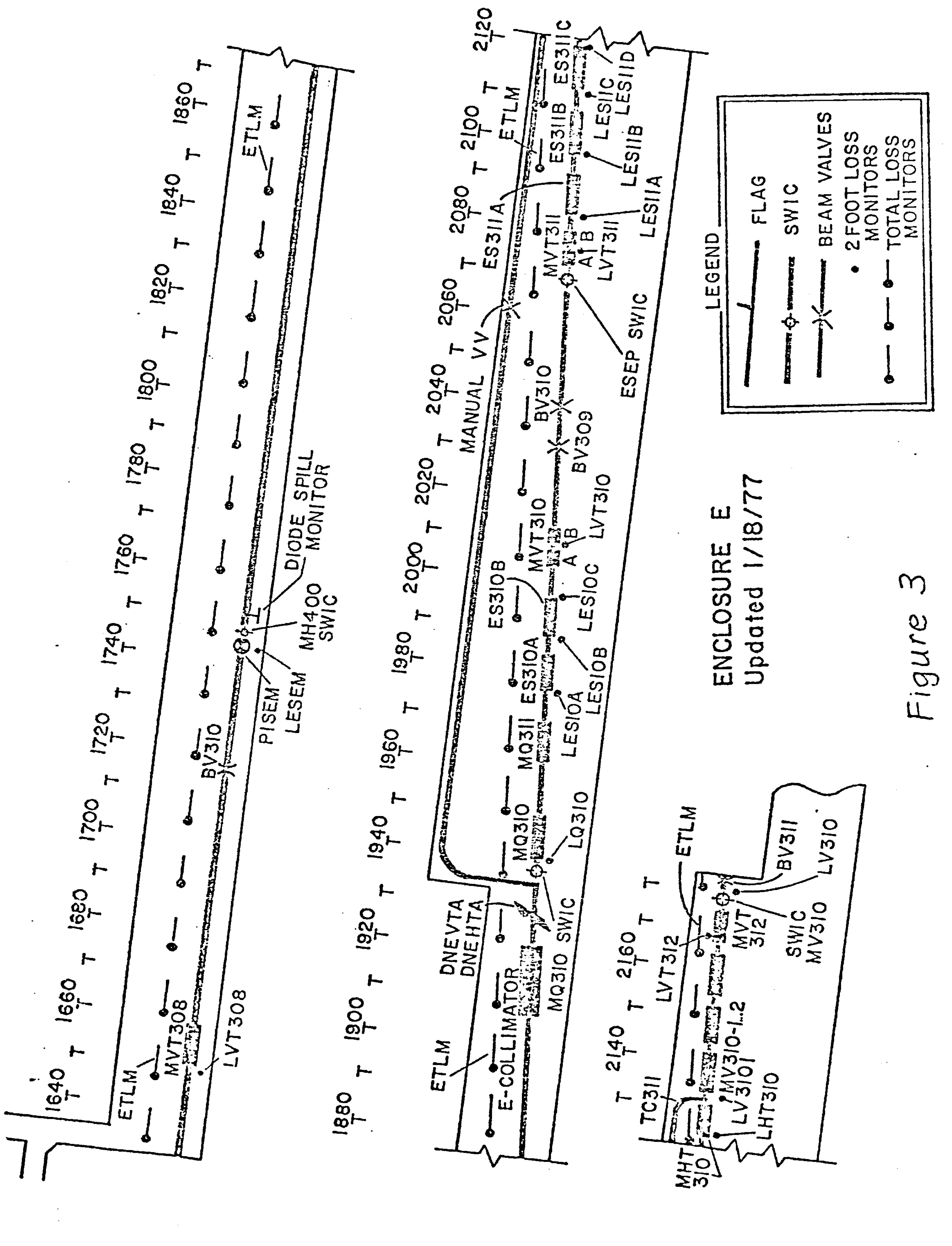
TEVATRON EXT. CHANNEL
TRANSFER HALL
T.H. EXTENSION
ENCL.

Figure 2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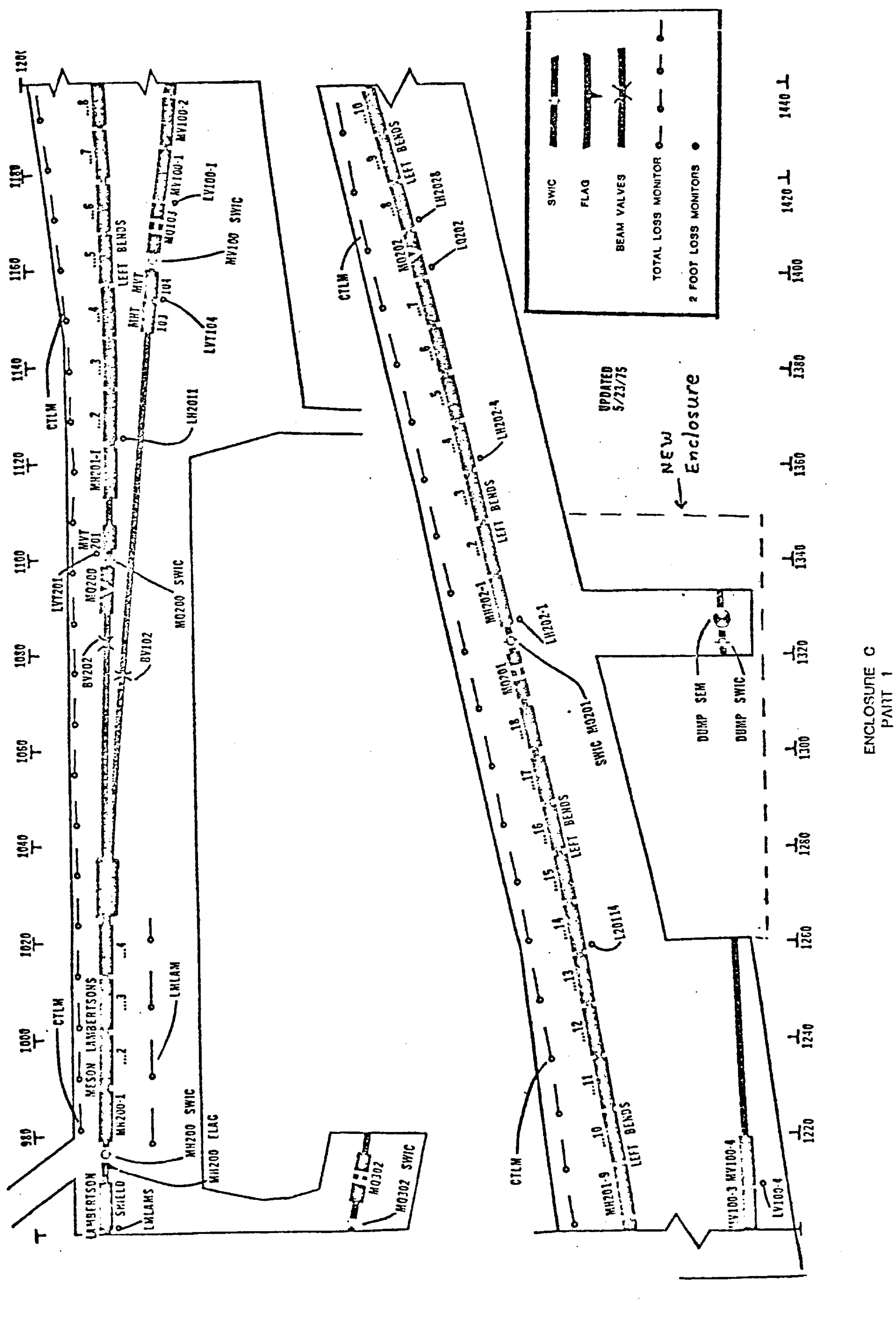
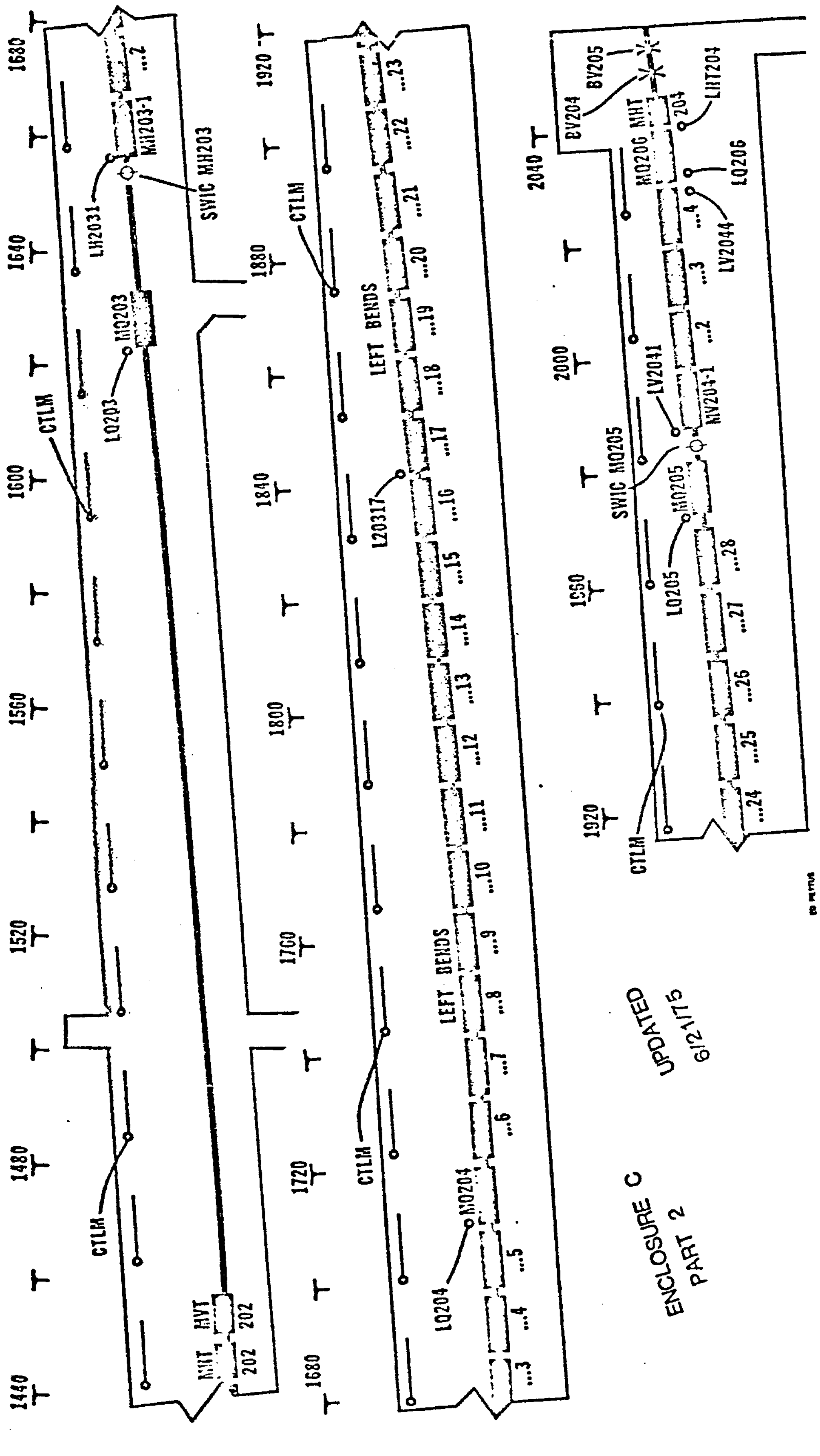
ETLM
MVT308
LVT308
BV310
PISEM
LESEM
MH400
SWIC
DIODE SPILL
MONITOR
E-COLLIMATOR
DNEVTA
DNEHTA
MQ310 SWIC
MQ310
LQ310
MQ311
ES310A
LES10A
LES10B
ES310B
LES10C
MVT310
A B
LVT310
BV309
BV310
MANUAL VV
ESEP SWIC
ES311A
MVT311
A B
LVT311
LES11A
ES311B
LES11B
ES311C
LES11C
LES11D
TC311
MHT
310
LV3101
MV3101
MV310-1,2
LHT310
LVT312
MVT
312
SWIC
MV310
BV311
LV310
LEGEND
FLAG
SWIC
BEAM VALVES
2 FOOT LOSS
MONITORS
TOTAL LOSS
MONITORS
ENCLOSURE E
Updated 1/18/77

Figure 3



ENCLOSURE C
PART 1

Figure 4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LH2031
MH203-1
SWIC MH203
MQ203
LQ203
MHT 202
MVT 202
LEFT BENDS
L20317
MQ204
LQ204
MQ206 MHT
BV204
BV205
LHT204
LQ206
LV2044
LV2041
MV204-1
SWIC MQ205
MQ205
LQ205
ENCLOSURE C
PART 2
UPDATED
6/21/75

Figure 5

b. Air Cooled Heat Exchangers: The after coolers are also ready to run. These are also surplus and were reconditioned at Fermilab. The helium gas flows through bronze tubes with aluminum fins which are cooled by air blown upward by 14 ft diameter fans. The tube cores were completely redesigned and rebuilt to fit in the original duct towers and use the original 30 and 40 hp fans and duct towers.

c. Main Warm Gas Flow System: The routing of the main flow of helium gas is shown in Figure 4. It is evident that either compressor can circulate gas independently. The setpoint for the control loops shown in Figures 3 and 4 for suction and discharge pressure can be monitored and adjusted in the usual manner from the control room. The charcoal trap and the demister are both rated for the full flow of the two compressors. See Table III for specifications. The piping from the charcoal trap to the cold box has not yet been completed.

TABLE III

Specifications for the Monsanto Mist Eliminator

Gas	Helium
Flow rate	10,1086.1b/hr
Operating pressure	235 psia
Inlet mist loading	100°F
Oil	Rarus 427

Specifications for the Charcoal Vapor Trap

Operating pressure	180 psia
Temperature	100°F
Charcoal bed	300 cu ft
Flow	10,000lb/hr helium gas

d. Seal Gas Cleanup System: The seal gas is the leakage past the piston rod packings on each cylinder of the main helium compressors. This gas leaks into a low pressure volume between the cylinder and the crankcase and tends to be somewhat contaminated with air due to air being carried in from the crankcase by the piston rod. Seal gas is collected in a manifolding system and brought to the suction of the screw compressor and on to the scrubber. The guaranteed leakage rate is 50 SCFM per compressor, which should be well within the capacity of the cleanup system. The main specifications of the scrubber are given in Table IV. Figure 5 shows the main flow of the seal gas system.

TABLE IV

Specifications for the Gardner Low Temperature Purifier (Dual)

Flow	300 lb/hr
Composition	99% helium, 1% air (by weight)
Pressure	250 psig
Temperature	100°F
Output purity	5 ppm air for 12 hours
LN_2 requirements	45 lb/hr at 15 psig

<u>Specifications for the Seal Gas Screw Compressor</u>

Size	46 1/2" x 35" x 65" high
Weight	~2200 lb
125 hp motor	440 V 30 60 Hz
Full power estimated at	93 kW
Cooling water	40 GPM at 40 psig 85°F maximum supply temp.
Rotor	127 mm x 152 mm - female driven by 3600 rpm motor
Rotor displacement	233 cfm

Expect 70 to 75% volumetric efficiency

Expected throughput	180 scfm at 16.5 psia suction
Volume ratio	4.5

Oil removal system expected to reduce carry-over to less than 1 ppm by weight

V. Control System

a. General Plan: In designing the control system for the compressors a major factor was an attempt to make the system compatible and integrated with the helium reliquefier supplied by Helix Process Systems. In addition, as much information and logic as possible was centralized in the control room to facilitate operations as well as debugging. Thus, the main feature of the control system is a Texas Instruments Model 5000 programmable sequencer which controls the logic for trips, interlocks, alarms, timers, and status displays. Figure 6 shows a simplified block diagram of the control system used on the helium compressors. The control system for the cold box is independent and has essentially the same block diagram except that it does not have an analog alarm system.

b. Data Display Panel and Control Consoles: The cold box system has the sequencer, process controllers, data and alarm display panel all mounted in a custom-built cabinet. This cabinet also contains all the necessary control and selector switches and digital readouts for pressure, temperature, and flow. The data panel is illuminated and various process flows can be displayed in various colors. Valve status and alarm indicators also light under sequencer control. An identical cabinet has been installed to control the compressor and gas system. Furthermore, a data display panel of similar construction and function has also been installed so that the corresponding process flows displayed on the two consoles match. Figure 7 shows a photograph of the console installation.

c. Process Control: The most common control loop used consists of the following elements:

1. A sensing probe which transmits an electric signal to the control room, which is proportional to the process variable.
2. A Fisher process controller in the control console which compares the electrical signal representing the process variable with an operator adjusted set point and generates a correction based on the difference of the two input signals. This correction signal is transmitted back to the vicinity of the valve.
3. An "E to P" unit converts this electric signal to an air signal which is transmitted to a pneumatically operated control valve.
4. An operator-positioner package attached to the valve moves the valve stem an appropriate amount.

VI. Helium Reliquefier

a. Introduction to the System: This liquefier, with its control panel, is designed to liquefy helium into a remote dewar. Cold gas from the dewar will be returned to the system through the cold box.

The reliquefier uses four stages of refrigeration: liquid nitrogen and three oil bearing turboexpanders designed and manufactured by Sulzer. Heat exchangers are manufactured by the Trane Company. Design liquefaction rate is 4875 liters/hour at 4.6K.

1. Cold Box

   The cold box assembly is 37 feet high and consists of: a 10 ft diameter vacuum shell; a supporting frame that attaches to the top head of the vacuum shell; three oil bearing turboexpanders; a vacuum pumping system; and an instrument panel. Components inside the vacuum shell are: the heat exchanger system and interconnecting cold piping, turbine inlet filters, control and shutoff valves, and connections to the three turbines. Figures 8 and 9 are views of the reliquefier.

2. Control Console

   The main control console (see Figure 7) contains all the controls for one-man operation. A display panel contains a system flow diagram, indicator lights, and all instrument identification necessary for system operation.

   Digital readouts in the appropriate units are used for temperature pressure, flow, and elapsed time.

b. Theory of Operation: The process cycle for the Fermilab Central Helium Reliquefier is shown on the TS diagram, Figure 10 and the flow diagram, Figure 11. Compressors, provided by Fermilab, will deliver 1267.7 grams per second (g/s) of pure helium gas at 11.9 atm pressure to the cold box.

Liquid nitrogen, provides the first stage of refrigeration by counterflowing with high pressure helium in heat exchanger HX1, 1A (E16). A flow of 588.6 g/s (2665 liters/hour) of liquid nitrogen at 1.3 atm, together with 1109.3 g/s of low pressure return helium, will cool 1267.7 g/s of helium from 311.1K to 80.7K.

In heat exchanger HX2 (E17) the high pressure helium is cooled to 45.67K by the low pressure return gas.

At the entrance of HX3 (E17) the flow divides with 916.7 g/s going to the turbines. Some gas, 0.7 g/s, is extracted and injected into the labyrinth seal isolating the oil from the helium in the turbine cartridge. The remaining 916 g/s flows through the first turbine (T-1) where helium is expanded from 11.5 atm to 6.0 atm at 37K. Power developed by the turbine in the work extraction process, is 42.0kW. Exhaust gas will pass from the turbine (T-1) through HX4 (E17) where it is cooled by the low pressure return gas to 25.66K. The flow is again divided with 471.9 g/s going to turbine T2, and 444.1 g/s of the remaining flow going to turbine T-3.

Gas, 0.2 g/s, is injected into the labyrinth seal of turbine T-2. The remaining 471.7 g/s flows through T-2 expanding from 5.9 atm to 1.3 atm at 16K resulting in turbine power of 23.3kW. Low pressure, 1.3 atm, helium exhausting from the turbine, returns via the low side exchanging refrigeration with the high pressure stream.

The 444.1 g/s at 5.8 atm is cooled by the return flow in heat exchanger HX5 and HX6 to 12.83K. Gas, 0.1 g/s, is injected into the labyrinth seal of turbine T-3. The remaining 444 g/s expands through turbine T-3 from 8-5 atm to 1.37 atm at 8K. The turbine power developed in the work extraction is 9.5 kW. Turbine exhaust gas exchanges its refrigeration with the high pressure gas flowing to the J-T valve in heat exchanger HX7.

When the flow divided to the turbine circuit the remaining high pressure helium flow of 351 g/s went directly to the J-T valve (PCV183). High pressure helium is cooled to 6.16K by the return stream in the heat exchangers HX3, 4, 5, 6, 7 and 8 (E17, E18, E19) before isenthalpically expanding to 1.397 atm, and 4.6K producing 4875 liquid liters/hour (l/h) of helium.

The liquid/gas mixture will separate in the Fermi dewar, 193.5 g/s of gas at 4.6K will return to the low side of the system.

c. Description:

1. Cold Box Assembly

The vertical cold box assembly consists of a carbon steel vacuum shell that encloses the heat exchangers, three turbines, turbine filters, interconnecting piping and valves; most of these components are covered with multilayered insulation.

The vacuum shell includes upper and lower flanges with O-ring seals. The top head of the vacuum shell contains all penetrations to the internal components. A support frame with legs is attached to the top head which allows the vacuum shell to be lowered into a pit to expose the cold box internal components for maintenance.

The overall dimensions of the cold box are 37 feet high by 12 feet square.

2. Heat Exchangers HX1, 1A (E16) HX2, 3, 4 (E17) HX5, 6 (E18) HX7, 8 (E19)

There are four brazed, aluminum, heat exchanger blocks in the system, all manufactured by the Trane Company. The cores are the plate-fin type using 1/8-inch serrated fins, and constructed of 3003 aluminum alloy. The headers and nozzles of the assemblies are made of 5083 aluminum alloy.

The heat exchangers, are all mounted vertically with the cold end down and are interconnected with aluminum piping, except where stainless steel elements, such as valves, are required. Connections to stainless steel elements are made through aluminum to stainless steel transition joints.

Schedule 5, 304 stainless steel and schedule 40 6061-T6 aluminum pipe are used for interconnections.

The high pressure passages of all the aforementioned exchangers are designed to operate at a maximum pressure of 300 psig and were tested to 600 psig. The medium pressure passages of the exchangers are designed for 100 psig maximum operation and were tested to 200 psig, while the low pressure passage is designed for 50 psig maximum operation and was tested to 100 psig. The heat exchanger configurations are as follows:

HEAT EXCHANGER	DIMENSIONS	TYPE
HX1, 1A (E16)	36" x 23" x 170" long	Three-pass
HX2, 3, 4 (E17)	25" x 23" x 260" long	Three-pass
HX5, 6 (E18)	25" x 21" x 254" long	Three-pass
HX7, 8 (E19)	17" x 12" x 222" long	Two-pass

The heat exchangers are supported from their top end by stainless steel rods extending down from the top head of the vacuum shell. The heat exchangers are interconnected with lateral stainless steel angle supports and micarta spacers. The supports are rigid from side to side but are somewhat flexible in the principal shrinkage direction. The heat loss via conduction through the supports between components is negligible.

Heat exchanger HX1, 1A can be decontaminated with solvent. If the high pressure section of heat exchanger HX1, 1A becomes contaminated with oil, connections are provided for attaching a pump to circulate solvent through the heat exchanger.

3. Turbines (T-1, T-2, and T-3)

The turboexpanders are single stage turbines of the centripetal type with oil bearings and oil braking. The turbine rotor is vertically mounted and is carried radially and axially in two oil lubricated bearings. Between the two bearings is the oil brake which dissipates the mechanical work performed by the turbine as heat. An oil-to-water heat exchanger removes the heat generated. A speed-sensing device is incorporated into the turbine which insures safe operation.

3.1 Low Temperature Housing. - The stainless steel turbine housing is installed in the cold box turbine mounting plate. This housing is covered by the turbine vacuum cover. All cryogenic helium pipework is assembled to this turbine housing. All turboexpander maintenance can be performed outside the cold box. (See Figures 12 and 13.)

3.2 Turbine Cartridge (Figure 14). - The fully equipped turbine cartridge includes the following parts:

- impeller (7) and impeller shaft (9)
- thrust (71) and journal (35)
- oil brake (42)
- labyrinth seal
- slinger ring (8)
- speed sensor (61)
- oil and seal gas connections

The cartridge is shop assembled, tested, and ready for assembly into the turbine housing from the lower side. All necessary connection unions for oil and seal gas lines are circular at its mounting flange.

3.3 Turbine Lower Casing. - The turbine lower casing contains an oil reservoir for the oil leaving bearings and brake. From the collector the oil leaves through an oil return line to the oil vessel. The ring space of the lower casing is part of a buffer volume to ensure safe working conditions in case of heavy process pressure changes. In this case, gas from the buffer volume will be injected to the labyrinth to guarantee a correct flow of gas to the oil-wetted parts.

3.4 Speed Measuring System. - The speed of the turbines is measured by an inductive pick-up. A speed indicator with the necessary safety contacts is installed in the control console.

3.5 Speed Indicator Type TMA 3. - The speed safety trips are adjusted as follows:

	Turbine No. 1 (T33B-60) (rps)	Turbine No. 2 (T22B-60) (rps)	Turbine No. 3 (T21B-50) (rps)
Warning Trip	1417	1583	1583
Shut-down Trip	1500	1667	1667

The speed switch system is based on a photo-optical circuit. The speed setting is made by means of an adjustable brake oil supply valve to the oil brake of the turbine.

VII. Cryogenic Fluid Flow System

The input and return for the helium portion of this system comes from the cold end of the reliquefier shown on the righthand side of Figure . Figure shows the main parts of this flow system. At the present time, the helium dewar is complete but the phase separator and transfer lines are in construction. It is our intention to complete the cold box acceptance test without the use of the 5000 gallon helium dewar. The test will be conducted using the phase separator, its pressure control loop, and the concentric line to the reliquefier. The liquid nitrogen dewar will be connected with temporary foam insulated transfer lines, and we intend to use the scrubber to clean up the plant inventory.

We are scheduled to test the compressors in November and the reliquefier in March and April.

FIGURE CAPTIONS

Figure 1. Approximate layout of major plant equipment.

Notes:
1. Main helium compressors.
2. Main nitrogen compressor.
3. 4000 hp synchronous motors.
4. 4kV switchgear for main motors.
5. CTi-Helix helium refrigerator.
6. Valve cabinet.
7. Control room, second level.
8. 1200 ampere motor control center.
9. Oil removal equipment.
10. Seal gas cleanup system.
11. Transformers for incoming power.
12. Air-cooled heat exchangers.
13. Nitrogen cold box.
14. Liquid nitrogen dewar.
15. Liquid helium dewar.
16. Intermediate pressure gas storage.

Figure 2. Footing and machine model used for computer analysis.

Figure 3. Simplified flow system for a single helium compressor.

Notes:
1. First stage of compression.
2. Second " " "
3. Third " " "
4. Stage unloading valves. These must be open to start compressor.
5. Discharge pressure control (kickback valve).
6. 2 micron particle filters.
7. Intermediate pressure storage tank.
8. Inventory control valve, from gas storage.
9. Inventory control valve, to gas storage.
10. Isolation valve.
11. Main suction relief valve, 16 inch.
12. Air-cooled heat exchangers.

Figure 4. Main gas flow system.

Figure 5. Seal gas cleanup system.

Figure 6. Block diagram of control system for helium compressors.

Notes:
1. Indicates multiwire connections.
2. Two-way data bus.

Figure 7. Control consoles for compressor and helium cold box.

Figure 8. Taop of helium cold box.

Figure 9. View of heat exchangers in helium cold box assembly.

Figure 10. TS diagram for helium liquefaction cycle.

Cont'd.

FIGURE CAPTIONS (Cont'd.)

Figure 11. Main helium flow in helium cold box.

Notes:

1. Liquid nitrogen in
2. ambient temperature nitrogen gas return.
3. 12 atm. helium gas in
4. 1.1 atm helium gas return.
5. 6.2°K, 11.2 atm cold helium gas.
6. 4.6°K liquid, 4875 liters/hr.
7. Cold gas return, 1.4 atm, 4.6°K.
8. Refrigerated gas delivered by turbine 3, 1.3 atm and 8.0°K.

Figure 12. View of turbine inlet filters.

Figure 13. Turbine access and gas ports.

Figure 14. Cross sectional view of the Sulzer oil bearing turbine.

Figure 15. Cryogenic transfer line system.

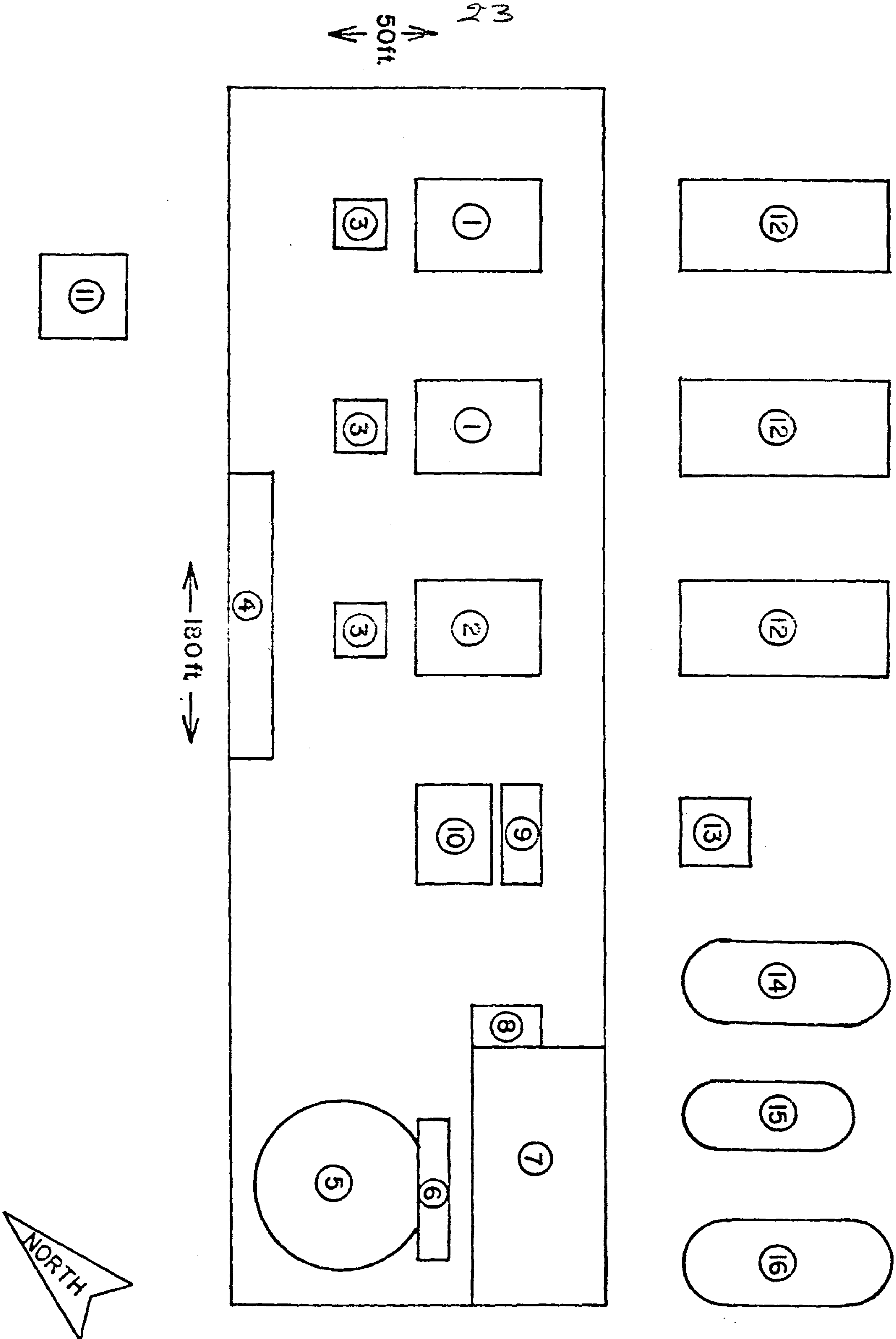

Figure 1. Approximate layout of major plant equipment.

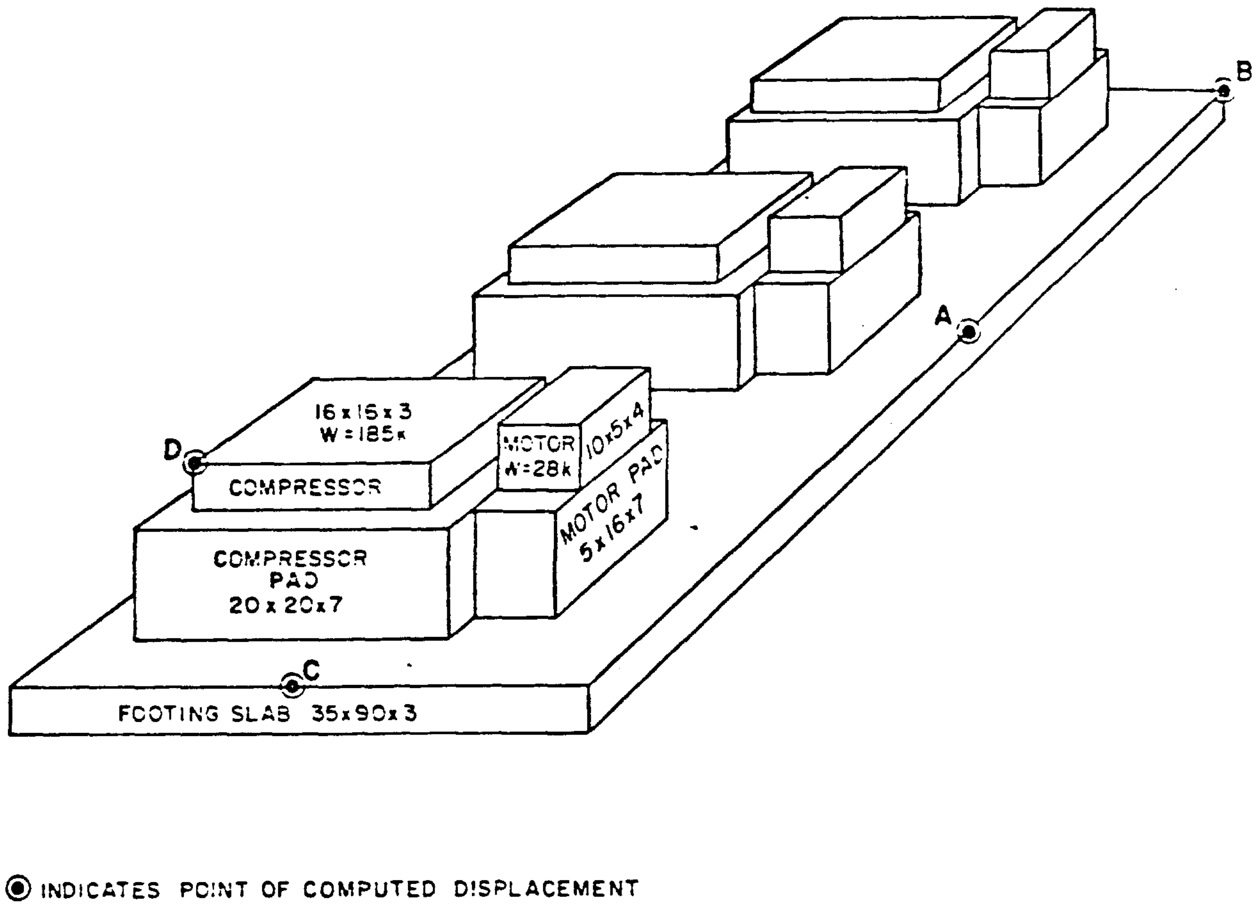

Figure 2. Footing and machine model used for computer analysis.

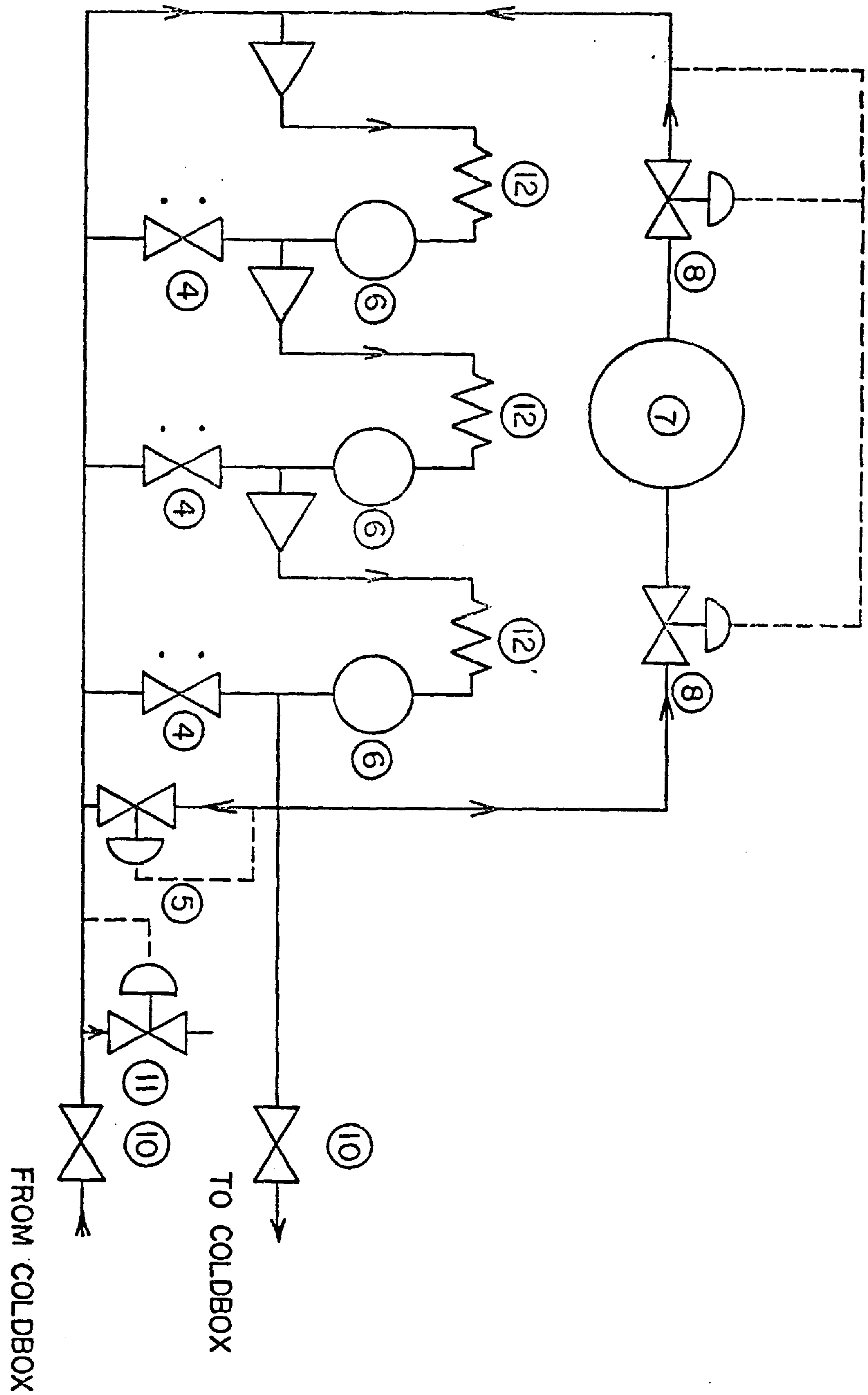

Figure 3. Simplified flow system for a single helium compressor.

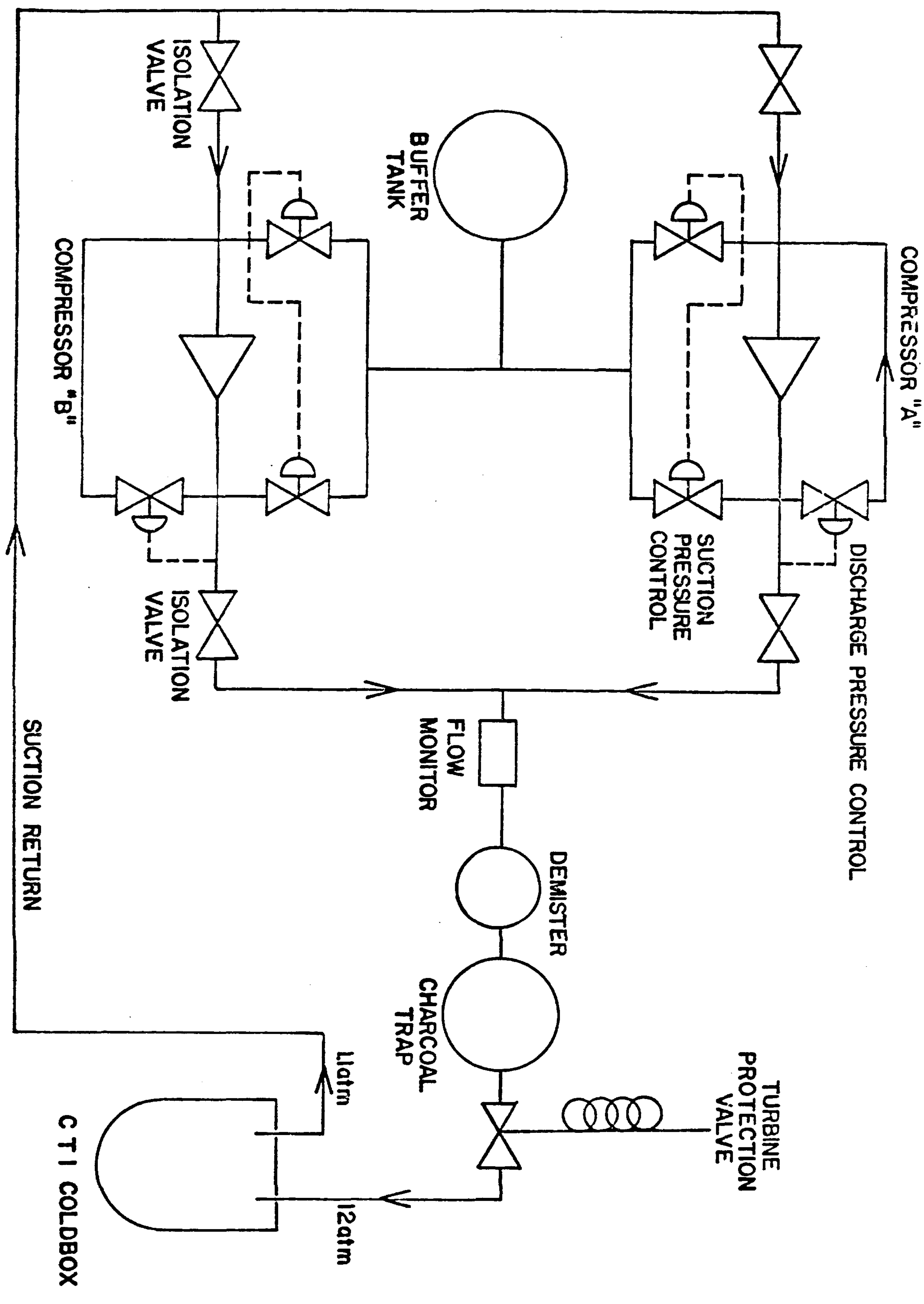

Figure 4. Main gas flow system.

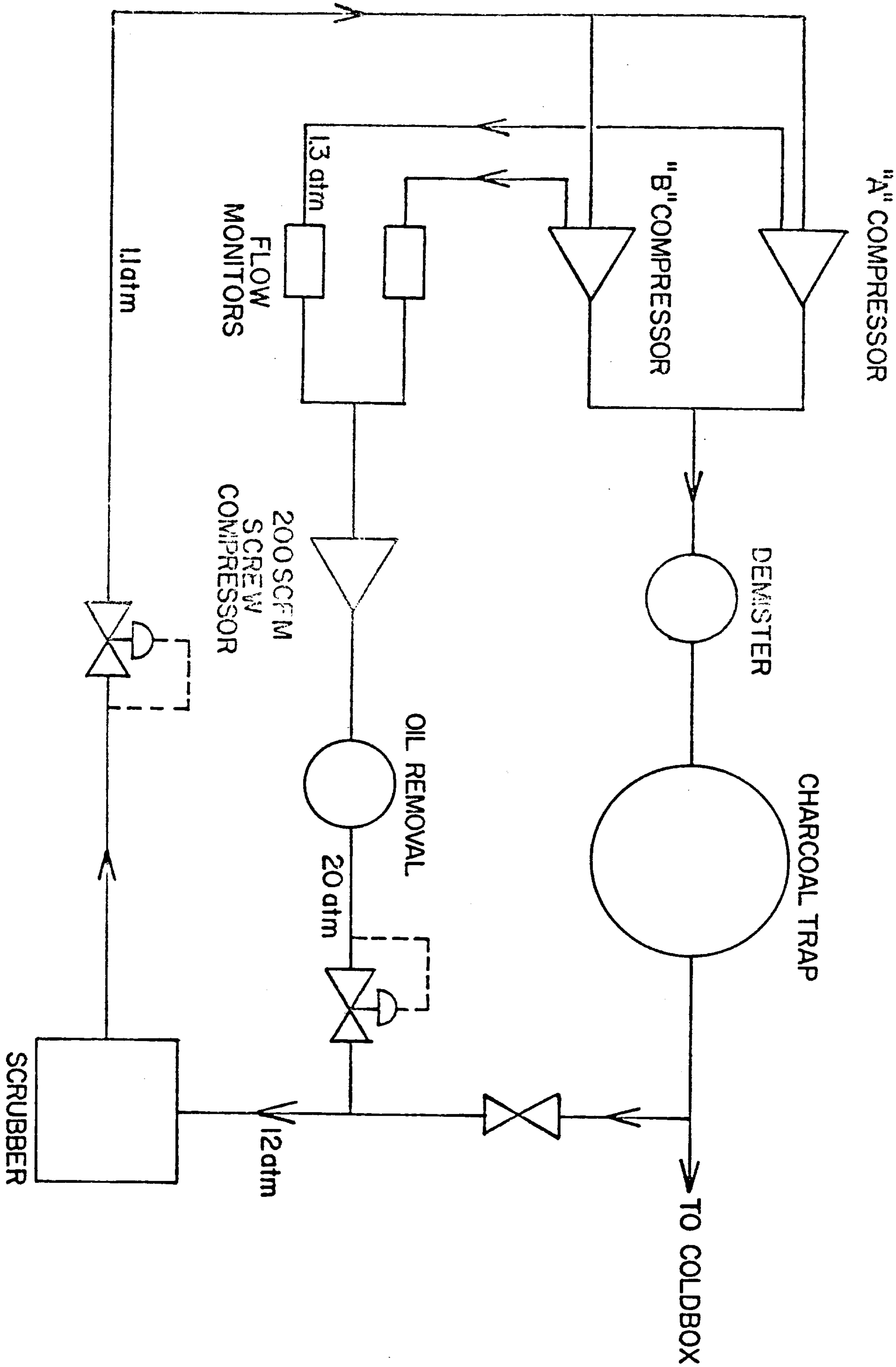

Figure 5. Seal gas cleanup system.

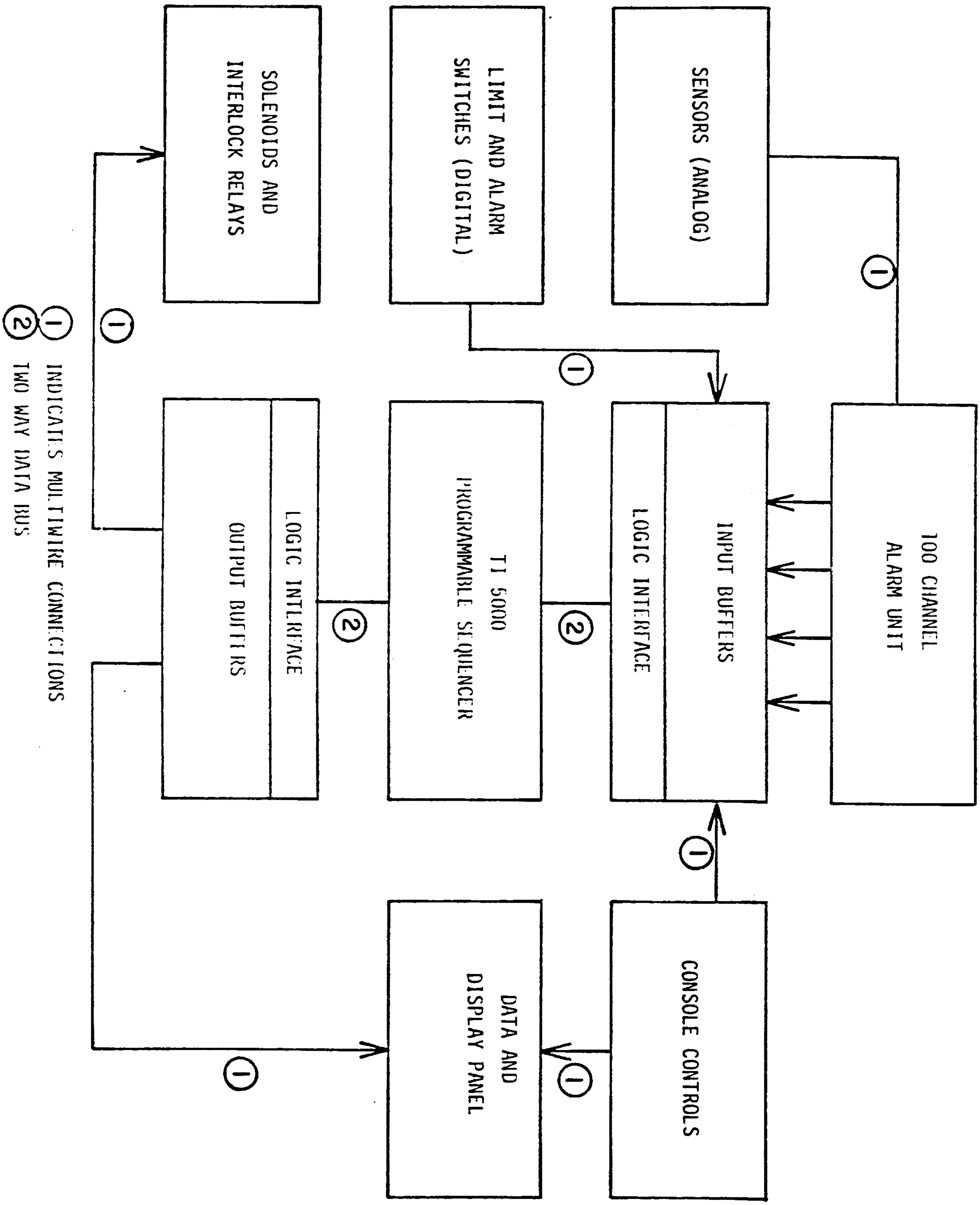

Figure 6. Block diagram of control system for helium compressors.

Notes: 1. indicates multiwire connections.
2. two-way data bus.

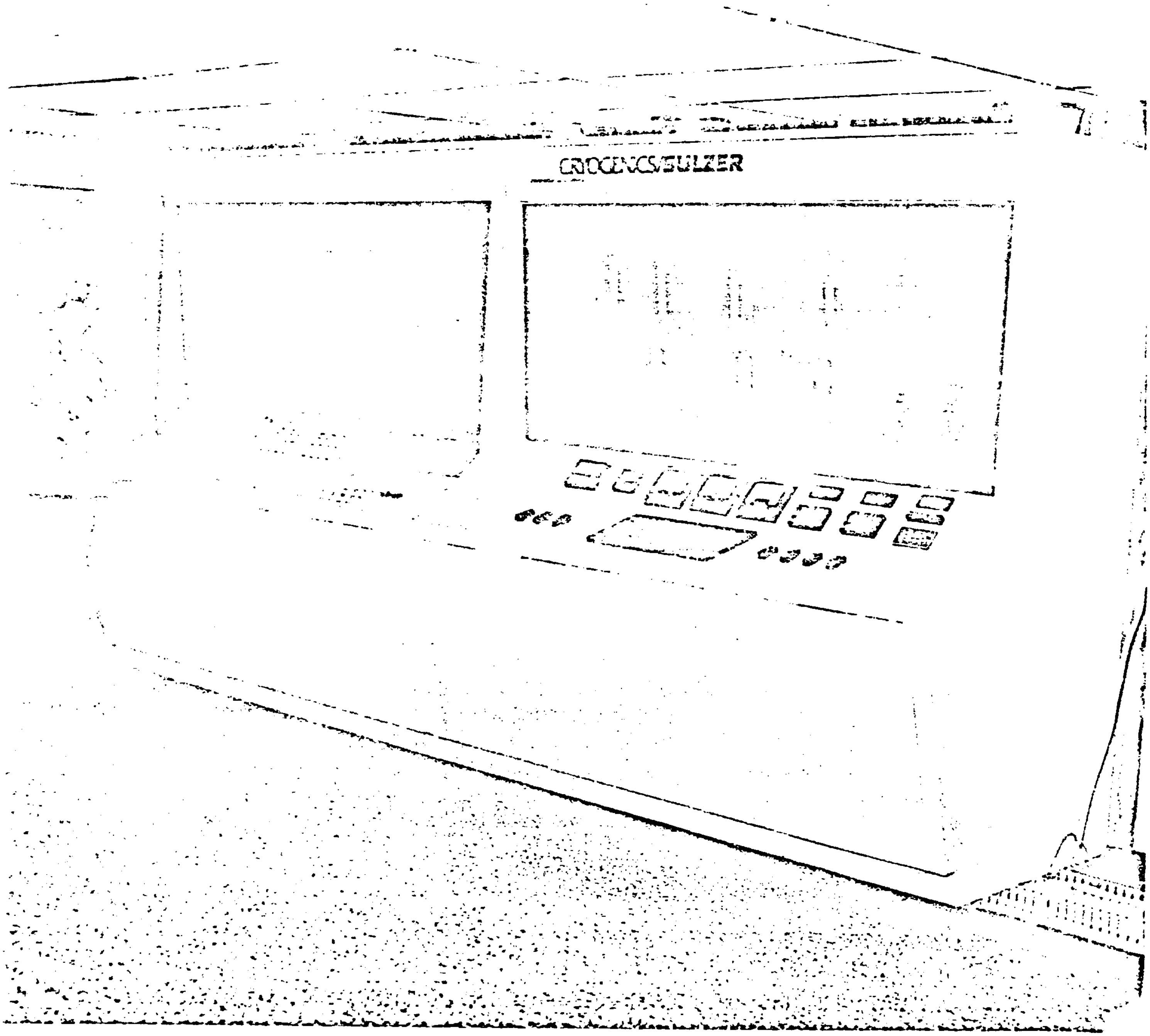

Figure 7. Control consoles for compressor and helium cold box.

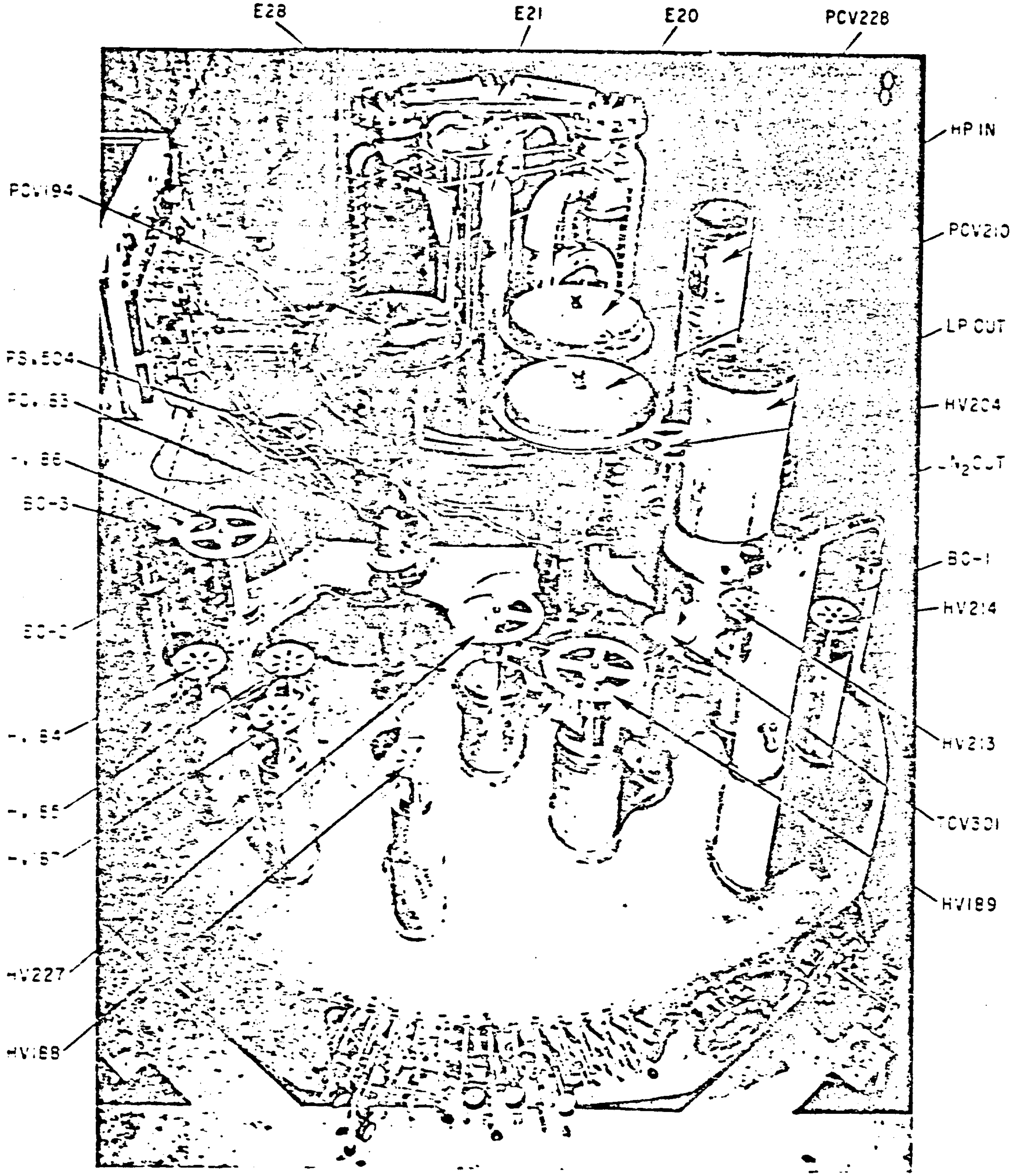

Figure 8. Top of helium cold box.

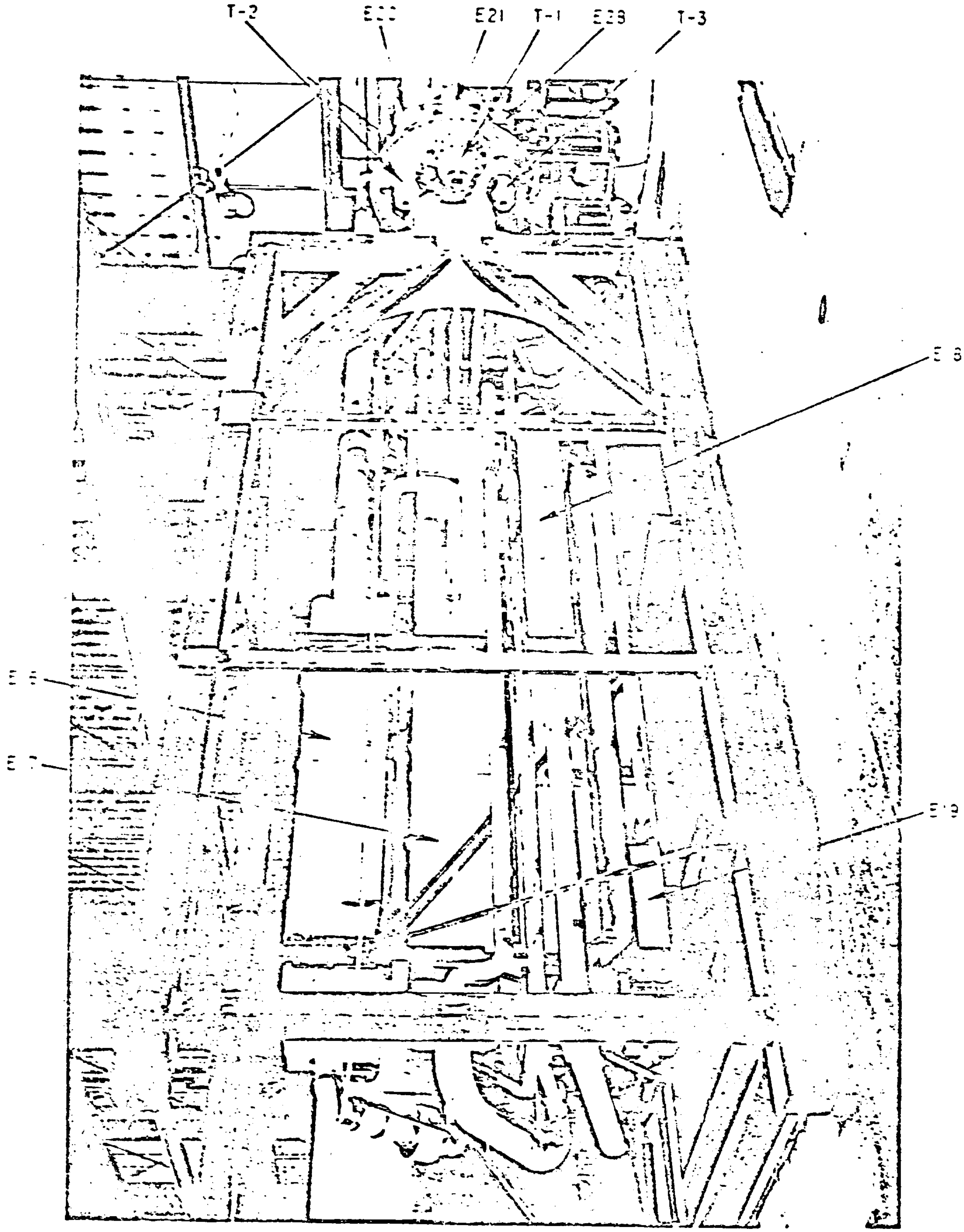

Figure 9. View of heat exchangers in helium cold box assembly.

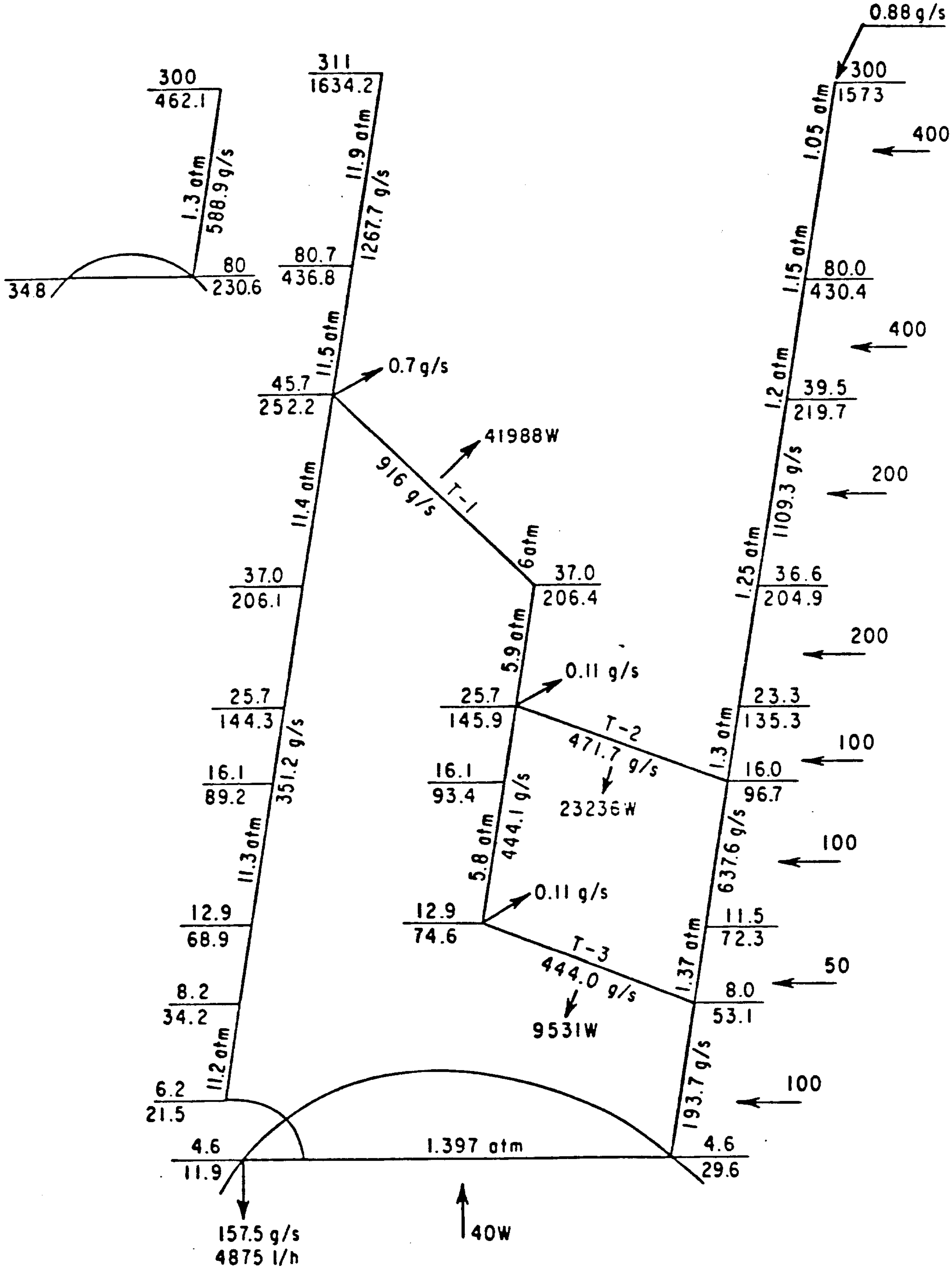

Figure 10. TS diagram for helium liquefaction cycle.

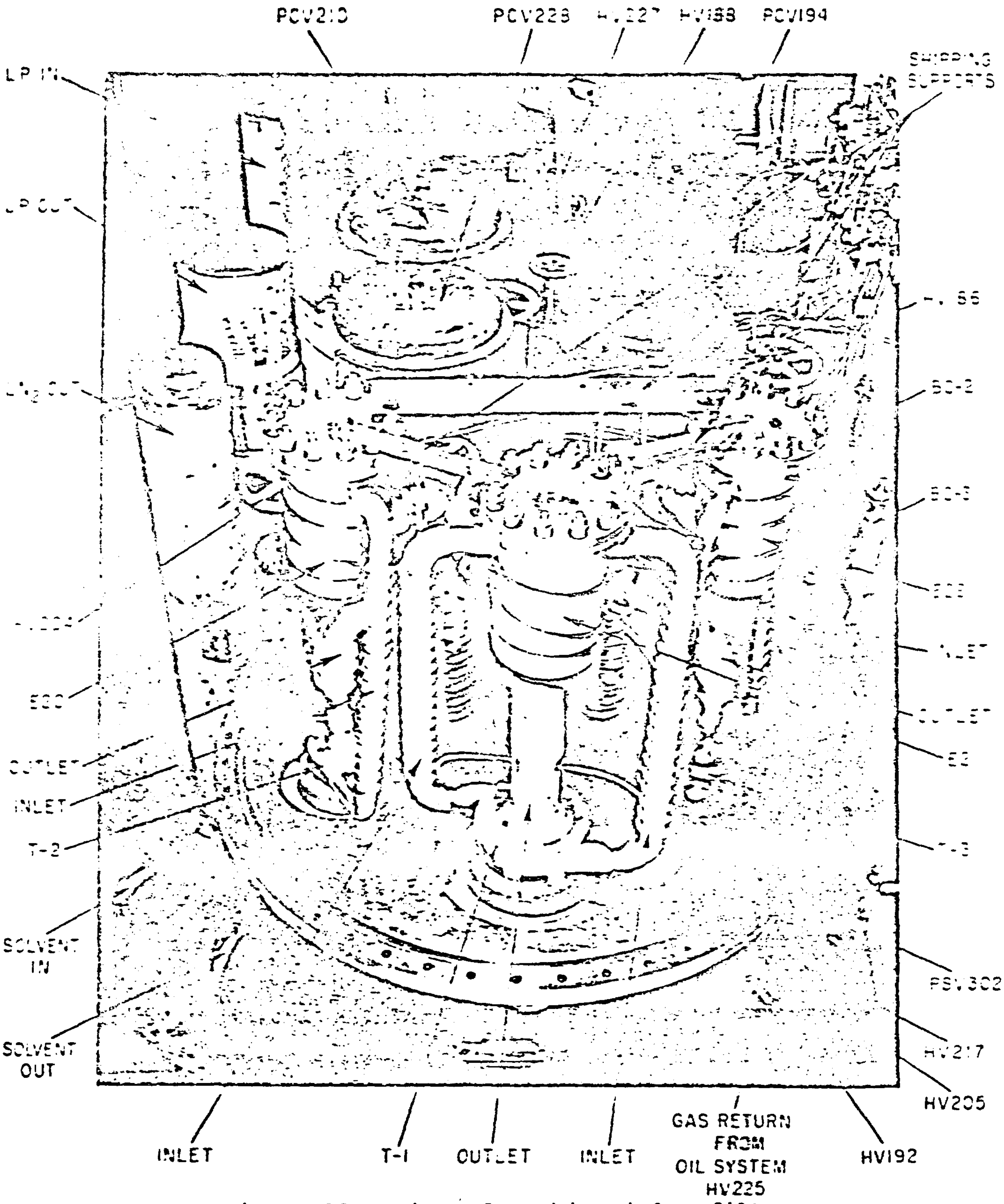

Figure 12. View of turbine inlet filters.

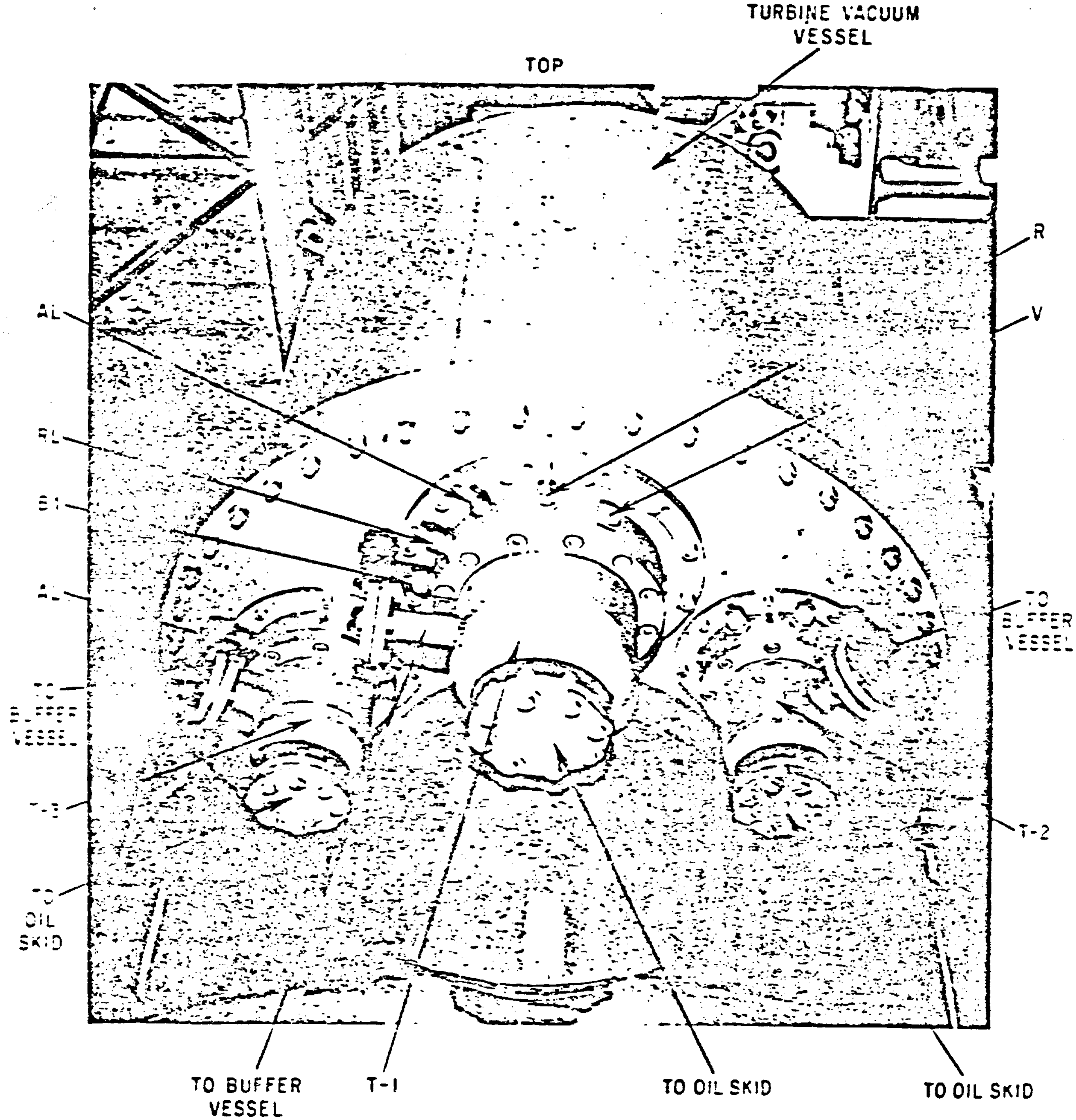

Figure 13. Turbine access and gas ports.

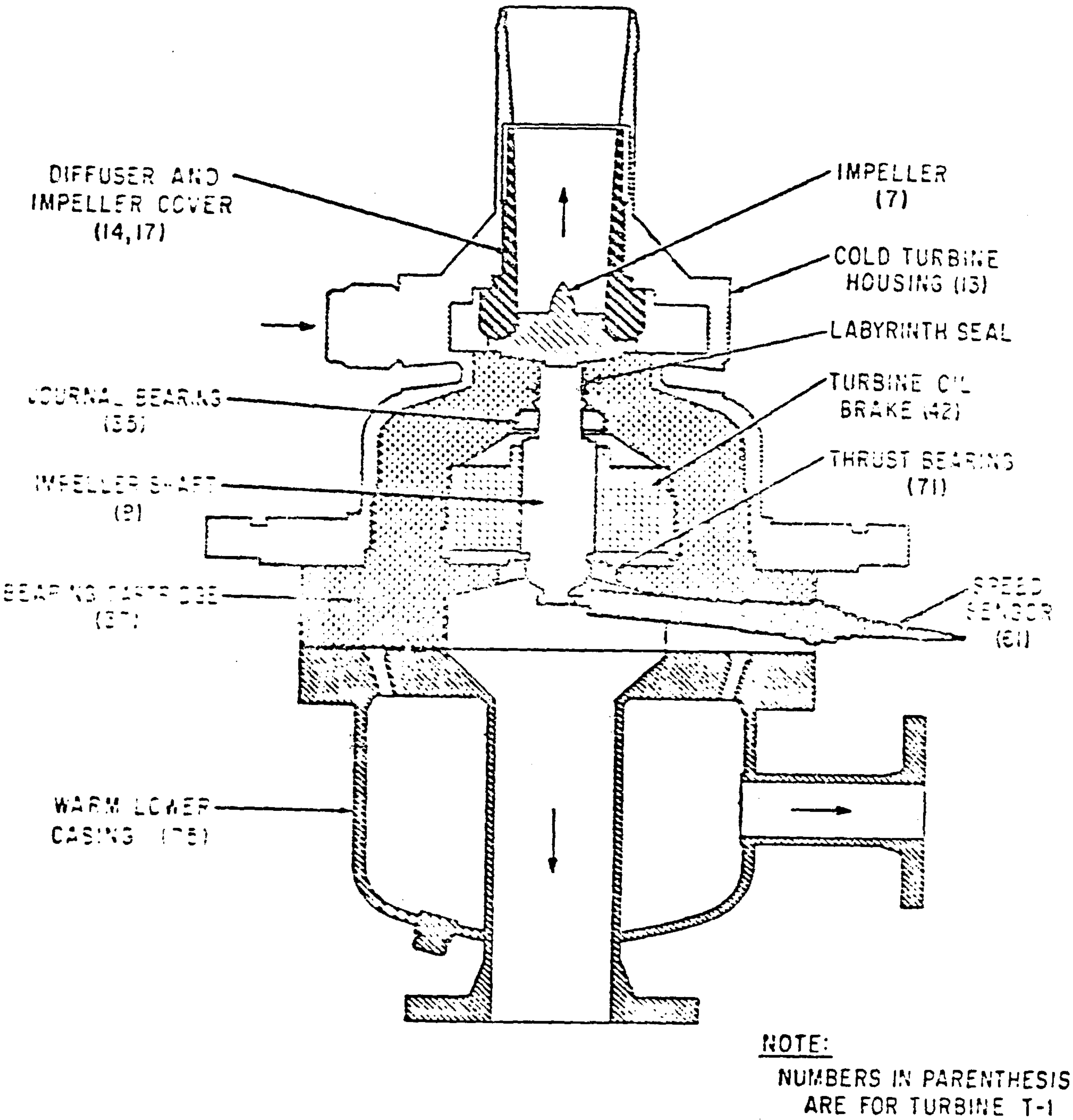

Figure 14. Cross sectional view of the Sulzer oil bearing turbine.

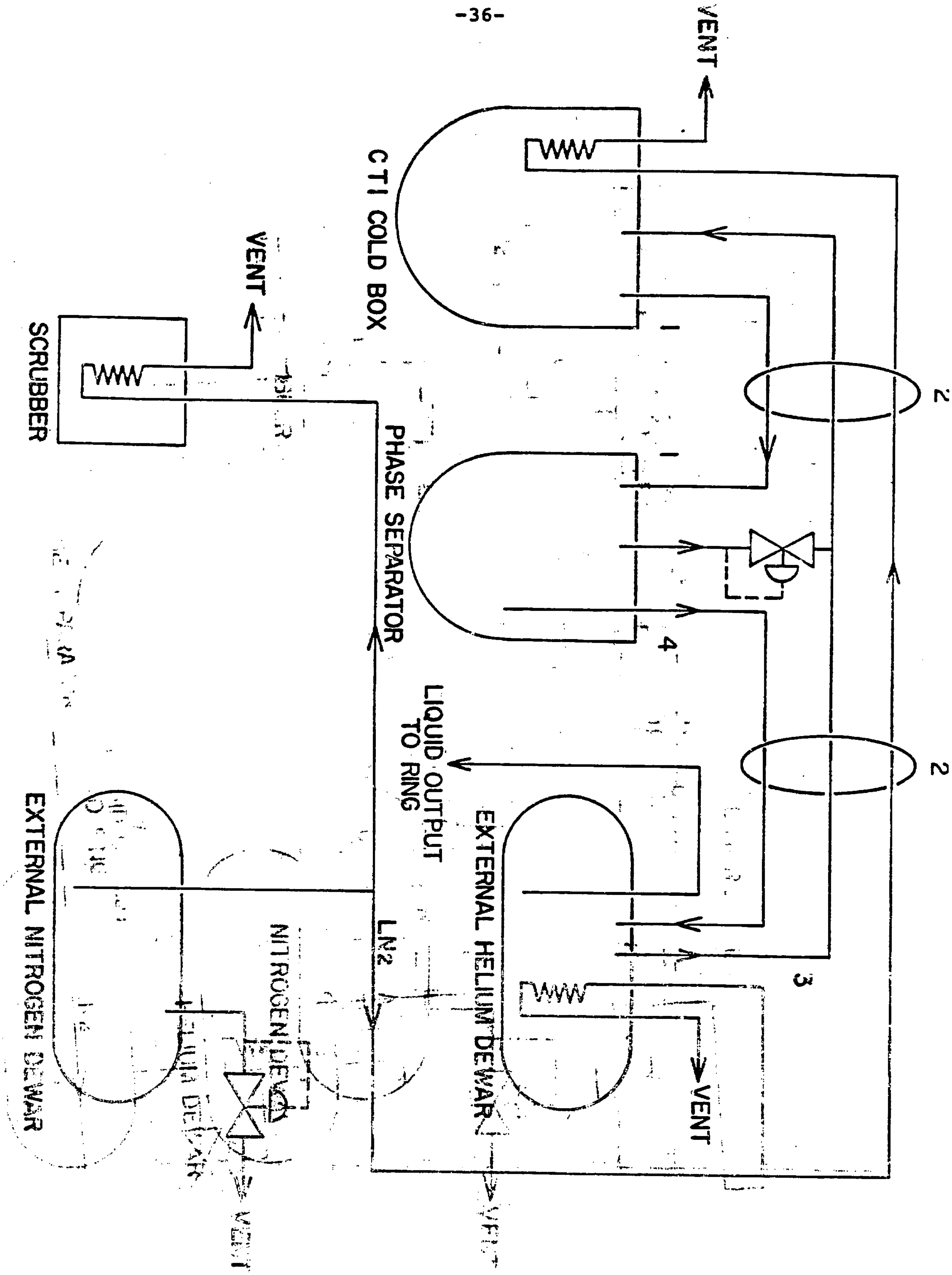

Figure 15. Cryogenic transfer line system.