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CEBAF: an accelerat\ground up.



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**CEBAF: AN ACCELERATOR PROJECT  
FROM THE GROUND UP**

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## INTRODUCTION

Large research and development projects have characteristics in common with other large projects and many of the management techniques employed are similar. However, there are also some important structural and environmental differences which present special problems to management. This paper attempts to illustrate some of those problems and their solutions, using the Continuous Electron Beam Accelerator Facility (CEBAF) project as an example. CEBAF is being built by the Southeastern Universities Research Association (SURA) for the Department of Energy (DOE), which is the funding agency and the owner of the facility.

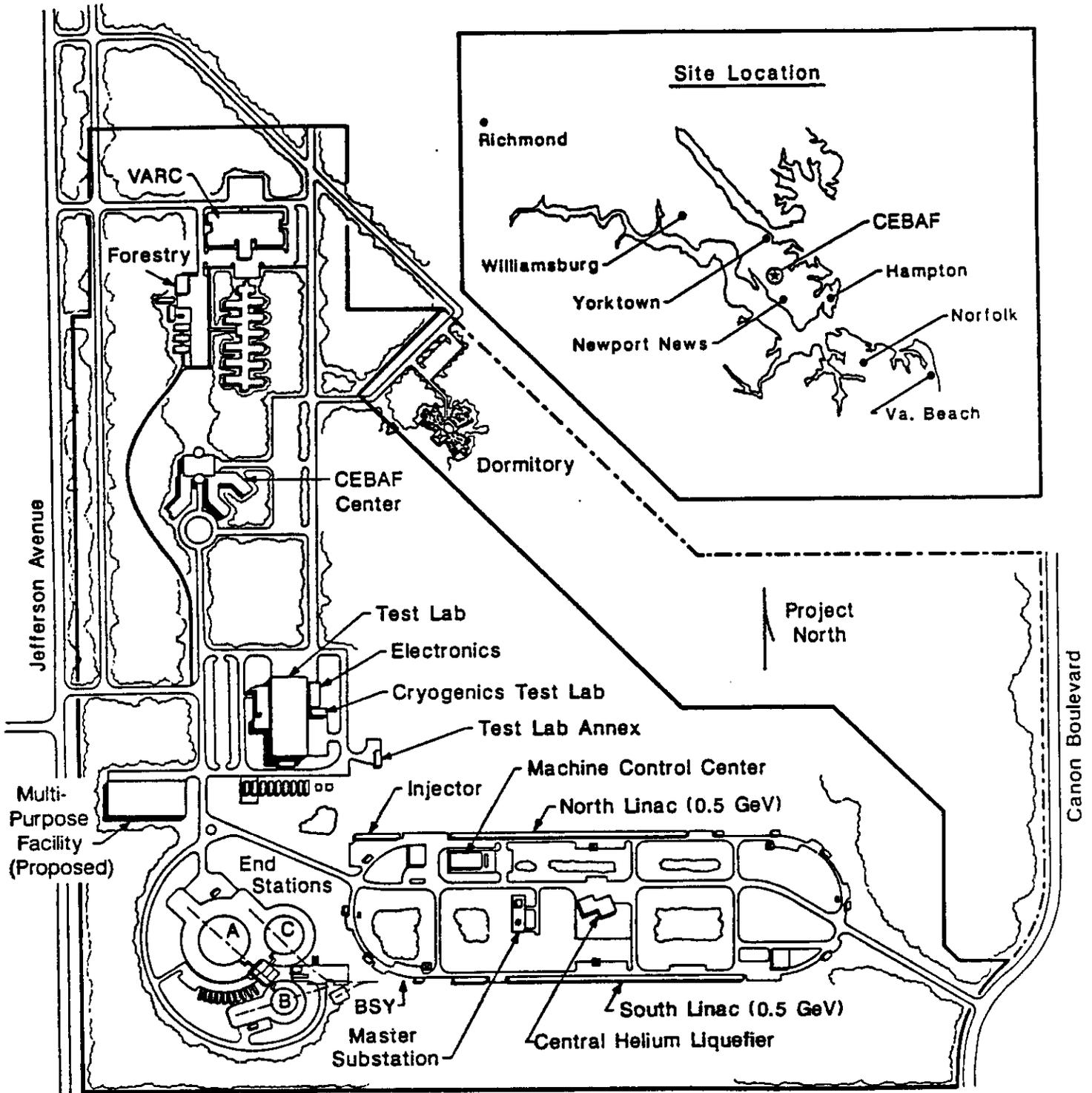
## CEBAF PROJECT DESCRIPTION

CEBAF is a high-intensity, 4-GeV, continuous wave electron accelerator facility for nuclear physics research. Its principal scientific purpose is to serve as an experimental tool to help physicists understand the structure of nuclear systems, their quark substructures, and the strong and electroweak force interactions governing the behavior of this fundamental form of matter. Quickly one realizes that a facility of this sort is extending the frontiers of science and must involve complex technology.

CEBAF is located on a 210-acre DOE-owned site in Newport News, Virginia (see Fig. 1). When complete, the facility will include a recirculating linear electron accelerator housed in an oval shaped concrete tunnel approximately one-half mile long and one-quarter mile wide. The accelerator employs superconducting radio frequency technology which requires that the equipment installed in this large structure be cooled with liquid helium to 2K. (See Fig. 2.) A central refrigeration plant will supply the necessary liquid helium for this ultra-low temperature operation. After five orbits through the accelerator, the electron beam is sent to one of three experimental end stations where it strikes a target. These end stations are essentially cavernous concrete arenas ranging in diameter from 100 ft. to 185 ft., and in height from 55 ft. to 72 ft. They house complex nuclear particle detectors weighing thousands of tons. Sophisticated controls maneuver this equipment into precise placements for

# SITE PLAN

# CEBAF

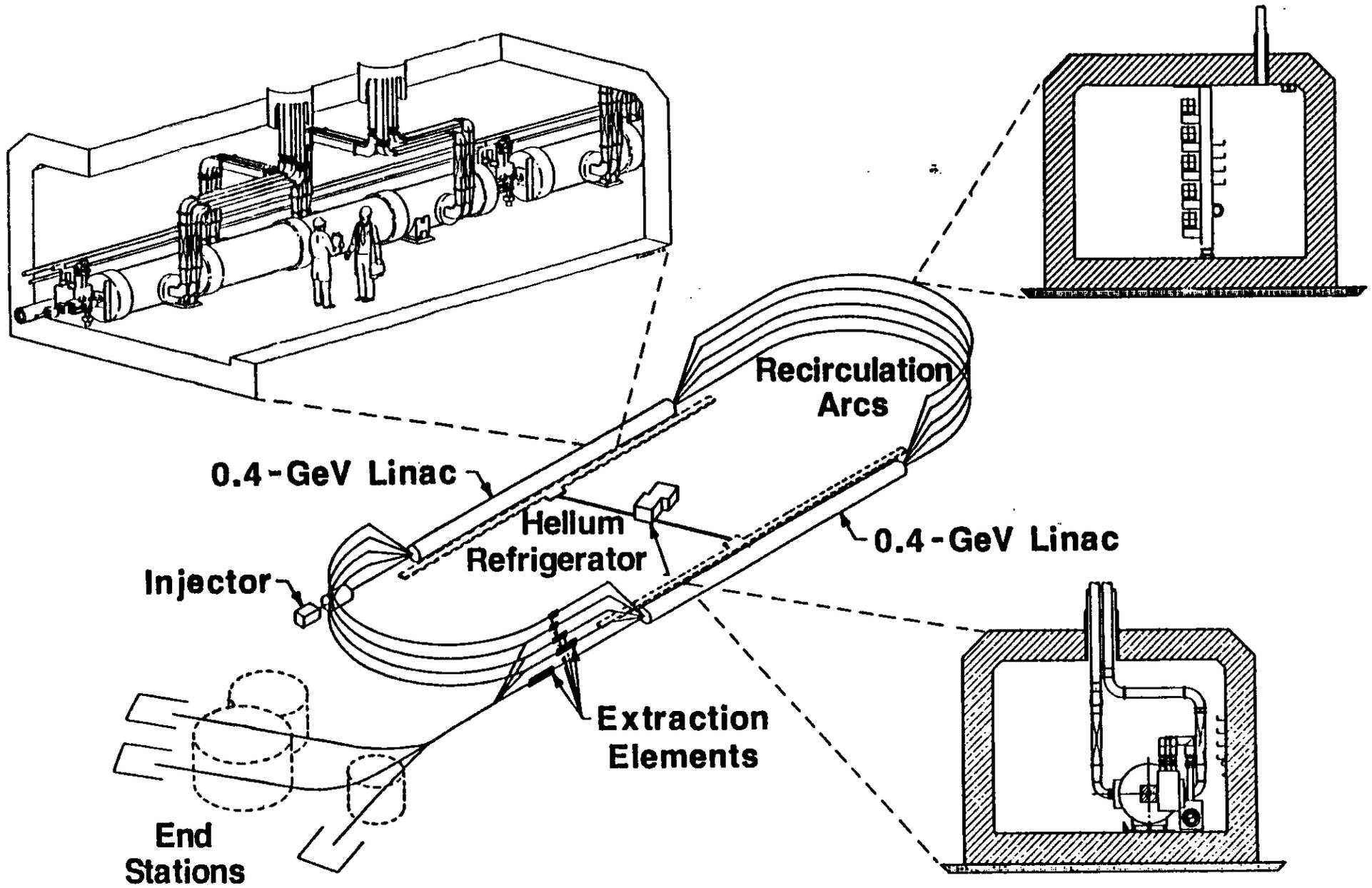


June 1988

Scale: 0 500'

# MACHINE CONFIGURATION

CEBAF



conducting experiments. Additional buildings, facilities, and utilities necessary to support the accelerator, its users and staff, will also be constructed.

The CEBAF Project is a DOE-funded construction project which has been designated a Major Systems Acquisition. The funding profile is a yearly line item in the President's Budget Request and the Congressional Appropriation Bill. The Total Estimated Cost (TEC) to build the facility is \$265 million. The Total Project Cost (TPC), including pre-construction R&D, is \$304 million. The project construction started on February 13, 1987, and is scheduled to be complete in June 1993.

To construct a reliable operating accelerator and related experimental facilities within the desired time-frame, many diverse tasks must be accomplished in parallel. Nuclear physicists, at CEBAF and from the user community, are continuing to explore the types of experiments they would like to perform and the facilities and equipment necessary to perform them. At the same time, other physicists are extending the theoretical and practical knowledge of superconducting radio frequency technology, upon which CEBAF depends. Meanwhile, design engineers are converting the requirements and specifications which result from this scientific inquiry into an accelerator design while construction has already begun. The project management team oversees and controls these diverse efforts.

### SELECTED CEBAF PROJECT CHARACTERISTICS

Coordinating these significantly different tasks to accomplish the stated CEBAF project objectives, within the allotted time period and budget constraints, poses a difficult management challenge, made more complex by several CEBAF characteristics which differentiate it from many other projects. While these characteristics may be shared by some other large R&D projects, they may be considered unusual or unacceptable to project management practitioners in other fields. Several of these characteristics are discussed below.

### CEBAF TECHNOLOGY IS NEW

By the very nature of R&D projects, many are on the forefront of science and engineering. The success of an R&D project depends upon a technology with little previous application. Fundamental technical problems have to be overcome, requiring innovative solutions, before the project is complete.

CEBAF will generate its unique electron beam through a quantum leap of technology: superconducting radio frequency (SRF). SRF is able to provide the desired continuous electron beam and do so at a substantial power savings; however, SRF requires producing several hundred accelerating cavities made of niobium and refrigerating them by liquid helium to a temperature near absolute zero. Several successful prototype superconducting accelerating cavities have been fabricated for CEBAF by industry, but CEBAF is SRF's first large-scale application. It remains to be determined whether this technology can be taken out of the laboratory and expanded to produce an operating facility.

Extensive preconstruction research and development has been conducted and more is required before equipment design can be completed. To preserve the schedule, this development is being undertaken concurrent with construction.

#### CEBAF DESIGN IS EVOLVING

There are many reasons why the CEBAF design is not firm, the previously mentioned state of the technology being just one of them.

The CEBAF design is dictated by its use as a research tool. The experiments which are being contemplated determine the desired characteristics of the electron beam and the capabilities of the three end stations where the experiments will reside. Although the beam specifications are now firm, there are several forces at work which have kept the end station design in flux.

As the facility becomes more of a reality, greater numbers of physicists are including CEBAF in their thinking when planning future research. This increased base of users is a source of additional end station requirements. Furthermore, the current world of nuclear physics is dynamic. New ideas

and discoveries are being reported. This stimulates further research and expands the potential applications of a tool such as CEBAF. Additional experiments requiring revisions to end station capabilities are proposed with regularity. Thus end station building specifications, including their position, size, and configuration, were still evolving as we began construction.

## CEBAF IS A SINGLE PROJECT ORGANIZATION

SURA is a consortium of universities formed in 1980 to manage large, cooperative, state-of-the-art facilities and projects for science, engineering and medicine. It manages CEBAF for DOE. To accomplish this task, SURA established the CEBAF laboratory, which has the primary responsibility for meeting the technical objectives of the project within the cost and schedule authorization provided by DOE.

CEBAF is a single project organization. This is an advantage in that all the energies of the organization can be focused on the single goal of accomplishing the CEBAF project. However this also presents difficulties which must be overcome. For example, there is no reservoir of personnel with required skills at the division or corporate level who can be utilized when needed, then returned when their contributions are complete. There are also no other projects in the pipeline which can contribute needed talents or absorb surplus personnel.

Yet CEBAF exhibits the characteristics of many large projects in that personnel requirements vary over time both in numbers and in mix of skills. To some extent this variation is accommodated through the use of subcontractors, especially in the more available skill classifications such as the building trades. However, many of the scientific and engineering skills are more esoteric, are not available on a subcontract basis, and are difficult to obtain and keep productive over the life of the project.

## THE CEBAF PERSONNEL MIX IS EXTREMELY DIVERSE

Many projects require a wide mix of talents, but few require as diverse an array of skills as CEBAF. The spectrum ranges from general construction workers to some of the most brilliant and creative scientific people in the country. In the three years of the CEBAF existence, the staff has been built to 270 people, where 1/3 are from other national laboratories, 1/3 from industry, and 1/3 from universities, state and federal government. Management is faced with the task of effectively communicating with, leading and coordinating the efforts of this disparate group.

Some of the individuals assembled for CEBAF possess unique knowledge, irreplaceable skills, and valuable experience which is vital to the success of the project. Because of their pre-eminence and superlative abilities, these scientists, engineers, technicians and administrators deserve, and sometimes demand, the instantaneous and full support of other institutional organizations. This can manifest itself in many ways, such as a low tolerance for the time and energy it takes to solve problems in a discipline other than one's own.

Some of the CEBAF staff is not accustomed to the operations of large projects. Laboratory and academic research is often conducted in small working groups, with informal communication, documentation and control. All project members are easily accessible to one another, and results are frequent and visible.

On a large project such as CEBAF, these conditions may not exist. With a seven year time horizon, immediate satisfaction may be lacking. Because of the large number of participants and complex technology, communication, documentation and control must be structured. It is important in this environment that the needs of the individual be balanced against the needs of the project. Management must find ways to keep an individual productive and channeled toward project goals without impairing personal recognition, interest, and motivation.

#### CEBAF HAS MANY CLIENTS

The CEBAF Project serves two groups of clients, the sponsors and the users. Each is represented by several advisory, review and control boards to

help ensure that the design is sound, the facility serves the nuclear physics community, and the construction project proceeds in an orderly, well managed fashion.

Representing the users are the National Advisory Board (NAB), the Program Advisory Committee (PAC), and the Users Executive Committee. The NAB consists of nuclear physicists, accelerator physicists, and technology or project management experts. It reviews CEBAF Laboratory performance and provides advice to the laboratory Director on the development of the facility to assure that its design and equipment are technologically appropriate and that it meets the needs of the scientific community. PAC has a membership of experimental and theoretical nuclear and particle physicists. During the construction project it provides advice and guidance on the design and selection of the experimental equipment included as part of the project. As the CEBAF accelerator approaches operation, the PAC will evaluate proposals for experimental programs and make recommendations on the allocation of beam time. The Users Executive Committee is elected by the CEBAF User Group to advise on interests and concerns of the facility's users.

These committees all support the ultimate users, but they do not represent the project funders, DOE. Within DOE's Office of Energy Research (ER), the Division of Nuclear Physics (DNP) is responsible for the management of the CEBAF Project, providing programmatic guidance and technical assistance, securing resources, controlling key milestones, and approving overall cost and technical baselines. Also within ER, the Division of Construction, Environment and Safety supports DNP on a broad range of construction issues, specifically establishing and monitoring project schedule and cost baselines, organizing and chairing project semi-annual reviews, and recommending management actions to DNP. Outside ER, the DOE's Oak Ridge Operations Office, via its CEBAF Site Office, exercises primary responsibility for overseeing the day-to-day management of the project to assure it is within the approved baseline cost, schedule and technical envelope. CEBAF management must be adept at balancing the interests and directions of these many constituencies.

## CEBAF FUNDING HAS BEEN INCONSISTENT

CEBAF was originally planned and approved as a 5 year, \$236 million construction project. Under budgetary pressures, the DOE and Congress have re-profiled the project several times, with extended schedules and reduced fiscal year spending, resulting in an increase in total estimated cost to \$265M. The semi-annual review cycle and annual budget submissions continue to keep funding in a state of flux and make future planning and commitments difficult.

In this environment, cost effectiveness suffers. As the project is rebaselined, the same level of expenditure no longer achieves the same level of performance. This is caused by cost growth due to: level of effort activities which must now be performed over longer time periods, inability to adjust staff levels as quickly as work scope, and improved understanding of the nature of the tasks to be performed. The adequacy of the preconstruction R&D funding must continually be addressed with the client.

## IMPACT ON PROJECT MANAGEMENT

Perhaps in other fields one would not attempt to undertake a project in the uncertain environment described. However, by its nature, the world of research and development is uncertain. Progress occurs when these uncertainties are confronted and overcome. Where possible, the project management approach must be tailored to these conditions.

Following is a description of some of the project management philosophy and policies we have adopted at CEBAF to help us operate in this environment.

## STAY FLEXIBLE

In a constantly changing technological and programmatic environment, it is difficult to regard many decisions as final. A frequent periodic review process allows us to reexamine many of the decisions and the assumptions they were based upon, and to change them if desirable. As an example, the superconducting radio-frequency technology was not proposed initially, but when

this technology matured to the point where it appeared practical, a change was made to adopt it.

Maintaining a cost, schedule and technical baseline for a performance measurement system in this environment is a challenge. We have attempted to mechanize as much of our planning effort as possible, using commercially available PC-based project management systems and databases. PC-based systems were chosen specifically for their interactive capabilities and quick feedback turnaround time. Currently, our cost and schedule databases are separately maintained. While we have to be careful to preserve concurrent configuration over the two, this does allow us more flexibility to make changes at the detail levels in one database without impacting the other. Again the quick feedback time is important.

We have also streamlined change control procedures by predetermining the level of management review required. Each proposed change is classified for its potential impact to the technical requirements, schedule and cost. One of four approval authorities is assigned dependent upon the scope of the change. That authority is kept as low in the organization structure as possible so that only major changes are surfaced for top management and customer attention.

A corollary to remaining flexible is to delay decisions until they must be made. In a world of rapidly changing technological developments, the conditions which lead to a decision might not exist shortly thereafter. Often the benefits of an early decision are canceled by a premature start down the wrong path. This is a standard dilemma in R&D projects: early design freeze results in less than an optimum project and late design freeze causes cost and schedule overruns. In order to determine when decisions are required, we rely upon schedule networking in our project planning, but we are as cognizant of decision points and information needs as we are of activities when formulating the network.

#### USE THE WORK BREAKDOWN STRUCTURE AS THE ORGANIZATION FRAMEWORK

Because we were not required to matrix with a functional organization from a parent division, we

had some flexibility in designing our organization structure. We chose to create an organization structure parallel to the upper levels of our WBS.

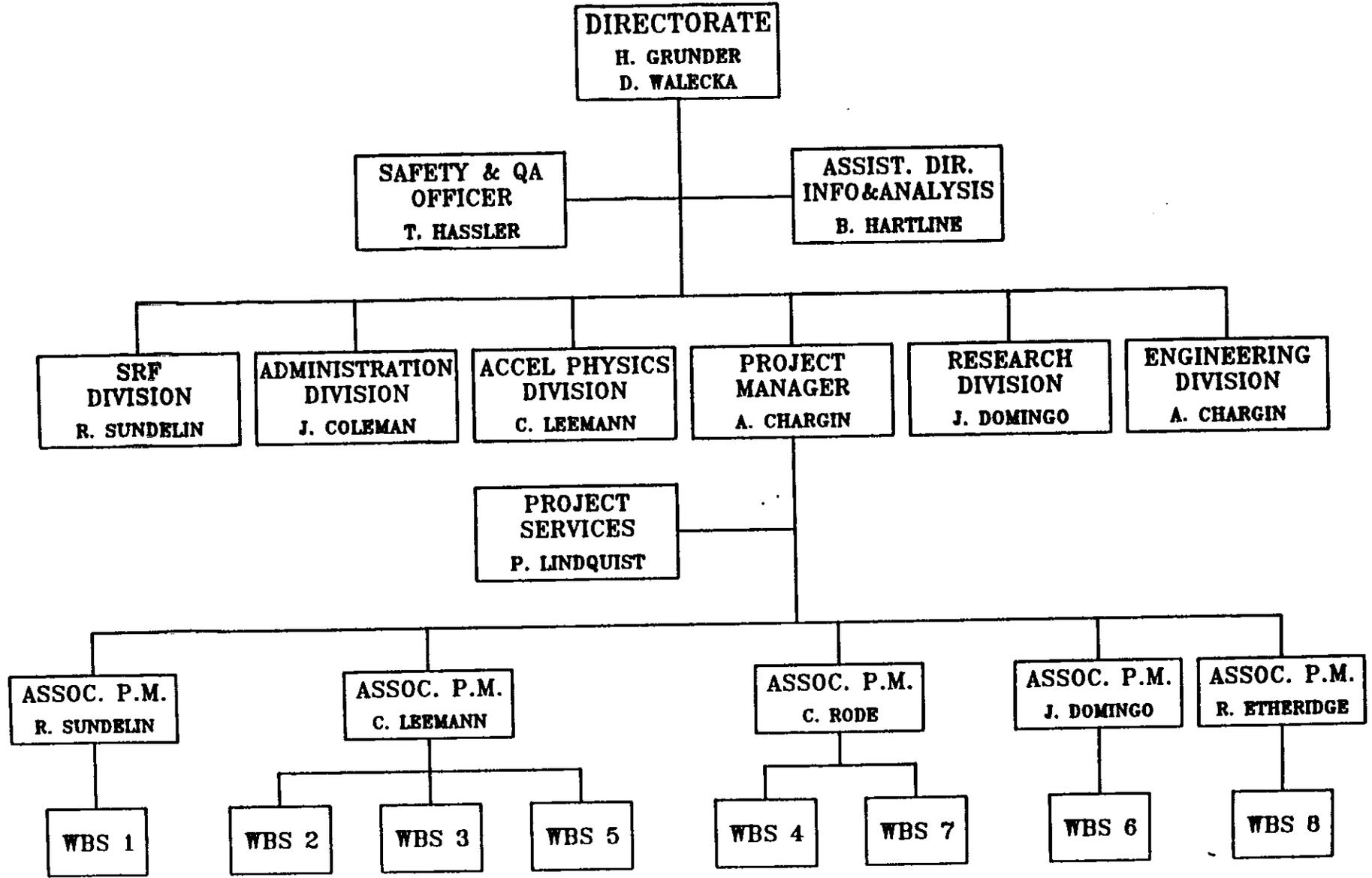
Each Level II of our WBS is a major hardware system, such as the beam transport, radio frequency systems, D.C. power systems, and instrumentation and control. Within each WBS element there are three main types of efforts; physics, engineering design, and construction. The physicists determine the requirements and specifications for the element, the engineers develop a design to meet the specifications, and construction builds to the design. After attempting several other structures, we have settled upon assigning an Associate Project Manager (APM) total responsibility for each Level II WBS element, from physics to construction (see Fig. 3). This places the important interfaces between the major activities under a single authority. We believe this start-to-finish responsibility will increase the likelihood that the systems as built, will perform to the requirements as specified. We also achieve the added benefit of keeping our scientists involved in the project during the period between development of the specifications and testing of the completed facilities.

## SCHEDULING INNOVATION

By the very definition of innovation, it is something that is creative and spontaneous and cannot be scheduled. A great deal of innovation must occur on the CEBAF Project if we are to meet our objectives. Therefore, even though we cannot schedule innovation, we must count on it. Our method for planning this activity has been to develop our construction schedules from the required completion dates to determine when designs have to be frozen, then to develop our design schedules to carefully determine a comprehensive set of need dates. These need dates are published on interface schedules so that all participants are aware of the requirements for their contributions. This does not guarantee that all technological problems will be solved on schedule, but it does provide us with a tool for assessing the impact of late deliveries and developing new plans to keep the project on schedule.

## ACT AS OWN SYSTEM INTEGRATOR

# CEBAF ORGANIZATION



Because the design is still evolving, we are unable to approach Architect and Engineering firms with a completed design concept and specifications for bid. Instead, we are releasing individual portions of the project when they mature to the stage where design work can proceed. This places us in the position of system integrator. To be effective in this role we must perform the following:

- o Partition the effort into easily definable, assignable, measurable tasks,
- o fully define the inputs, scope and outputs required of each task, to the extent of completing the design and preparing the drawing package ourselves, if necessary,
- o define the physical, functional and schedule interfaces with other portions of the project,
- o assign the tasks to an internal or externally contracted organization for performance (this may mean contracting directly with companies conventionally considered subcontractors), and
- o monitor progress against the technical, schedule and cost baseline.

These steps apply to both our conventional construction tasks and to the purchase and installation of our accelerator equipment.

## PARTITIONING OF TASKS

The assignment of defined tasks to internal and external organizations creates a responsibility matrix. One axis is the Work Breakdown Structure, where each branch is extended to the level where sensible partitioning is possible. The other axis is the organization structure, which includes internal and external (contracted) organizations. Where a WBS task is assigned to a performing organization, it is indicated on the matrix. These assignments become the control points (cost account) for the project and each is individually defined, scheduled and budgeted. If we have accomplished our goal as integrators properly, and have designed an effective organization structure and WBS, the number of points, i.e.

interfacing organizations, on the matrix is minimized. In mathematical terms, this is a sparsely populated matrix, and therefore, more determinate. In other words, the more we are able to unambiguously define and assign our tasks, the more we improve the probability of having them completed to our specifications. Organizing tasks into manageable chunks gives opportunity for the staff to achieve intermediate successes before the project completion. In this way personal recognition, interest and motivation can be enhanced.

### CONTAIN RISK

In the course of partitioning our effort, one feature that we must be cognizant of is the risk involved in performing each contracted task. To reduce our cost exposure, we like to seek multiple sources for contracts requiring delivery of a critical component in large numbers. In critical systems areas, we conduct competition on technical proposal merit basis, look at the price and then award a fixed price contract. The liquid helium refrigerator was bought this way, as well as A/E design services on a task by task basis. Of course, low bid fixed price contracts apply to less risky components. However, because of the technical risks involved in certain areas, some potential contractors prefer cost plus contracts. Therefore, we have undertaken a conscientious effort to separate the technically risky tasks from those that are not, so that we can contract for the low risk effort on fixed price basis, and reserve cost plus contracts for the high risk tasks. Even in our highly technical environment, we believe that almost all procurement funds will be spent on fixed price contracts. At the 30% level of total project funds committed, as yet there have been no cost-plus contracts awarded. We have accomplished this by early development of potential sources in terms of many meetings to familiarize industry with CEBAF problems and by placing small contracts with potential suppliers for development of critical components which need to be replicated many times.

### DO WHAT YOU CAN, WHEN YOU CAN

Another policy we have followed is to do those parts of the job that can be done, while awaiting developments which will allow us to proceed in

other areas. This often means breaking down tasks into their subcomponents for accomplishment. This is partly due to the fact that the project schedule is driven by available funding. The priority by which the funds are allocated is: first to technically riskiest systems, then to long lead systems regardless of risk, and lastly, to those systems which we perceive we know how to execute technically.

This policy, dictated by funding levels, leads to managing many activities at or near the critical path. Subdividing a task and accomplishing part of it immediately, while rescheduling the remainder might remove all of the task from the critical path. For example, much development and design work remains to be done on the accelerator cavities before a vendor can be selected and fabrication can begin. However, whatever the design and vendor, it is known that the cavities will be constructed of niobium. Rather than wait for an as yet unknown vendor to purchase the niobium, we are currently proceeding with this task ourselves. This will shorten the fabrication period and allow us to remain on schedule.

## CONCLUSION

R&D projects span a wide variety of disciplines and activities. Nevertheless, it is possible to apply conventional project management techniques with judicious modifications, to help achieve the project goals of delivering technical performance with budgeted cost and on schedule.