VII. Anticipated Progress for FY91

During FY91, the calculations to aid in the design of the scintillating plate calorimeter will be expanded and refined. Benchmark and design calculations which were started during FY90 will be completed and those which are to be compared with experimental data will be further analyzed. Differences between experimental and calculated results will be determined and the differences resolved. Additional calculations needed for the prototype will be started. Improvements in the CALOR system as it relates to scintillation calorimetry will be continued.

VIII. Budgets for FY91 (See overall budget sheet for breakdown)

University of Mississippi	$ 98.64K
University of Tennessee	$ 42.37K
ORNL	$130K*

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*Will be supplemented by Oak Ridge Detector Center funds.

FY91 SSC SUBSYSTEM R&D PROPOSAL

Development of a Compensating Scintillator Plate Calorimeter System for the SSC

Ames Laboratory/Iowa State University
Argonne National Laboratory
Bicron Corporation
Fermi National Accelerator Laboratory
Florida State University
Lawrence Berkeley Laboratory
Louisiana State University
Michigan State University
University of Michigan
University of Mississippi
Oak Ridge National Laboratory
Purdue University
University of Rochester
Rockefeller University
University of Tennessee
Virginia Polytechnic Institute and State University
Westinghouse Electric Corporation
University of Wisconsin

Co-Spokespersons:

G. W. Foster
Fermi National Accelerator Laboratory
708/840-3906

J. Proudfoot
Argonne National Laboratory
708/972-4357

COLLABORATING INSTITUTIONS AND THEIR MEMBERS

Ames Laboratory/Iowa State University

Physicists
- H. B. Crawley
- W. T. Meyer
- E. I. Rosenberg*

Electronic Engineer
- W. D. Thomas

Argonne National Laboratory

Physicists
- R. E. Blair
- R. Hagstrom
- P. Job
- T. Kirk
- L. E. Price
- J. Proudfoot* (Prin. Invest.)
- H. Spinka
- R. Talaga
- H.-J. Trost
- D. Underwood
- A. B. Wicklund

Electronic Engineer
- J. W. Dawson
- T. Ekenberg

Mechanical Engineer
- N. Hill
- J. Nasiatka
- E. Petereit

Bicron Corporation

C. Hurlbut, Manager, Organic Scintillator Group

Fermi National Accelerator Laboratory

Physicists
- A. Baumbaugh
- M. Binkley
- A. Bross
- A. Byon
- D. Finlay
- G. W. Foster* (Prin. Invest.)
- J. Freeman
- D. Green
- D. Kim
- R. Vidal

Electronic Engineers
- R. Yarema
- J. Hoff
- T. Zimmerman

Florida State University

Physicist
- V. Hagopian*
- K. Johnson
- P. Rulon
- H. Wahl
- J. Xu

Electronic Engineer
- J. Thomaston

Mechanical Engineers
- M. Bertoldi
- K. Hu

Lawrence Berkeley Laboratory

Physicist
- D. E. Groom*

Louisiana State University

Physicists
- A. Fasley
- R. Imlay
- R. McNeil*
- W. Metcalf

Michigan State University

Physicists
- C. Bromberg*
- J. Huston
- R. Miller

Engineers
- R. Richards

University of Michigan

Physicist
- R. Gustafson*

University of Mississippi

Physicists
- L. Bolen
- L. Cremaldi
- B. Moore
- J. Reidy*

Oak Ridge National Laboratory

Physicist

R. G. Alsmiller, Jr.
C. Y. Fu
T. Gabriel*

Purdue University

Physicists

V. E. Barnes*
A. F. Garfinkel
A. T. Laasanen
J. Tonnison

University of Rochester

Physicists

A. Bodek
H. Budd
P. de Barbaro
W. Sakumoto
R. Walker
H. W. Zheng
S. Ohlsen*

Engineer

T. Haelen

Rockefeller University

Physicists

T. Chapin
N. Giokaris
K. Goulianos
P. Melese
R. Rusack
S. White*

University of Tennessee

Physicist

T. Handler*

Virginia Polytechnic Institute

Physicists
- B. Lu
- L. Mo*
- L. E. Piilonen

Electronic Engineer
- T. Nunamaker

Science and Technology Center
Westinghouse Electric Corporation

- M. Burke
- C. Einolf
- D. T. Hackworth*, Manager, Electromechanics
- T. Hordubay
- D. Marshik
- D. Scherbarth
- R. Swensrud

University of Wisconsin

Physicists
- D. Carlsmith
- C. Foudas
- D. Loveless
- D. Reeder*
- W. H. Smith

Electronic Engineers
- M. Jaworski
- J. Lackey
- P. Robb

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* Institutional Contact Person

06 September 1990

Introduction

This revised collaboration has been formed to continue development of a sampling scintillator plate calorimeter for the SSC based on the use of embedded wavelength shifting (WLS) fiber to transmit scintillation light to the photon transducer. This decision is based on our consensus that this solution, if developed to its potential, yields significant advantages over alternative techniques.

The proponents of this approach arrived at the above conclusion from results reported in the subsystem FY90 R&D program in the development of compensating plate calorimetry (reported by Spinka et al.,) and the SSCINTAL collaboration (reported by Para et al.). The former group is pursuing the development of a calorimeter based on lead as the absorber and a subset of the latter group is investigating the use of iron as the principal absorber. Both groups advocate the use of scintillator tile with embedded wavelength shifting fiber and a lead/scintillator electromagnetic calorimeter. This revised collaboration reflects the fact that we have chosen to combine our efforts and thereby increase our effectiveness in addressing the common problems. The work described herein is a continuation of both these efforts.

The remaining questions still to be resolved concern the two absorber options for the hadron calorimeter: their relative mechanical and magnetic issues, cost effectiveness and performance. The first major objective of the work proposed herein is to prototype and evaluate these two options and thereby determine the appropriate choice for an SSC detector. The second major objective is to continue work on the development of radiation hard scintillator and to fabricate radiation hard optical systems which achieve the necessary uniformity for the lifetime of the experiment.

The physics performance goal for this calorimeter system is

- $e/h < 1.05$ in 16 nsec
- $\sigma E/\sqrt{E} < 18\%/\sqrt{E}$ with a $\lesssim 1\%$ constant term for electromagnetic showers
- $\sigma E/\sqrt{E} < 50\%/\sqrt{E}$ with $\lesssim 2\%$ constant term for hadronic shower
- Maximum hermeticity in $|\eta| < 3$
- < 10% degradation in performance (resolution, uniformity) from radiation damage for a life time in the barrel section of 10 years at a luminousity of 10^{34} $cm^{-2}s^{-1}$ (and a calibration scheme capable of dynamically recovering this loss).
- Endcap electromagnetic sections capable of being refurbished and having a life time at a luminosity of 10^{34} $cm^{-2}s^{-1}$ of $\gtrsim 3$ years.

Goals

The principal goal of this collaboration is to produce, by the end of FY92, a fully engineered design of a radiation hard calorimeter meeting the above performance criteria for use in an SSC detector. To demonstrate the performance of this design it is our intent is to fabricate full scale prototypes for evaluation in the FNAL 92-93 testbeam cycle which will include a calibration system and an optical system, digitisation, trigger and readout sensitive to a single RF bucket.

A second major goal is the completion of sufficient system level engineering to allow accurate cost and schedule estimates.

To meet this schedule, the following issues will be addressed in the FY91 testbeam schedule: the performance of the chosen design for the electromagnetic section must be established; the performance and in particular the level of compensation obtained by a hadron calorimeter based on iron absorber must be determined. A key element of this study is the reconfigurable-stack calorimeter as we propose to feed back the results from tests with this calorimeter into the second round iron-based hadron calorimeter. On the same timescale a viable design of a hadron calorimeter based on lead composite will be produced.

The critical R & D issues for this project are:

- Continued work on radiation hardness of plastic scintillator
- Testbeam demonstration of an EM prototype module constructed of radiation hard scintillator and waveshifter
- Optimisation of fiber placement and masking techniques to achieve uniformity of response across tile faces and tile boundaries.
- Demonstration of credible mechanical designs for the hadron calorimeter based on iron and lead absorbers
- Testbeam demonstration of a compensating iron/scintillator hadron calorimeter
- Optimisation of the photon collection and detection system
- Demonstration of a pipelined digital trigger on the calorimeter
- Demonstration of high resolution data pipelines based on both analog storage and high dynamic range digitisation techniques

The set of tasks identified by this collaboration to address these issues are given below in the proposed program of work.

PROGRAM OF WORK

Task 1 Development and Evaluation of Radhard Scintillator Plate and WLS Fiber

1.1 Continue to work with industry on modification of the polymer base, polymerisation process and fluor systems optimized for radiation hardness and suitability for the tile/fiber application.

1.2 Measure radiation-induced damage in tile/fiber components and completed assemblies. This will include irradiation in an electron beam at a variety of total doses and dose rates. The measurements will include changes in attentuation length; light loss from fluor; spectral response, recovery, and long term stability.

TASK 2 Optical System Fabrication

2.1 Improve and develop automation schemes for measurement of the light collection uniformity and formation of masking patterns.

2.2 Evaluate the effect of bending radius and annealing on optical properties of the WLS fiber & develop an automated fabrication process to perform these functions.

2.3 Optimise tile thickness, fiber placement, fiber diameter and fluor dopant level to give maximum uniformity and light yield.

2.4 Match fluor system with photon transducer to give maximum signal and system resistance to radiation damage. Optimise the UV reflective foil used for masking with respect to mask fabrication and long term stability in the expected radiation field.

2.5 Develop and automate the tile/fiber fabrication process and identify a cost effective solution capable of yielding the necessary structural strength, uniformity, and resistance to radiation damage.

2.6 Identify the most cost effective photon transducer for the tile/fiber application.

TASK 3 Mechanical Design

3.1 Perform Detailed Engineering Design and Finite Element Analyses:

3.1.1 Reinforced Lead Matrix with Tile/WLS Fiber readout for barrel and endcap hadron calorimeters.

3.1.2 Iron based hadron calorimetry for barrel and endcap

3.2 Calculate the magnetic properties of large staggered plate assemblies and evaluate their impact on the mechanical design.

3.3 Evaluate Magnetic Considerations for Calorimetry Choices

3.3.1 Shielding for designs with non-magnetic hadron absorbers

3.3.2 Evaluation of designs in which the barrel is magnetised

3.3.3 Evaluation of magnetic forces on iron endcap design

3.4 Optimise the placement and thickness of coil support structures

3.5 Optimise lead-composite materials and casting techniques appropriate for their application to the fabrication of hadron and electromagnetic calorimeters.

3.6 Perform design optimisation and mechanical analysis of barrel and endcap electromagnetic calorimeters based on cast lead technology.

3.7 Perform optimisation and mechanical design of barrel and endcap electromagnetic calorimeters based on conventional sheet lead fabrication.

Task 4 Simulation

4.1 Evaluate the staggered plate geometry for both electromagnetic and hadronic showers.

4.2 Investigate strategies using the suppression of the electromagnetic response to obtain compensation in an iron composite calorimeter.

4.3 Study effect of scintillator properties (proton number density, Birk's constant) on compensation mechanism.

4.4 Compute e/pi and resolution vs thickness of scintillator plate, thickness ratio of absorber to scintillator, integration gate and for absorber composition.

4.5 Optimise scintillator layer and sampling distribution to minimise the total number of plates for a given resolution.

4.6 Study impact of the coil and mechanical support structures on hermeticity of calorimeter.

4.7 Determine optimal location and granularity of pre-shower and/or shower maximum detector for use in electron and photon identification.

Task 5 Electronics

Trigger and digitization systems will be developed to take advantage of the unique ability of scintillation calorimetry to complete a compensating energy measurement in a 16ns crossing time, with at most a few percent crosstalk from previous beam crossings.

5.1 Build and test high resolution PMT readout using two techniques:

5.1.1 Implement analog pipeline techniques including the LBL chip designed by Kleinfelder and the radhard capacitor storage array designed by Dawson at ANL and test them against the waveform digitised at 80 MHz using a Lecroy Waveform analyser. Evaluate the performance of the candidate systems using a 16 nsec integration gate or shaping circuit with a short characteristic time constant as needed for operation at the SSC.

5.2.2 Build and test high resolution RF clocked PMT digitization and readout using Bipolar front-end ASICs and commercial FADCs. This project includes the characterization and testing of commercially available FADCs.

5.2 Measure the performance of the trigger and DAQ pipeline options with the calorimeter prototype in the testbeam.

Task 6 Construction and Evaluation of Prototype Modules*

6.1 Build and test realistic iron based hadron calorimeter prototypes (for both barrel and magnetised endcap geometries) with the goal of obtaining adequate compensation in a 16 nsec gate.

6.2 Build and test a realistic cast lead/composite based hadron calorimeter model and demonstrate fabrication and mechanical feasibility.

6.3 Build and test a realistic cast lead electromagnetic calorimeter prototype and demonstrate fabrication and mechanical feasibility.

6.4 Test an iron absorber hadron calorimeter and tune cell structure using medium energy electrons and pions to obtain e/h closest to one consistent with target resolution.

6.5 Evaluate performance of cast lead em prototype for electromagnetic calorimetry and electron identification. Tests will include: measurement of linearity; measurement of cell-to-cell, module to module and position uniformity; measurement of crack response and angular dependence; measurement of the effects of radiation damage and recovery.

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* Further details of the testbeam program associated with prototype evaluation are given in Appendix I.

6.6 Exploration of e/π separation using the correlation between calorimeter data and those from the preshower/shower-maximum detector prototype being prepared for the '91 test beam run under a separate subsystem.*

Task 7 <u>Calibration System</u>

7.1 Design and integrate radioactive source calibration systems into hadronic and electromagnetic calorimeter designs.

7.2 Evaluate use of low energy neutron calibration via DT tube.

7.3 Evaluate use of pulsed UV laser for in situ calibration.

Task 8 <u>Reconfigurable-Stack Scintillating Tile Testbeam Calorimeter</u>

A number of important issues for the lead vs. iron choice for scintillating tile calorimetry could be addressed by a large ($1m^3$) test beam calorimeter which contained a Pb/Fe/scintillating-tile stack which could be reconfigured to vary sampling fractions, material ratios, etc.

Among these are:

- Which combinations of Pb, Fe, and scintillator are actually compensating?
- What is the effect of a non-compensating EM front end on the hadron resolution?
- In a 3-component laminate, does the compensation depend on the sequence of materials: i.e. is Pb/Fe/scintillator equivalent to scintillator/Fe/Pb?
- How is compensation affected by "dead" plastic cladding?

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* "Subsystem Proposal for Preshower and Shower-Maximum Detectors", P. Cushman and R. Rusack, co-spokespersons.

- How is compensation affected by "dead" low-Z non-hydrogeneous cladding?
- How does calorimeter depth, and depth segmentation affect resolution?
- How equal is the energy leakage from Pb and Fe calorimeters which are an equal number of interaction lengths deep?
- Can we save money by altering the density of samples (while preserving sampling fraction) at the rear of the hadron calorimeter?

We propose to address these issues by constructing a rectangular stack formed by a series $1m^2$ plates which can be any combination of scintillator tile, Pb, Fe, Al, or G10. The readout plates would be 2.5mm thick $1m^2$ tile/fiber assemblies. Each plate is read out by about 20 1mm fibers each, running the full length of the piece to ensure uniformity. Somewhere between 1 and 10 tiles (depth segments) would be ganged to a single phototube. It probably makes sense to individually light-tight each tile assembly, so that the tile response and uniformity can be checked with a source at any point. This is a big consideration if you want to measure e/π accurately, since the e and π will be sampling different sets of tiles in depth, and so the relative calibration of the depths has to be controlled.

The mechanics of the stack must allow easy replacement or reshuffling of individual layers, with minimal possibilities of damaging the scintillators. One possibility is to have a structure similar to a "hanging folder" file, with I-beam side rails. Supporting the lead sheets is apt to be a problem in any scheme.

The basic tasks comprise:

8.1 Fabricate a simple hanging file folder to accept varying thicknesses and compositions of absorber and scintillator.

8.2 Perform beam measurements of varying unit cell structures to measure e/h as a function of absorber composition and thickness of absorber and scintillator.

Distribution of Labor

The tasks to be performed by individual collaborating institutions are given below. All institutions will provide testbeam support. More detailed statements of work for ANL, FNAL, and Westinghouse are given in the Appendices.

University Tasks

- Florida State University will provide:
  - radiation hardness testing of plastics and dyes for scintillator and wavelength shifter plates and fibers at their electron accelerator facility
- Louisiana State University will perform:
  - simulation studies of the calorimeter design
  - optimization of the optical design of the calorimeter
- The University of Michigan will provide:
  - optical uniformity measurements using cosmic rays and radioactive sources
  - radiation damage studies
- Michigan State University will provide:
  - development of a prototype fiber/splicing machine for large scale production
- The University of Mississippi will perform:
  - simulation studies of the calorimeter design
- Purdue University will provide:
  - module calibration systems for moving radioactive sources
  - simulation programs for tile and fiber optics and source response

- The University of Rochester will provide:
  - development of a prototype tile/fiber fabrication machine for large scale production
  - testbeam support
- Rockefeller University will provide:
  - support of interface issues with regard to the pre-radiator subsystem
  - tests on fiber splicing
  - radiation damage tests
- The University of Tennessee will perform:
  - simulation studies of the calorimeter design*
- Virginia Polytechnic Institute and State University will perform:
  - simulation studies of the calorimeter design
  - optimization of the optical components and photon transducer for the calorimeter
- The University of Wisconsin will provide:
  - mechanical design analysis and fabrication
  - materials evaluation in consort with industry
  - trigger electronics design and realisation for analog data acquisition approach

Laboratory Tasks

- Lawrence Berkeley Laboratory will provide:
  - Contribution to beam test of the reconfigurable-stack calorimeter for compensation studies

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* Justification for a workstation in support of this task is given in Appendix II.

- Argonne National Laboratory§ will provide:
  - simulation studies of the calorimeter design
  - assembly of an EM calorimeter test section for testbeam studies
  - mechanical design studies for the electromagnetic calorimeter based on the cast lead-composite fabrication technique
  - mechanical design studies of an endcap hadron calorimeter based on cast lead composite fabrication
  - radiation hardness studies of optical materials
  - optical system design studies
  - testing of electronic components
  - radhard electronics design and realisation for analog data readout acquisition approach
  - testbeam DAQ system and support
- Fermi National Accelerator Laboratory* will provide:
  - mechanical design studies and prototype fabrication of iron based hadron calorimeters (barrel and endcap)
  - mechanical design magnetic studies
  - mechanical design studies for the electromagnetic calorimeter based on conventional lead sheet fabrication methods
  - prototype fabrication for hadron and electromagnetic calorimeters
  - optical system design studies
  - optical system fabrication studies
  - electronics design and realisation for digital trigger and data acquisition approach
  - testbeam support

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§ Further details in Appendix III.
* Further details in Appendix IV, V, and VI.

- support and materials for test calorimeter used in compensation studies
- radiation damage studies of scintillator dyes and of polystyrene scintillator

• The Ames Laboratory will provide:
  - evaluation of front-end electronics devices and studies of data compaction schemes

• Oak Ridge National Laboratory will provide:
  - simulation studies of the calorimeter design

Industry Tasks

• BICRON Corporation will provide:
  - development of radiation-hard scintillators and wavelength shifters with appropriate mechanical and optical properties for use in this calorimeter design

• Westinghouse Electric Corporation Science and Technology Center* will provide:
  - design and analysis of the mechanical systems for a Pb based hadron calorimeter
  - design and analysis of casting techniques of a Pb based electromagnetic calorimeter
  - electronics fabrication support
  - lead assembly for EM calorimeter test section
  - fiber optic link design and prototype
  - instrumentation for em test modules

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* Further details in Appendices VII, VIII, and IX.

- tile fiber manufacturing studies

Test Beam Requirements*

Two test beam periods are projected in the scope of this project. As determined by the development schedule, these are anticipated to take place:

- 12/1/90 - 5/1/90, during which models of the iron based unit cell and an em cast lead prototype will be tested (Task 6.4, 6.5)
- 6/4/92 - 12/31/92, during which a fully equipped prototype will be evaluated

At present, beamlines for these studies have not been identified. However two Fermilab testbeam lines are being considered for the tests to be carried out in FY91. A separate proposal with regard to this work will be submitted to Fermilab in the near future.

Many of the measurements of radiation damage to plastic scintillator will be performed with the 3-MeV electron accelerator at Florida State University. It is also anticipated that the Intense Pulsed Neutron Source, a 20 MeV electron accelerator, and another Co^{60} source at Argonne in addition to a Co^{60} source at the University of Michigan will also be used for these radiation damage studies.

Milestones

($T\phi$ = date of receipt of funding at the collaboration institutions)

• Identification of optimal unit cell(s) size(s), absorber composition(s) for prototype	$T\phi$ + 6 mo.
• Test beam studies to evaluate unit cell(s)	Dec. 1990- Apr. 1991

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* Further details of the testbeam program are given in Appendix I.

• Identification of radiation resistant polymers and fluors	Tϕ + 9 mo.
• Final decision on mechanical configuration (hadron absorber composition and em fabrication technology)	Tϕ + 9 mo.
• Decision on photon transducer and associated electronics complete	Tϕ + 12 mo
• Evaluation of front-end electronics schemes complete	Tϕ + 12 mo
• Full mechanical design	Tϕ + 12 mo
• Final decision for prototype front-end electronics to be used in EM test section readout	Tϕ + 3 mo
• Commencement of full scale prototype fabrication for testing in FY92/93 test em cycle	Tϕ + 12 mo

APPENDIX I

Testbeam Program

Several aspects of system performance require early verification in a test beam. During FY 1991, we will make the highest priority tests of both electromagnetic and hadronic calorimeters, using one or more test beams at FNAL. Final verification of system performance will come from tests of full scale prototypes of calorimeters designed for use in a specific detector during the 1993 fixed target run at FNAL.

For FY 1991, the major goals of test beam measurements are the following:

1) Verify the general performance of the hadron and em test calorimeters.
2) Verification of radiation hardness of a Pb-scintillator EM calorimeter;
3) Measurement of e/h vs energy for hadronic calorimeters using scintillator with Fe or a mixture of Fe and Pb as absorber;
4) Tests of front end electronics and low-level trigger processing designed for scintillator calorimetry.
5) Exploration, via simulation and testbeam studies, of compensation with absorber configurations other than simple iron and lead unit cells.

The electromagnetic calorimeter to be tested will be constructed by the cast Pb technique identified during FY 1990 by this subsystem collaboration and by sheet Pb fabrication. We will use the best available radiation hard scintillator for the test device. We plan a device that will have the geometry and materials of a piece of the final calorimeter as presently designed. Since measurement of radiation hardness is the major goal of testing the EM calorimeter, we will verify that the planned suite of materials is collectively radiation hard in addition to their individual properties. The test device will be an array of four towers in the azimuthal direction by 5 towers in the beam direction. The section along the beam direction will start with the first whole tower nearest to 90 degrees and contain five towers of the correct geometry to be successive towers on the same side of 90 degrees. Thus the transitional response between towers can be explored for tower boundaries at different angles.

The electromagnetic calorimeter will be tested with electrons at a minimum of 5 energies from 10 to 150 GeV. At each energy, we will need an exposure of 1000 to 10000 electrons, with higher energies requiring a bigger sample to match the better resolution. At one energy, a series of tests will be made scanning the location and angle of the calorimeter relative to the beam. From 20 to 100 points using roughly 5000 electrons of energy 30 GeV will be used, depending partly on the availability and intensity of the electron beam. This whole set of measurements will have to be repeated several times, since with a test device it can be anticipated that interaction will be needed as experience is gained. Cosmic ray and source testing will be done before use of the accelerator beam, but additional time will be required for calibration of the 15-20 towers in the calorimeter (some towers may not be instrumented). Calibration will require 10000 electrons per tower, and will probably also need to be repeated for satisfactory results.

Following this intial measurement of the performance of the EM calorimeter, we will irradiate the calorimeter with the equivalent of 10 years of operation at a luminosity of 10^{33} cm-2 sec-1 at $\eta = 1.5$. This irradiation would ideally be done with an intense electron beam that could provide the radiation pattern resulting from operation of the calorimeter at the SSC, but may have to make use of gamma sources or lower energy electrons. Following the irradiation, the light output and resolution of the calorimeter will be remeasured as soon as possible to assess the immediate radiation damage. The calorimeter will then be allowed to recover for 2-4 weeks and remeasured to determine the extent of recovery. Both of these measurements following irradiation will require measurements at 5 energies as described above, preceded by recalibration.

Because iron may be desirable as a component of the hadronic calorimeter absorber for magnetic or structural reasons, but previous iron calorimeters have not explored the possibility of improving the resolution by providing at least partial compensation, we will test an iron/scintillator hadronic calorimeter along with the electromagnetic test device described above. This program will also be a test of the construction technique described elsewhere in this report using punched laminations to construct the absorber assembly with slots for inserting scintillator plates. The slots will be large enough to allow varying the thickness of scintillator used in the calorimeter as well as adding layers of lead to improve the e/h ratio.

In order to explore thoroughly the response of the calorimeter at tower boundaries, the hadronic test calorimeter will be four towers wide in both azimuthal and beam directions. Radiation hard scintillator may not be employed for the hadronic test calorimeter because radiation doses are much lower than at shower maximum in the EM calorimeter and radiation tests will be confined to the EM device.

The basic test of the hadronic calorimeter will measure energy resolution and uniformity with position and angle, as for the electromagnetic calorimeter. Both electrons and pions will be needed to measure e/h. The resolution measurements will be made at five or more energies from 10 to 150 GeV and will require 100 to 1000 each of electrons and pions per point. 20 to

100 position and angle points will be used, requiring about 300 each of electrons and pions at 30 GeV. Calibration of each of the 16 towers will require 1000 each electrons and pions. As before, it can be anticipated that several iterations of these measurements will be needed.

The hadronic calorimeter will not require irradiation and remeasurement. However, several additional configurations of scintillator thickness and added lead sheets will be tested. There may be 10 additional configurations, each requiring the basic set of 5 energies with 100 to 1000 of each particle type.

Major milestones for the testbeam program are shown below. If the FNAL fixed target run schedule changes, the dates for our work may have to change to match.

Complete design of test calorimeters	10/31/90
Mechanical	
Optical system	
Readout	
Support system	
Complete Construction	1/1/91
Mechanical	
Optical system	
Readout	
Complete Installation	1/31/91
Take Data	2/1/91-4/30/91
Complete Analysis	5/31/91

APPENDIX II

Justification for Request for High End Work Station To be Placed at the University of Tennessee

To properly design and implement a calorimeter for the Superconducting Super Collider and then to fully understand its operation will require Monte Carlo simulation. Programs that fully simulate all the processs that occur as a particle traverses a calorimeter are both large in size and complexity. These programs aLso take time to run and then understand their results.

Currently the CALOR89 code system is running at the University of Tennessee on an IBM 3090/200 system. This system is used by students, administrators, and other researchers on campus. The CALOR89 code therefore has to compete for resources on the computer with all of these other users. Turnaround for one simple slab calorimeter simulation through the CALOR89 code can be and has been up to five days. This makes it difficult to fully explore the properties of a design as a function of the various possible absorbers and active materials that might be used.

An estimate for a simple exploration of the phase space for a simple slab calorimeter of one type of absorber of four thicknesses and one type of active medium also of four thicknesses is 60 hours of CPU time. When you fold in turnaround time into this, the total elapsed time can easily become several weeks.

A high end workstation would have several advantages. These being:

1) Turnaround time would be greatly shortened, so that the total time to explore a given combination of materials approaches the CPU time.

2) With an Ethernet and/or Telenet connection(s), other institutions involved in the collaboration would be able to access the work station and run their respective materials through the SAME code. This would then take out the uncertainties that develop when running codes at different locations.

APPENDIX III

ANL STATEMENT OF WORK

Mechanical Engineering Tasks for Lead-Based Calorimeter

Much of the mechanical design and engineering tasks being carried out at ANL will be done so in direct collaboration with engineers at Westinghouse STC. Principal tasks are:

- Design and engineering analysis of EM calorimeter test sections using reinforced cast lead technology

- Design and engineering analysis of barrel and endcap electromagnetic calorimeters using reinforced cast lead technology (also in collaboration with FNAL)

- Design and engineering analysis of endcap hadronic calorimeter using reinforced cast lead technology

- Engineering and design of interface between electromagnetic and hadronic calorimeters (also in collaboration with FNAL)

	Cost ($K)
Technician (0.5 FTE)	27.89
Eng. Designer (1 FTE)	91.45
Mech. Engineer (0.75 FTE)	68.59
Tech. Support	15.0
Mech. Models	75.0
SUBTOTAL	277.93

Simulation

- Perform GEANT (ANLSIM), EGS and CALOR simulation studies in support of the mechanical design
- Perform CALOR simulation studies to determine optimal absorber/scintillator unit cell
- Perform simulation studies in support of calorimeter-detector integration (coil, calorimeter support structure etc.)
- Perform physics simulation studies to determine detector performance requirements

Simulation

	Cost ($K)
Tech. Specialist (1FTE)	91.45
Computing	50.0
Supplies	6.0
Tech. Support	15.0
SUBTOTAL	162.45

Optical System Development

- Setup tile uniformity measurement teststand for use in 20 MeV linac
- Design and fabricate a collimated Ruthirium source for use in response uniformity measurements
- Evaluate optical uniformity of tile/fiber system in above test station as a function of fiber joint, placement, size geometry and reflective mask. Optimise these parts of the optical system.

- Irradiate tile/fiber samples using Co60 source and neutron source and measure the properties of the scintillator after damage. Remeasure their optical uniformity in above test station after damage and re-evaluate optimisation of the optical design with respect to it.
- Implement candidate optical designs in a small lead-scintillator stack (< 6 layers) and irradiate in a beam dump. Measure the effect on layer and system performance.

	Cost ($K)
Technician (0.75 FTE)	41.83
Parts & Supplies	30.0
Tech. Support	15.0
Use of local irrad. facilities	15.0
Linac operating time for tests (50 hours @ $200/hour)	10.0
SUBTOTAL	111.83

Electronics Development

- Produce an integrated radhard and deadtimeless memory chip design and fabricate in non-radhard technology (continuation of electronics generic program directed by J. Dawson).
- Provide digital readout based on the existing ZEUS prototype a/d cards in VME for use in electronics tests
- Provide the DAQ system for electronics bench tests with a VME link to a workstation via a DR11W VME/CAMAC interface (CBD 8201)
- Setup electronics teststand using a UV pulsed laser. U.V. laser with pulsing capability. Fiber optics connected to scintillator to excite primary fluor.

	Cost ($K)
Elec. Engineer (2 FTE)	182.9
Test Setup & Parts (Inc. Waveform Analyser, laser)	30.0
Materials	50.0
Tech. Support	15.0
SUBTOTAL	277.9

EM Beamtest Model Fabrication and Testing

- Design and fabricate EM test sections
- Support testbeam effort

	Cost ($K)
Technician (1.0 FTE)	55.78
DAQ System	35.0
Tech. Support	15.0
Materials for calorimeter assembly	20.0
SUBTOTAL	125.78

APPENDIX IV

FNAL Statement of Work

The engineering and technical support requested in this proposal - consisting of engineers, designers, and technicians already experienced in the design and support of High-Energy Physics experiments -- is consistent with what the FNAL management indicates can be made available to the project. This work is a continuation of the program initiated in FY90 and includes further analysis of testbeam and fabrication data obtained in this period.

I. MECHANICAL DESIGN AND TEST BEAM PROTOTYPES

Barrel Hadron Calorimeter Second-round Prototypes:

- Engineering design and analysis of laminated iron barrel hadron calorimeter
- Perform testbeam optimization of Pb/G10 inserts for tuning compensation in Fe prototypes
- Perform testbeam optimization of compensation in combined (Pb EM + Fe Hadron) calor.
- Test of trimming fiber lengths to correct for hadronic shower propagation velocity, to minimize calorimeter output pulse width
- Fabricate second-round laminated iron hadron prototype (if needed for compensation)

	Cost ($K)
Technician (1 FTE)	40.4
Mechanical Engineer (1 FTE)	94.0
Designer (1 FTE)	57.4

Materials for Prototype

	Cost ($K)
Scintillator (100 m^2)	40.0
Fiber (20 km)	25.0
Absorber Materials	40.0
Readout (32 channels)	32.0
Technical support	35.0
Rigging	5.0
Stacking fixture	15.0
Subtotal: - Prototype	232.34
Subtotal: - Engineering Design	151.39

Barrel EM Lead-Plate Calorimeter Design & Prototype

(in collaboration with ANL)

- Engineering design and analysis of EM calorimeter based on sheet lead fabrication
- optimise structures for suspension of EM calorimeter from hadron
- determine strategy to protect readout fibers in "plate" design
- Prototype fabrication

	Cost ($K)
Mechanical Engineer (0.5 FTE)	46.9
Designer (0.5 FTE)	28.7
Technician (1.0 FTE)	40.4

Materials for Prototype

	Cost ($K)
Radhard Scintillator	17.0
Fiber	6.0
Readout (32 channels)	32.0
Technical Support	15.0
Absorber Materials	10.0

Subtotal: - Prototype	120.4
Subtotal: - Engineering Design	75.7

Iron End-Cap Hadron Calorimeter Design and Prototypes

- Evaluate mechanical performance of laminated iron and staggered-disk structures
- Perform magnetic & structural modeling
- prototype fabrication to be proposed at a later date

	Cost ($K)
Mechanical Engineer (0.5 FTE)	46.9
Designer (0.5 FTE)	28.7

Subtotal: - Engineering Design	75.6

End-Cap EM Lead-Plate Calorimeter Design and Prototype

(in collaboration with ANL)

- Engineering design and analysis of EM calorimeter based on sheet lead fabrication

- Structural suspension of EM calorimeter from hadron endplug
- Determine optimal fiber routing scheme for replaceable EM insert at high Eta.
- Prototype fabrication to be proposed at a later date.

	Cost ($K)
Mechanical Engineer (0.5 FTE)	46.9
Designer (0.5 FTE)	28.7
Subtotal: - Engineering Design	75.62

Mechanical Strength Testing of Laminated Iron Prototypes

- Calculate and measure lamination strength under compression, shear, etc. for completed full scale hadron prototype and test samples
- Comparison with mechanical modeling simulations

	Cost ($K)
Work performed at Pittsburgh Testing Laboratory, Elgin, IL (including transportation)	40.0
Technician (0.1 FTE)	4.1
Engineer (0.25 FTE)	23.5
Subtotal	67.6

Magnetic Testing of Staggered-Palte Assembly

- Perform tests on barrel and endcap samples (5 samples x 3 orientations)
- Compare result with magnetic modeling simulations

	Costs ($K)
Sample Tests	10.0
Technician (0.1 FTE)	4.1
Engineer (0.25 FTE)	23.5
Subtotal	37.6

Perform Radiation Testing of Iron/B-Stage Epoxy Laminations

- Measure mechanical stability & damage to scintillators from outgassing under radiation. This work includes the preparation of samples.

	Cost ($K)
Technician (0.1 FTE)	4.1
Materials & Shipping	10.0
Subtotal	14.1

Compute Field Maps for Magnetized-Barrel Options

- Type "I" with flux return through barrel
- Type "W" with barrel magnetized in same direction as solenoid
- External coil design and cost for type "W"

  (No separate request; work to be done in conjunction with Solenoidal Magnet Subsystem work at FNAL)

Perform Magnet Integration Design for Iron Calorimeter

- Develop workable solenoid support structures for type I magnet
- Optimization of "chimney" design for minimal impact on physics.
- Determine most cost-effective field strength for type-I coil
- Control of magnetic forces in endcap & barrel during quench.

	Cost ($K)
Engineer (0.25 FTE)	23.5
Subtotal	23.5

Fabrication of Coil End Mockup for Calorimeter and Preradiator Beam Tests

	Cost ($K)
Materials	5.0
Designer (0.1 FTE)	5.8
Technician (0.2 FTE)	8.1
Subtotal	18.9

Thermal Analysis

- Complete a thermal evaluation of the calorimeter electronics heat load. Document analysis and provide requirements and constraints (e.g. size, weight, power, cooling, shielding, cabling, etc.). Determine optimum location of electronics based on requirements for reliability, availability, and maintainability and perform conceptual layout for cables and cooling times.

	Cost ($K)
Designer (0.5 FTE)	28.7
Subtotal	28.7

Mechanical Design Engineering Support Totals

Mechanical Engineer	3.25 FTE
Designer	3.1 FTE
Technicians	2.0 FTE

Cost Summary

	Cost ($K)
Barrel HAC Engineering Design	151.4
Barrel HAC2 Prototype	232.3
Barrel EM Engineering Design	75.5
Barrel EM Prototype	120.4
Endcap HAC Engineering Design	75.6
Endcap HAC Prototype	To be proposed later
Endcap EM Engineering Design	75.6
Endcap EM Prototype	To be proposed later
Mechanical Strength Testing	67.6
Magnetic Testing	37.6
Radiation Testing	14.1
Field Map Computations	At No Cost
Magnet Integration Design	23.5
Coil Mockup	18.9
Thermal Analysis	28.7
TOTAL COST	921.2

II. OPTICAL CONSTRUCTION TECHNIQUES

Assembly, Fabrication, and Routing Design Development

- Develop construction and quality control techniques for large volume tile manufacturing (UV lamp and source movers for completed tower assemblies).

- Identification of radiation-hard masking materials
- Develop and implement automated trimming techniques to adjust the light yield of completed tile assemblies after manufacture.
- Develop assembly fixturing for insertion of pre-assembled and pre-tested towers of tiles into absorber block.
- Fabricate mechanical prototype for use in determining optimal designs for optical fiber routing, moveable source routing and assembly schemes
- Study long term stability

	Cost ($K)
Designer (0.5 FTE)	28.7
Engineer (0.25 FTE)	23.5
Technician (0.5 FTE)	20.3
Materials	50.0
Subtotal	122.5

Study Tile Fiber Uniformity

- Fabricate several tile sets and measure uniformity and reproducibility.
- Evaluate completed tile sets in prototype calorimeters

	Cost ($K)
Machinist (1 FTE)	57.4
Technician (1 FTE)	40.4
Materials	60.0
Subtotal	157.8

Develop Production Injection-Molding of Scintillator Tiles

(To be proposed at a later date.)

Explore Alternative Scintillator Technologies

- Contract to be negotiated with the University of Florida as proposed in Appendix V.

	Cost ($K)
	80.0

Procure High Rate, High Quality, Collimated Source for Use in Uniformity Measurement

- Requirements 20% energy spread

  Energy $\gtrsim$ 2.5 MeV

  Rate > 10^5 Hz

  Spot size < 2 mm

	Cost ($K)
High Rate Collimated Source	30.0

Optical Design Technical Support Summary

Mechanical Engineer (or Equivalent)	1.25 FTE
Designer	0.5 FTE
Technician	1.5 FTE

Optical Design Cost Summary

	Cost ($K)
Assembly and Fabrication Tests	122.5
Tile/Fiber Manufacturing Tests	157.8
Scintillator Injecting Molding Production System	To be proposed later
Exploration of Alternative Scintillator	80.0
High Rate Collimated Source	30.0
Total	390.3

III. PIPELINED CALORIMETER ELECTRONICS

The overall project described in detail in attached document, "Pipelined Electronics Development at FNAL".*

Principal Tasks and Components are:

* Test and characterization of ICs already fabricated:
  - RF-clocked photomultiplier digitization circuit
  - binary storage with delayed CPU readout
  - ultra-low-power digital trigger line driver/receiver
  - floating-point pipelined adder tree
  - programmable clock phase vernier/ gate position vernier
  - identify flash ADC suitable for PM digisation (in collaboration with Ames/Iowa, State)
* Fabricate prototype integrated trigger/DAQ digital IC (the one which occurs on each tower of calorimetry).

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* Appendix VI.

* Prototype multi PMT card with integral digitization, trigger, & DAQ, and HV distribution.
* Formulate trigger logic conceptual design (in collaboration with University of Wisconsin and others in subsystem)
* CAMAC interface for pipelined electronics in test beam.
* Use of Tektronix laser-trim of PMT digitization circuits to avoid individual calibration constants.

	Cost ($K)
Electronic Engineer (3 FTE)	282.0
Tektronix laser trim costs	75.0
Continued pipelined IC fabrication (MOSIS)	30.0
Materials	50.0
Subtotal	437.0

The FNAL EE department has agreed to provide access to probe stations, clean rooms, bonding equipment, CAD plotting equipment, seats for ASIC design, etc.

IV. RADIATION DAMAGE STUDIES AT FNAL (A. Bross et. al.)

We plan to continue R&D on radiation-resistant scintillator and scintillating fiber. Polystyrene scintillator systems will be extensively studied. In addition, we will continue work on damage to undoped polystrene and study changes in optical and chemical properties. Scintillator studies will include work on both single step (proton transfer dopants) systems and conventional multiple step scintillator systems. Fiber studies will focus on improving the optical waveguide properties of scintillating fiber. New cladding materials compatible with polystyrene will be identified and studied. In collaboration with industry, we wish to optimize fiber drawing techniques. This will involve using fiber preforms produced at Fermilab.

The facilities to do this work at Fermilab include: A wet chemistry lab for organic synthesis and scintillator fabrication, analytical intruments including UV-visible spectrophotometers, GC-Mass Spec. analysis of compounds, and HPLC analysis of polymers. These facilities will also be made available to all members of this subsystem collaboration. In addition, the Scintillator Fabrication Facility is capable of producing clad fiber preforms out of numerous test scintillators.

This facility has already produced more than 1 million meters of fiber and two detectors built from fiber from this facility are currently in operation at Fermilab. One of these detectors, a small electron-dump calorimeter has operated successfully at an integrated dose of approximately 20-25 Mrad. Detailed studies of this detector's performance as a function of dose are beginning.

	Cost($K)
Scintillator Development	
Chemicals	15
Fluorescence spectrometer	12
Fiber R&D	
Fiber Optimization studies	25
Fixturing (optical)	10
New cladding studies	25
Scintillator Fab. Facility upgrades	20
Radiation damage studies	
Fiber and bulk scintillator prep.	20
Neutron exposures	ANL at no cost
Subtotal	127

IV. Test Beam and Related Costs

This section assumes that sufficient beam time will be made available, and the collaboration will not be charged for, the use of a momentum analysed, computer equipped FNAL test beam such as CDF or Zeus. More funds may be requested if negotiations between SSCL and FNAL are unable to bring this about. The level of support requested assumes the use of the CDF testbeam.

	Cost ($K)
Infrastructure for safe operation of deuteruim-tritium neutron flast tube for calibration (collaboration with Purdue)	30
Stand motion control system	30
Technical Support	20
Subtotal	80

V. Reconfigurable-Stack Calorimeter: in Collaboration with LBL

- Fabricate a reconfigurable stack calorimeter comprising

Transverse size	100 x 100 cm
Depth	2.2m
Transverse segmentation	none
Maximum number of samples (tiles)	100
Scintillator thickness	2.5mm
Total weight	~ 20 tonnes
Depth segmentation	20 PMT's

- Measure e/h as a function of absorber and scintillator composition and geometry

	Cost ($K)
Scintillator plate ($200/m^2)	20
Readout fibers	5
Pb Plate (20 tons @ $1/50/lb?)	60
Fe Plate (10 tons @ $0.50/lb?)	10
Al Plate (1 ton @ $2.50/lb?)	5
G10	5
Tile routing and assembly	20
Mechanical support	30
PM tubes, etc.	At no cost
High quality PMT ADC's	10
Test beam sundries	20
Subtotal	185

Subtotal - FNAL: Materials and technical support $135K

Subtotal - LBL: Materials and technical support $ 50K

APPENDIX V

Submission to Tile/Fiber Scintillator Sub-System

Proposal to the Superconducting Super Collider

University of Florida

Gainesville, Florida

Submission to Tile/Fiber-Scintillator Sub-System

Proposal to the Superconducting Super Collider

September 1, 1990

J. K. Walker
University of Florida

J. P. Harmon
University of Florida

TABLE OF CONTENTS

1. INTRODUCTION

Great progress has been made towards defining an attractive geometry of scintillator and read out system for the calorimeter in the solenoid detector.[1] Scintillator plates of 2.5 mm thickness will be read out with 0.7 mm wavelength shifting fibers and clear fibers as described in detail elsewhere in this subsystem proposal. It is now important to explore the optimum materials for use in the geometry. This is the object of this proposal.

Our group at the University of Florida has been funded by DOE/SSC for the last three years to explore the potential of polysiloxane as a scintillating/wave length shifting medium, for the development of suitable dyes, and for the development of the co-extrusion technology for fiber production. We are now proposing to apply what we have learned in the last three years to produce prototypes of the specific geometry suitable for calorimetry in the solenoid detector (tasks A and B). We believe that our material and fabrication technology will result in

a) the most long term radiation stable scintillator optical systems, and
b) the most cost effective solution. These prototypes will be available for evaluation by other members of the collaboration and will be evaluated in a variety of ways internally.

Efficient and reliable evaluation of the long term radiation stability of these systems is of critical importance for the calorimeter. One of us, Dr. Julie Harmon, has made recent major progress in the basic understanding of the time dependence of radiation induced damage (annealing) to optical polymers in general, and scintillator systems in particular. It is appropriate here to describe in some detail this new understanding. This is important since it determines the optimum approach to conducting reliable measurements of the long term radiation effects of the optical systems. Specifically, we believe this will provide a reliable methodology for exploring in the shortest possible time the damage induced by the ten year period of low irradiation rates which will be experienced at the SSC. We call this facility a Time Optimized Radiation Facility (TORF). This will be discussed under Task C. Of course, as a facility, TORF will be available for use by other experimenters at the SSC.

Finally, in collaboration with other members of this sub-system proposal we propose using TORF to evaluation various plate/WLS/read out fiber systems. These will include systems from a variety of manufacturers both in the USA, Japan, Europe and the prototypes developed under Tasks A and B.

2. <u>TASKS TO BE PERFORMED AT U. of F.</u>

A) <u>Develop Casting Technique of Electromagnetic Calorimeter Siloxane Scintillator Plates with Embedded Wavelength Shifting Fiber.</u>

We will not review our data on the radiation resistance of siloxane scintillator which was presented at the March 1990 Tallahassee Conference on Scintillating Techniques and has now been submitted in three papers to N.I.M. It suffices to say the light output is comparable to polystyrene scintillator and shows no observable (< 10%) loss of light for > 10 Mrads of irradiation. The scintillator is stable during the irradiation, immediately after the irradiation, and remains stable thereafter.

The wavelength shifting fiber which we have developed uses highly flexible material. It can actually be bent with the required 1 cm radius of curvature without heat treatment and without undue stress being developed. However, we will use heat to release the small amount of induced stress. We believe that the inherent flexibility of our fiber will help ensure the long term stability of the system.

The method adopted at Fermilab for making conventional polystyrene based plate/WLS systems has been:

1. Start with a large plate of 2.5 mm thick scintillator.
2. Cut to desired plate dimensions.
3. Mill/laser cut a grove to accommodate a WLS fiber.
4. Pre-form a WLS fiber using a thermal process.
5. Insert the fiber into the grove.
6. Cover the fiber and plate with a glued sheet of kapton.
7. Manually inject low viscosity glue into a hole which permits the glue to uniformly fill the void in the grove between the fiber and the scintillator plate along the entire length (> 20 cm) of the grove.

This series of steps is straightforward and highly successful, however, it may be expensive in manpower costs when it is remembered that one million plates are required.

Proposed Technique

We propose developing the following technique characterized by these steps:

1. Start with a mold formed with two sheets of glass and a rubber gasket. Before adding the top glass plate, a pre-formed WLS fiber will be placed in the mold. The tails of the fiber will be threaded through holes in the gasket.
2. Inject liquid pre-polymer siloxane scintillator into the mold through a separate hole in the gasket.

3. Place the filled mold in an oven and polymerize. This can be made to occur in less than ·inutes.

4. ʀemove the plate/WLS system from the mold.

This technique was suggested by Dr. W. Foster who indicated that it had been tried using styrene monomer as the base. However, the styrene had degraded the WLS fiber before polymerization. We have verified that no such degradation occurs with the use of siloxane pre-polymer.

If this technique is successful it should minimize handling time and utilize only low skilled labor.

A sufficient number of systems will be fabricated to permit extensive testing by other members of the sub-system proposal. Specifically, enough systems will be made to perform as an E.M. calorimeter at Fermilab and, secondly, enough for radiation tests at F.S.U. If other group members wish to do further tests, additional systems will be provided.

B) Develop Transparent Optical Fiber for Read-Out of Electromagnetic Calorimeter

Two 2 m long clear read-out fibers are required for each plate. These fibers must be spliced to the WLS fibers which emerge from the plate. The actual position of the fiber to fiber splice will occur a few mm inside the plate and be made prior to placing the WLS into the mold. This location of the splice confers excellent mechanical integrity to the splice. Techniques for performing the splice will be developed.

We have synthesized a ne· ' copolymer for fiber cladding which has both low refractive index (< 1.38) and high adhe: ι to a core polymer. The polymer is transparent, unlike the semicrystalline Teflon type polymers that have a low refractive index, but scatter light. It also has much higher adhesion than other fluorinated polymers which have been used in the past for this purpose. The transmission spectra of a 0.5 cm sample of this novel copolymer is shown in figure 1.

The processing properties of this new copolymer are entirely suited to this application. Both siloxane and other polymers will be studied in the production of clear fibers.

C) Construct a Time Optimized Radiation Facility (TORF)

Many optical polymers discolor when subjected to high doses of ionizing radiation. It has been known for many years that the discoloration reduces with time (the so called annealing effect). In fact, the region of discoloration shrinks with time. Specifically, the boundary of the discolored region withdraws from each of the outer surfaces of the polymer until the entire volume of marked discoloration has been eliminated. This phenomenon has been generally interpreted as related to the diffusion of the gas environment into the polymer and some chemical reaction(s) occurring at the discolored/clear boundary.

Dr. Harmon suggested and directed experimental studies on several optical polymers which strongly indicate that the above interpretation is incorrect. A consistent quantitative theoretical model of the phenomenon has been constructed by assigning primarily a physical plus chemical rather than chemical origin to the discolored region and to obtain a description of the velocity of this boundary. We let υ_b (cms/second) be the boundary velocity. Two important qualitative features of the model that apply to all optical polymers are:

1. The more brittle the polymer, the higher the velocity of the boundary region, υ_b. In figure 2 the boundary movement in PS is compared to that of the more flexible PMMA. Both polymers were given doses of 10 Mrad i[illegible] both polymers have a glass

transition ≈ 100°C. υ_B is 14 times faster in PS than PMMA.

2. As the temperature is raised above the glass transition, recovery is almost instantaneous. Note: Part of the radiation induced damage is recoverable. The bathochromic shift at lower wavelengths induced by radiation damage is irreversible.

This is illustrated in figure 3. Here, PS was irradiated in air to 10 Mrad with ^{60}Co. The 1 inch disk was placed in a glass lined piston mold and heated to 110°C for 2 minutes. Recovery at wavelength > 410 nm is essentially complete. Of course, it is the small residual loss of transmission after a low level and long duration irradiation which is important for SSC operation. The magnitude of this residual loss of transmission can be affected by the creation of a high density of annealable color centers from short term intense irradiation. Thus it is important to perform a test irradiation over a time long compared to the time for boundary movement through the optical polymer.

The important implication of this work is that at $T > T_g$ discoloration due to this type of annealable color centers cannot exist at all. Therefore, it is advantageous to use polymers where T_g < room temperature. This theory is verified by irradiation of PMMA and n-hexyl PMMA. PMMA has a glass transition of 100°C. N-hexyl PMMA has a glass transition of -5°C. PMMA was irradiated in a 1 cm thick sheet. N-hexyl PMMA was irradiated in a 1 cm path length quartz cuvette. Both samples were given 10 Mrad in air. The results are shown in figure 4. PMMA shows severe radiation damage whereas n-hexyl PMMA shows no damage at wavelength > 450 nm immediately after irradiation.

The University of Florida is in the process of filing for a patent on the subject of depressing glass transition temperature to suppress radiation damage of optical properties in polymers.

The nature of the gas environment and its diffusion into the polymer with subsequent chemical reactions initially plays a secondary role. During a short intense irradiation of a polymer, chemical reactions occur rapidly within the polymer and can use up all the available dissolved gas. In this way, misleading results on the stability of a scintillating system can occur when extrapolating to the slow exposure rate characteristic of conditions at the SSC. Thus it is essential to perform irradiations over a time which is long compared to the time constant for oxygen diffusion into the polymer.

In summary, both the boundary velocity and the gas diffusion flux, which are unique to a given polymer must give rise to time constants which are small (say by a factor of five) compared to test irradiation time. Specifically, if T_r is the test irradiation time, then to ensure reliable predictions for SSC operation we insist that:

a) $T_r \geq 5\ T_B$

where T_B is the time required for the recovery boundary to sweep to the mid plane of the sample. T_B was measured in PMMA and PS using a magnifying reticle.

b) $T_r \geq 5\ T_{D0.5}$

where $T_{D0.5}$ is the time to replenish 50% of the solubility limit of O_2 by diffusion

The solution of the diffusion equation for non-steady state conditions in one dimension can be written in terms of the dimensionless parameter A[2]:

$$A = \frac{Dt}{l^2}$$

where D is the diffusion coefficient of O_2 in a particular polymer, 2l is the sample thickness and t is time. Reference 2 shows that when A = 0.4, 50% of the solubility limit of gas will be reached in the central plane of a sample ie. A = 0.4 for $t = T_{D0.5}$. $T_{D0.5}$ values were then calculated using the above equation to construct table 1 based on a plate of 0.25 cm thick.

In the table, we take the recommended irradiation time T_R = 5x (largest value of $T_{D0.5}$ or T_B). Some experimentation can determine whether the factor of five is adequate.

Table 1

Polymer	$D(\times 10^{6} cm^2/sec)$	$T_{D0.5}$	Boundary Velocity† υ_B (cm/sec)	T_R	Recommended Irradiation Time
Siloxane Elastomer*	25	0.07 hours	(-)	(-)	≥ 0.35 hours
PMMA**	0.67	2.5 hours	1.9×10^{8}	75 days	≥ 375 days
PS*	0.11	17 hours	28×10^{-8}	5 days	≥ 25 days

*Taken from table 18.2 in ref. 3
**Calculated from equation (18.15) in ref. 3
†Measured by the U. of F. Detector Group

The irradiation exposures will be conducted at several elevated temperatures and at room temperature in the conventional method[4] to then extrapolate to the very low irradiation rates typical of the SSC. The great importance of the present approach is to perform the irradiation at a low enough rate to ensure that no discontinuity exists between the conditions of measurement and those of the SSC. At the same time the period of test irradiation is as short as possible consistent with obtaining reliable predictive data. For this reason we refer to this approach as a Time Optimized Radiation Facility.

It is important to note that all existing radiation data on glassy polymer scintillator systems have not satisfied the above criteria and hence are unreliable in their predictive power.

The criteria for a TORF are the following:

1. Total integrated irradiation level - 10 Mrad.
2. Irradiation Time - depends on the polymer, but is typically at least several weeks for glassy polymers in the size of interest. Although it is much less for an elastomer, we will use similar irradiation times for elastomers.
3. Volume of cell should be large enough to accept four complete calorimeter scintillator plate/WLS fiber and readout fiber systems. The radiation level should be uniform throughout the volume.
4. Temperature control of the scintillator system during irradiation should be available.

At the University of Florida, we have a cobalt x-ray irradiation facility which can be easily modified to meet the TORF criteria.

D) Perform Irradiation Tests in the TORF

Other groups in this subsystem proposal will prepare prototype scintillator systems made of a variety of polymers, dyes, glues, etc. It is proposed to conduct tests in two phases.

Phase I

In this phase, four identically shaped scintillator systems made of different materials will be irradiated simultaneously. The irradiation will be conducted at room temperature in air. If there are additional candidate material systems, then they will be irradiated subsequently in an identical fashion. Measurements of light output, optical transmission, etc., will be performed to evaluate the radiation resistance of the systems.

Phase II

The systems which perform best in Phase I will be subjected to additional irradiation tests. For a given type of material system, irradiations will be made on four identical systems with each one at a different temperature. The conventional activation energy analysis will be performed on the optical results to predict the response of the system to actual SSC conditions. Similar analyses will be performed on each type of system which performed well in Phase I.

The result of this effort will be the most reliable data on the long term radiation resistance of the optical components of the solenoid detector calorimeter. Since it is anticipated that this calorimeter will cost about $160 Million, it is appropriate and indeed essential to perform this detailed examination of the long term radiation stability of its operation.

3. SCHEDULE

1. Approval to proceed	T_0
2. Modification of existing radiator to make TORF	T_0 + 1 month
3. Start Phase I exposures	T_0 + 1 month
4. Fabrication of siloxane systems complete	T_0 + 3 months
5. Start second round of Phase I exposures	T_0 + 3 months
6. Completion of Phase I irradiations and Initiation of Phase II irradiation	T_0 + 6 months
7. Completion of Phase II irradiation for one type of scintillator system	T_0 + 9 months
8. Completion of Phase II irradiation for second type of scintillator system	T_0 + 12 months

4. BUDGET

A) Salaries

Dr. J. P. Harmon @ 50%	24,000
Dr. Z. Chen @ 30%	9,000
Graduate Student @ 100%	11,000
Benefits (24% of Harmon plus insurance and 2.1% of Chen)	6,870
Total Salaries	50,870
B) Materials (molds, polymers, dyes, etc.)	5,000
C) Conversion of Radiator to TORF	5,000
D) Travel to Collaboration Meetings	4,000
E) Miscellaneous	3,000
Total Direct Costs	67,870
Indirect Costs @ 45%	30,542
TOTAL COST	98,412

5. PARTICIPATION IN THIS PROPOSED RESEARCH

This research will be conducted by the High Energy Physics Group at the University of Florida in collaboration with other interested members of the group. A patent on Dr. Harmon's mechanism of radiation damage suppression is being filed by the University of Florida. The proposed work is separate from work conducted by Nanoptics, Inc.

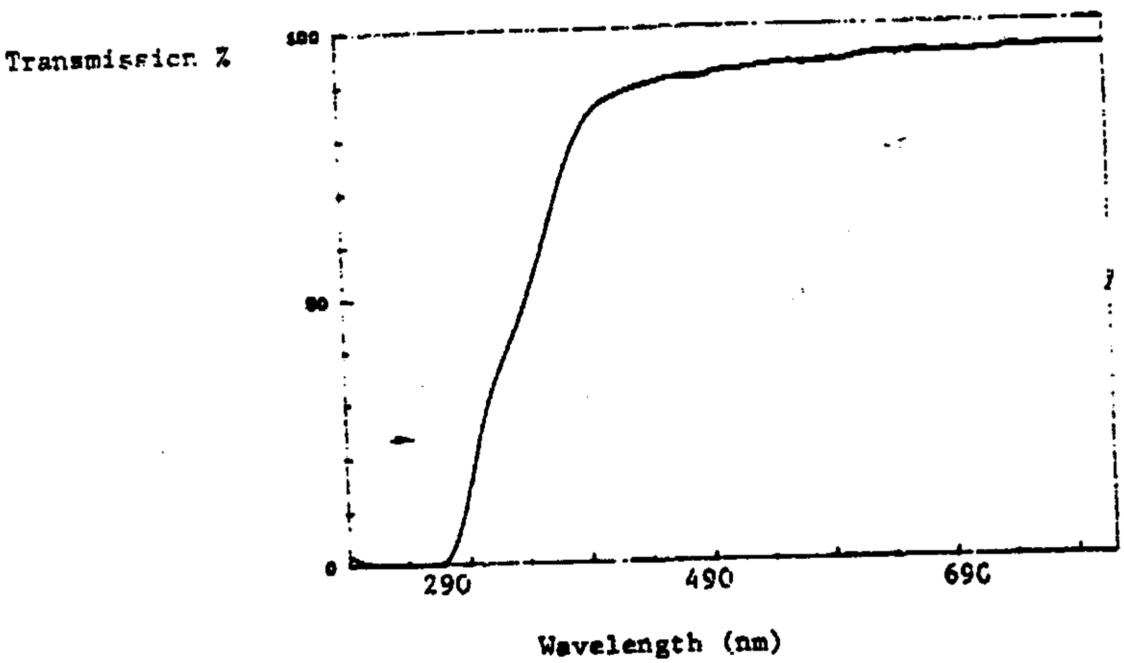


FIGURE 1. TRANSPARENT FLUOROCARBON CLADDING MATERIAL.

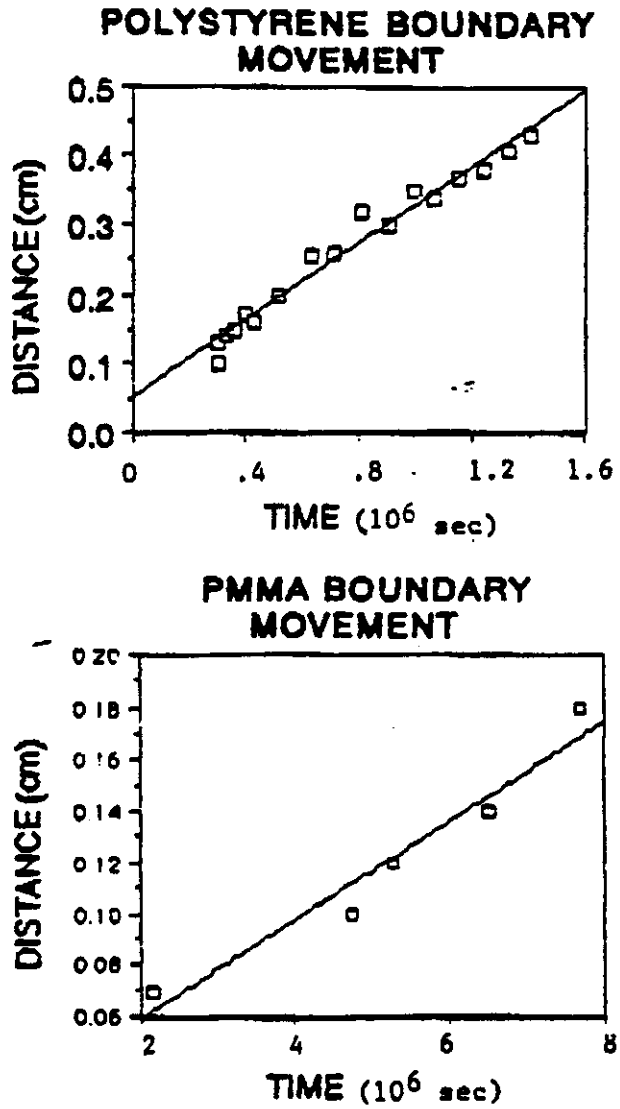


FIGURE 2. THE VELOCITIES ARE 28×10^{-8} AND 1.9×10^{-8} cm/sec FOR PS AND PMMA, RESPECTIVELY.

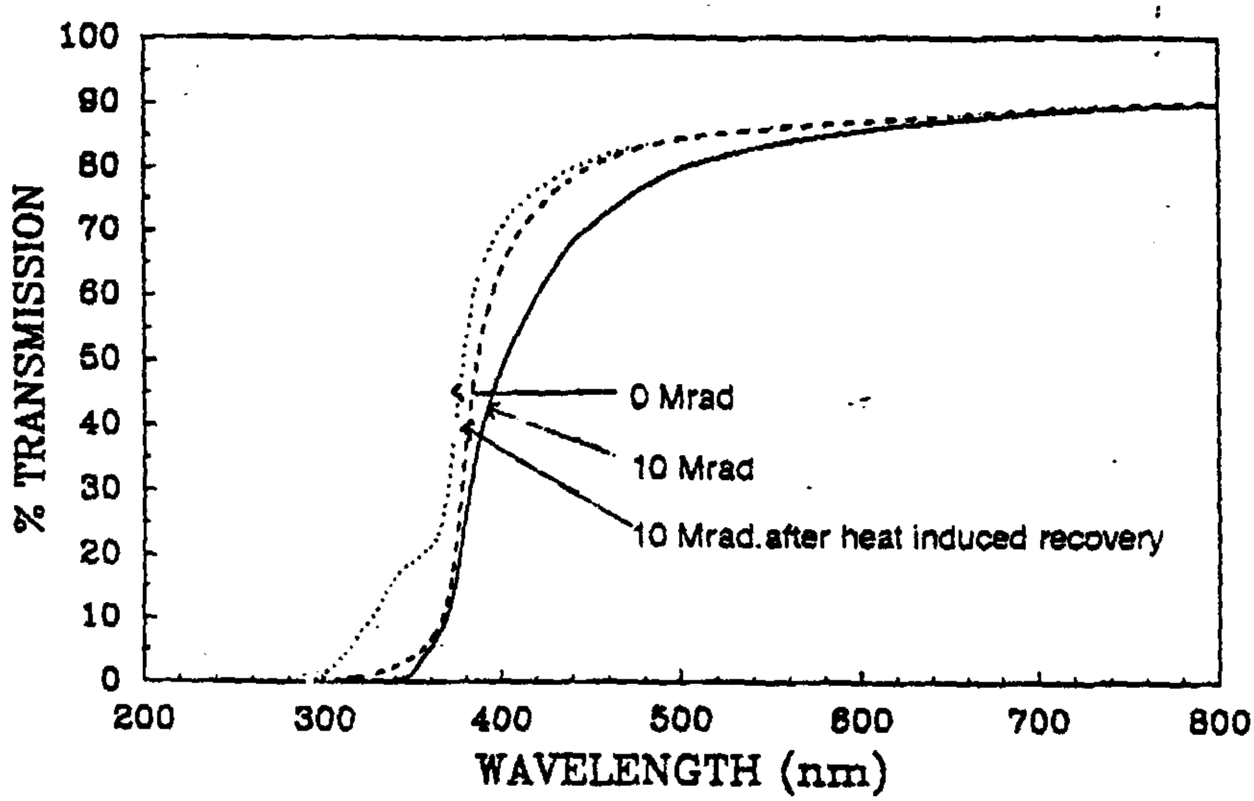
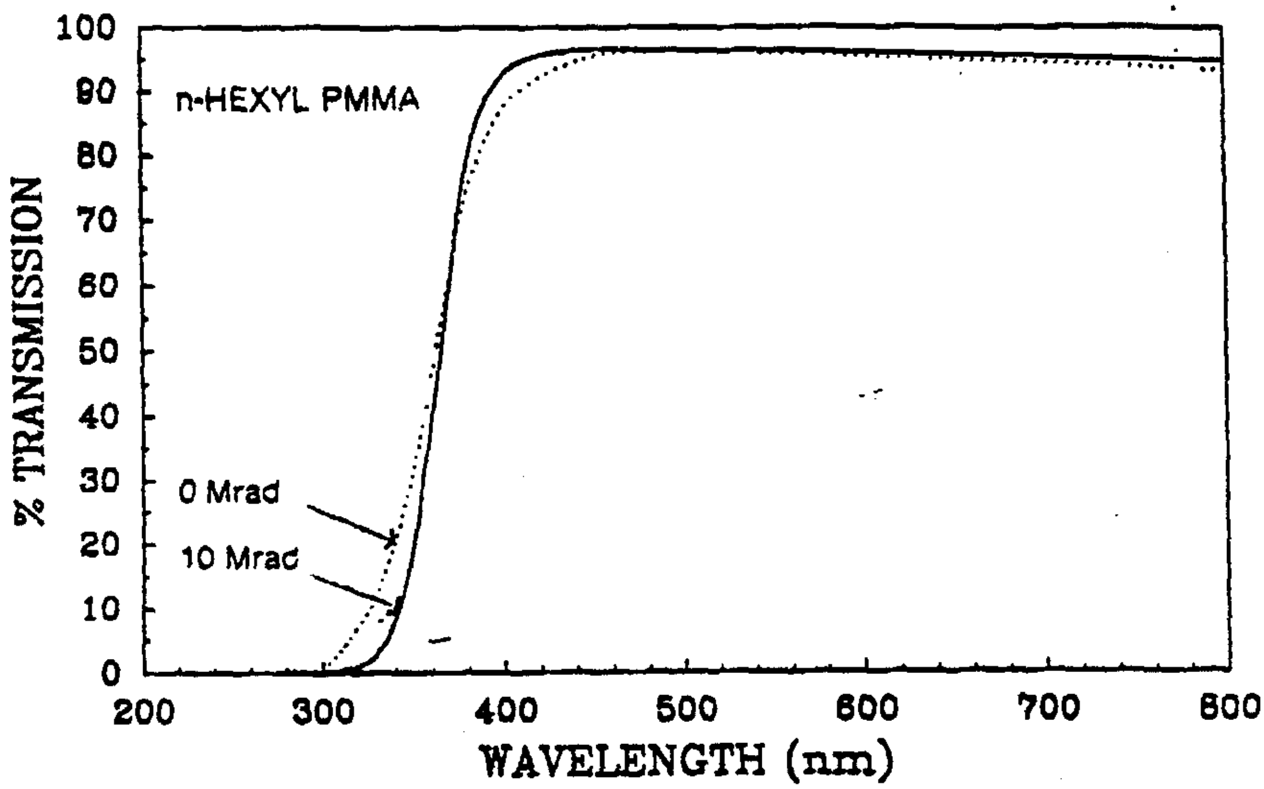


FIGURE 3. PS BEFORE AND AFTER HEAT INDUCED RECOVERY.



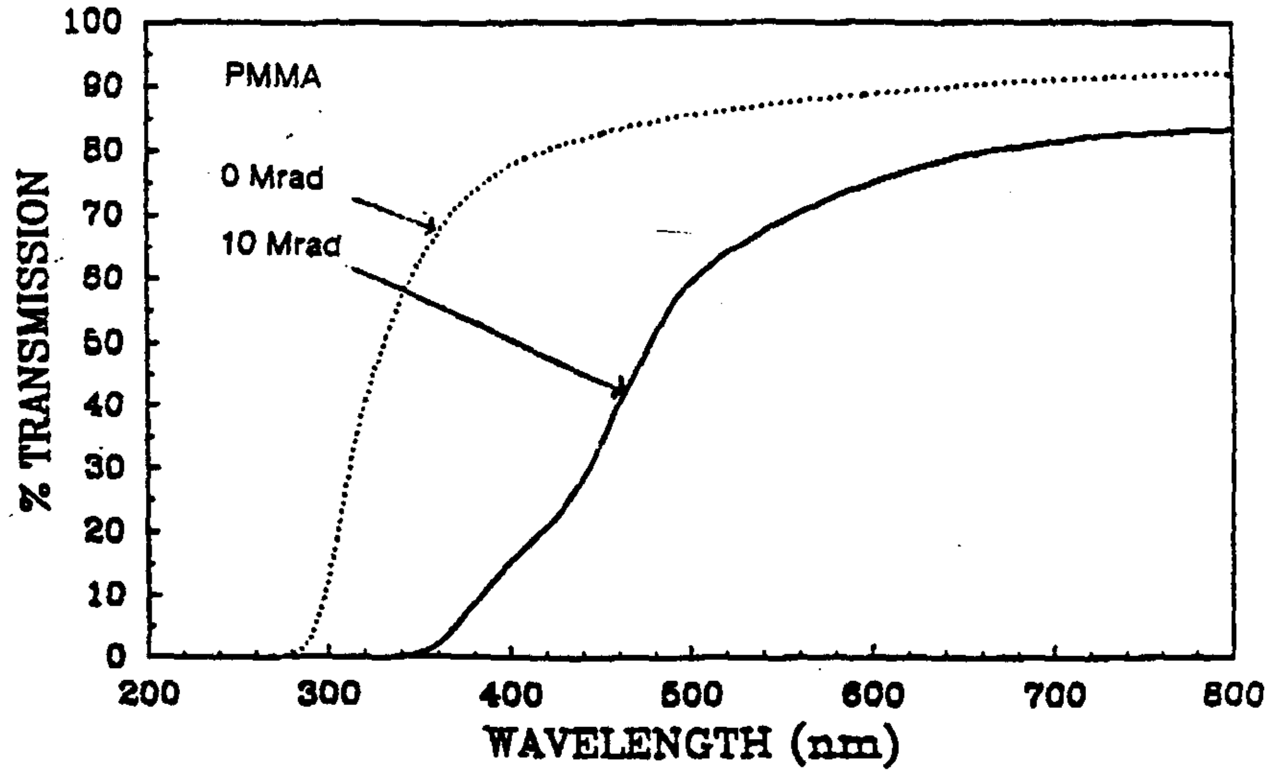


FIGURE 4. n-HEXYL PMMA BEFORE AND AFTER EXPOSURE TO 10 Mrads IN ARGON AS COMPARED TO PMMA. BOTH SAMPLES ARE 1 CM THICK.

6. BIBLIOGRAPHY

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APPENDIX VI

FNAL Work on a Pipelined Digitization/Trigger

System for the SDC

FNAL Work on a Pipelined Digitization/Trigger System for the SDC

Draft September 6, 1990

Morris Binkley, John Elias, G. William Foster, Catherine Newman-Holmes, Dave Christian
Al Bambaugh, Jim Hoff, Ray Yarema, Tom Zimmerman

1 Introduction

This note describes the integrated front-end/digitization/trigger/DAQ system being developed at FNAL for use with the calorimeter and tracking prototypes in the 1990-91 test beam. The system is designed to satisfy SSC requirements for speed, power, and trigger capabilities. The electronics are targeted for use by the Solenoidal Detector Collaboration (SDC), but have obvious applicability to high rate fixed target and collider experiments.

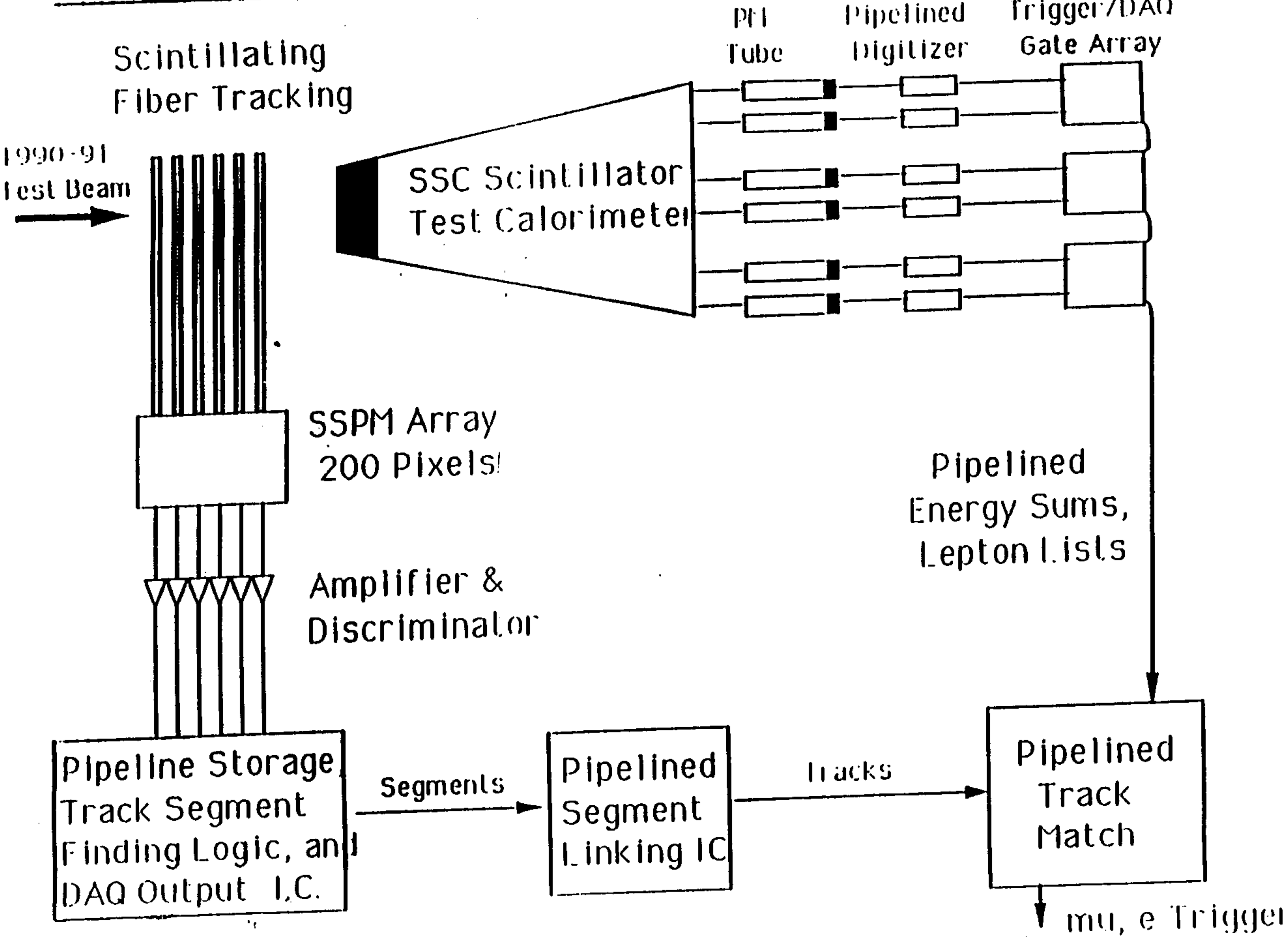
Several IC's have been designed and fabricated for this project for initial testing in the FNAL 1990-91 test beam. The work was funded through FNAL infrastructure, and "bridge" funding from the SSC. Continued support for this effort is being applied for through the Scintillator Plate Calorimetry Subsystem and the Fiber Tracking Subsystem collaborations.

1.1 Key Features

- *Digitize Every Crossing* approach. Photomultiplier signals are digitized each crossing to 8-9 bit accuracy with 20-bit dynamic range.
- *Track Reconstruction every crossing.* Digital pixel information from fiber tracking is latched and processed every 16ns. Full 2-dimensional reconstruction is performed on tracks with $P_T > 5$ GeV/c. on each crossing. The sagitta error of the track reconstruction is 1mm, corresponding to 10% resolution at $P_T = 20$ GeV/c. Reconstructed tracks are put into a pipelined coincidence with calorimetry and muon information to produce highly selective and robust lepton triggers at the lowest trigger level.
- *Full Integration of Digitization, Trigger, and DAQ* on front end ICs.
- *Pipelined Storage of the Digitized Information* is provided by a single DAQ/trigger digital IC on each calorimeter tower.
- *Deadtimeless Serial Transmission of Data to DAQ System* is provided on the same front-end IC.
- *Low Cost.* The target production costs are \$50/channel for the phototube electronics, and <\$2/pixel for the (digital part of the) fiber tracking and trigger.
- *Low Power.* The power dissipation targets are 500 mw/channel for calorimetry, 10 mw/pixel for tracking DAQ/trigger. Custom IC's are being fabricated to demonstrate low power techniques to drive digital trigger signal cables.
- *Single Level Trigger.* Trigger calculations which are normally performed by microcoded processors, etc. in higher-level triggers, are performed by dedicated logic at the lowest trigger level.
- *All Digital Trigger.* No analog summations or thresholds are performed at any point. This permits complete full-speed testing of DAQ and trigger systems prior to detector turn-on. The front-end digital storage RAMs can be "played back" at full speed with

Figure 1-1: Prototype Digitization/Trigger/DAQ system for SSC test beam prototypes

FNAL Pipelined Digitization/Trigger/DAQ Project



real or simulated detector data to verify trigger/DAQ performance and to reproduce faults.

- *Very High Rejection Factor* ($\sim 10^6$) *in Lowest Trigger Level.* For those triggers capable of great selectivity (i.e. the lepton triggers) all of the standard cuts are performed digitally by dedicated logic at the lowest trigger level. For those triggers which are incapable of great selectivity (Sum E_T, Missing E_T, etc.), the trigger decision is based on the same information which is available offline, thereby avoiding trigger threshold turn-on effects which result in throwing away most of the data written to tape from these triggers.

- *Trigger Decision Based on the Same Information as Offline.* There is no separate source for low-precision trigger data, hence no "trigger efficiency curves" to study offline. The performance of the trigger can be exactly modeled in the Monte Carlo detector simulations.

- *Straight Fall-Through Digital Pipeline.* All trigger calculations are performed in a series of pipeline stages. Each pipeline stage consists of a digital storage register, feeding a set of combinatorial logic to perform a specific part of the trigger calculation, which feeds the input to the storage register for the next stage. After a fixed number of clock cycles, the data from each crossing has been distilled to a single (wide) binary word representing (Sum E_T, Missing E_T, highest P_T track, E_T of biggest Electron. 2nd biggest electron, muon, etc.). This "Trigger Decision Word", which is produced every 16ns, is examined for the the physics content required to pass any of the active triggers.

- *Computer Controlled De-Skewing of Clock and Gate Signals.* ICs and functional subunits are being fabricated to demonstrate programmable phase control of multi-channel 60 Mhz clock and gate fanouts. Programmable gate positioning allows automated correction for time-of-flight, propagation delays in the phototubes and electronics, and considerably ease cable timing tolerances. Programmable clock phases in the digital pipeline allow for timing margin testing, and correction for unanticipated propagation delays and/or cable lengths.

- *No Homemade Computers.* None of the trigger logic can perform a conditional jump, loop, or crash. It simply performs the same trigger calculation every 16 ns, and if the computation comes up "yes", the event is taken.

- *Use of "Bucket-Brigade" Connections to achieve an economy of trigger cabling.* Only a single trigger data cable emerges from each phi-slice of calorimetry. This cable contains the Sum E_T, lepton lists, etc. found in this wedge.

- *Reduction in DAQ bandwidth and "Level 3" processing needs.* Since the logic present in the lowest level trigger is sufficient to get to essentially the physics rate for each trigger, there is very little rejection factor available in "the farm".

2 Phototube Digitization

A circuit is being produced to digitize the charge deposited from a Phototube in each 16 ns clock period. The circuit has 8-9 bit accuracy and 20-bit dynamic range. It uses a bipolar (semi-)custom IC as a deadtimeless, multi-range gated integrator, and a commercial flash ADC. The digitized result is a "floating point" number with an 8-bit mantissa (provided by the flash ADC), and a 4-bit exponent (provided by the analog ASIC) indicating the scale factor.

The gated integrator approach was chosen (as opposed to waveform sampling of an integrating amplifier) to take full advantage of the capabilities of Scintillator/Photomultiplier calorimetry. Since the PMT functions as essentially an ideal noise-free amplifier, the best estimator of the energy deposited is simply the integral of the charge. Signal sizes are well above the noise limits of small geometry transistors, and no bandwidth-limiting shaping is needed for noise control. The pulse from the PM tube can be clipped so that is is at (or near) baseline at either edge of the 16-ns gate, so that the digitized charge is not sensitive to the exact position of the pulse inside the gate. Finally, a PM tube with a proper base is a DC coupled current source, so that DC coupling can be maintained throughout the circuit to eliminate rate dependent pedestal shifts, etc.

An analog ASIC design has been initiated using the Tektronix Quick-Chip design tools. This process has been used several times at FNAL by D. Christian et. al. to design and build ICs for the Silicon Strip Detector readout. The design simulations look sufficiently encouraging that we plan to produce prototype chips which will be tested with one of the SSC prototype calorimeters.

2.1 Phototube Digitization System: Target Specifications

Unit Cost: Using 1989 parts costs in high quantities: \$60/channel. This is broken down as follows: \$10 for the analog ASIC, \$40 for the commercially-purchased Flash ADC, and \$50 for a Trigger/DAQ gate array chip which is shared among 5 Phototubes in a tower (\$10/PM tube). For an SSC calorimeter with 50,000 PM tubes, this is \$3M.

Power dissipation: Using 1989 commercially available parts: 650 mw/channel. This is broken down as follows: 100 mw for the analog ASIC, 250 mw for the commercially-purchased Flash ADC, and 1W for a Trigger/DAQ gate array chip which is shared among 5 Phototubes in a tower (200 mw/tube). For an SSC calorimeter with 50,000 PM tubes, this is 32 kw. Since all of this power is dissipated on the outside of the detector, this poses no particular problem.

Dynamic Range: 20 bits.

Least Count Sensitivity: = 1 fC
= 1mV on a 1 pf capacitor
= $0.1\mu A$ x 10ns current pulse from phototube
= 10 MeV for a calorimeter with 100 Photoelectrons/Gev
and a Phototube gain of $\sim 10^4$

Full Scale Sensitivity: = 1 nC
= 1 volt on 10pf after 1/100 current attenuation
= 100ma x 10 nsec current pulse from phototube
= 10 TeV for a calorimeter with 100 Photoelectrons/Gev
= and a Phototube gain of $\sim 10^4$
= 10^6 Least Counts (20-bit dynamic range)

Binary Output: A 4-bit scale code (floating point exponent) is produced by the ASIC. This scale code has a range of 0-11, corresponding to the twelve binary-weighted scale factors. An 8-bit Mantissa is produced by the Flash ADC. Since the flash ADC will only be used to digitize voltages between 1/2 scale and full scale, the Flash ADC output codes of 0-255 will actually correspond to 256-511. Thus, the value of the digitized charge will be:

$Charge(infC) = (FADCMantissa + 256) \times 2^{SCALECODE} - I_{PEDESTAL}$

The bias current $I_{PEDESTAL}$ will be chosen to produce a nonzero digitized signal on the lowest range scale, for zero charge deposited from the phototube. Thus, typical signals will be digitized to an accuracy of between 1/256 and 1/511 of themselves, depending on where they land on the ADC range. This compares well with a calorimeter resolution of 15%/sqrt(E) + 1%, since the digitization error will average about 0.2%.

Large-Signal Recovery Time Constant of < 2ns. Note that this will not allow recovery to full 20-bit accuracy within 16 ns following a full-scale hit. The actual goal is to have > 98% rejection of calorimeter energy depositions in the preceeding and subsequent 16 ns RF buckets. This matches what one can obtain with fast scintillators and PM tubes.

Input Characteristics: The analog ASIC is optimized for placement in close proximity to the Phototube (i.e. no cable). The input stage (basically a common-base NPN transistor with feedback) must have a low enough input impedance to drain off the charge from the anode ($\sim$ 15pf) with the 2ns RC recovery time mentioned above.

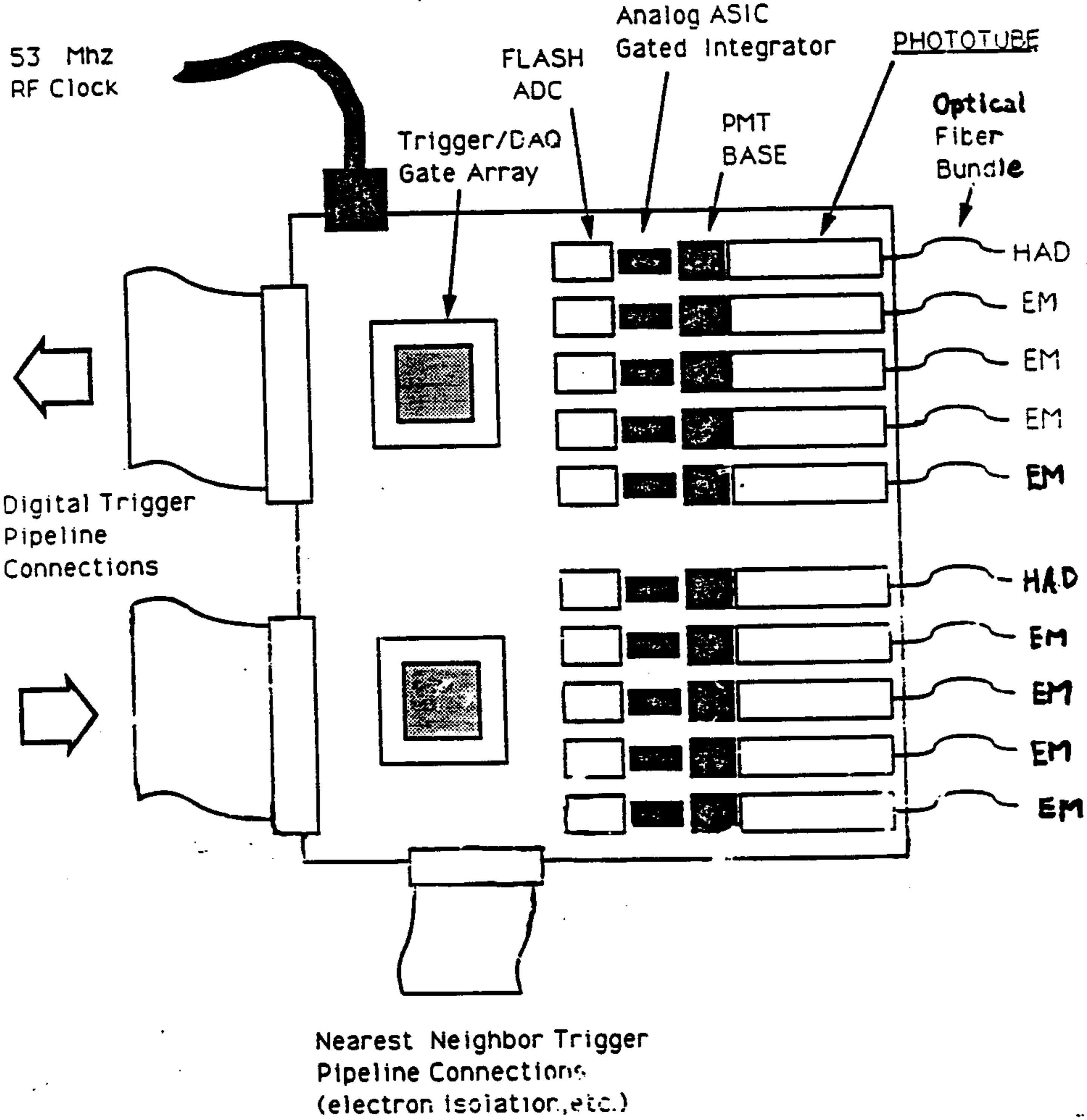
Pulse Clipping. The input is compatible with a passive phototube pulse-clipping network, either delay-line or R-C. Such clipping techniques (which effectively subtract off the exponential tail of the scintillation light pulse) have been used to bring the pulse from PM tubes back to baseline within 10ns. This enables one to completely reject energy deposited in adjacent RF buckets. This technique is most effective in EM calorimeters for which the energy deposition is essentially instantaneous, and for hadron calorimeters such as Iron/Scintillator which have a very small delayed neutron component and can be made compensating inside a 16-ns gate.

Another important feature of pulse clipping (or the use of fast shifter fluors such as the NE Technology's recently announced 2ns waveshifters) is that it allows the PM signal remain at baseline at either edge of the sampling gate. When this is not the case, the digitized charge is sensitive to the exact position of the pulse inside the gate. A pulse which fits comfortably inside the ADC gate considerably eases the timing requirements on the timing of the gate fanout.

DC Coupling. The unit will be DC-coupled throughout to eliminate rate-dependent

Figure 2-4: Multi-Phototube PC card with digitization and trigger circuitry.

Photomultiplier Digitization & Trigger Module Project



Design Goals:

Dynamic Range:	20 Bits	Cost:	< $200 / Channel
Accuracy:	9 Bits	Power:	600 mw/Channel

⇨ ALL-DIGITAL TRIGGER BASED ON SAME INFO AS OFFLINE ⇦

pedestal effects, gain saturation, etc. This is especially important at the SSC where hundreds of GeV are being dumped into the calorimeter every crossing – and the abort gaps are producing a cyclical pulsation of the average energy deposition.

Gate Characteristics: Switching time less than 100psec. Furthermore, the total digitized charge will be constant to within 1% whether the pulse is centered on the gate, or straddles two adjacent gates.

2.2 PMT Digitizer Theory of Operation

Input Stage: This is a low-impedance amplifier which functions to drain the charge off of the anode capacitance ($\sim$ 15 pf) of the PM tube. It consists of a common-base NPN transistor amplifier with feedback to lower the input impedance. The input stage basically passes the Phototube current through with a gain of ~ 1, and serves to isolate the current-splitting stage from the anode capacitance.

Current Splitting Stage: The instantaneous phototube current is split onto a number of binary-weighted outputs using bipolar current-splitting techniques (i.e. multiple collector transistors, etc.). These binary-weighted outputs are used to generate the different scales for the floating-point result.

Current Switching Stage: This is a standard emitter-coupled current switch which routes the scaled phototube currents to one of 2 sets of integrating capacitors each 16 nsec. Current switching times of $<$ 100 psec are be obtained, generating a very sharply defined gate. Simulations indicate that nearly ideal "gated integrator" behavior is obtained: the total charge registered by the circuit is independent of the pulse position within the gate, and the total charge registered by a pulse which straddles a gate is equal (to within 1%) to the charge registered when the pulse is centered in the gate.

Timing Sequence: The circuit toggles between the two sets of capacitors each RF bucket. During the 16-ns period that charge is being integrated on one set of capacitors, the following operations are performed on the other set:

i) Each binary-weighted capacitor signal has an individual latched comparator on it. This is used to identify which one of the capacitors is between 1/2 scale and full scale. This capacitor voltage is the one that will be chosen to be routed off-chip to the commercial FADC. The comparator outputs are valid 2ns after the end of the ADC gate.

ii) The comparator outputs are latched, and and a single level of ECL logic is used to identify the capacitor of interest. This process is completed 4ns after the end of the ADC gate.

iii) This signal is used to enable an analog multiplexor (a shottkey-diode sampling bridge) which selects the correct capacitor voltage for routing to the Flash ADC. Simulations indicate that the analog multiplexor settles to 9-bit accuracy in within 3ns, or 7ns after the end of the ADC gate. At the end of this period, the sampling bridge is opened. This "freezes" the analog signal at the output of the multiplexor and allows most of the 16-ns clock period as settling time for routing the analog signal off-chip to the FADC.

iv) The digital range selection bits are encoded to produce a 4-bit scale code which is routed off-chip. This happens in parallel with the settling of the analog signal to the FADC.

iii) Finally, the capacitors are reset in preparation for the next gate. again using a Shottkey sampling bridge. This takes < 4ns, so that the complete readout and reset cycle is finished 11 ns after the end of the gate. The capacitors remain idle until the end of the 16ns period, when the next gate begins.

2.3 PMT Digitizer Calibration and Diagnostics Features; Trimming

Since the digitization circuit is a DC-coupled, current sensitive device, it can be accurately calibrated over its full dynamic range with a programmable DC current source. This allows absolute calibration, scale overlaps, etc. to be accurately determined with a single procedure.

Two approaches to the question of the relative accuracy of overlapping range scales are being considered. The first (digital correction) is to rely on intrinsic device matching and device design only to guarantee that all scales are linear and that they have small regions of overlap at the high and low ends. This ensures that there will be no analog "dead bands" without ADC sensitivity. The 12-bit floating point result would then be calibrated and linearized with 4096 entry lookup table on the trigger/DAQ gate array IC in the calorimeter tower.

The second approach under consideration utilizes laser-trimming of the wafer (the Tektronix arrays in question offer Nichrome resistors which can be laser-trimmed to 0.1% accuracy). This approach in principle would allow all parts to be trimmed to an absolute accuracy of 10 bits on all range scales, so that individual gain corrections would be unnecessary. We plan to produce several wafers which are identical except for metallization. The first wafers will be fabricated and tested without laser trims, the final ones will be trimmed if the procedure is warranted.

3 Trigger

3.1 Single Level Trigger

All triggers are implemented in the lowest-level trigger, i.e. one that has a fixed delay between the crossing and the trigger decision. The trigger logic is constructed as a straight "fall-through" digital pipeline. What is meant by this is that all trigger calculations are performed in a series of stages, with the time taken in the logic for each stage being equal to the time between crossings. After the calculations at each stage, the data is entered into a digital "pipeline storage" register, where it resides until the next clock period. In this manner, one can perform a calculation which is too complicated or time-consuming to perform in a single clock period, while still maintaining a "throughput" of one calculation per clock period. Such techniques are commonly used in RF-clocked fixed target experiments, as well as collider experiments: the CDF track processor [ref CFT NIM article], for example, is implemented as a 17-stage 35 Mhz digital pipeline.

The digital pipeline for the SDC trigger begins with the digitized information on the detector (approx. 1.5M bits), and ends with a single bit yes/no trigger decision approximately 50 clock cycles (800 ns) later. The size of the data is reduced a series of pipelined operations, the largest of which happen via local computations on the front end ICs. Thus, only a relatively small number of signals get passed to a central location for a final decision.

3.2 Pipeline Timing Sequence of Operations

- After 5 Clock Cycles: Local calculations have performed E_T weighting for energy sums, identified $e/\gamma/\mu$ candiates in the calorimetry, and identified track segments in the fiber tracking data;
- After 25 Clock Cycles: E_T sums and lists of $e/\gamma/\mu$ candidates have been formed for each wedge, and track segments have been linked to form complete tracks;
- After 35 Clock Cycles: Data from wedges has been transported to a central location, and track candidates have been put into coincidence with data from the wedges to form "tracked" lepton candidates. E_T sums from each wedge are being combined to form the X and Y components of the Missing E_T.
- After 40 Clock Cycles: All event data has been reduced to a single binary word which contains a summary of the data from each crossing. This word has bit fields representing (Sum E_T, Missing E_T, highest P_T track, E_T of biggest Electron, 2nd biggest Electron, Highest P_T Muon, 2nd highest, etc.).
- After 50 Clock Cycles: This "Trigger Decision Word" has been examined for the the physics content required to pass any of the active triggers, and a single bit (accept/reject) decision is made.
- After 60 Clock Cycles: The single bit (accept/reject) decision has been pipelined back (fanned out) to the front-end ICs, who use this bit to store the outputs of their digital pipelines into a FIFO for transmission to the DAQ system. If desired, the trigger system can save data from several sucessive crossings in the vicinity of the triggered crossing as an aid in debugging and to study bucket-to-bucket crosstalk.

3.3 Sum E_T and Missing E_T Triggers

These are basically pipelined digital adder trees, with appropriate weighting and thresholding of the digitized PMT data. The bulk of the logic is contained on the same ASIC/gate array (one per tower of calorimetry) which also stores the digitized data from the ADCs and performs the DAQ functions.

In order to ensure adequate dynamic range while minimize cabling, we preserve the ADC's floating point format (8+1 bit mantissa, 4-bit exponent) in the Sum E_T and Missing E_T calculations. Thus, E_T calculations will be performed with a "least count" of 10 MeV and a "full scale" of 10 MeV x 511 x 2^{15} = 150 TeV. This 12-bit floating-point format also allows the calibration and E_T weightings to be performed in a single, pipelined, 12-bit RAM lookup operation.

A full layout of a 12-bit pipelined floating-point adder has been performed in order to determine the silicon real estate required, and a test IC is being prepared for fabrication which will allow us to construct a 16-tower(32 phototube) floating-point pipelined adder tree for the Sum E_T trigger in the test beam prototypes.

Local processing which will be performed on each digitized PMT signal before inclusion into the Sum E_T includes: 1) summation of the Hadron & EM energy in each tower, 2) SinΘ weighting to obtain the transverse component of the energy, and 3) optional thresholding of the data, i.e. zeroing the digitized energy of the PM tube if it does not exceed a programmable value (a few tens of MeV). This last procedure may be useful in optimizing the resolution of the Missing E_T trigger.

The DAQ/Trigger gate array will also have the ability to remove a malfunctioning channel from these (and all other) energy sums.

In order to minimize both trigger cabling and the number of components needed for the trigger, these sums are calculated in a "bucket brigade" manner. What this means is that intermediate results in the trigger sums are passed along a chain of nearest-neighbors. At each step, a neighbor (in η) receives a partial trigger sum from his upstream neighbor, adds his contribution to the E_T for this (appropriately delayed) RF bucket, then passes the result to his downstream neighbor on the next clock cycle. After some number of clock periods, the E_T sum will have propagated through an entire Φ-slice of calorimetry. Eventually only a relatively small number of cables ($\sim$ 1/wedge) are needed to transport the trigger signals to a central location. Here the global Sum E_T is calculated, as well as the same sums weighted by sinΦ and cosΦ for the calculation of missing E_T. These three sums are made available for use in the final trigger decision.

3.4 Electron/Photon Triggers

The electron and photon triggers are identical in the calorimetry, and the pipelined track match is only applied to electrons. The electron/photon signature is calculated locally on the detector, using local digital tube sums, in the lowest level trigger. The e/γ trigger demands:

- A minimum Electromagnetic E_T deposition in an overlapping sum of 1,2,or 4 nearest-neighbor PM tubes. This guarantees full efficiency for electrons which straddle tower boundaries in η and ϕ.
- A cut on the ratio of EM to Hadronic energy in the towers involved in the sum.
- An optional "isolation" cut on the total energy in a guard ring around the EM signal tube sum. This cut can be either a fixed energy, or a fraction of the energy in the EM cluster.

Figure 3-6: Bucket-Brigade trigger calculations for digitally pipelined calorimeter trigger. Energy sums and lepton lists are formed by passing information to nearest neighbors in η. At the end of each "Bucket Brigade", a small number ($\sim$ 1/wedge) of cables are sent to a central location for final summing.

- (electrons only) a high P_T track in ϕ-coincidence with the calorimeter signal. The track will be reconstructed with a sagitta error of 1mm corresponding to a momentum error of 10% at $P_T = 20$ Gev/c.

The calculation of overlapping EM energy sums and isolation sums involves the exchange of information between nearest-neighbor and next-to-nearest-neighbor trigger gate arrays. This is done by pipelining digitized PMT energies (and intermediate energy sums) between nearest-neighbor gate arrays. This takes place along dedicated digital trigger lines, which number approximately 200 per tower of calorimetry. These are discussed further in a section below.

Track matching with the electron is performed in a fully pipelined manner, in the lowest trigger level, as follows: 1) The exchange of local energy sums allows the gate array on each tower to identify that an electron/photon candidate has been identified in that tower on a given crossing. 2) This allows a "electron/photon list" to be assembled in each "wedge" of calorimetry. This is done by passing a list of the most promising electron candidates from tower to tower in a bucket-brigade manner similar to the accumulation of E_T sums. A single pipelined cable containing only the two highest E_T e/γ candiates leaves each wedge.

4 Summary of IC designs Completed to Date

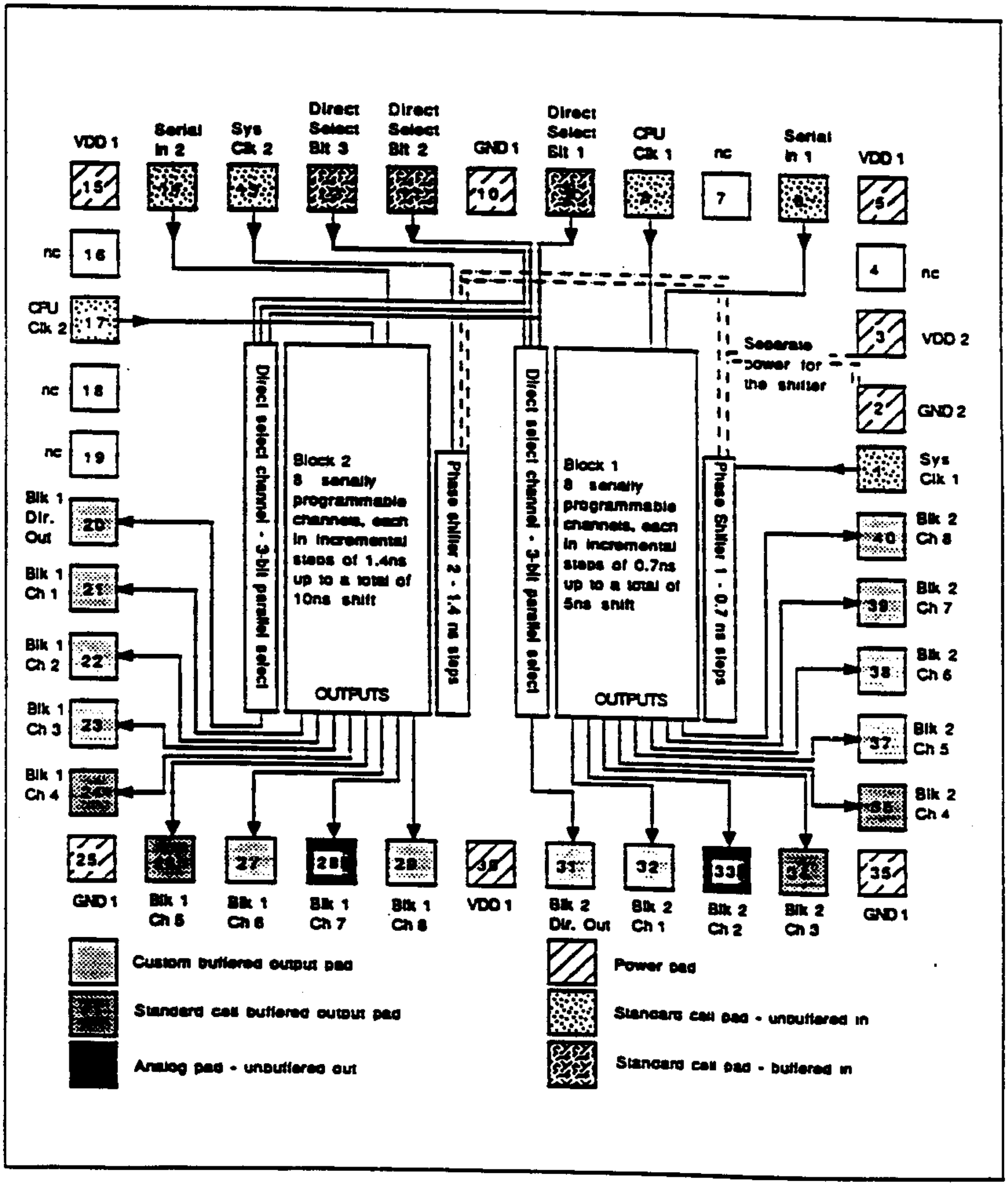
- **Clock/Gate Timing Fanout** One of the major challenges for an SSC experiment is simply the distribution of a 60 MHz gate/clock signal to a large array of PM tubes and other components. This signal must be precisely timed to the accelerator RF crossing signal, and must take into account the time of flight to each detector component, as well as individual optical and electronic propagation delays. A similar problem occurs in the operation of a large digital pipeline system, wherein care must be taken to ensure the proper relative phases of clock and data. As one component in this fanout, we have fabricated a custom IC which contains a multi-channel digitally programmable clock delay/fanout. It allows adjustments of individual output clock phases with a resolution of ~1ns and a range of 16 ns (1 clock period).

- **Phototube Digitization Circuit** This is described in section 2 above.

- **IC for Pixel Storage for Fiber Tracking Trigger, DAQ and Readout** This design (only the pixel storage IC has been fabricated) is described in the submission from the fiber tracking subsystem.

- **12-bit Floating-Point Pipelined Adder for Trigger Sums** described in section 3.3 above.

- **Ultra-Low Digital Line Driver for Pipelined Applications.** Power dissipation is one of the main constraints in the design of a large digitally pipelined system. A major component in this power dissipation comes from simply driving the large number of nearest-neighbor digital interconnects on the calorimeter trigger. For the designs



Floorplan for the Programmable Clock Vernier being contemplated, each tower has typically 100 point-to-point interconnections with a typical lengths of one foot. The worst case power dissipation when all cables are toggling at 60 MHz can exceed several watts. In order to address this problem we have fabricated a test IC which reduces this worst-case power to ~200 mw by the following techniques: a) back-termination achieved by controlling the output impedance of the driver, b) reducing the logic swings from the 5v levels internal to the ICs to between 1.5 and 2v. The test circuit includes two stages of low-threshold reciever gates in order to buffer the incoming 1.5v signals back up to the 5v internal levels. The propagation delays in these drivers and recievers are small enough to permit operation in a 60 Mhz pipeline.

APPENDIX VII

STATEMENT OF WORK FOR WESTINGHOUSE CALORIMETER SUBSYSTEM LEAD CASTING PROCESS DEVELOPMENT

Westinghouse is in the process of completing a calorimeter subsystem materials study that evaluated lead based materials properties to determine the feasibility of a lead absorber based calorimeter system. The following list attempts to summarize the results and conclusions.

- Lead alloy data obtained and assessed
- Mechanical requirements obtained
- Lead alloys evaluated for application and found to be lacking
- Composite concepts development and projected to be adequate
- Cast lead-composite proof-of-concept demonstrated
- Identified property, processing and performance issues

A cast lead calorimeter with integral slots for scintillators would have advantages, such as simplicity and cost effectiveness to produce, when compared to other technologies. Casting feasibility has been demonstrated. Manufacturing issues remain to be resolved. These issues include:

- Teflon insert precision casting optimization
- Matrix Teflon Surface
- Optimum casting geometry (horizontal, vertical)
- Reinforcement selection, optimization, and matrix wetting
- Mechanical performance
- Fiber-Matrix interface optimization

A process development program consisting of 6 tasks, to address the above issues of optimizing material and processing options and verifying mechanical and physical performance has been developed. Since proof of principal is deemed to be of primary importance, the tasks are prioritized to first develop required precision casting techniques and secondly to verify required mechanical strength. These tasks would consist of the following:

Task 1 <u>**Casting Process Development**</u>

Cast model test samples to resolve module casting issues such as:

- Pour, mold temperatures
- Liquid flow directions (top, bottom pour)
- Solidification control
- Surface finish

and Teflon insert issues such as:

- Slot size precision to be within 5 to 10%
- Re-use of insert
- Insert material and production
- Coating requirement

Resulting in a final model that consists of three towers with three offset slots per tower.

Task 2 <u>**Mechanical Performance Verification**</u>

Cast test specimens and test to determine issues such as the following:

- Reinforcement selection - physics based options, allowables
- Tensile and bend creep tests

- Correlate structure-property relationships (Matrix adhesion-mechanical performance)
- Provide reliable data to mechanical designers

Task 3 Reinforcement Surface Optimization

Cast test specimens and test to:

- Evaluate structure of current reinforcement matrix interface
- Evaluate cleaning and pretreatment effects on interface
- Evaluate simple coating processing
- Correlate process effects on structure of interface

Task 4 Preprototype Tower Casting

Cast preprototype to further develop techniques for larger scale models

- Preprototype has key elements of module
- Casting feasibility is demonstrated
- Manufacturing issues will be identified
- Cast preprototype
- Mechanical testing of tower bend and compression tests
- Proof-of-concept demonstration

Task 5 EMC Module Casting

Cast sample production type EMC modules for assembly and test beam work as follows (develop fundamental mechanical EMC design drawings) by collaboration:

- Incorporate design and casting knowledge into mold drawings
- Cast EMC modules
- Inspect/QC module

(Assemble EMC modules including scintillators) by collaboration

(Test module in Fermi Laboratory beam) by collaboration

Task 6 <u>HAC Module Casting</u> - to be proposed at a later date

Cast prototype sample production type Hadronic module for mechanical testing as follows (develop fundamental mechanical HAC design drawings) by collaboration:

- Incorporate design and casting knowledge into mold drawings
- Cast prototype HAC module
- Inspect/QC module
- Mechanically test module

The deliverable will consist of:

- Cast lead samples with precision slots
- Cast lead samples with reinforcement
- Measurements of thickness and gap uniformity
- Cast lead EMC modules suitable for test beam work
- Mechanical test report including data such as stress-strain curves developed from samples
- A preliminary lead casting process specification encompassing techniques, processes and procedures developed by this program

The schedule duration estimate is as follows (1990/1991 Schedule Task Duration):

- Program driven by beam availability (Spring 1991)
- Sequential and parallel task activities
- Task duration estimates

  Task 1 - 2 months

Task 2 - 2 months

Task 3 - 3 months

Task 4 - 3 months

Task 5 - 4 months

Task 6 - 3 months

Since this program is in its early stages and many unknowns still remain, this statement of work and its associated deliverables and estimated costs must be considered on a level of effort basis. It is believed, that based on an engineering appraisement, that the deliverables can be achieved within the projected costs. Additional engineering efforts provided by collaboration members are not included in the cost estimates.

Estimate: For Tasks 1, 2, 3, 4, and 5

- One senior level mechanical engineer for 4/12 year (640 hr) Primary responsibility for all effort	$66K
- One senior level metallurgical engineer for 4/12 year (640 hr)	$74K
- Draftsman/designer for 1/12 year (160 hr)	$16K
- Materials technician for 4/12 year (640 hr)	$45K
- Mechanical technician 1/24 year (80 hr)	$ 6K

Materials Estimate

Mold	$ 24K
Materials	$ 4K
Testing	$ 8K
Grand Total	$243K

1990/1991 PROGRAM PROPOSED SCHEDULE

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                                      SEP       OCT       NOV       DEC       JAN       FEB       MAR       APR       MAY

  J    J
Teflon Issue                          0-------------0
Casting Geometry                             0----------------0
Casting Conditions                                     0---------0

Task 2
Tensile Test                           0------0
Creep Test                             0-------------0
Data                                                   0

Task 3
W/Pb Structure                         0-----0
Cleaning/Structure                     0--------------0
Coated Structure                            0-------------0

Task 4
Mold System                                                0----------0
Cast Towers                                                           0-------0
Bend Test                                                                 0--------0
Creep Test                                                                      0---------------0

Task 5
Mold Design                                                      0------------0
Frame Prep                                                                  0------0
Cast EM Test Modules                                                                   0--------0
Beam Test                                                                              0----------

Task 6
Mold Design                                                                                    0----------0
Frame Prep                                                                                          0--------0
Cast Prototype Module                                                                                          0------0
Mechanical Tests                                                                                               0--------
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APPENDIX VIII

STATEMENT OF WORK FOR WESTINGHOUSE CALORIMETER SUBSYSTEM
MECHANICAL ENGINEERING DESIGN EFFORT
FOR A LEAD BASED CALORIMETER

PROPOSED FOR FY1991

Westinghouse is in the process of completing a preliminary conceptual evaluation/analysis of the feasibility of a lead based absorber-scintillator-fiber readout calorimeter system. The following list attempts to summarize the results and conclusions:

- A specification describing and documenting the system analyzed has been written.
- Concept layouts of the selected concept have been developed:
  - Scintillator fiber readout
  - Lead, lead composite absorber material
  - Stacked module support between modules
  - Structure rebar mesh/integrated absorber support within modules
  - Side of tower projective readout orientation
  - Azimuthal segmentation module shape
- A preliminary design evaluation using several finite element models supported by classical stress analysis indicates that the design holds significant promise.

- Preliminary fabrication and material investigations indicate that the design is potentially buildable.
- Very rudimentary material cost estimate shows that the design would be financially very attractive to build when compared to competing technologies.

A cast lead based calorimeter with integral slots for scintillators would have advantages, such as simplicity and cost effectiveness to produce, when compared to other technologies. Casting feasibility has been demonstrated as part of another program. The manufacturing issues which remain to be resolved are to be addressed in the next fiscal year as part of that continuing program. With respect to mechanical engineering design issues, conceptual feasibility has been demonstrated per the above listing, but many conceptual as well as preliminary design and analysis tasks remain to be addressed.

A design and analysis program consisting of three tasks to address conceptual/preliminary design and analysis issues has been developed. These task would consist of the following:

Task 1 <u>Preliminary Design Analysis of the Barrel Calorimeter Such As</u>:

- Conceptual design and 3D analysis of reinforced composite lead module at center of barrel HAC.
- Conceptual design and 3D analysis of reinforced composite lead module, projected at end of barrel HAC.
- Conceptual design and analysis of perforated, segmented steel ring for barrel support and flux return.
- Conceptual design and analysis of fastening of HAC modules.

- Conceptual design and analysis of bottom support for barrel calorimeter.
- Conceptual analysis of BEMC.
- Design fiber routing through all areas of barrel. Specify module segmentation (axial direction) and module-to-module joint design for barrel calorimeter.

Task 2 <u>Preliminary Design Analysis of the End Cap Calorimeter Such As</u>:

This work will be carried out in support of the endcap design being carried out by ANL.

- Conceptual design and 3D analysis of reinforced HAC module(s) for end cap calorimeter.
- Conceptual design and analysis of bottom support for end cap calorimeter.
- 3D finite element analysis of entire end cap calorimeter.
- Conceptual design and analysis of connection between endcap exterior steel structure with barrel steel.

Task 3 <u>Continuation of Tile Manufacturing Study</u>:

The scintillator tile-fiber calorimeter will contain over 1.5 million tiles. Each tile is embedded with a wave-shifting (WLS) fiber and requires numerous manufacturing and assembly operations. These operations include: 1) cutting tiles for specific calorimeter locations; 2) cutting an optimal groove pattern in each tile for the WLS fiber; 3) bending and forming the WLS fiber for insertion into the groove; 4) cementing the WLS fiber into the groove; 5) attaching a clear exit fiber to the tile assembly; 6) calibrate the response uniformity of each individual tile; 7) produce a compensation mask for each tile; 8) wrap each tile with the customized mask; 9) assemble tile and fiber assemblies for each calorimeter tower; and 10) assemble calorimeter sections.

The objective of this task is to develop a coordinated approach to the tile and fiber manufacturing. The use of automation is fundamental in order to reach reasonable cost objectives. As a continuation of the FY90 effort Westinghouse will complete the following:

1) Complete a functional requirements specification which will identify the key elements and needs for the manufacturing of the calorimeter tile assemblies.

2) Identify, evaluate, and document the efforts by the various collaborators who are developing techniques for tile-fiber construction and assembly. Evaluate those techniques which are appropriate for automation and identify remaining needs.

3) Complete an engineering systems design of the automation equipment required for the tile manufacturing.

Task 4 <u>Assist the Subsystem Collaboration in Addressing General Calorimeter Issues Such As:</u>

- Compiling and updating cost estimates.
- Developing a module assembly plan.
- Developing a shipping plan.
- Developing an assembly/erection plan.
- Developing end cap EMC refurbishment plan.
- Developing general maintenance/repair plan.
- Documentation of calorimeter/detector interfaces.
- Continue dialogue with lead vendors to determine capabilities.