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HYBRID CENTRAL TRACKING CHAMBER COLLABORATION,
Summary Report - Part II: Proposal for FY91

Contact person: A. T. Goshaw

August 1990

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Hybrid Central Tracking Chamber Collaboration

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Submitted to

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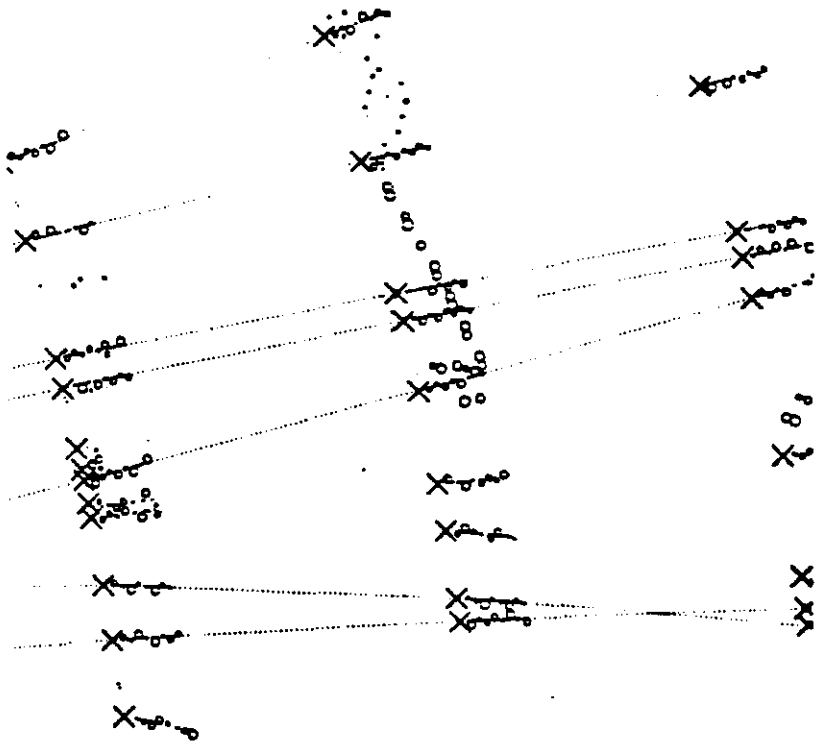

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Hybrid Central Tracking Chamber Collaboration

Summary Report – Part II: Proposal for FY91

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1.0 Executive Summary

1.1 Introduction

During the past year, the Hybrid Central Tracking Chamber (HCTC) Collaboration has established a comprehensive research program designed to develop a large volume tracking detector for the SSC. The HCTC detector concept and a detailed description of our R&D results from FY1990 are presented in Part I of this Summary Report. The conclusions of our first years work are that the HCTC detector concept is sound and appears to be a highly attractive option for particle tracking in the central rapidity region of an SSC detector. This Proposal describes a natural continuation of our HCTC detector development into FY1990. The proposed R&D program is broad enough to test all critical features of the HCTC design. It includes the construction of prototypes which will investigate the fabrication and automation procedures needed for the construction of a full scale detector. We will also develop a detailed Work Breakdown Study (WBS) and cost estimate for the construction of a HCTC for the SDC detector. As discussed in more detail below, we have made contacts with other tracking subsystem groups to coordinate R&D work where possible.

1.2 Overview of FY1991 R&D program

The R&D program spans four tasks that are basic to development of the HCTC detector: straw tube drift chambers (task 1); scintillating fiber tracking (task 2); mechanical engineering (task 3); and Monte Carlo detector simulation and pattern recognition (task 4). Readout electronics development and radiation hardness studies are distributed over tasks 1 and 2. The details of our program are presented in Sections 2 to 5 of this Proposal. Section 6 summarizes the administration of the project. This includes responsibilities of personnel and institutions, a project timeline with milestones and the FY1991 budget by institution and task.

Some of the major R&D goals of the HCTC Collaboration for FY1991 are summarized below.

Task 1: straw tube drift chambers

- continued evaluation of existing 2.7 meter straw tube superlayer

- construction of long (~6 meter) straw tubes with midtube terminators
- construction of a straw tube superlayer on a cylinder; study of assembly automation procedures
- frontend electronics testing and assembly into end plate ring
- gas selection and aging studies
- radiation hardness evaluation of all components

Task 2: scintillating fiber tracking

- study optical and mechanical properties of fibers and ribbons
- development and testing of avalanche photodiode arrays
- radiation hardness evaluation of all components

Task 3: mechanical engineering

- carbon composite cylinder design and prototype fabrication
- end plate design and prototype fabrication
- support structure design, assembly and alignment concepts
- WBS with cost estimate for complete HCTC detector

Task 4: Monte Carlo simulations

- detector response and pattern recognition studies
- optimization of HCTC parameters within SDC detector
- evaluation of neutron backgrounds in central tracking chambers

As our Progress Report has shown, we have made steady advancement in most, of the areas listed above. For FY1991 we have further strengthened our Collaboration. The addition of University of Pennsylvania, KEK and an electronics group from ORNL have made it possible for us to quickly evaluate and improve readout electronics. Mechanical engineering has always been a strength of the HCTC collaboration. ORNL will broaden their engineering contribution to the HCTC effort in FY1991.

The HCTC work will be coordinated with ongoing SSC Subsystem R&D efforts where useful. We will make direct use of the frontend electronics being developed by the Frontend Electronics Subsystem Collaboration (PC031, Williams, et al.) and by KEK. Rick Van Berg (University of Pennsylvania) and Hirokazu Ikeda (KEK), members of our collaboration, will expedite the transfer of electronics developed by these groups to our straw tube superlayer prototypes. We will cooperate with the straw tube work of the Wire Chamber Subsystem Collaboration (PC024, Hanson, et. al.) where possible. We note that the R&D work needed to develop the straw tube

modules being proposed by Hanson, et al., differs significantly from the HCTC concept, and therefore parallel R&D efforts are required. We will be working closely with the Scintillating Fiber Tracking Subsystem Collaboration (PC023, Atac, Elias, Ruchti, et. al.) since this group will also be developing scintillating fiber superlayers on carbon composite stable base cylinders. Finally, we have agreed to closely cooperate with a group proposing a new Subsystem Proposal (A Compact Central Tracker for the SSC, Ahlen, et. al.). This group also recognizes the advantages of the HCTC concept but will direct it toward an application in the smaller tracking volume of the L* detector.

1.3 HCTC development in FY1992

Our FY1991 R&D program will examine all the critical features of the HCTC design and will probably identify some areas needing further study. The details cannot be specified at this time, but the general program is clear. If the HCTC tracking system emerges as a viable option for one or more SSC detectors, we would construct at least one full-scale carbon composite cylinder with end plate rings. This cylinder would be used to develop and perfect the automated assembly of straw tube and scintillating fiber superlayers. We anticipate that major developments of front-end readout electronics will be continuing in FY1992 and these would be incorporated into the geometric constraints imposed by the end plates. In addition, we anticipate a need to continue a modest investigation of radiation hardness of plastic scintillating fiber, in view of the complexity and importance of this issue.

The FY1992 program would therefore produce one or more full-scale HCTC superlayers which would be partially instrumented for readout using state-of-the-art electronics. These superlayers would be subjected to a variety of mechanical, electrical and radiation hardness tests and their measurement performance evaluated in particle test beams.

2.0 Straw Tube Drift Chambers (Task 1)

In the HCTC design the majority of the precise, large-volume tracking is provided by straw tube drift cells. A central theme in the design is simplicity of mechanical construction (straw tubes laid axially on support cylinders). This will produce maximum overall measurement precision and, we believe, result in a detector which is of lower cost than other alternatives.

Because of the critical importance of straw tube superlayers to our design, a large fraction of the HCTC effort will be devoted to basic straw drift tube development (this task) and the mechanical engineering of support structures (task 3). This section describes our straw tube R&D program. The work includes the construction of superlayers on a cylinder and the development of realistic end plate rings containing gas flow, electronics and cooling. Electronics provided by Penn and KEK will be promptly adapted to and evaluated with our straw tube superlayers. We will continue our gas selection and aging studies, and the radiation hardness evaluation of all other superlayer components.

2.1 Straw tube construction

As described in the progress report, we have completed construction of a 2.7 meter long straw tube prototype array consisting of 60 tubes, 28 of which have been strung with sense wires. They are holding high voltage and signals are seen both from cosmic rays and beta and gamma sources using several different types of preamplifiers. We are in the process of instrumenting these signals with available amplifier-discriminators and CAMAC TDC's to do studies of the superlayer's resolution using cosmic rays.

We will also be conducting tests of amplifier-shaper circuits being developed at Penn and KEK as they become available. We have prototype chips from both Penn and KEK which have been mounted on circuit boards and have been connected to the readout end of the straw tube sense wires. The KEK chip has five channels and the Penn chip contains a single channel. For straw tube detector operation in the SSC environment it is important to reduce the operating voltage as much as possible. To achieve good resolution at the lower voltage the signal to noise of the amp-shaper-discriminator will have to be excellent; careful circuit board design will

be essential. We are relaying the results of our tests to the designers to assist in development of the next generation of circuits.

In the coming year we will continue to study manufacturing techniques for our sense wire support design with the help of private companies. Presently, we are evaluating prototype samples developed by an injection molded plastics company. Careful measurement with a microscope shows that the center of the spiral hole in the 2.5 cm long pieces is offset by about 120 microns. We have discussed this with the company and a second generation sample of 1.2 cm length is in design and production at this time.

The straw tubes we have used for the prototype array are constructed of 50 micron mylar with 12 micron aluminum cathodes. Tubes of different material and thickness are being studied. We will purchase several different types of tubes for electrical, mechanical and radiation hardness testing.

To reduce cell occupancy in the central tracking chamber it will be necessary to construct the superlayers of two half length arrays. In order to avoid the presence of additional material in the detector at the midpoint, we have devised a scheme to make a straw tube cell which is electrically composed of two isolated detectors but which is a single mechanical element, thus eliminating the need for wire tension support in the middle. Figure 2-1 illustrates the concept we intend to develop. This will require research and development in several areas. The sense wire will have to be constructed so it has a nonconducting segment in the middle with mechanical properties similar to the sense wire material (tensile strength, diameter, etc.). The sense wire on either side of the central insulator will have to be terminated to the cathode coating on the inside of the straw tube through about 300 ohms resistance. A capacitive coupling to provide an AC ground at the midpoint of the cell will also be necessary. We believe our scheme for terminating the wire at the midpoint will be a straightforward development task which we expect to complete over the coming year.

To facilitate studies of midwire termination schemes we will construct a ≥5 m straw tube cell. This apparatus will also be useful for extending our studies of signal attenuation.

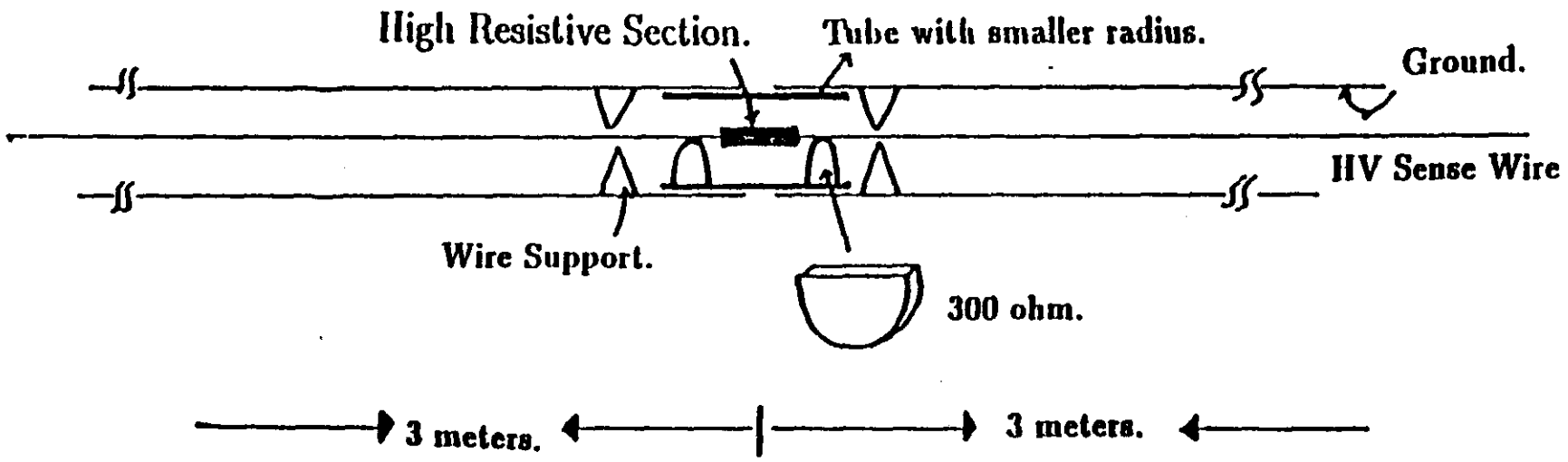


Figure 2-1. Conceptual representation of proposed mid-tube termination.

2.2 Superlayer construction

A major project for the coming year will be construction of a cylindrical prototype chamber at ORNL. The proposed cylinder is to be about 60 to 80 cm in radius and 3 meters long. After construction, it will be transported to Duke for straw tube assembly. The number of straw tubes to be attached to the cylindrical surface will be about 500, compared to 60 in the present prototype array (still 8 layers deep).

This project will demonstrate the ability to lay straw tubes on a cylindrical surface with precision alignment and will allow us to investigate methods of automating superlayer assembly as much as possible. We will also test end plate design for a superlayer on the cylindrical prototype. End plate design is critical since electrical, mechanical, cooling and chamber gas supply and power connection are done through the end plate. For the cylindrical prototype, the end plate design concept will be similar to that used on the present 2.7 m prototype array, consisting of two thin walls with a space between to serve as a gas supply plenum to the straw tubes.

Finally, we will test the first compact front end electronics packages from KEK and/or Penn, depending on availability. Emphasis will be on testing for cross talk and noise pickup. These will be directly influenced by the end plate construction.

2.3 Development and testing of straw tube readout electronics

2.3.1 Overview

An electronic readout system will be developed for a portion of the central tracking prototype. Because of the costs associated with constructing a full-sized cylinder made from composite materials and the costs of instrumenting a full-sized cylinder, it has been decided to construct a cylinder using a less expensive material and only instrument a portion of the channels for readout. Therefore, out of the few hundred straw tubes we plan to install, approximately half of these channels will be instrumented at any one time. We believe critical issues such as crosstalk, packaging, materials, and mechanical alignment can be addressed using this more cost-effective approach. The ultimate goal is to develop readout electronics modules that can be interchanged quickly. To that end we plan to implement the readout electronics in plug-compatible modules incorporating

custom integrated circuit (IC) designs from both Japan's National Laboratory for High Energy Physics (KEK) and the University of Pennsylvania (Penn). These modules will be interchangeable so data can be taken using both and a performance comparison can be made. A combination of commercial and full custom electronics will be used to acquire the data from the front-end electronics. A review of whether the sense wire should be at high voltage or at ground potential will be conducted and a final decision made. We will design inner-tube wire termination plugs which will permit the construction of long (>6 m) straw tube layers with no central end plate. Finally, we also plan to perform in-situ radiation tests both with gamma and neutron irradiation to investigate background noise and circuit degradation issues.

This electronics development program is directed specifically toward the readout needed for the HCTC straw tube superlayers. We intend to keep in close communication with two other groups developing straw tube detectors for the SSC. In particular, we plan to cooperate with a group proposing to develop a Compact Central Tracker (Steven Ahlen, et al.), which has features in common with our design. In addition, we will work with the Wire Chamber Subsystem Collaboration (Gail Hanson, et al.). However, the modular straw tube bundles proposed by this group will require end plates appreciably different than those proposed here.

2.3.2. Front-end electronics

The objective of the HCTC collaboration is to avoid development of custom integrated circuits if circuits being developed by other groups can be used. Therefore, the front-end electronics modules will be based on custom readout circuits developed at Penn and KEK.

The front-end architecture being considered from Penn is based on a preamp/shaper circuit that was implemented in a bipolar array technology from AT&T. Tests on this chip show a noise performance of ~1500 e- rms and a power consumption of ~10 milliwatts per channel. The enhanced version of this circuit will include not only the preamp and shaper but also a discriminator. Penn plans to include four channels of this preamp/shaper/discriminator configuration per chip and to fabricate the chips using a full custom bipolar process from Analog Devices. It is this new version of the Penn chip, packaged in surface mount or equivalent technology, that we would like to use for the work described here.

A readout module will also be designed and constructed using custom front-end electronics from KEK. One version of these chips has been fabricated using a Super Self-aligned Technology (SST) bipolar process from NTT and presently contain five channels per chip (preamp and shaper). The five channel chip has been tested at Duke using the 2.7 meter prototype chamber. Although the chip performed quite satisfactory, improvements are needed to be made in the areas of tail cancelling and overshoot. The results of our tests were sent to the designer and the next version will be better. A version with 16 channels of preamplifier and shaper will be fabricated and manufactured by Fall of 1990. At the same time, another version with discriminators and at least 8 channels of preamplifier-shaper is expected to be manufactured.

As soon as the chips are available (either from Penn or KEK), circuit boards will be designed to fit the 28 channel 2.7 meter prototype for the first test. If the test is satisfactory, then the circuit design for the cylindrical prototype will be started.

If these chips are not available within our time constraints we plan to pursue one of the following options:

1. Establish a joint NCSU/ORNL/Penn development to expedite the redesign or refabrication of the Penn circuits.
2. Use an earlier version of the Penn chip that does not have discriminators on-chip. This option means an increased overhead in components count (we would have to add discriminators and the density of channels/chip would be low) and increased design complexity.

2.3.3 High voltage and straw tube terminations

The high-voltage bias for the straw tubes will likely be between 1600 and 2000 volts dependent upon the gas used in the tubes. This voltage will be generated by an external power supply and will be applied to the straw tubes via limiting resistors. An issue that will be addressed concerns the method used for supplying the high voltage bias between the sense wire and the tube wall. Traditionally, high voltage is applied to the sense wire through a limiting resistor while the tube wall is held at ground. The resistor protects the supply in the event of a broken wire and prevents sustained arcing. The disadvantage of this scheme is that a physically large, high-voltage capacitor is required to couple the sense wire to the preamplifier. This capacitor will affect the mechanical design, may be a source of interchannel

crosstalk, and may add appreciable mass to the end plates. In contrast, if the high-voltage bias is applied to the tube walls, the sense wires can be DC coupled to the charge sensitive preamplifiers. It might be possible to introduce limiting resistors by using an anodized contact surface where the end plate contacts the aluminized surface of the tube. However, this approach may aggravate electromagnetic interference as the cathode does not act as a grounded shield. These and other related design concepts will be analyzed further.

Another issue that will be addressed involves the terminating resistors used to reduce signal reflections within the straw tubes. In present configurations using ~3 meter tubes, the terminations are done on one end and readout is done on the opposite end. Ultimately we would like to use 6 meter tubes that are electrically divided in half. This would allow readout on both ends but would require terminations inside the tubes. We are currently developing ideas about how this might be accomplished, as discussed in Section 2.1.

2.3.4. End-cap design

The concept of an end cap or end ring, on which to mount the readout electronics, will be demonstrated with this prototype. Although we plan to install only a few hundred straw tubes, we will construct a full 360 degree end cap. Provisions will be made to instrument the regions occupied with straw tubes using the readout electronics modules. This arrangement will allow us to verify our concepts of making contact with the straw tubes, properly terminating the straw tubes, and high-density packaging of readout electronics. The end cap design will be an extension of the termination/readout board concepts prototyped in FY90, as discussed in Part I: Progress Report for FY90.

2.3.5. Data acquisition

The custom front-end electronics being considered do not have the necessary timing functions built in. Penn is working on a TVC (time-voltage chip) and KEK is working on their TMC (time memory chip). In the event these chips are available within our time constraints we will evaluate them in our prototype system. If not, it is likely that we will use commercially available data acquisition hardware such as TDCs to process the timing data from the front-end electronics. Data acquisition for this prototype will be controlled by a CAMAC-based computer

system available at Duke. The complete data acquisition is shown conceptually in Fig. 2-2.

2.3.6. Issues and tradeoffs

The first issue to be dealt with involves the suitability of both the KEK and Penn chips for use in high density straw tube readout. Samples of both chips are currently being evaluated with a small number of straw tubes. In the event it becomes necessary, the distance between KEK and ORNL/NCSU will probably make it difficult to work closely with KEK to optimize and enhance their architecture for straw tube readout. In the case of the Penn chips, however, there is the possibility of a Penn/ORNL/NCSU collaborative effort to optimize the existing Penn architecture for use by the HCTC collaboration. It may also be reasonable to incorporate new features into this architecture especially suited to the HCTC design.

The second critical issue is the susceptibility of the straw tube system to electromagnetic interference (EMI). The detection scheme conventionally used is a single-ended (ground referenced) measurement, which is extremely sensitive to electromagnetic interference and noise in the ground lines. The feasibility of a fully differential approach will be considered where common-mode signals, such as ground noise and EMI, can be rejected (Fig. 2-3). The planned Analog Device versions of the Penn chips will have a true differential input facilitating this approach.

2.3.7. Testing plan

The electronic readout system will be bench tested at ORNL. After this phase of the testing is complete, the electronics will be shipped to Duke where they will be mounted on the end cap assembly and connected to the straw tubes. Electrical tests will be conducted at intermediate steps during the assembly process. After the end cap assembly is complete, the front end electronics will be interfaced with the data acquisition electronics. Testing of the complete electronics system will then be conducted. At this point, collection of test sets of data will begin using radioactive sources and cosmic rays. ORNL engineers and physicists from Duke will work together during the testing phases.

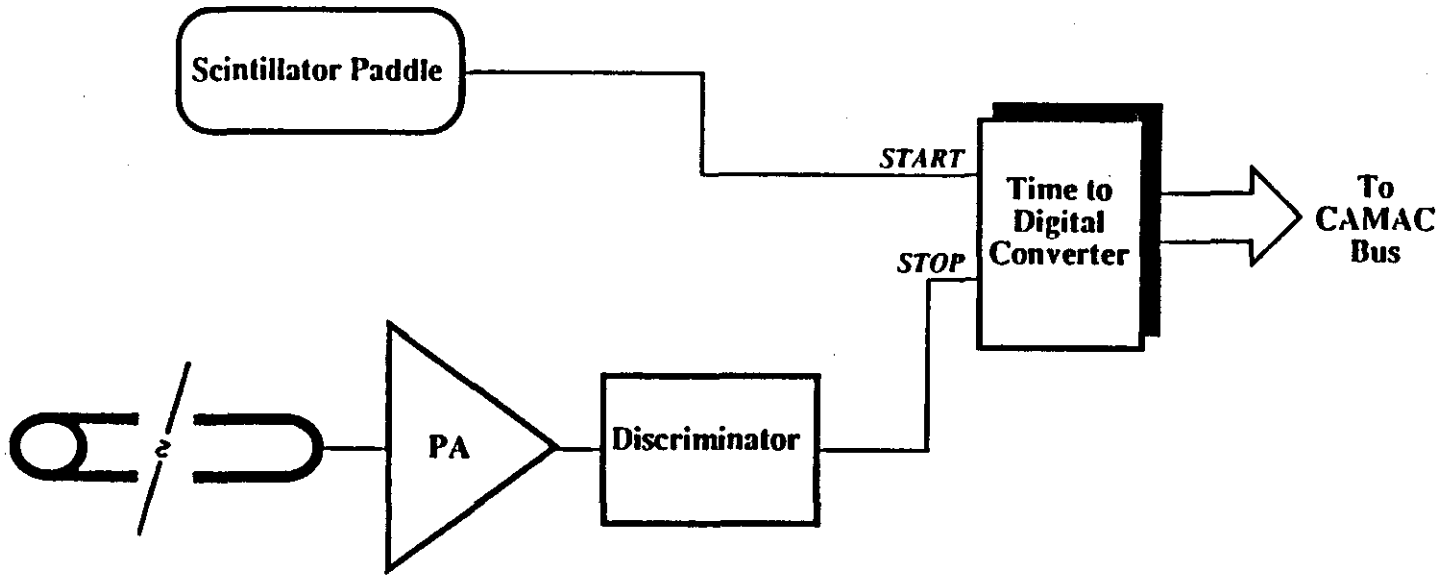


Figure 2-2. Data flow diagram.

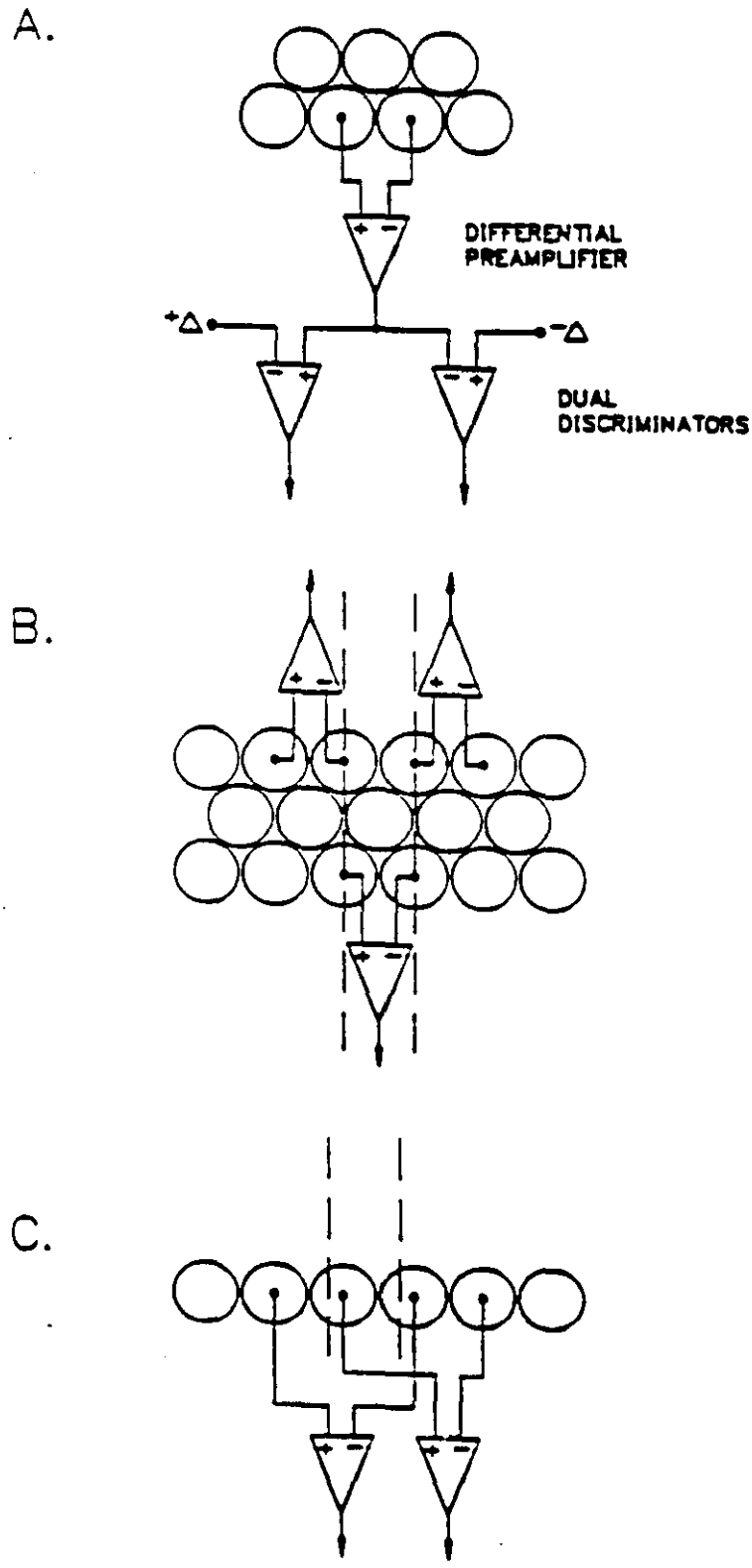


Figure 2-3. Possible schemes for differential preamplifier connections.

In parallel with the above tests, we will evaluate the effect of electron, neutron, and gamma radiation on the noise level and general performance of the front-end electronics. This work, which will be carried out by FSU, NCSU, and Quantum, is described in Section 2.5

2.4 Gas selection and aging studies

Our aging results from last year's work have established that the gas mixture CF_4/Isobutane (80:20) is an excellent candidate for use in Central Tracking Chambers at the SSC. The high cost of the CF_4/Iso mixture and the higher voltage necessary to operate at useful gas gains are possibly the only impediments to an unreserved recommendation of its use. The testing program proposed for next year will attempt to answer four questions:

1. Are there other gas mixtures containing CF_4 which retain the desirable characteristics (aging, drift velocity, specific ionization, etc.) but have a lower operating voltage?
2. Can CF_4 gas mixtures be recirculated without affecting the performance characteristics of the gas? If they can, operating costs could be cut by a factor of 10 or more.
3. Are there any as yet unseen aging problems caused by the exact geometry or materials used in the proposed HCTC when operated for extended periods in CF_4 gas mixtures?
4. What is the mechanism which inhibits polymer formation in some CF_4 gas mixtures?

Preliminary tests by one of our colleagues have indicated that the electron drift velocity in a gas mixture of Argon/Ethane/CF_4 (33:33:33) is adequate for use in the HCTC and has a lower operating voltage. We will be conducting aging studies of this mixture as well as mixtures of argon with isobutane and CF_4. We will of course remain open to testing any other promising mixtures suggested by any of the subsystem collaborations. Initial tests will be done at higher current densities in order to accelerate testing. Promising candidates will then be tested at lower more realistic rates for longer (6-9 month) durations. Tests will be conducted in our standard test cells, individual straw tubes, and small scale superlayer "clones" provided by other members of the collaboration. We will continue our practice of conducting many tests in parallel using identical source gas supplies, while keeping the number of parameters varied in any single test to a minimum. CF_4/Iso (80:20)

tests will be run in parallel as the standard to which other performance can be compared. Since many of the tests must be done at low ionization rates for long durations, conducting large numbers of tests in parallel is the only way to increase the number of tests which can be done in a fixed time. We have also found that careful parallel testing considerably simplifies the task of sorting out the many possible causes of aging effects.

A superlayer with 13,700 4-mm straws and a linear gas flow of 1 cm/sec will consume about 100 litres/min of gas. Since CF_4/Iso (80:20) costs approximately 23 cents/litre, this implies an operating cost of approximately of 12 million dollars per year. Even cheaper gas mixtures such as Ar/Et (50:50) would still cost ~1 M$/year/superlayer. A recirculation system with a 10% exhaust rate would result in savings of the order of 11 M$/year/superlayer with the CF_4/Iso (80:20) mixture. Clearly, recirculation of the detector gas should be given serious consideration. We have built 2 recirculation systems for Ar/Et (50:50) and Ar/Me (80:20) gas mixtures which have been used at TRIUMF in the TPC and RMC experiments. In addition we are currently designing a 100% recirculation system for a Xenon/Methane gas mixture for the HERMES collaboration at HERA. Our experience has been that the extra filtration and contaminant removal systems necessary for recirculating systems tend to improve the gas quality and aging performance in Ar/Et (50:50). However, because of the possibility of failing to remove damaging contaminants, adding new contaminants, or reactions between the gasses and the filtration systems of the recirculator, we believe it is prudent to test the aging performance of any new recirculated gas mixture. We intend to build a small (~2 litre/min) recirculator, and test the aging performance of CF_4/Iso (80:20) and other promising gas mixtures when they are recirculated.

A complete understanding of the chemical processes which lead some gas mixtures to form polymers, while others are resistant or even capable of etching polymers off of the electrodes would greatly simplify the task of selecting gas mixtures for high flux environments. The complexity of the chemistry involved in which many of the reaction cross sections have not even been measured makes such an understanding a distant goal. It is hoped however that through empirical studies such as those proposed here, combined with chemical analysis of the gas mixtures used, and analysis of any deposits formed, some understanding of the process can be achieved.

Several other groups are currently studying the problem of aging in detectors. We are in contact with John Kadyk's group at Berkeley and have informally agreed to cooperate and coordinate our research in a way which will be complementary and minimize unnecessary duplication of effort. The exact nature of the cooperative effort will be developed as the research proceeds. We have also been in contact with Steve Ahlen's group at Boston University, who are conducting gas studies for the L* collaboration. We intend to share results, and communicate frequently with this group as well. In particular we understand they will be studying drift velocities and magnetic field effects in various gas mixtures. We intend to test the aging properties of any new potential gas mixtures arising from their research.

CEBAF will perform complementary aging studies, and possesses the major components necessary to carry them out. For FY90, CEBAF requests only $2,000 in additional funding, to cover costs for various miscellaneous detector and gas system mechanical parts (connectors, valves, etc.).

2.5 Radiation hardness studies

In project year two, Quantum and NCSU will continue their joint radiation damage testing of straw tubes and glues, and will initiate tests of prototype straw tube electronic devices for radiation damage. The testing of electronics will include performance testing during neutron and photon bombardment. In addition, Quantum will perform neutron slowing-down calculations, benchmarking against neutron dosimetry measurements carried out by NCSU, in order to further characterize the neutron spectrum in the reactor irradiation port. This information will be used in conjunction with ORNL work – intended to more completely characterize the radiation environment in the central tracking region of an SDC-like detector (see Section 5.6) – to determine equivalent displacement damage between the reactor spectrum and the SSC spectrum.

The following second-year reactor irradiation testing program for straw-tube components is planned:

- Further testing of straws and glues in order to identify the threshold for measurable degradation of performance. Preliminary indications are that the glues exhibit slight, but detectable, loss of adhesive power at neutron fluences of about 10^{15} cm^{-2}, fast, and 10^{16} cm^{-2}, thermal. We would like to repeat the tests at reduced fluences to see where the damage threshold is.

- Testing of at least one alternative glue, which has high aromatic content and known radiation resistance.
- Irradiation of straw-tube prototype electronic devices (developed by NCSU/ORNL/Penn) to verify design hardness and to investigate the effects of mixed-field exposure on electrical performance. This will involve two types of tests: pre- and post- irradiation testing to determine the extent of residual damage, and device monitoring under bias during irradiation. The electronics testing will be carried out at different fluxes, in order to investigate rate effects.
- Irradiation and testing of a small assembly of straw tubes with end caps, central wires, and (static) filling gas. The assembly will be glued together using one or more of the candidate glues, and will be tested using a radioactive source before and after irradiation. The total fluence will be on the order of 10^{15} cm^{-2} fast neutrons.

NCSU will build an additional sample-holder capsule, which is required because of the significant ^{28}Al production in the aluminum capsule during the high-fluence exposures. This will allow sequential tests to be performed, irradiating a second sample while the short-lived ^{28}Al is decaying in the first capsule. NCSU will also perform supplementary neutron dosimetry to benchmark Quantum's slowing-down calculations.

Studies have shown that the neutron *energy spectrum* is peaked just above 1 MeV, and so there has been strong interest in fast neutron damage studies. However, the neutron flux (as opposed to energy times flux) will be much flatter; we thus contend that there will be a broad spectrum of neutrons present in the central tracking region of an SSC detector and that testing should involve neutrons at all energies from thermal to several MeV. A ^{235}U fission spectrum (see Fig. 2-4) is thus quite suitable for damage testing of SSC components. We will attempt to identify spectral effects by filtering out parts of the spectrum, using absorbers such as cadmium. We will also compare the reactor spectrum (a partially thermalized version of Fig. 2-4) with spectral predictions developed by ORNL (see Section 5.6) for the SSC. In addition, we will irradiate with gammas only, by exposing samples to the fission fragments in the reactor core with the reactor shut down, and compare with results from the mixed neutron-gamma exposures. This testing program will allow a fairly comprehensive analysis of neutron and ionizing radiation effects on straw tube components.

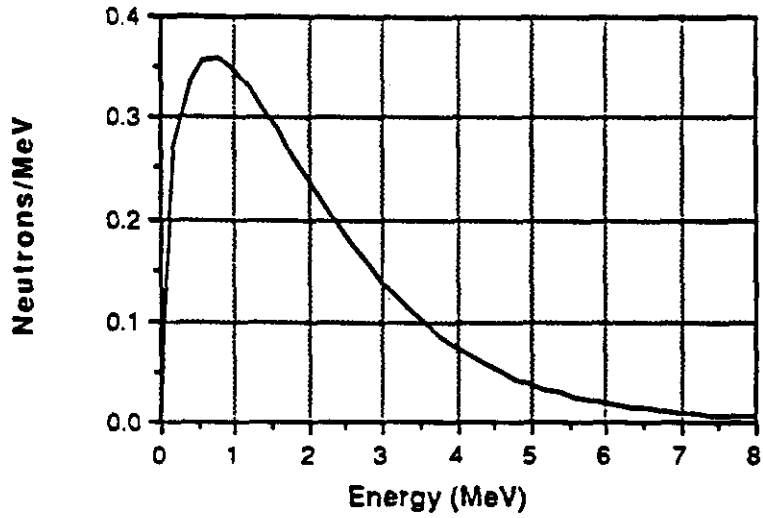


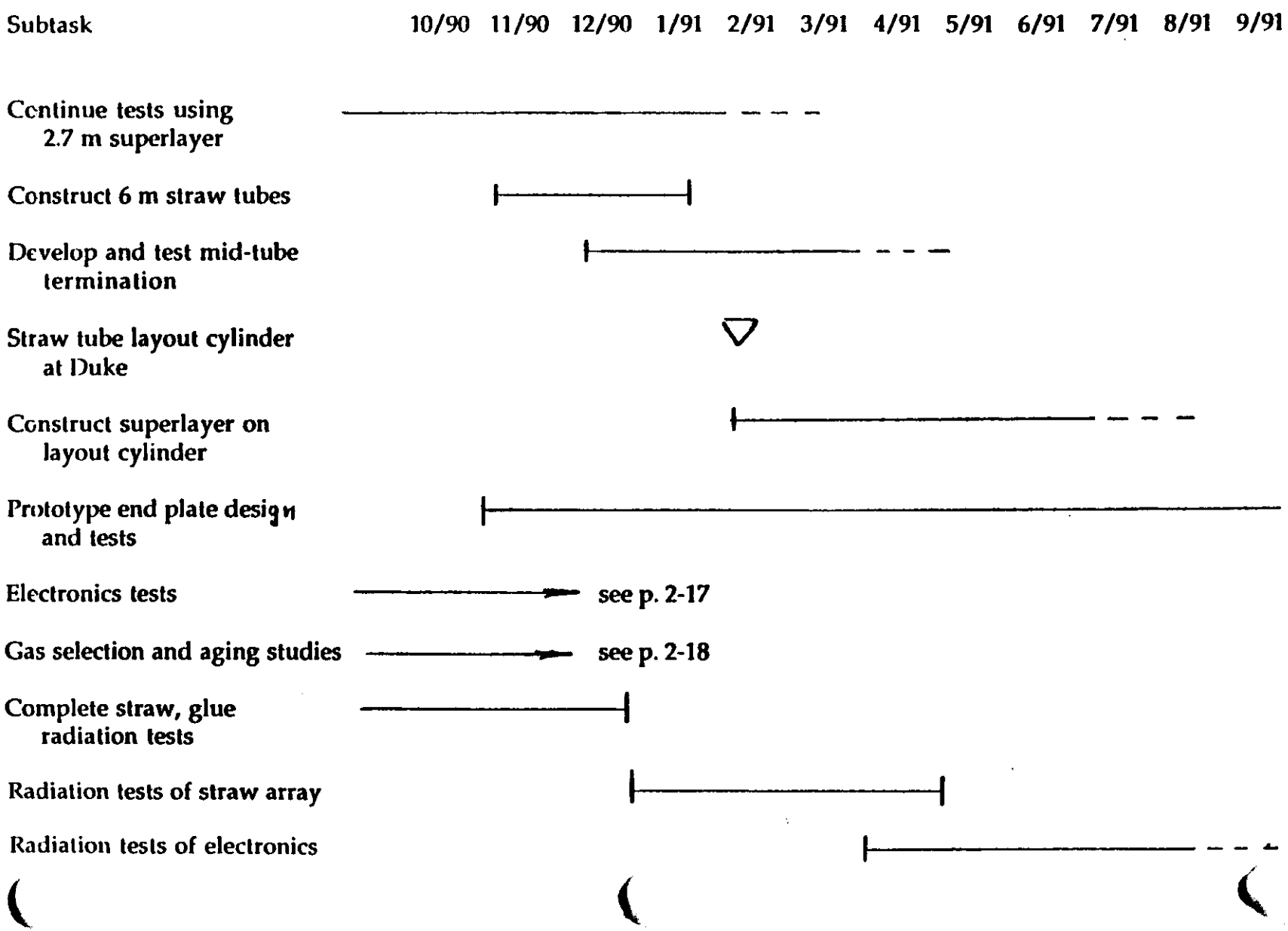
Figure 2-4. Uranium-235 prompt neutron fission spectrum.

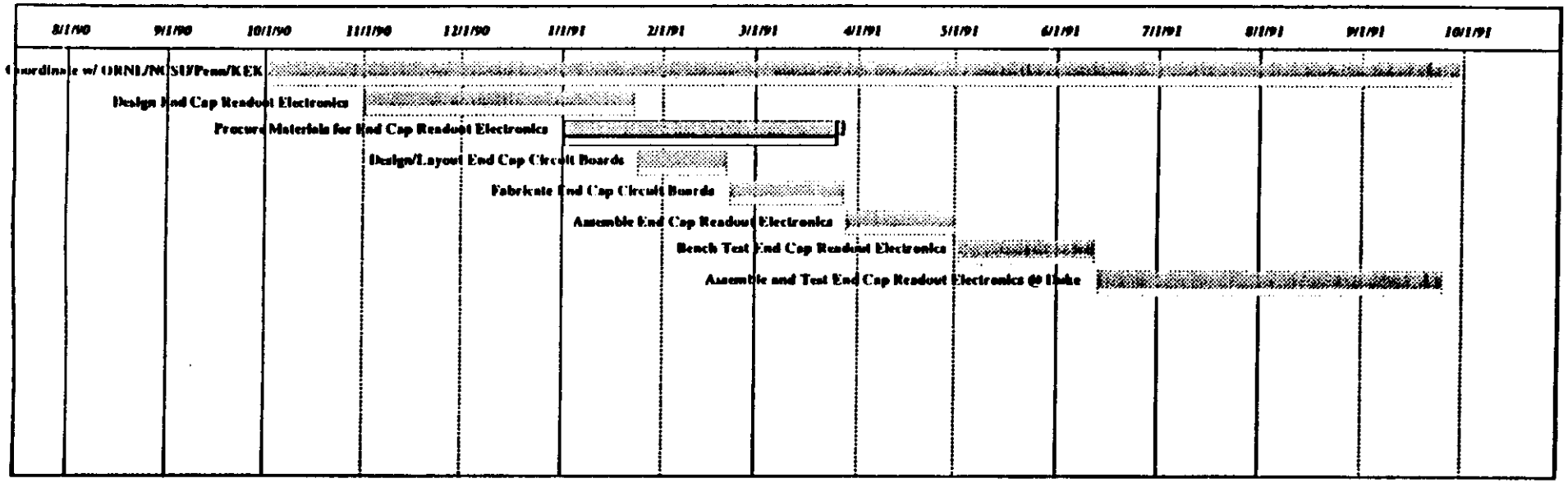
2.6 Task timeline

A task timeline is shown on the following page.

HCTC Timeline FY1991

Task 1: Straw tube drift chambers





Schedule for Strawtube Electronics R&D Activities

Gas

ACTIVITY SCHEDULE -- AGEING TESTS

ACTIVITY	MONTH 1	MONTH 2	MONTH 3	MONTH 4	MONTH 5	MONTH 6	MONTH 7	MONTH 8	MONTH 9	MONTH 10	MONTH 11	MONTH 12
BUILD RECIRCULATOR	<---------->											
TEST RECIRCULATOR		<---------->										
AGEING TESTS CF4/ISO 80:20 RECIRCULATED			<---------->									
AGEING TESTS ALTERNATE GASSES RECIRCULATED						<---------->						
HIGH RATE AGEING TESTS AR/ET/CF4, AR/ISO/CF4, OTHER CANDIDATES	<---------->											
AGEING TESTS CF4/ISO IN STRAW TUBES	<---------->											
AGEING TESTS AR/ET/CF4, ALTERNATES IN STRAW TUBES	<---------->											
LOW RATE AGEING TESTS SELECTED GASSES				<---------->								
AGEING TESTS CF4/ISO AND SELECTED GASSES IN SUPERLAYER "CLONES"				<---------->								

3.0 Scintillating Fibers (Task 2)

The plastic scintillating fiber (PSF) research task associated with the HCTC collaboration will concentrate on four study areas. We shall continue to evaluate the optical and mechanical characteristics of individual fiber samples and aim at the selection of tracker fiber type by the end of 1990. We shall continue to investigate ribbon manufacture alternatives. We shall continue our evaluation of the avalanche photodiode as a fiber readout device. We shall continue in-depth radiation hardness studies of both fiber samples and readout devices. All of these are discussed in the following along with a timeline estimate of this research task.

3.1 Fiber studies

We intend to purchase substantial quantities of PSF from all of the 4 vendors (Bicron, Kurary, Optectron and NE). Our work this past few months with the free samples provided by these vendors allows us to select fiber types which should be adequate for our tracking purposes. A small sample of PSF cannot, however, yield statistically significant results and cannot give any feeling for the reliability of fiber characteristics over the kilometers of fiber needed to build a tracking system. With the large purchased samples, we shall continue to evaluate the optical characteristics (photon yield and attenuation length) of individual fibers and the dimensional stability over large fiber distances.

Our aim is to select (by the end of 1990) fiber types which provide adequate light yield, have a large enough attenuation length and have a good enough size tolerance to be suitable for manufacture of fiber ribbons which can then be positioned on the HCTC support structure.

3.2 Ribbon fabrication and superlayer construction

In parallel with our fiber studies we shall investigate the alternative ribbon manufacturing techniques. To date we have used ribbons made from fibers rolled onto a grooved drum from the fiber spool (in both the L3 experiment at LEP and in E774 at Fermilab). The fiber size tolerance and straightness was ~10% of the fiber size in these ribbons and we plan to improve that by at least a factor of 2 for the HCTC application.

Other ribbon fabrication techniques have been discussed with our PSF vendors. These include laying individually cut fibers of the proper length onto a grooved master plate and laying up to 100 fibers at once (from 100 spools fed through an alignment comb) onto an adhesive surface.

We intend to purchase several prototype ribbons from each of the PSF vendors and test them thoroughly in our laboratory to determine the location of each fiber in the ribbon.

In addition to mono-layer ribbons, we also intend to investigate the problems associated with the manufacture of a multi-layer ribbon. With round cross-section fibers, in principle the nth fiber layer will position itself in the grooves between fibers of the $(n-1)^{th}$ layer. Again, we intend to test this in the laboratory to see if the needed fiber precision is maintained in a multi-layer ribbon.

3.3 Development and tests of readout devices

Our initial work with single devices indicates that the avalanche photodiode (APD) is a device well-matched to the readout needs of small core scintillating fiber. The device itself is inexpensive and compact and does not need sophisticated electronics – especially when it is operated in Geiger mode. The dark current noise problems are minimal even when operated at room temperature. The only potential problem we have encountered is an increase in the dark current after subjecting the device to a modest neutron environment ($\sim 4 \times 10^6$ cm^{-2} fast neutrons). This is a soluble problem which simply dictates that the location and/or shielding of the APD has to be carefully chosen to avoid excessive neutron exposure.

We intend to continue to investigate the APD as a PSF readout device. By the end of 1990 we should be testing a 4 APD array and we would like to quickly work up to 128 or 256 APD arrays and investigate, in collaboration with GE (our APD supplier), the cross-talk, alignment and packaging problems of such arrays.

3.4 Radiation hardness studies

Radiation hardness of plastic scintillators is a critical issue, not only for PSF in central tracking and calorimetry applications but also for bulk scintillator in a variety of possible SSC applications. As is well known, many variables (e.g.,

temperature, gas atmosphere, base polymer, clad material, UV exposure, time since irradiation) affect hardness, and simple answers concerning scintillator suitability for SSC applications are not yet available. In recognition of these facts, the HCTC collaboration has assembled a strong group of researchers interested in PSF hardness and proposes in the second year to undertake a broad-based, coordinated investigation of this matter. One aspect of this coordinated investigation that should prove useful is that a common set of fibers will be tested by each of the groups equipped to do so on a regular (probably quarterly) basis. This will help insure consistency and reproducibility of results.

Although all hardness issues will not be resolved within the next year, we anticipate that we can make excellent progress both in understanding the interplay of the many variables that affect PSF hardness and in evaluating a wide variety of fibers from several manufacturers. It is our intention to test fibers from four sources (Bicron, Kurary, NE, and Optectron), and to down-select a list of several promising fibers for further intensive study.

Five institutions will be actively involved with this effort: CEBAF, FSU, NCSU, Quantum Research Services, and TRIUMF. Quantum will coordinate the radiation hardness studies, in view of its proximity to Duke and NCSU and its close ties with Northeastern University (Quantum is a collaboration member with NU on the TEXAS EOI). This coordination will take the form of collecting and distributing information among the various institutions, which will independently conduct their own programs. In addition to the researchers involved in last years work, Dr. Thomas S. Elleman (a Chemist by training and currently Professor of Nuclear Engineering) of NCSU will assume an active research role and TRIUMF, in addition to it gas aging studies, will investigate some fiber and electronic components. The proposed efforts of the various groups are briefly discussed below.

3.4.1 CEBAF

We will continue our current program of performing high dose rate irradiations of prospective fibers (utilizing the 3 MeV electron beam facility at Florida State University in collaboration with Dr. Kurtis Johnson), and continue our new and important studies exploring the consequences of low-dose-rate irradiations of the same types of fibers (utilizing the ^{60}Co sources of the Reactor Facility at the

University of Virginia). These will provide an appropriate comparison of results obtained with low dose rate neutron irradiations carried out by Quantum Research Services, Inc.

We have a need for another fiber scanner of a similar design to that being used. First, this device was constructed with minimal funding via CEBAF. As a result, although decent results can be obtained, there are some deficiencies in the design whose improvement could result in a device with improved accuracy, precision, and ease of use. (In addition, other CEBAF groups require the use of a dedicated scintillator plate scanning device for their own attenuation and light output measurements.) Hence it would be wise to plan for the construction of another dedicated fiber scanner that also makes up for the shortcomings of its predecessor. We ask $2.5K for the design and construction of this improved scanner. In addition, we request an additional $7K for purchasing a Macintosh IIx computer system (including a control card for the stepper motor on the scanner) that will act both as the control for the scanner, and be used for the analysis of the data. The required software is available at CEBAF, or can be developed.

Furthermore, we require funding for the use of facilities such as the Reactor Facility at the University of Virginia. This will cover the cost of travel, labor, design and construction of any special equipment (sample holders, dosimetry, gas delivery) required for low (and possibly high) dose-rate irradiations. We ask $2K to cover these expenses. Finally, we require some travel funding to attend HCTC collaboration meetings and appropriate SSC workshops and symposia. We ask $1.5K to cover these travel costs.

3.4.2 Florida State University

In the past, most of our radiation damage study effort was concerned with the evaluation of various fibers supplied by industry. The number of photons that a one millimeter fiber produces (e.g., BICRON G) is sufficient, if the detection medium has over 60% quantum efficiency. If the efficiency is closer to phototube efficiency of 20% to 25%, then the number of photons are marginal. We propose to continue our effort with industry to formulate new materials that will increase the number of photons without compromising the radiation hardness. The next major project is the evaluation of fiber ribbons and connection to clear fibers to be able to

get the light signals out. Approximately 20% to 30% of our total SSC effort on scintillator work will be devoted to the HCTC collaboration.

3.4.3 North Carolina State University/Quantum Research Services, Inc.

In last year's effort, NCSU primarily provided neutron irradiation services, including sample cannister construction and neutron dosimetry; this year, Dr. Thomas S. Elleman, Professor of Nuclear Engineering, intends to take a more active research role, especially with respect to PSF hardness. Last year, Quantum planned the APD and PSF irradiation program, defined the design specifications for the irradiation cannister, interfaced with NU, GE, and NCSU, and analyzed the test results; this year, Quantum will supplement those functions with some spectral and damage calculations. Because NCSU and Quantum, which are only about 20 miles apart, will work together so closely, their efforts are described together below.

The primary emphasis will be on mixed-field (neutron-photon) irradiations; however, some strictly gamma-ray exposures (from the shut-down reactor core) will be included in order to isolate effects between neutrons and photons. We have some indication that neutron fluences of about 10^{16} cm^{-2} or greater can cause severe physical effects – even disintegration – of polystyrene, which is used in many fibers as a base polymer. Although such fluences are higher than those expected in the HCTC, we want to see if neutron damage is fundamentally different from photon damage or whether – as Groom suggested at the FSU workshop on plastic scintillator – the damage mechanisms are so similar that neutron fluence can simply be scaled to an equivalent ionizing radiation dose. We should be able to answer this fundamental question by the end of FY91. We also want to investigate neutron spectral effects.

Quantum will perform neutron slowing-down calculations, in order to more fully characterize the neutron spectrum at the irradiation port used. These calculations will be benchmarked against a set of neutron dosimetry measurements that will be carried out by NCSU. The groups will also perform gamma-ray dosimetry measurements and calculations, in order to adequately characterize the photon spectrum. This is more difficult than for neutrons, partly because the neutron fluxes and spectra tend to scale directly with reactor power whereas the

photon doses, which are dependent on complicated fission-product half-lives and production rates, do not.

Another major emphasis will be to down-select from a rather diverse set of fiber types, provided by four manufacturers, a smaller set of the more promising candidates. This will allow a more thorough test program to be carried out, in a systematic fashion, than could be accomplished with a large number of fiber types. Also, by studying the short list, it may be possible to identify chemical, manufacturing, or other characteristics that are favorable, thus guiding the direction of future fiber development efforts.

Specific components of the second-year PSF hardness testing program planned by NCSU/Quantum include the following:

- Comparison of extent of damage among a large group of fiber types irradiated to similar neutron fluences and gamma doses.
- Repeating some of these tests with cadmium filters to remove the thermal neutrons, in order to ascribe damage to an appropriate part of the neutron spectrum.
- Calculation of equivalent displacement damage within the fibers for the reactor spectrum and the expected SSC spectrum, and investigation of scintillator damage processes, with a goal of identifying structures that are potentially more radiation resistant.
- Exposure to the reactor core with the reactor shut down, to isolate gamma-ray effects.
- Irradiation to the same total fluence at different reactor powers, to assess rate effects.
- Comparison of fibers irradiated in oxygen-rich (air) and oxygen-free (argon) atmospheres.
- Annealing and recovery studies; potential for recovery through annealing at less than 50 °C, and testing of PSF after nominal heating.

We also plan to perform confirmatory testing of APD arrays, to verify that their damage thresholds are similar to those of the single APD's, at about 4×10^6 cm^{-2}, fast neutrons.

3.4.4 TRIUMF

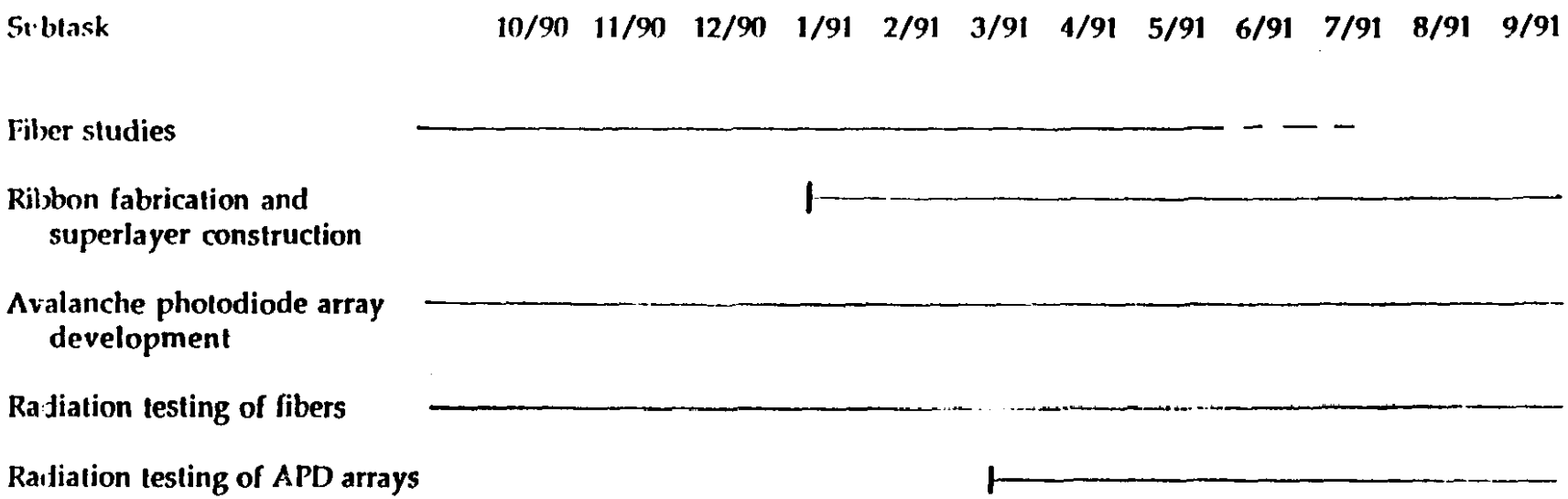
We have purchased a new set of avalanche photodiodes with better light collection properties, which will arrive at TRIUMF in the near future. We plan to measure gain, noise and other important properties of these devices. We will also be conducting tests on a new series of scintillating fibers with better efficiency and emission spectra at longer wave lengths. These fibers should make better use of the superior quantum efficiency of the photodiodes. Several improvements in the measurement apparatus are currently being implemented. In particular, a better electronics system with reduced noise is being employed to amplify the diode signals.

3.5 Task timeline

A task timeline is shown on the following page.

HCTC Timeline FY1991

Task 2: Scintillating fibers



4.0 Mechanical Engineering (Task 3)

Continued development and refinement of the Hybrid Central Tracking Chamber (HCTC) will require significant mechanical engineering design. This section of our proposal discusses those items which have been identified as critical issues to be addressed in the coming year. These include the fabrication of a simple straw tube layout cylinder and end plate to be used for perfecting straw tube layup techniques and for assembly and automation studies. This layup cylinder and end plate will not be made from the carbon composite in order to speed up construction. In addition, design studies of the complete stable base cylinder will continue along with fabrication of a small prototype carbon composite cylinder for material and fabrication studies. The design and fabrication methods for the production of the end plates will be improved. Evaluation of these items will determine the requirements for individual superlayers. Additional studies will be required at the system level, including support structure design for interconnecting the superlayers and for the connection of the HCTC to the external detector structure. The final area that has been identified for engineering support is cost estimating. This will be essential in determining a realistic cost of the entire HCTC.

4.1 Straw tube layout cylinder

The HCTC collaboration has constructed a prototype section of a straw tube superlayer on a flat, aluminum surface. In order to more accurately model an actual superlayer, a similar project needs to be executed on a cylindrical structure. The straw tube layout cylinder mentioned above will provide this structure. This can be constructed quickly and at relatively low cost. The proposed cylinder, approximately 60 to 80 cm in radius and 3 meters long would be fabricated from a thin, lightweight metal (see Fig. 4-1). Its surface finish would simulate that of a composite material. The layout cylinder would be mounted on a spindle arrangement to allow rotation, and provided with a means of fixing rotational steps. The ends of the cylinder will be designed to accept two full end plate rings.

The end plate section for the straw tube layout cylinder will be fabricated from a lightweight material and fixed to the end of the cylinder. The end plate cross section will be machined to match that of the proposed HCTC end plate so that compact electronic installation can be tested. It will also provide passages for ion gas and

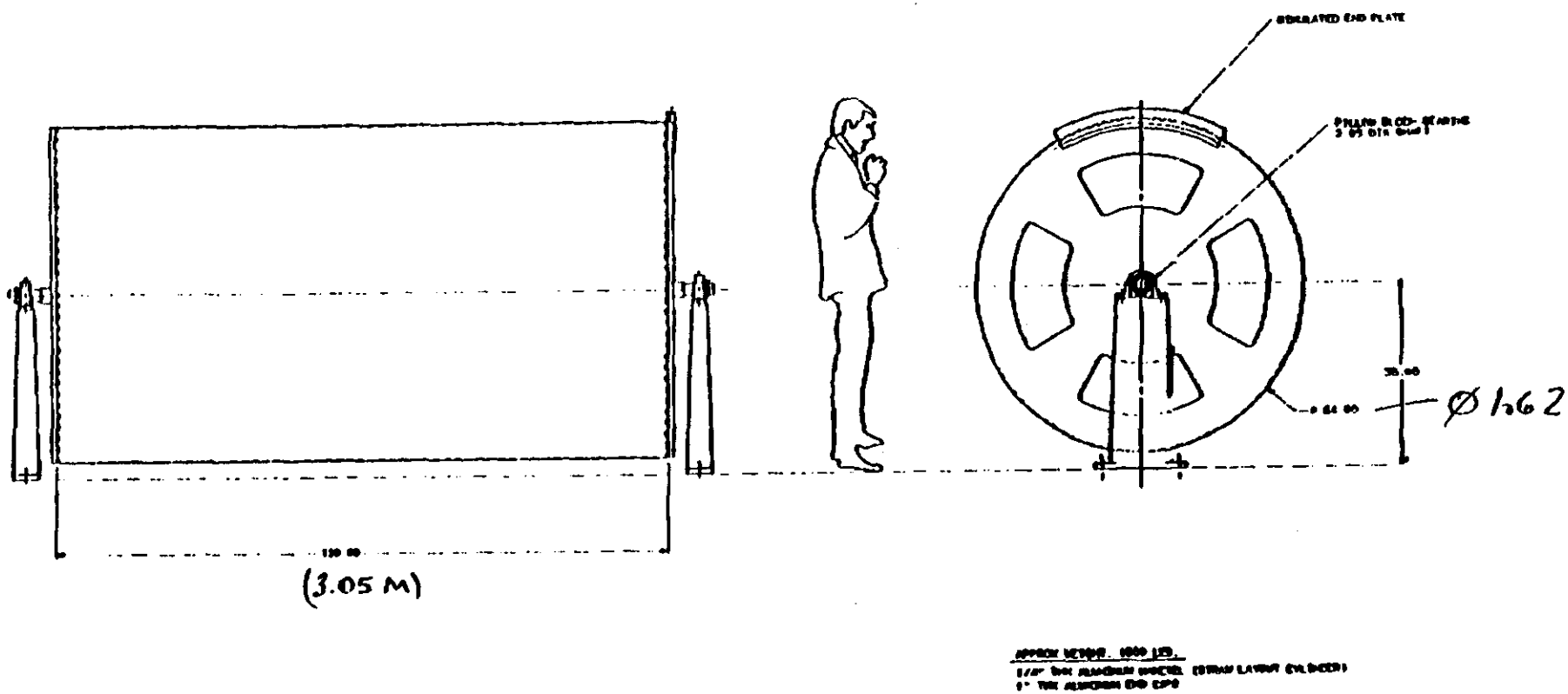


Figure 4-1. Straw tube layout cylinder.

electronics cooling fluid. The end plate will also be drilled to accept a number of straw tubes arranged in a production sequence. An end plate section will be fabricated for each end of the cylinder to allow an actual superlayer section to be fabricated, assembled and tested.

The straw tube layout cylinder will also be used for assembly and automation technique studies. Various mechanical components to locate and position straw tubes onto the cylinder will be tested. This portion of the testing will be done in parallel with design efforts pertaining to the assembly and automation issues.

4.2 Carbon composite cylinder design and prototype fabrication

The stable base cylinder which is to be composed of a carbon composite remains the single most important component in the success of the HCTC. This device must provide structural support and alignment for every other component associated with this tracker. Preliminary design studies of the stable base cylinder were discussed in detail in the accompanying Progress Report. These show the general soundness of the stable base cylinder concept. This proposal for FY91 includes continued design and analysis of this cylinder, as well as the production of a prototype carbon composite cylinder. The primary issues to be addressed with the cylinder are how to optimize the material thickness for minimum radiation lengths, and how to produce a structure with very large overall dimensions but with minimum creep and sag. The cylindrical design and prototype fabrication will be instrumental in proving that these concerns can be eliminated or minimized. We are confident that our approach will result in a cost effective design for meeting performance requirements.

One proven approach to fabrication of such a stable base cylinder is described below.

Step 1. Tooling in the form of a rotatable cylinder is manufactured to the required cylinder size and tolerances.

Step 2. The cylinder is mounted in a winding machine which controls rotation and feeds fibers and adhesive onto the cylinder in a controlled manner to produce winding layers at orientations to meet engineering established mechanical property requirements.

Step 3. The first (inner) shell layer is wound.

Step 4. After the first layer is complete, a foam core is added on top of this layer.

Step 5. The foam core is machined to tolerances.

Step 6. A second (outer) shell layer is wound.

Step 7. A sacrificial layer of material is added.

Step 8. The outer surface is machined to final tolerances providing a very flat surface for mounting the straw tubes or scintillating fibers.

The design and material selection of the carbon composite laminate, and core and foam materials are achieved by an iterative process which will take into account structural requirements as well as availability of materials to build that structure. The selected materials will be especially highly radiation resistant and adequate testing of all materials will be accomplished to verify performance against requirements.

The ultimate fabrication of all the above components will require some preliminary attempts to assure the success of the fabrication and to avoid jeopardizing loss of investment and materials at this stage. The fabrication process will of course require sequential operations that must be successfully and carefully performed. These specific processes are quite labor intensive and studies will be made to determine means of reducing this cost.

Other approaches to produce a stable base cylinder will be investigated and the most cost effective one selected for design and fabrication of the cylinders and other structure. A cross sectional view of the carbon composite stable base is given in Fig. 4-2 and shows the various components as well as the straw tubes.

4.3 End plate design and prototype fabrication

The termination point for all straw tubes is the end plate. An end plate is illustrated in Fig. 4-3. The end plates must provide registering for the straw tubes as well as supply them with all electrical and mechanical services. Additionally, the end plates will play a significant structural role in the HCTC design. These components will provide structural stiffening to the stable base cylinders and also provide attachment points for structural ties to the remainder of the tracker. For

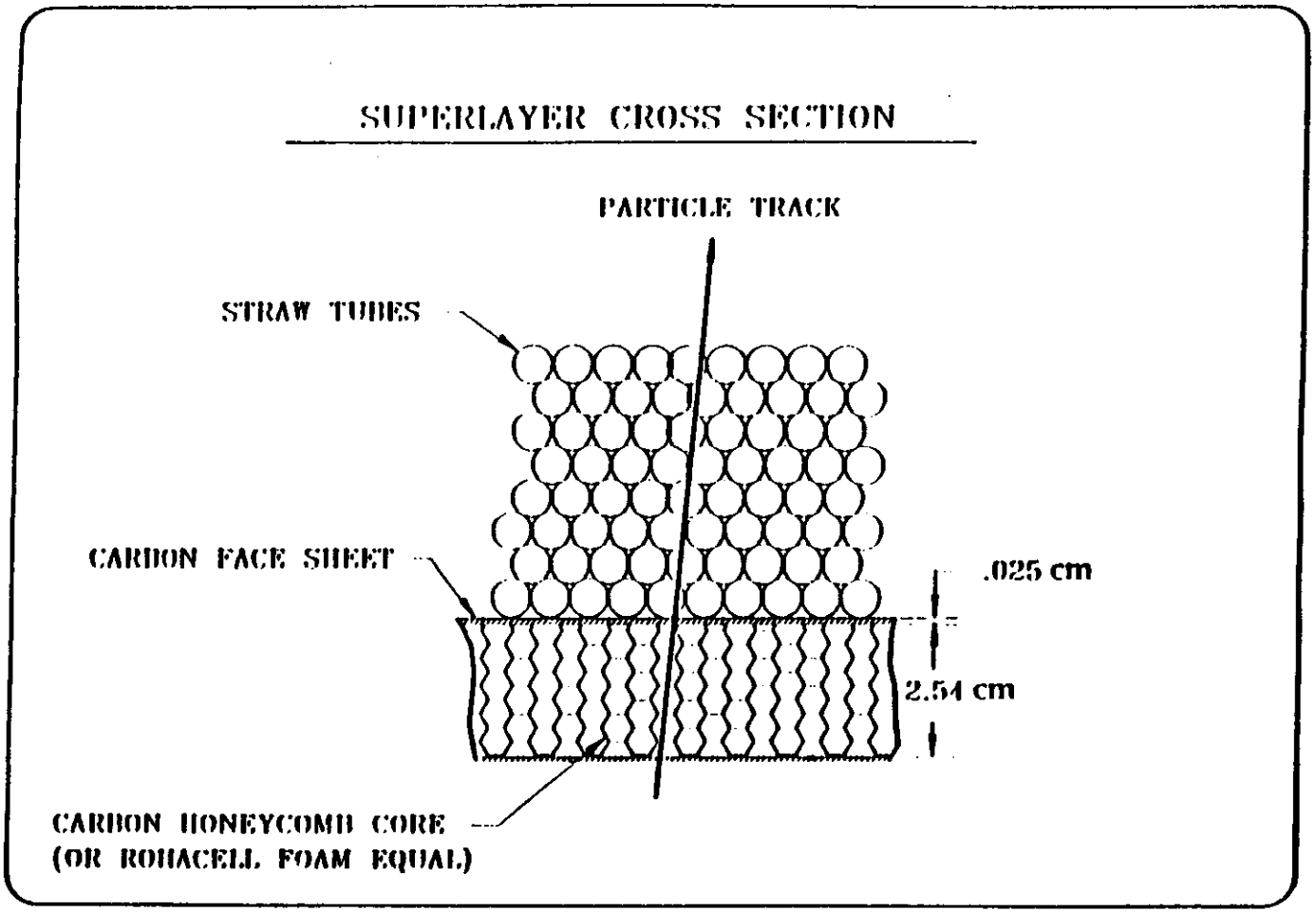


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Figure 4-2. Composition of a carbon composite stable base cylinder (preliminary design).

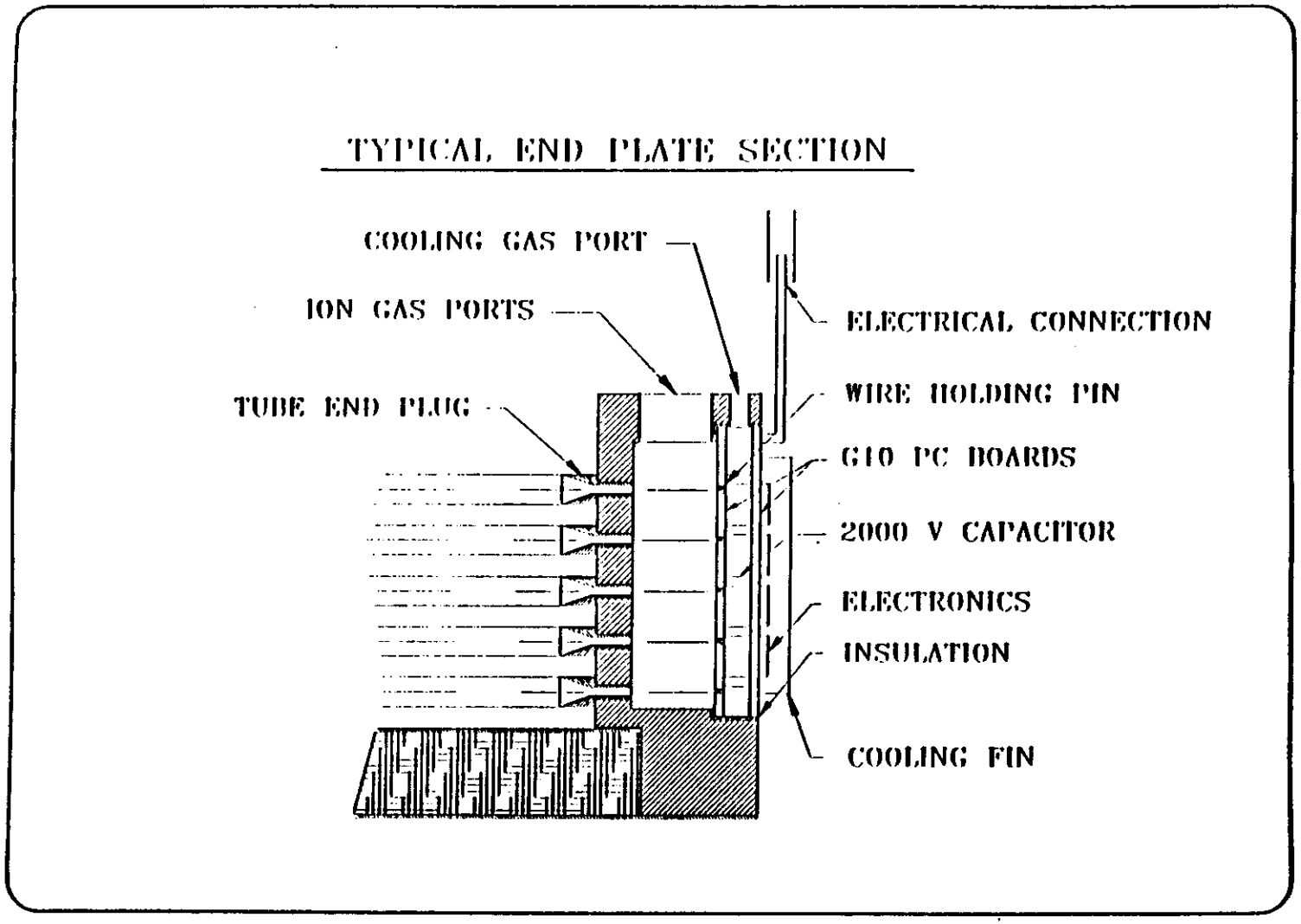


Figure 4-3. The end plate of the tracker indicating gas flow chambers, ion gas ports and electronics.

these reasons, it is proposed that additional design and fabrication work be performed to complement the functional work that is currently under progress.

There are several components to the end plates. The end plate assembly contains straw tube terminations, sense wire terminations, multiple electronics boards, ion gas supply for the straw tubes, cooling fluid supply for the electronics and a number of other items. It must also include a minimum amount of material to reduce the radiation length in this very busy region of the HCTC. The design work will provide guidelines for development and a fabricated prototype will enable us to test the suitability of our design concepts.

4.4 Support structure design

The above tasks deal with the superlayer level of the HCTC. From the perspective of the overall structure, support must be provided to integrate the superlayers into a single rigid assembly. Preliminary design work has indicated that a conical structure intersecting each of the superlayers is the most efficient way to accomplish this interconnection (see Fig. 4-4). In order to verify these concepts, an analysis is required that will model the entire tracker as a system and provide load paths and stresses for each component. This analysis will be done in conjunction with a 3-dimensional design and layout work on support structure concepts. The overall package should provide a high degree of confidence that this is indeed a viable proposal.

4.5 Assembly and alignment concepts

A significant portion of the proposed manpower for FY91 is committed to studies and simulation of assembly and automation techniques. It becomes obvious upon examining the quantity of components associated with the HCTC that a completely manual assembly would be extremely time consuming and expensive. To deal with this reality, the prospect of automated assembly and alignment becomes a necessity. A breakdown of the components identifies the areas where these techniques would be most beneficial. These areas include the straw tubes, the sense wires and their connection requirements, and the scintillating fibers. In conjunction with the straw tube layout cylinder outlined above, we propose to develop devices or processes that would expedite the assembly process.

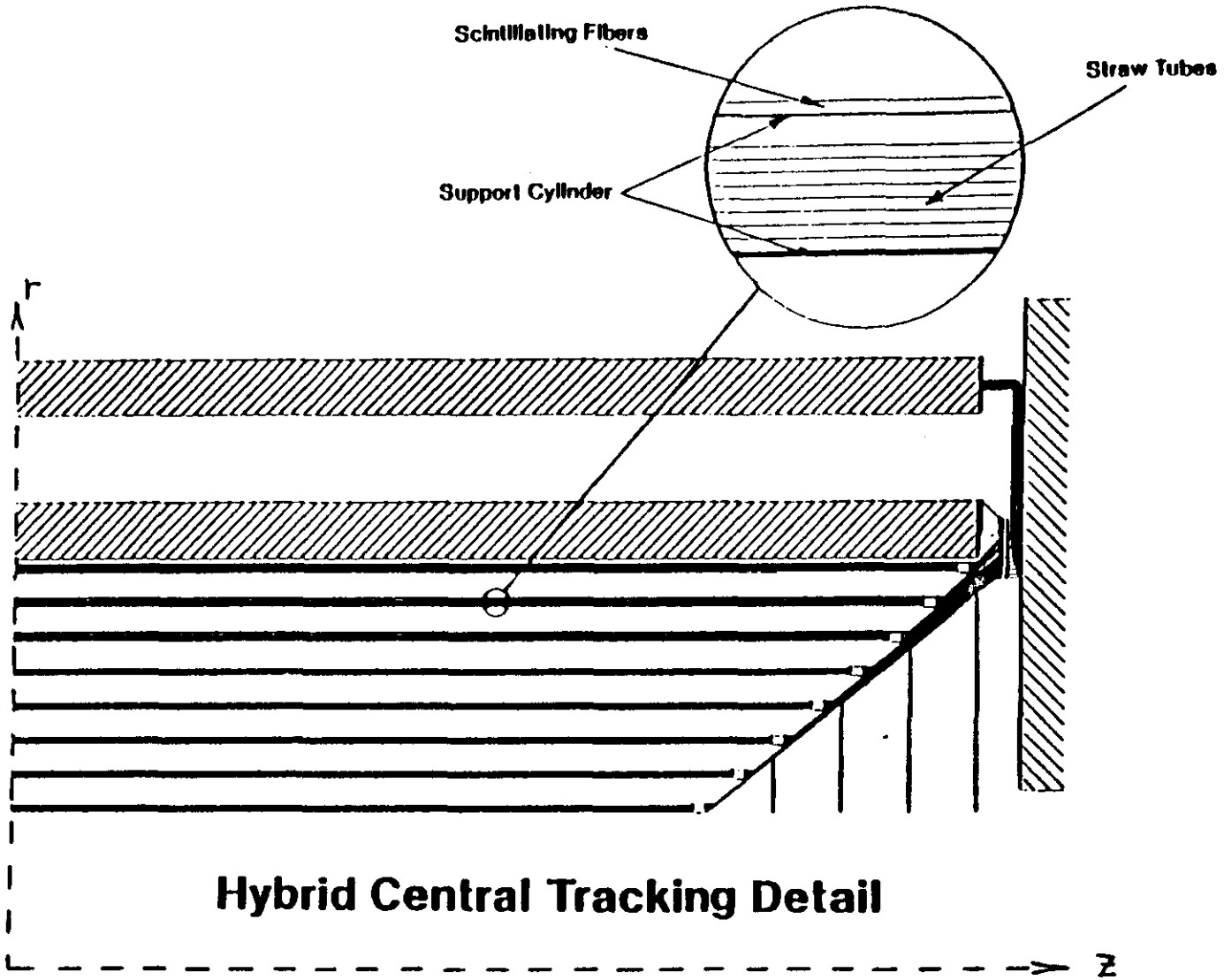


Figure 4-4. Support structure for the superlayers.

The straw tubes in the 2.7 m prototype were placed by hand on a flat surface. The straw tubes were then aligned visually and manually inspected for compliance with the requirements. This occurs after each straw has had its wire support and end plugs inserted. There are approximately 250,000 straw tubes, two end plugs per tube and 6 to 8 wire guides per tube, so these areas must be addressed first. Preliminary studies of automation have begun in the area of placing the straw tubes onto the cylinder. This work will continue along with conceptual development for expediting the sense wire insertion method. The current method for this process is to use air pressure to blow the wires down the tubes, and it appears that this may be a relatively simple process to automate.

The placement of the scintillating fibers onto the cylinder will require additional studies. The current proposal is to have the fibers bonded into ribbons which are wound onto the stable base cylinder. This work will have to be coordinated with the fiber ribbon manufacturers for tolerance control and handling restrictions. Efficient automation of these procedures is essential to the reduction of cost associated with the fabrication of the detector.

4.5 Task timeline

During FY91, ORNL will provide updates on the cost estimate for the HCTC to support the Tracking System Review in March, 1991, the Baseline Design in April, 1991, and the 92 R&D Plan in June, 1991. These estimates will be based on the latest information available at the time.

To support the Detector Proposal due in late 1991, a complete bottoms-up cost estimate for the HCTC will be made based on the conceptual design established during FY91. This cost estimate will be complete by September 30, 1991.

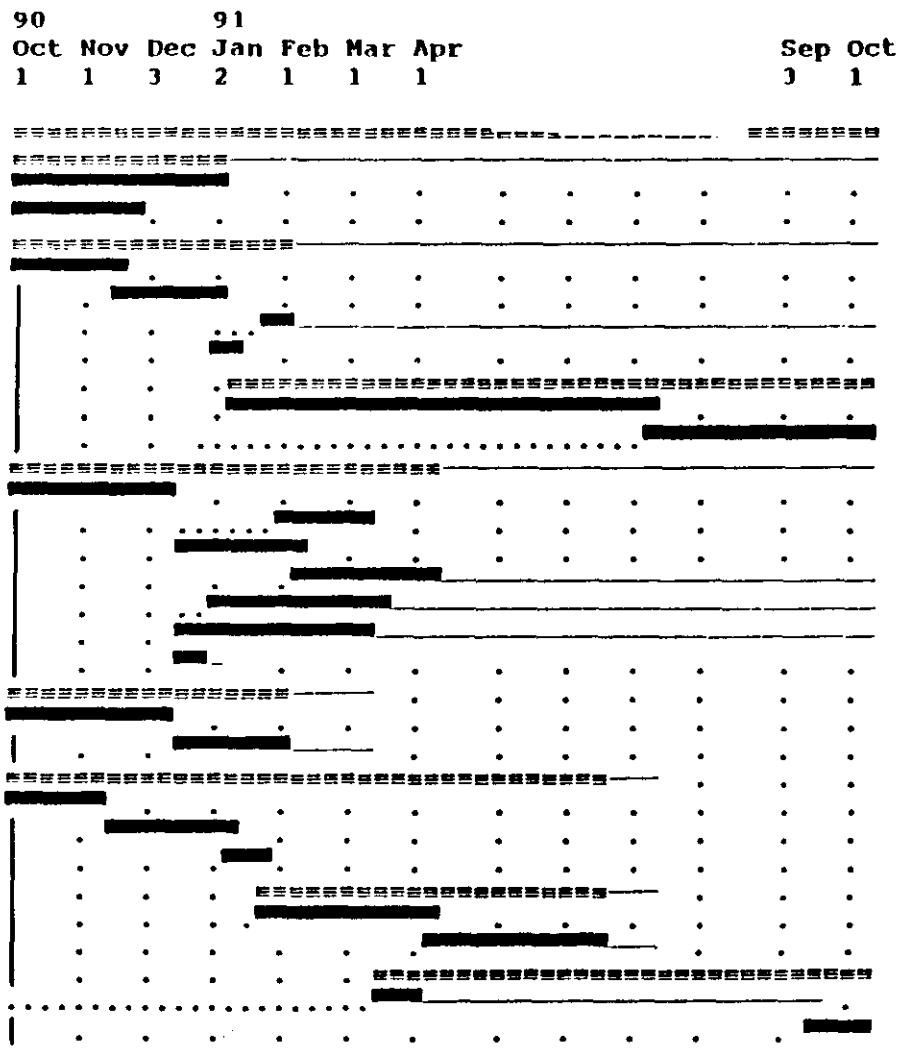
The bottoms-up cost estimate will be itemized according to WBS Engineering, assembly labor and materials, tooling and procurement. Confidence levels and methods of arriving at cost numbers will also be provided. The data will be provided in both electronic (spread sheet) and paper formats.

The project timeline for this section is presented on the next page and the budget is summarized in Section 6.

ICTC Timeline FY1991

Task 3: Mechanical Engineering

Task Name	Total $ (EAC)
1991 ORNL/Hybrid M.E.	595,000.00
Straw Layout Cylinder	43,000.00
Aluminum Cylinder	29,375.00
End Plate	13,625.00
Cylinder Design	51,750.00
Cylinder Design/Analysis	18,750.00
Envelope Drawing and Spe	9,000.00
Fabrication Drawings	9,000.00
Tooling Design	15,000.00
Prototype Fabrication	337,500.00
Cylinder Fabrication	300,000.00
End Plate Fabrication	37,500.00
End Plate Design	65,625.00
End Plate Configuration	7,500.00
End Plate Analysis (FEA)	15,000.00
End Plug Design	5,625.00
Wire Termination	6,000.00
Ion Gas Feed and Manifol	7,500.00
Electronics Cooling	9,000.00
Engineering Drawings	15,000.00
Support Structure Design	33,750.00
3D Layout and Modeling	15,000.00
Finite Element Analysis	18,750.00
Assembly/Alignment Concepts	40,875.00
Tolerance Stack-ups	9,000.00
Assembly/Alignment Requi	5,625.00
Assembly/Alignment Drawi	11,250.00
Tooling Design	15,000.00
3D modeling of assemb	7,500.00
Conceptual Fab/Assemb	7,500.00
Cost Estimating	22,500.00
Cost Update	11,250.00
Final Cost Estimate	11,250.00



5.0 Monte Carlo Simulation of HCTC (Task 4)

The simulation work proposed for FY91 will continue and extend the performance simulation work of the first year to consider track reconstruction, pattern recognition, design optimization, and radiation environment calculations. New features to be investigated in the second year include the use of artificial neural network algorithms and interfaces to CAD systems. The second-year simulation effort is briefly discussed in the following five subsections.

5.1 Detector response simulation

We propose to build on the performance simulation work described in the progress report for FY90. This will include efficiency improvements to allow greater numbers of events to be simulated, extended graphics, better data structures, and porting the code to other computer architectures, with the aim of making the simulation code more widely accessible. A more accurate simulation of the readout electronics being developed at the University of Pennsylvania will be incorporated. Nevertheless, we anticipate that in FY91 there will be much less emphasis on development of the simulation package itself, and more on reconstruction techniques and comparison of alternative detector parameters.

5.2 Reconstruction studies

It is proposed to develop a full three dimensional track reconstruction, which will allow a study of effective mass resolution for processes such as Higgs or vector boson production. Sensitivity to longitudinal spatial resolution and to alternative stereo layer configurations will be studied. Specifically, the consequences of a move to 1 mm fibers and the omission of the axial fiber layers will be investigated. Work will continue on tuning the current reconstruction algorithms, particularly for high transverse momentum tracks. We also plan to investigate alternative track finding algorithms, especially those suited to alternative computer architectures, and using techniques such as look-up tables and neural networks (see Section 5.3). This will include algorithms designed specifically to find high transverse momentum tracks in conditions of high occupancy (due to high luminosity or high background), both offline and at the trigger level. This background will be folded into the analysis (see Section 5.6).

5.3 Pattern recognition studies

A critical issue in the design of the central tracking chamber is the type of algorithms and hardware necessary to construct and identify particle tracks from the data. Triggering time requirements impose severe limitations on the complexity of algorithms that are implemented in hardware to determine whether valid tracks exist in the data stream. Current processing techniques employ very crude heuristic algorithms (e.g., stiff tracks [1]). These techniques offer very little real discrimination between events of interest and background events. Artificial Neural Network (ANN) algorithms implemented in specially designed hardware circuits have the potential to vastly exceed current hardware tracking techniques. This research effort will investigate their potential use in the triggering hardware for the central tracking chamber.

The construction and identification of particle tracks are a classical problem in optimization theory known as the Data Association Problem (DAP) [2]. The DAP for tracking is where, under a given set of constraints, each data point must be associated with one of the hypothesized tracks such that a measure (usually taken to be the chi-square) of the quality of association is an extremum. This problem is NP-complete [3]. Therefore, the globally optimal association cannot be found except for when the number of data points and tracks is very small. The best one can do is to find a "good" association, *i.e.*, a local extremum that yields an association which is near the globally optimal association.

ANN algorithms have been applied to a wide variety of association problems [4], and have been shown to yield "good" solutions. In particular, ANN algorithms have been designed to construct and identify tracks of aircraft and missiles from sensor data in military scenarios [5]. The advantage of ANN algorithms lies in their speed of execution. ANN algorithms can be executed in a fully parallel computation, and the computation time is independent of the number of data points and tracks. ANN algorithms can be implemented in specially designed VLSI and/or optical circuitry [4].

In addition, ANN hardware circuits can produce track solutions at rates that can only be matched by the fastest mainframe supercomputers. Thus, ANN algorithms implemented in the trigger hardware could provide a detector system

with on-line track construction far superior to those using conventional heuristic techniques. This, in turn, would offer a significant improvement in the detector system's event discrimination efficiency.

Our research effort for this proposal period will focus on the design and testing of ANN algorithms to solve the particle tracking problem for central tracking chamber data. The first step will be to design an ANN optimization algorithm that contains the constraints imposed by the central tracking problem. The next step will be to implement the algorithm in software and test its performance on a scaled-down version of the SSC tracking problem. This will allow us to adjust the algorithm's parameters; such that it will be the fastest, high-quality solution possible. Scalability issues will be addressed by applying an ANN algorithm to a simulated SSC event. The data will be generated by the Monte Carlo code from the Supercomputer Computations Research Institute (SCRI) at Florida State University, which simulates central tracking chamber response to SSC events. This research will be performed to determine the extent to which ANN algorithms can improve particle tracking solutions over the currently used techniques.

5.4 CAD Interfacing

We plan to more fully utilize CAD systems in the design representation and specification of the HCTC during the second year; this will allow better visualization of complex design issues, easier consideration of structural and other constraints, quicker exchange of critical information between designers and simulators, and better eventual integration of the HCTC subsystem into a larger detector.

One of the collaboration members, Quantum Research Services, is currently developing a CAD-to-GEANT software interface, under DOE support within the Small Business Innovation Research (SBIR) program. The HCTC collaboration intends to take advantage of this effort in two ways:

- utilize portions of the interface, as they become available, to expedite the transfer of CAD geometry representations of alternative HCTC designs into GEANT input for the simulation studies at SCRI
- construct interface routines to go from CAD to CALOR89, as a similar expedient for the simultions that will take place at ORNL.

In addition, Quantum will work directly with Duke University to set up a local CAD library of HCTC design alternatives, which all collaboration members can access. This effort will greatly simplify the interchange of critical information, so that design decisions made by one group are quickly and accurately incorporated by all affected groups.

5.5 Optimization of parameters

The detector response simulation technology developed during the first year, and supplemented in the early part of the second year, will be used to compare alternate designs and to study the effects of design decisions (such as the decision to go from 0.5- to 1.0-mm fibers). It will not be possible to fully simulate all possible design considerations in the next year, since so many parameters can vary over so many parameter values. Thus, it will be necessary to be judicious in the selection of the cases for simulation. A limited iterative procedure will be employed, wherein new design parameter values will be fed to the simulation team and the results of the simulations will be quickly fed back to the design team so that some optimization of parameters can take place. In this regard, the CAD interface software will be used to the extent possible and will help facilitate this iteration.

We will also investigate the possible use of the Inverse Monte Carlo (IMC) method, developed by the investigators from Quantum Research Services [6], as an aid in performing the parameter optimization study. IMC is a Monte Carlo simulation procedure for performing inverse problems in a way that is noniterative in the simulation. Since many optimization problems can be posed as inverse problems, use of IMC may provide an efficient way of performing parts of the design optimization procedure.

5.6 Background and radiation damage studies

5.6.1 Introduction

A systematic simulation study of the background and radiation damage introduced in the central tracker by the primary particles produced from the p-p collisions and by albedo particles produced from the primary particles in the calorimeter and tracker is important and must be considered before the overall performance of this system can be determined. This study will utilize the CALOR89

code system [7] to determine the background and radiation damage levels. In order to have a strong experimental central tracking program, a substantial effort must be involved in the calculational analysis of the detector system. This calculational capability must be fundamentally sound and based on previous interchanges between theoretical calculations and experimental test programs as has CALOR89.

Due to financial constraints, only a few prototype detectors can be built and tested. However, once the calculated results have been shown to agree with the test program data, a much wider variation of the design can be calculationally investigated. This will be the approach followed in this proposal so as to maximize effort and minimize cost.

5.6.2 Methods of Calculations

The calculations to be carried out in this proposal will be performed with the new CALOR89 computer system following approximately the procedures used in previous calculations [8-12]. The major changes in CALOR are in an improved high energy collision model following FLUKA88 [8] and a better low energy neutron transport by the code MICAP. A flow diagram of the codes in CALOR is given in Fig. 1. The three-dimensional multimedia, high-energy nucleon-meson transport code HETC88 [13] was used with modifications to obtain a detailed description of the nucleon-meson cascade produced in the absorbers considered in this paper. This Monte Carlo code takes into account the slowing down of charged particles via the continuous slowing-down approximation, the decay of charged pions and muons, inelastic nucleon-nucleus and charged-pion-nucleus (excluding hydrogen) collisions through the use of an intermediate-energy intranuclear--cascade evaporation (MECC) model ($E < 3$ GeV) [14], a scaling model (3 GeV $< E <$ 5 GeV), and a multi-chain fragmentation model ($E > 3$ GeV), and a fragmentation model ($E > 3$ GEV) [13]. Also accounted for are elastic neutron-nucleus ($E < 100$ MeV) collisions, and elastic nucleon and charged-pion collisions with hydrogen.

In recent years, a large amount of experimental and theoretical work has been done, and more reliable models are now available for the description of high energy (> 5 GeV) hadron-proton and hadron-nucleus collisions, in particular, a multi-chain fragmentation code by J. Ranft, et al. [15], following the work of A. Capella and J. Tran Thanh Van [16]. The version of the model that is used in the updated version

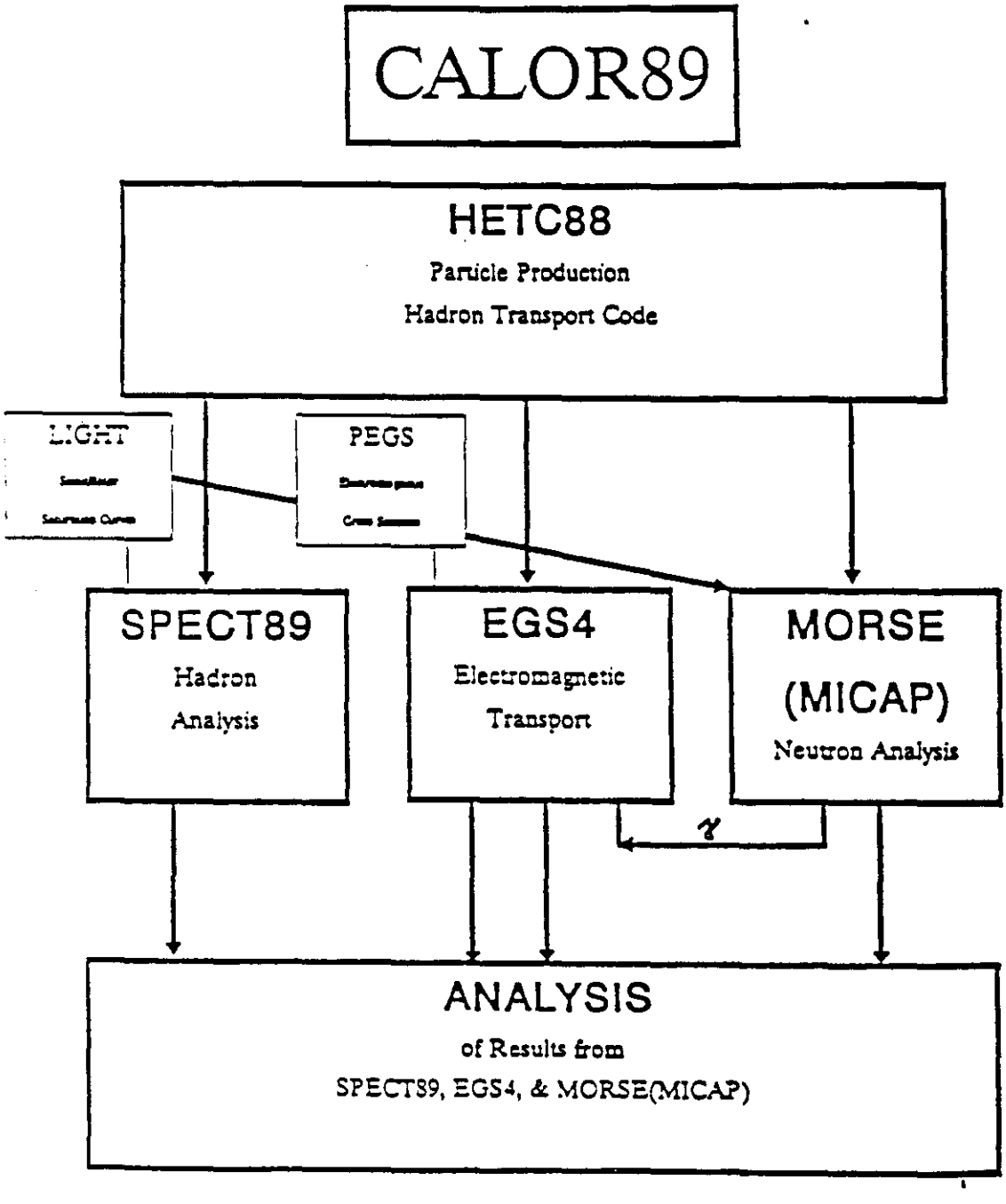


Figure 4-1. The CALOR89 Code System.

of HETC with some modifications is that provided by the transport code FLUKA88. The modifications that have been made are mostly those necessary to predict such things as residual nuclei and excitation energies [17,18]. This information is needed in HETC for evaporation calculations which yield the production of low-energy neutrons, protons, deuterons, alpha particles, etc.

The source distribution for the electromagnetic cascade calculation is provided by HETC. It consists of direct photon production from hadron-nuclear collisions, photons from neutral pion decay, electrons and positrons from muon decay (although this is usually not of interest in calorimeter calculations because of the long muon lifetime), de-excitation gamma rays from nonelastic nuclear collisions and fission gamma rays. Since the discrete decay energies of the de-excitation gammas are not provided by HETC and only the total available energy, a uniform sampling of the available energy is utilized to select the specific gamma energies. The transport of the electrons, positrons, and gammas from the above sources is carried out using the EGS4 system [19].

Neutrons which are produced with energies below 20 MeV are transported using the MORSE [20,21] or MICAP [22] Monte Carlo transport codes. The neutron cross-sections used by MORSE or MICAP are obtained from ENDFB/V. Gamma rays (including those from capture, fission, etc.) produced during this phase of the calculations are stored for transport by the EGS code. The MORSE code was developed for reactor application. The MICAP code was developed specifically for detector analysis. Both codes can treat fissioning systems in detail. This ability is very important since a majority of the fissions results from neutrons with energies less than 20 MeV. Time dependence is included in MORSE and MICAP, but since neither HETC nor EGS has a timing scheme incorporated, it is generally assumed that no time passes for this phase of the particle cascade. Therefore, all neutrons below 20 MeV are produced at t = 0. General time cuts used in the MORSE or MICAP codes are 50 to 75 ns for scintillator and 100 to 300 ns for TMS or Argon.

The nonlinearity of the light pulse in scintillator due to saturation effects is taken into account by the use of Birk's law [23]

$$\frac{dL}{dx} \alpha \frac{dE/dx}{1 + k_B \, dE/dx} \tag{5-1}$$

where k_B is the saturation constant. For plastic scintillator k_B is generally between 0.01- and 0.02-g cm^{-2} MeV^{-1}. A similar law is assumed to apply to the charge collected in ionization detectors. This takes into account the lost of signal resulting from recombination effects in the ionization column [24]. For electrons at all energies, it is assumed that $k_B = 0$.

Efficient collection of scintillation light produced by the energy deposition of a charged particle (or of wavelength shifted light) is important in the overall performance of a scintillator detector system. The detection efficiency is determined by many factors including the geometry of the modular section, the index of refraction characteristics of the scintillating material and external material, the internal reflection efficiency of the phototubes, and the size of the phototubes. The MORSE Monte Carlo code has been modified to include all of the above factors and more so that accurate scintillation light transport can be carried out. This code will be referred to as MORLIGHT.

A simplified flow of the calculations is as follows:

1. Determine the wavelength group of the scintillation photon.

2. Determine the direction of the photon from an isotropic distribution.

3. Determine the flight path distance from $e^{-\lambda x}$, where λ is the inverse absorption length for the group.

4. If the total path distance is completed before the next boundary is encountered, kill the photon (no downscatter or wavelength change allowed in current calculation, but can be included).

5. If the next boundary encountered is not the phototube or wavelength shifter boundary, determine angle of incidence and compare to critical angle.

6. If the angle of incidence is less than the critical angle, kill the photon (leakage). This assumes no reflective boundary other than critical angle reflection.

7. If the angle of the incidence is greater than the critical angle, then continue transport after reflection until the path length is completed or the photon reaches the phototube or wavelength shifter. (Kill the photon as in statement 4.)

8. If the photon reaches the phototube, determine the probability that the photon will produce a photoelectron. If an electron is produced, score and kill the photon, otherwise, just kill the photon. If the wavelength shifter is reached, convert photon and transmit down wavelength shifter to phototube.

9. Start at statement 1 again.

Several modifications to the above procedure currently implemented in MORSE will have to be carried out in order to study the light gathering characteristics. For example, changes will have to be made to include the conversion probability of the wavelength shifter when the scintillator light enters the fiber.

5.6.3 Design Calculations

5.6.3.1 Effect of the Hadronic Background, Tracking Sensitivity and Resolution. In many instances, the ability of separate detector signals from many incident particles separated by very short time and spatial intervals determines the success or failure of an experiment. The CALOR89 code system will be modified to include time dependence so that the spatial dependence of the energy deposition in the hybrid central tracking chamber can be monitored in time. By utilizing this time dependence through pulse shaping and proper segmentation, the background generally associated with a large number of soft particles (neutrons, protons, pions and electrons) can potentially be identified on a single or at most a multiple particle basis. The geometry of the tracking detector will be fashioned after those defined in this and previous proposals. The CALOR89 system, which has a large energy range of applicability (20 TeV to 10^{-3} eV) has been shown to be substantially superior to the other simulation codes in terms of the treatment of the low energy particles, especially albedo particles, and should be able to realistically generate the response of the tracking system to these low energy particles.

At present, timing is included only in the MORSE and MICAP codes in CALOR89. Neither EGS4, or HETC88, which are also included in CALOR89, having a timing scheme incorporated. It has been assumed from past calculations that no time passes for this phase of the particle cascade (roughly correct) and that all neutrons produced below 20 MeV are produced at $t = 0$. For the proposed calculation, this is not sufficiently accurate.

The geometry of the calorimeter, which through hadronic collisions yields the particle albedo, will be fashioned after the SDC detector. The calorimeter materials considered in the first series of calculations will be lead and plastic.

$$t = t_0 + \frac{|\vec{r} - \vec{r}_0|}{\vec{v}} \tag{5-2}$$

where t_0 and $\vec{r}_0$ are the previous time and spatial coordinates of the particle, t_0 and $\vec{r}$ are the current time and spatial coordinates of the particle $\vec{v}$ is the velocity of the particle.

For charged particles, since the velocity is constantly changing, the timing is not as straightforward, but can be obtained from the following:

$$t = t_0 + \int_{r_0}^{r} \frac{dx}{\vec{v}} = t_0 + \frac{1}{c}\int_{E_0}^{E} \frac{\left(\frac{dx}{dE}\right) dE}{\left(\frac{P}{\varepsilon}\right)} + t_0 + \frac{1}{c}\int_{E_0}^{E} \frac{\varepsilon dE}{\left(\frac{dE}{dx}\right)\left(\sqrt{\varepsilon^2 - m^2}\right)} \tag{5-3}$$

where the variables have the same meaning as before and ε is the particle total energy, E is the particle kinetic energy, and dE/dx is the ionization energy loss per unit path length, x.

At the same time that timing is being incorporated into CALOR89, the geometry will be developed to incorporate the inner core of the SDC detector.

Once the above improvements and geometry have been debugged, calculations will be carried out to determine the time tagged "hits" in the tracking chambers due to albedo particles produced in the calorimeter. (The source of particles produced in the initial p-p collisions will be obtained from ISAJET.)

5.6.3.2 **Radiation Damage Considerations.** During the calculations to be carried out as described in section 5.6.3.1, the neutron flux, charged particle flux, and energy deposition profiles in the tracking section will be calculated in detail. The particle spectra will be useful in helping to determine experiments which will be relevant for radiation damage. It is well known that the amount of damage anticipated in plastic, silicon, or other active media is very dependent on the shape of the particle spectra. In addition to using the dose profiles to determine damage levels, the flux will be folded with damage response functions to yield more realistic

profiles in damage. This will be especially true for silicon devices located in the central tracking volume.

5.6.3.3 **Light Transport in the Scintillating Fibers.** As part of this analysis, the light collection efficiency must be included in the calculation. The MORLIGHT code will be modified and data added so that scintillation light transport can be carried out for the scintillating fibers. The data that are necessary for such calculations include frequency distribution of the emitted scintillation light, the number of scintillation photons emitted per 100 eV of energy deposition, the light absorption characteristics and index of refraction of the scintillator, the conversion probability of light in the wavelength shifter fibers, the light absorption characteristics of the light guide fibers, phototube conversion efficiency, etc. Much of these data are available and can be easily obtained. If data cannot be found, realistic data based on past experience will be substituted. Since there are variations in the types of data needed, some sensitivity studies will be carried out. The final results of the MORLIGHT calculations will be spatial and energy deposition dependent light collection efficiency include fluctuations. By varying the light absorption characteristics of the scintillator and the light guides, levels of radiation damage can be simulated so that performance degradation can be studied.

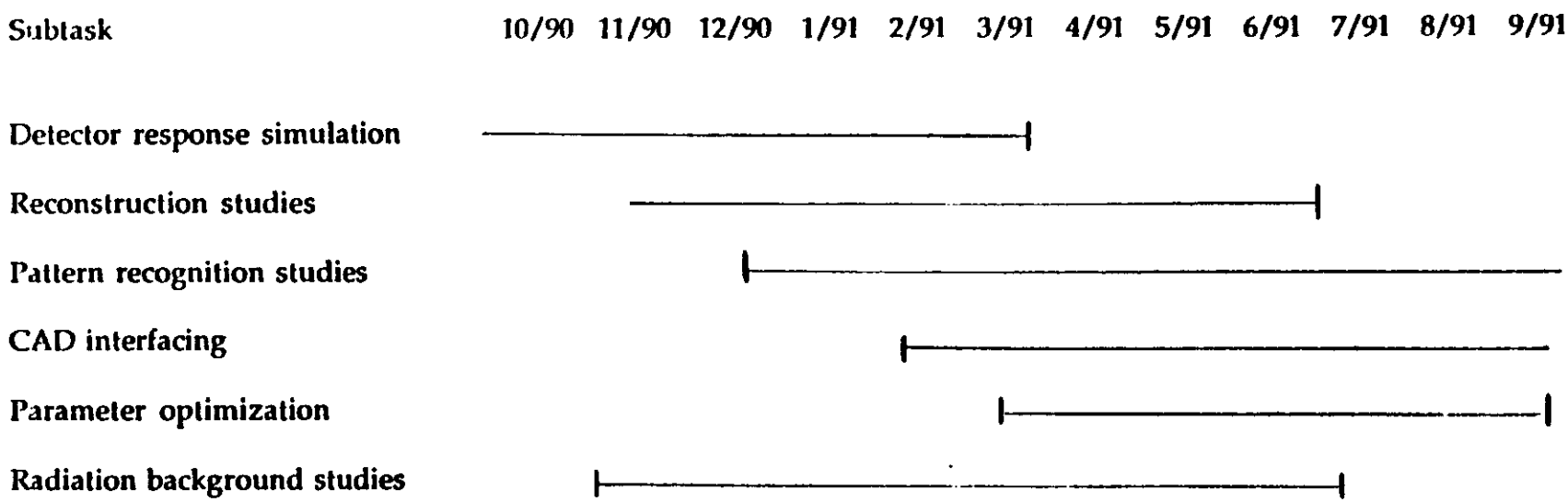
In some showers, particles may undergo a hydrogen collision within the shifter leading to a "Texas tower event." The frequency of occurrences of such events and the magnitude of the signal will be determined to see what detrimental effects this has on the response of the scintillating fibers.

5.7 Project timeline

The Monte Carlo simulation of the HCTC and of the background will continue throughout the year. A task timeline is illustrated on the following page.

ECTC Timeline FY1991

Task 4: Monte Carlo Simulation



6.0 Administration

6.1 Project organization and personnel

The HCTC Collaboration consists of 40 people from 12 institutions. Alfred Goshaw (Duke) will serve as the primary contact person between the Collaboration and the SSC Laboratory. The overall coordination of research activities will be carried out by Goshaw and Steve Reucroft (Northeastern). The principal investigator (bold type) and reseach staff at each institution are given on page ii of this proposal.

Listed below are the research responsibilities for each participating institution.

CEBAF:
radiation damage testing of scintillating fibers

Duke University:
straw tube cell and superlayer construction and testing; gas selection; readout electronics tests; conceptual design of HCTC detector

Florida StateUniversity:
radiation damage testing of scintillating fiber

General Electric Canada Inc.:
development of scintillating fiber readout device arrays

KEK:
design and fabrication of straw tube frontend electronics chips

North Carolina State University:
development of straw tube frontend electronics, and radiation damage testing of straw tube and scintillating fiber components

Northeastern University:
coordination of scintillating fiber task; fiber studies (both before and after irradiation), ribbon manufacture, superlayer construction, and fiber readout devices

Oak Ridge National Laboratory:
straw tube frondend electronics; all aspects of the mechanical engineering task; neural networks and radiation background calculations within the simulation task.

Quantum Research Services:
straw tube and scintillating fiber radiation hardness studies; CAD interfacing and design optimization within the simulation task

Supercomputer Computation Research Institute:
simulation of HCTC detector response to SSC events; trigger simulation; pattern recognition studies; optimization of HCTC parameters for SDC

TRIUMF:
selection and radiation hardness evaluation of straw tube gases

University of Pennsylvania:
design and fabrication of straw tube frontend electronics

6.2 FY1991 budget summaries

The HCTC budget request for FY91 is summarized in Tables 6-1 through 6-3.

Table 6-1. FY91 Institutional Budgets

Institution	Institution Budget
Continuous Electron Beam Accelerator Facility	$ 15,000
Duke University	231,500
Florida State University	30,020
General Electric Canada Inc.[1]	100,000
KEK[2]	10,000
North Carolina State University	60,000
Northeastern University	168,238
Oak Ridge National Laboratory	974,738
Quantum Research Services[3]	105,287
Supercomputer Computations Research Institute	6,000
TRIUMF	73,000
University of Pennsylvania	0
Total	$1,773,783

1 Administered through Northeastern University.

2 Administered through Duke University (50% overhead is included in Duke budget).

3 Administered through ORNL (4.5% offsite overhead is included in ORNL budget).

Table 6-2. FY91 Budget Requests by Subtask and Task

Subtask	Budget[4]	Task Budget
Straw/superlayer construction	$146,300	
Readout electronics	276,100	
Gas selection and aging studies	75,000	
Radiation damage studies	22,662	
Straw tube drift chambers (Task 1)		**$ 520,062**
Fiber studies	57,628	
Ribbon and superlayer construction	110,610	
Readout electronics	100,000	
Radiation damage studies	111,006	
Scintillating fibers (Task 2)		**$ 379,244**
Straw layout cylinder	54,609	
Carbon composite cylinder	425,600	
End plate design/fabrication	83,248	
Support structure design	47,710	
Assembly/alignment concepts	55,484	
Mechanical engineering (Task 3)		**$ 666,650**
Detector response simulation	2,000	
Reconstruction studies	2,000	
Neural networks	22,500	
CAD interfacing	55,979	
Optimization of parameters	15,660	
Background/radiation damage	99,950	
Simulation (Task 4)		**$ 198,089**
Subtotal		**$1,764,045**
Overhead on KEK, Quantum	9,738	
Total		**$1,773,783**

[4] The ORNL contingency has been allocated between Tasks 3 and 4.

Table 6-3. FY91 Budget Summary by Institution and Task

Institution	Task	Budget	Institution Budget
CEBAF	Gas aging studies	$ 2,000	
	Radiation Damage to PSF	13,000	$ 15,000
Duke	Straw tube drift chambers	211,500	
	Simulation (CAD)	15,000	
	OH on KEK subcontract	5,000	231,500
FSU	Radiation hardness studies	30,020	30,020
GE	Scintillating fiber electronics	100,000	100,000
KEK	Straw tube electronics	10,000	10,000
NCSU	Straw tube electronics	20,000	
	Radiation damage studies	40,000	60,000
Northeastern	Plastic scintillating fibers	168,238	168,238
ORNL	Straw tube electronics	161,000	
	Mechanical engineering	597,000	
	Simulation	112,500	
	Contingency	99,500	
	OH on Quantum subcontract	4,422	974,738
Quantum	Radiation damage studies	50,648	
	Simulation (CAD)	54,639	105,287
SCRI	Simulation	6,000	6,000
TRIUMF	Gas aging studies	73,000	
	Radiation damage to PSF	0	73,000
Penn	Straw tube electronics	0	0
Total			$1,773,783

6-3. Projected FY1992 budget

The primary goal of the HCTC program in FY92 will be to construct and test a partially instrumented full scale superlayer cylinder. The cost for this program, described briefly in the Executive Summary, will be determined by our FY91 R&D results. A preliminary estimate for the complete HCTC budget in FY92 is $1.5 - 2.0M.

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