SLAC-PUB-658
September 1969
(ACC)

HELIUM REFRIGERATION SYSTEM FOR A 100 GEV SUPERCONDUCTING ACCELERATOR*

G. Ratliff

Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

Introduction

The Stanford Linear Accelerator Center[1] is now in its third year of operation of the 20 GeV linear electron accelerator. The experimental physics program presently underway will exploit the usefulness of the facility for many years. Thereafter, to keep up with demands of physics research, the accelerator should be upgraded. This could be accomplished by converting the accelerator to a 100 GeV machine by taking advantage of basic properties of superconducting microwave cavities.[2] The great advantages of the resulting superconducting accelerator would be its higher maximum energy and its capability of operating at a higher duty cycle. Such an accelerator would have a profound impact on the methods and costs of high energy physics research. It should be noted, however, that no authorization for the conversion of the present accelerator exists and no specific date for the submission of a conversion proposal has been set, although a preliminary feasibility study has been underway for some time.

The helium refrigeration system required for a 100 GeV superconducting accelerator would be the largest known system of its kind. Its cooling capacity would be 14.2 kW at the operating conditions of 1.85°K and 14.82 torr using the tentative parameters which have been adopted. The capacity

---

*Work supported by the U. S. Atomic Energy Commission.

(Submitted to Cryogenics and Industrial Gases)

would be 47 times that of the largest system existing today which is installed at the Hansen Laboratories at Stanford University.[3] The magnitude of the project is aptly illustrated by the 14.2 MW operating power and the 450,000 liters of liquid helium required to fill the dewars.

Accelerator Complex

The existing facilities would be used for the 100 GeV accelerator. The present accelerator and its related equipment are located in two parallel housings, one above the other as shown in Fig. 1. The accelerator housing is 11 feet wide and 10 feet high. The Klystron Gallery which houses the auxiliary equipment is 30 feet wide and 15 feet high. The two structures are separated by 25 feet of earth which serves as radiation shielding. The Accelerator Housing and Klystron Gallery are both 10,000 feet long and are subdivided into 30 sectors of equal length. The accelerator proper (see Fig. 2) is a 4-inch diameter, water-cooled, copper disc-loaded waveguide, through the center of which passes the electron beam. It is this structure which would be replaced by an assembly consisting of superconducting niobium cavities. Figures 3 and 4 show typical sections of the superconducting accelerator structure and dewar.

The Refrigeration System

A refrigerator for the superconducting accelerator must provide both the low temperature needed to make the niobium cavity structure superconducting and the stable environment for the microwave fields in the accelerator structure. The operating temperature of the superconducting accelerator has been set at 1.85°K.[4] Three principal considerations led to this decision. The first of these was the exponential decrease in resistance of the superconducting surface with temperature. The second was the practical problem of refrigeration at very low temperatures;

as the temperature drops, the vapor pressure of helium decreases approximately logarithmically and the difficulty of reaching lower temperatures increases correspondingly. The third consideration was the advantage gained from the properties of superfluid helium which comprises about one half the fluid at 1.85°K. The operating temperature chosen was a compromise between these factors.

The refrigeration system currently under consideration is based on a two-expansion Claude cycle providing two stages of isobaric refrigeration at the 60° to 70° K and 10° to 15° K temperature levels for a Linde-Hampson cycle to furnish refrigeration at 1.85°K. A simplified flow diagram is shown in Fig. 5. The temperature-entropy diagram is shown in Fig. 6.

There would be 16 refrigeration stations, 16 vacuum pumping stations and one compressor station. Figure 7 is an isometric drawing of a system serving two typical sectors. Fifteen would be operating. One would be on standby.

Purified helium from the compressor station would be supplied to the refrigeration stations located in the Klystron Gallery. At each sector refrigerators supply 1.85°K liquid helium to the dewars. The vaporized helium then is recovered and compressed to 1.5 atmospheres by the vacuum pumps and returned to the compressor station. At the compressor building, the helium is compressed to 12.0 atmospheres to complete the cycle.

System Components

The helium refrigeration system represents an approach using state-of-the-art components. Even within these bounds it offers a wide selection of cycle variations and system component sizes. The determination of the optimum balance of cost and reliability then becomes the basis for establishing the system component design criteria.

Except for sectors one and two, there would be one refrigeration station each for two sectors with a combined rating of 1,000 watts. At sectors one and two, an additional system would be provided to assure continuous operation of these sectors which are critical to the operation of the accelerator. Temporary shutdown of the refrigeration system in other sectors would not necessitate shutting down the entire accelerator. The refrigeration system would also provide helium gas for the $70^{o}K$ dewar shield system. The shield refrigeration requirement is approximately 1.3 kW for two sectors.

Each sector would have an independent set of first-stage vacuum pumps. The remaining stages would be combined for two sectors. The vacuum pumps will compress the helium gas from 10 torr to 1.5 atmospheres in five stages of compression.

The compressor station would be located at the midpoint of the Klystron Gallery and would include three compressor units of which one will be standby. Each unit would be rated for 18,000 SCFM at full load from an inlet pressure of 1.0 atmospheres to an outlet pressure of 12.0 atmospheres. The compressors would be of the non-lubricated type with special shaft seals to minimize loss of helium and to eliminate the possibility of oil contamination. The full-load compressor flow would be 36,000 SCFM and the minimum flow required for the passive load would be 6,000 SCFM.

A full-flow system of helium purifiers would be provided at the compressor station. The purifiers would be designed to provide ultra-high purity helium containing not more than 1.0 parts per million total impurities. In addition to these purifiers, there would be small purifier units in the low temperature sections of the refrigerators.

In the selection of the equipment and sizing of the system components no provision has been made for a higher refrigeration load. This is in accordance with the basic design parameters. The equipment selected would normally be specified to have an operating range which would include a 10% over-capacity for balancing the system. A higher load would require additional components operating in parallel.

System Operation

The refrigeration equipment would be designed to operate continuously for at least 5,000 hours between overhauls, repairs or routine maintenance. It will be necessary to establish an effective preventive maintenance program to assure continuous operation of the equipment.

Standby emergency power would not be provided for the refrigeration system. During a failure or outage of the principal 220 kV power feeder line, the separate 60 kV standby line would supply the necessary power to operate at reduced loads. Power failures of both lines can be disregarded as its occurrence is extremely unlikely.

Future Research and Development

In addition to alternate system arrangements and component sizes, there are various cycles to select from and an almost infinite number of variations on the cycles. It is to be expected that during the period up to authorization the system will be changed in favor of lower cost and higher reliability.

A major reason for a feasibility study at this time is the need for determining those technical areas in which significant research and development effort must be made which could lower the cost of the system. It appears that there are three areas which can be explored immediately where significant progress could be made. One is the use of He^3 in a portion of the system to take advantage of its higher vapor pressure. About 15,000 liters of gas at standard conditions would be required. Another prospect is the use of ejector expanders to reduce the number of vacuum pump stages. The third is the development of a booster pump to compress the cold return helium, preferably at temperatures below $80^{\circ}K$. Obviously these areas will be investigated as a part of our continuing feasibility study.

Cost Analysis

In any study of this kind the cost estimate plays a very major role in evaluating various alternates and making decisions. The cost estimate for this system in the early stages was developed by the use of the six-tenths factor.[5] By knowing the costs of similar small systems, it is possible to estimate the cost of much larger systems. However, it proved necessary to first adjust the cost of the smaller systems since they operate at higher temperatures, do not in general use vacuum pumps, and use liquid nitrogen precooling. The result of the analysis is the following equation:

$$C = 12,000\ (P)^{0.6}$$

where

C = cost in dollars

P = power in watts

Using the above equation it was determined early in the study that the cost of sixteen 1,000 watt systems would be approximately $12,100,000. Additional estimated costs totaling $6,800,000 for engineering, distribution piping, gas storage, building, power and cooling water were not included in the equation since these items are unique to each refrigeration system installation. Contingency and escalation would also have to be added. Later cost estimates based on specific component costs resulted in an estimate which deviated only slightly from the equation.

Conclusions

There are many unknowns in a refrigeration system of this type and magnitude. In the future it is expected that the design will change significantly; therefore many of the questions pertaining to the details of this particular refrigeration system are not yet relevant. This study is still in its infancy and requires the help and support of various industries so that the system criteria will eventually represent the most economical and sound approach for providing the required refrigeration for a superconducting accelerator.

References

1. The Stanford Two-Mile Accelerator, R. B. Neal, Editor (W. A. Benjamin Inc., New York, 1968).
2. Proceedings of the 1968 Summer Study on Superconducting Devices and Accelerators, Part 1, Report No. BNL 50155, Brookhaven National Laboratory, Upton, New York (1968).
3. W. M. Fairbank and H. A. Schwettman, Cryogenics Engineering News 2 (1967).
4. M. S. McAshan, "Heat transport and refrigeration for a superconducting linear accelerator," Advances in Cryogenic Engineering, Vol. 13 (Plenum Press, New York, 1968); p. 428.
5. Perry's Chemical Engineers Handbook, fourth edition, "Cost and profitability estimation," Section 26 (McGraw Hill, Inc., 1963); p. 26-19.

FIGURE CAPTIONS

1. Cutaway drawing of the two 2-mile-long structures.
2. Cutaway drawing showing internal configuration of copper accelerating waveguide showing three cavity-forming disks.
3. Proposed basic design of disk-loaded waveguide niobium structure.
4. Dewar cross section at waveguide connection.
5. Simplified schematic flow diagram.
6. Temperature-entropy diagram helium refrigeration system.
7. Typical refrigeration system for two sectors.

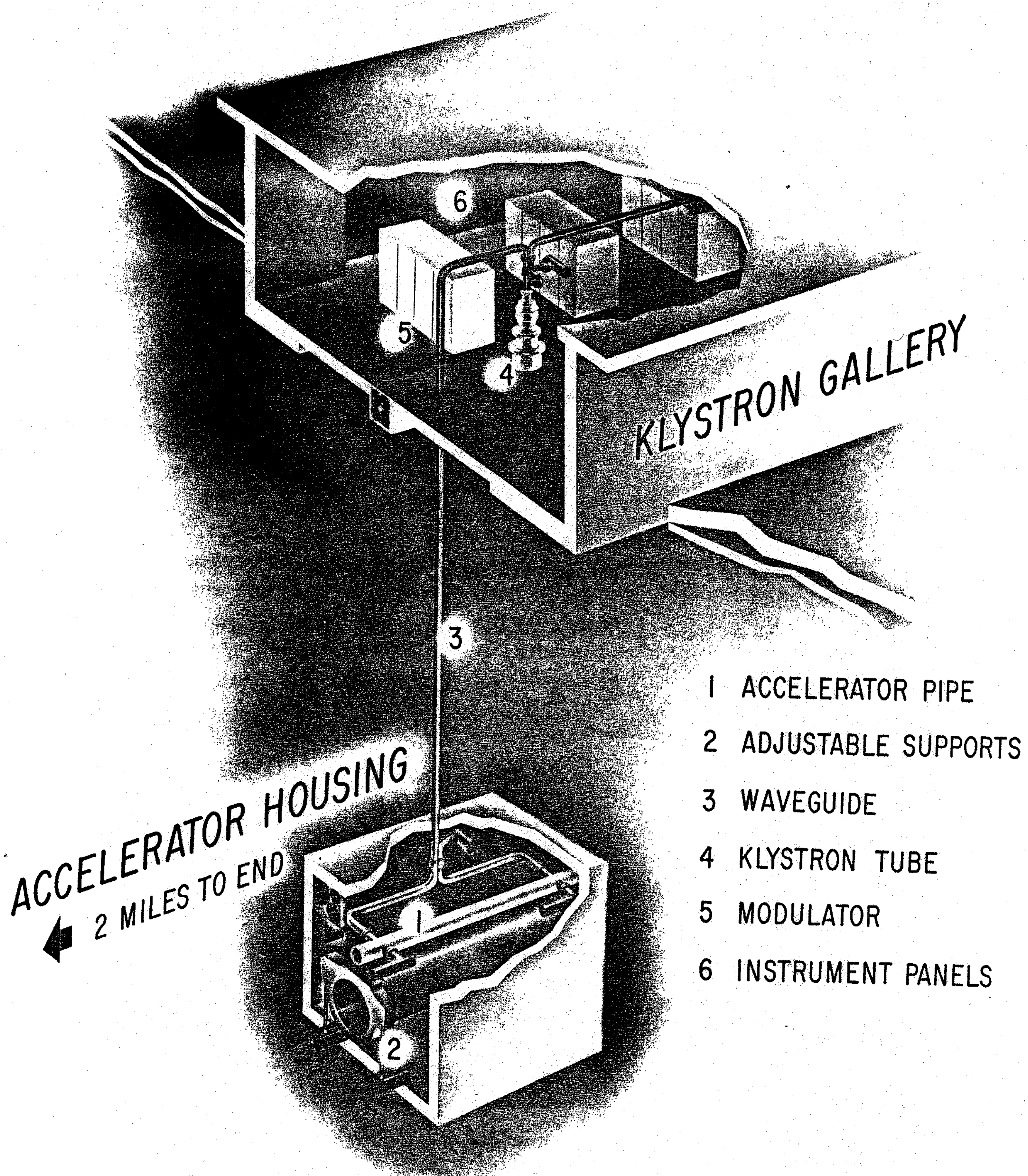

KLYSTRON GALLERY
6
5
4
3
ACCELERATOR HOUSING
2 MILES TO END
1
2
1 ACCELERATOR PIPE
2 ADJUSTABLE SUPPORTS
3 WAVEGUIDE
4 KLYSTRON TUBE
5 MODULATOR
6 INSTRUMENT PANELS

Fig. 1

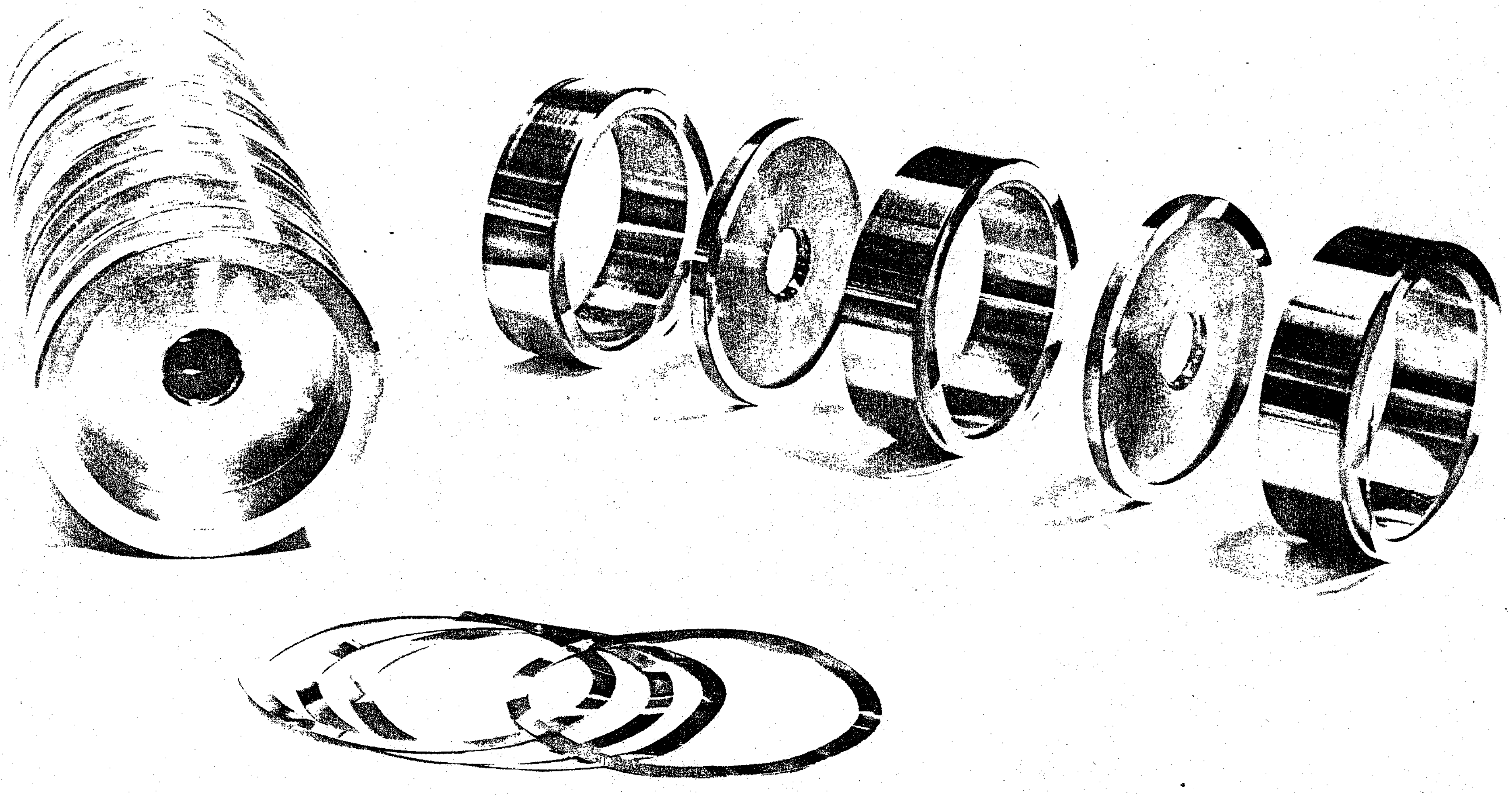
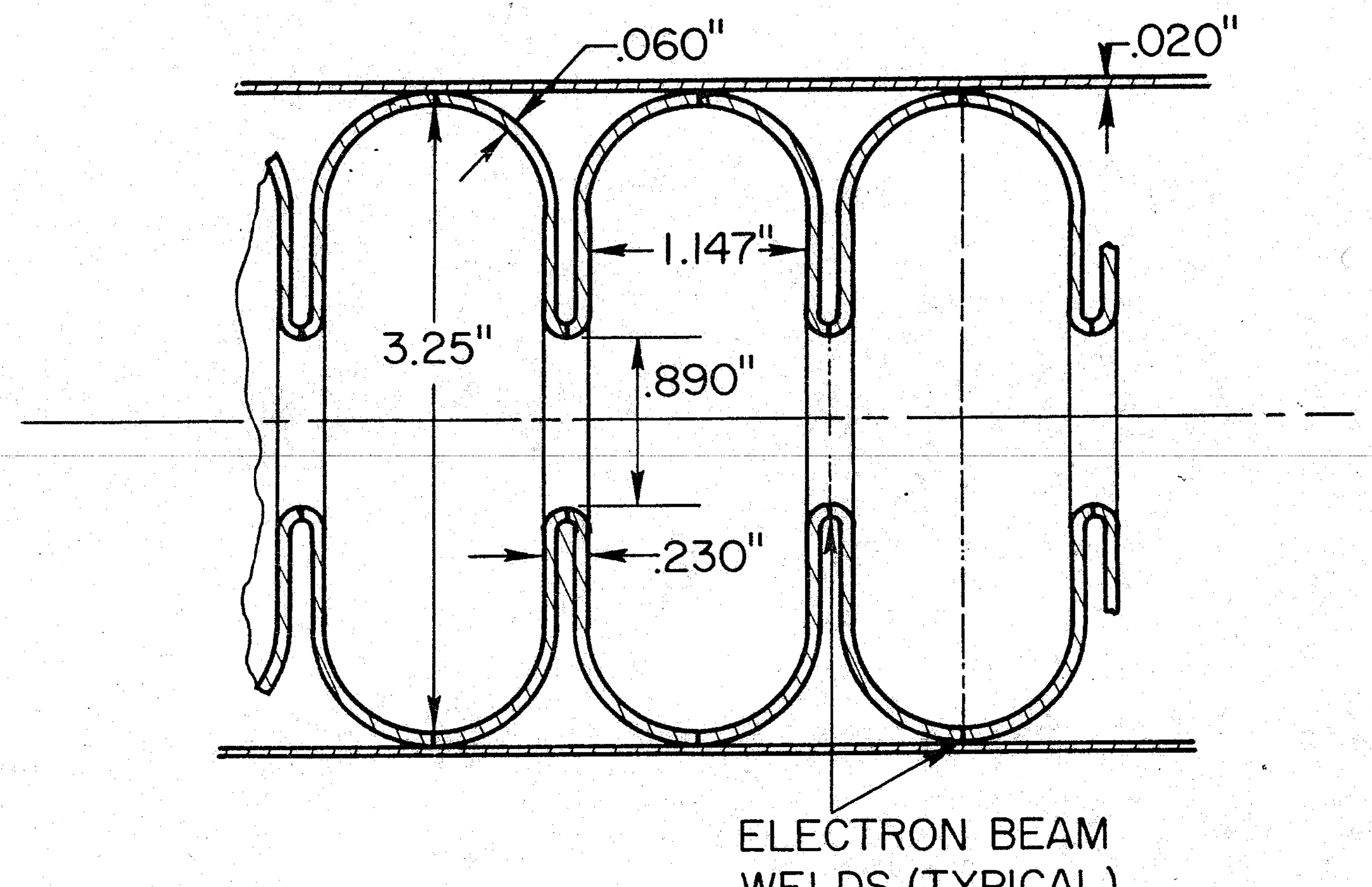


Fig. 2



1265A12

Fig. 3

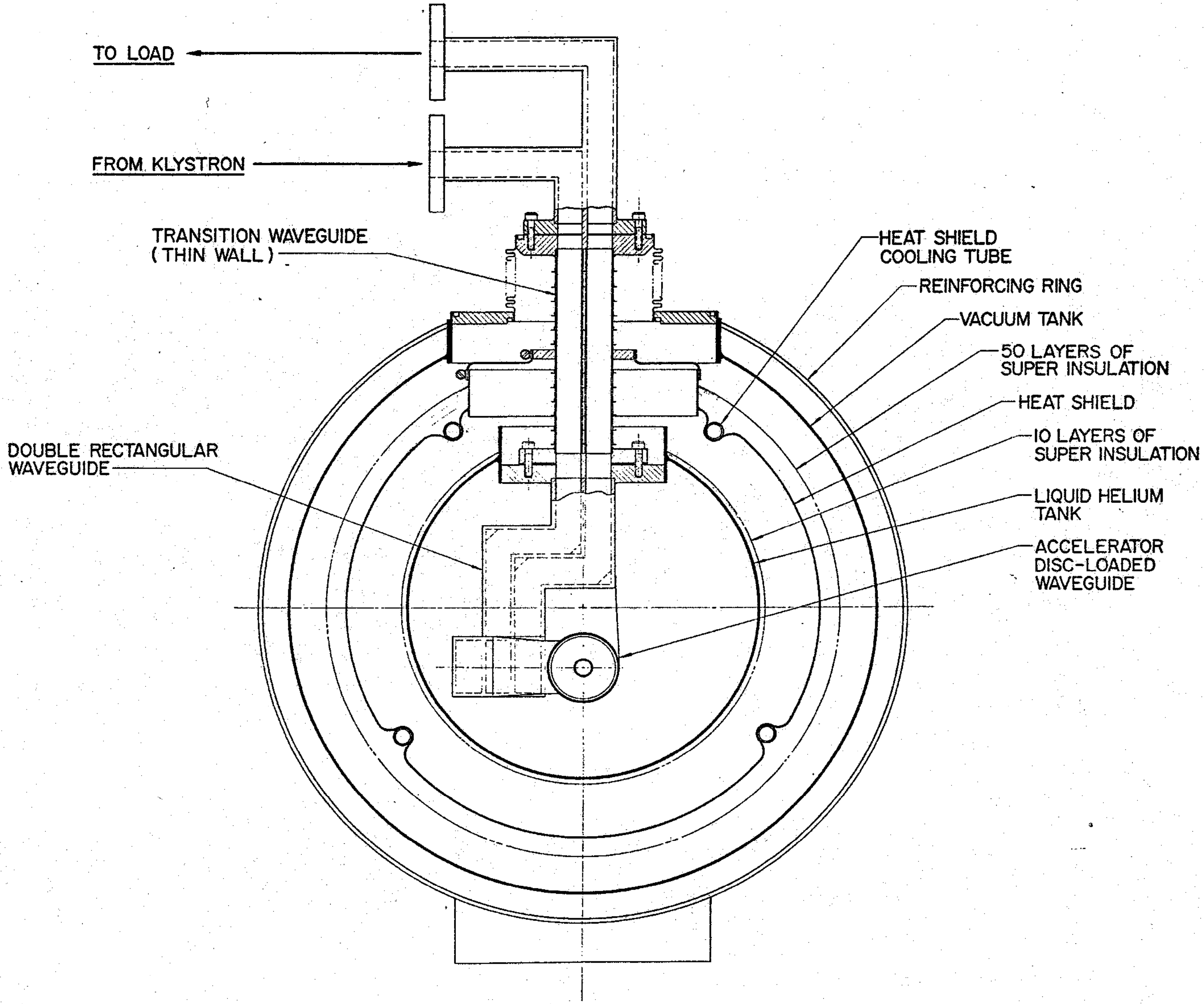

TO LOAD
FROM KLYSTRON
TRANSITION WAVEGUIDE (THIN WALL)
HEAT SHIELD COOLING TUBE
REINFORCING RING
VACUUM TANK
50 LAYERS OF SUPER INSULATION
HEAT SHIELD
10 LAYERS OF SUPER INSULATION
DOUBLE RECTANGULAR WAVEGUIDE
LIQUID HELIUM TANK
ACCELERATOR DISC-LOADED WAVEGUIDE

Fig. 4

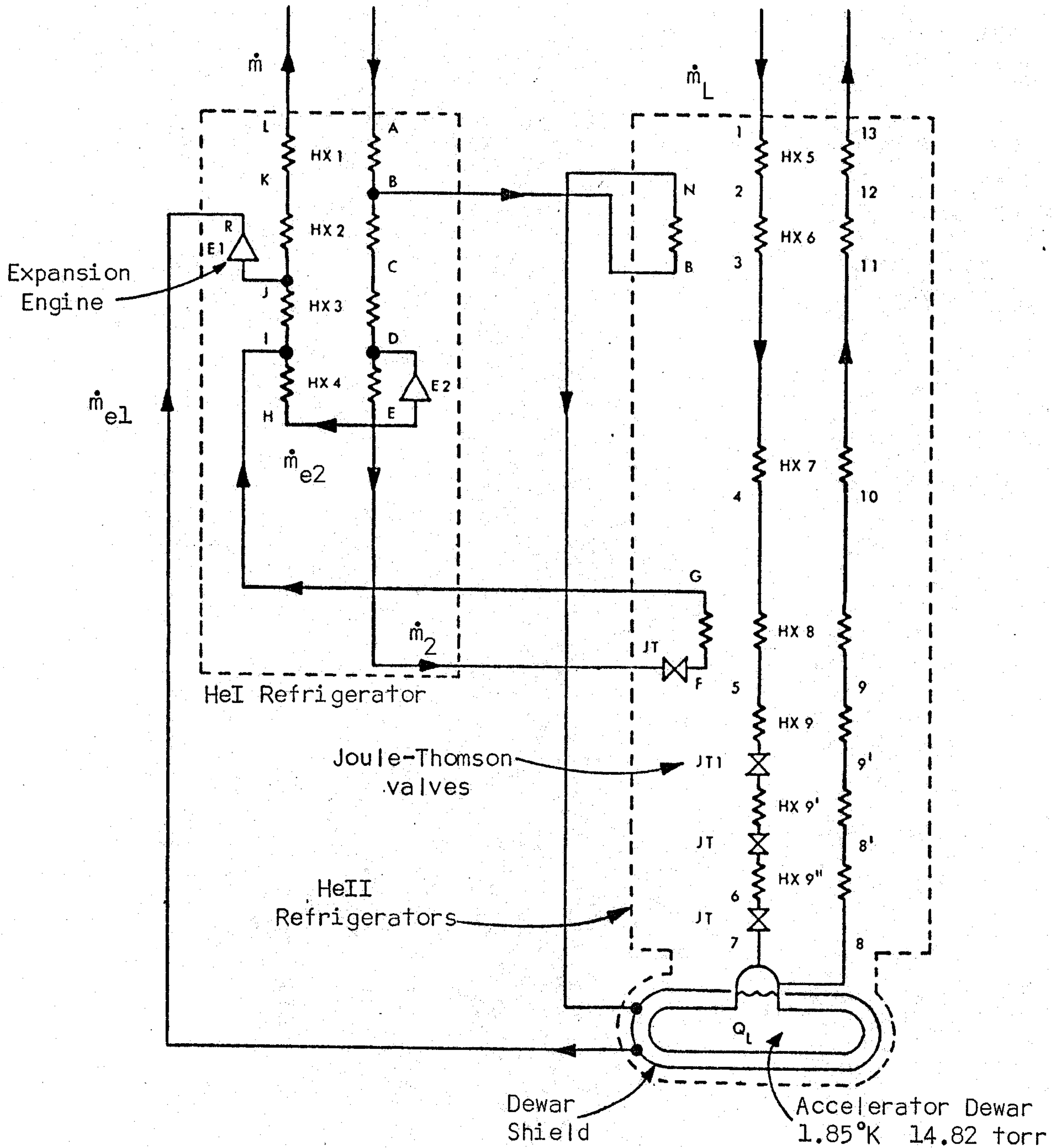

ṁ
ṁL
L
A
HX 1
K
B
HX 2
R
E1
Expansion Engine
J
HX 3
C
I
D
HX 4
E2
H
E
ṁe1
ṁe2
G
ṁ2
JT
F
HeI Refrigerator
1
HX 5
13
N
2
12
HX 6
3
B
11
HX 7
4
10
HX 8
5
9
HX 9
Joule-Thomson valves
JT1
9'
HX 9'
JT
8'
HX 9"
6
JT
7
8
HeII Refrigerators
QL
Dewar Shield
Accelerator Dewar
1.85°K 14.82 torr

Fig. 5

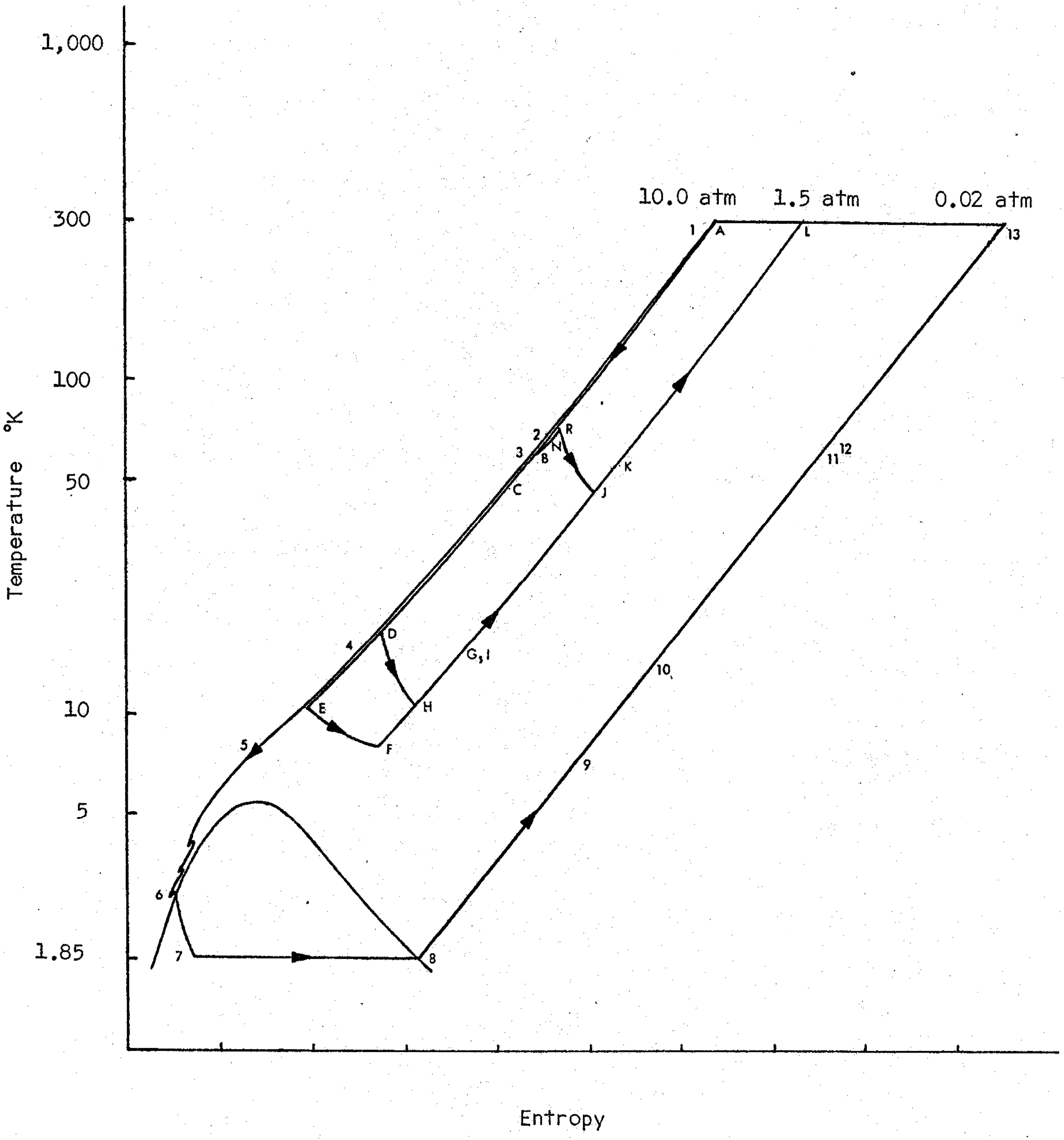

1,000
300
100
50
10
5
1.85
Temperature °K
Entropy
10.0 atm
1.5 atm
0.02 atm
1
A
L
13
2
R
N
3
B
C
J
K
11
12
4
D
G, I
E
H
F
10
5
9
6
7
8

Fig. 6

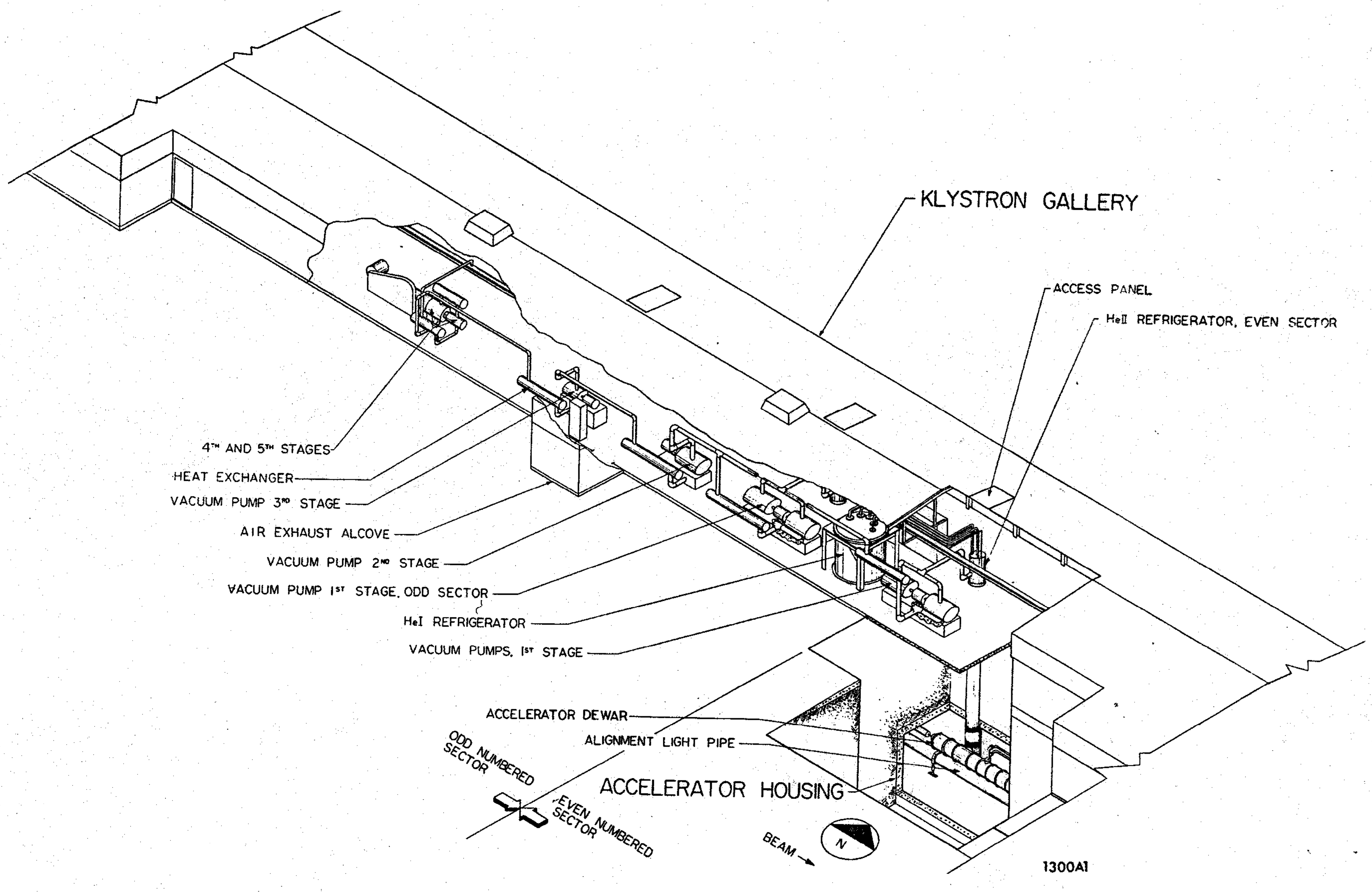

KLYSTRON GALLERY
ACCESS PANEL
HeII REFRIGERATOR, EVEN SECTOR
4TH AND 5TH STAGES
HEAT EXCHANGER
VACUUM PUMP 3RD STAGE
AIR EXHAUST ALCOVE
VACUUM PUMP 2ND STAGE
VACUUM PUMP 1ST STAGE, ODD SECTOR
HeI REFRIGERATOR
VACUUM PUMPS, 1ST STAGE
ACCELERATOR DEWAR
ALIGNMENT LIGHT PIPE
ACCELERATOR HOUSING
ODD NUMBERED SECTOR
EVEN NUMBERED SECTOR
BEAM
N
1300A1

Fig. 7