EVOLUTION OF THE SUPERCONDUCTING LINAC PROGRAM AT STANFORD

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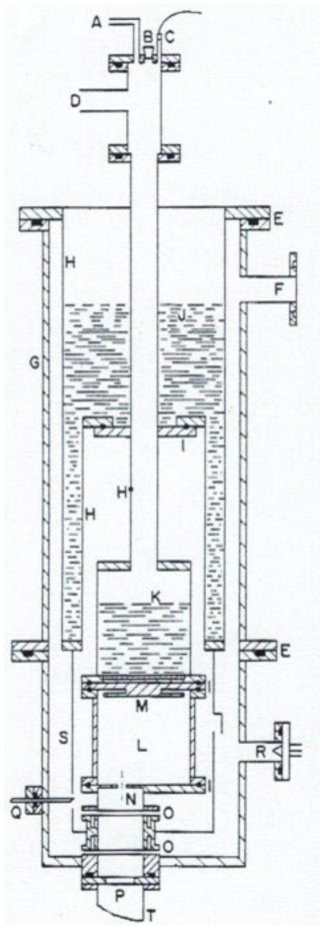
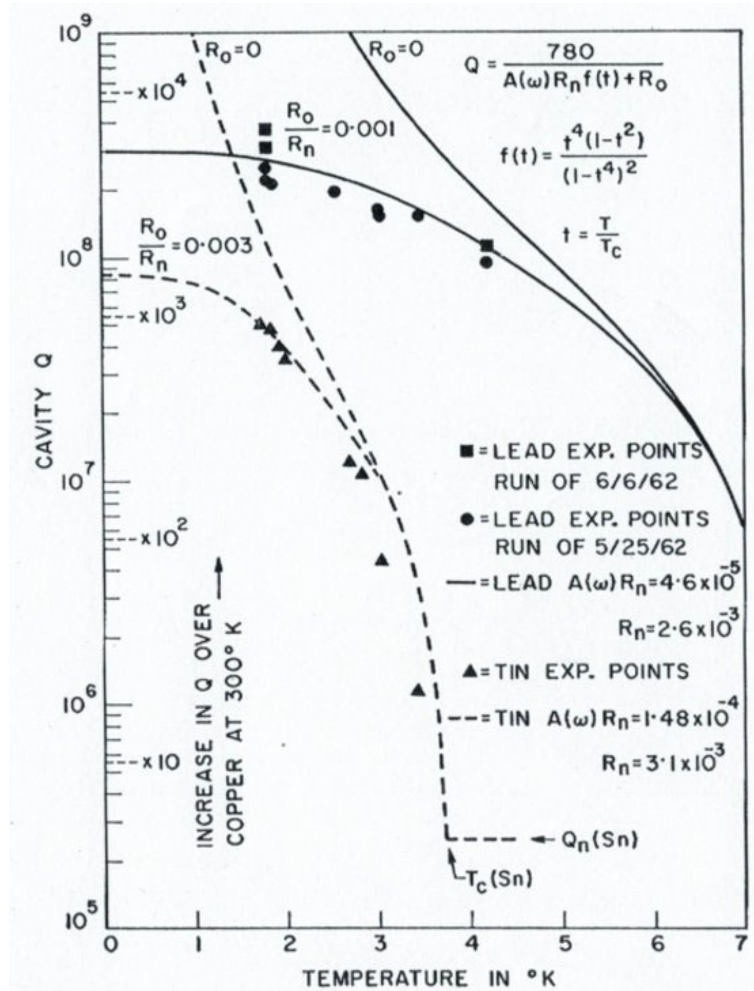
Funded by the Office of Naval Research and the National Science Foundation

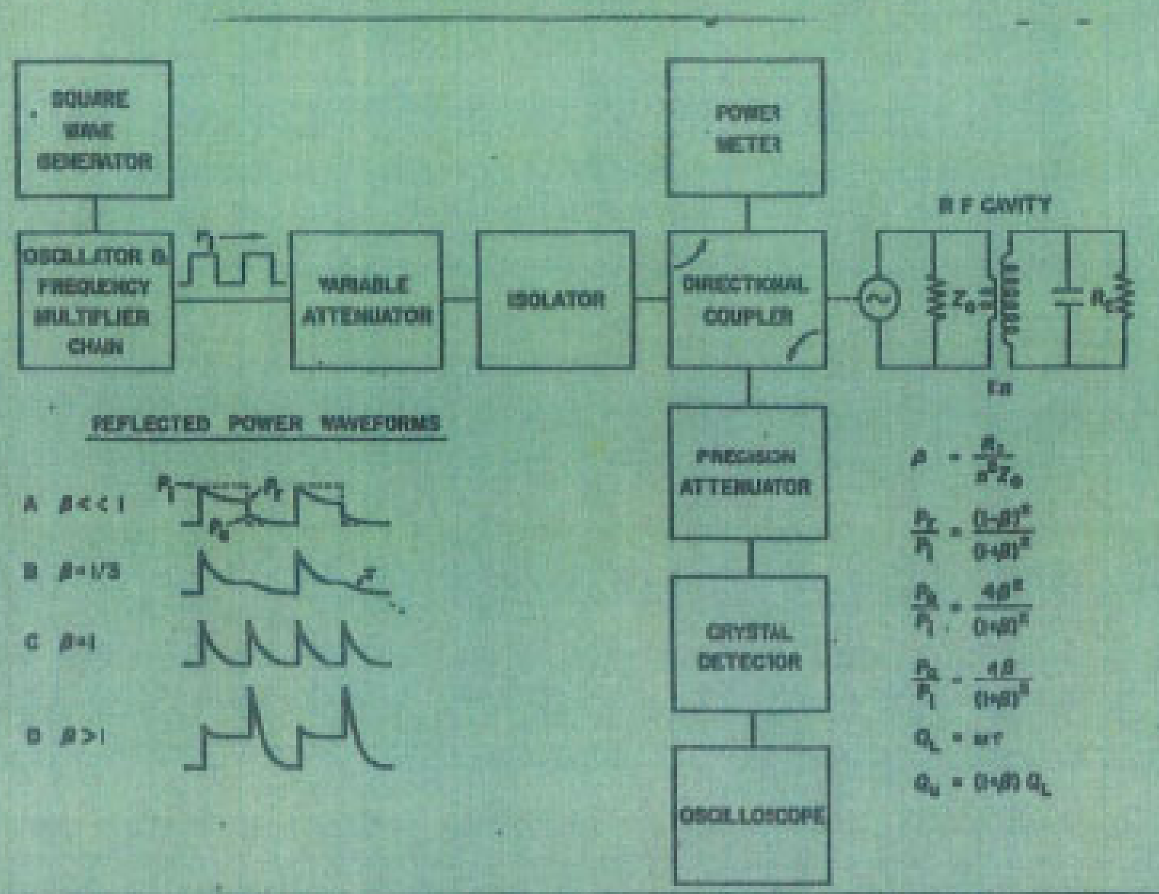
Cryostat and Cavity



Cavity Q Data



MICROWAVE CIRCUIT FOR DECREMENT METHOD



IMPACT OF 1962 EXPERIMENT

LOW TEMPERATURE PHYSICS

Cavity mode enabled BCS Study

Broke Q value barrier, but …

Q (6 K) = 3×10^{7}

Q (3 K) = 3×10^{8}

Validate BCS ?

Required Q = 3×10^{9}

ACCELERATOR PHYSICS

Cavity mode optimized plating

Broke Q barrier, but …

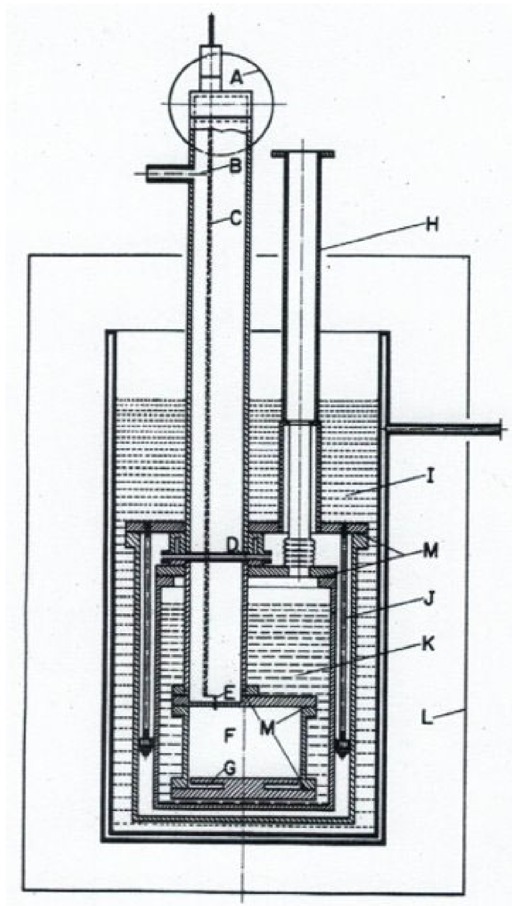
Duty Factor 3×10^{3}

Carnot Eff. $\times 10^{2}$

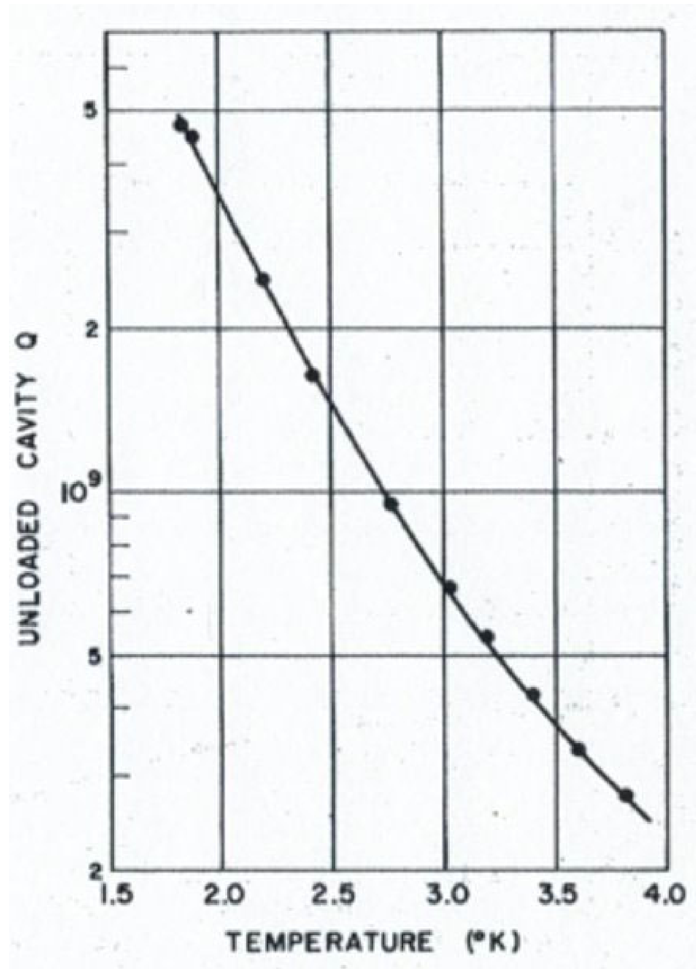
P(rf) = P(refrigerator) ?

Required Q = 3×10^{9}

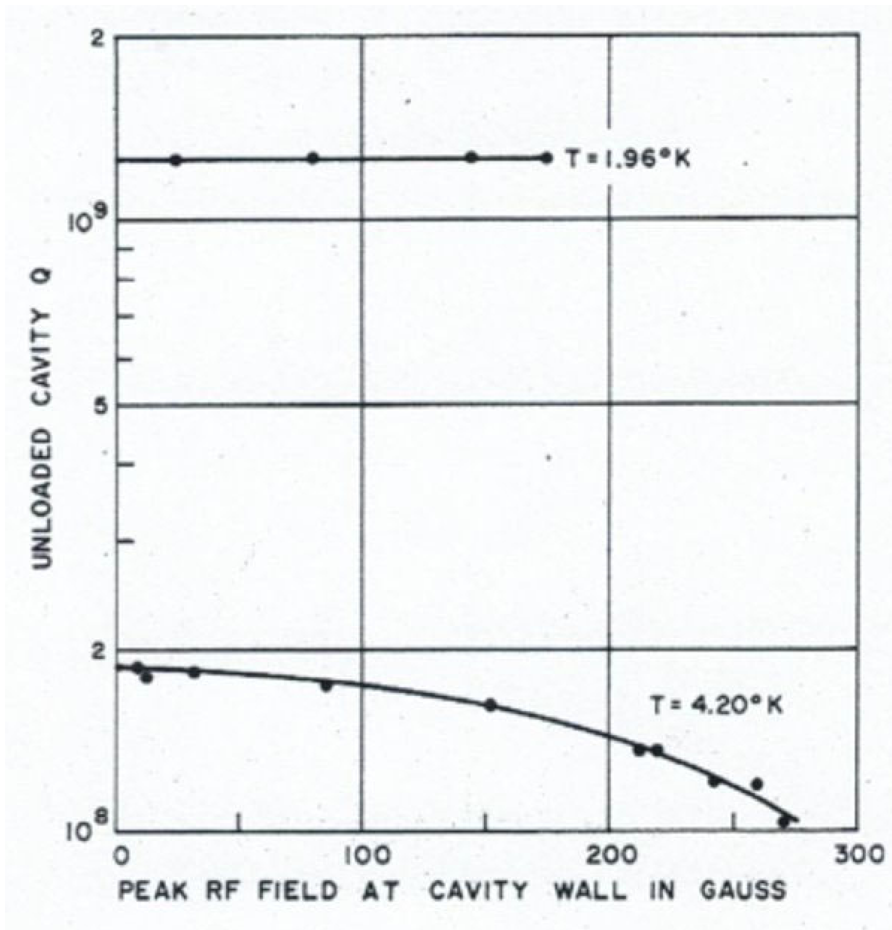
CRYOSTAT AND CAVITY



CAVITY Q DATA



CAVITY Q VERSUS PEAK RF MAGNETIC FIELD



IMPACT OF 1964 EXPERIMENT

LOW TEMPERATURE PHYSICS

Immersion in SF Helium Possible

SF Helium Justified

Q Approaches BCS Requirement

H(rf) = 200 Oe is 25% of H_c

ACCELERATOR PHYSICS

Immersion in SF Helium Possible

SF Helium Justified

Q Approaches CW Requirement

H(rf) = 200 Oe Implies 3.7 MeV/m

WHEN PLOWING VIRGIN SOIL, SURVEY TERRAIN

SCHWETTMAN: LINAC OPPORTUNITIES

Improve Beam Energy Resolution by 100 x

CW Operation: reduced rf & current fluctuations

SF Helium: access to large thermal reservoir

SW Structure: access to large EM stored energy

Opportunity for Dynamic Stabilization

Opportunity for Low Emittance Injector

Improve Average Beam Current by 10 x

WILSON & WIIK: RACETRACK MICROTRON

RT Microtron provides large beam acceptance

RT Microtron places less demand on gradient

Turneaure Thesis (1965 – 1967)

Make detailed calculation of the BCS surface Impedance and compare to precise rf cavity measurements

- Theory was extended to rf fields by Mattis & Bardeen. The rf surface impedance was expressed as a quadruple integral that Turneaure reduced to a set of double integrals that could be numerically integrated using computers of that epoch

Experimentally determine the rf critical field of a Type 1 superconductor and compare to it dc critical field

- Turneaure adroitly shifted the experimental focus to superconducting tin which has a lower transition temperature and a lower critical field. He then plated the cavity cylindrical wall and one end plate with lead, plating only one end plate with tin

EXPERIMENTAL SURFACE RESISTANCE VERSUS BCS SURFACE RESISTANCE FOR LEAD AT 11.2 GHz

Parameters of theory

(known from other measurements)

Temperature dependent energy gap

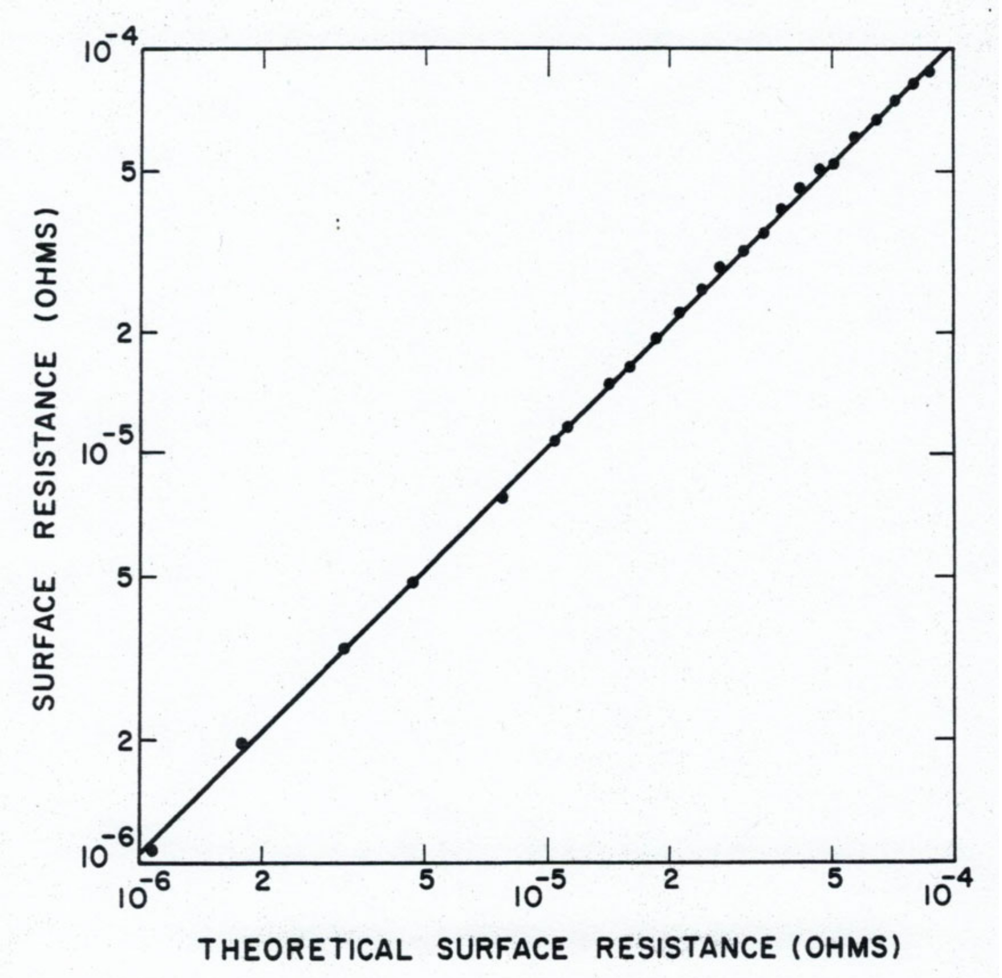
London penetration depth

Fermi velocity

Electron mean free path

Diffuse surface scattering

Temperature & frequency

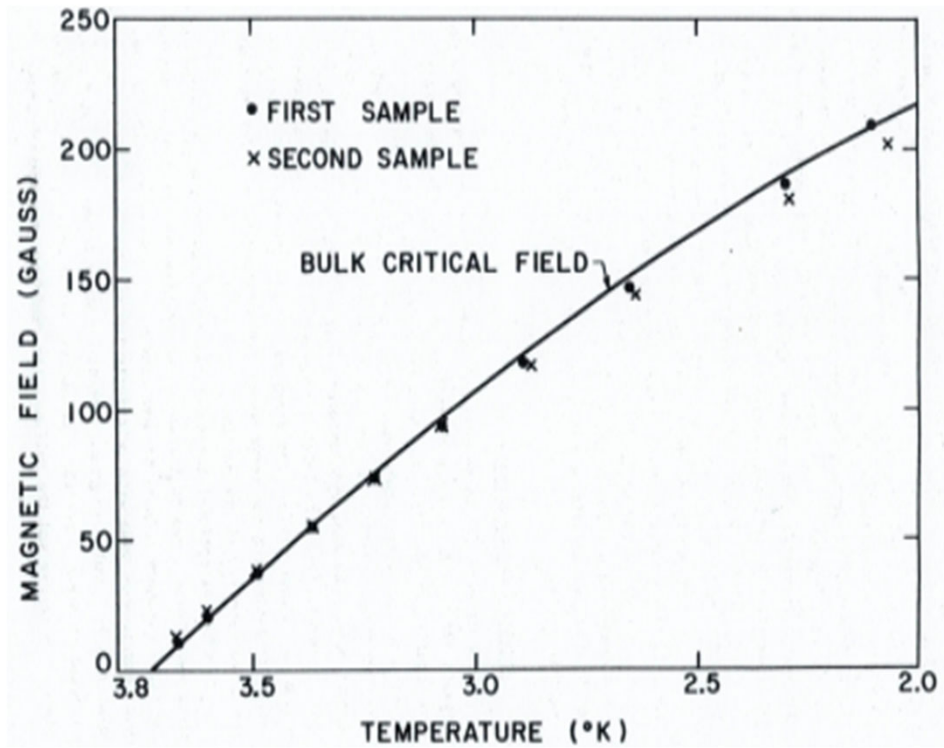


RF CRITICAL MAGNETIC FIELD VERSUS DC CRITICAL MAGNETIC FIELD FOR TIN AT S-BAND

Experiment accounted for:

Surface temperature rise due to rf dissipation

Differences between electroplated tin and bulk



ACCELERATOR PROGRAM

(Targeting 1965 Accelerator Conference in Frascati)

TM_{010} – Mode Tests	**Beam Acceleration Test**	**Racetrack Microtron**
Gradient 3.7 MeV/m	Assemble Simple Beamline	Energy: 200 MeV
$Q = 2.5 \times 10^8$	Build Horizontal Cryostat	Duty Factor: 100 %
	Build Multicell Structure	Resolution: 0.1 %
Submitted Paper	**?? Accelerate Electrons ??**	**Submitted Paper**

RESPONSE TO FIRST ACCELERATION OF ELECTRONS

High Level discussions between Stanford physics department and the ONR

CONTEXT OF DISCUSSION

Hofstadter wanted a 2 GeV linac with improved duty factor
The Office of Naval Research wanted to support their 1961 Nobel Prize winner
Both labored under the spectre of the Mansfield Amendment

NEGOTIATED PLAN

Low Temperature Tech	**Linac Technology**	**High Energy Facilities**
S F Helium Refrigerator	Low Emittance Beams	Tunnel
Distributed Cryogenics	High Average Current	End Station
SRF Development	Beam Recirculation	2 GeV Spectrometer

WHEN EMBARKING ON A TECHNOLOGY CHALLENGE

Attenuate noise from Doubting Thomases

Keep Vision Focused on what Physics will allow

Assemble a brilliant Team and reward them Handsomely

Att

SUPERFLUID HELIUM REFRIGERATOR

Central Problem: The low vapor pressure of Superfluid Helium.

Cold compression technology not well developed in 1966.

Warm compression imposes a huge heat exchanger challenge

Given technical and financial constraints:

RFP in June, 1966 for a 300 Watt, 1.85 K helium refrigerator.

Contract with Arthur D. Little, inc. in September 1966.

Collins liquefier converted to 10 Watt superfluid helium refrigerator.

Installation and acceptance test at Stanford in 1968-1969.

DISTRIBUTED CRYOGENIC SYSTEM

Design moved forward with the arrival of Michael McAshan in September, 1967.

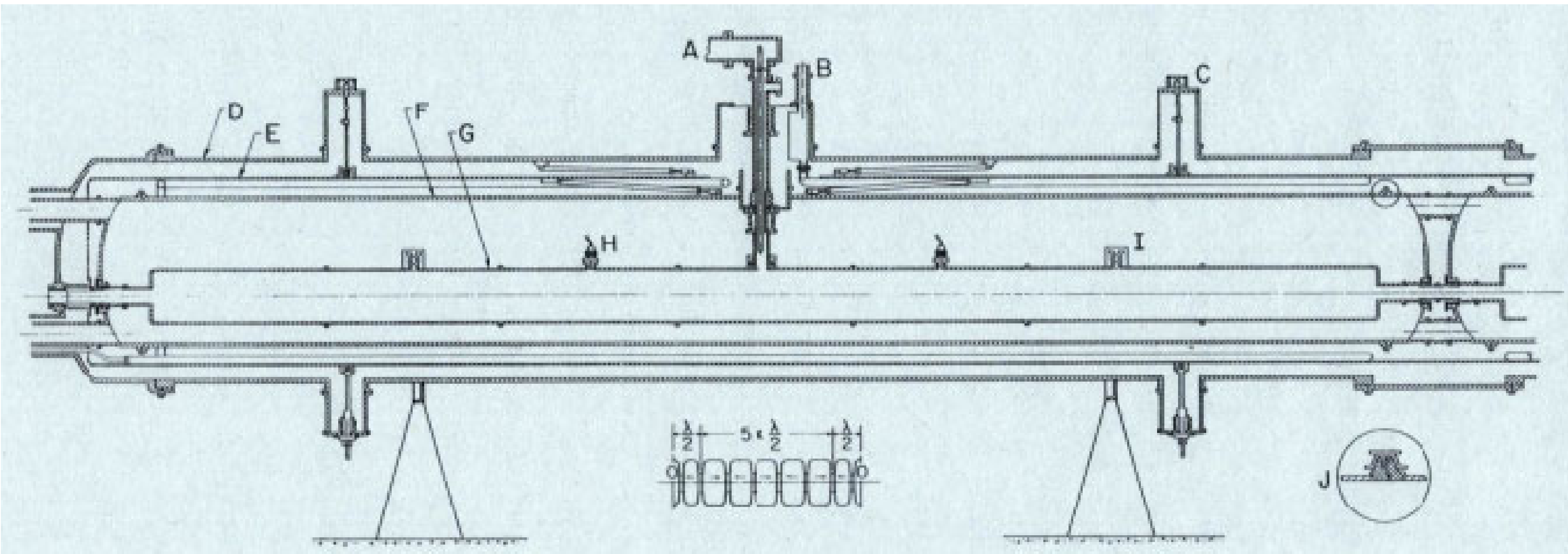
- Oversight of refrigerator construction, site preparations, and acceptance tests.
- Design of suitable liquid/vapor separator and cryogenic distribution line.

McAshan envisioned a modular design of cryogenic system. But what length?

- Hofstadter was committed to 2 GeV, and enthusiastic about 100 microamps.
- 20 klystrons at 10 KW matches beam power.
- 20 foot niobium structure fabrication length seemed manageable .

In 1972 the refrigerator, feeding superfluid helium through a 300 foot long distribution line, delivered 200 Watts of cooling at 1.8 K to the superconducting capture and pre-accelerator sections and one 20 foot long accelerator module. The refrigerator had been operated more than 2,000 hours in the previous year.

ASSEMBLED TWENTY FOOT ACCELERATOR DEWAR MODULE



DEVELOPMENT OF SUPERCONDUCTING RF

Concerns about electroplated lead TM_{010} – mode performance.

Status: Gradient of 5 MeV/m with Q = 2 x 10^8.

Susceptible to local heating and arcing damage.

Surface chemistry.

Wanted to explore possibilities for niobium.

Karl Brown arranged a meeting with Ira Weissman of Varian Associates.

In 1967 we established a collaboration between Turneaure and Weissman. Before the 1968 Brookhaven Summer Study they had produced TE_{011} – mode cavities at X–band with Q = 1.3 x 10^{10} at a magnetic field of 436 Oe.

In 1969 Turneaure and Viet developed practical niobium processing methods, demonstrated the viability of electron beam welding, and achieved in TM_{010}–mode X–band cavities: Q = 8.0 x 10^9 at a gradient of 23 MeV/m.

Low Emittance Beam

In 1967, when Larry Suelzle arrived, the 35 MeV Mark II accelerator was removed and the vault prepared for tests of a prototype low emittance injector.

The design incorporated an 80 KeV source, a superconducting 5 – cell capture section and a superconducting rf separator cavity provided for beam analysis.

Achieving a low emittance beam requires both careful injector design and dynamic stabilization of the accelerating fields.

By the time of the 1968 Brookhaven Summer Study, Suelzle had demonstrated feedback stabilization of the amplitude and phase of rf cavity fields.

Design and installation of the prototype injector took longer.

However, in 1969 the transverse phase space of the 80 KeV beam was manipulated to yield an emittance of 5 π mm mrad, and longitudinal bunches of 20^{o} phase width were obtained by chopping. After capture and acceleration, the measured bunch phase width was less than 2^{o}.

HIGH AVERAGE CURRENT

Addressing the problem of Regenerative Beam Breakup in superconducting structures was particularly challenging. There was no alternative to determining the interaction of every relevant mode with the accelerated electron beam, and then providing external loading for that mode, sufficient to prevent breakup.

Karl Mittag came to Stanford from Karlsruhe and we used a method developed at Karlsruhe to complete this task in 1972. External loading was designed and provided, sufficient to permit beam currents as high as 500 microamps.

COMPETING INTERESTS

Heavy Ion Accelerator

1969 letter to Paul Donovan
(array of single gap cavities
driven by independent sources)
1970 NSF Proposal
(arrival of Ilan Ben-Zvi)

Pion Radiotherapy

1970 NSF (RANN) Proposal
(arrival of Doug Boyd)
Revolutionize radiotherapy
CT– scan patent
SC toroidal spectrometer

Free Electron Laser

1971 Madey discussions
1972 Proposal to AFOSR
1975 gain measurement
1977 First FEL