LIGO-G890001-00-M

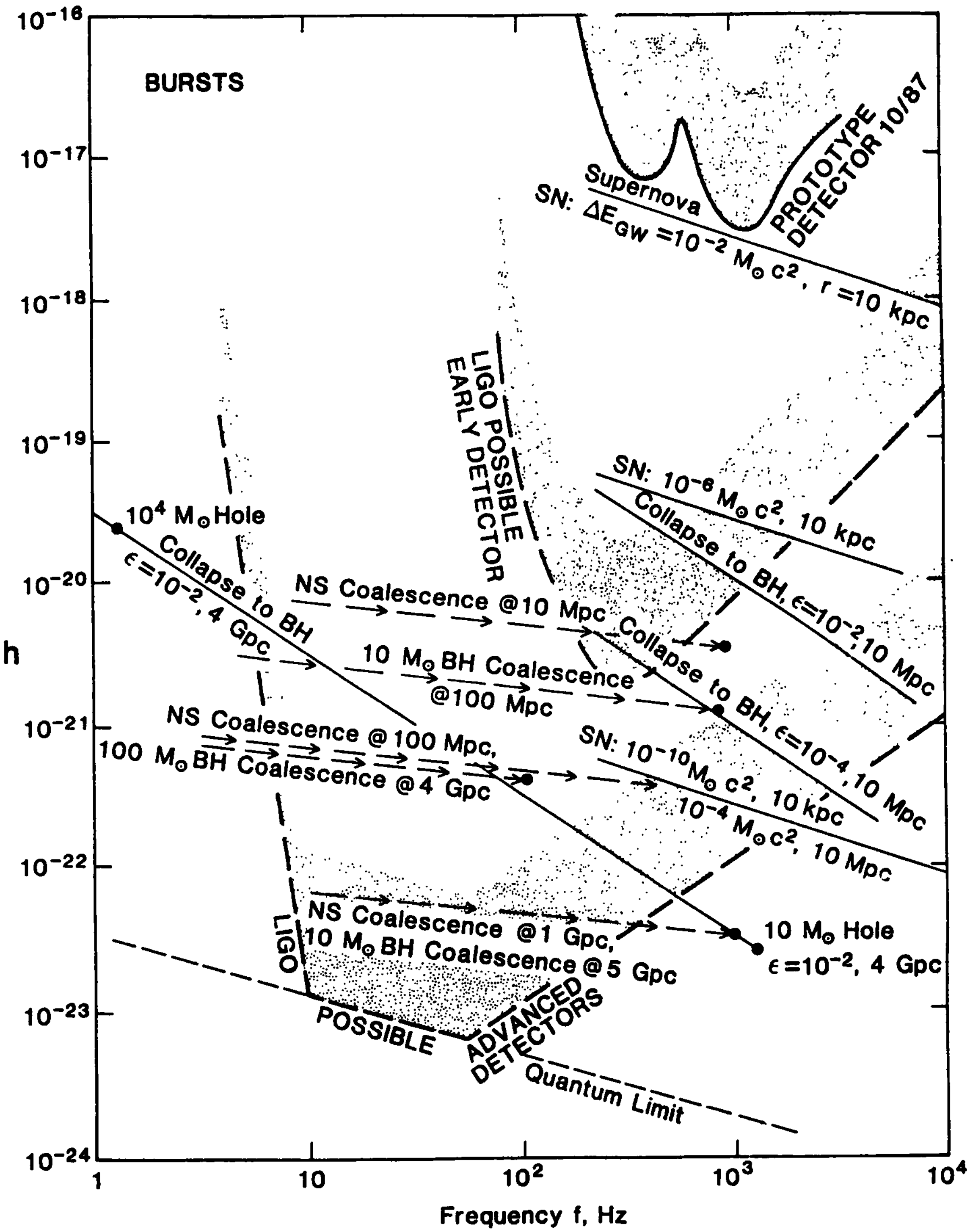
AGENDA
NSF/LIGO Meeting, Caltech

Monday, 4/10/89

Time	Location	Topic	Participants
9:00	101 E. Bridge	Introduction	NSF Visitors
		Review of Agenda	R. Vogt
9:30	22 Bridge Annex	LIGO Briefings I	NSF Visitors
			Caltech Administration
		1. Overview	W. Althouse, Chief Eng.
		2. Vacuum System	R. Drever, Prof.
			E. Franzgrote, Asst. to Dir.
			F. Raab, Asst. Prof.
12:00	Athenaeum	Lunch	K. Thorne, Prof.
			R. Vogt, Director
13:30	22 Bridge Annex	LIGO Briefings II	R. Weiss, Prof.
		1. Enclosures	
		2. Equipment and Support Facilities	
		3. Sites	
		4. Staffing and Operations	
		5. Costs and Schedule	
17:00		Adjourn	

Tuesday, 4/11/89

Time	Location	Topic	Participants
9:00	22 Bridge Annex	Programmatic Issues	NSF Visitors
			Caltech Administration
		Work Plan	W. Althouse, Chief Eng.
			R. Drever, Prof.
		Management Issues/LIGO Team	E. Franzgrote, Asst. to Dir.
		Project organization and supervision	F. Raab, Asst. Prof.
		Manpower planning	K. Thorne, Prof.
		Caltech/MIT Issues	R. Vogt, Director
			R. Weiss, Prof.
		LIGO Approval Strategies	
		Proposal Contents	
12:00	Athenaeum	Lunch	
13:30	22 Bridge Annex	Discussions	
16:00	101 E. Bridge	Wrapup	NSF Visitors
			R. Vogt
17:00		Adjourn	


BURSTS
h
Frequency f, Hz
PROTOTYPE DETECTOR 10/87
Supernova
SN: ΔE_GW =10^-2 M⊙ c², r =10 kpc
LIGO POSSIBLE EARLY DETECTOR
SN: 10^-6 M⊙ c², 10 kpc
Collapse to BH, ε=10^-2, 10 Mpc
10^4 M⊙ Hole
Collapse to BH ε=10^-2, 4 Gpc
NS Coalescence @10 Mpc
10 M⊙ BH Coalescence @100 Mpc
Collapse to BH, ε=10^-4, 10 Mpc
NS Coalescence @ 100 Mpc,
100 M⊙ BH Coalescence @ 4 Gpc
SN: 10^-10 M⊙ c², 10 kpc
10^-4 M⊙ c², 10 Mpc
NS Coalescence @1 Gpc,
10 M⊙ BH Coalescence @ 5 Gpc
10 M⊙ Hole
ε=10^-2, 4 Gpc
LIGO
POSSIBLE
ADVANCED DETECTORS
Quantum Limit

LIGO MISSIONS

- The LIGO will be designed and constructed to accommodate three primary missions:

  1) **DEVELOPMENT** - the capability for full functional testing of new interferometer-based detector concepts, whose component parts have been maximally developed in campus R & D facilities.

  2) **OBSERVATION** - the capability for conducting continuous observations with previously developed detector(s) subsequently dedicated to the observation mission.

  3) **SPECIAL INVESTIGATIONS** - the capability to accommodate competitively selected detectors to carry out scientific investigations with unique objectives.

- The three LIGO missions will be conducted independently without mutual interference.

LIGO EVOLUTION

The LIGO will evolve in two phases:

- **PHASE A** will provide for effective conduct of the **development** and **observation** missions with minor technical constraints on the capabilities provided, consistent with economy.

- **PHASE B** will provide for the removal of the technical constraints permitted in Phase A and will add the capability for the **special investigations** mission.

LIGO CAPABILITIES

- The LIGO will consist of an **L-shaped vacuum system** at two sites to provide for spatially separated coincidence detections.

- **Ports** will be provided in the vacuum system to accommodate one detector for each mission.

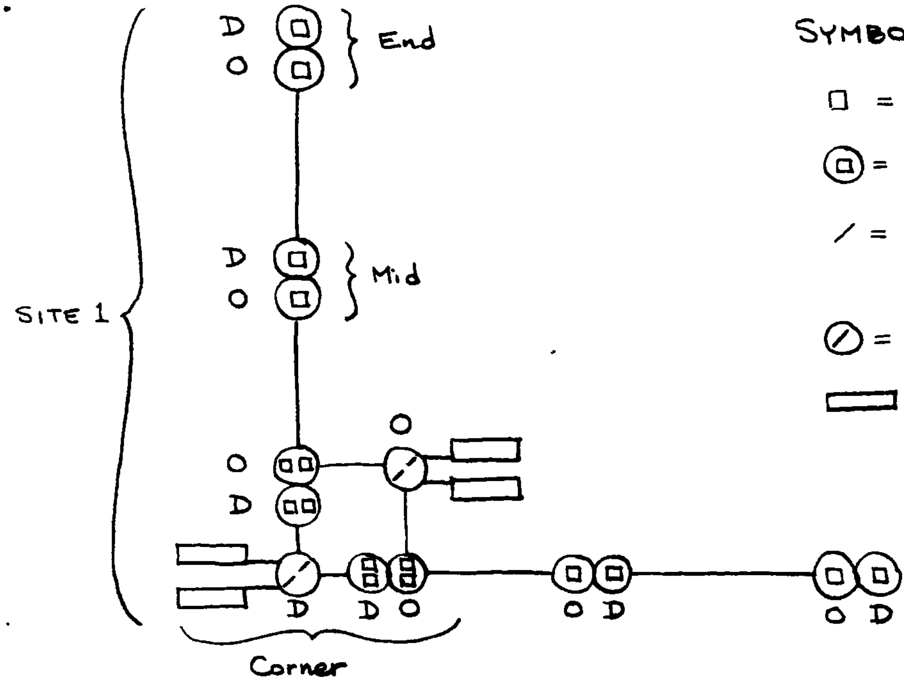
- One **detector** will consist of up to three interferometers, as follows:

  One full-length interferometer at each site.

  One mid-length interferometer at one site.

- It is permissible, during Phase A, for parts of one detector (of a given mission) to share a port to the vacuum system with some loss of functional capability (i.e., two test masses in a corner station test mass tank; two beam splitters in a single tank).

LIGO Configuration — Phase A



SYMBOLS:

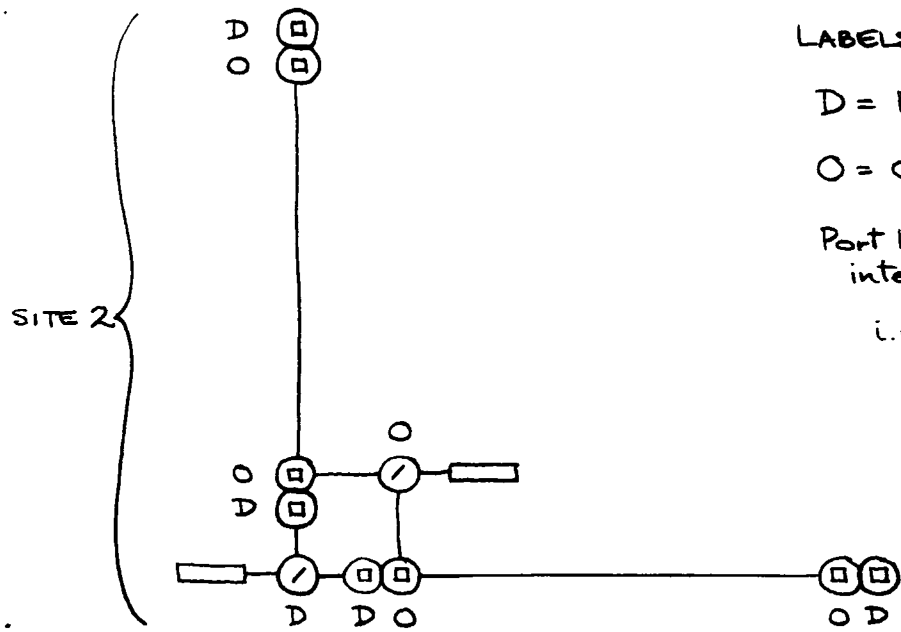
□ = Test Mass

(□) = Test Mass Port

/ = Beam Splitter, Input & Output Conditioning Optics, Detector

⊘ = Beam-Splitter Chamber(s)

▭ = Laser



LABELS:

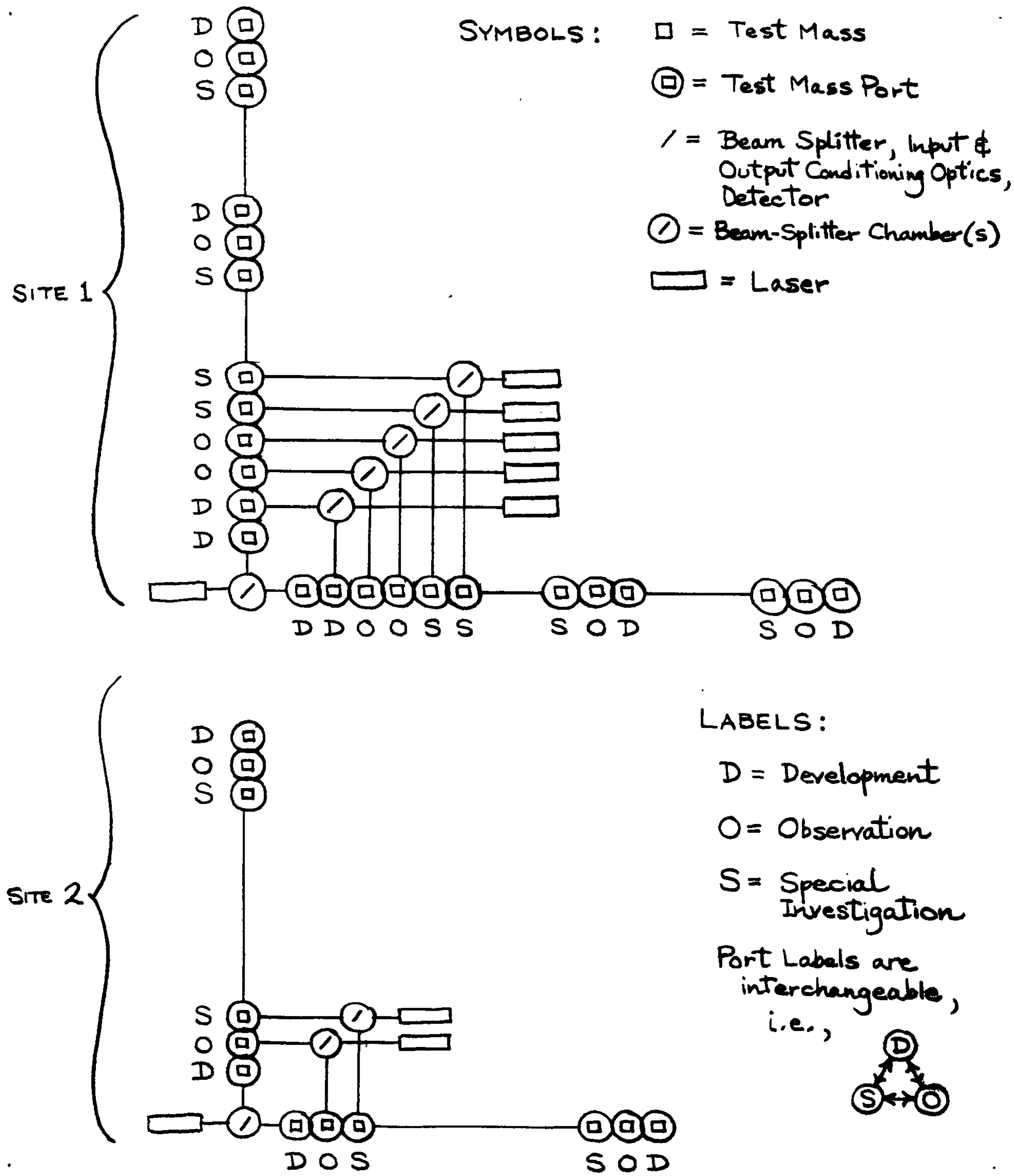
D = Development

O = Observation

Port Labels are interchangeable, i.e.,

(D)↔(O)

LIGO CONFIGURATION — PHASE B



4/10/89

EARLY LIGO OPERATIONS

YEAR 1 (upon completion of vacuum system at site 1):

- Site 2 still under construction
- Install and debug 1st full length interferometer at site 1
- Shake down site 1 facilities

YEAR 2:

- Install/debug mid-length interferometer at site 1
- Install/debug full-length interferometer at site 2
- Shake down site 2 facilities

YEAR 3:

- Declare 1st observation detector operational
- Major effort to understand 1st coincidence detector
- Shake down data analysis procedures, equipment, software
- Begin campus development of Mark II interferometer

YEAR 4:

- Install/debug Mark II interferometers at sites 1 & 2

LIGO MEMORANDUM

To: Distribution

From: E. Franzgrote

Subject: Updated List of Studies and Reviews

Date: 04/06/89

The following is an updated listing of LIGO studies and reviews that adds papers received since the listing of 03/15/89. The additions and revisions (see pages 5 and 6) are indicated with a plus sign (**+**) in the right-hand margin.

Complete reference sets of these 103 papers, numbered according to these lists, are available in the files of B. Behnke, C. Akutagawa, and S. Merullo. If any project member needs one of these papers, please have a copy made from these files. The reference papers are to be removed from these files *only* for the purpose of making copies. If a paper has been revised, only the latest revision is included in the reference sets.

#	Title and Date of Study	Author
01.	Laser, interferometer efficiency and LIGO power, cooling requirements (07/06/88).	R. Weiss
01R.	Review of Rai's memo on laser power and cooling requirements (07/22/88).	F. Raab
02.	Pressure changes in the beam tubes with temperature and some theory of outgassing (06/15/88).	R. Weiss
02R.	[Review of] Memo 61588 "Pressure changes..." (08/30/88).	R. Spero
02a.	Dubinin-Radushkevich Isotherms ["Appendix to Pressure changes..."](01/30/89).	R. Weiss
03.	A Model Calculation of Vibration Isolation from Bellows (06/21/88, **revised 02/02/89**).	P. Saulson
03R.	[Review of] "A Model Calculation of Vibration Isolation..." (07/22/88).	A. Abramovici
04.	Elementary geometric considerations of light baffles in a tube (07/05/88).	R. Weiss
04R.	Comments on "Elementary geometric considerations..." (07/21/88).	Y. Gürsel
05.	Control Systems and Data Analysis for Large Gravitational Detectors (06/09/88).	A. Jeffries, et al.
05R.	Comments and Additions to Draft Document "Control Systems and Data Analysis..." (07/20/88).	M. Zucker

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05a.	[Archiving Data...] (05/23/88).	S. Smith
06.	Wind-induced Motion of Unprotected LIGO Vacuum Pipes (06/07/88, **revised 11/16/88 and 02/02/89**).	P. Saulson
06R.	Review report [of "Wind-induced Motion..."] (07/20/88).	A. Čadež
07.	Aspects of Leak Detection in LIGO Beam Tubes (04/28/88, **revised 12/16/88**).	B. Moore
07R.	Comments on "LIGO Internal Report 88-1—Aspects of Leak Detection..." (07/21/88 & 12/01/88).	Y. Gürsel
08.	Vacuum Test Facility Description and Experiment Plans (06/07/88).	B. Moore
09.	Mechanical Noise from Optical Contacting (07/16/88).	R. Weiss
09R.	Comments on "Mechanical Noise..." (08/11/88).	A. Čadež
10.	LIGO interferometer light budget (2nd draft, 08/03/88).	A. Abramovici
11.	[re: Scattering in Fabry-Perots...] (08/21/88).	K. Thorne
12.	Notes on the Concept of a Half-Length/ Full-Length Interferometer System (08/28/88).	R. Drever
12R.	Review of Ron Drever's Memo on Half-Length/ Full-Length Interferometer System (11/16/88).	P. Saulson
13.	Zeroth pass at "Receiver/Facility Interface" questions (06/16/88).	M. Zucker
14.	Variable Transmission Mirror for Recycling (08/19/88).	A. Abramovici
14R.	Review of "Variable Transmission Mirror..." (09/30/88).	J. Livas
15.	Memo on scattering in LIGO vacuum pipes (08/30/88, **revised 01/26/89**).	A. Čadež
16.	Test of Optical Homogeneity of Thick SiO_2 (09/06/88).	M. Burka
17.	A Reflective Quadcell Position Sensor (07/05/88).	J. Kovalik & P. Saulson
18.	Electrical Vacuum Feedthrough Research (07/25/88).	J. Livas

19.	Requirements on the Building Structures that will House the Vacuum Chambers of the LIGO Detectors (09/30/88, **revised 10/03/88**).	Y. Gürsel
19R.	Review of "Requirements on the Building Structures..." (11/30/88).	M. Burka
20.	Do Wiggle Effects Depend on Mode Cleaner Length? (10/06/88, **revised 1/10/89**).	A. Abramovici
21.	Notes on Reasons for Incorporating Gate Valves in Test Mass Tanks, and on possible scenario near start of LIGO operations (10/05/88).	R. Drever
22.	Vibration Isolation using Rubber and Metal Springs: An Overview of Past Experiences and the Planned Tests in the Gravitational Physics Laboratory at Caltech (09/01/88).	Y. Gürsel
23.	Preliminary Seismic Survey of the Livingston LIGO Site (10/22/88).	[LSU report]
23R.	Comments on the Preliminary Seismic Survey of the Livingston Site Including Recommendation of Site Suitability (11/14/88).	YG, FR, PS, RS
24.	Notes on Baffle and Beam Parameters Relevant for Scattering Estimates (11/14/88).	R. Drever
25.	Proposed Layout of LIGO Office and Shop areas (11/02/88).	W. Althouse (Engineering Staff)
26.	Proposed Power Handling and Reflectivity Tests of Mode Cleaner Mirrors (11/18/88).	M. Zucker
27.	Pressure Specification for LIGO (11/19/88, **revised 02/05/89**).	A. Abramovici
27R1.	Comments on "Pressure Specification..." (11/20/88).	W. Althouse
27R2.	Comment on "Pressure Specification..." (12/12/88).	B. Moore
28.	Draft of Site Chapter for LIGO Design Handbook (11/28/88, **revised 02/03/89**).	P. Saulson
29.	Report on Seismic Isolation and Suspension Systems – Introduction to the Issues and Status of Research at MIT and Caltech (10/28/88).	Y. Gürsel, et al
30.	LIGO Electrical Power (11/30/88).	W. Althouse (Engineering Staff)
30R.	Comments on LIGO Electrical Power Study (03/02/89).	R. Spero

31a.	Operations Scenario (12/01/88).	F. Raab
31b.	Outline of Draft on Phase A Operations (12/07/88).	P. Saulson & R. Weiss
31c.	Thoughts on LIGO Phase A Operations Scenario (12/14/88).	P. Saulson
31d.	Initial Notes on Strategy and Tactics in Operation of the LIGO over Two Stages in the Program (12/15/88).	R. Drever
32.	Measurements of Stainless Steel Hydrogen Content (12/06/88).	B. Moore
33.	Dust Accumulation on optics, scattering and requirements on clean area for the LIGO (12/09/88).	R. Weiss
33R1.	Review of "Dust Accumulation..." (01/05/89).	A. Čadež
33R2.	Comments on Memo "Dust Accumulation..." (01/06/89).	R. Spero
34.	Draft Specification for the Slope of LIGO Arms (12/10/88).	P. Saulson
35.	Seismic Noise Surveys of a Chosen LIGO Site (12/14/88).	Y. Gürsel
36.	Light Scattering and Proposed Baffle Configuration for the LIGO (01/11/89).	K. Thorne
37.	Estimate of Receiver Gas Load (12/23/88).	M. Burka
38.	Orientation of LIGO Receivers (12/29/88) (and Addenda, 01/08/89 and 01/10/89).	Y. Gürsel & M. Tinto
39.	Draft on Phase A Operations (12/30/88).	R. Weiss
40.	Thermal Considerations for LIGO Tubes (12/30/88).	R. Weiss
41.	Optical Properties of the LIGO Beam Tubes (01/17/89).	R. Weiss
41a.	An error in "Optical Properties..." (02/19/89).	R. Weiss
42.	Some Notes on the Effect of Slope (02/02/89).	F. Raab
43.	Draft Report on Imported Noise (01/02/89).	P. Saulson

44.	Delay Line Scaling (02/08/89).	R. Weiss
44a.	The ingredients of the choice of 43 inches for a LIGO delay line at 1.06μ (02/16/89).	R. Weiss
45.	Notes on Sapphire (02/21/89).	M. Burka
46.	On Local Coincidences, Mid-Stations, and Correlated Noise (02/21/89).	P. Saulson
47.	An Optimal Solution to the Inverse Problem for Gravitational Wave Bursts (02/24/89).	Y. Gürsel & M. Tinto
48.	LIGO Optics Vibration Levels Equivalent to Shot Noise in the Advanced Detectors (02/24/89).	A. Abramovici
49.	Draft: Scattering by Residual Gas (Oct 88, typed Feb 89).	R. Weiss
50.	Shot Noise in Two Beam Interferometers (Nov 88, typed Feb 89).	R. Weiss
51.	Proposed Plan for Developing LIGO-Scale Optical Components (02/07/89).	R. Spero
52.	LIGO: Rationale for a Two-Site Observatory Under One Management (02/08/89, **revised 04/03/89**).	R. Vogt +
53.	Followup Comments to the Tutorial on Power Spectral Density (03/02/89).	R. Spero
54.	Contrast, Throughput, and Storage Time of Two-Mirror Cavities (03/02/89).	R. Spero
55.	Report on Vibration Isolation Requirements for LIGO Optical Components (03/02/89).	A. Abramovici & P. Saulson
55a.	Addendum to Report on Vibration Isolation Requirements for LIGO...(03/06/89).	A. Abramovici & P. Saulson
56.	"Chamber Concepts" (Notes by WA & FR) (~03/06/89).	WA, RD, FR, RV, MZ
57.	Environmental Specifications (03/07–08/89).	AA, YG, PS, RW
57a.	Draft Summary of Environmental Specifications (03/08/89).	P. Saulson & R. Weiss
57b.	Comments on the Environmental Specifications (03/08/89).	R. Weiss
58.	Auxiliary Physical Measurements for the LIGO (03/06–08/89).	AA, MB, YG, PS, RW
58a.	Draft Summary of Requirements for Auxiliary Physical Measurements (03/08/89).	P. Saulson

59.	Report on the LIGO Receivers/Facilities Interface — Electrical and Optical Feedthroughs for Phase A Vacuum Chambers (03/09/89).	AJ, RS, MZ	
59a.	Receiver/Facility Interfaces — Outline (Draft 01/25/89, transmitted 03/02/89).	P. Saulson	
59b.	Concerning: Receiver/Facility Interfaces (03/13/89).	R. Weiss	
59c.	Re: Report on Receiver-Facility Interface (03/13/89).	P. Saulson	
60.	Specifications for Optical Link Pipe Between Beam Generating Systems of Interferometers in Separate Mass Tanks (03/10/89).	R. Drever	
61.	LIGO Support Facilities (03/13/89; **typed copy ~03/20/89**).	AA, MB, FR, MZ	+
62.	Report on LIGO Control Systems and Data Analysis — Computer and Data System Requirements for Phase A Facilities and Interferometers (03/13/89).	YG, AJ, RS	
63.	Evaluation of Baffle Requirements for LIGO Beam Tubes (03/01/89, with cover memo by WEA, 03/15/89).	R. Weiss	
64.	LIGO — Mission, Evolution, Configuration, & Early Operations (03/01/89; adopted as Chapter 1 of Design Handbook, 04/03/89).	WA, RD, FR, RV	+
65.	... Fabry–Perot Properties (received 03/14/89).	R. Weiss	+
66.	Frequency Stabilization Fundamental Noise Terms (received 03/14/89).	R. Weiss	+
67.	Analysis of Steady State Reflection Sensing of a Cavity by Pound/Drever Technique (received 03/14/89).	R. Weiss	+
68.	Summary of Contrast Changes as a Function of Misalignment of two Gaussian Beams ... (received 03/14/89).	R. Weiss	+
69.	A Note on Reasons to Place LIGO Optical Components in Vacuum (03/15/89).	P. Saulson	+
70.	Alignment of LIGO Beam Tubes (03/17/89).	M. Burka	+
71.	Initial Assessment of Scattering Effects in Vacuum Enclosures of LIGO Interferometers Outside the Main Beam Pipes (03/15/89, received 03/27/89).	R. Drever & R. Weiss	+
72.	Outline of a Proposed Design for a First Receiver for Installation in the Long-Baseline Facilities, of Fabry–Perot Type (09/10/87).	R. Drever	+

Distribution:

A. Abramovici	E. Franzgrote	B. Moore
C. Akutagawa (file)	Y. Gürsel	F. Raab
W. Althouse	J. Harman	P. Saulson
F. Asiri	G. Hiscott	R. Spero
B. Behnke (file)	A. Jeffries	K. Thorne
M. Burka	L. Jones	R. Vogt
R. Drever	S. Merullo (file)	R. Weiss
		M. Zucker

EF/bb

LIGO VACUUM SYSTEM DESIGN
KEY REQUIREMENTS

- L-SHAPED VACUUM SYSTEM:
  TWO BEAM TUBES CONNECTING CHAMBERS

- 4 km TUBES WITH 40" CLEAR APERTURE (STRAIGHT)

- 6 FABRY-PEROT BEAMS (BACK-UP: 1 MICHELSON)

- NON-INTERFERING ACCESS TO BEAM TUBES

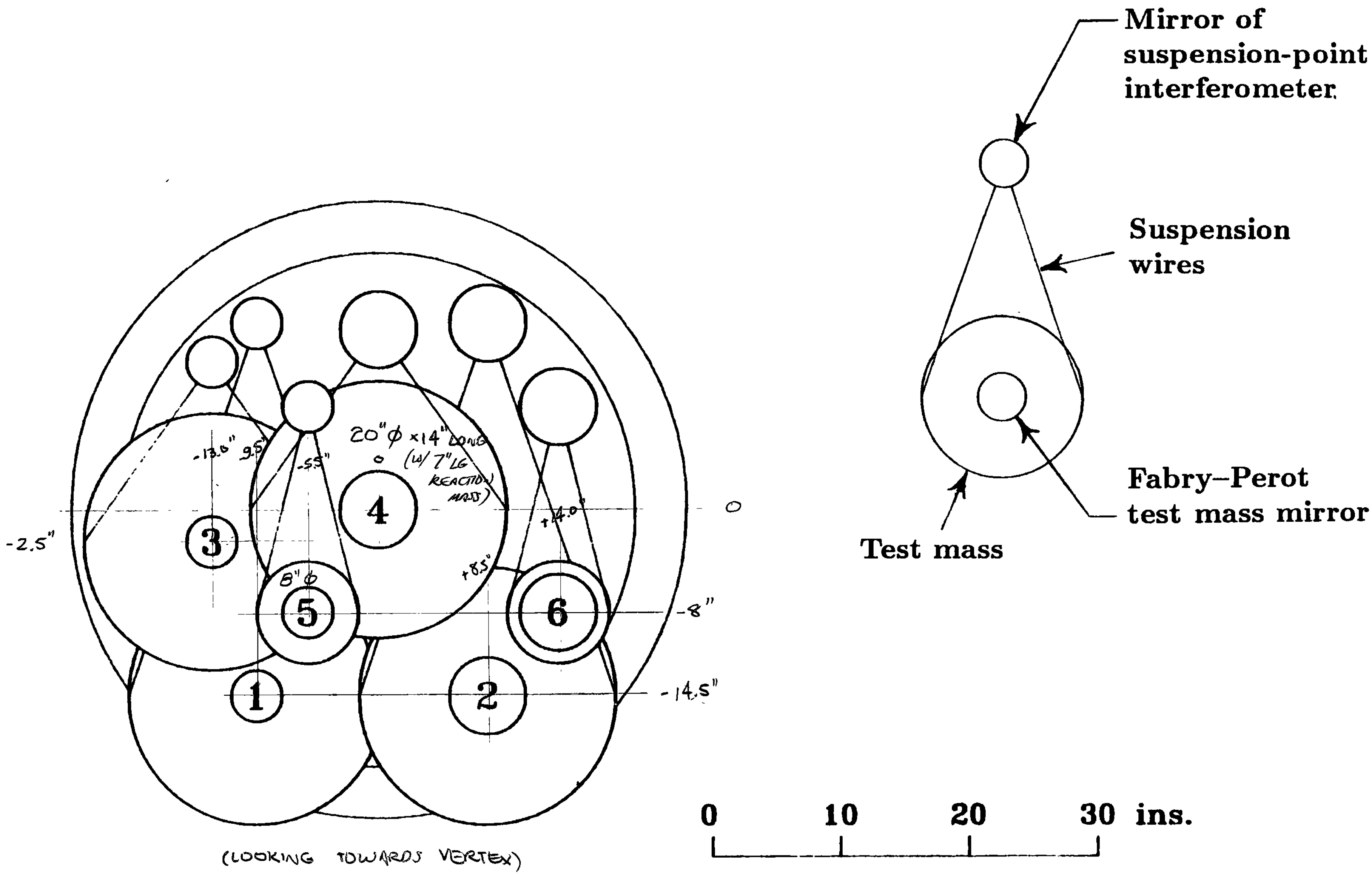
- LOW VIBRATION ENVIRONMENT

- ALLOWABLE GAS COLUMN DENSITIES:
  H_2: $< 10^{14}$ MOLECULES/CM^2 (10^{-8} torr @ 300 K)
  H_2O: $< 10^{13}$ MOLECULES/CM^2 (10^{-9} torr @ 300 K)
  N_2: $< 7\times10^{12}$ MOLECULES/CM^2 (6×10^{-10} torr @ 300 K)

- BEAM TUBE VACUUM: SINGLE PUMPDOWN

- CLEAN ENVIRONMENT FOR OPTICAL COMPONENTS

4/10/89



Numbering of main beams, and positions of beams in pipe.

4.289rd
bmsnc

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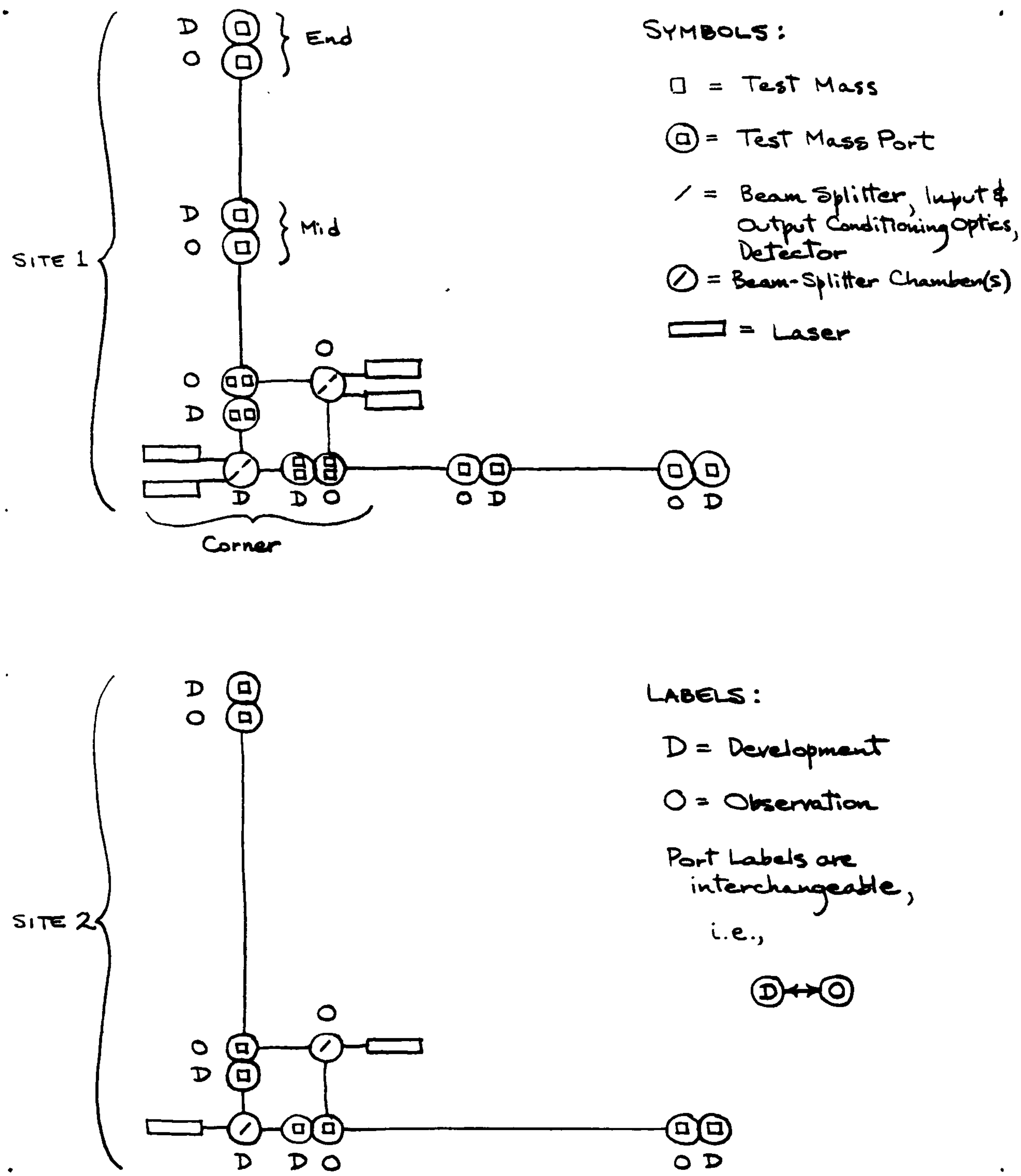
LIGO CONFIGURATION — PHASE A



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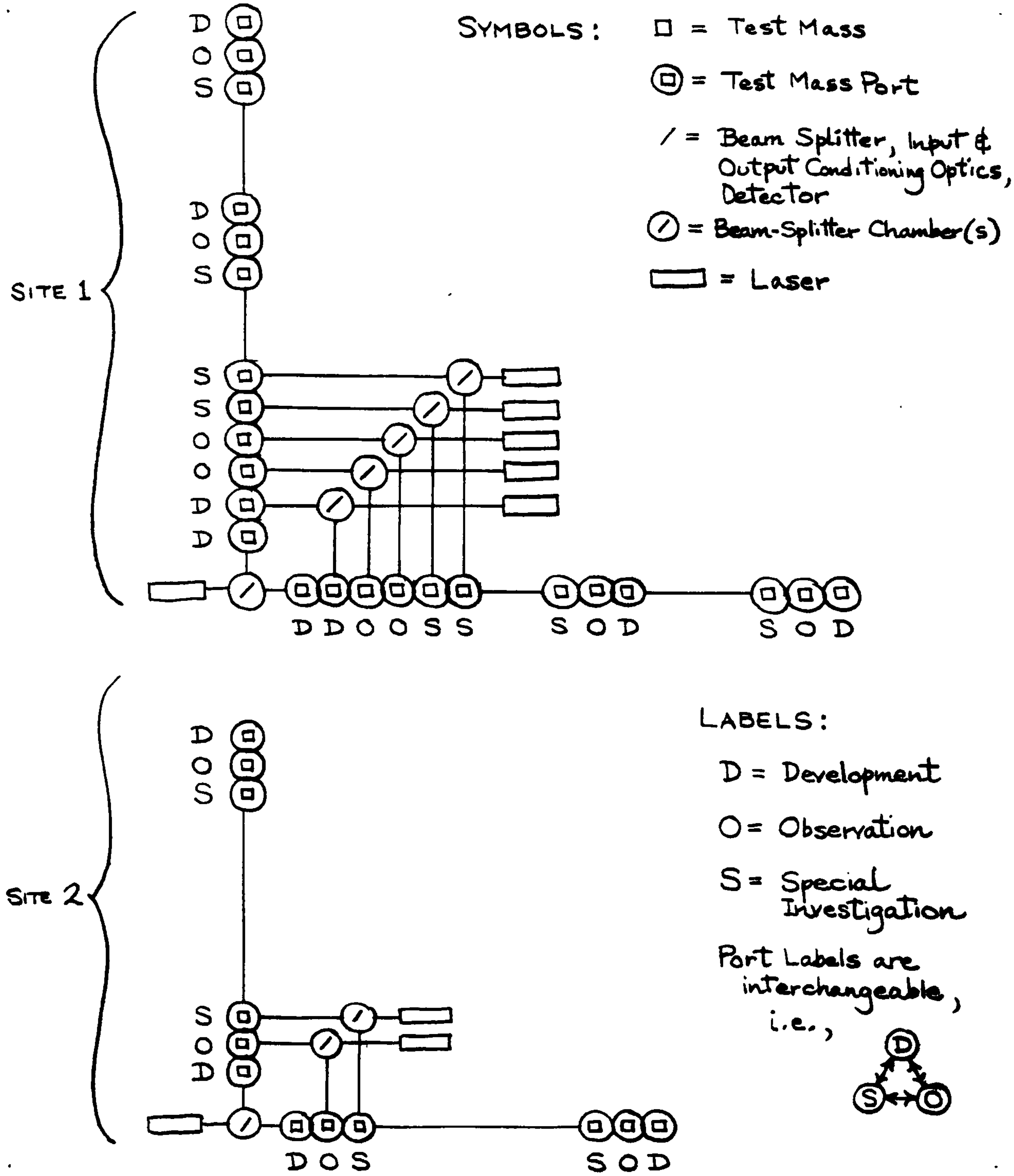
LIGO CONFIGURATION — PHASE B



LIGO VACUUM SYSTEM DESIGN
TUBE DESIGN CHOICES

- STRAIGHT WALLS WITH STIFFENERS
  - — CHOICE OF A. D. LITTLE, JPL STUDIES
- CORRUGATED WALLS
  - — BRITISH, AUSTRALIAN CONCEPT
  - — DEVELOPMENT REQUIRED

TUBE COST (One Site)

	4/87	7/88	11/88	3/89	Corrugated
Steel price ($/lb)	$0.90	$1.30	$1.54	$1.87	$1.87
		CONSTRUCTION COST ($K)			
Steel cost (8 km)	3042	4400	5233	6333	1620
Tube fabrication (40' sections)	2550	2550	2550	2550	?
Flanges/ports/expansion joints	615	615	568	568	84
Installation	492	492	492	492	?
Supports	939	939	939	939	939
Pumps/valves	576	1445	1445	1624	1624
Cleaning	100	100	100	100	100
Bakeout power distribution, insulation	1738	—	—	—	—
Total construction cost	10,052	10,541	11,327	12,606	?
Contractor G&A, Profit @ 25%	2,513	2,635	2,832	3,152	?
TOTAL ESTIMATED COST	12,565	13,176	14,159	15,758	?

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LIGO VACUUM SYSTEM DESIGN
ROLE OF BAFFLES IN BEAM TUBES

- DESIGN GOAL:

  PREVENT NOISE DUE TO SCATTERED LIGHT MODULATED BY TUBE OR BAFFLE MOTIONS FROM EXCEEDING 1/10 QUANTUM LIMIT OF STRAIN SENSITIVITY

- DESIGN STRATEGY:

  USE BAFFLES TO CONVERT SHALLOW INCIDENT ANGLES TO STEEP ANGLES, WHERE MULTIPLE REFLECTIONS WILL RESULT IN A HIGH PROBABILITY OF ABSORPTION

- DESIGN STUDY STATUS:

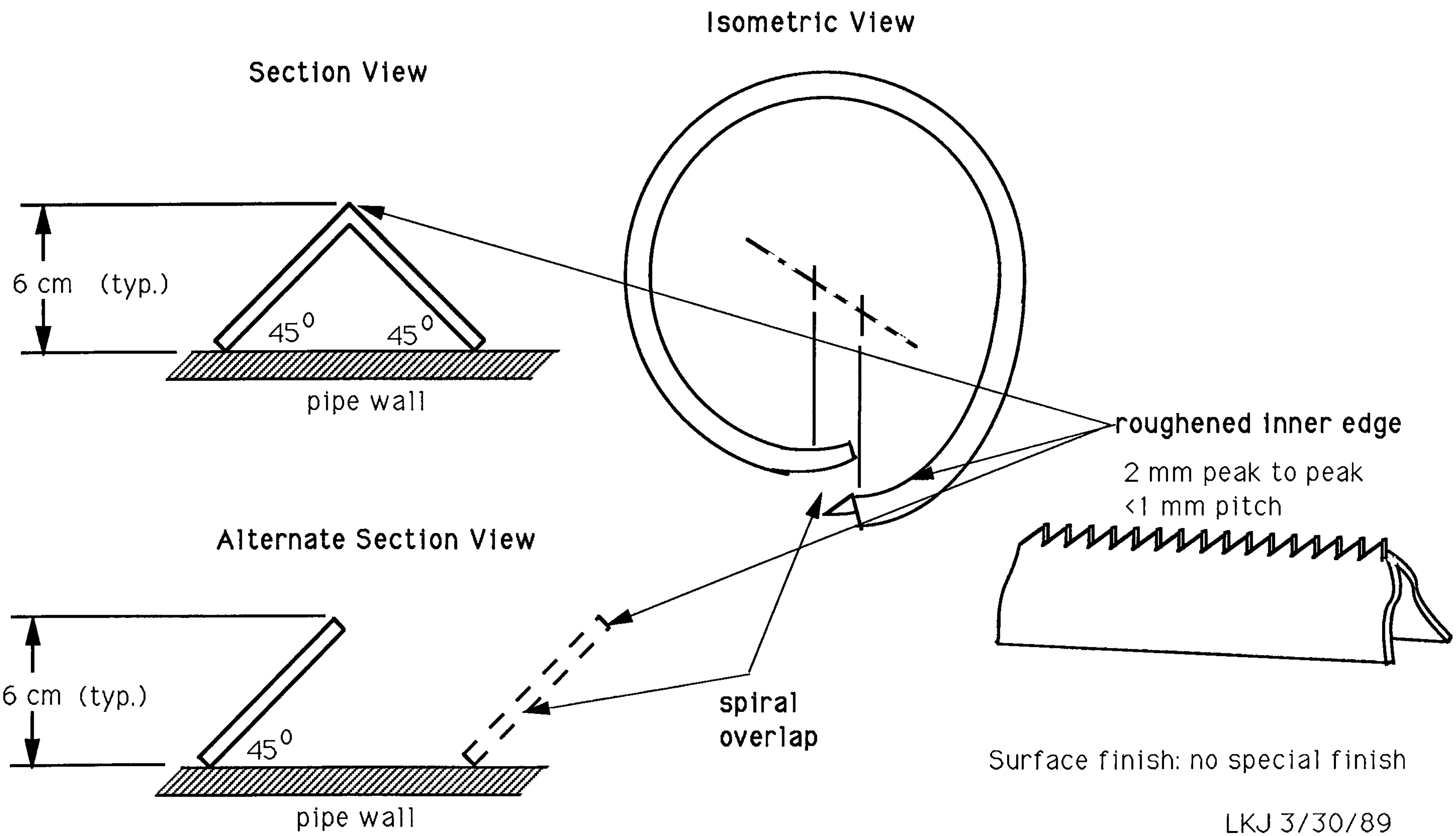
  — ANALYTICAL MODEL COMPLETE

  — SIMPLE BAFFLE IMPLEMENTATION CONCEPT COMPLETE

  — COMPUTER SIMULATIONS PLANNED TO CONFIRM ANALYTICAL MODEL

4/10/89

Tube Baffle Implementation



LKJ 3/30/89

LIGO VACUUM SYSTEM DESIGN
NUMBER OF BAFFLES REQUIRED

PARAMETERS:

θ_0 —	CRITICAL ANGLE (BETWEEN LIGHT RAY DIRECTION AND TUBE AXIS) CHOSEN SUCH THAT, FOR $\theta > \theta_0$, SCATTERED LIGHT IS ATTENUATED BY > 80 *db*
H —	BAFFLE HEIGHT (USE 6 *cm*)
δH —	BAFFLE HEIGHT SAFETY MARGIN (USE 1 *cm*)
L,R —	TUBE LENGTH, RADIUS (4 *km*, 61 *cm*)

	UNIFORM SPACING	LOGARITHMIC SPACING
ALGORITHM:	$\frac{2R}{H-\delta H}\left[\frac{L\theta_0}{4R}\right]$	$\frac{2R}{H-\delta H}\left[1+\ln\left[\frac{L\theta_0}{4R}\right]\right]$
NUMBER OF BAFFLES:		
SMOOTH-WALL TUBE (θ_0=0.05)	2000	179
CORRUGATED TUBE (θ_0=0.0023)	91	68

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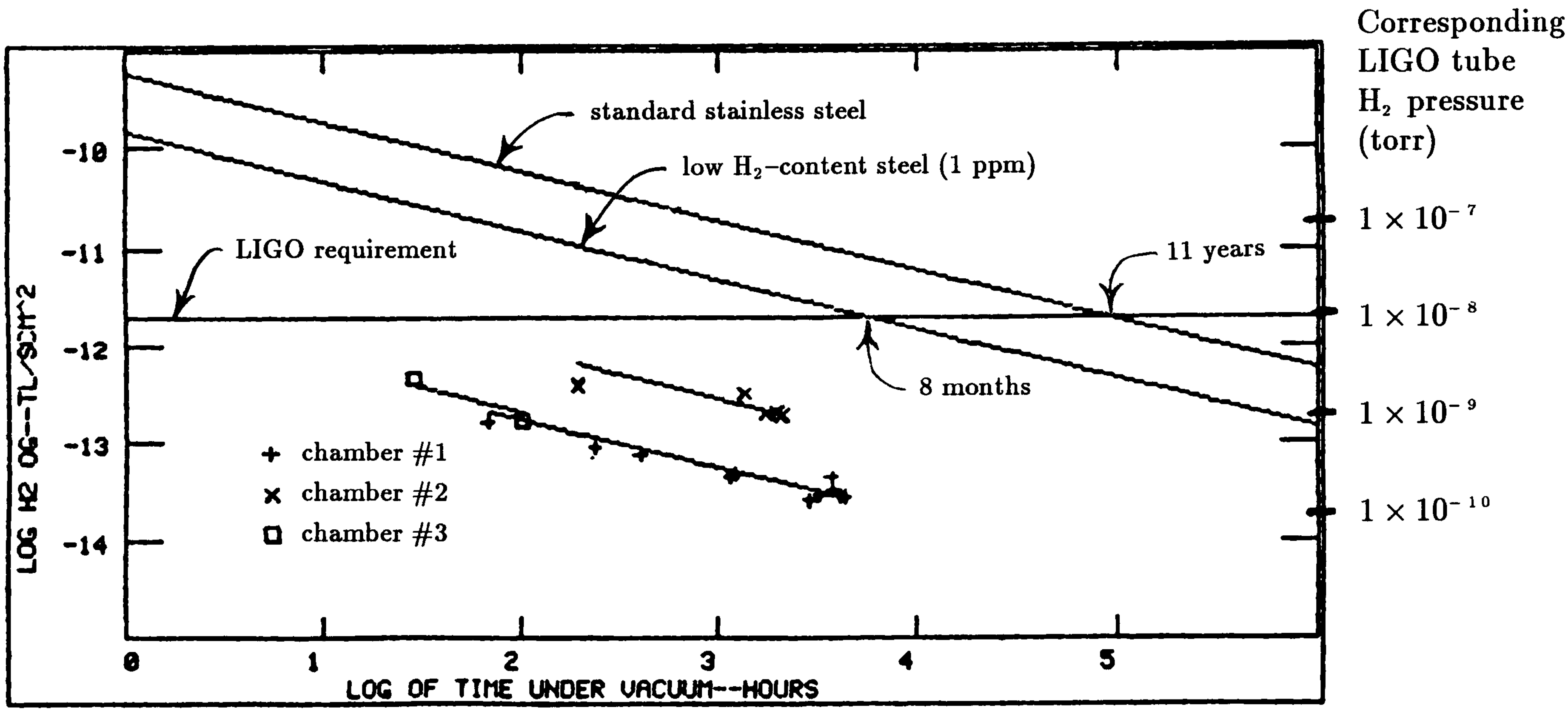
LIGO Hydrogen Outgassing
VTF Results



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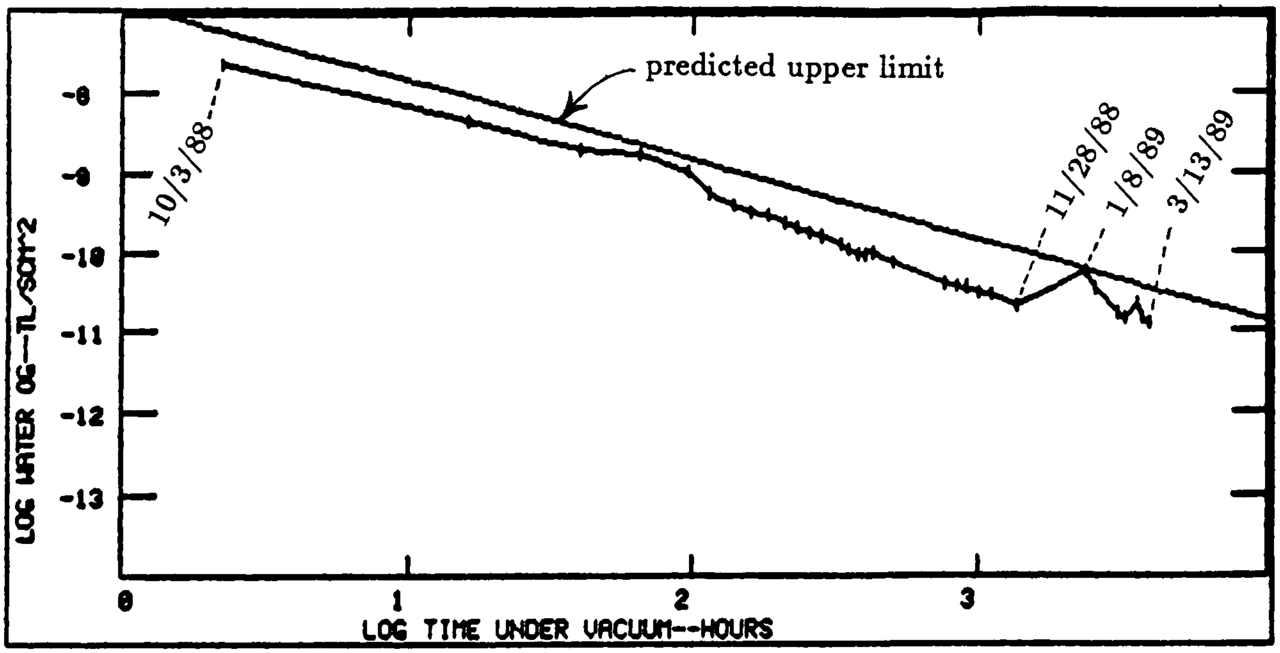
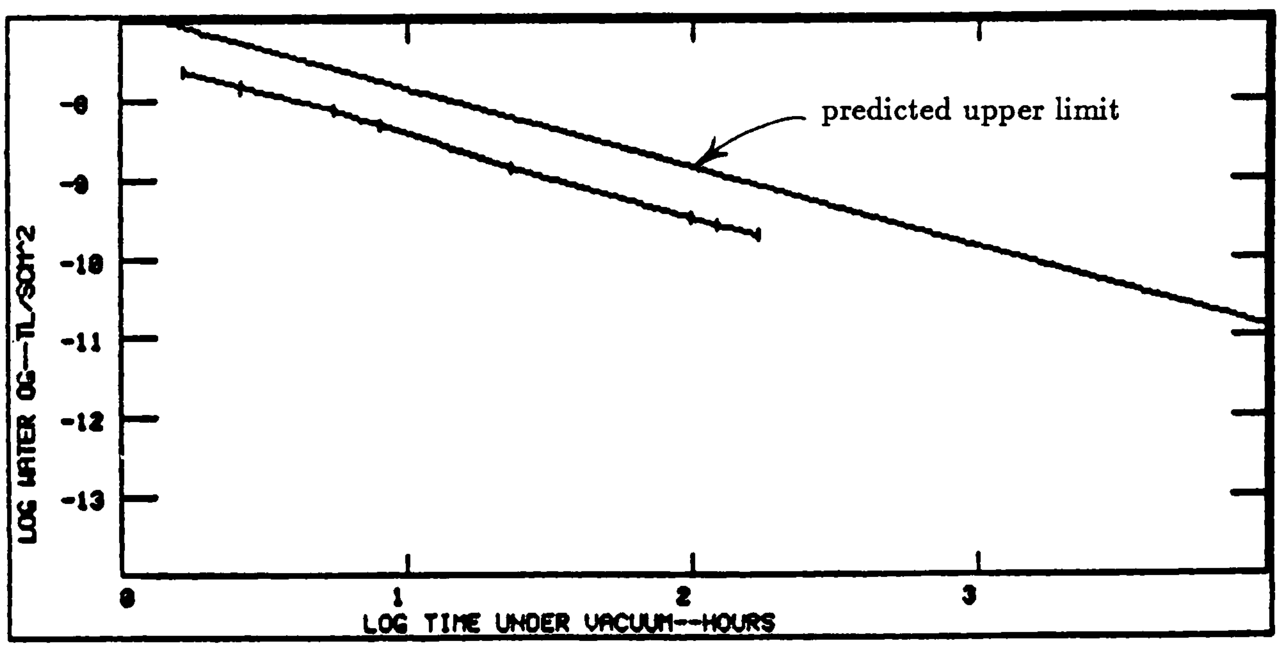
Water Outgassing — VTF Chamber #1



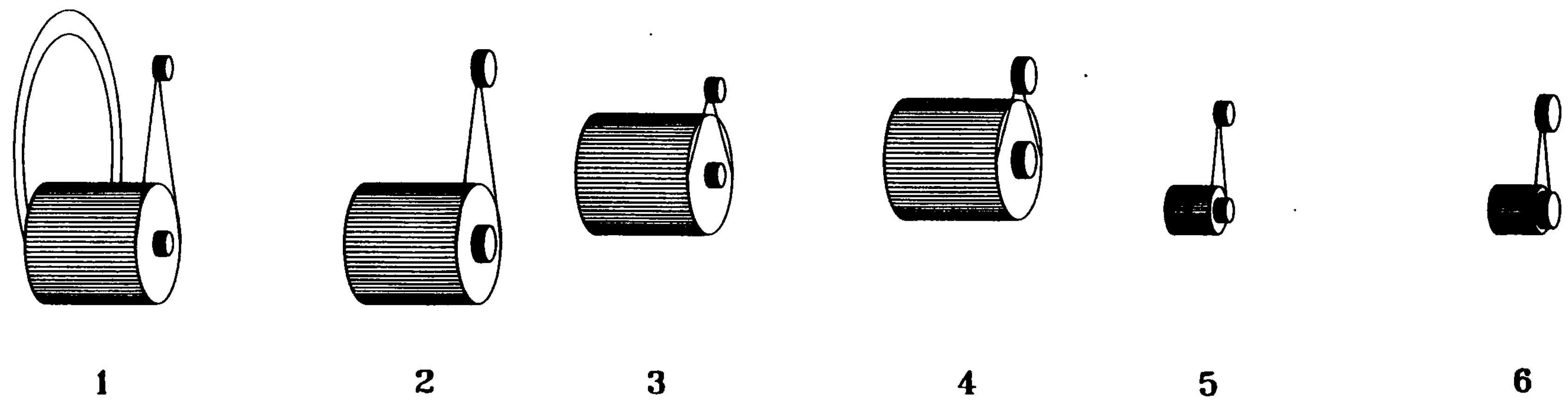
Water Outgassing — VTF Chamber #3



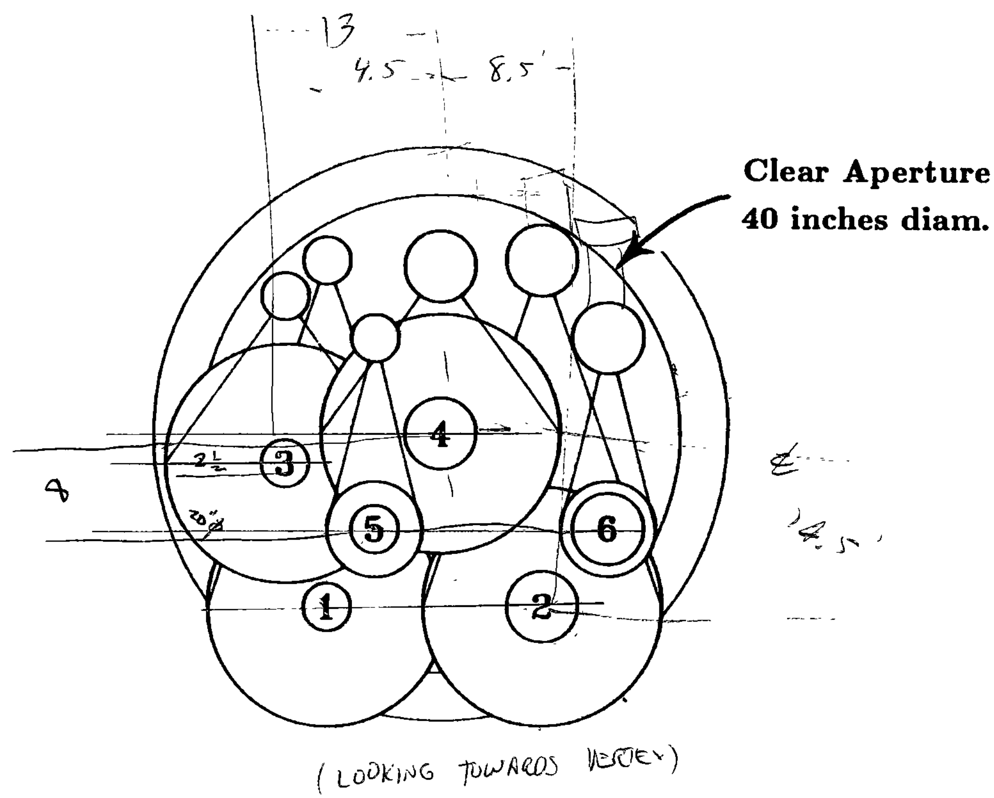
LIGO VACUUM SYSTEM DESIGN
METHODS TO REDUCE WATER OUTGASSING

- **PRE-CONDITIONING**
  - WASH
  - POLISH
  - BAKE
  - RADIATION (UV)
- **VACUUM EXPOSURE**
  - 1/T DECREASE
- **HEAT UNDER VACUUM (BAKEOUT)**
  - SOLAR EXPOSURE
  - EXTERNALLY APPLIED
  - INTERNALLY APPLIED
- **DESORPTION BY ELECTRONS UNDER VACUUM**
  - UV EXPOSURE
  - VACUUM ENVELOPE AS ANODE
- **DESORPTION BY IONS UNDER VACUUM**
  - GLOW DISCHARGE

4/10/89

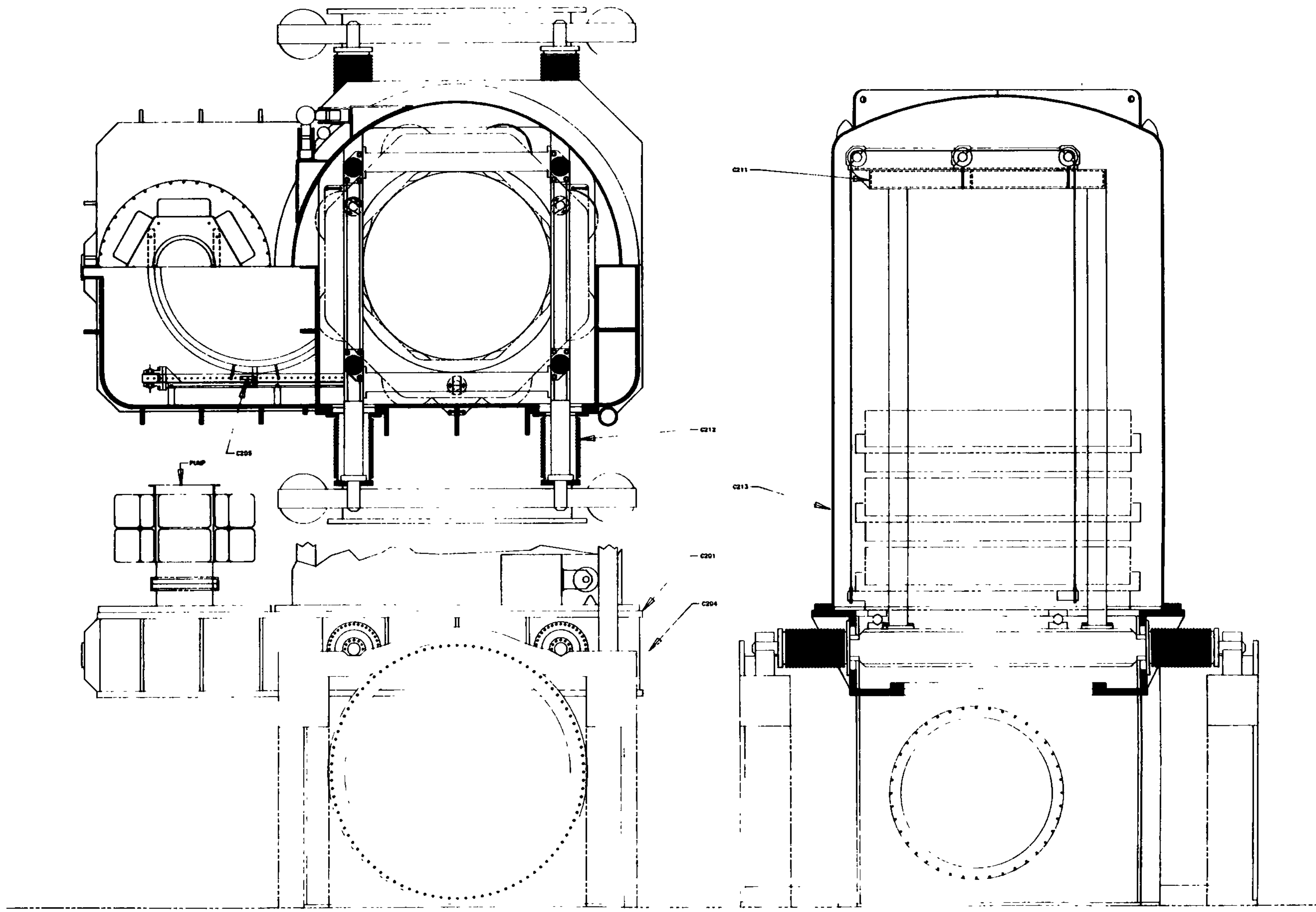


Test Mass Placement



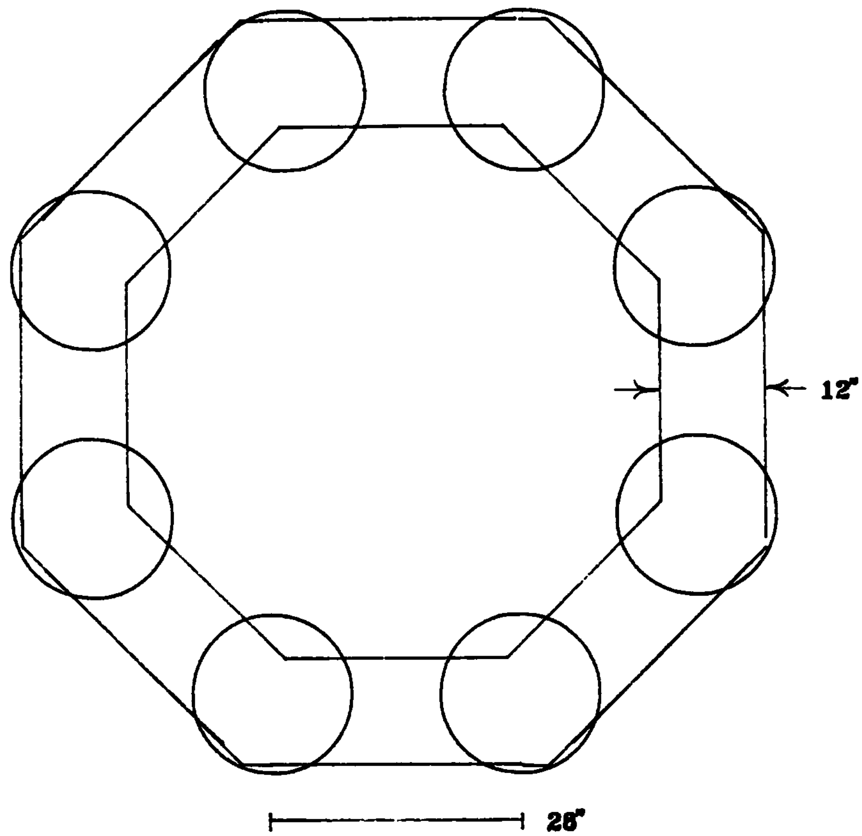
4/10/89

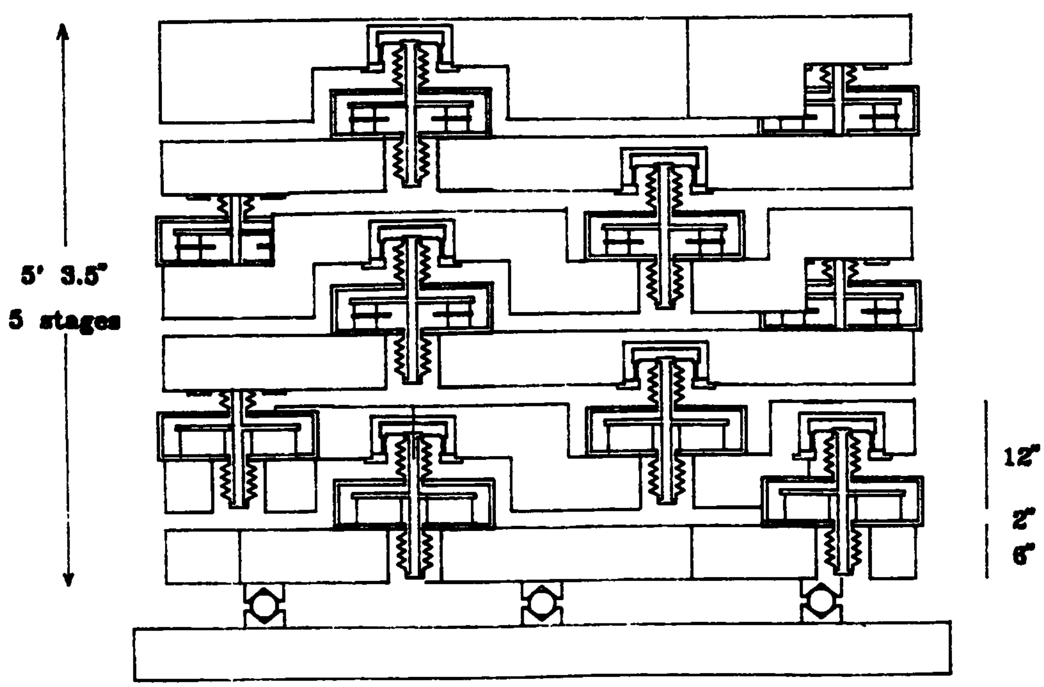
Test Mass Chamber



4/10/89

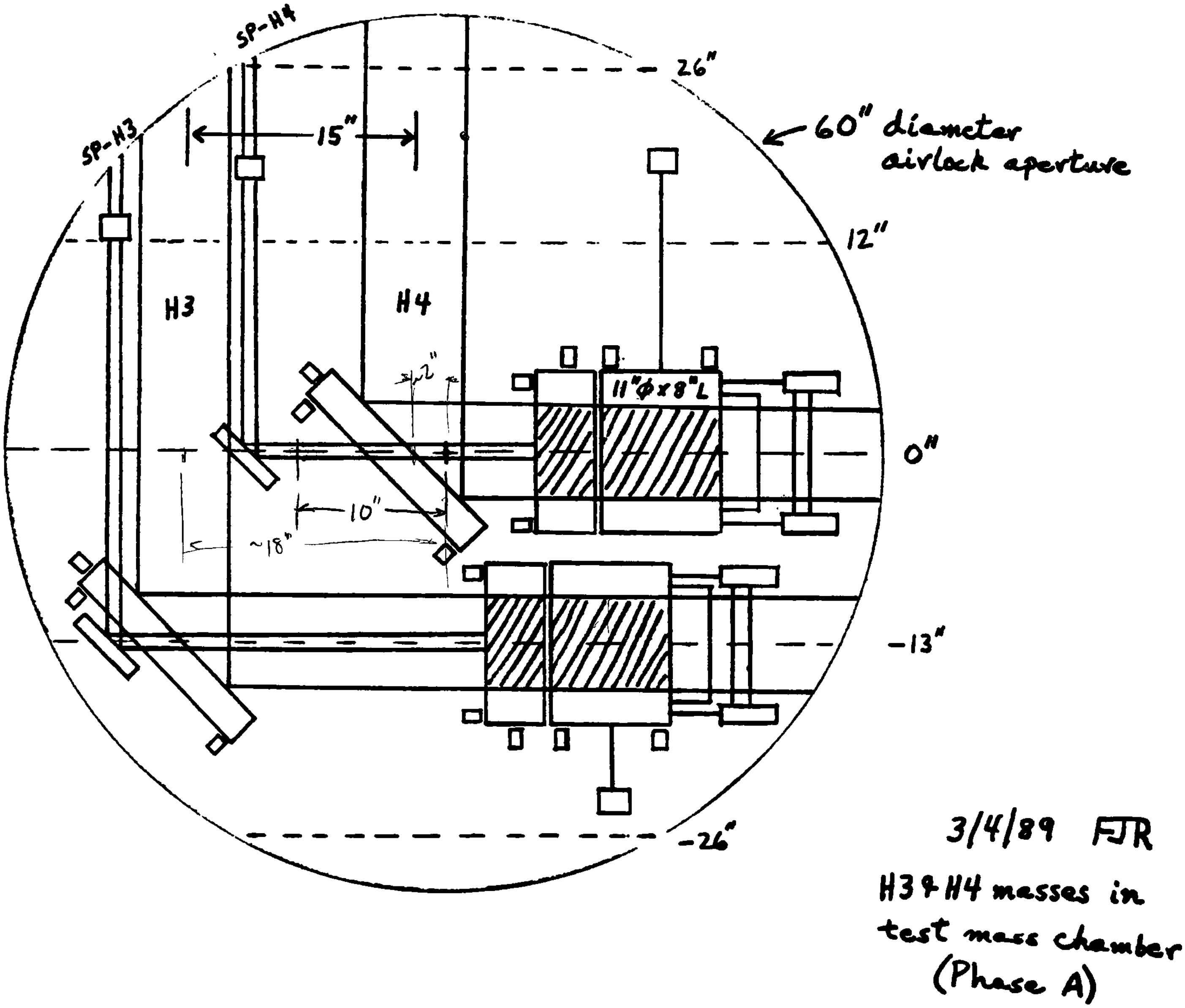
Seismic Isolation Stack
for Test Mass Chamber



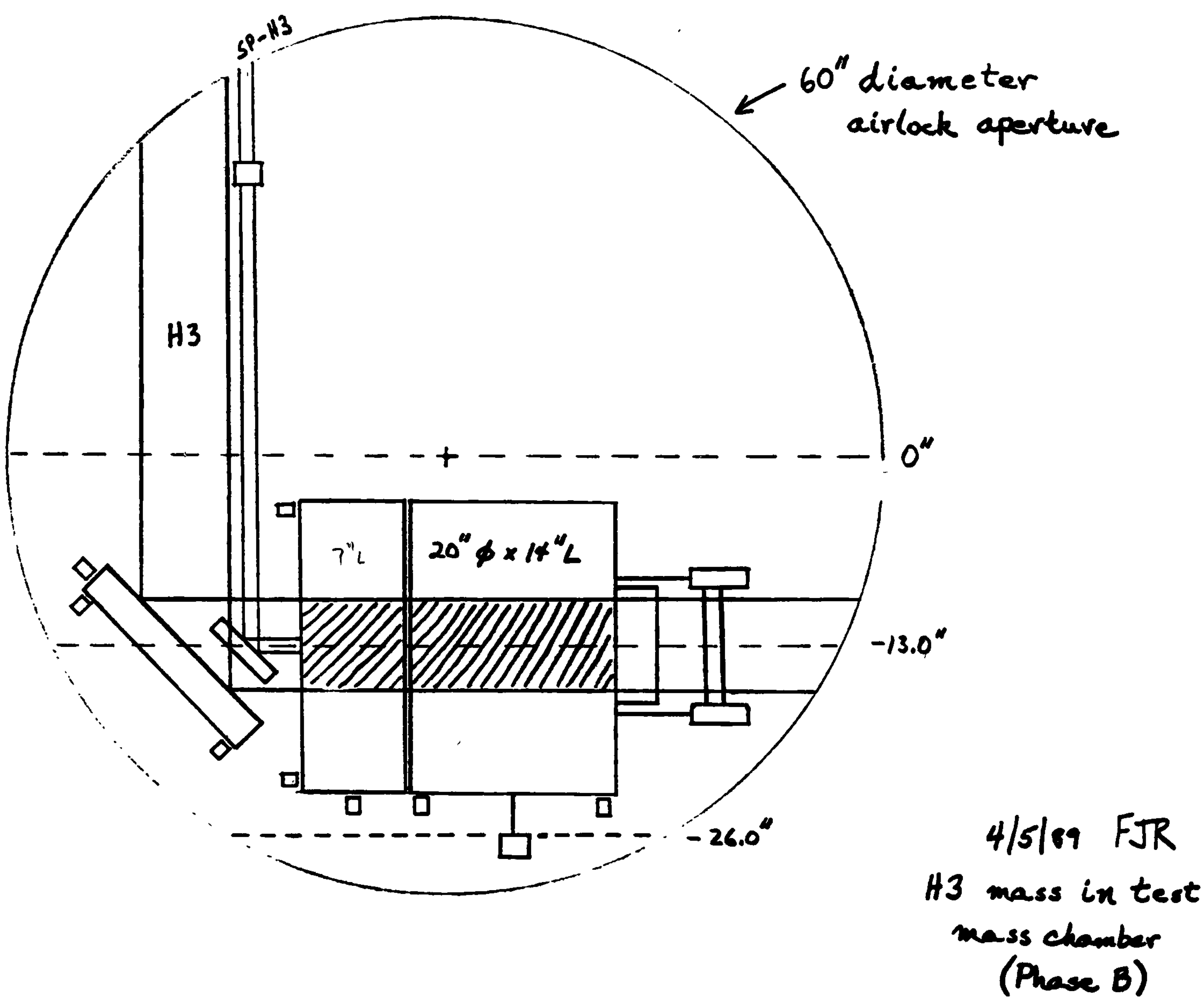


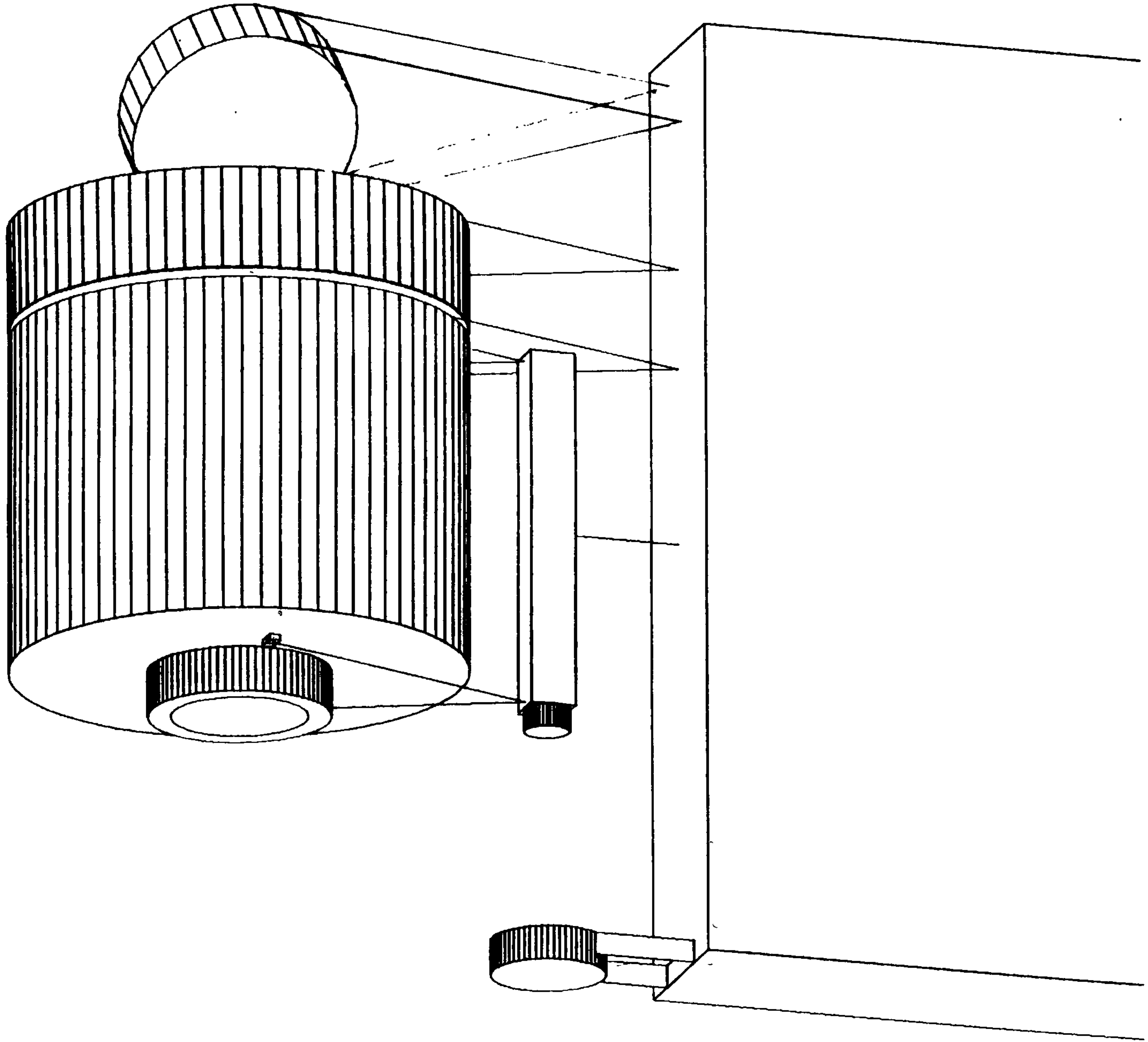
4/10/89

Two Test Masses in one Phase A Test Mass Chamber (Plan View)

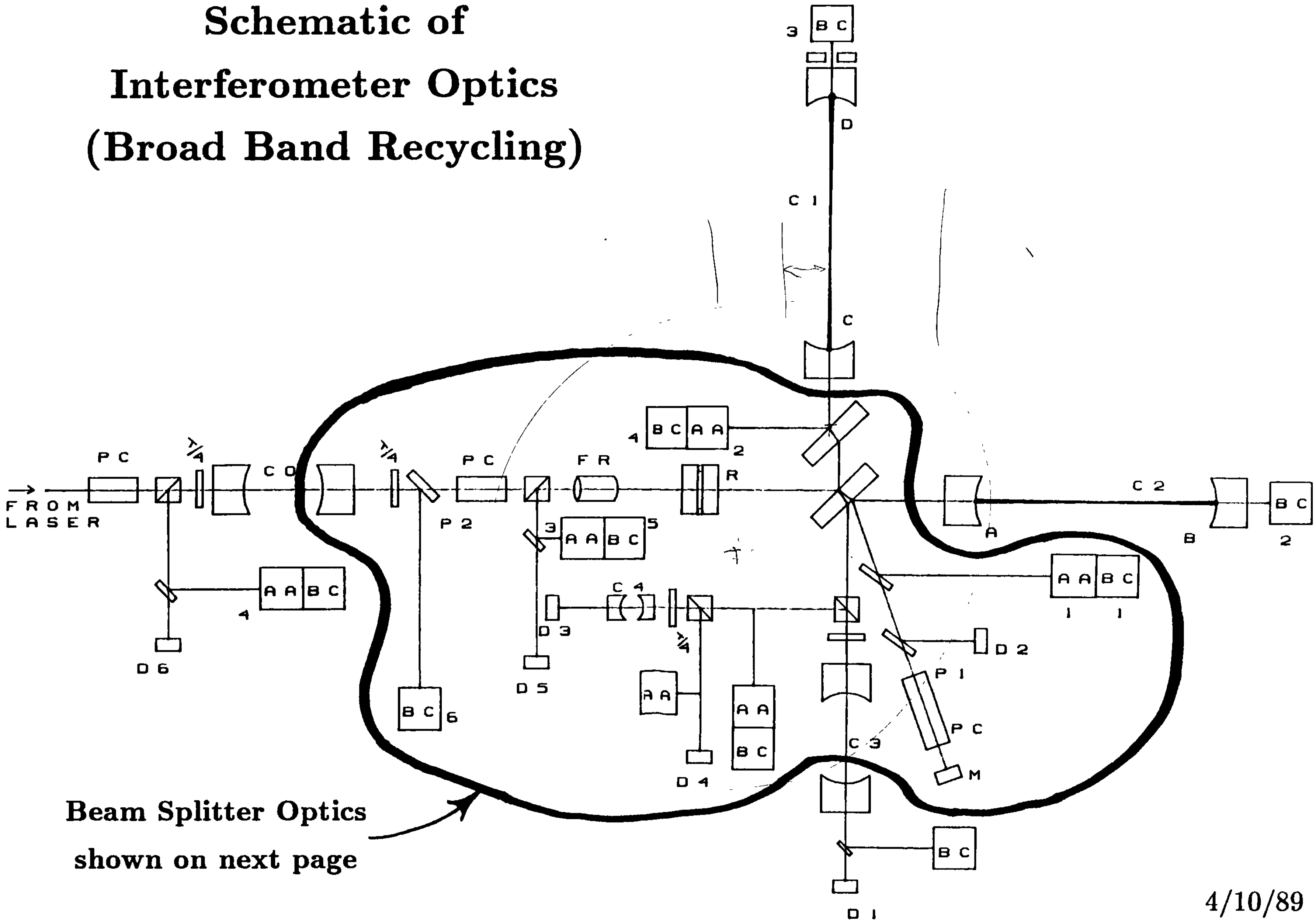


One Large Test Mass
in a Phase B Test Mass Chamber
(Plan View)



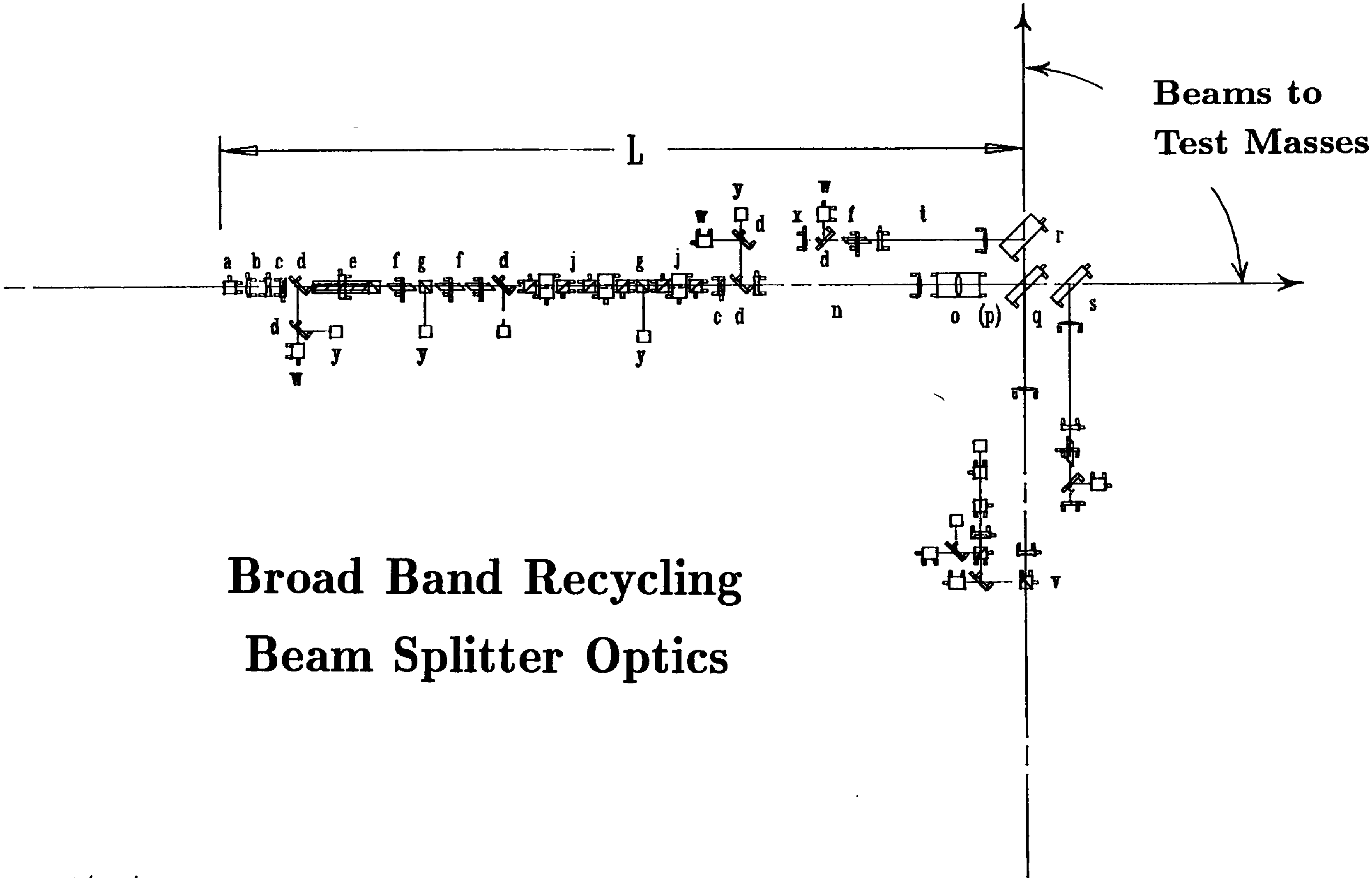


Schematic of Interferometer Optics (Broad Band Recycling)



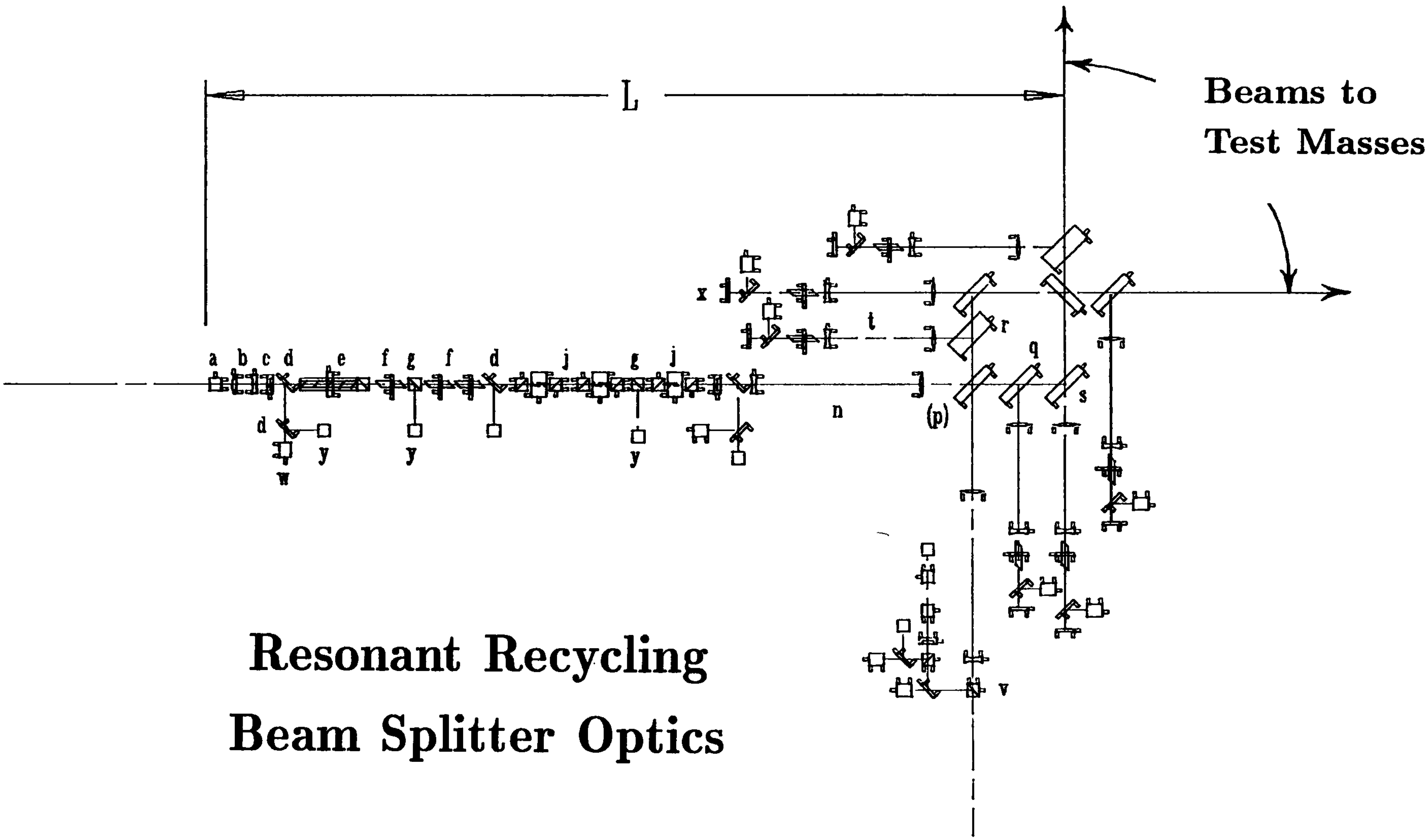
Beam Splitter Optics shown on next page

4/10/89



Broad Band Recycling
Beam Splitter Optics

4/10/89

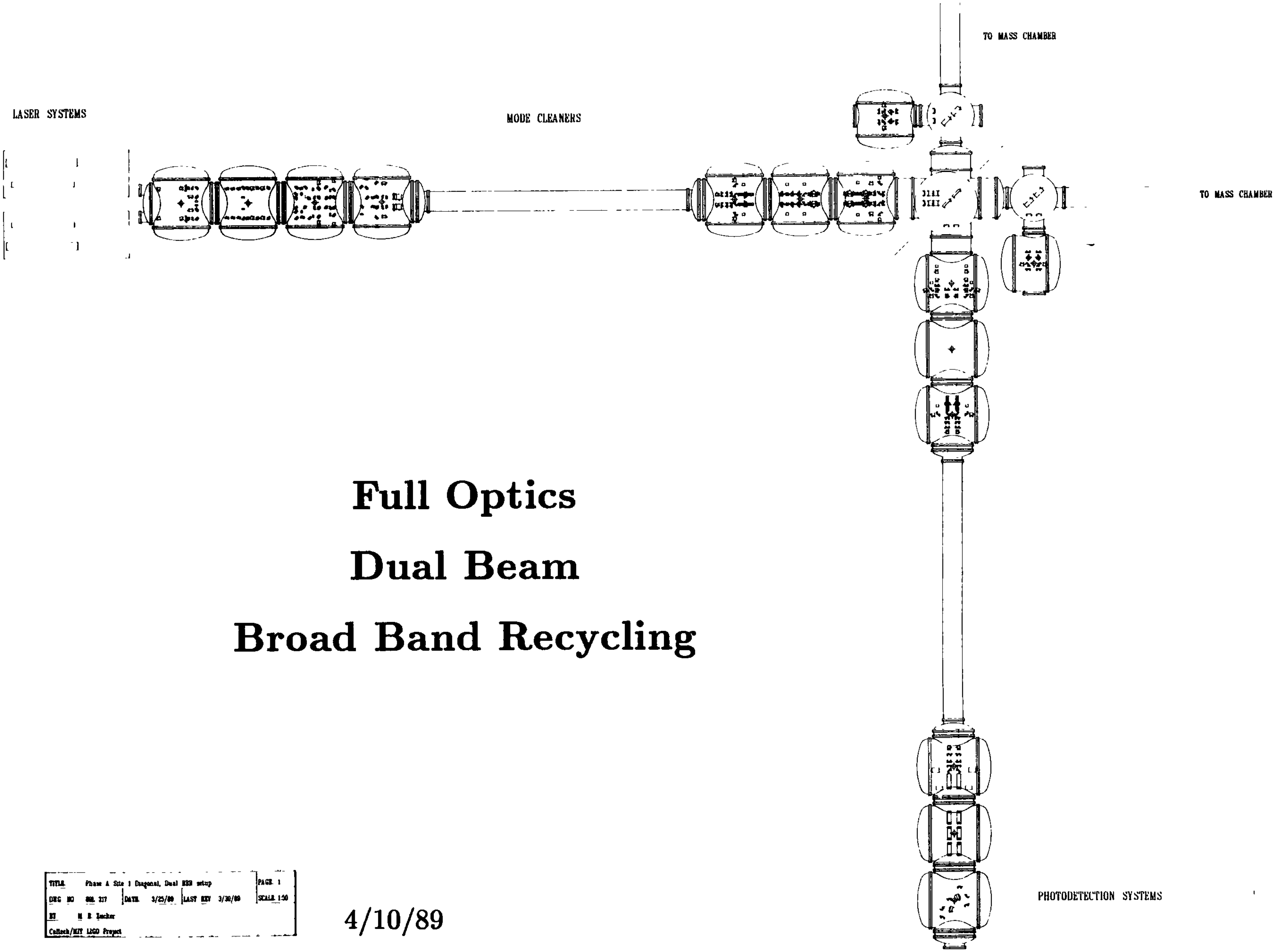


Resonant Recycling
Beam Splitter Optics

4/10/89

Optical Components in
LIGO Beamsplitter Vacuum System
To Serve Single Interferometer
M.E. Zucker
2/28/89

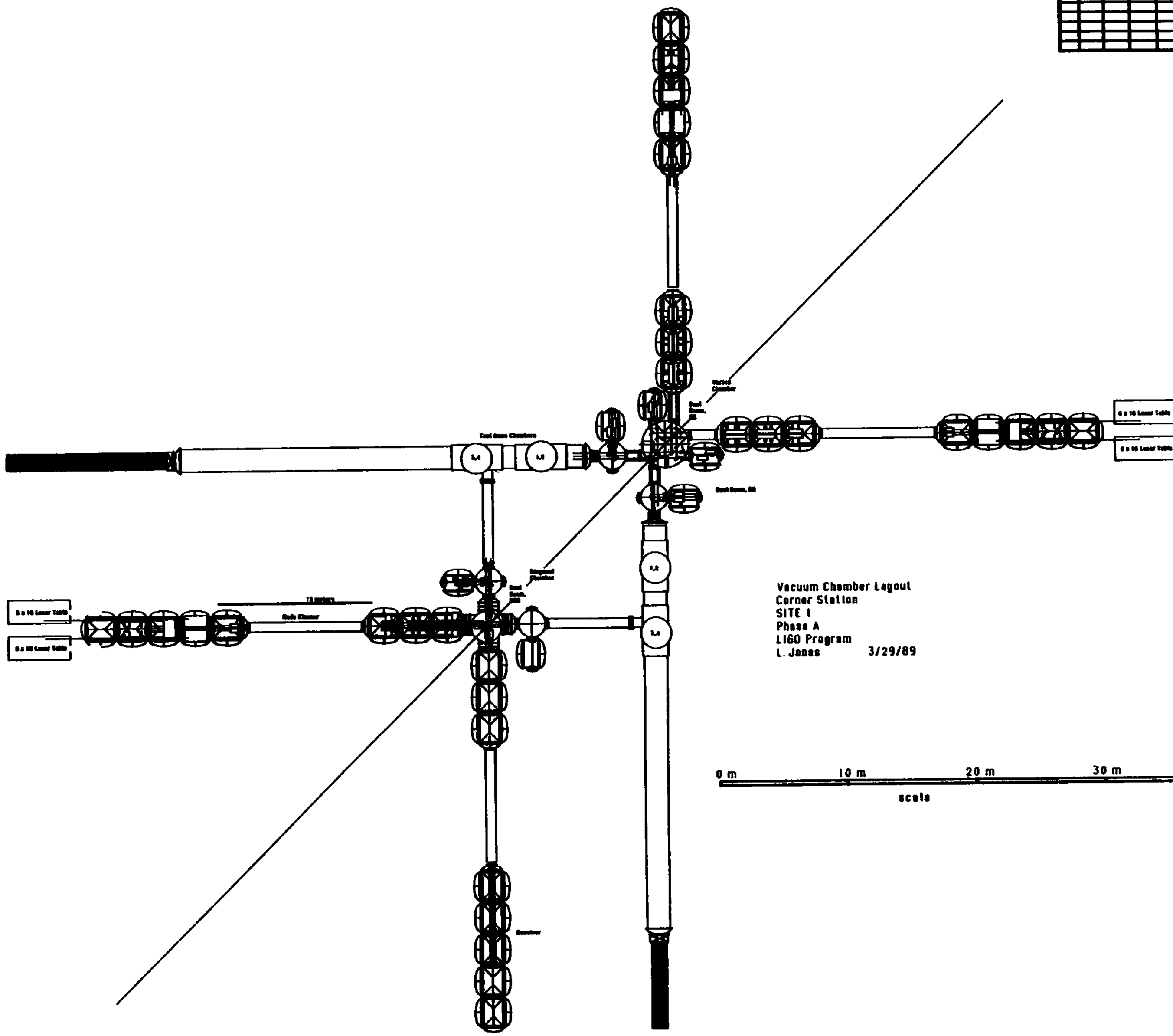
Key	Item	Number Req'd min	Number Req'd bg	Number Req'd max	Item Length (in.) min	Item Length (in.) bg	Item Length (in.) max	Delta L bg
	(Items Pushing Dimension L)							
a	MC end mirror		1		7	14	24	14
b	MC telescope	0	1		8	12	16	12
c	retarder		2	3		4		8
d	pickoff	2	3			8		24
e	AM modulator	0	1			23		23
f	Pockels cell	1	3			10		30
g	test pickoff	0	2	5		4		8
j	Faraday isol.	1	3			20	22	60
n	big telescope		1		40	60	100	60
o	recyc. mirror		1		10	18	24	18
p	dust caps	0	2			2		4
q	beamsplitter		1			14		7
							Total L	268"
	(Resonant Recycling Option)							
-o	(no RM)		-1		10	18	24	-18
z	RR ring		1			48		41
							RR Total	291"
	(Items Not Contributing to Dimension L)							
r	compensator					15		
s	cavity pickoff					15		
t	sm. telescope					30		
v	PBS cube					8		
w	AA/BC unit					8		
x	mirror					4		
y	PD/TV unit					5		



Full Optics
Dual Beam
Broad Band Recycling

TITLE Phase A Site 1 Diagonal, Dual BBR setup			PAGE 1
DRG NO 317	DATE 3/25/89	LAST REV 3/30/89	SCALE 1:50
BY M E Zucker			
Caltech/MIT LIGO Project			

4/10/89



Vacuum Chamber Layout
Corner Station
SITE 1
Phase A
LIGO Program
L. Jones 3/29/89

0 m 10 m 20 m 30 m
scale

LIGO PROJECT

Corner Station Vacuum System
Site 1, Phase A

SCALE 1"= 10'

V100

1 of 1

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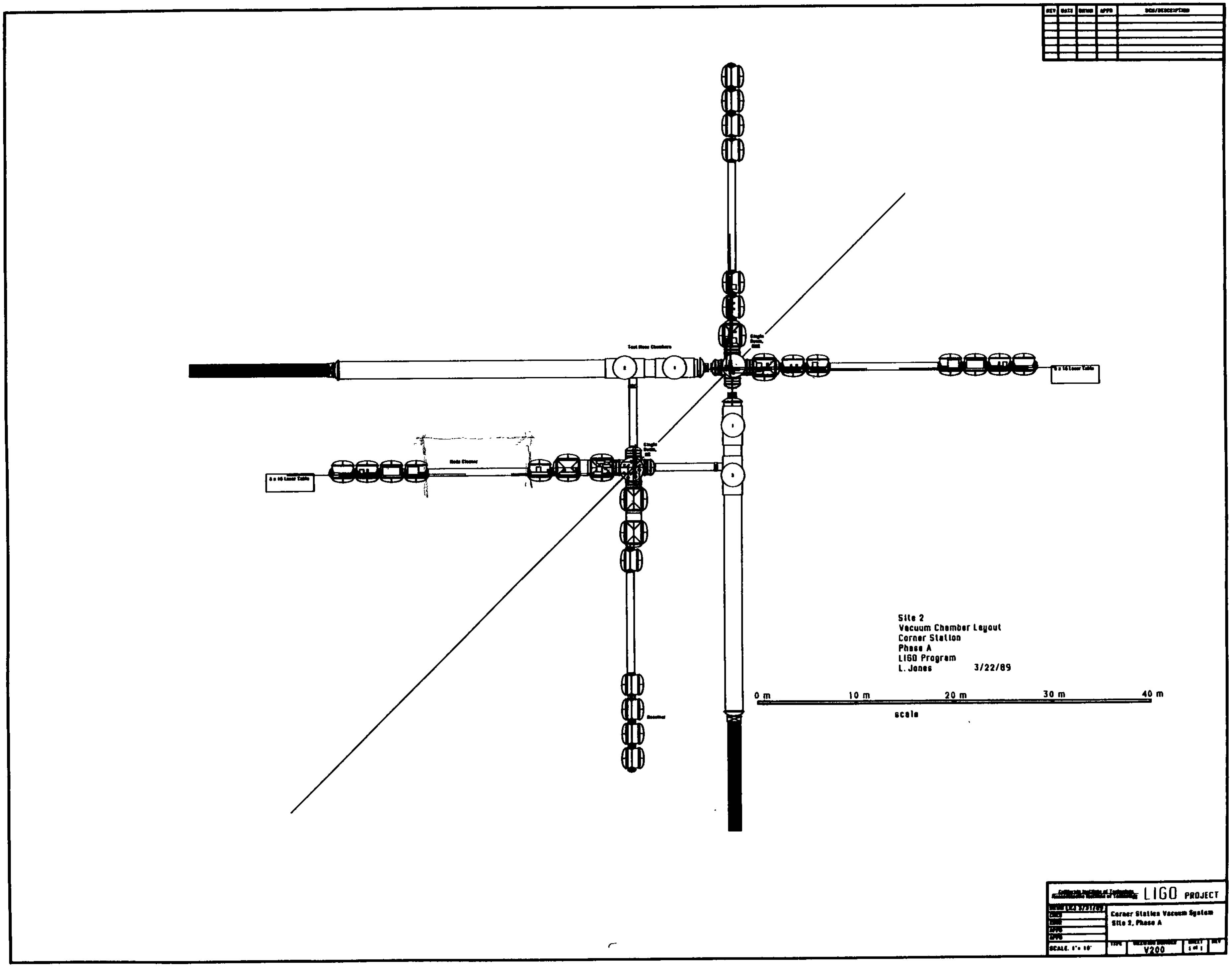
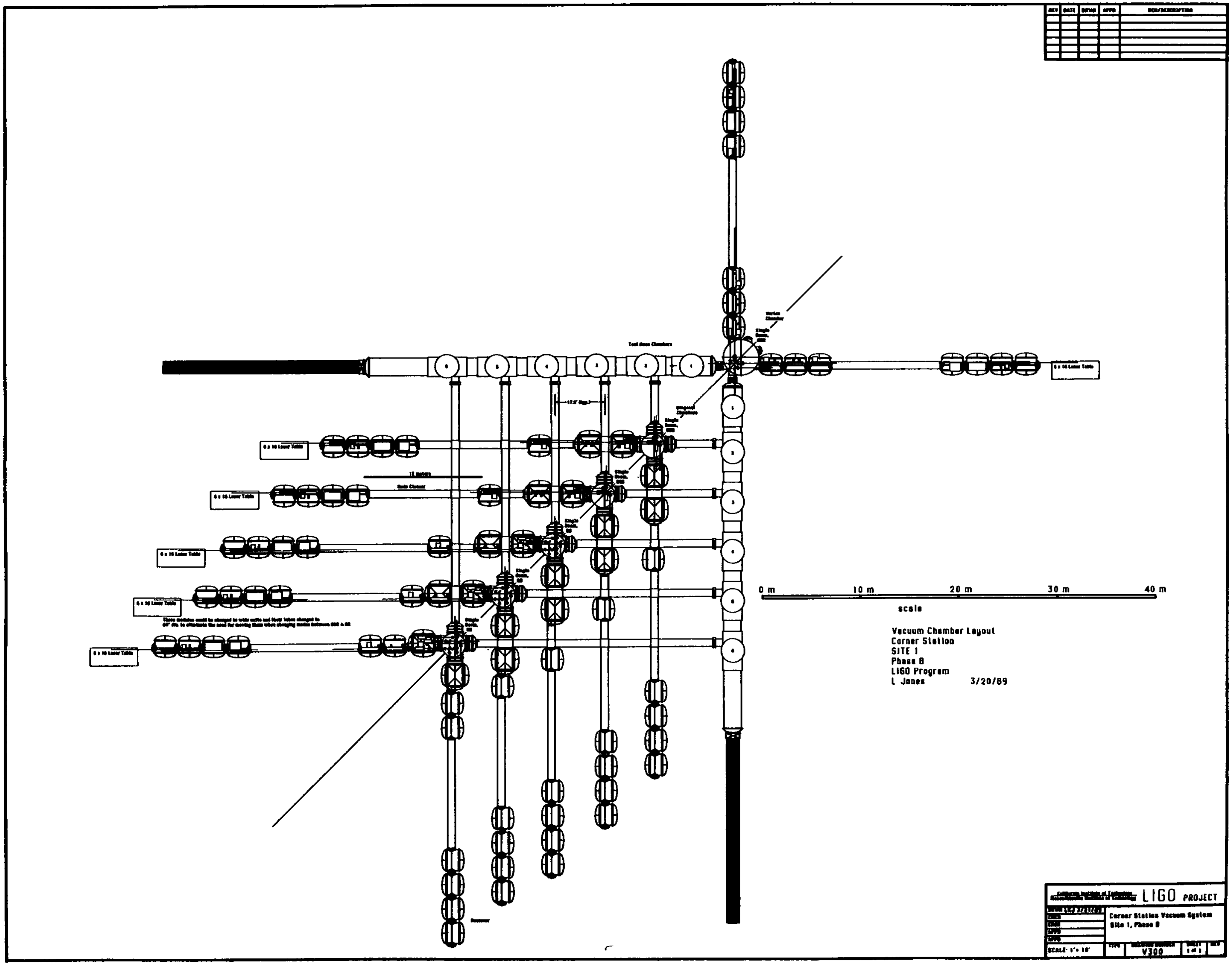
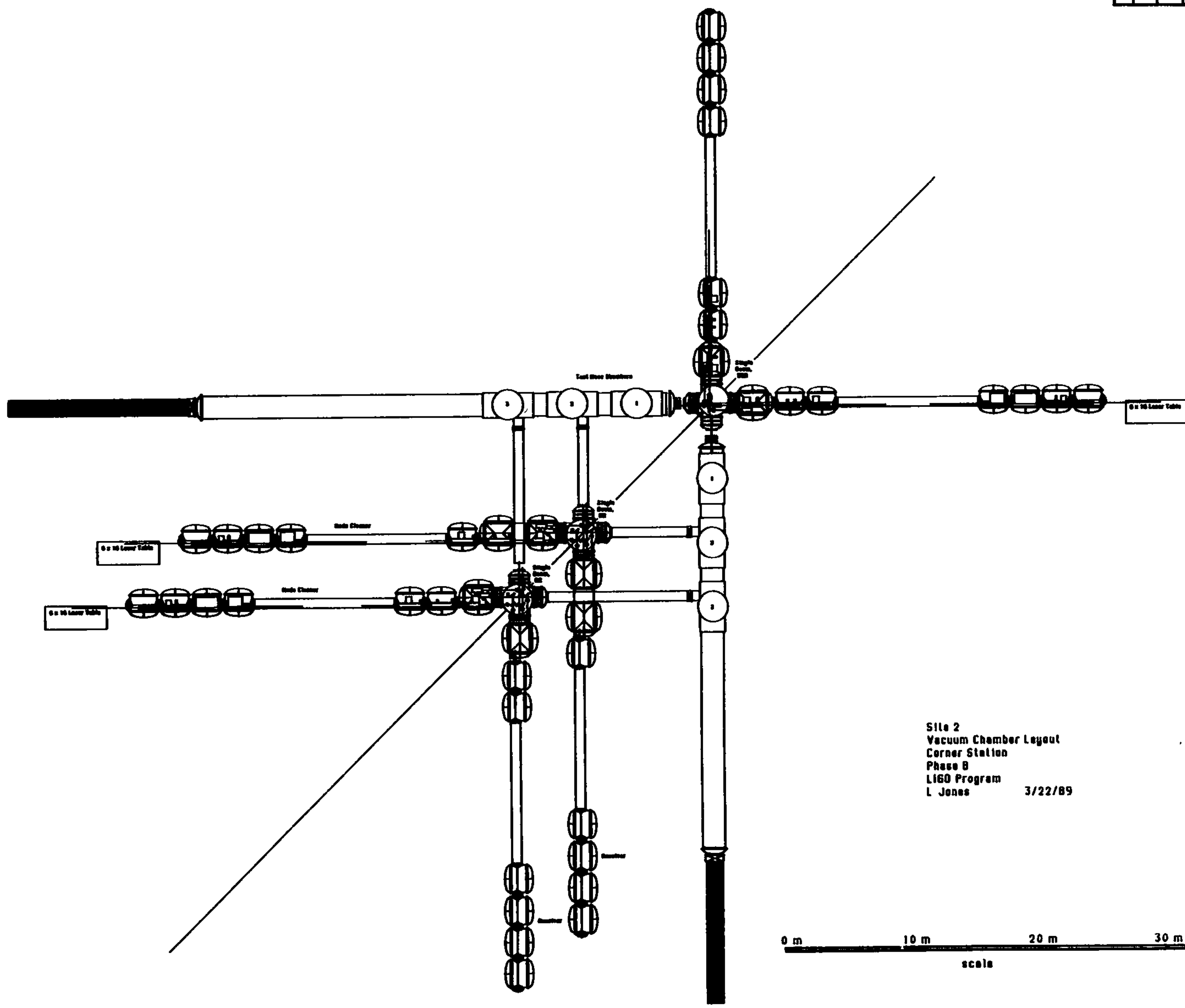

Site 2
Vacuum Chamber Layout
Corner Station
Phase A
LIGO Program
L. Jones 3/22/89
0 m
10 m
20 m
30 m
40 m
scale
LIGO PROJECT
Corner Station Vacuum System
Site 2, Phase A
SCALE 1"= 10'
V200


0 m
10 m
20 m
30 m
40 m
scale
Vacuum Chamber Layout
Corner Station
SITE 1
Phase B
LIGO Program
L Jones 3/20/89
LIGO PROJECT
Corner Station Vacuum System
Site 1, Phase B
V300



Site 2
Vacuum Chamber Layout
Corner Station
Phase B
LIGO Program
L Jones 3/22/89

0 m 10 m 20 m 30 m 40 m
scale

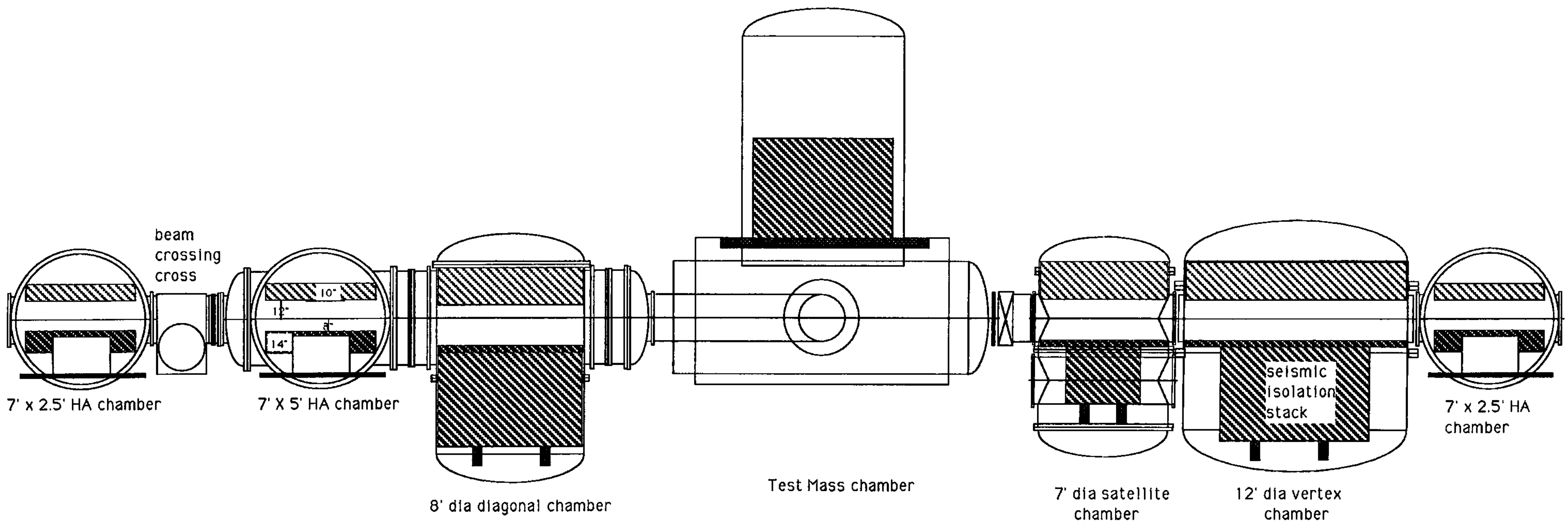
LIGO PROJECT

Corner Station Vacuum System
Site 2, Phase B

SCALE 1" = 16'

V400

1 of 1



Vacuum Chamber Layout
Elevation
L. Jones 3/29/89

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LIGO VACUUM SYSTEM DESIGN
VACUUM PUMPING STRATEGY

- REQUIREMENTS:

  LOW TUBE PRESSURE
  LOW VIBRATION
  RAPID PUMPDOWN (~10 hrs.) FOR CHAMBERS
  MINIMUM DISTURBANCE TO OBSERVING INTERFEROMETERS
  CAPABILITY TO HANDLE LARGE TRANSIENT GAS LOADS

- REQUIREMENTS MET WITH COMBINATION OF

  ION PUMPS
  LN_2 PUMPS ("TRAPS")

- ION PUMPS — 2500 L/S UNITS

  ONE ON EACH TEST MASS CHAMBER
  TWO ON EACH BEAM SPLITTER CHAMBER
  SEVEN DISTRIBUTED ALONG EACH 2 KM TUBE SECTION

- LN_2 PUMPS

  ONE 10^6 L/S ON EACH ARM (CORNER STATION)
  ONE 10^5 L/S AT EACH MID-, END-STATION
  > 60 DAYS BETWEEN REFILLS
  > 1 YEAR BETWEEN SERVICING

4/10/89

LIGO VACUUM ENCLOSURE DESIGN
VACUUM CHAMBER/LASER ENVIRONMENTAL REQUIREMENTS

• ALLOWED TEST MASS DRIFT	$< 1\ cm$
(OVER 4 KM)	$< 4\times10^{-2}\ cm/day$
• TEMPERATURE	$23 \pm 1.5\ °C$
• HUMIDITY	$40 \pm 5\%$
• VIBRATION	$< 2\times10^{-9}\ m/\sqrt{Hz}\ \ (f < 10Hz)$
	$< \frac{2\times10^{-7}}{f^2}\ m/\sqrt{Hz}\ \ (10Hz < f < 10kHz)$*
• SOUND PRESSURE	$< 10^{-4}\ Pa/\sqrt{Hz}\ \ (10Hz < f < 10kHz)$*
	$< 45\ db$ (A-weighted) rms
• AIR QUALITY (DUST)	
VACUUM CHAMBER AREA	FED. STD. 209 CLASS 50,000
EXPOSED OPTICS	FED. STD. 209 CLASS 200
CLEAN ROOM (WORK SURFACE)	FED. STD. 209 CLASS 100
POSITIVE PRESSURE	> 10 Pa (0.1 mbar)
• POWER QUALITY	ISA RP52.1 TYPE II
• ELECTROMAGNETIC INTERFERENCE	
RADIATED E-FIELD	$< 1mV/m\sqrt{Hz}\ (f > 10kHz)$*
	$< 100\mu V/m$ rms
RADIATED B-FIELD	$< 2nT/\sqrt{Hz}\ (f > 10kHz)$*
	$< 100nT$ rms $(f = n\times60Hz)$

* NARROW-BAND EXCEPTIONS PERMITTED

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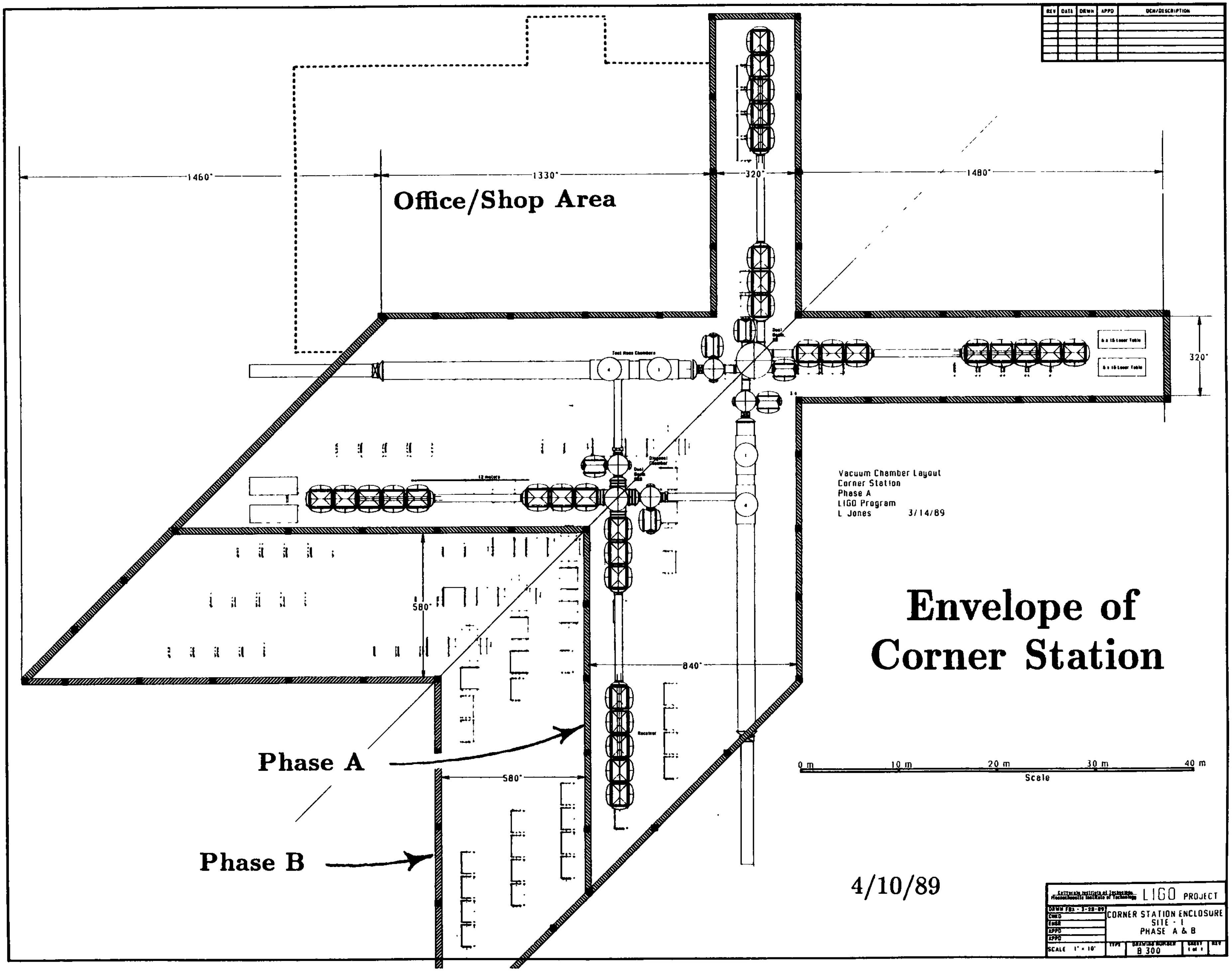
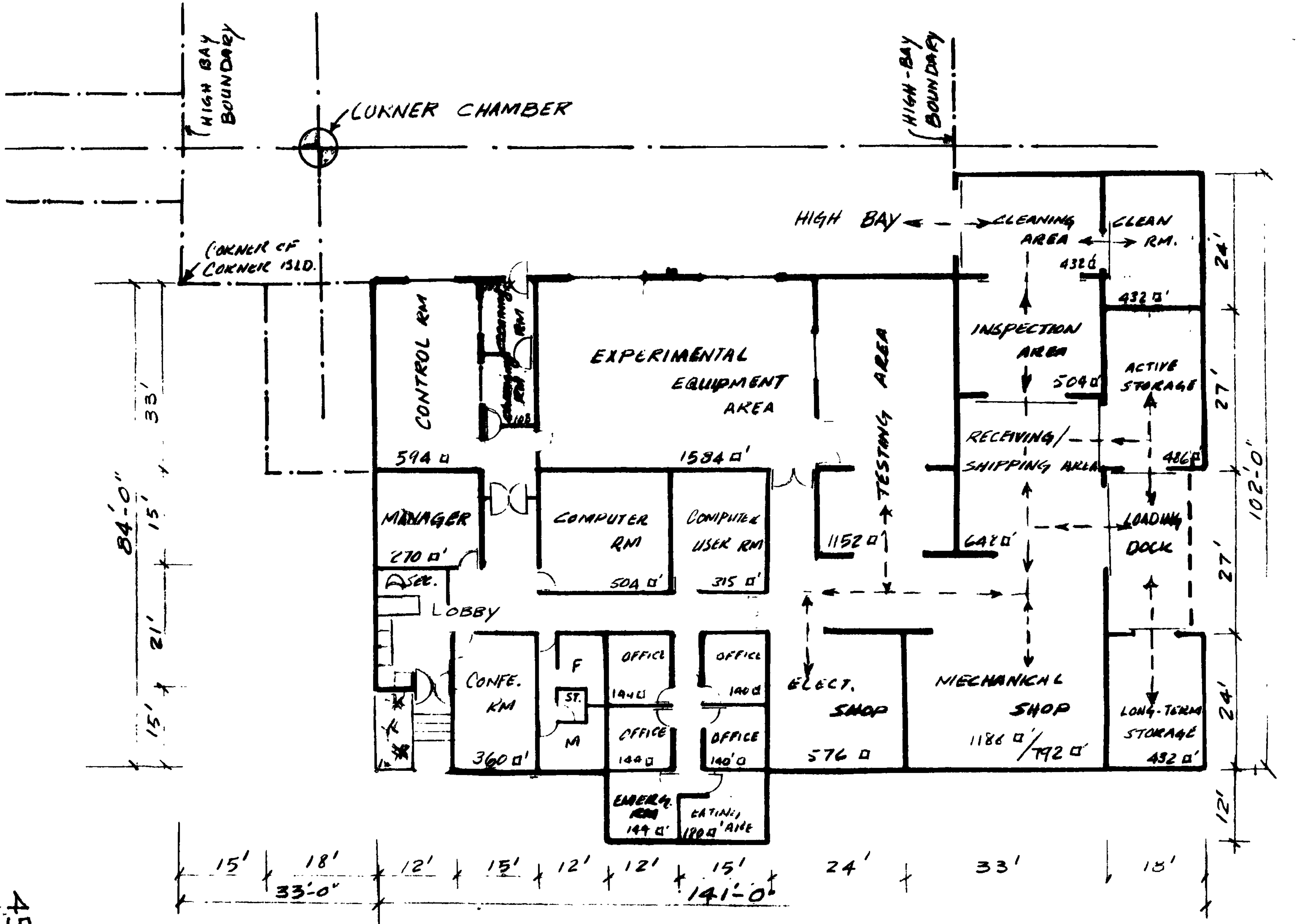
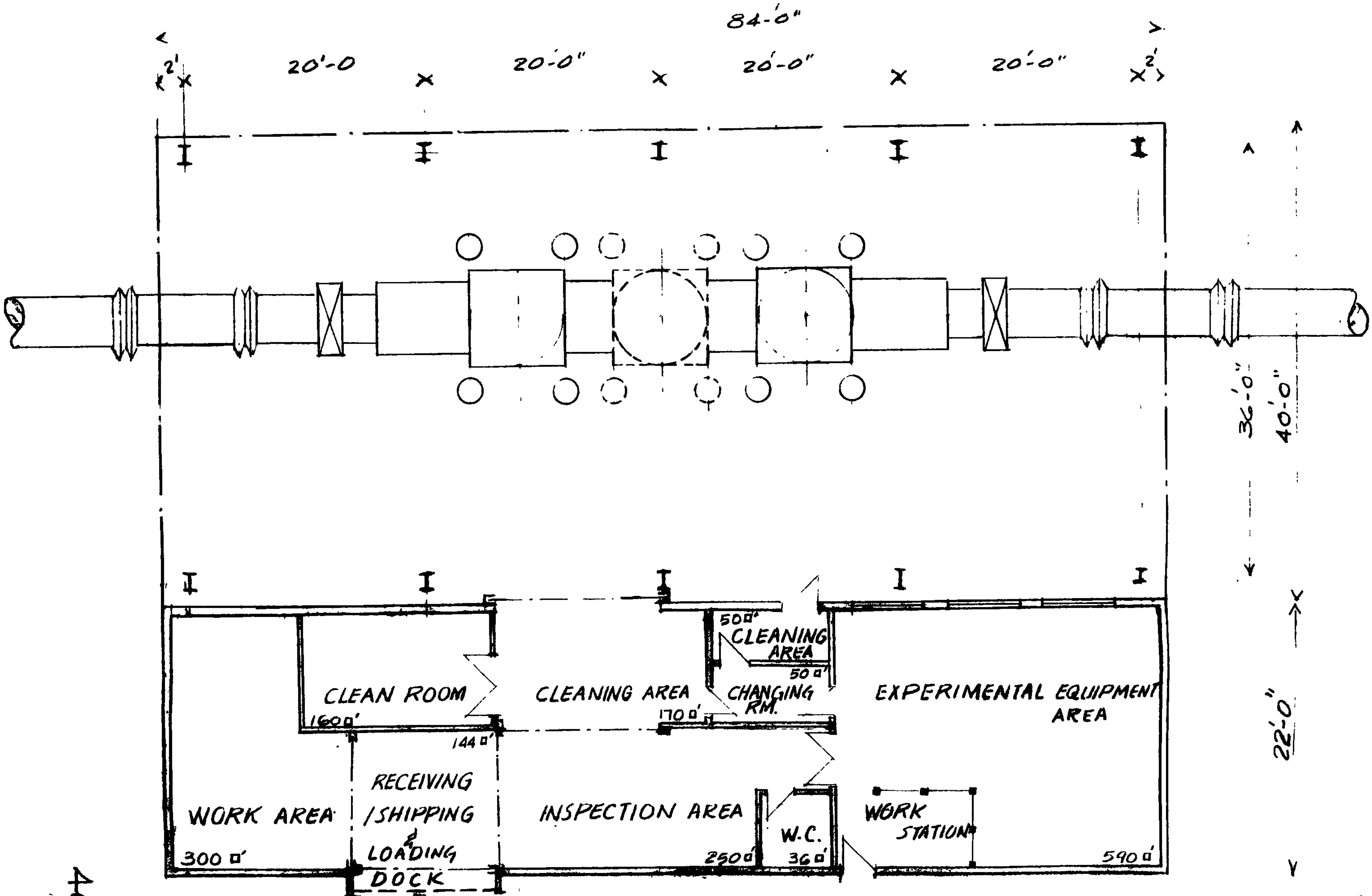


Office/Shop Area
1460"
1330"
320"
1480"
320"
580"
840"
580"
Test Mass Chambers
Diagonal Chamber
Vacuum Chamber Layout
Corner Station
Phase A
LIGO Program
L Jones 3/14/89
Envelope of
Corner Station
0 m
10 m
20 m
30 m
40 m
Scale
Phase A
Phase B
4/10/89
LIGO PROJECT
CORNER STATION ENCLOSURE
SITE - 1
PHASE A & B
SCALE 1" = 10'
B 300



TOTAL SQ. Ft ≃ 12,000

FLOOR PLAN OF OFFICES & SHOPS



FLOOR PLAN OF MID-STATION

46

7BA
REV. 2
12/12/88

LIGO VACUUM ENCLOSURE DESIGN
TUBE COVER REQUIREMENTS

ENVIRONMENTAL REQUIREMENTS:

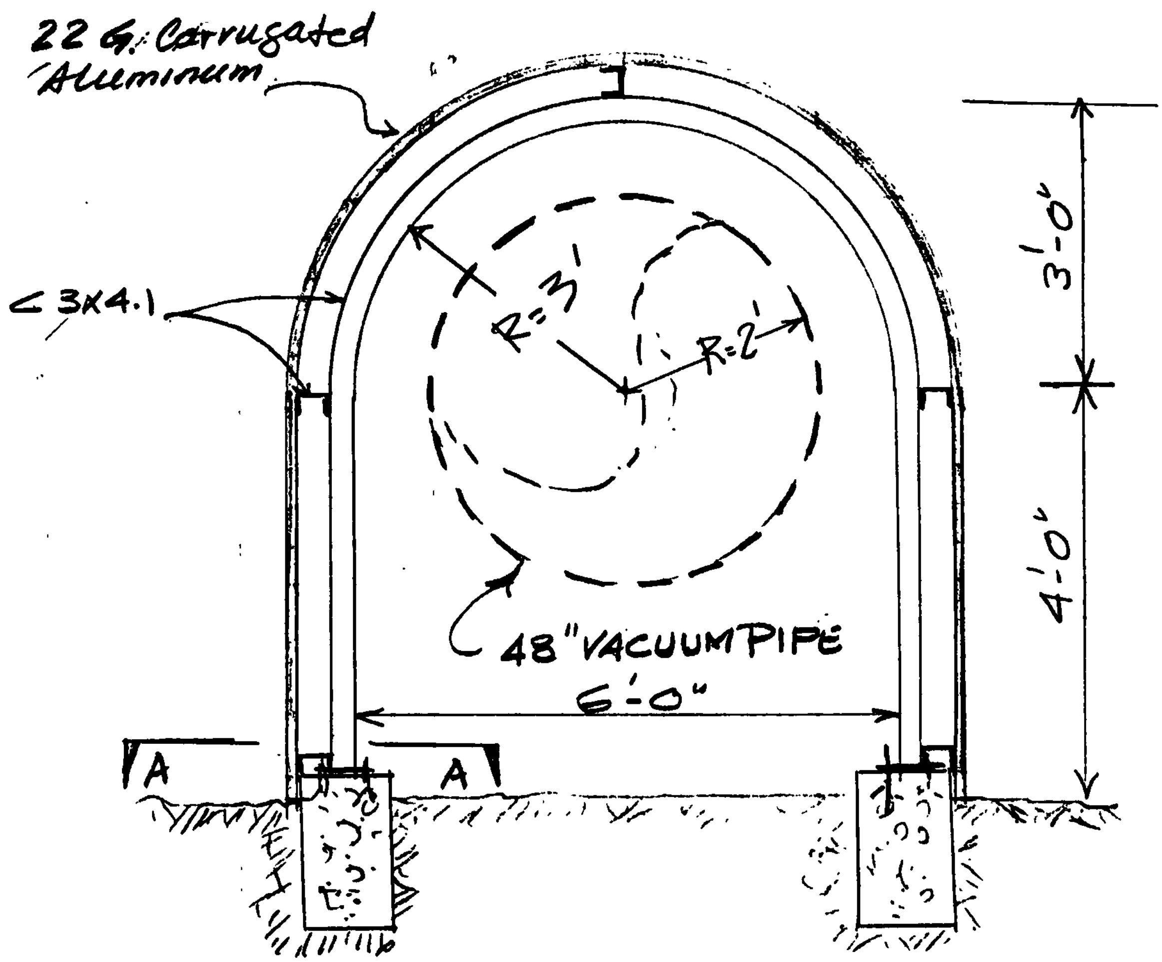
• ALIGNMENT AND DRIFT (OVER 4 KM)	AS NEEDED TO MEET CLEAR APERTURE REQUIREMENT
• TEMPERATURE	AS NEEDED TO MEET PRESSURE REQUIREMENT
• VIBRATION	$< 2\times10^{-9}\ m/\sqrt{Hz}\ \ (f < 10Hz)$ $< \frac{2\times10^{-7}}{f^2}\ m/\sqrt{Hz}\ \ (10Hz < f < 10kHz)$
• SOUND PRESSURE	$< 10^{-4}\ Pa/\sqrt{Hz}\ \ (10Hz < f < 10kHz)$

COVER DESIGN FEATURES:

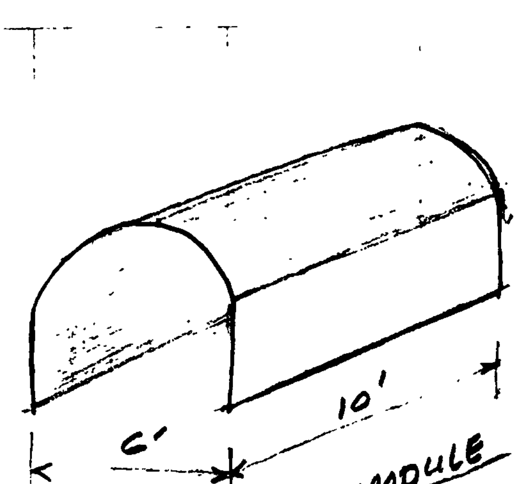
- PROTECTION AGAINST WIND-INDUCED VIBRATION
- ACCESS FOR LEAK REPAIR, ALIGNMENT ADJUSTMENT
- CAPABILITY FOR REMOTE SENSING OF LEAKS AND ALIGNMENT ERRORS
- BULLET-PROOFING

4/10/89

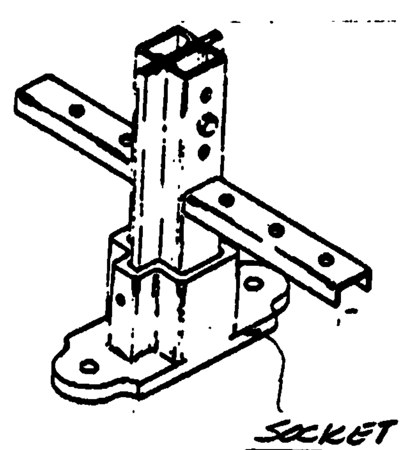
Example of a Lightweight Tube Cover



SCHEME II-A-1-α



10 FT. MODULE



SECTION A-A

LIGO EQUIPMENT AND SUPPORT FACILITIES

ON-SITE:

- POWER DELIVERY AND DISTRIBUTION
  — LASER CAPABILITY: 1 Ar^{+} LASER (5W) PER INTERFEROMETER
- VACUUM SYSTEM MONITORING AND CONTROL
- INTERFEROMETER DATA ACQUISITION, RECORDING, ANALYSIS, DISPLAY
- AUXILIARY PHYSICAL PARAMETER INSTRUMENTATION
- LASERS
- OPTICAL TABLES (LASERS)
- LONG BASELINE OPTICAL COMPONENT TESTING STATION
- VACUUM CONDITIONING/BAKEOUT STATION
- ELECTRONIC, OPTICAL AND VACUUM TEST EQUIPMENT
- CLEAN ROOM EQUIPMENT
- SHOP EQUIPMENT
- BACKUP POWER EQUIPMENT
- LN_2 SUPPLY AND DISTRIBUTION
- LASER COOLING EQUIPMENT
- ENCLOSURE AIR CONDITIONING EQUIPMENT
- SECURITY MONITORING AND ALARMS
- TRANSPORTATION AND LIFTING EQUIPMENT

OFF-SITE — CAMPUS FACILITIES:

- HIGH PHASE SENSITIVITY INTERFEROMETER
- HIGH δx SENSITIVITY INTERFEROMETER
- OPTICS DEVELOPMENT/COMPONENT TESTING STATION
- VIBRATION ISOLATION DEVELOPMENT STATION
- VACUUM COMPATABILITY TESTING STATION (VTF)
- AUXILIARY SYSTEMS/COMPONENTS TESTING STATION

SITE CANDIDATES

Group I

Edwards Air Force Base (EAFB), California

Owens Valley Radio Observatory (OVRO), California

Idaho National Engineering Laboratory (INEL), Idaho

Skull Valley (SV), Utah

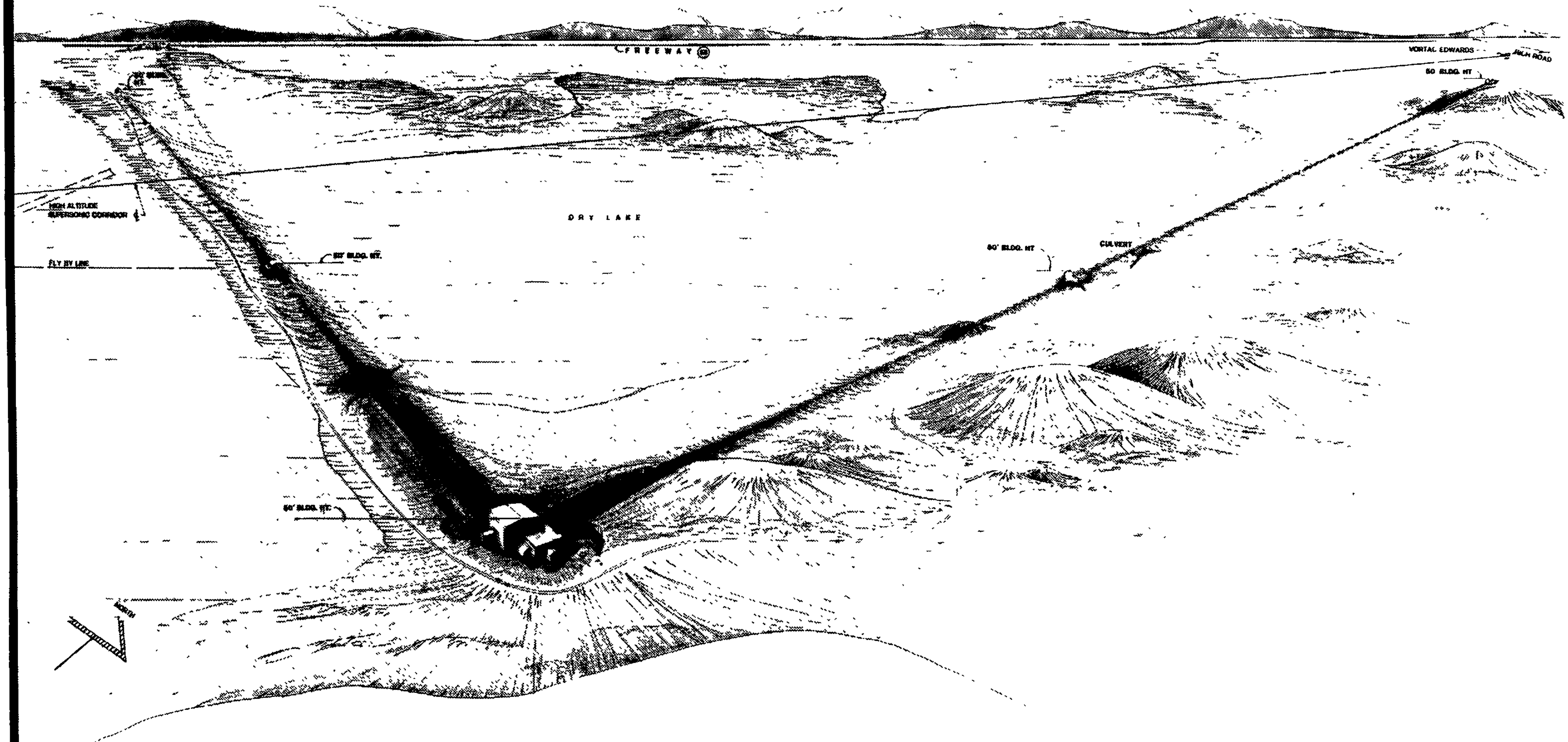
Group II

Columbia (C), Maine

Livingston Parish (LP), Louisiana

NRAO Greenbank, West Virginia

RV-4
4/10/89



51

EDWARDS AIR FORCE BASE SITE
ROSAMOND, CALIFORNIA

ENVELOPE ISOMETRIC

CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LIGO PROJECT

LIGO SITE SELECTION/CERTIFICATION

TASK	EAFB	OVRO	INEL	SV	C	LP	NRAO
1. Preliminary Layout	X	X	X	X	X	X	X
2. Seismic Survey	X				X	X	
3. Biological Survey[a]	$40K				X		
4. Archeological Survey[a]	I.P.				X		
5. Paleontological Survey[a]	I.P.				N.R.		
6. Hydrological Survey	$5K						
7. Preliminary Ground Survey	X				X		
8. Preliminary Geotechnical Survey	$48K				X		
9. Detailed Geotechnical Survey	($140K)				($380K)		
10. Topographical Survey[b]	($40K)				$40K	N.R.	

Note: Items 2 through 10 need landowners' approval.

(a): Environmental & Cultural Impact
(b): Aerial photo contains mapping
$XK: $s expended
($YK): Estimated cost (not expended)
I.P.: In progress
N.R.: Not required

4/10/89

LIGO OPERATIONS PERSONNEL — "STRAWMAN LIST"

PERSONNEL	DAY SHIFT, "ENGINEERING"	"OBSERVATIONS" SHIFT 2	"OBSERVATIONS" SHIFT 3
1. Mechanical/Vacuum Technician	———		
2. "Physical-Plant" Technician	———		
3. Electronics Technician	———		
4. Computer Analyst	———		
5. Site Manager (Physicist)	———	- - - - -	- - - - -
6. Operator 1 *	———		
7. Operator 2 *		———	
8. Operator 3 *			———
9. Operator 4 *	- - - - -	- - - - -	- - - - -
10. Operator 5 *	- - - - -	- - - - -	- - - - -

* Note: Total of 5 operators required for continuous operations

4/10/89

STAFFING AND OPERATIONS

A. LIGO SITE

I. Personnel:

10	Technical
1	Secretarial
11	

II. Power:

Design for 1 MW capacity

$\sim$ 320 KW for 4 lasers

$\sim$ 500 KW for plant and equipment

III. Operations Cost:

Personnel	$800 K/yr
Power	500
Facilities	700
	$2 M/yr

4/10/89

B. CAMPUS OPERATIONS

Science Staff:	Director 4 Professors 12 Physicists
Engineering Staff:	Chief Engineer 1 Vacuum Engineer 1 Mechanical Engineer 2 Electronics Engineers 1 Computer Analyst

Staff supports both observatory and campus operations.

Present support:	~ \$4M/yr
Construction phase:	~ \$5M/yr
Operations phase:	~ \$5M/yr
Interferometer construction:	~ \$nM/yr

Total:	2 sites	\$4M/yr
	Campus ops	5
	IF	n
		\$(9+n)M /yr

4/10/89

PROGRAMMATIC ISSUES: WORK PLAN

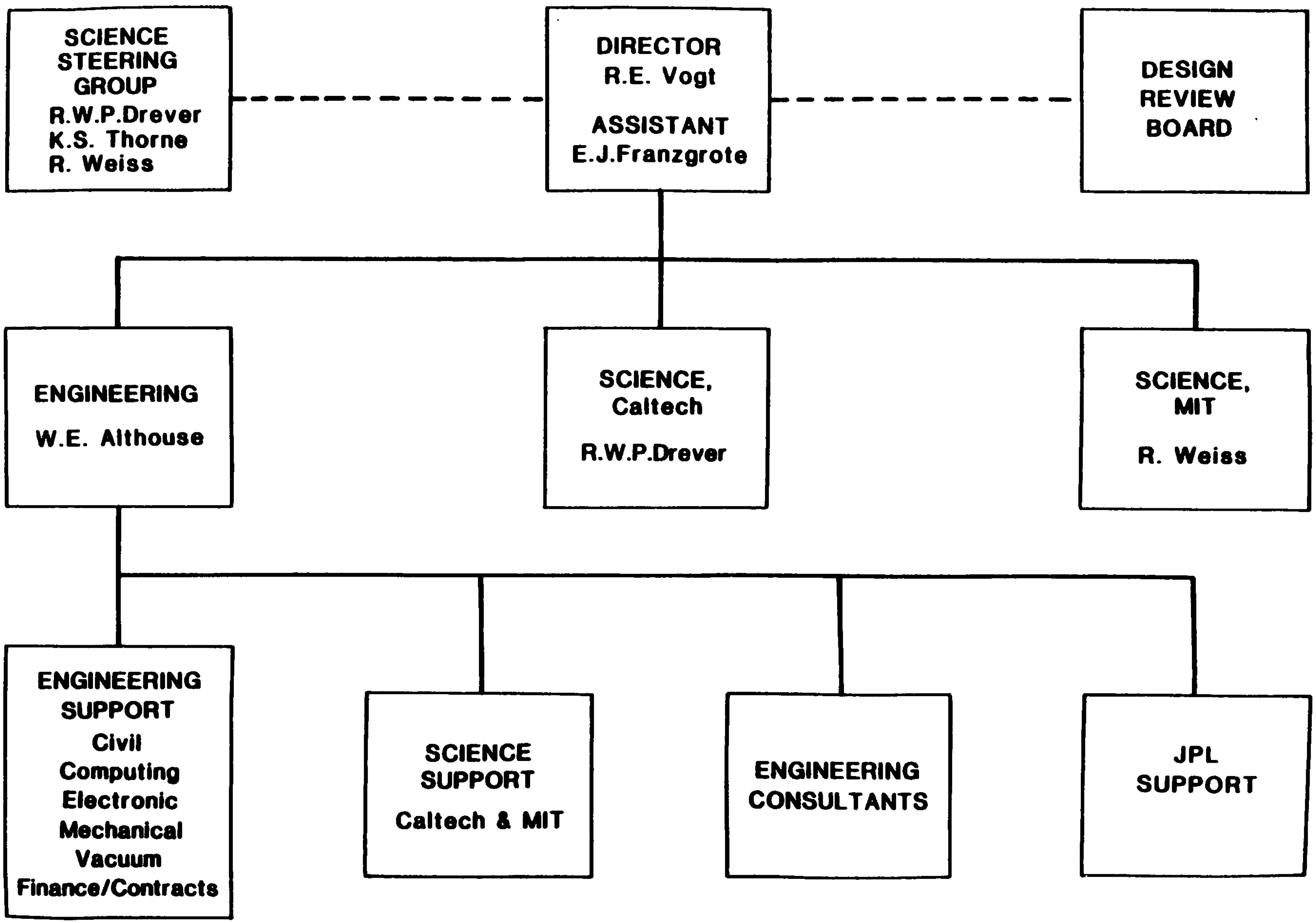
6 mo: 4/1–10/1/89:

1. Construction proposal
2. Continuation of conceptual design
3. 40-m: separation of central mass
4. 5-m: recombination and recycling
5. Optics R&D

12 mo: 10/1/89–10/1/90:

6. Support of proposal review
7. Refinement of conceptual design
8. Site selection and certification
9. Completion of (3) & (4), plus further R&D for sensitivity enhancements of prototypes and development of LIGO scale concepts
10. Laser development with Stanford
11. Document preparation for industrial contracting
12. Selected industrial development

LASER INTERFEROMETER GRAVITATIONAL WAVE PROJECT (LIGO)



LASER INTERFEROMETER GRAVITATIONAL WAVE PROJECT (LIGO)