Managing the LIGO Project

Ecole de Conduite de Projets - La Londe
11 au 16 Fevrier 1996

Gary H. Sanders

LIGO Project Manager

California Institute of Technology

Caveat

- These lectures are my personal approach to organizing and managing a project.
- Assume audience is a technically experienced group of engineers and scientists, but novices in project management of large projects. I apologize in advance if I insult the audience at this school.
- Assume a USA approach to project management, though I am familiar with organization of European projects.
- I will mix details of the LIGO Project Management with philosophical and personal comments.

Organization of Two Talks

- LIGO Organization and Management
  - » The LIGO Project - Technical Introduction
  - » Work Breakdown Structure
  - » Organization
  - » Management Processes
  - » Review and Advisory Processes
- LIGO Cost, Schedule and Performance Control
  - » Cost Estimate and Cost Baseline
  - » Schedule Baseline
  - » Performance Measurement Baseline
  - » Tracking and Controlling Performance
  - » Change Control

The Goal of the Project Manager

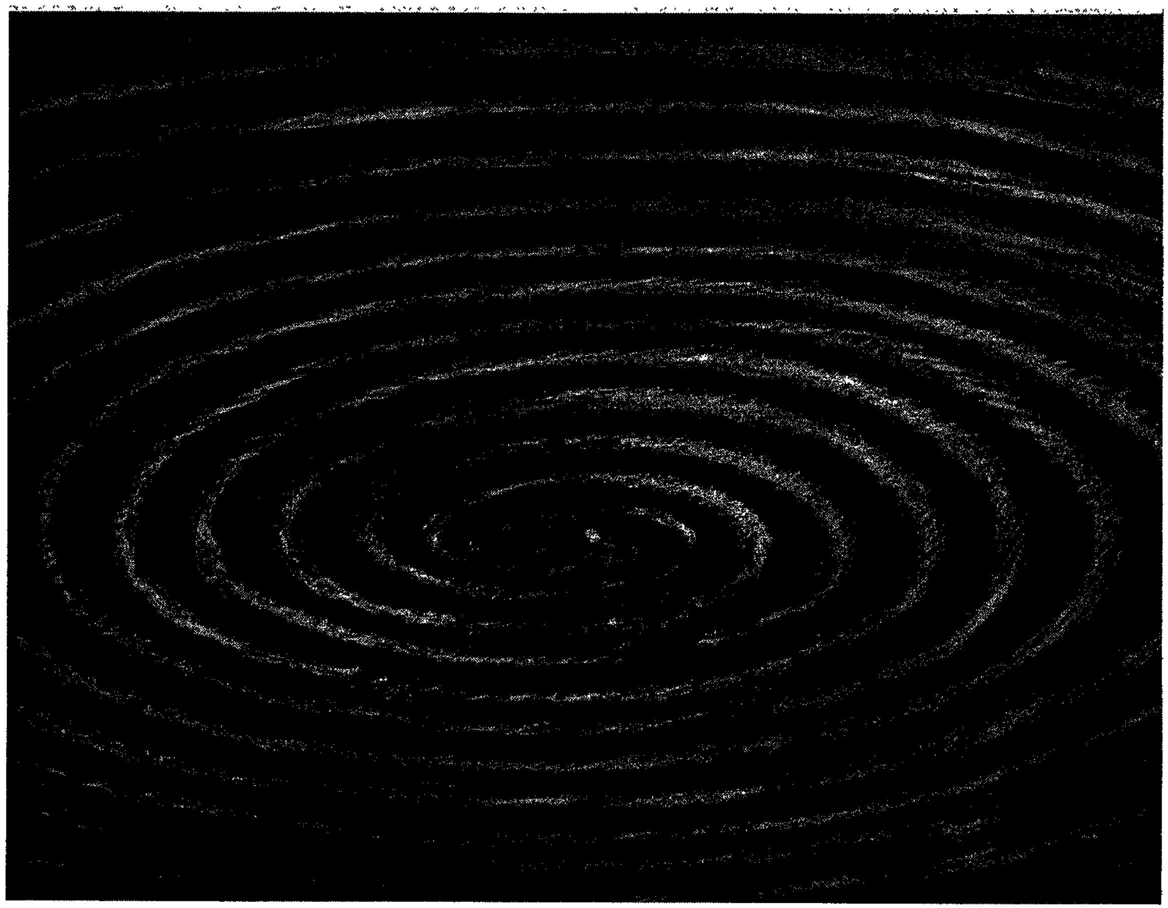
"See first that the design is wise and just: that ascertained, pursue it resolutely; do not for one repulse forego the purpose that you resolved to effect."

William Shakespeare

The LIGO Project - Technical Introduction

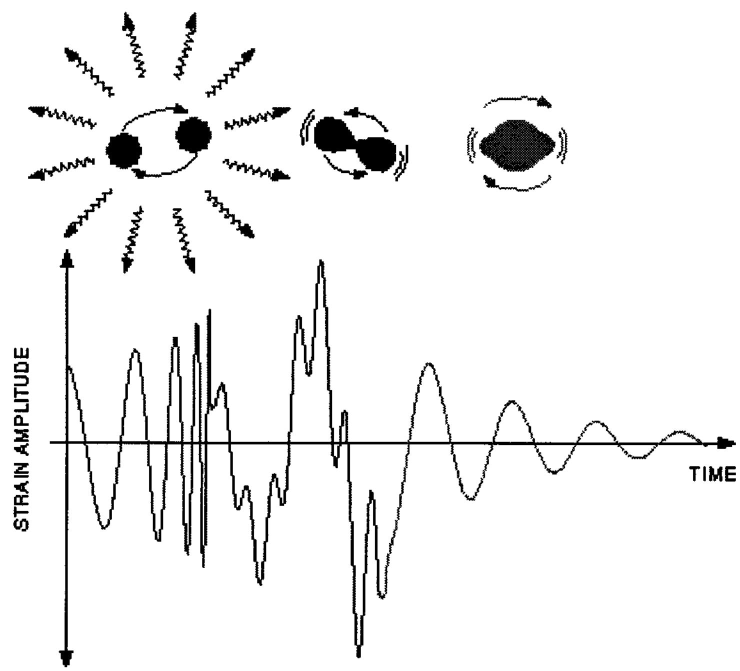
Laser Interferometer Gravitational Wave Observatory

Sources of Gravity Waves



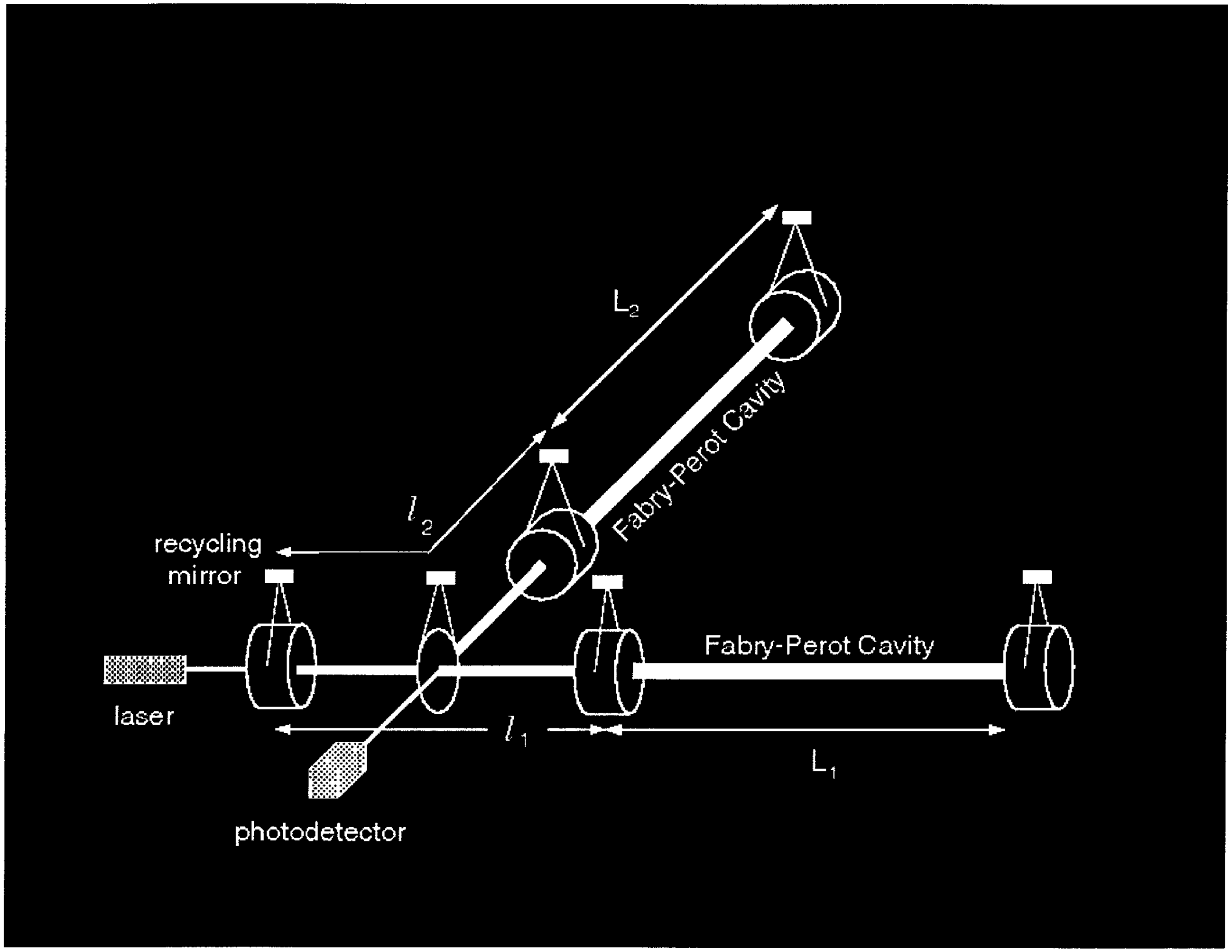
2-dim. display of space-time ripples from neutron star inspiral

A Gravitational Wave Signal

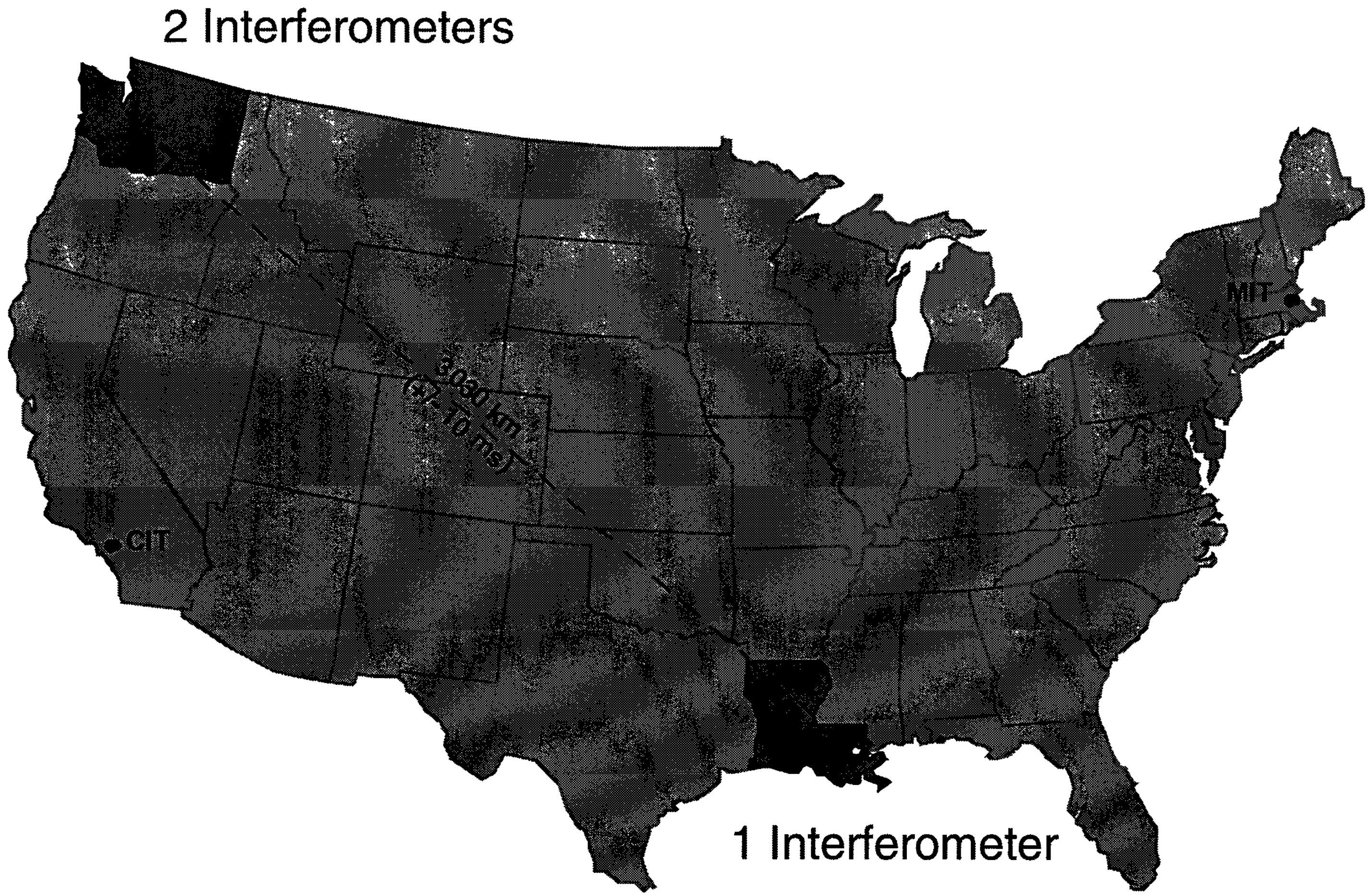


Signal from a neutron star - neutron star binary inspiral/coalescence

A LIGO Interferometer



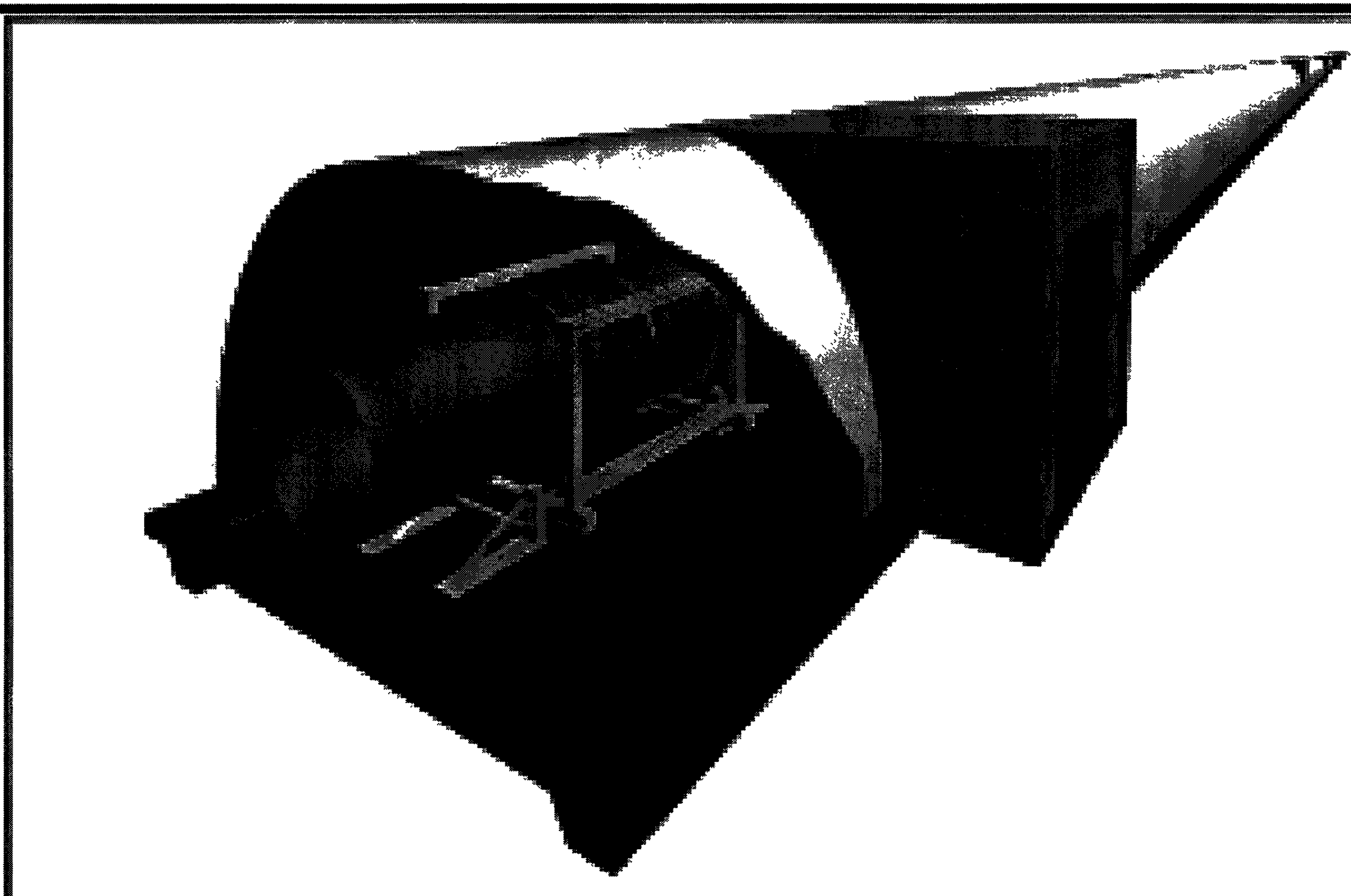
Two Sites - Three Interferometers



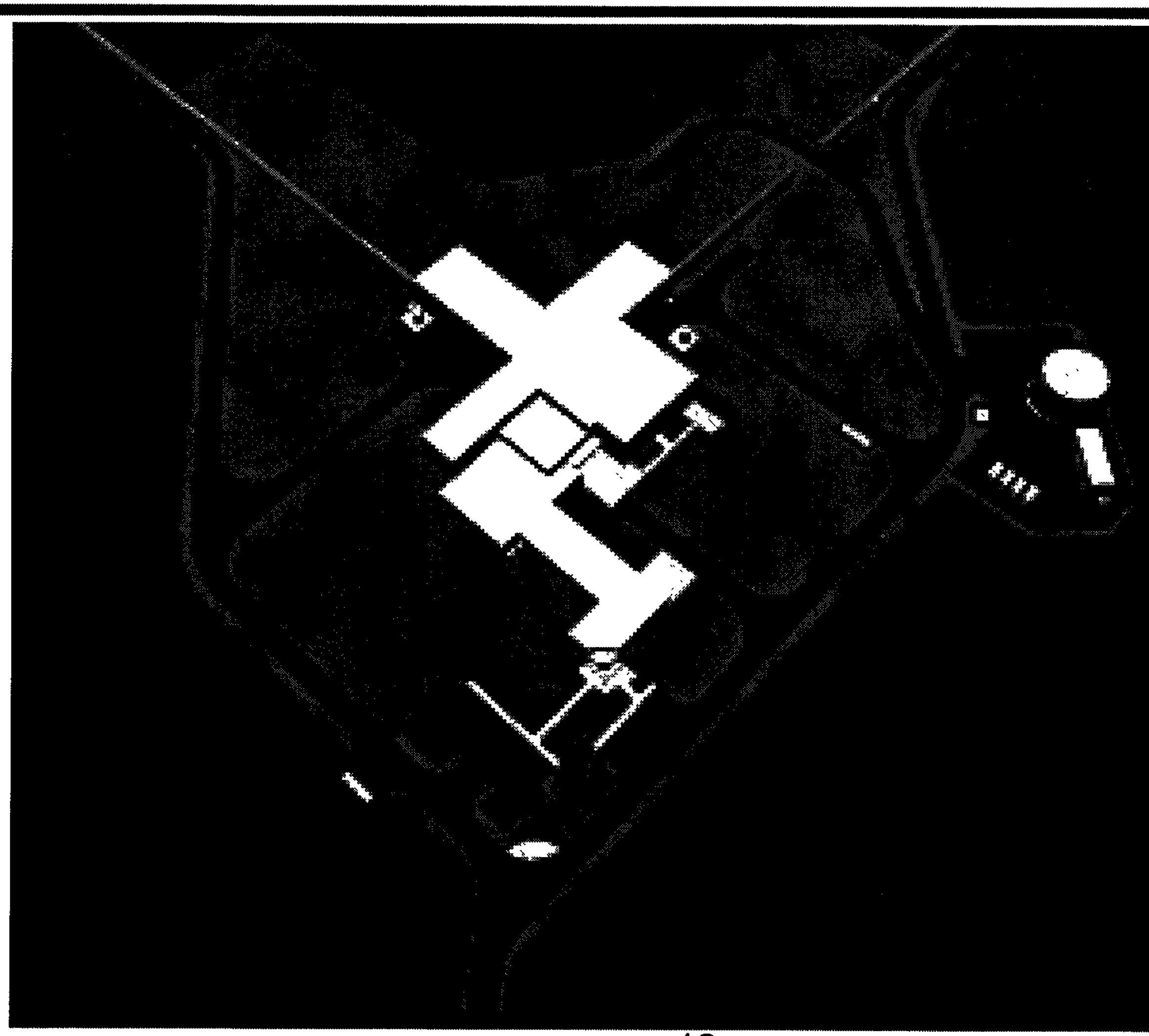
LIGO Vacuum System

LIGO Beam Tube

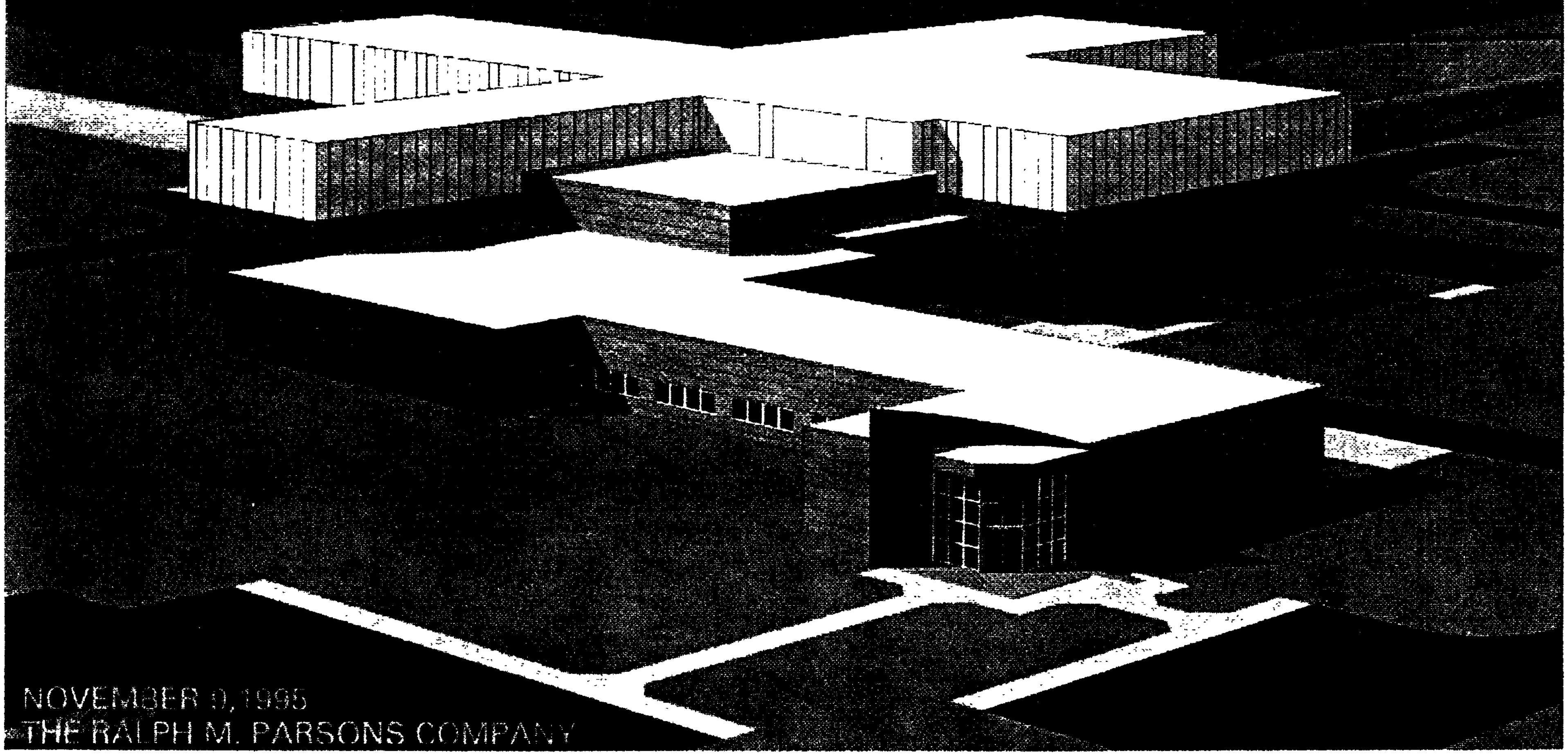
LIGO Beam Tube Enclosure

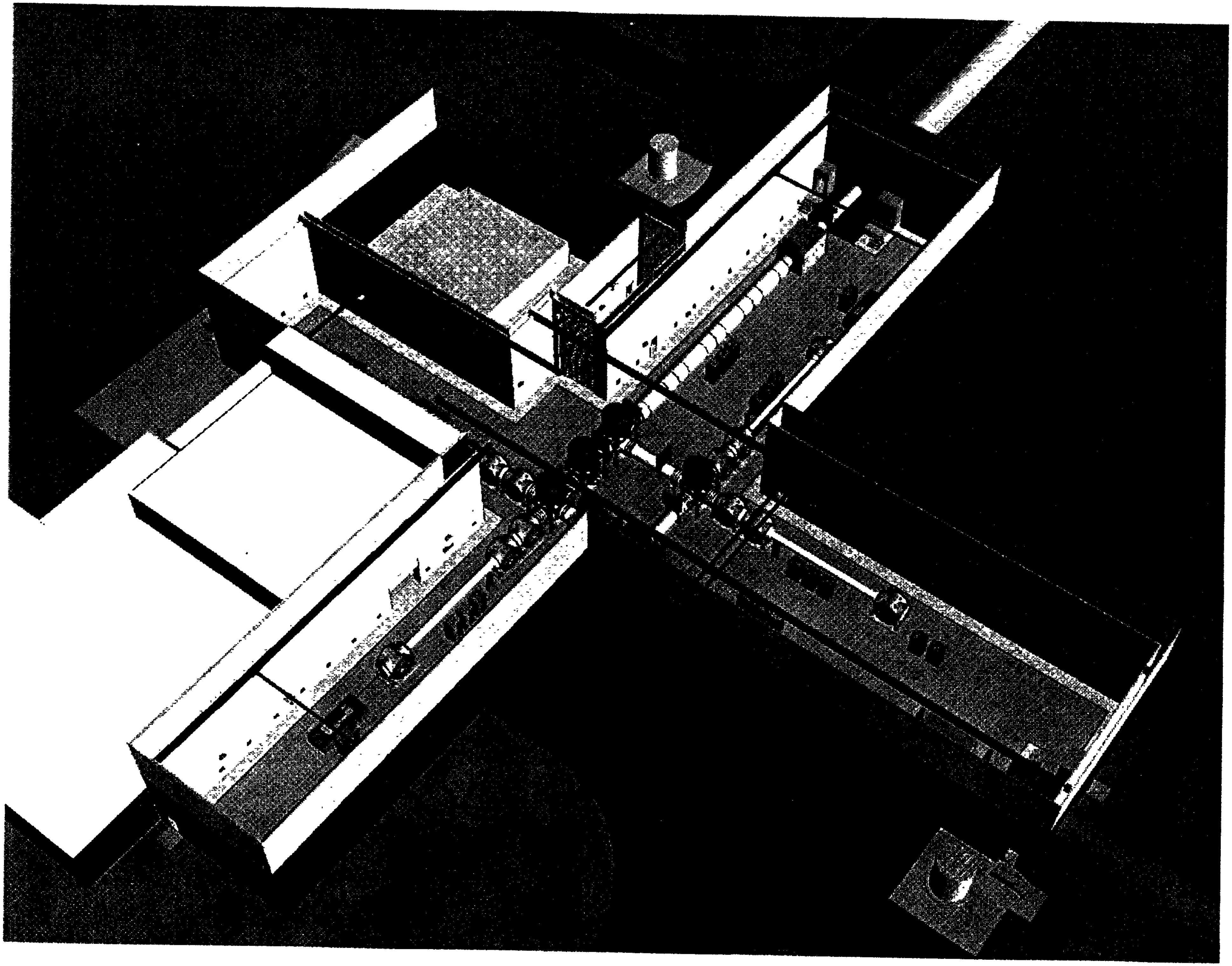


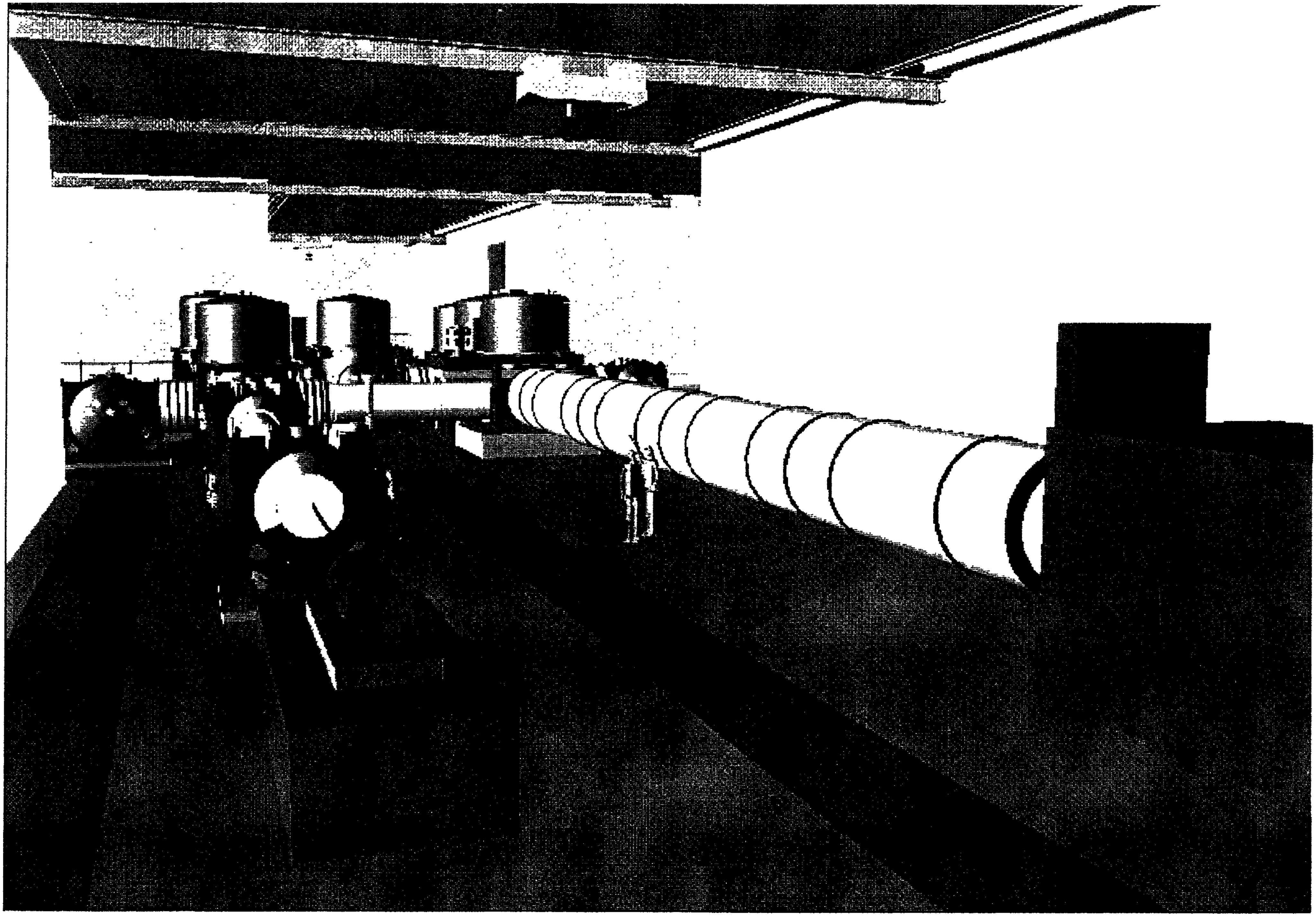
LIGO Conventional Facilities



LIGO PROJECT
FACILITIES PRELIMINARY DESIGN

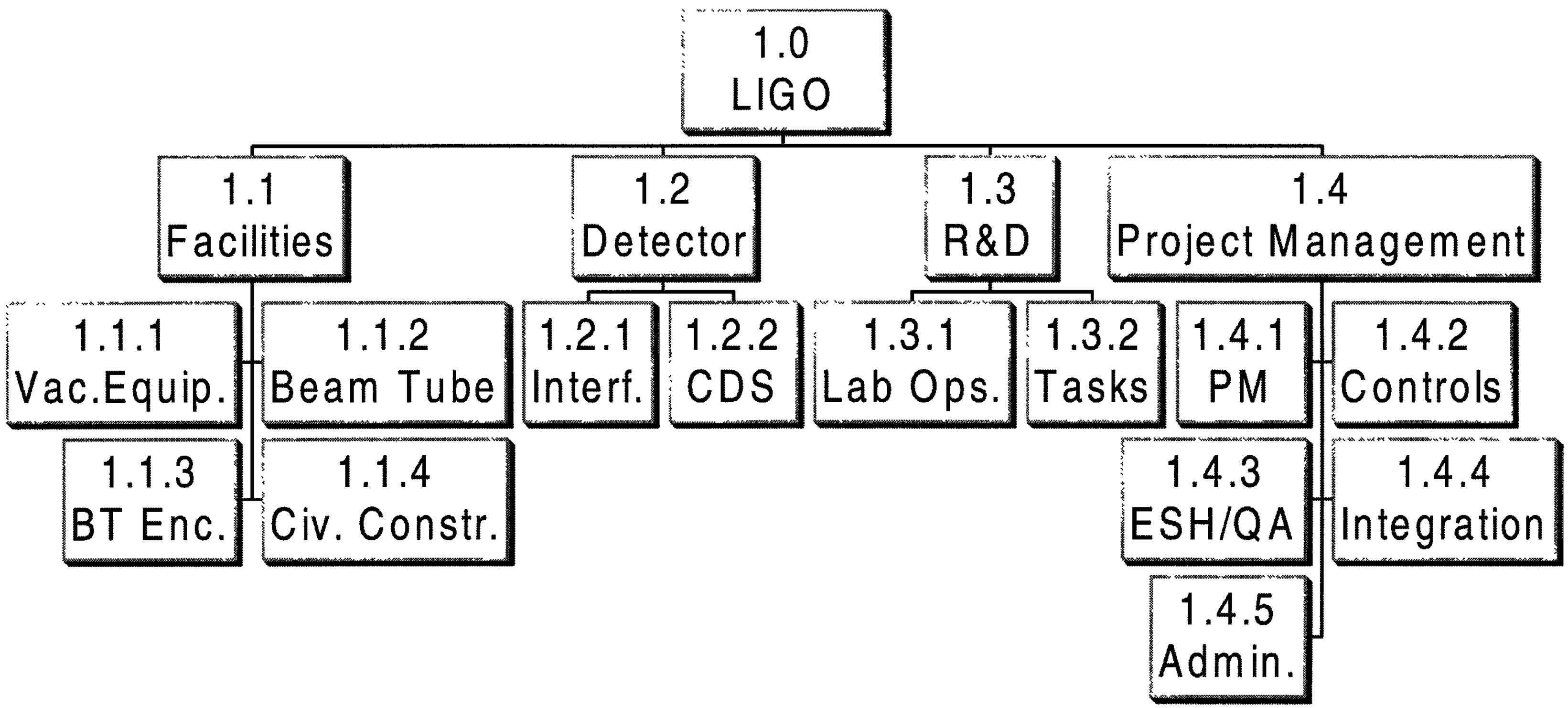






Work Breakdown Structure
Organization
Management Processes
Review and Advisory Processes

LIGO Work Breakdown Structure



522. GEM

- **522.5010 Tracker**
  - 10.01 R & D
  - 10.02 Silicon Tracker
  - 10.03 IPC Tracker
  - 10.04 Reserved
  - 10.05 Reserved
  - 10.06 STS/IPC Assembly
  - 10.07 Installation andFinal Test
  - 10.08 Project Management
  - 10.09 Conceptual/ Preliminary Design
- **522.5020 Calorimeter**
  - 20.01 R & D
  - 20.02 Inner Barrel Calorimetry
  - 20.03 Scintillating Barrel Hadronic Sections
  - 20.04 Endcap Calorimetry
  - 20.05 Forward Hadronic Calorimetry
  - 20.06 Passive Absorber
  - 20.07 Vacuum
  - 20.08 Cryogenics
  - 20.09 Instr., Power & Operational Control
  - 20.10 Final Assembly
  - 20.11 Hall Installation
  - 20.12 Calibration and Test Beam Program
  - 20.13 Subsystem Management
  - 20.14 Conceptual/ Preliminary Design
- **522.5030 Muon**
  - 30.01 R & D
  - 30.02 Barrel Region - CSC
  - 30.03 Endcap Region - CSC
  - 30.04 Installation - CSC
  - 30.05 Project Management - CSC
  - 30.06 Conceptual/ Preliminary Design
- **522.5040 Magnet**
  - 40.01 R & D
  - 40.02 Design Completion
  - 40.03 Fabrication & Assembly
  - 40.04 Installation and System Testing
  - 40.05 Project Management
  - 40.06 Conceptual/ Preliminary Design
- **522.5050 Electronics**
  - 50.01 R & D
  - 50.02 Front End
  - 50.03 Data Acquisition
  - 50.04 Trigger
  - 50.05 Integration
  - 50.06 Project Management
  - 50.07 Conceptual/ Preliminary Design
- **522.5060 Computing**
  - 60.01 R & D
  - 60.02 Global Control System
  - 60.03 On-line Computing
  - 60.04 Network and Communications
- **522.5070 Interface**
  - 70.01 CDS Support
  - 70.02 Beam Pipe
  - 70.03 Detector Access Equipment
  - 70.04 Detector Safety Systems
  - 70.05 Utility Services
  - 70.06 Cranes
  - 70.07 Auxiliary Equipment
  - 70.08 Gas Services
  - 70.09 Survey Systems
  - 70.10 Magnetic Shielding
  - 70.11 Test Beam/Calibration Hall
  - 70.12 Cable & Plumbing Routing
- **522.5090 Project Management**
  - 90.01 Planning & Controls
  - 90.02 Engineering & Integration
  - 90.03 ES&H & QA
  - 90.04 Administration

gem DETECTOR PROJECT

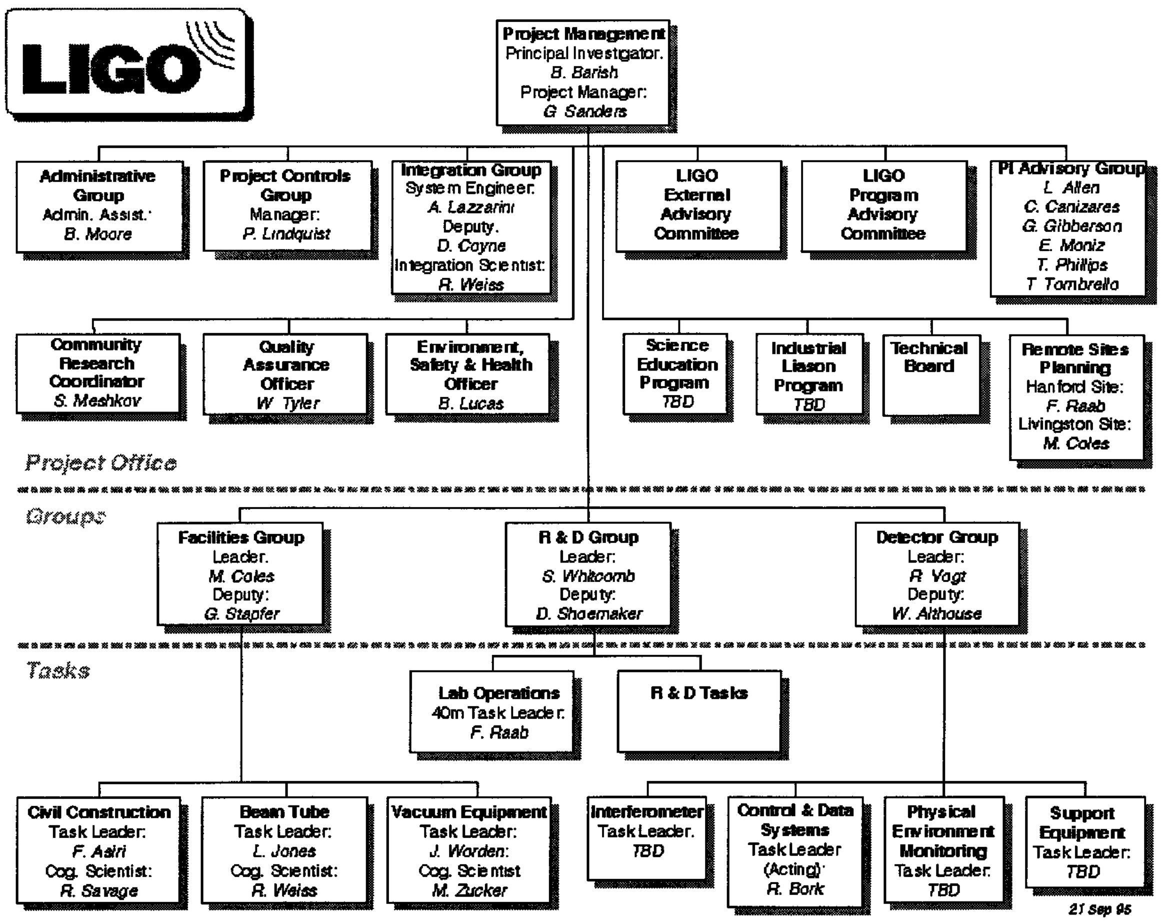
Work Breakdown Structure (WBS)

- Break down <u>all</u> of the work required to complete the project
  - » Include all physical deliverables, subsystems
  - » Include R&D, design, prototyping, fabrication, installation, acceptance testing leading to a deliverable product
  - » Include administration, integration, purchasing, reporting not directly related to deliverable products
  - » Break work down to 5-8 levels from top when mature
- Organize work in a way to support delivery of "products"
- If work will be accomplished through major contracts, represent them in the WBS

Work Breakdown Structure (WBS)

- WBS will structure cost estimating, schedule planning, tracking of actual costs and progress
- It should reflect how you will manage the project toward its goals
- Do not make the common mistake of organizing it to keep accountants happy, or to reflect geography or existing organizations
- Structure your organization to parallel the WBS
- Write a Work Breakdown Structure Dictionary and maintain it

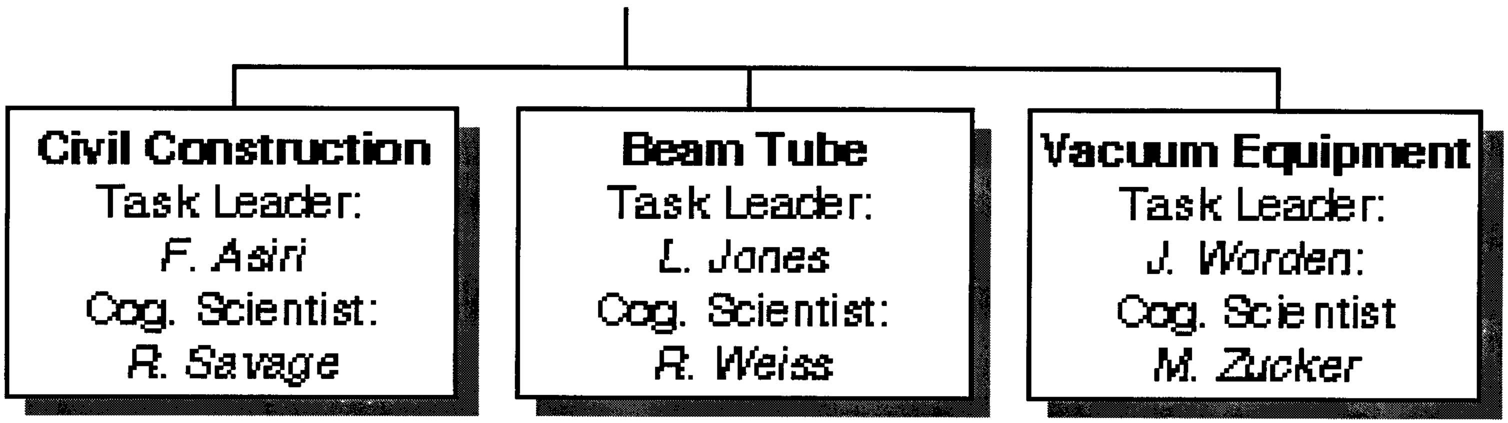
LIGO Organization



LIGO Organizational Philosophy

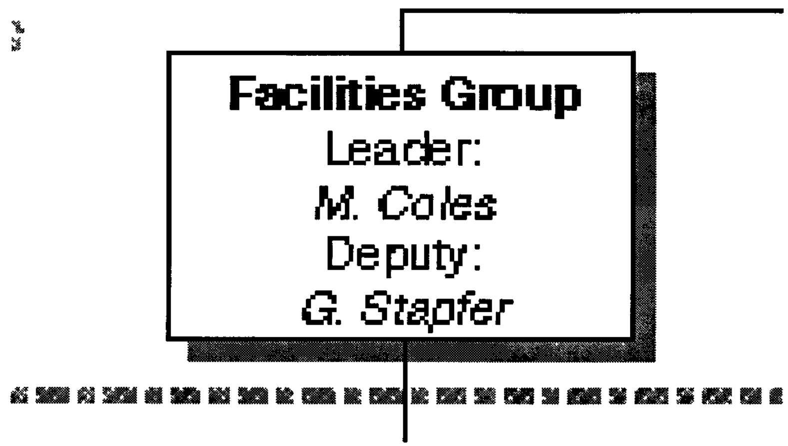
- Organization has only three levels
  - » Tasks - execute specific tasks
  - » Groups - coordinate related work
  - » Project Office - integrate and insure progress and control
- "Product Oriented"
  - » Middle managers under pressure to deliver a "product"
- Integration
  - » Project Management at top level provides integration

Facilities Task Leaders



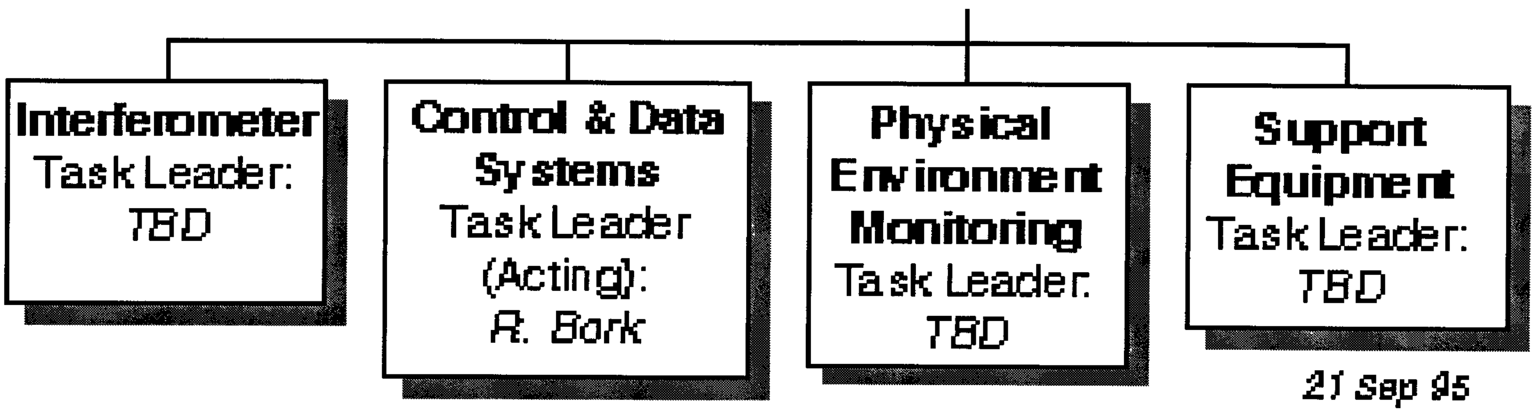
- Task Leader is an experienced engineer
- Cognizant Scientist provides scientific support, but not management of task, nor signature responsibility
- Task Leader has sole signature authority for written directions to outside contractors
- Project approval required for cost/schedule actions >$50K/one month or technical changes affecting other systems

Facilities Group Leader



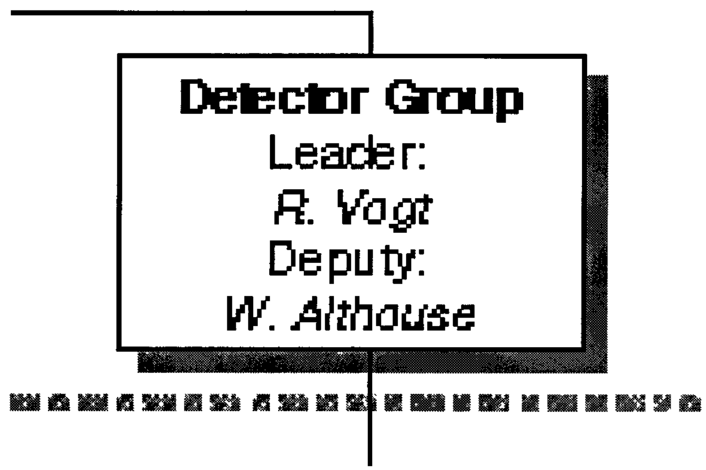
- Group Leader is a physicist, Deputy is an engineer
- Both will move to a site as operating site leaders strengthening responsibility
- Responsible to deliver functioning facilities ready for detector
- Responsible to manage interfaces between subsystems
- Responsible for cost/schedule integration and corrective actions in execution of project

Detector Task Leaders



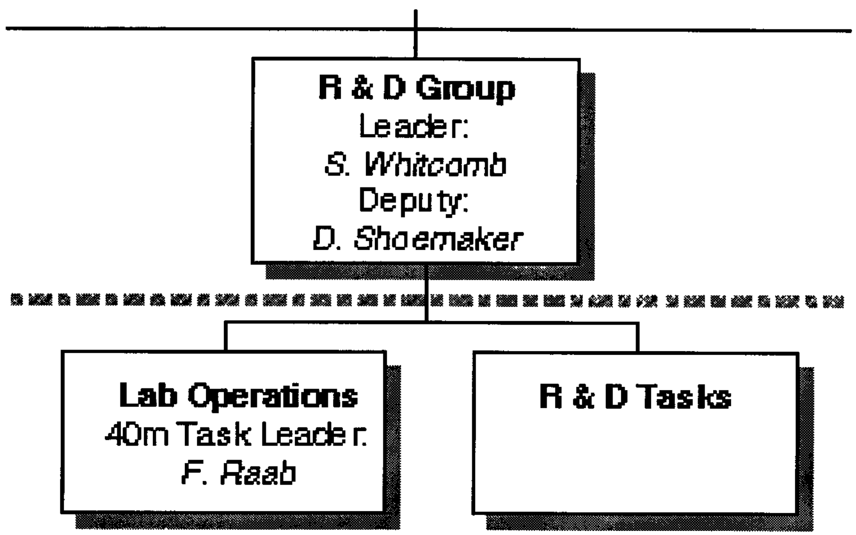
- Task Leaders are scientists or engineers
- Responsibilities similar to Facility Task Leaders
- As design/fabrication is more in-house, these Leaders are more directly responsible for managing the design and fabrication and acceptance process
- CDS electronics could be organized within other subsystems

Detector Group Leader



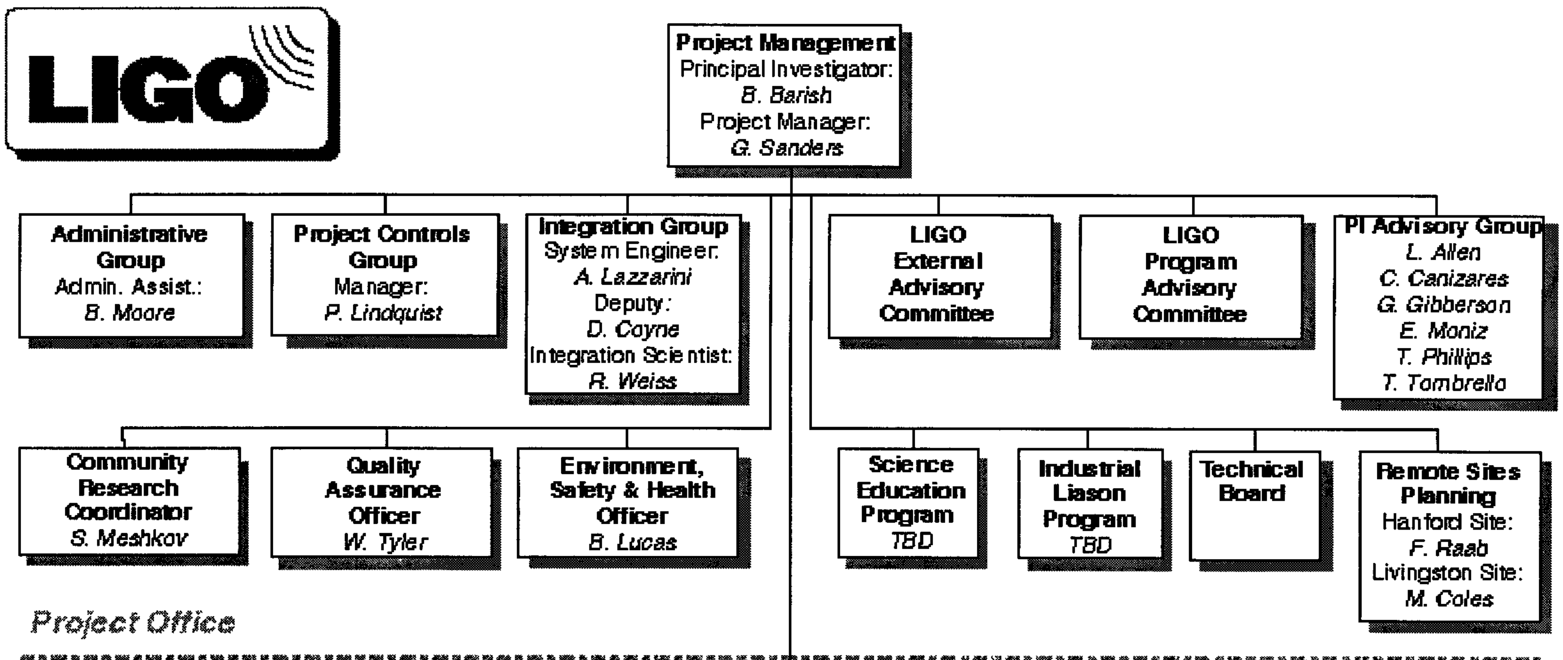
- Group Leader is a physicist, Deputy is an engineer
- Responsible to deliver functioning detector (3 interferometers)
- Responsible to manage interfaces between subsystems
- Responsible for cost/schedule integration and corrective actions in execution of project

R&D Group



- Led by scientists
- Responsible to deliver R&D results when needed by Detector schedule
- Responsible to deliver operational expertise and competence needed at operating sites
- Managed as a "level-of-effort"

Project Office



- Principal Investigator and Project Manager are both scientists
- Responsible for overall technical/cost/schedule integration
- Left side chart are Project Office functions
- Right side chart are Project advice, review, external relations

Project Management

Project Management
Principal Investigator:
B. Barish
Project Manager:
G. Sanders

- Responsible to deliver the Project

  Manage integration and Project cost/schedule/technical progress

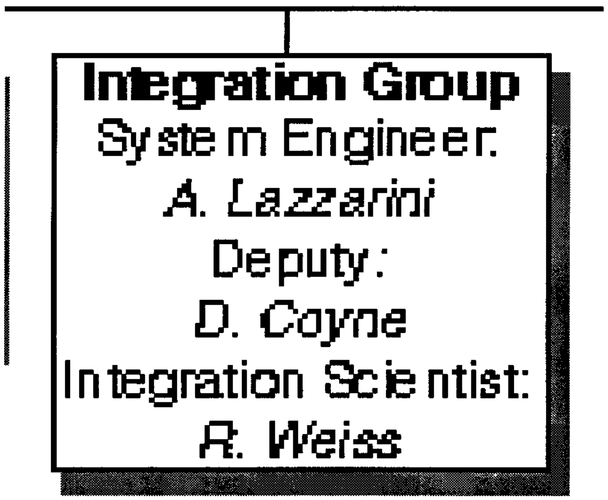
  Assure scientific success

  Chair Technical Board/Change Control Board
- Chair weekly Project Control Meeting
- Chair monthly Cost/Schedule Meeting
- Responsible for interactions with funding agency (NSF)

Project Controls Group

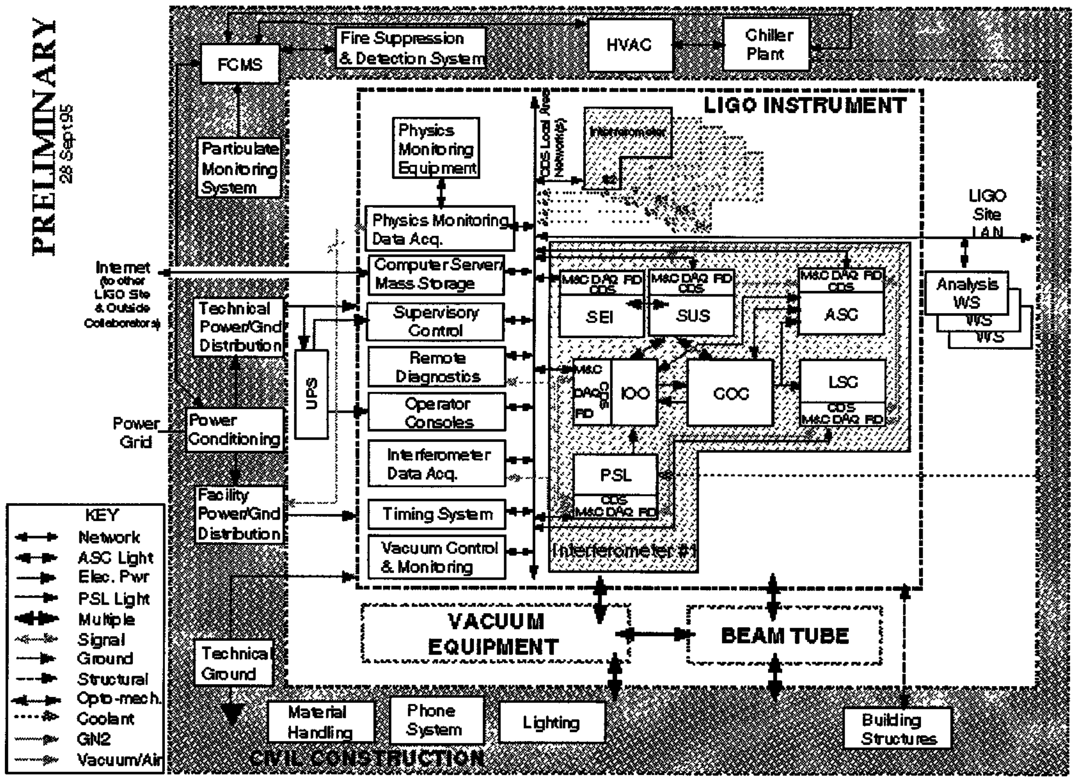
- Responsible to provide detailed visibility of Project performance in cost and schedule
- Manage review of technical configuration changes
- Manage cost estimating and revisions
- Manage schedule development and routine and urgent revisions
- Manage performance measurement
- Manage formal reporting to NSF
- Manage procurements, industrial contracting and payment actions
- Manage all documentation

Integration Group



- Technical integration of requirements, specifications, interfaces is a Project responsibility
- Led by a scientist with industrial experience
- Includes also all system modeling and simulation and computing
- All technical work in Project is visible to this Group
- Technical management of configuration changes
- Specialized external technical consulting

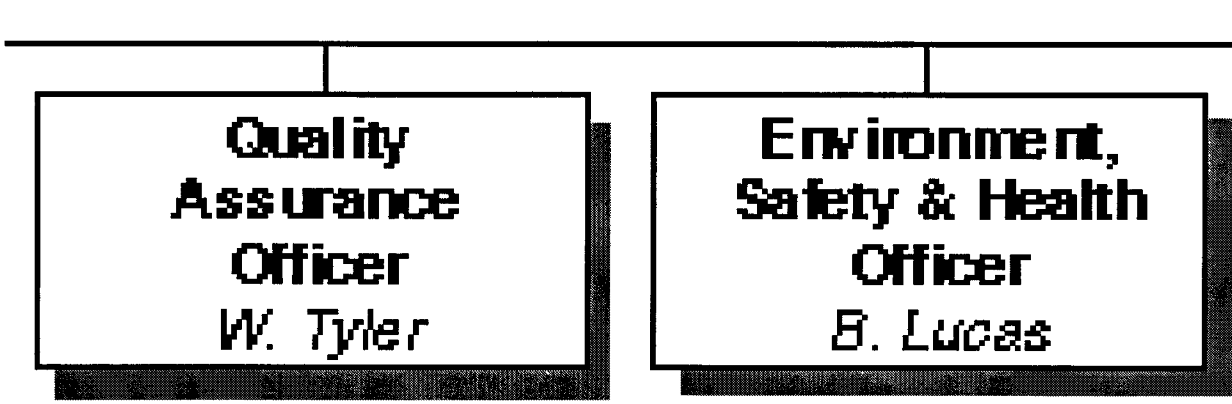
Interface Control



Document and control all interfaces between subsystems

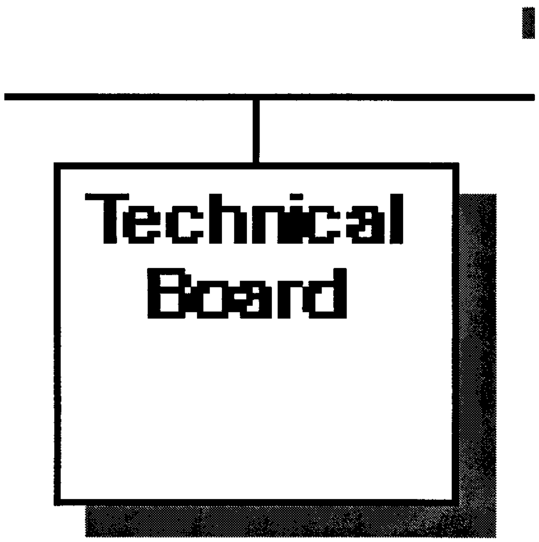
Detector - Civil Construction Interface example

ES&H/QA



- Responsibility of the Project Manager !
- QA Officer responsible for qualifying all processes, procedures, and materials, supervising technical oversight of fabrication and acceptance testing
  - » Most direct Quality Assurance done by technicians and engineers
- ES&H Officer responsible for identifying all hazard scenarios in system and insuring that hazards are addressed by design, procedures or training

Technical/Change Control Board



- Members are Group Leaders for Facilities, Detector, R&D, Integration, Project Controls
- Review of all requests for:
  - » cost changes >$50K
  - » milestone changes > 1 month
  - » technical interface or performance changes
- Recommendation to Project Management
- Reviews all major technical choices
  - » example Argon vs NdYAG laser

Remote Sites Planning

Remote Sites Planning
Hanford Site:
F. Raab
Livingston Site:
M. Coles

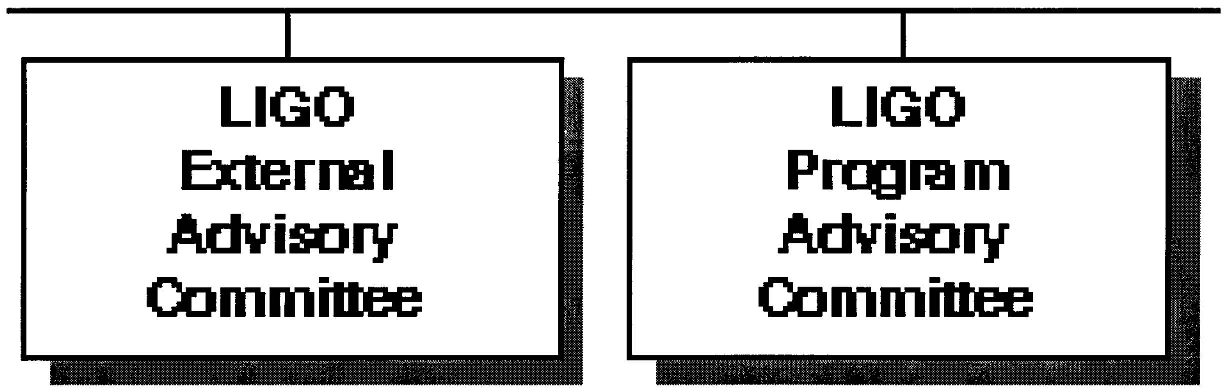
- Led by two scientists who will head the two LIGO sites
- Responsible for all LIGO systems delivered to the sites
- Responsible to build onsite staff
- Responsible to plan all infrastructure for onsite staff (office space, local technical resources, medical insurance...)
- Responsible to establish functional relations with local authorities and institutions
- Initiate onsite construction management

Advisory/Oversight Committee

PI Advisory Group
L. Allen
C. Canizares
G. Gibberson
E. Moniz
T. Phillips
T. Tombrello

- Chaired by retired Director of Jet Propulsion Laboratory
- Members include two senior faculty each from Caltech and MIT and a former senior manager of major space projects
- Reports to Caltech and MIT management
- Quarterly meetings to monitor progress and difficulties in Project with written reports to Caltech/MIT management
- Provides advice to LIGO Project Management

EAC/PAC



- External Advisory Committee provides technical advice on system choices and technical challenges (laser type, lightening protection, spiral welding of thin walled stainless steel...)
- Program Advisory Committee reviews proposals from outside LIGO to use LIGO facilities for experiments
- Both committees structured by a temporary committee

Project Management Plan

- Write a Project Management Plan
- Include:
  - » Project Description, Objectives and Scope
  - » Organization and Responsibilities
  - » Work Plan
    - – Subsystems, Integration, QA, ES&H, Procurement
  - » Cost Estimate Summary
  - » Major Schedule Milestones
  - » Management and Control
    - – Cost, Schedule, Subcontracts, Configuration Change Control
  - » External Reporting

LIGO Cost, Schedule and Performance Control

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LIGO Project Manager
California Institute of Technology

Cost Estimate - Basis

- Establish detailed Work Breakdown Structure
- All estimating to be done "bottom up" by the engineers and scientists directly responsible for each item
- Establish a written Cost Estimating Plan that defines uniform formats and procedures for all estimators
- Each estimated item should have all information supporting the estimate for that item recorded in a standard Basis of Estimate worksheet for that item. The Basis sheet should be signed and dated by the estimator.

GEM COST ESTIMATE SUMMARY

FY93 U.S. Dollars

GEM DETECTOR SYSTEM

WBS Code	Description	WBS Level	Material, k$	ManHours	Labor, k$	M + L, k$	Markup, k$	%	Contingency, k$	%	TOTAL, k$
	-GEM DETECTOR SYSTEM	00	274,531	3,657,544	167,306	441,837	6,029	1%	103,362	23%	551,228
10	-CENTRAL TRACKER	01	12,168	190,275	9,786	21,954	0	0%	5,369	25%	27,324
20	-CALORIMETER	01	68,570	1,012,430	37,976	106,546	0	0%	28,870	27%	135,415
30	-MUON	01	40,631	891,791	36,819	77,449	0	0%	20,897	27%	98,347
40	-MAGNET	01	64,787	348,234	33,232	98,019	6,029	6%	21,277	21%	125,325
50	-ELECTRONICS	01	52,619	465,971	22,552	75,171	0	0%	17,100	23%	92,272
60	-COMPUTER & CONTROLS	01	10,390	168,299	5,478	15,869	0	0%	3,591	23%	19,460
70	-INTERFACE SYSTEMS	01	21,814	122,305	3,567	25,381	0	0%	4,433	18%	29,813
90	-PROJECT MANAGEMENT	01	3,551	458,239	17,897	21,448	0	0%	1,825	9%	23,274

40.03.1.2.3 VESSEL SUPPORT STRUCTURES FAB/ASSY

LINE ITEM	ITEM CODE	ITEM DESCRIPTION	QUANTITY	UNIT MEAS	COST BASIS	MATERIAL UNIT COST	MATERIAL TOTAL MAT'L,$	LABOR CRAFT/ TEAM	LABOR HOURLY RATE	LABOR MH/ UNIT	LABOR TOTAL HOURS	LABOR UNIT COST	LABOR TOTAL LABOR,$	TOTALS MAT'L+ LABOR,$
1	I&A	Coordinator Suppt During Const	3.00	MM	BU			INSPAD	60	147	441	8,859	26,578	26,578
2	M&S	Weld Inspec Qa Time	0.50	MY	BU	97,610	48,805							48,805
3	P/F	Saddles 304l Ss W/ 8% Waste	262.00	TON	BU	4,154	1,088,243							1,088,243
4	P/F	Support Blocks 304l Ss	80.00	TONS	BU	4,154	332,288							332,288
5	P/F	Transportation	20.00	LOADS	BU	2,596	51,920							51,920
6	P/F	Plate Section Burning	120.00	SECTION	BU	623	74,765							74,765
7	P/F	Web Section Burning	8.00	WLDMNTS	BU	1,817	14,538							14,538
8	P/F	Weld Fixturing & Alignmnet	1.00	LS	BU	41,536	41,536							41,536
9	P/F	Welding	8.00	WLDMNTS	BU	10,384	83,072							83,072
10	P/F	Blasting	16.00	WLDMNTS	BU	2,596	41,536							41,536
11	P/F	Rigging	1.00	LS	BU	103,840	103,840							103,840
12	P/F	Hydraulic Jacking System	1.00	LS	BU	207,680	207,680							207,680
13	P/F	Transporter Grease Pads	24.00	EA	BU	8,650	207,597							207,597
14	I&A	On/off Site Inspections	2.00	MM	BU			INSPAD	60	147	294	8,859	17,719	17,719
SUBTOTAL -	40.03.1.2.3	VESSEL SUPPORT STRUCTURES FAB/ASSY					$2,295,819				735		$44,297	$2,340,117

PRIME CONTRACTOR MARKUP	7.71%	$180,373
		$2,520,490
CONTINGENCY	22.00%	$554,508
<u>COST PLUS CONTINGENCY</u>		$3,074,998

COST MATRIX

	ENG/DES	M&S	INSP/ADM	PROC/FAB	ASSBLY	INSTALL
LABOR	0		44,297		0	0
MATERIAL	0	48,805	0	2,247,015	0	0
TOTAL, $	0	48,805	44,297	2,247,015	0	0
MANHOURS	0		735		0	0

LABOR

TOUCH LABOR =	$0
EDIA LABOR =	$44,297

RISK

Technical Risk	6%
Cost Risk	8%
Schedule Risk	8%

ESTIMATOR: G. DEIS/J. BOWERS
DATE OF ESTIMATE: 06/15/92

Magnet
Basis of Estimate

WBS: 40.03.1.2.3 Item: Vessel Support Structures
Date: 6/15/92 Rev: 0C By: G. Deis/J. Bowers

Element Scope: This element includes all of the hardware required to physically support the coil, vessel, and muon sector assemblies in the underground hall. This will include the saddles to support the outer vessel as well as any jacking hardware provided to align the magnet, to compensate for ground motion, or to move the magnet assemblies. This does not include any concrete structures, such as piers or support beams, which are assumed to be parts of the hall facility.

Technical design description:
The saddle support structures are low carbon steel weldments consisting of large flat plate sections. Four saddle weldments are provided to support each vessel assembly, including the magnet and all internal detectors. Total weight supported by four saddle supports is conservatively 3000 tons.

It is assumed that all four saddles see equal dead loads and horizontal loads.

All saddles can be hydraulically jacked to transport the vessel system and for alignment. The jacking system is part of the transporter, and will be capable of lifting the weight of the vessel system plus the saddles, and have sufficient control to enable pitch, roll and elevation positioning.

Interface to the building foundation is through shim blocks mounted to the floor.

Total weight of four saddle support weldments is 121 tons

Two sets of four are required, one set for each vessel.

Inspection/Admin
Basis:

coordinator support during construction 3 mm
off-site/on-site inspections 2 mm

EDIA/QA Material&Services
Basis: Quality Assurance weld inspection time .5my

Procurement/Fabrication
Basis: each vessel
raw materials
saddles:
121 tons 304L stainless steel in finished structures
add 8% waste giving 131 tons of raw material
mill rate = $2.00/ lb yielding $524K

support blocks:
40 tons 304L stainless steel in finished structures
mill rate = $2.00/ lb yielding $160k

weld material cost is included in welding cost

transportation $2500/load x 10 loads = $25k

plate section burning 0.5 days/ section, $600/ section x 60 sections = $36k

machine base plate 2 days/ weldment x 4 weldments = 8 days = $7k

weld fixturing and alignment $20k

welding $10k per weldment x 4 weldments = $40k

blasting $2.5k per weldment x 8 weldments = $20k

rigging $50k

total cost per vessel= $882k

total cost for two vessels = $1764k

Cost of hydraulic jacking system $200k

Cost of 24 transporter grease pads $200k

Installation/Ass'y
Material ($k): 0
Basis:
This is covered in WBS 40.02.9.2.1, 40.04.1.1 - Magnet Installation

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Unit type: ea   Number of units: 2
Estimate Type: BU

Risk Factors:

Technical: 2 Basis: Fabrication techniques are standard. Simple shapes and interfaces. Loose tolerances. Common materials.

Cost: 4 Basis: Vendor quotes on hydraulics and bottom up construction factors for structural assemblies. Mill costs for steel will vary based on the state of the national economy at the time of construction.

Schedule: 8 Basis: If built in sections off site, will have minimal inpact on vessel installation schedule.

Misc Comments:

Current assumptions of floor movement vary up to 15 cm up and down.

Cost Estimate - Base Currency Year

- All estimates to be performed in the currency for the year in which the estimate is made, as if the work is performed or contract placed in the current year
- Define a standard table of currency inflation for all years in which the project is to be executed
- Old industrial price quotations should be corrected for inflation up to the current year if a new estimate is not obtained from industry

DATE	RATE

RATE TABLE: ADMIN [ADMINISTRATION]

01DEC91	23.0300

RATE TABLE: COST [COST (RATE OF 1, USED FOR COST CALCS)]

01JAN91	1000.0000

RATE TABLE: ENG [ENGINEERS]

01DEC91	37.7900

RATE TABLE: ESCALATION [Escalation]

01DEC91	.0000
01DEC92	.0000
01DEC93	.0000
01DEC94	.0220
01DEC95	.0450
01DEC96	.0700
01DEC97	.0965
01DEC98	.1240
01DEC99	.1900
01DEC00	.2240
01DEC01	.2600
01DEC02	.0000

RATE TABLE: FRINGE [FRINGE BENEFITS]

01DEC91	.3400

RATE TABLE: GRAD [GRAD STUDENTS]

01DEC91	9.3500

Cost Estimate - Source of Estimate

- Clearly identify the type of the source of the estimate
  - » Engineering Estimate (EE) - least reliable
  - » Vendor Quotation (VQ) - better, but likely to increase
  - » Placed Order (PO) - even better
  - » Actual Costs (AC) - best
  - » Other methods include Parametric, Trends, Specific Analogy
- For every material subsystem, work to increase the fraction of the estimate based upon industrial vendor quotations

Cost Estimate - Roll Up

- Structure estimate so that all costs for a component can be "rolled up" and costs for the subsystem including the component can be "rolled up" and costs for the entire system can be...
  - » This creates a framework for tracking actual costs during the Project execution

Cost Estimate - Labor Rates

- Define all generic labor categories for labor charged to the Project (manager, engineer, scientist, technician, secretary, construction worker,...)
  - » Use appropriate level of detail for maturity of Project
- Establish a standard labor rate for each category based upon market survey in base currency year
- Use labor "crew" mixes if appropriate for an operation
- Replace standardized rates with specific rates only when actual labor source is certain
- Consider vacation/sick time factors

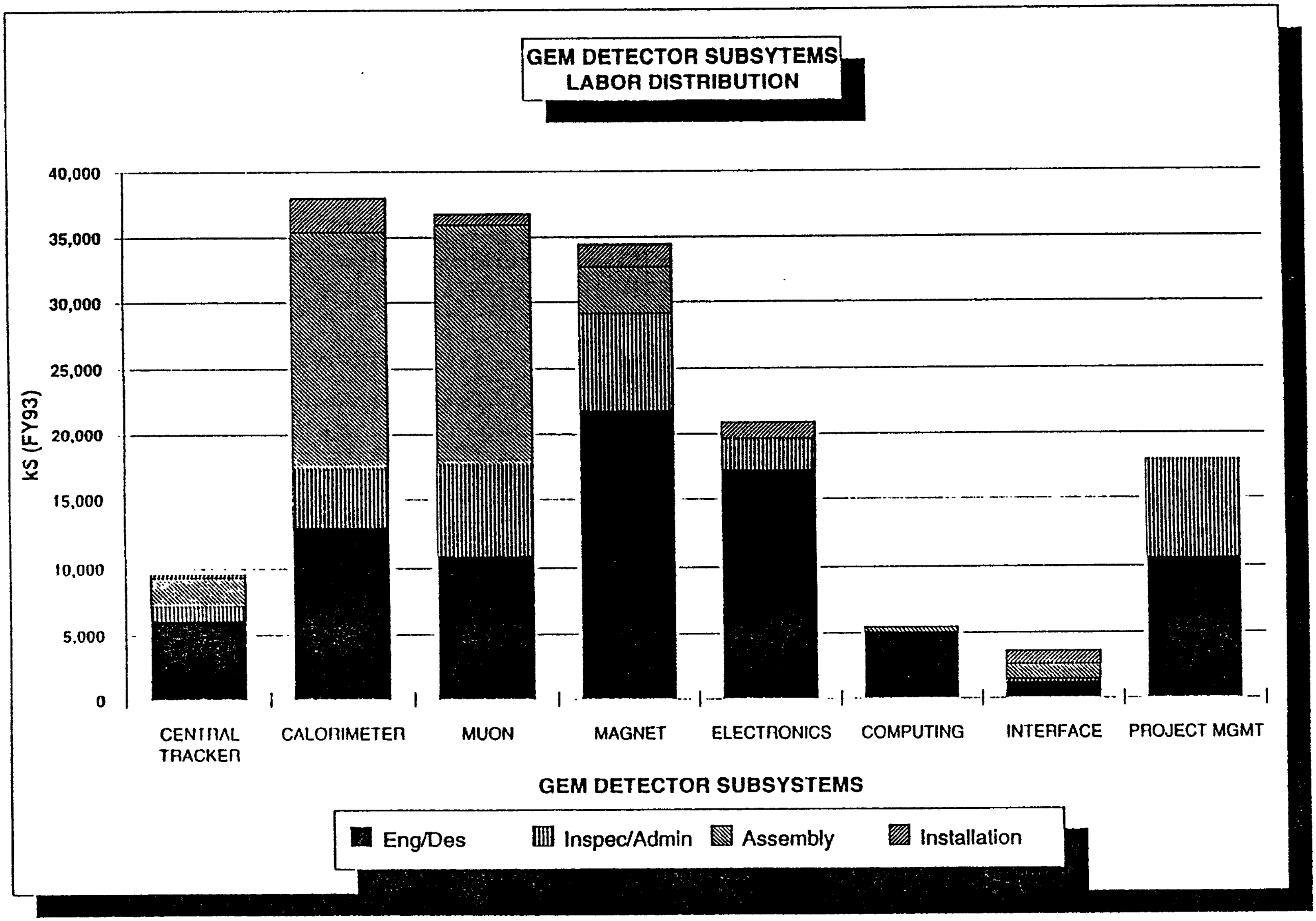
DATE	RATE
RATE TABLE: MGMT	[MANAGEMENT]
01DEC91	54.2400
RATE TABLE: MM	[Manmonths mm = HOURS / MM]
01DEC91	.0068
RATE TABLE: OVERHEAD	[OVERHEAD RATES]
01DEC91	.5800
RATE TABLE: PROF_FAC	[PROFESSIONAL FACULTY]
01DEC91	85.0000
RATE TABLE: SCI	[SCIENTISTS]
01DEC91	33.9400
RATE TABLE: TECH	[TECHNICIAN]
01DEC91	22.0000
RATE TABLE: UNDERGRAD	[UNDERGRADUATE STUDENTS]
01DEC91	9.3500

Cost Estimate - Labor Rates

- Do estimate in man-hours and apply rates later!
- In mass production operations, include the “learning curve” factor
- In mass production operations, consider “crew” quality and trade off cost for productivity

Cost Estimate - Audit

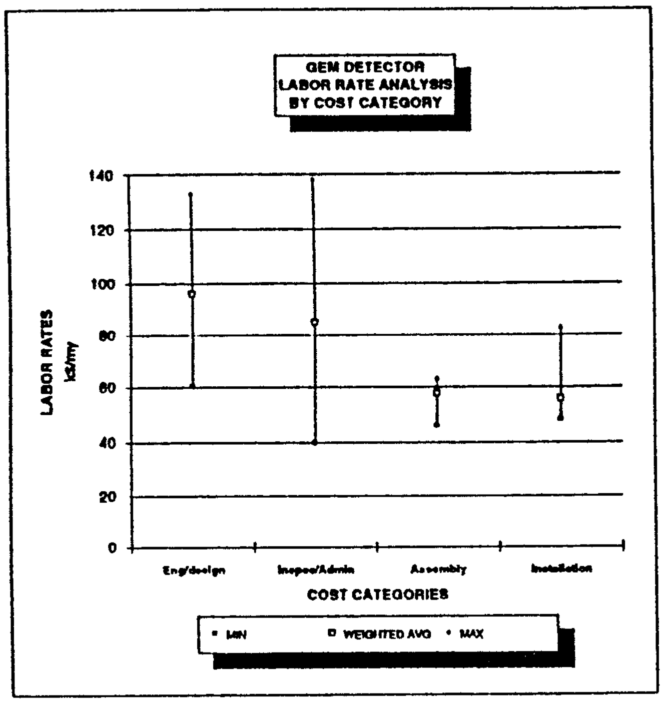
- Audit all detailed estimates for uniform application of Cost Estimating Plan
- Compare labor estimates for comparable operations
- Compare material costs
- Compare fraction of estimate based upon vendor quotes
- Compare risk analysis
- Use an outside and disinterested firm to independently develop or audit estimate

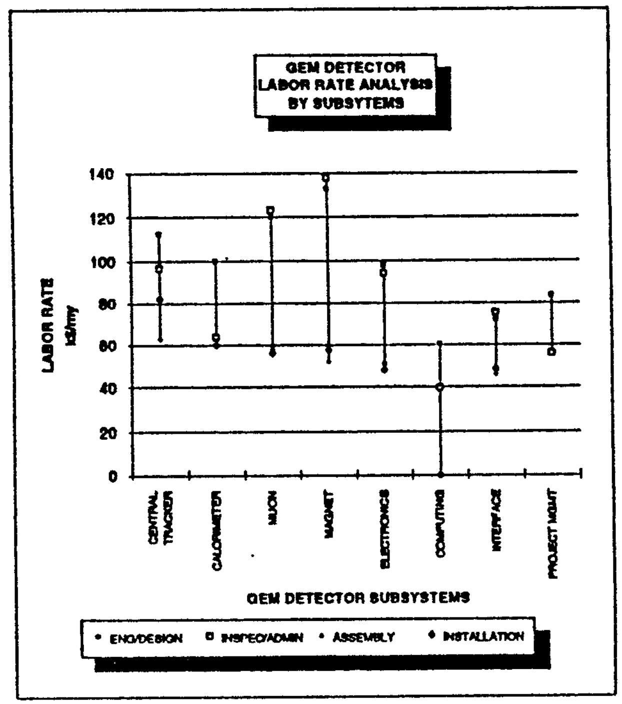


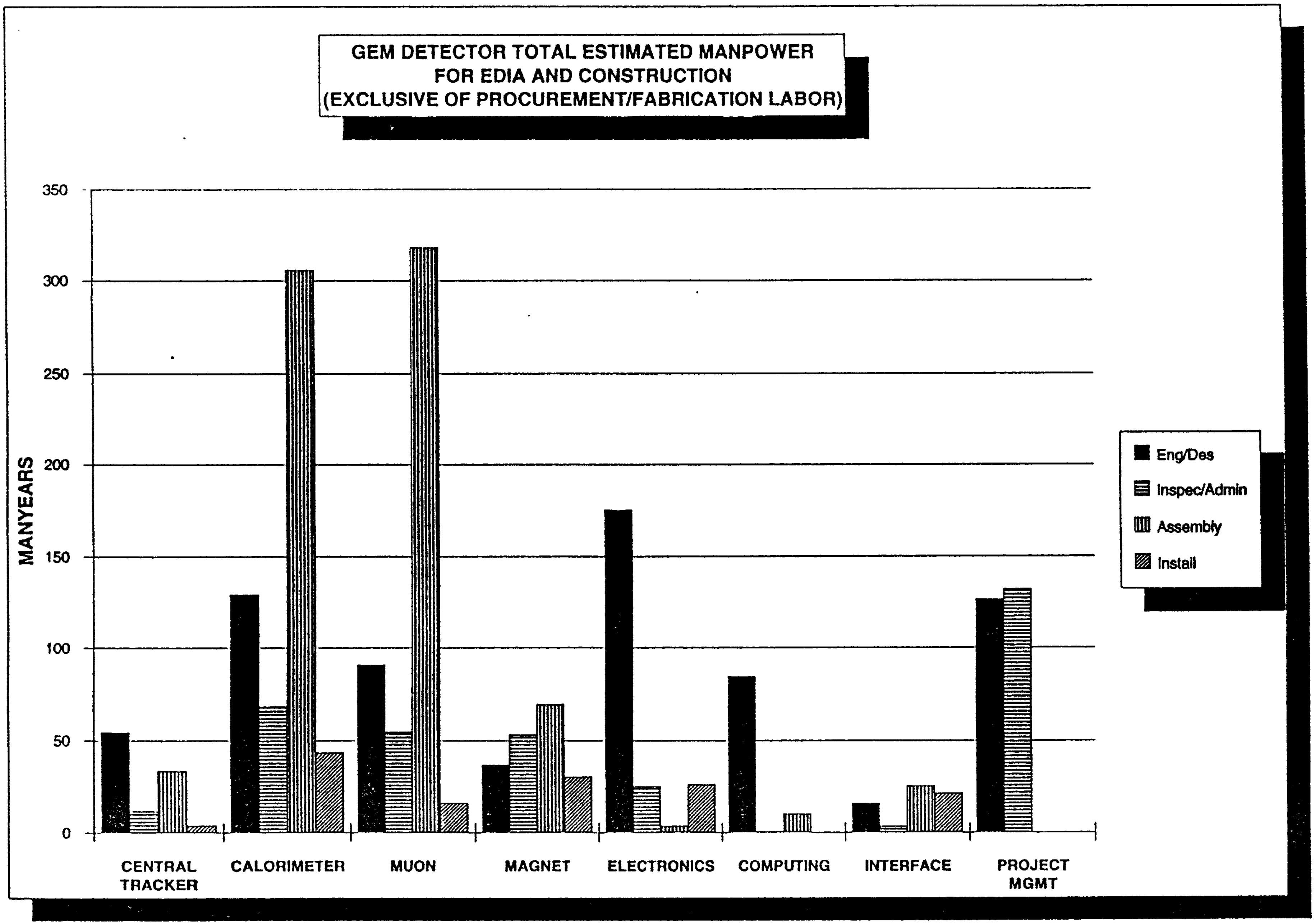
GEM DETECTOR PROJECT

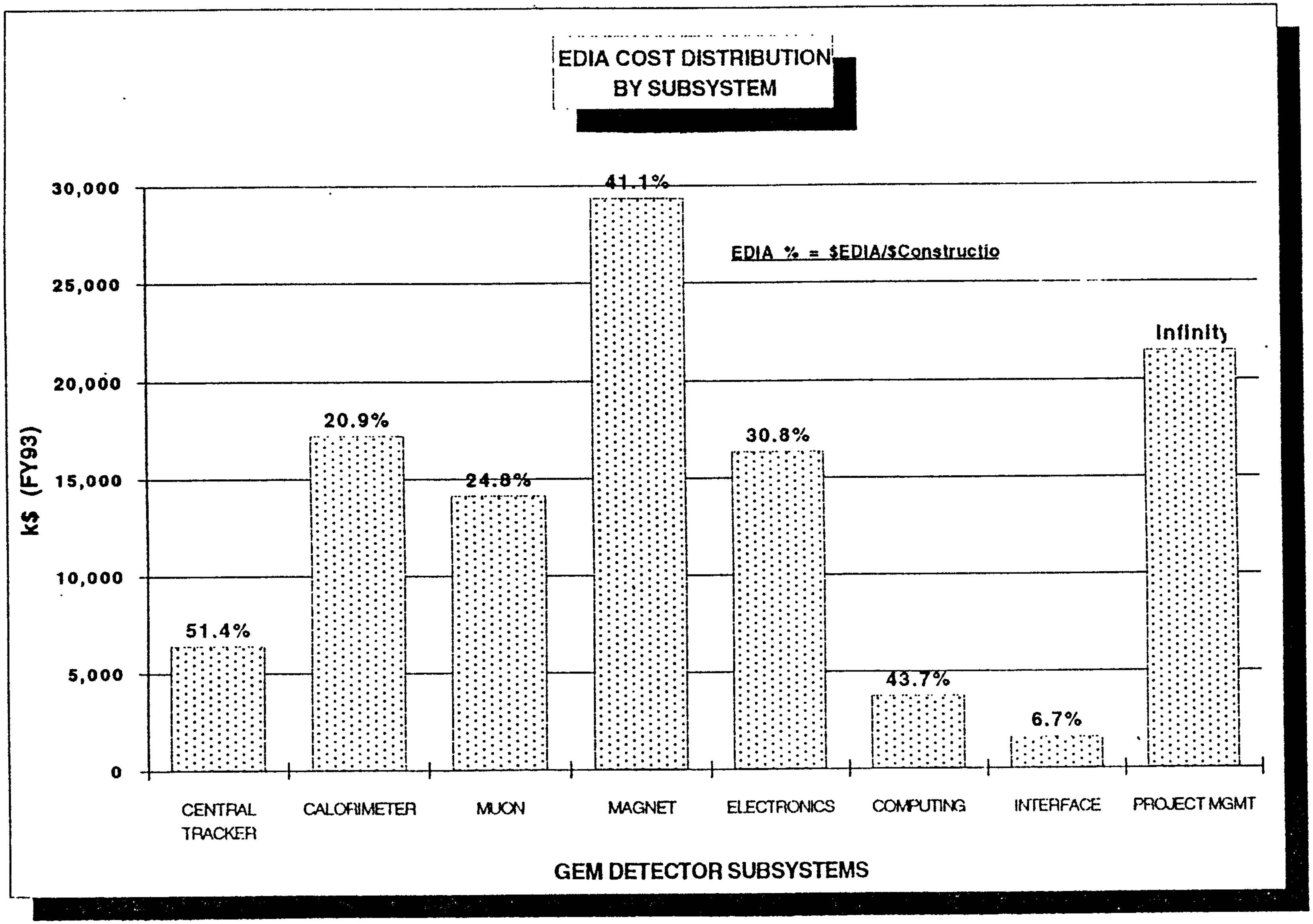
GEM DETECTOR LABOR RATE ANALYSIS

	COST CATEGORIES							
	Eng/design		Inspec/Admin		Assembly		Installation	
	Labor	Rate	Labor	Rate	Labor	Rate	Labor	Rate
SUBSYSTEMS	my	k$/my	my	k$/my	my	k$/my	my	k$/my
CENTRAL TRACKER	54	112	11	97	34	63	4	82
CALORIMETER	129	100	68	64	306	59	43	60
MUON	90	120	55	123	318	58	16	50
MAGNET	37	133	53	138	69	52	30	57
ELECTRONICS	175	98	25	94	4	51	26	48
COMPUTING	84	60	1	40	10		0	---
INTERFACE	16	72	3	75	25	46	21	48
PROJECT MGMT	127	83	132	56	0		0	
MIN		60		40		46		48
WEIGHTED AVG		96		85		57		56
MAX		133		138		63		82






GEM DETECTOR TOTAL ESTIMATED MANPOWER
FOR EDIA AND CONSTRUCTION
(EXCLUSIVE OF PROCUREMENT/FABRICATION LABOR)
MANYEARS
350
300
250
200
150
100
50
0
CENTRAL TRACKER
CALORIMETER
MUON
MAGNET
ELECTRONICS
COMPUTING
INTERFACE
PROJECT MGMT
Eng/Des
Inspec/Admin
Assembly
Install


EDIA COST DISTRIBUTION
BY SUBSYSTEM
30,000
25,000
20,000
15,000
10,000
5,000
0
k$ (FY93)
EDIA % = $EDIA/$Constructio
51.4%
20.9%
24.8%
41.1%
30.8%
43.7%
6.7%
Infinity
CENTRAL TRACKER
CALORIMETER
MUON
MAGNET
ELECTRONICS
COMPUTING
INTERFACE
PROJECT MGMT
GEM DETECTOR SUBSYSTEMS

Cost Estimate - Risk Analysis

- Estimate for each item should be the expected cost of the item excluding unusual or adverse risks
- For each item, separately estimate the technical, cost and schedule risks for that item. Use a standardized and disciplined method for all items and all estimators. Develop an estimate of an amount of money to be held in reserve to deal with the average of all risks. Not all risks will actually take place during the Project. This amount of money is "contingency".
- Primitive method - bulk percentage rule of thumb
- Better method - Standard Risk Factor/Percentage

Cost Estimate - Risk Factors

Risk factor	Technical	Cost	Schedule
1	Existing design and off-the-shelf hardware	Off the shelf or catalog item	not used
2	Minor modifications to an existing design	Vendor quote from established drawings	No schedule impact on any other item
3	Extensive modifications to an existing design	Vendor quote with some design sketches	not used
4	New design within established product line	In-house estimate for item within current product line	Delays completion of non-critical path subsystem item
6	New design different from established product line. Existing technology	In-house estimate for item with minimal company experience but related to existing capabilities	not used
8	New design. Requires some R&D development but does not advance the state-of-the-art	In-house estimate for item with minimal company experience and minimal in-house capability	Delays completion of critical path subsystem item
10	New design. Development of new technology which advances the state-of-the-art	Top down estimate from analogous programs	not used
15	New design way beyond the current state-of-the-art	Engineering judgment	not used

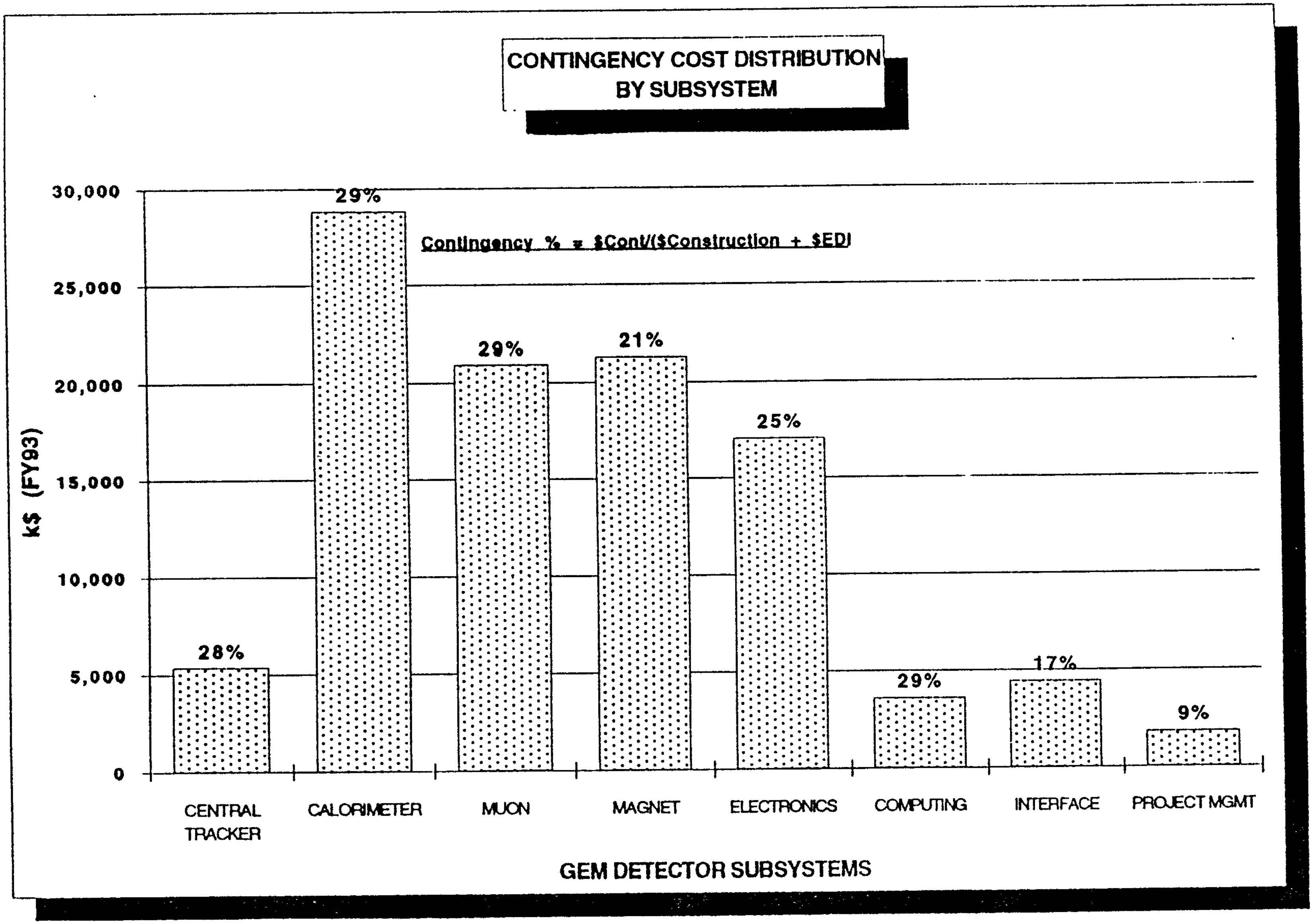
Cost Estimate - Risk Percentages

	CONDITION	RISK PERCENTAGE
TECHNICAL	Design or mfg concerns only	2%
	Design and mfg concerns	4%
COST	Material cost or labor rate concern	1%
	Material and labor rate concern	2%
SCHEDULE		1%

Cost Estimate - Contingency %

Contingency (%) = Technical risk factor x Technical risk % +
Cost risk factor x Cost risk % +
Schedule risk factor x Schedule risk %

- Risk Factors - from 1 to 15
- Risk Percentages - 1% to 4%
- Range of contingency generated falls between 5% and 98%
- Best technical judgment used to override this specific graded approach to risk analysis


CONTINGENCY COST DISTRIBUTION
BY SUBSYSTEM
Contingency % = $Cont/($Construction + $ED)
K$ (FY93)
30,000
25,000
20,000
15,000
10,000
5,000
0
28%
29%
29%
21%
25%
29%
17%
9%
CENTRAL TRACKER
CALORIMETER
MUON
MAGNET
ELECTRONICS
COMPUTING
INTERFACE
PROJECT MGMT
GEM DETECTOR SUBSYSTEMS

Cost Estimate - Contingency

- Estimate of contingency made for each item at lowest practical level
- Percentage is converted to currency
- Contingency funds are held by the Project Manager and they lose their identification with each item!
- Each Task Leader controls the budget for a subsystem without the contingency funds
- Remember that the contingency pool is not designed to cover every possible risk all occurring during the Project

Cost Estimate - Request for Contingency Funds

- As the Project progresses, contingency funds can be requested by written application to the Project Manager
- Requests are reviewed by Technical Board/Change Control Board consisting of all other system leaders
- Project Manager grants requested funds, or rejects request, or requests change in schedule, technical scope or requests other corrective action
  - » Scope contingency - require subsystem leaders to identify 10% reductions in subsystem scope
- Funds can be returned to contingency

Cost Estimate - Actual Costs and Estimate to Complete

- If Project is estimated properly, 100% completion of Project will use 100% of direct estimate + contingency
- As Project progresses, direct cost estimate is exceeded and contingency funds are used
- Periodically (annually?) cost estimate is revised to reflect all new information including actual costs and use of contingency funds. New estimate is called Estimate To Complete
- Track (%contingency used)/(% Project complete)

Cost Baseline

- Original full cost estimate including the separate pool of contingency funds is entered into a database and maintained throughout the life of the Project as the Cost Baseline
- All Project cost performance is measured monthly against the Cost Baseline in order to detect cost deviations as early as possible
- New Estimate to Complete is used after reestimate but original Cost Baseline is preserved in database
- Define time spread of costs using inflation factors in Cost Baseline for later use with schedule

Schedule - Basic

- Prepare Integrated Project Schedule consisting of all linked schedules for each subproject in total Project
- Subproject structure organized to agree with Work Breakdown Structure and integrated together following WBS
- Project Management defines a set of useful major project milestones and requests development of lower level detailed schedules to conform to top level milestones. These top level milestones define the overall project strategy and priorities and the attention of project staff.

Significant Facility Milestones

MILESTONE NAME	WASHINGTON LATE DATE	LOUISIANA LATE DATE
Initiate Site Development	03/14/94	08/07/95
Beam Tube Final Design Review	04/21/94	common
Select A/E Contractor	11/15/94	common
Complete Beam Tube Qualification Test	01/16/95	common
Select Vacuum Equipment Contractor	03/28/95	common
Complete Performance Measurement Baseline	04/28/95	common
Initiate Beam Tube Fabrication	01/22/96	common
Initiate Slab Construction	02/05/96	01/06/97
Initiate Building Construction	06/11/96	01/06/97
Joint Occupancy	09/02/97	03/30/98
Accept Tube and Cover	03/16/98	09/28/98
Beneficial Occupancy (Accept Buildings)	03/16/98	09/28/98
Accept Vacuum Equipment	03/16/98	09/28/98
Initiate Facility Shakedown	03/16/98	09/28/98

Schedule - Bottom Up

- Detailed schedules developed in same manner as cost estimate
  - » follow WBS
  - » developed by responsible task leaders
  - » basis recorded in standardized manner
  - » schedule risks considered in developing details
  - » technical estimate made of each task duration and dependence on other tasks
- Detailed schedule development is closely related to development of cost estimate detail

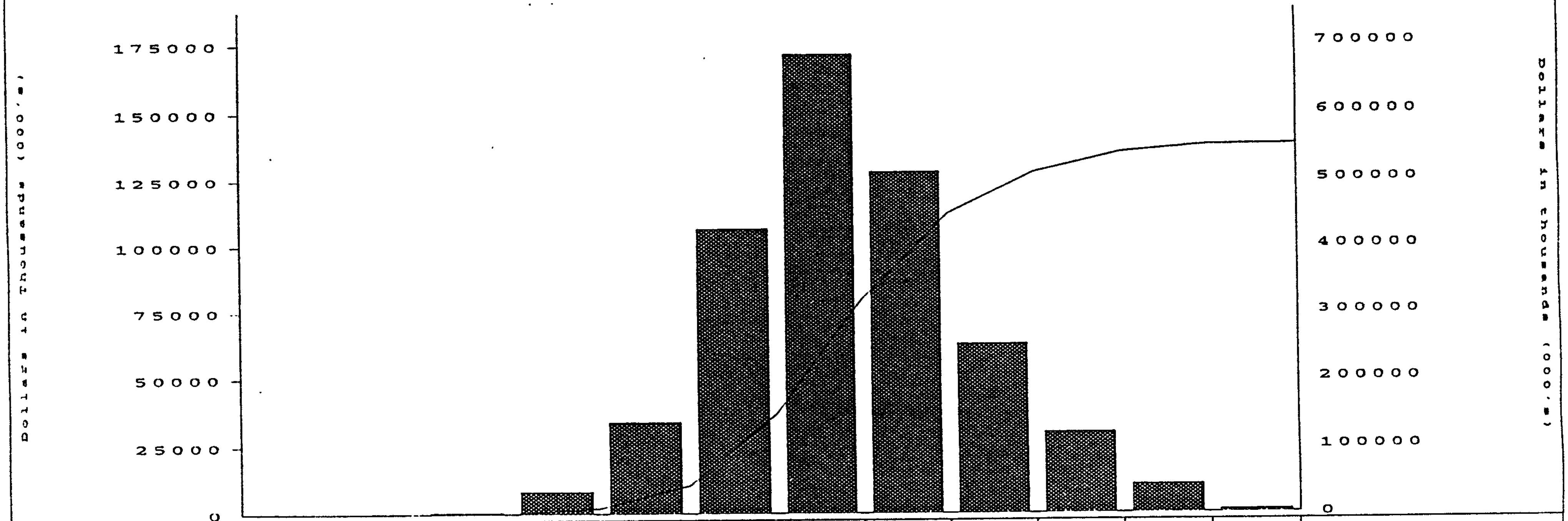
Schedule - Integration

- Project Management integrates detailed schedules and reviews all schedule ties between subprojects with those developing detailed schedules
- Identify all Critical Paths (paths through schedule with no extra time (slack))
- Test alternate approaches to Critical Path
- Test alternate project strategies
- Attempt to build schedule slack in critical operations
- Develop menu of “work arounds” for anticipated schedule risks

Performance Measurement Baseline

- Cost Baseline and Integrated Project Schedule are held by Project Management
- Create PMB by loading costs for each task into schedule task
  - » select flat, growing, falling, bell curve cost profile for each task
  - » select an appropriate level in WBS for combining costs and schedule tasks. Goal is performance measurement by Project Manager with lower level flexibility left to task leaders
  - » match to likely funding profile from funding source
- Load into database as Budgeted Cost of Work Scheduled

GEM DETECTOR
WBS 522.50 - DETECTORS & EXPERIMENTALS SYS



	FY91	FY92	FY93	FY94	FY95	FY96	FY97	FY98	FY99	FY00
Incr Bud $100K	4	83	339	1062	1708	1278	625	299	105	9
Cum Bud $100K	4	87	426	1488	3196	4474	5099	5397	5502	5512

WBS 522.5010	$27,323,488	TRACKING SYSTEMS
WBS 522.5020	$135,415,178	CALORIMETRY SYSTEMS
WBS 522.5030	$98,346,729	MUON SYSTEMS
WBS 522.5040	$125,324,910	MAGNETS
WBS 522.5050	$92,271,560	ELECTRONIC SYSTEMS
WBS 522.5060	$19,415,423	DETECTOR COMPUTIN
WBS 522.5070	$29,813,084	INTERFACE SYSTEMS
WBS 522.5090	$23,273,612	PROJECT MGT & DETECT

Tracking and Controlling Performance

- Require contractors to report costs and schedule progress monthly to Task Leaders responsible for contract
- Task Leaders report cost and schedule progress to Project Management each month
  - » Only this system used by Task Leaders for performance measurement
  - » Must be implemented so as to be truly useful
- Progress measured by standardized methods and accumulated as Earned Value

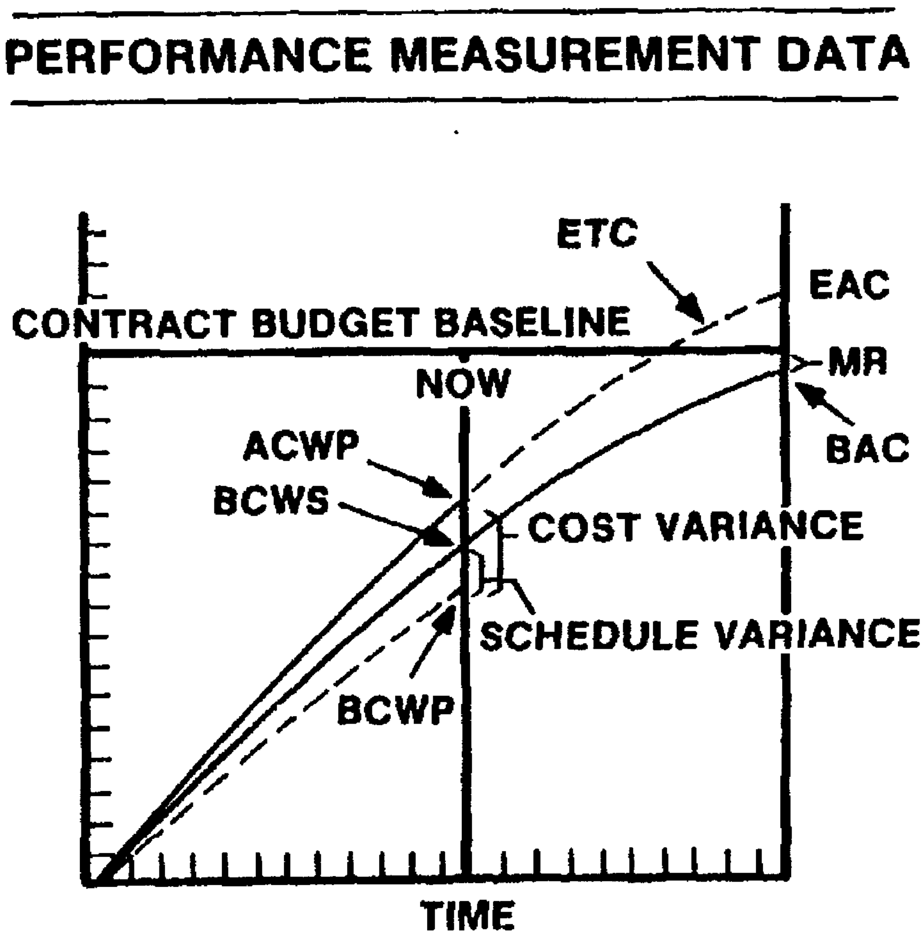
Earned Value Reporting

- Monthly measurement of progress in each task accumulated as Earned Value
  - » % Complete
  - » Milestones Completed
  - » Progress Payments Earned
  - » Level of Effort

Performance and Variances

- Budgeted Cost of Work Scheduled (BCWS)
- Budgeted Cost of Work Performed (BCWP)
  - » earned value
- Actual Cost of Work Performed (ACWP)
- Cost Performance Index (CPI) = BCWP/ACWP
- Schedule Performance Index (SPI) = BCWP/BCWS
- Cost Variance (CV) = BCWP - ACWP
- Schedule Variance (SV) = BCWP - BCWS

Performance Measurement Display

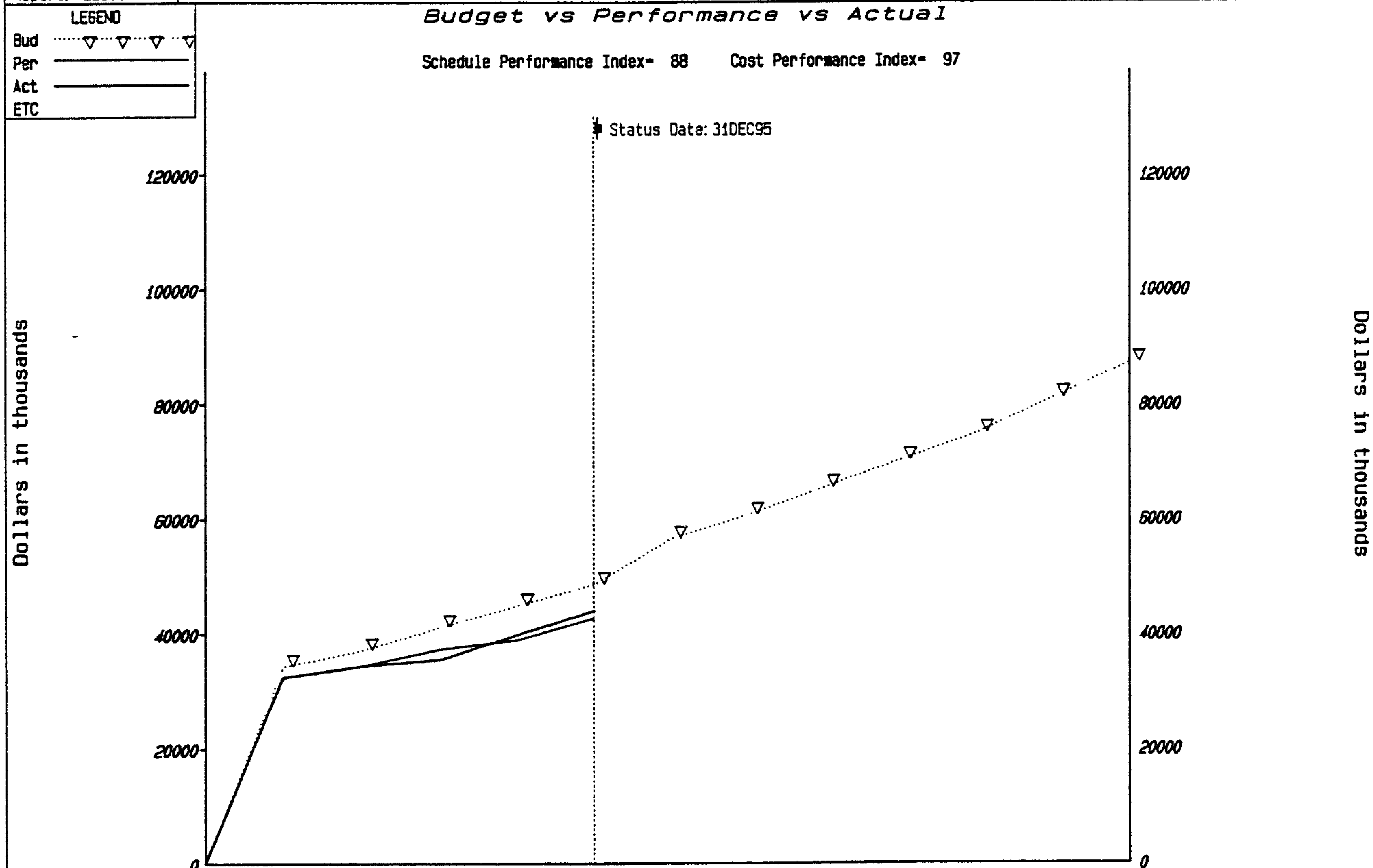


C/A - W/P	Description	PMT	BAC	EAC	% Comp	Cumulative BCWS	Cumulative BCWP	Cumulative ACWP	Current Period BCWS	Current Period BCWP	Current Period ACWP	Status	Scheduled Start	Scheduled Finish	Act/Est Start	Act/Est Finish
1.2.1: * Interferometer Design/Fab																
5E511	SEISMIC ISOLATION DESIGN															
Milestone	Description	Weight														
21111013	HAM REQUIREMENTS	8			30									01MAR96		E 01MAR96
21111015	HAM PRELIMINARY DESIGN	6			0									01AUG96		E 01AUG96
21111017	HAM FINAL DESIGN	5			0									22NOV96		E 22NOV96
21111020	HAM 1ST ART. ASSEMBLY/TEST	1			0									27JUN97		E 27JUN97
21112029	BSC/TMC REQUIREMENTS	8			30									01MAR96		E 01MAR96
21112031	BSC/TMC PRELIMINARY DESIGN	6			0									01AUG96		E 01AUG96
21112033	BSC/TMC FINAL DESIGN	5			0									22NOV96		E 22NOV96
21112036	BSC 1ST ART. ASSEMBLY/TEST	57			0									26JUN97		E 26JUN97
21112038	TMC 1ST ART. ASSEMBLY/TEST	3			0									29JUL97		E 29JUL97
		M/S	968	968	5	127	46	27	21	0	0	0	02JAN95	29JUL97	A 02JAN95	E 29JUL97
5E512	PSL DESIGN															
Milestone	Description	Weight														
21120102	PSL REQUIREMENTS SPEC	4			100									01FEB95		A 01FEB95
21120104	PSL PRELIMINARY DESIGN	6			100									02MAY95		A 01JUN95
21120105	PSL PROTOTYPE TESTS/MODS	30			100									01NOV95		A 30NOV95
21120108	PSL FINAL DESIGN	36			0									17APR96		E 10JUN96
21120111	PSL 1ST ART. ASSEMBLY/TEST	24			0									15SEP97		E 15SEP97
		M/S	220	220	39	118	87	167	17	0	8	0	08DEC94	15SEP97	A 08DEC94	E 15SEP97
5E513	I/O OPTICS DESIGN															

COBRA (R) Report: LIGOSPA	LIGO PROJECT 1 LIGO Construction	Date: 8FEB96 Program: PMB_1295

Budget vs Performance vs Actual

Schedule Performance Index= 88   Cost Performance Index= 97



	AUG95	SEP95	OCT95	NOV95	DEC95	JAN96	FEB96	MAR96	APR96	MAY96	JUN96	JUL96	SCALE
Budget	34,294	37,088	41,125	44,887	48,616	56,547	60,645	65,366	70,152	74,826	81,000	87,090	K$
Performance	32,435	34,444	37,305	38,974	42,671								K$
Actual/Forecast	32,427	34,402	35,509	39,863	44,008								K$
Schedule Variance	-1,859	-2,644	-3,820	-5,913	-5,945								K$
Cost Variance	8	42	1,796	- 889	-1,337								K$

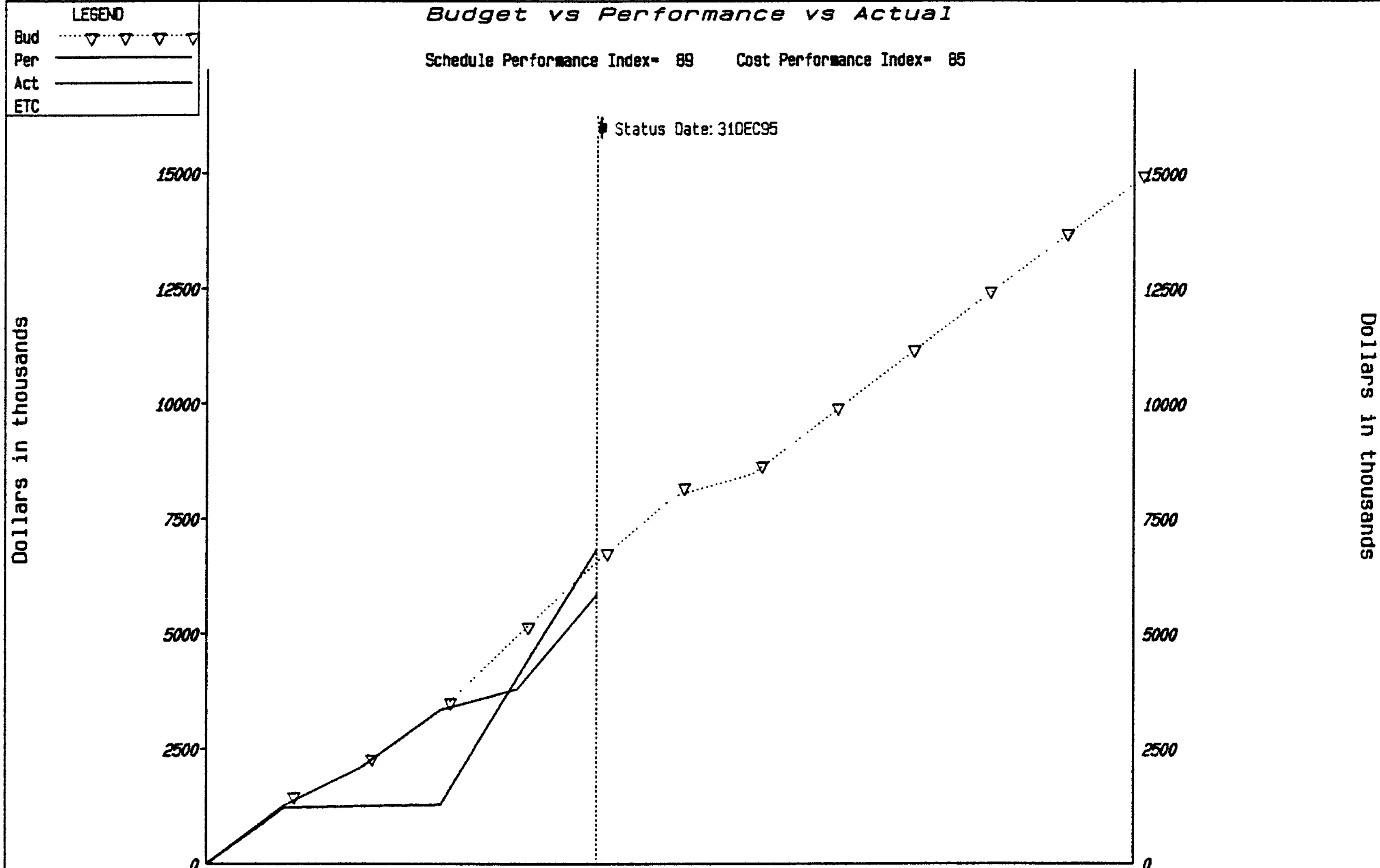
Schedule Variance = Perf-Budg Cost Variance = Perf-Actual Schedule Performance Index= Perf/Budg Cost Performance Index= Perf/Actual

*** Prepared by LIGO Project Controls Group ***

COBRA (R) Report: LIGOSPA	LIGO PROJECT 1.1.1 Vacuum Equipment	Date: 8FEB96 Program: PMB_1295

Budget vs Performance vs Actual

Schedule Performance Index= 89   Cost Performance Index= 85



	AUG95	SEP95	OCT95	NOV95	DEC95	JAN96	FEB96	MAR96	APR96	MAY96	JUN96	JUL96	SCALE
Budget	1,277	2,095	3,324	4,976	6,575	7,997	8,463	9,724	10,986	12,248	13,510	14,772	K$
Performance	1,277	2,100	3,336	3,801	5,839								K$
Actual/Forecast	1,226	1,260	1,290	4,080	6,855								K$
Schedule Variance	0	5	12	-1,175	- 736								K$
Cost Variance	51	840	2,046	- 279	-1,016								K$

Schedule Variance = Perf-Budg Cost Variance = Perf-Actual   Schedule Performance Index= Perf/Budg Cost Performance Index= Perf/Actual

*** Prepared by LIGO Project Controls Group ***

COST/SCHEDULE STATUS REPORT

CONTRACTOR: Caltech LOCATION: Pasadena, CA	CONTRACT TYPE/NO: PHY-9210038	PROJECT NAME/NO: LIGO Master Merged PMB - WBS 1.0	REPORT PERIOD: 30NOV95-31DEC95	SIGNATURE: TITLE / DATE:

CONTRACT DATA

ORIGINAL CONTRACT TARGET COST	NEGOTIATED CONTRACT CHANGES	CURRENT TARGET COST	ESTIMATED COST OF AUTHORIZED UNPRICED WORK	CONTRACT BUDGET BASELINE
	292, 100, 000	292, 100, 000		292, 100, 000

PERFORMANCE DATA

	CUMULATIVE TO DATE					AT COMPLETION		
	BUDGETED COST		(3) ACTUAL COST WORK PERFORMED	VARIANCE				
MPR Level	(1) WORK SCHEDULED	(2) WORK PERFORMED		(4) SCHEDULE (2-1)	(5) COST (2-3)	(6) BUDGETED	(7) ESTIMATE AT COMPLETE	(8) VARIANCE (6-7)
1.1.1 : Vacuum Equipment	6575	5839	6856	(736)	(1016)	41957	41957	0
1.1.2 : Beam Tubes	2963	2963	2789	0	174	43922	43922	0
1.1.3 : Beam Tube Enclosur	517	517	477	0	39	18062	18062	0
1.1.4 : Facility Design &	9943	7644	7221	(2299)	423	50405	50405	0
1.2 : Detector	3956	1872	2602	(2084)	(730)	48081	48081	0
1.3 : Research & Developme	14660	13834	13427	(826)	407	23400	23400	0
1.4 : Project Office	10002	10002	10636	0	(634)	22791	22791	0
SUBTOTAL	48616	42671	44008	(5945)	(1337)	248618	248618	0
CONTINGENCY						0	43482	(43482)
MANAGEMENT RESERVE						43482	0	43482
TOTAL	48616	42671	44008	(5945)	(1337)	292101	292101	0

Reestimate and Rebaseline

- Include revised information from actual experience and signed contractor cost/schedule commitments
- Must revise BCWS to reflect most realistic plan so that performance measurement is meaningful
  - » If not, Task Leaders will not use system
- Cost, Schedule and PMB changes made annually on average and only after careful review by Technical/Change Control Board

Contract Planning

- All contracts or purchases of $500K or more go through a formal planning process
  - » market survey
  - » careful consideration of contract type
    - – fixed price
    - – cost reimbursable + fee
    - – incentives/penalties
  - » structure of bid package or tender
    - – competition
    - – multiple awards followed by final selection
- Contract change management is a crucial element of project management

Reviewing a Procurement (Source Selection)

- RFP (Tender) includes Statement of Work, legal requirements and criteria for selection of contractor
- Proposals are reviewed by Proposal Evaluation Team which develops a rigorous selection recommendation
- Recommendation reviewed of Review Committee which comments to Project Management
- Selection is finalized by a Source Selection Board from outside LIGO representing Caltech

Managing Contractors

- Crucial to manage multiple contractors on "non-interfering" basis
- Crucial to have a rigorous system to track and control all contacts between Project and contractors
- Crucial to rigorously, but quickly, manage contractor change orders
- Managing "fixed price" contracts is very different from managing "cost reimbursable" contracts

Other Crucial Factors

- People
- Clear, shared agendas
- Communicating openly and listening
- Teambuilding
- Share project goals and subordinate individual goals
- Delegate authority to lowest appropriate level but make accountability very clear
- Draw organization around people, instead of trying to fit people into a predetermined organization
- Clear process