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# Teamwork in the Workplace: A Discovery of the Work Processes One Team Used to Meet Its Goals

Thomas Andrew Hassler
*Old Dominion University*

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# TEAMWORK IN THE WORKPLACE: A DISCOVERY OF THE WORK PROCESSES ONE TEAM USED TO MEET ITS GOALS

by

Thomas Andrew Hassler

B.S. June 1959, U.S. Naval Academy

MEM May 1988, Old Dominion University

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Approved by:

Frederick Steier

Resit Unal

Billie Reed

Claire Jacobs

# ABSTRACT

## TEAMWORK IN THE WORKPLACE: A DISCOVERY OF THE WORK PROCESSES ONE TEAM USED TO MEET ITS GOALS

Thomas Andrew Hassler
Old Dominion University
Advisor: Dr. Frederick Steier

A century-old disagreement in academia surrounds the question of whether individuals acting alone accomplish all work or whether workers can truly act in concert to meet management's production requirements. Total Quality Management (TQM) is a powerful force today in the industrial world, and the formation of teams to solve short-term problems is one of its fundamental techniques. This dissertation focuses on a particular TQM team with the purpose of understanding the processes it used to meet its goals. This ten-member team functioned for about one year and was assigned goals leading to improved accelerator reliability. The investigator was a member of this team.

Applicable theories and practices from the literature about teams in the workplace and about reliability engineering are discussed. The dissertation also includes a chronological account of the projects the team completed and a detailed analysis of nine of them. This analysis indicates that the resources used to start and finish a project are a function of many variables, including: the specific talents of the team members, their availability, the time-frame allowed, and project scope and complexity.

Analysis of the nine work processes showed that only one project required initial input from everyone, and none were completed by just one member. Most projects were accomplished by two, three, or four-person mini-teams. This correlates with a theory

which postulates that the fewer people involved in a collective effort, the harder each person still involved will work. At the same time, the full team had its uses; it made decisions by consensus and was a talent pool for selecting members of the mini-teams. It also acted as a review panel; when a mini-team needed advice, a critique, or encouragement, it went to the full team for help and got it.

The processes that team members use to divide the labor and accomplish the work are as complex as human nature, but this team achieved economy of effort simply by using the members best fitted for each project and by using only the minimum number that could reasonably do the work.

# DEDICATION

This dissertation is dedicated to the following:

Virgil Roy Hassler, my late father, and my inspiration
Mary Gwendolyn Packwood Hassler, my dear mother
Ellen Hassler, my loving wife of thirty-four years
Catherine Hassler, our daughter
Amy Hassler Marflake, our daughter
Laura Hassler, our daughter
Danny Marflake, our son-in-law
Matthew Marflake, our grandson
Christopher Marflake, our grandson
Mary McConnell, my sister, and her family

And all the members of the CEBAF Hardware Checkout and Reliability Team

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# INTRODUCTION

This dissertation is presented in partial fulfillment of the requirements of Old Dominion University for a Doctor of Philosophy degree in the field of Engineering Management. This document is the capstone of scholarly effort spanning nine years and is evidence for the knowledge gained during sixty credit hours of graduate-level courses and thirty-three credit hours of individual research.

More specifically, this dissertation is the end product of two years of intense reading, observing, participating, reflecting, analyzing, and writing. It represents a major life experience, one that is never forgotten and changes a person forever, for the good.

This dissertation is at once a story, a report, a set of thoughts and revelations, and a permanent record. It is neither poetry nor epic drama. There are no heroes and no villains. There is a plot, and there is mystery. The story is that of ten employees, including the author, who were assembled as a team by upper management in the spring of 1993 and given goals and deadlines. This team was given basic training in the fundamentals of Total Quality Management (TQM) and put to work to improve the reliability of the accelerator at the Continuous Electron Beam Accelerator Facility (CEBAF) in Newport News, Virginia.

CEBAF is a single-purpose national laboratory which is funded primarily by the U.S. Department of Energy and operated by Southeastern Universities Research Association (SURA), a consortium of forty universities located in the southeastern United States. SURA employs an international staff of nearly 500 scientists, engineers, technicians, and administrators at CEBAF. Construction of the laboratory began in 1987 and will conclude in 1996. However, experiments will begin in early 1995 in the first of the three planned experimental halls. CEBAF is a "user" facility; that is, teams of scientists and engineers from universities and laboratories world-wide compete on the basis of their proposals for experimental time at CEBAF.

CEBAF consists of two main components, an accelerator producing a stream of 4 GeV electrons, and three experimental halls where the electrons interact with atomic nuclei and the resultant shower of particles is tracked by large and sensitive detectors. An array of computers selectively record the data. Teams of theoretical physicists will analyze the data and compare the results with theoretical predictions. The end product will be new information published in scientific journals. It is possible, but not necessary, that a new and practical application will result from this research.

The accelerator facility is housed in a race-track shaped concrete tunnel nearly a mile in length. The floor of the tunnel is about twenty-five feet underground. The electrons, which are formed in an electron gun, are accelerated in two opposing linear accelerators called “linacs”. When the electrons leave a linac, they are bent through a semi-circle or “arc” by large, powerful magnets. Then they are accelerated in the other linac before entering the other arc. The complete accelerator machine consists then of two linacs connected by two arcs, and the electrons can make as many as five trips around the machine before being diverted to an experimental area.

The energy used to accelerate the electrons is provided by radio-frequency energy generated by electronic equipment housed in service buildings above the accelerator. The electrons are actually accelerated by the radio-frequency energy in sine-curve shaped components called cavities, which are made of niobium, a metallic element which superconducts below nine degrees Kelvin. Liquid helium at two degrees Kelvin is used to cool the cavities. The cavities are positioned deep inside highly-insulated cylinders about ten meters in length. Throughout its path, the electron beam travels within a space-like vacuum to avoid interactions with gas molecules. Accelerator operations are totally dependent on modern computers and specialized software.

This team that is the subject of this dissertation was called the Hardware Checkout and Reliability Team, and it will be referred to throughout the dissertation by that name or in one of two abbreviated forms: the HC&R Team or simply, the Team. The Team was officially founded in June 1993, and was disbanded in May 1994. The dissertation is an account of the activities of this team and its contributions to CEBAF. The focus of the research was on exploring, understanding, and explaining the processes the Team used to distribute the labor and meet its goals efficiently and effectively. The dissertation includes comparisons of the Team experience with what scholarly and business-oriented literature have to say about teams, and attempts to explain the differences and similarities. The most significant contributions of this research to the literature are expected to be the very detailed account of a TQM team for the period of its life and the discoveries made about the processes it used to accomplish its work.

This research connects with a century-old argument within academia. The argument is about the relative productivity of individuals working independently and members of a group working together. Simply put, one school asserts that only individuals do work. The other school champions the synergistic effect of teamwork. This research will explore one aspect of this argument: the decision-making process that a team uses to apportion the work that must be done to meet team goals. The researcher will examine the data and answer these questions: What are the significant variables that affect the decision-making process? Why is an equitable division of labor not of primary importance? What is significant about the number of members participating in a particular team project? What part does the total membership, acting as a single entity, play in completing all projects? The answers to these questions will show that the extreme positions taken by the two schools are too exclusive. Both individuals and groups do work, and the factors determining how a team will decide to apply its labor resources to a particular project is both interesting and rational.

The dissertation contains seven chapters, including this one, and the other six chapters are discussed briefly in the paragraphs that follow:

The Literature Review Chapter is a survey of recent writings about the use of teams in the work place. It describes various models of group behavior developed by academicians in various branches of social science and psychology. It discusses more fully the argument referred to earlier about the productivity of individuals and groups. It describes the formation of quality circles in Japan and their subsequent formation in other countries, including the United States. It describes the evolving Japanese experience with teams and the recent American experience. The advice of consultants, corporate engineers, and other practitioners about forming and sustaining TQM teams is included, and a case study of a team formed to develop software is presented. This survey of the latest quality writings about teams in the work place gave the investigator a reference baseline for comparison with the single team being observed. The same advantage is given the reader, although observation of the Team is of necessity vicarious and the reading is limited to the chapter rather than an array of books. This chapter contains a set of questions about the Team and its conformance with theoretical models. These questions will be answered in the Analysis Chapter. The Literature Review Chapter also contains a brief introduction to the field of reliability engineering and refers the reader to Appendix 1, which is a more thorough introduction to the same field.

The Methodology Chapter attempts to establish the credibility of the investigator and the usefulness of the research. It explains and justifies the use of participative, action research, and it describes the differences between research in the basic and applied sciences. It advises the reader familiar with objective, rational, quantitative scientific scholarship, that this research is different, because it is subjective and qualitative. It even tries to relieve the concern of those unsettled by the investigator's active participation in the investigation. In short, this chapter prepares the scientific reader for the unfamiliar search for a scholarly understanding of human activity in an engineering context.

The Hardware Checkout and Reliability Team Chapter is an account, mostly chronological, of the activities of the Team. This account includes the formation of the Team, a listing of its prescribed goals, a detailed account of its projects, and a description of its products. This chapter is supported by fifteen appendices which include copies of its papers and presentations. Appendix 1 is original work by the author and is a brief review of the literature about theories and practices in the field of reliability, maintainability, and availability, including definitions and equations. Briefly, equipment reliability is measured by failure rate. Maintainability is measured by the time it takes to repair or replace a failed item. Availability is the percentage of the available time that an item is operational. Appendix 1 includes detailed explanations of these three terms and their interrelationships, which are mathematical and very interesting. Appendix 1 closes with several questions about the application of reliability theory to the practical needs of the Team. The answers to the questions are presented in the Analysis Chapter.

The Work Processes Chapter describes nine of the projects that the Team completed. The descriptions include the journalistic details of who, what, when, where, and why. A figure is included with each of the nine accounts, and the figure attempts to visually represent the sequence of people and products which led to completion of the project. Reliance on a computer is indicated at each stage to emphasize the importance of computer literacy to Team members and modern work methods. The figures lay bare the processes the Team used to divide the labor and complete the work. They show the interactions of the members involved in a single project and the utility of the Team as a reviewing, advising, and encouraging peer group.

The Analysis Chapter begins the process of taking the information in the preceding chapters and forming a coherent theme. This chapter includes a discussion that leads to findings. The findings are important statements which are based on the information about the Team that was presented in the previous two chapters. This chapter has three main sections, and the first section addresses the questions posed at the conclusion of the Literature Review Chapter. The Team is compared with the latest models in the literature in terms of the stages it experiences as it matures and in terms of its purpose, structure, and organization. In addition, the Team is compared with Japanese quality circles and the American experience with teams. The Team's performance record is compared with various lists; a list of the seven advantages of using circles, a list of eight essential characteristics, and a list of five pit-falls that lead to failure.

The second section of the Analysis Chapter reflects on the Work Processes Chapter and dissects the processes that led to completion of the nine projects. The analysis peels back layers of the anatomy of the Team effort and finds commonality, which gives bone-like structure to the otherwise different processes. The Chapter reveals the usefulness of the Team as a source of diverse talents and demonstrates the methods used by the Team to make the most of its human resources. The Analysis Chapter expands on the graphical displays of the nine work processes in figures 1 through 9, which show how the members effectively apportioned the work so that all would be involved, yet particular talents were tapped when and where most needed.

The third and final section of the Analysis Chapter is devoted to responding to the questions posed at the conclusion of Appendix I, the literature review of engineering texts about reliability, maintainability, and availability. This section discusses the value to the Team of understanding and applying the theoretical and practical principles of reliability engineering. It also discusses the Team's contributions to improving accelerator availability; for example, the introduction of a software program for recording and tracking equipment failures and subsequent corrective action.

The last chapter, Summary and Conclusions, briefly summarizes all that precedes it and then distills the findings presented in the Analysis Chapter into a set of conclusions. These conclusions are a set of interpretations, inferences, understandings, and revelations about work-place teams, about how Team members worked together to meet their goals, and about the usefulness of applying the theory and practices of reliability engineering to the accelerator equipment. The final chapter also includes some suggested topics for additional research which should complement this research. The chapter concludes with some final thoughts after a comparison of the Team's work processes with those of other kinds of teams from sports and entertainment. This comparison indicates that sport and entertainment teams divide the labor based on the nature of their activity, and some of them work in very similar fashion to the Team.

That concludes the introduction with the exception of the author asking the reader for two indulgences. The first indulgence is to recognize that the author of this dissertation refers to himself in various places in the third person, as is the convention, as the investigator, the researcher, and the author. The only rational explanation is one of recognition of changing roles. The investigator role applied during the life of the Team. The researcher role applied during the analytical process, and the author role was predominant at the end when the dissertation took shape. There is some overlap of names within the text because this inconsistency sprang from the subconscious. The author also has one other pseudonym, which is explained in the next paragraph.

The second indulgence regards the privacy afforded to the Team members. The author made every effort to protect the privacy of the other members, and with the exception of self, the dissertation is gender and race neutral. In addition, names are not used; instead, one or two initials are used to distinguish one member from another. For example, the author will be referred to as "T.", without the quotation marks, in discussions about his role in accomplishing the work of the Team. Appendix 3 provides the complete list of symbols used for the members and a brief professional biography of each person. Keeping the text genderless sometimes leads to awkward sentences, and the reader's indulgence is requested. Finally, the author hopes that the reader finds the reading easy, understandable, stimulating, enlightening, informative, and worthwhile.

# LITERATURE REVIEW

## Teams in the Workplace

### Purpose

The team that was the subject of this research was one of the first total quality management (TQM) teams established at CEBAF, and from the beginning, some employees raised serious questions about the usefulness of such teams. In fact, many questions were asked by many employees. Why was one person selected to be on a team and not a co-worker? Why complicate our organization? Does a team control any funds? What can teams do that the regular organization cannot do? These and other questions marked the birth pangs of teams at CEBAF, and a "wait and see" attitude prevailed among the doubters.

One purpose of the literature search was to provide a standard against which to measure the Hardware Checkout and Reliability Team as it evolved. The literature should provide a history of teams in other organizations with accounts of successes and failures, of growth amid changing environments, and lessons learned through experience. The lives of successful teams, from start to finish, could be standards for comparison and guideposts to success.

A second purpose of the literature search rested with the idea that this team might not fit all of the "theoretical truths" and models of teams portrayed in the literature. Social science is not exact, and it should come as no surprise that a team under the close scrutiny of a researcher will not coincide with all that is predicted in theory or encountered in practice. The reading of the literature, then, provides a set of expectations which will be verified during the course of the research and the analysis of the data.

The research depended on the team surviving for a reasonable length of time, and to survive, it had to meet the goals established by upper management. In a sense, the team had to be successful for there to be sufficient interaction, problem solving, and accomplishment to be worthy of a dissertation. Therefore, the lessons learned by other teams and gained from the reading could be used, per action research, to help the CEBAF team to succeed. This purpose may have been selfish, but was of considerable value to CEBAF, and led to valuable research in its own right.

The three preceding paragraphs may seem to contain an inconsistency or flaw. If a standard for comparing teams can be gleaned from the literature, yet that literature contains "truths" and content that either do not apply to the research subject, or worse yet are erroneous, how is the distinction made between what is worth emulating and what should be avoided? The answer lies in the diversity and quantity of the sources. When all or nearly all sources send the same message, that message has significant credibility. And when one author goes against the majority, that message is interesting, but must be considered thoughtfully and monitored closely if tested. Timing can be of help in this instance; a new book may overturn, when supported by research, an earlier concept that was widely accepted.

A final purpose of the literature review was to provide an understanding of the contemporary issues which are being addressed and affect the usefulness and evolution of teams in the workplace. The value of the research would be enhanced if any of these current issues are detected during the research and lead to a new understanding.

## Introduction

The literature contains a plethora of writings about the use of problem-solving teams in the workplace. Indeed, the increasing adoption of TQM methods in the industrialized world assures for the near future a steady stream of books about work teams. Likewise, textbooks which present the mathematics of reliability, maintainability, and availability (RMA) are plentiful. Considerably rarer, are useful texts which describe one or more organization's actual experiences with improving equipment RMA. No where to be found by this researcher is a scholarly record of the use of a team to improve the availability of a complex, technical system such as CEBAF.

Credit is sometimes wrongly given to the TQM movement for introducing the small work group to organizations as a means for improving productivity. The traditional, autocratic, hierarchical organization does not exclude small groups, and indeed is reliant upon small groups of employees working together in an integrated fashion to achieve organizational goals. There are significant differences, however, between the traditional small group and the TQM small group, primarily in the processes associated with selection of members, selection of tasks, selection of methods for accomplishing tasks, and the chain of authority. This chapter will address these differences in detail and summarize the latest thinking of academic and industrial writers about the use of teams in the work place.

This chapter contains four sections: Theory of Small Groups in the Work Place, Quality Circles in the Japanese Style, The American Experience, and Cultural Comparisons. The first section is the only one with subsections and contains four: An Historical View, A Business School Theory about Small Groups, Small Group Models, and Theories about Small Group Performance and Productivity.

## Theory of Small Groups in the Workplace

### An Historical View

The study of groups of humans goes on in many academic fields, and fine distinctions are drawn in closely related fields such as sociology, social psychology, clinical psychology, and organizational psychology. Sociology might look at the use of power and hierarchies in groups. Clinical psychology might emphasize the treatment of dysfunctional families. Organizational psychology is interested in productivity and leadership in groups. Social psychology considers looking at personal functions served by group membership and how group members construe their role in the group within its domain. Such distinctions are too fine for the needs of this research, which seeks a more macro understanding of group dynamics. However, to delve into theoretical understandings of group processes, a researcher must read the writings from a variety of fields, however closely related (Simpson and Wood 1991).

There are many examples of group dynamics in ancient writings. One need look no further than the Old Testament to find many examples of successful and unsuccessful groups, of successful and unsuccessful group leaders, and successful and unsuccessful group decision making. However, useful theoretical writings about group dynamics are much more modern, and no reference prior to 1898 is cited in this research.

According to Worchel et al. (1991), Emile Durkheim, in 1898, probably without knowing it, started an argument that continued for many years and may not be over. He took the position that by studying the individual, he would learn little about the group. Worchel et al. (1991) also point out that Floyd Allport expressed the opposite point of view in 1924 when he said in effect, groups do not think, feel, or act, but people do. No one ever tripped over a group, and therefore they are not real and are not worthy of study. Worchel et al. (1991) cite a third researcher, Solomon Ash, who took the middle ground, making an analogy between groups and water. It is necessary to know the characteristics of its elements, hydrogen and water, but that is not sufficient to understand water. That must be studied as a unique material. The arguments for individuals and for groups have each had periods of supremacy during the twentieth century.

Research on the role of the individual on a team has produced some interesting and conflicting concepts. Pennier and Craiger (1992) report that in 1898, N. Triplett published in a report that bicycle racers do better against competition than against the clock. Pennier and Craiger (1992) report further that Triplett's findings led to further studies about the influence of an observer or witness on individual performance. “Social facilitation” was the term given to the tendency for the presence of others to cause an improvement in an individual's performance. Further research uncovered quite the opposite effect, and the term “social impairment” was created for the tendency for a decline in an individual's performance as a result of working with others on a task.

Pennier and Craiger (1992) also relate that M. Ringelmann, in 1913, noted that people, when alone, pulled harder on a rope in a tug-of-war than when on a team. In fact, he was able to measure this phenomena, and reported that pulling alone was 1.31 times that when on a seven person team and 1.39 times that when on a fourteen person team. The loss in performance was attributed to difficulties in coordinating the activities of several people who are engaged in the same task simultaneously.

Continuing their chronological account, Pennier and Craiger (1992) report that discovery of social facilitation and social impairment led to searches for the psychological variables which affect an individual's performance and motivation on a particular task. For example, in 1965, Zajonc asserted that the degree of difficulty of the task determined the outcome. For simple tasks, the presence of others would inspire a performer to do better. For complex tasks, particularly ones involving choices between competing responses, the presence of another could impair performance. This was tested with the "witness" blindfolded and ears covered. Impairment occurred even though the witness could not evaluate the performance. The latest thinking on this subject is that fear of criticism interferes with the performance of complex tasks and anticipation of a favorable evaluation improves performance of easy tasks.

Fleischmann and Vaccaro (1992) state that other factors can influence individual behavior. For example, Mullen and Baumeister coined the term "diving" in 1986 to describe a situation in which an individual is motivated to perform at less than optimum level because of group norms. Members will punish anyone who violates a norm that discourages excellence. A memory from years ago confirms this situation. A coworker told me that in his youth, he worked at a factory on an assembly line. On his first day at work within the first hour, the box that was his "in" box was empty, and his "out" box was full. At the first break, his coworkers surrounded him and told him in no uncertain terms to slow down or else.

Pennier and Craiger (1992) note that in 1981, Latane identified another phenomena that reduced individual performance and called it "social loafing". He claimed that as the number of people in a group increases, the social pressure to perform well decreases, and motivation may decrease as well. This could explain the difference in Ringleman's rope pull experiment between the seven person team )1991)and fourteen person team performances.

According to Samuelson (1991) research on groups in the 1920s and 1930s compared the performance of individuals versus groups on problem solving and decision-making tasks, but focused on the outcomes rather than the processes which lead to results. Jury decision making was an example of the type of group effort studied. Marjorie Shaw conducted an experiment in 1932 about the methods groups use to solve problems. Her conclusion was that groups solve problems better than individuals because the members engage in checking each other's errors and eliminate incorrect answers.

According to Simpson and Wood (1991), Kurt Lewin popularized research of groups in the 1930s and 1940s. Lewin asserted that the behavior of individuals could be understood based on the nature of the groups to which they belonged. Group research flourished in the early 1950s, but then the focus shifted to the individual. Steiner and Jones, for example, attributed the demise of group research to a lack of theories and a lack of statistical tools and methods.

Group research is more time consuming and involves more subjects than studies of individuals. Group research is also more difficult than individual research because the interactions between the group members are uncontrollable. Research methods emphasizing precision and control are persuasive against conducting group research (Worschel et al. 1991).

As cited by Simpson and Wood (1991), Thibaut and Kelley developed a group-based theory, the Theory of Interdependence, which tried to explain and predict individual behavior given the current reward-cost outcomes relative to other members. The theory did not work well in practice except for analyzing two-person groups. This failure led to a theoretical dark ages for studying groups which lasted into the 1970s.

Samuelson (1991) reports that in 1972, Ivan Steiner's book, *Group Processes and Productivity,* sparked a resurgence of interest in group processes. Steiner argued that actual productivity did not equal potential productivity because of inefficient group processes, but he was pessimistic about improving group productivity. Examples of inefficient group processes include: members talk about information that all members already know rather than exchanging unique knowledge held by single members, and the superiority of on alternative is obscured because no one member has all the needed information although all the information is known collectively by the group (Samuelson 1991).

Samuelson (1991) relates that in 1975, Hackman and Morris built on Steiner's work, focusing on the process-productivity relationship, and they became more optimistic about improving productivity than was Steiner. They looked at three variables: member efforts, task performance strategies, and member knowledge and skill. Their conclusion was that the key ingredient to improving productivity was to intervene in the process in such a way to affect the variables most relevant to the task demands.

Recent group research has focused on groups of strangers brought together temporarily for the research. This approach has proved to be economical and controllable. However, members of such groups have little sense of belonging to a group and little sense of purpose. The questions remains whether this research is valid for understanding tightly knit, committed groups (Worschel et al. 1991).

The difficulty of studying groups in natural settings also led researchers to prefer laboratory settings where variables can be controlled; however, the constraints of the laboratory can keep the research from being valid for real-world situations. Steiner, in 1986, made such an argument against highly structured group research. Others, such as Driskell and Salas, stoutly defend laboratory research. They admit that few areas of scholarship are as wrought with self-doubt and general pessimism, but they argue against the usual criticisms. Driskell and Salas place this criticism in four categories: (1) Results are sterile and artificial. (2) Results are unique and not generalizable to the real world. (3). The theories and concepts are too abstract. (4). Research conducted is often simply common sense and of questionable practical value. They agree that these are true at first glance, but are misleading and inaccurate descriptions (Driskell and Salas 1992).

Driskell and Salas categorize three types of research activity: (1) Research that attempts to predict real world behavior. (2) Research that attempts to test hypotheses about the real world. (3) Research that attempts to apply hypotheses to the real world. Most of the psychological research that interests Driskell and Salas tests hypotheses about the real world, and according to them this can be done in the laboratory. There is no attempt to generalize a result from one setting to another setting; for example, the group researcher is more likely to be interested in the question of what makes a soccer crowd riot and want to test a theory that explains rioting than to develop a theory that would predict a particular crowd's propensity to riot (Driskell and Salas 1992).

Continuing their defense of laboratory research, Driskell and Salas point out that the greater the control a researcher has of extraneous variables, the greater the artificiality of the settings, and the more artificial the setting, the more rigorous is the test of the hypothesis. In this sense, research needs greater artificiality. Conditions that can not be found in the real world can be created in the laboratory, where the researcher tries to find out what *can* happen rather than what *will* happen (Driskell and Salas 1992).

Driskell and Salas provide some well-documented "findings" about small groups: (1) Teams under stress experience a constriction in control or authority, with team leaders consolidating authority for decision making. (2) Highly cohesive groups are more productive than less cohesive groups. (3) Allowing team members to generate problem solutions in an open, uncritical manner in a group setting results in greater variety and creativity of responses. Then they inform the reader that these common sense statements are wrong or at least need qualification. (1) The team leader is also ready to relinquish authority to the team when under stress. (2) There are contradictory findings about cohesiveness. A group so cohesive that its goals are different from those of the larger organization is not productive in the sense of meeting organizational goals. (3) Brainstorming should be very productive, but individuals working alone have proven to be more productive. Their point is that conclusions drawn from a few experiences may not apply in all situations. Laboratory research can be better than empirical experience at revealing rules which apply in most if not all situations (Driskell and Salas 1992).

There is no doubt that the community of small-group researchers has been in distress. The lack of progress in developing utilitarian theories has not helped their cause. Science for the sake of science is fine if you are spending your own funds, but in today's funding climate, basic research activities such as the nuclear physics research at CEBAF and the type of research Driskell and Salas enjoy, are in jeopardy. However, some members of the group research community believe that modern technical advances are going to make a positive difference because advances in computers and statistics allow much better determination of correlations and make significantly better data analysis possible. Also, modern audio-visual recording equipment makes it possible to detect and study minute details such as facial expressions and body language. Whether technology will revitalize this community of scholarship remains to be seen (Simpson and Wood 1991).

## A Business School Theory about Small Groups

*Organizational Behavior* by Gray and Stark is a graduate level textbook which was used by the Business School at Old Dominion University in 1989. An entire chapter in this book is devoted to examining the role of small groups in business organizations from a management and business school perspective. It should be noted that TQM methods had minimal influence on this perspective.

According to Gray and Stark, small group processes are more behavioral and less technical than large group processes and each member occupies a role that contains certain expectations. Small groups are made up of leaders, regular members, deviates, and isolates. Leaders exert the most influence on a group. There is a leader appointed by management, and there may be an informal leader who best satisfies the needs of the group. As needs change, the informal leader will change. Groups develop "norms" of acceptable behavior, and regular members follow the norms. Deviates violate group norms because their goals are different from group goals; i.e., a deviate may want to increase production while the group wants to promote job security. Group members interact with deviates to increase their conformity with group norms. When regular members give up on a deviate, that person becomes an isolate, and members will isolate him or her psychologically and socially (Gray and Stark 1984).

Time and lots of communications are needed to turn a group of strangers into a cohesive, productive group. This process may have four stages. The initial stage is a trying out stage and a reaching for mutual acceptance. Some members may be reluctant initially to express their opinions and feelings. Members begin to talk more openly and honestly in the second stage, and the group will begin to propose solutions to common problems and analyze alternatives. The third stage is reached when posturing and conflicts reach a minimum. The group focuses on the tasks in a group atmosphere, and the regular members are motivated and productive. In the final stage, group norms control individual behavior and establish the social structure (Gray and Stark 1984).

Research on groups in stage four has revealed some interesting problems. Groups which are stable and spend more time on tasks which support the larger organizational goals are an asset. In contrast, groups can become too involved in interpersonal problems, can fall into a “group think” climate, can become involved in goals which are in conflict with the larger organization’s goals, and can become too conservative to deal with novel ideas. Such groups can be a liability (Gray and Stark 1984).

Group think can be especially troublesome for small groups. Indicators of group think include: those who disagree keep silent, silence is mistaken for agreement, members apply pressure to anyone who appears to challenge group decisions, and members resist challenges to their assumptions. One way out of group think, is to appoint someone to be a deviate who is tasked to make the group reexamine problems and alternatives. In this way, conflict is managed and may become a creative force (Gray and Stark 1984).

The relationship between group cohesiveness and productivity has been a major subject of management research. Gray and Stark (1984, 443) define cohesiveness as “the degree of attraction the group has for the members”. Fleishman and Zaccaro (1992, 38) attribute this definition of group cohesion to Cartwright: "the degree to which the members of a group desire to remain in the group.”which is essentially the same thing. Cohesiveness is measured by the degree to which the members share attitudes, interests, and values and is indicated by low absenteeism and turnover. Intra-group competition negatively affects cohesiveness, whereas inter-group competition, which results when resources are scare, affects cohesiveness positively. The research indicates that cohesiveness is a major influence on productivity because of the energy attributable to the synergistic effects of group behavior. However, cohesiveness can be seen as dysfunctional by upper management if the group does not identify with and pursue organizational goals. Research also indicates that inter-group competition may have a negative affect on cohesiveness when there are multiple groups. Winning reinforces cohesiveness, and losing degrades cohesiveness, and because there will be more losers than winners, an overall negative impact may result (Gray and Stark 1984).

Charles C. Manz and Henry P. Sims, Jr., who taught respectively at Arizona State University and Maryland University, add to the business-school perspective by asserting that sociotechnical systems theory (STS) has influenced the team concept. STS theory emphasizes the importance of both social and technical aspects of work. An STS analysis of a work organization has influenced companies to shift to working in autonomous groups. The rationale is that teams prove to be more effective in applying resources to deal with the total variance in the work load than are individuals acting on their own (Manz and Sims 1993).

## Small Group Models

Gray and Stark present two models of group behavior; the Bales model, which focuses on the types of interactions that occur as a group goes about its tasks, and the Homans model, which focuses on the process of accomplishing tasks. Models can be used to analyze cause-and-effect relationships in small groups. In addition, they can be useful for understanding and predicting small group behavior and answering questions such as: Why does a group pick a specific norm? How are deviates determined? What variables affect group productivity (Gray and Stark 1984)?

The Bales model is based on the theory that groups proceed through distinct steps while reaching a decision, and individuals occupy various roles which contribute to the process. The Bales model also is based on a two-dimensional theory of group leadership. It divides group behavior into two areas: socio-economic and task. The model divides these areas into two more areas: questions and answers, and positive and negative reactions (Gray and Stark 1984).

The Homans model establishes four stages for understanding the group process. Stage one includes looking at background factors such as personal backgrounds of the members, the external environment, organizational policies, and the physical aspects of the work. Stage two includes looking at group requirements such as required behavior, required activities, and required interactions. Also to be determined are behaviors, activities, interactions, and the like which are neither required nor prohibited. Stage three is a look at emergent behavior, the norms that develop with time during the life of the group. Stage four is a determination of the consequences of the emergent behavior; such as the degree to which norms influence productivity, individual satisfaction, and personal development. Moreover, the observer carries this one step further and assesses the degree to which the consequences of the norms are fed back by group members into the background factors identified in stage one (Gray and Stark 1984).

As cited by Salas et al. (1992), J. R. Hackman developed a normative model which is a comprehensive conceptualization of group process in an organizational environment. This model is based on the assumption that the organizational context, the resources given to the group, and the group design are the input variables which affect the member interaction process. The member interaction process affects the quality of team performance; i.e., the output variable. Team effectiveness depends on the level of effort by the members, the amount of knowledge they can apply to the task, and the appropriateness of their strategy for accomplishing the task.

Salas et al. (1992) discuss how Gersick proposed a time and transition model based on observing work teams in action. Gersick noted only one clear pattern of behavior in all teams; they established a method of performing their given tasks in the first meeting and maintained that strategy until midway through the predetermined time given to complete the task. At the midway point, all teams decided to use a different strategy to complete their task, and this new approach was maintained until the task was completed. He concluded that some type of internal clock heightened member awareness at the mid point.

The team evolution and maturation model (TEAM) is based on the theory that task-oriented teams evolve through a series of developmental phases. More specifically, teams must follow two tracks to be successful. One track consists of the operational and task-oriented skills that are necessary to complete the task. The second track consists of the team skills that include behavioral interactions and attitudinal responses necessary for team work. Training is necessary for most groups to traverse both tracks. The TEAM model, which Salas et al. (1992) attribute to Morgan et al., is the origin of the widely-used string of terms: "preforming, forming, storming, norming, performing, reforming, conforming, deforming" for the phases of development. The model allows for teams to spend different times in each phase and to skip a phase depending on the experience level of the members and the difficulty of their task.

## Theories about Small Group Performance

Theories about small group performance and productivity may be particularly useful to this research. Moreland and Levine state the problem simply: there are three distinct steps to problem solving: identify the problem, develop alternative solutions, and select a solution. Productivity is improved if the group identifies the problem quickly and accurately, develops good solutions, picks the best solution, and implements it effectively. Moreland and Levine contend that most group research has been focused on selection of the best solution, and very little research has been conducted on identifying the problem and developing good alternative solutions (Moreland and Levine 1992).

Productivity as a concept is defined in many ways. Such diverse terms as output, performance, effectiveness, production, profitability, cost effectiveness, and components per employee are examples. Pritchard and Watson attempt to clarify the concept. They assert that efficiency is a ratio of output to input and effectiveness is a ratio of output to goals. Productivity is not the simple sum of the performance of all the workers. Factors such as availability of needed resources, how well priorities are set, and cooperation among employees affect productivity. Their definition of group productivity includes measures of group efficiency and group effectiveness (Pritchard and Watson 1991).

Fleishman and Zaccaro define team performance as "the goal-directed behaviors/activities/functions accomplished by the team in performing the task." In this sense, performance is a set of independent responses that is separated from the task. Fleishman and Zaccaro (1992) borrow from Nieva et al. a model of team performance which includes four classes of variables: (1) External conditions imposed on the team. (2) Member resources. (3) Task characteristics and demands. (4) Team characteristics. These four variables and their interaction and ability to complement each other determine team performance according to this theory (Fleishman and Zaccaro 1991, 34).

According to Salas et al., Gladstein developed a Task Group Effectiveness model, and it is one of the few models tested with a large sample from the work environment. Gladstein defines group effectiveness as a group's terminal performance and its satisfaction with the job done. This model has group composition, group structure, organizational structure, and available resources as inputs to group processes. Group processes are the intra-group and inter-group events and behaviors that transform group and organizational resources into group effectiveness. These processes are modified by task demands, which determine group effectiveness. Gladstein found that open communications, supportiveness, active leadership, experience, and training were positively related to group satisfaction and performance. He agreed that training alone does not enhance team effectiveness, and this underscored the complexity of team performance.

Salas et al. developed an integrated model of team performance which combines the ideas of Gersick, Hackman, the TEAM model, and Nieva's work. This model is not so overly complex as one might imagine from its being a mix of models. It is based on the idea that team performance is the outcome of dynamic team processes involving coordination and communications patterns that mature with team experience. There are six inputs to the dynamic processes: the organizational characteristics, situational characteristics, task characteristics, work characteristics, individual characteristics, and team characteristics. Team performance is determined by the influence of the six input characteristics on the team process. Training is a special case of team process which is influenced by the six characteristics and then influences the other processes. The model also includes a feedback loop which allows the output to impact on the task, work, individual, and team characteristics (Salas et al. 1992).

Salas et al. suggest some ideas for future research. In their view, the TEAM model, which provides for two tracks of team development, is a good source of research. It is not clear how team members should coordinate the performance of task and team behaviors or how they can be trained to develop this coordination strategy. Such research could lead to practical applications; i.e., training programs and strategies for interweaving task and teamwork behaviors (Salas et al. 1992).

J. R. Hackman and fifteen other researchers observed twenty-seven teams and reported on their findings in the book *Groups that Work (and Those That Don't).* The groups were placed in seven categories: top management groups, task forces, professional support groups, performing groups, human service teams, customer service teams, and production teams. This research suggests a three dimensional conception of group effectiveness, with the three dimensions being: (1) The degree to which the group's output meets the standards of quantity, quality, and timeliness of the people who receive, review, or use that output. (2) The degree to which the process of carrying out the work enhances the capability of members to work together interdependently in the future. (3) The degree to which the group experience contributes to the growth and personal well-being of the team members. The relative weights to be assigned to the three dimensions depends on the circumstances (Hackman 1991).

Hackman et al. believe that the factors which influence group effectiveness are not in easily separated and distinguishable packages. No one factor has a overwhelming effect, and each factor loses some influence when examined alone. Effectiveness is the product of multiple, dependent factors, and their influence is due in part because they are redundant (Hackman 1991).

The principle of equifinality proposed by Katz and Kahn in 1978 illuminates the intuitive idea that a group can behave in many different ways and still perform well. Similarly, a group can reach the same outcome from various initial conditions and by a variety of means. This does not mean a similar strategy will work well for all groups, but does mean that usually there is more than one path to success (Hackman 1991).

Pritchard and his associates developed the Productivity Measurement and Enhancement System (ProMES) between 1988 and 1990. ProMES quantifies productivity and is based on expectancy behavior theory, which proposes that individuals are motivated to the extent that they are able to perceive a connection between their behavior, the consequences of their behavior, how those consequences are evaluated by the organization, and the value of the outcomes from this evaluation. It is assumed that there is a deterministic relationship between the amount of productivity and how that amount is valued (Pritchard and Watson 1991).

The ProMES process has four steps: develop products, develop indicators, develop contingencies, and create feedback. Developing products entails identifying the organization's products; i.e., the important objectives that the group is expected to accomplish. Products are usually services, tangible items, or a combination of services and items. High attendance at meetings is an example of a product. Developing indicators means identifying methods for measuring how well each product is being accomplished. Products must have at least one indicator, which preferably is quantitative, but can be a measure of customer attitudes. It is desirable that a small change in product causes a large change in indicator. An indicator for high attendance could be total hours at meetings divided by maximum hours possible at meetings (Pritchard and Watson 1991).

In ProMES, step 3 is a graphical evaluation of the relationship between the value of the indicator and how that value is judged. This relationship is termed a contingency, and contingencies are normally nonlinear. Typically, the expected level of the indicator is the zero point, the worst possible value is -100, and the best possible value is +100. In step 4, overall productivity is quantified by adding the indicator values for all groups' products, and effectiveness is the overall productivity divided by the maximum possible expressed as a percentage. The ProMES process allows comparison between groups and between present and past productivity. Publication of results provides useful information and motivation to employees who desire to improve their productivity. The original evaluation of ProMES was conducted at a U.S. Air Force Base during a multiyear test, and productivity increased by 50% and overtime decreased. A control group showed little or no change over the same time period (Pritchard and Watson 1991).

The previous discussion makes it apparent that many academic disciplines are investigating many aspects of small groups in the workplace. Small group dynamics and the impact of small groups on the larger organization are difficult theoretical subjects. Some research on groups is admittedly disconnected from real situations, and the results do not necessarily lead to improvements in real small group activity. Moreover, as Salas et al. suggest, research on team training is expensive, difficult, and labor intensive (Salas et al. 1992.). This dissertation will add to the argument that practitioners are ahead of theorists in this field. The theorists do not argue with this assertion. Manz and Sims lament that management and psychology text books lag the problem, and companies are well ahead of academia (Manz and Sims 1993).

## Quality Circles in the Japanese Style

The impact of TQM on small group theory and practice in the business world is large and growing. Credit for initiating and cultivating small groups in the context of TQM goes to the Japanese. Quality circles, as small groups are best known in Japan, were first tried in Japan in 1962. Within twenty years, more than one million quality circles were registered with the Japanese government. Imai estimates that more than one half of the companies in Japan have introduced quality circles. Circle activities are interconnected in a national network, giving members easy access to what is going on in many industries. There are eight regional chapters in Japan, and each chapter holds regional meetings where circle leaders report and share their experiences. There are about one hundred regional meetings every year and about six national meetings per year (Imai 1986). One assessment gives quality circles about ten percent of the credit for Japan's post World War II industrial success (Gryna 1981). This section presents and discusses the Japanese experience with quality circles, and points out some important differences and similarities between a traditional American business small group and the nominal Japanese quality circle.

From a theoretical standpoint, quality circles upset Taylorism. There were two aspects to Frederick Winslow Taylor's approach to work: One was that work methods and conditions were based on scientific principles, and the methods would be rigidly followed in the shop. The workers did not decide on the methods. The methods were the results of analyses conducted by specialists in work planning. Secondly, workers were to be motivated by a system of wage incentives. The more pieces produced, the more pay. Quality circles are not governed by these policies; circle members select the problems to be solved and solve them. In addition, a sense of accomplishment replaces the direct economic incentives favored by Taylor (Gryna 1981).

Why do quality circles work better today than Taylor's method? This could be a subject for someone else's dissertation, but the short answer is that what worked in 1900 will not work with the better educated and more independent workers who live in industrialized countries today. Carr cites a study by the MacFletcher Company of Scottsdale, Arizona, which supports this argument. The study showed that workers increasingly do not want to be supervised, and they want a reasonable opportunity for self management (Carr 1992). Manz and Sims are convinced that younger workers today are slower to commit and are less loyal to organizations than previous generations. Organizations are less loyal to their workers, too. The same younger workers do not bow to the boss, but they want to learn, to be competitive, and they want self-fulfillment. Manz and Sims agree that work teams come closer to meeting these needs than the traditional, hierarchical, boss-based organization. Team membership gives workers freedom to grow and gain in respect and dignity (Manz and Sims 1993).

A spectrum of processes and activities allow Japanese quality circles to complement and support the natural work groups (supervisor and workers), which continue to exist along side circles in business organizations. As with most if not all human activities which are popularized, some myths about quality circles have been perpetuated by anecdotal communications and the media. The discussion of quality circles that follows is based on the works of other scholarly researchers and business men with extensive experience with circles. This same discussion will include some history, a generalized description of characteristics of circles, and a description of the processes inherent in circles. When it is useful, the case against popularized myths is made.

Circles were started in Japan in 1962 under the auspices of the Japanese Union of Scientists and Enigneers (JUSE) to improve the workplace environment. They were not formed initially to improve productivity and quality control. Employees formed the circles on their own to make their work more meaningful and worth while. At first they were little more than study groups and only later turned their efforts to problem solving. The earliest circles tried to organize the work, improve safety, and bring foremen and workers together to study and learn new knowledge and techniques (Imai 1986).

The American Management Association published a study of the Japanese experience in 1981, under the authorship of Frank M. Gryna, Jr., acting dean of the College of Engineering and Technology at Bradley University. Gryna had prior experience with Martin-Marietta in the quality assurance field. Gryna's small booklet, *Quality Circles, A Team Approach to Problem Solving*, is a rich source of information.

According to Gryna, the circle concept requires a basic change in management style, from autocratic to participative. Those employees most involved in a process, begin to work together to improve the process. Workers become more intimately involved in the design of their own labors, and communications are increased and enhanced among workers and between workers and management. Worker participation in decision making normally leads to better understanding, individual development, greater self respect, and stronger commitment. The circle experience makes shy people more outgoing and teaches supervisory skills to those with leadership potential. These benefits and advantages lead to producing improved results. However, circles are not a quick fix; they are one part of a comprehensive program to improve organizational productivity. Circles do not cure all problems, but do solve some (Gryna 1981).

Imai sees two dimensions in industrial relations: confrontation versus cooperation and formal versus informal. He sees quality circles as a non confrontational and informal method for solving problems and introducing improvements. In his schema, collective bargaining is confrontational and formal (Imai 1986).

The Japanese experience indicates that circles are a modest investment in company resources; the typical circle meets once a week for one hour and solves three problems per year. However, much of the work to analyze problems and develop solutions is done outside the one-hour meeting. The format for a circle meeting might be ten minutes on the last meeting, twenty minutes on new training material, and thirty minutes for discussing the current circle project. Circles typically have three to thirteen members, and membership is voluntary. A particular circle has a life time; it does not go on indefinitely like a natural-work group. Management may set a specific life time for a circle or may dissolve the circle when its original goals are met. Implicit in the success of circles is the requirement that management and workers must trust and respect each other. This has not been a requirement for a traditional organization (Gryna 1981).

Cole cites a 1983 survey conducted by the Japanese Union of Scientists and Engineers which showed that Japanese circles typically had five to eight members, about sixty percent chose their leaders, and about twenty percent rotated leadership. Workers learn simple statistical techniques and modes of problem solving, concentrate on job-related problems, and must present their solutions to management for action (Cole 1989).

Gryna identifies two general benefits from circles: improved attitudes and behavior of people at all levels of the organization and measurable savings from circle projects. These benefits correlate to the two categories of problems that circles tend to solve: those problems primarily concerned with the personal well-being of the worker, and those primarily concerned with the well-being of the company. Worker problems tend to be with the work environment, convenience, or safety. A new circle may start out solving worker problems, and this gives the members confidence in their collective abilities. As the members improve their work environment, they become more motivated to solve company problems; i.e., problems with processes and products (Gryna 1981).

Looking back on years of working with Japanese circles, Imai's list of the major advantages of using circles includes:

1. The process of setting objectives and working for their attainment strengthens the sense of teamwork.

2. Group members share and coordinate their respective roles better.

3. Communication between labor and management, as well as between workers of different ages, is improved.

4. Morale is greatly improved.

5. Workers acquire new skills and knowledge and develop more cooperative attitudes.

6. The group is self-sustaining and solves problems that would otherwise be left to management.

7. Labor-management relations are greatly improved. (Imai 1986)

It is legitimate to ask why the line organization does not solve the problems circles solve. The record indicates that circles tackle problems that may have been around a long time, but no person acting alone or group was able to solve them. Groups which have been in a fire-fighting mode for a long time, for example, will have a backlog of unsolved problems which have had too low a priority to receive attention. Also, some problems do not fit neatly into the responsibility of any person or group. Other characteristics of circle problems are that they are limited in scope and produce only modest tangible savings (Gryna 1981).

It does not follow that a circle will be able always to solve a modest problem that the functional organization has neglected. However, when a circle selects a problem, there is an inherent increase in that problem's priority. Circles document their meetings and track their progress in solving problems. Circulation of circle meeting minutes increases the visibility of a problem throughout the organization. Furthermore, it seems likely that circles devote more resources to problem follow-up (than a busy supervisor can afford) because of the weekly circle meeting and the mutual obligation between members to perform (Gryna 1981). But teams do not only identify problem areas, they identify causes, analyze them, and implement and test new procedures (Imai 1986).

A major difference between traditional small groups and quality circles is the quantity and content of training provided by management. The Japanese, following the tutelage of Deming and Juran, ensured that their workers had the tools to solve problems rationally. There are extensive writings and training video tapes available which provide instruction on the tools most commonly used by quality circles. It is not the intent of this dissertation to elaborate on the tools except to name a few and to give them a strong endorsement as very essential elements for successful quality circles (Gryna 1981).

Brainstorming, Pareto analysis, cause and effect diagrams, and histograms are four of the most widely used tools for problem solving. Many of the tools are statistical and present data and alternatives visually so that the analysts may make comparisons readily. The tools tend to simplify the available information and point toward the alternative solution with the best probability for success. No less important, the learning process and practical application increase the self esteem of the workers and increase their worth to the organization. Worker training and application of problem-solving tools are key ingredients for developing a successful quality circle program (Gryna 1981).

Where do quality circles fit into the functional organization structure? How is the work of all circles coordinated? Do the workers have a problem working for both their supervisor and their circle leader? An axiom of successfully implementing circles in an organization is that top management must be enthusiastic and provide resources. This support is provided through a Steering Committee made up of five to fifteen upper managers. The Steering Committee oversees and directs the circle program by performing the following functions: defines circle objectives, provides resources, provides advice, and removes obstacles. Note that the Steering Committee is not a quality circle; it is a committee of the functional organization. All circle leaders are responsible to the Steering Committee (Gryna 1981).

Circle membership includes a coordinator, a facilitator, and a leader. the coordinator may be a member of the Steering Committee, supervises the facilitator, and directs the administration of the program. The facilitator helps get a circle started, acts as a technical consultant, and helps the team overcome obstacles. Hughes Aircraft looks for these qualities in a facilitator: likes people, is a leader, is a trainer, is responsible, and is available. At Honeywell, one facilitator handles twenty-four circles, and facilitators rotate every eight to ten weeks. This prevents the facilitator from competing with the circle leader. The leader directs circle members by promoting participation and involvement, encourages open and effective communication, develops and utilizes the available human resources, and monitors the effectiveness of the circle. In Japan, the supervisor is frequently the circle leader, but Gryna believes that not using the supervisor as circle leader is the better approach. He suggests that the supervisor be asked to recommend a circle leader (Gryna 1981).

The introduction of quality circles into an organization must be very carefully managed if the experiment is to be successful. There are numerous "how to" books published in the US, and this dissertation will not elaborate on this aspect of small group activity. What is germane, is the general record of reaction to the introduction of quality circles and the support given the effort by various levels of management. Top management usually favors circles because circles have a record of improving communications between management and workers and because they improve morale. Some middle managers oppose circles because they fear a loss of personal control, because the training and work takes up too much time, and because they think control exercised by workers can lead to chaos (Gryna 1981).

There is evidence that middle managers go through four stages when faced with teams being introduced to their organization. Stage one is one of initial suspicion, uncertainty, and resistance. Stage two is a gradual realization of the positive potential offered by teams. Stage three is understanding their leadership role. Stage four is learning the language of teams and the quality movement and gaining the necessary verbal skills (Manz and Sims 1993).

The reaction of first line supervisors depends on: (1) Their opinion of the value of circles to themselves, the workers, and the company. (2) The degree to which they are comfortable with worker involvement in decision making, and (3) The priorities and the actions of their superiors with respect to circles. The traditional functions of supervisors ; direction, instruction, command, goal and task assignment, conflict resolution, and discipline; are threatened by introducing the team concept (Manz and Sims 1993). Usually, supervisors overcome an initial skepticism, but if circles are forced on them, they may not give them their full support. A Theory X approach to a Theory Y concept should not work. A spokesperson for Pontiac indicated that six to nine months are required for each management level to accept quality circles (Gryna 1981).

Evidence that circles are being supported by various levels of management is indicated by the following: Top management is represented on the Steering Committee. Top-notch people are selected to serve as facilitators. Funds, meeting space, and clerical support are provided to circles. Meetings are not called that conflict with circle meeting times. Recognition for significant work is given to circle members (Gryna 1981).

Experience with Japanese circles has shown that there are rational means for evaluating circle productivity. Examples include tracking the following metrics: the number of projects started and the number completed. The average number of circle labor hours to complete a project. The average number of working days between implementation and completion of a project. The average estimated value of the resultant change per project. Cost savings per idea. Conducting a survey of circle members is one method used to measure cooperation, communication, management responsiveness, and a sense of accomplishment. Indicators that circles are failing include: Slow response to requests made by circles, postponing of circle meetings, absenteeism at meetings, and an unreasonable time for implementing circle recommendations (Gryna 1981).

Imai tells many circle success stories which substantiate his list of seven major advantages of using circles. . A few are repeated to punctuate the importance of quality circles to Japan. Sanwas Bank, one of Japan's largest, has 2,400 circles involving 13,000 employees. The first Sanwas circle formed in 1977, and since then circles have dealt with about 10,000 subjects. In 1963, Komatsu Ltd. staked its future on quality circles because it was faced with increased competition when Mitsubishi Heavy Industries, Ltd., formed a joint venture with the American firm, Caterpillar. All levels of management attended training, with different types of training for different management levels. By 1986, Komatsu had more than 800 circles in manufacturing and about 350 circles in sales and service. Participation is 95% in manufacturing and 89% in sales and service. Each circle provides an average of 4.2 ideas per year. Komatsu has introduced circles to its overseas dealers, to manufacturing plants in Brazil and Mexico, and to its subsidiaries, affiliates, and subcontractors (Imai 1986).

## The American Experience

W. E. Deming, J. M. Juran, and P. B. Crosby are arguably the three most famous American TQM consultants. They have written extensively about changing the culture of an organization to emphasize quality. There are hundreds, if not thousands of lesser known consultants who have written "how to" essays, pamphlets, and books on some aspect of TQM. Some of these writings emphasize the small group process. There is no standout book on the small group process that I have found; however, there are many good books about using small groups in American industry. The books that I have read share many commonalties, but every author emphasizes at least one new idea which makes his or her book distinctive. A sample of current American writings is presented.

A definition of "team" is useful because "team" is used more often than "circle" in the U.S. A definition attributed to E. Salas et al. is sufficiently complete and clear for our purposes. A team is a distinguishable set of two or more people who interact dynamically, interdependently, and adaptively toward a common and valued goal, objective, or mission. Team members are each assigned specific roles or functions to perform, and they have a limited life-span of membership (Salas et al. 1992).

Experimental work with teams was in progress in the U.S. throughout the 1970s, such as at the Gaines dog food plant in Topeka, Kansas, but the story received very little attention from the business press. In the early 1980s, Manz and Sims thought more media attention was given in the United States to Japanese Quality Circles then to self-managing work teams in the United States. *Fortune* and *Business Week*, articles seemed to create a climate of interest and a pooling of information (Manz and Sims 1993).

J. Michael Crouch has observed American TQM teams in the workplace and provides justification for their superiority over traditional groups. He divides management techniques used by organizations into four categories, which are listed from least preferred to most preferred: inspection, fire fighting, problem solving, and prevention. Deming downplayed the importance of total inspection as a method for improving quality, and Crouch concurs. Fire fighting; i.e., moving from crisis to crisis, is prevalent in many organizations, but this management technique tends to treat symptoms without identifying the root causes of problems, so the problems come back. Problem solving is focused on current problems, whereas prevention is focused on future problems. The prevention process includes identifying a potential problem, analyzing and planning to eliminate the root cause, and taking appropriate action. Group activities should be optimized for both problem solving and prevention (Crouch 1992).

Crouch's approach to organizing small groups to prevent problems, is to form an Action Board under the Steering Committee. The Steering Committee identifies a large issue requiring attention. The Action Board divides the task into sub tasks and creates an action team to address each sub task. The action team investigates the specific problem, recommends solutions, and implements solutions approved by the Action Board. An action team should include an "owner", subject matter experts from all affected areas, and a facilitator. Crouch makes clear distinctions between his action teams and quality circles. The owner is selected by management rather than being elected by the circle. Team members are selected by the owner rather than being volunteers. The problem is selected by higher management rather than by circle members, and the action team is assembled to solve one problem rather than having an indefinite life (Crouch 1992).

Crouch's action team is clearly more results oriented than a quality circle because solving management's problems is preeminent. Unless the identified task is one of easing worker frustration, that is not a goal. As Gryna states, the American experience with small TQM groups indicates more emphasis on management's problems than on worker problems (Gryna 1981).

Shilliff and Motiska claim that too many companies still follow the adversarial approach to leadership. The forces of influence; i.e., management, do battle with the forces of resistance; i.e., the workers. The result is that company goals get lost in the battle. An adversarial relationship between management and labor is incompatible with becoming organized to empower employees and problem-solving work teams. Shilliff and Motiska also point out that discipline is an important characteristic for teams to develop. The discipline of a team, however, is quite different from that of the traditional organization. Self discipline and discipline between peers are what is needed by teams. Supervisor imposed discipline was essential to the security of a traditional autocratic organization, but is not essential for modern work teams (Shilliff and Motiska 1992).

John H. Zenger, et al., point out that the rush of industry to use worker teams is not just a matter of copying the Japanese, but is a response to economic pressures. Teams are just more efficient than vertical layers of management. Zenger comments that since the mid 1980s, about two million middle management positions have been permanently eliminated in the US. Companies see the benefits of shifting traditional management duties to teams, frequently made of non-managers. Workers often know more about customers and work processes than the more distant managers, and that is why teams often perform certain management work better, faster, and cheaper than layers of managers ever did. (Zenger et al. 1994)

Zenger cites three managerial traditions which inhibit progress in American industry: (1) Organizations are internally driven rather than customer driven. (2) Organizations are functionally focused "silos of vertical power" which compete for resources. (3) Managers see themselves as the central players in the organization and assume they need to control almost everything. Zenger does not see employee involvement as an end in itself, but just a superior means to increase customer satisfaction, reduce cycle times, and reduce costs. Successful team-based organizations use teams not to bypass management, but to create an expansion of roles. One result is that leaders spend more time with the next level up (Zenger et al. 1994).

Zenger makes a noteworthy comparison between the old management methods and the new: the traditional perspective is that maintaining control is a leader's most important job. The team perspective is that anticipating change is a leader's most important job. You try to make your organization more flexible rather than more stable. He also identifies four stages of team development: forming, storming, norming, and performing, using TEAM terms (Zenger et al. 1994).

Ciampa stresses the differences between leading and managing. Managing is a systematic planning, execution, and follow-up. Managing is mostly rational and depends on systematic tools such as goal setting, problem solving, analysis, and effective ways to process information. Leading involves creating and clearly articulating a vision of the future that is bright and compelling. Leadership depends on capacities that are non rational and non analytical. Leaders respond to and bring out powerful emotions that can spur people on to accomplish things they did not know they were capable of doing (Ciampa 1992).

Zenger recommends team leaders manage by principle rather than by rules; such principles as: (1) Focus on the issue rather than the person. (2) Maintain the self confidence and self esteem of others. (3) Maintain constructive relationships. (4) Take the initiative to make things better. (5) Lead by example (Zenger et al. 1994).

Manz and Sims assert that the all-powerful boss is as outdated as a dinosaur, and the need is for leaders rather than bosses because leaders help others to lead themselves. Bosses influence subordinate employees through command, instruction, and top-down goal assignments, with intimidation and reprimand added when useful. In contrast, leaders for self-managing teams encourage self goal setting, self evaluation, and self expectation. Such leaders facilitate self problem solving and develop self-initiative and responsibility among all their employees (Manz and Sims 1993).

Zenger advocates consensus decision making on teams rather than majority rule or unanimity. Consensus means all team members openly express a commitment to implement a decision even if it is not their first choice. A definition of consensus is that it is a general agreement by every team member to support a decision and actively participate in the related course of action. Consensus is preferred because it gives a more comprehensive decision because of the open discussion of alternative views, and because the process results in a high level of team commitment (Zenger et al. 1994).

Zenger identifies three types of teams: the intra-functional team which works within a functional unit such as a department; problem-solving teams, which are temporary forces assigned to particular problems; and cross-functional teams which are permanent teams which monitor, standardize, and improve work processes that cut across different parts of the organization (Zenger et al. 1994).

Dan Ciampa's view of small groups rests on cross-functional teams that emphasize those problems that cross department lines. Cross-functional teams consider an entire process rather than just the immediate problem. Whatever impact a cross-functional team has is intended to affect an entire process. Ciampa supports getting teams formed quickly and letting them learn by doing; however, this will only work if the members consider the problem to be solved very important (Ciampa 1992).

Ciampa supports a two-step process. First, a cross-functional analysis team investigates a problem and produces recommendations. If the analysis indicates that a solution looks promising, a cross-functional pilot team is formed with members coming from a variety of essential functional groups. Ciampa is against voluntary membership on pilot teams, saying it is not essential nor practical. It is important to have the right people on the pilot team rather than the wrong people, no matter how enthusiastic. Pilot teams need resources and a mentor in upper management. They also need freedom to experience and challenge some organizational “sacred cows.” A pilot team should determine the root causes of a problem and recommend a course of action to remove the cause. When a pilot team completes its task, it is disbanded, and the responsibility is transferred to appropriate line management. Line management may let the functional organization work the problem, or may form a team to solve the problem (Ciampa 1992).

Manz and Sims, who have been studying teams since 1981, are strong advocates of self-managing teams. Their research indicates that such teams offer the following advantages: increased productivity, improved quality, enhanced employee quality of work life, reduced costs, reduced turnover and absenteeism, reduced conflict, increased innovation, and better organizational adaptability and flexibility. Some examples of effective teams follow (Manz and Sims 1993).

Clay Carr, in his book *TEAMPOWER Lessons from America’s Top Companies on Putting TeamPower to Work,* documents many fine examples of teams helping companies to become more productive. Between March and August in 1989, Litel Telecommunications reduced order processing time from fourteen days to one day and reduced the error rate from 40% to 5% by using self-managing work teams. A Corning Plant in Blacksburg, Virginia, was organized around teams and had only three managers in a work force of 150. Corning projected a $2.3 million loss during the startup period. The plant produced a $2 million profit in the first eight months (Carr 1992).

The General Motors (GM) power-train plant in Bay City, Michigan, was losing up to $3.5M per year in the early 1980s. A new manager reported in 1985 and established forty-three teams. Thirteen of these teams evolved into fully self-managed teams. Grievances dropped to almost nothing. Lost time dropped to 35% of the GM average. Productivity increased 24% in eighteen months. Employees who were able to eliminate their own job were put on a cost-reduction team. The plant became profitable and saved $2.M by the late 1980s (Carr 1992).

Why were teams able to outperform traditional organizations in the previous examples? Carr speaks harshly of traditional work methods; of work being fragmented and organized into simple, repetitive tasks. This mechanical approach to work treats workers as though they were machines. People make relatively poor machines, and they simply do not like being treated as machines. Workers in this environment lose touch with the customer and the product. The new way of managing, according to Carr, is different. It means supporting the workers, not bossing or forcing them to perform. Creating empowered workers who are on self-managing teams is Carr's ideal for the future (Carr 1992).

Carr defines empowerment to mean "enabling employees to manage themselves in pursuit of organizational goals" (Carr 1992, 5) and points out that a supervisor can create the right conditions for an employee to be empowered, but only the employee can empower himself or herself. Self management is not just a matter of being empowered; it requires skills and motivation. Creating empowered, self-managing teams requires a lot of work. Carr advocates organizing for worker challenge, control, and cooperation. This will result in workers who are competent and committed, which is what management should want of their work force. However, Carr warns that team power cannot be grafted on top of an existing, traditional operation and be expected to work. His axiom in this regard is that the more you want to use teams, the more you have to find new ways to organize and manage. The new ways he speaks of are to make the work challenging, give the workers control, and promote cooperation (Carr 1992).

Three proven methods of making the work challenging are to provide variety, make the work complete, and create the opportunity for workers to solve problems. Learning a new skill adds variety, as does learning how to do all the jobs in a process. Traditional work divorces the worker from the finished product and the customer. Completeness means allowing workers to participate in the entire process. Most people like to solve problems, and solving some builds the confidence to solve more. Control of the work is the second characteristic of empowered workers. They must be in control of their work to tap their power individually or as teams. Studies have shown that workers who have challenging work but are not in control of the work do not experience the challenge; they experience stress. Carr has two findings: no one commits to a job he or she cannot control, and challenging work improves worker competence (Carr 1992).

Cooperation is the third characteristic of empowered workers. Carr candidly points out that firms such as Federal Express and SAS have empowered front line workers without using teams, but in his opinion, "only an empowered team can tap the full measure of worker resources." (Carr 1992, 18) However, teams only work when you have found the right problem. If one or more workers can do a job well working individually, a team is not needed. In practice, most activities in organizations require more than one person and a variety of skills to complete. People are social beings and enjoy working with others, and the human desire to cooperate is a tremendous resource when a team is formed (Carr 1992).

Carr's formula for empowered teams; challenge, control, and cooperation; is built on self-management and creating competence and commitment to customer satisfaction. As in many things, it is much easier to describe desirable characteristics than it is to develop those characteristics. Moreover, measuring progress towards achieving a subjective goal, such as developing a self-managed team, is a daunting task. Carr provides a formula by citing and describing eight essential characteristics of successful teams. If a team lacks a single characteristic, success will be much more difficult to achieve. If two or three characteristics are missing, failure is nearly certain (Carr 1992).

1. Shared Values that Support Teamwork. Important values include: respect for everyone and for all opinions, trust, commitment, and competence. Team members must have shared values and must value the right things.

AES, formerly Applied Energy Services, Inc., adopted as corporate core values the following four ideals: To act with integrity. To be fair. To have fun. To be socially responsible. These are the only things the company holds dear. By "fun" the company means people using their gifts and skills productively to help meet a societal need (Manz and Sims 1993).

2. Clear, Worthwhile Goals. The goals must be clear, and the result must be worthwhile. The goals must be consistent with the values. Also, workers must believe the goals are attainable and have the resources to achieve it. Establishing a team is never a primary goal. The goal creates the team rather than the reverse.

3. A Genuine Need for Each Member of the Team. A team is a team only if the members really need each other to accomplish its goals. Every member must be needed; and each one must contribute an important skill and have a clear interest in the outcome.

4. Genuine Commitment to the Goals. The most common cause of teams failing is their letting some other factor take over the focus of the team effort. The leader is responsible for keeping everyone committed to the goals. Any member not committed to the goals should be dropped from the team.

5. Specific, Measurable Objectives. A set of objectives supports each goal. Each objective must be a measurable quantity or a set of milestone dates. In this way, the team and management can assess progress. Team members must be as committed to the objectives as the goals.

6. Direct, Prompt, Dependable, and Usable Feedback to the Team. For feedback to serve its purpose well, it should have these four properties: (1) It goes directly to the team and not through intermediaries. (2) It is prompt; gotten in time to make corrections. (3) It is dependable; that is it is accurate, available, complete, and in the form the team expects. (4) It is usable; that is it is specific and detailed enough for the team's purposes. It is not inherent that a team will be able to use feedback to good advantage.

7. Rewards for the Team, Not Just for Individuals. This is the most violated requirement for effective teams. Individual rewards can be harmful to the team, and a

group of individual stars often results in an ineffective team. Carr insists that all members should be evaluated the same.

8. Solid Individual and Group Competence. Each member must have subject-matter competence, and the team must have the range of competencies needed to accomplish the goals. Also, members need to be competent at being a team. Training in group dynamics and problem-solving techniques is an important ingredient for developing team competence.

The eight characteristics of successful teams just described constitute a test for any team, and Carr developed a useful set of questions (not listed here) based on these characteristics which can assist a company in assessing its progress in developing work teams (Carr 1992).

Ciampa makes a strong case that vision is also essential to successful organizations, adding a ninth characteristic to Carr's list. Ciampa states that the leader must convey his or her vision to the employees, a picture of the future that is both inspiring as well as shared and consistent among the employees. A vision is not a mission statement nor is it a list of goals. It is a picture of what an ideal state will look like and what it will feel like to work in that state. Passion is important. Vision is different from purpose; purpose is a general direction, but vision is a destination. Purpose is abstract; we want to explore the solar system. Vision is specific; we want a human walking on the moon by the end of the decade. Ciampa asserts that much does get done without a vision, but rarely do things that really matter get done. When there is strong purpose and meaning but no vision, directionless passion results. However, vision must be based on core values that provide meaning and purpose (Ciampa 1992).

Hackman and his colleagues, in their study of twenty-seven groups, found that in some ways all groups work like all others, in some ways they were like some other groups, and in some ways each group was unique. All groups had a task to perform, and that determined the similar features. For example, they found that time limits proved to be a powerful organizing force for some teams, and the time available determined the pace of work. Groups encountered problems when deadlines kept changing, were fuzzy, or did not exist. Some groups which did not have fixed deadlines developed a rhythm or standard cycle which paced their work. Time limits, rhythms, and cycles also affected group climate and the quality of members' experiences (Hackman 1991).

Hackman et al. also coined the term "self-fueling spiral" to identify their observation that many teams which got off to a good start got better with time and other teams which got off to a bad start got worse with time. Their evidence suggested that the factors which set the spirals in motion include: the group's initial design and the occurrence of a positive or negative event which triggers the spiral. A negative spiral occurs when a poorly designed team encounters a negative event. A positive spiral occurs when a well-designed team encounters a reinforcing event. A bad sales region can set back any team, but particularly a bad sales team (Hackman 1991).

Once a team gets a label, good or bad, it is very difficult to change the perception. Bad teams get little praise and get few challenging opportunities. Eventually the members accept their label and give up. Intervention strategies do exist, but they must be carefully managed. The structure may have to be changed a bit, the team needs special support, and the team must be given a successful experience to build confidence. Good teams usually get lots of reinforcement and challenging assignments, and this combination generates a positive spiral (Hackman 1991).

All of the twenty-seven teams had to deal with authority issues, and there were four categories: (1) The amount of authority the group had to manage its own work. (2) The stability of the authority structure. (3) The timing of interventions by authority figures. (4) The substantive focus of those interventions. The researchers created three categories for teams depending on their degree of authority: Those with little authority are called manager-led teams. Those with unlimited authority are called self-governing teams. Those teams in between are called self-managing teams, and this type was predominant as should be expected. Hackman et al. stress that a stable authority structure is extremely important, as is the timing of interventions. On the other hand, frequent leadership changes are usually harmful to a team.. Interventions at the beginning and the mid-point of a group's term are usually positive, but intervention in the group process is usually negative at other times (Hackman 1991).

Hackman describes five “trip wires”, that is things not to do if a team is to succeed. Trip wire 1 is to call the group a team but manage the members as individuals. This may be difficult in some organizations. Organizational systems which are strongly individualistic are a particular challenge. The airline industry is an example. Pilots bid for flights, and crew membership changes every flight (Hackman 1991).

Trip wire 2 is for the manager to retain too much or to yield too much authority. A proper balance of authority is necessary, but difficult to achieve. When a team is formed it is tempting to give away too much authority, and when there are problems it is tempting to take away too much. The findings suggest that managers should be unapologetic and insistent about exercising their authority about the end results desired of the team and on the outer limits of team behavior; i.e., the things the team must do and must never do. Complementing this, the manager should assign the team full authority for the means by which it accomplishes its work and ensure that team members accept full responsibility for deciding how to do the work. Providing clear direction empowers a team because it focuses their effort and creates goals which provide feedback on their progress. When direction is absent, the uncertainty demotivates a team (Hackman 1991).

Trip wire 3 is to use this strategy: assemble the group, tell them in general terms what needs to be done, and let them work out the details. This is a false hope, and coaching will not fix it. Groups with insufficient or inappropriate structures tend to have process problems. The research indicated that an effective structure for a work team has three components: (1) A well designed team task that engages and sustains member motivation. It must be meaningful work, and there should be feedback about the results.

(2) A well-composed group that is as small as possible given the work to be done. There needs to be a good mix of people, people who are neither to similar to one another or so different that they have trouble working together. (3) A clear and explicit specification of the extent and limits of the team's authority and accountability (Hackman 1991).

Trip wire 4 is to assign demanding team objectives but skimp on organizational supports. The team must be well supported no matter how excellent the direction and structure. A lack of support will demotivate the best of teams. Organizational supports includes: (1). A reward system that recognizes and reinforces excellent team performance. (2) The opportunity to receive the help of technical consultants and the training in team and task skills needed to supplement present technical expertise. (3) An information system that makes available to the team the data members need to manage their work. (4) The mundane material resources such as equipment, tools, space, funding, and staff needed to sustain the effort (Hackman 1991).

Trip wire 5 is to assume that the members already have all the competence they need to work well as a team. Hands-on coaching may be helpful, but be cautious about intervening. The timing of intervention is important as discussed earlier, and getting off to a good start is crucial. Do not intervene when the team is deeply engrossed in the execution of their work. Another point from the research is that coaching activity is unlikely to have a lasting effect if a team's performance has been unfavorable. Try to fix the problem rather than the team. Hackman says that a team leader need not worry about the five trip wires if he or she: (1) Creates favorable performance conditions for the team. (2) Builds and maintains the team as a performing unit. (3) Coaches and helps the team at the right times (Hackman 1991).

A case history of a successful team organization is worth discussion to show how theory can be put into practice. Frederick P. Brooks, Jr., Professor and Chairman of the Computer Science Department at the University of North Carolina, Chapel Hill, describes in his book, *The Mythical Man-Month, Essays on Software Engineering,* his "ideal" team for developing computer programming. Brooks was project manager for the Operating System/360 software at IBM before returning to academia. He credits another IBM employee, Harlin Mills, with originating the programming team organization.

Brooks found that developing complex computer programs defied normal logic. He found that in some situations, adding more programmers slowed up work. If development was behind schedule, hiring more help was not necessarily the answer. His experience was that fragmenting the work and forming teams dedicated to a single task was most effective. His teams shared many characteristics with TQM teams in that each person must be competent in a useful subject. However, a programming team is autocratic in that the team leader acts unilaterally in decision making, and he likens the leader to a surgeon in a surgical team. Also, the programming teams are organized around production work rather than problem solving, but programming production work amounts to considerable problem solving and is similar to design work. Indeed, a programming team starts out with an end goal and a set of desired characteristics, but the path to the goal is a maze with many opportunities for wrong turns (Brooks 1982).

Brooks provides a title, which is underlined below for easy recognition, and a brief job description for each member of his ideal programming team. Enough will be repeated here for the reader to appreciate the organization and what is expected of each team member (Brooks 1982).

The surgeon is the chief programmer and defines the performance specifications, designs the program, codes it, tests it, and writes the documentation.

The copilot is able to do any part of the surgeon's job, but is less experienced. The main function is to be thinker, discusser, and evaluator. The surgeon tries out ideas on the copilot. The copilot is insurance against a problem with the surgeon.

The administrator handles the money, people, space, and machines. One administrator may serve two teams, depending on legal, contractual, and financial constraints. The surgeon has the last word, but does not have time for these matters.

The editor takes the surgeon's drafts or dictated manuscripts, and criticizes them reworks them, and shepherds them through the necessary rework to production.

The program clerk maintains all technical records in a programming-product library. All computer input goes to the clerk, who logs and keys it if required. All programs and data are team property.

The tool smith does file and text editing; debugging; and constructs, maintains, and upgrades special tools, such as utilities and macro libraries.

The tester acts as an adversary to the surgeon and devises system tests for testing pieces of the software as it is developed and for testing the final package. The tester also assists the surgeon with debugging problems discovered during the testing and subsequent usage.

The language lawyer is master of the intricacies of a programming language and finds efficient ways to use the language to do difficult tasks that are beyond the capability of the surgeon. One language lawyer can serve several teams.

Two secretaries serve the administrator and the editor.

Certainly the organization of and division of labor within Brooks' team does not match the generic quality circle, particularly the autocracy for decision making and the minimal flexibility for members exchanging jobs. Furthermore, it is unclear how frequent the team meets in a room to problem solve around a table. Nonetheless, this team is not a committee and is more than a traditional natural work group. It is an example of an American company using the team concept to increase corporate efficiency when the functional organization failed to meet a need.

There is no doubt that the use of teams in United States industry is increasing. E. Lawler of the University of Southern California estimated that in 1990 about seven percent of US companies were using some form of self-managing teams. Manz and Sims estimate that forty to fifty percent of the U.S. work force will work in some form of empowered team by the year 2000. Two team success stories follow to make the point that teams can be highly successful in the U.S. (Manz and Sims 1993).

General Motors established a plant in Fitzgerald, Georgia, in 1974 to build car batteries. Three-hundred and twenty employees were organized into three levels of teams from the start. The top managers were in a “support” team. Foremen and technicians were in the “middle” team, and there were thirty-three operating teams, each a business onto itself. Each operating team had is own physical space and task responsibilities, and products were measured according to input and output. The output of one team was the input for another, and inventories acted as buffers between teams. To get promoted, a worker had to demonstrate competence at all jobs on two teams, and this took about two years. Teams meet once a week for at least one half hour, and the teams elect their own leaders (Manz and Sims 1993).

C. Eberle, a former vice president at Proctor & Gamble, reported that a comparison of side by side results over a two decade period made it clear that the new work processes were much better than the traditional. The teams lowered manufacturing costs by thirty to fifty percent. Not only tangible, measurable indicators such as cost and quality were improved, but also harder-to-measure attributes such as the decisiveness, toughness, and resourcefulness of the organizations improved (Manz and Sims 1993).

## Cultural Comparisons

What effect does cultural diversity have on team productivity? Zenger says that language, cultural background, gender, stereotyping, and poor math and verbal skills can have a negative effect on team work. The challenge for a team leader is to focus on each person’s strengths and not their weaknesses. People of different backgrounds bring different perspectives to any task, but a diverse team can generate and implement very creative and workable ideas, given the right sense of purpose (Zenger et al. 1994).

Robert E. Cole has written a comparative study of small group experiences in Japan, Sweden, and the US. He collected data in Japan in 1977-1978 while a Fulbright research scholar. Later, he had a German Marshall Fund grant while at Gothenburg University where he studied Swedish industry. He has been associated with the International Association of Quality Circles since its inception in 1978 and has served on the Board of Directors. In 1984-1985 he wrote his book while on a grant at the Center for Japanese Studies and the School of Business Administration at the University of Michigan (Cole 1989).

Cole takes the position that American business has not fully used its human resources. and this inhibits quality and growth. He maintains that we can learn from other cultures. Circles are a strong democratizing force that can humanize the work. Worker participation in decision making is a strategy for improving employee motivation and helping employees reach their full potential (Cole 1989).

When the officials of a company in one country visit a foreign company, cultural differences can inhibit the learning process. Even if an observer is aware of this, powerful cultural stereotypes in each country bias how one assesses the impact of culture on the cross-national borrowing process. Cole cites as examples, how the US and Japan see Japan as a group based society and the U.S. as an individual based society (Cole 1989).

Cole refutes this conventional wisdom. He cites a 1989 study by Kelleberg and Lincoln which reports that Japanese employees are only slightly more inclined to favor working in groups than their American counterparts. The rigid adherence to orders style of work so prevalent in early twentieth-century Japan made being creative and independent very difficult for the Japanese. On the other hand, Americans have a strong sense of teamwork from sports and from our agricultural background. Furthermore, American blue collar workers are treated in the mass and receive little individual attention. In Japan, personnel policy gives individual treatment to blue collar workers, including training and wage increments. The Japanese reward system promotes tremendous competition between workers; however, the Japanese educational system does emphasize group problem solving, in contrast with American practices. Interestingly some Japanese say that circles have succeeded in spite of the culture and not because of it (Cole 1989).

Cole disagrees to a large degree with Gryna regarding autonomy given to Japanese quality circles. Cole implies that the circle experience has given the worker input into the decision-making process, but management maintains control of the decision-making process. The workplace has not been democratized in his view, and participation is considered a responsibility and obligation rather than an opportunity to express individual talent. Cole says that the Japanese did not talk about the motivational aspects and participation in management until the late 1970s, and thus lagged the U.S. in this regard. There is a subtle difference in the Japanese and American understanding about worker participation. To the Japanese, participation means that everyone will be involved; it is a part of work, and no one will be left out. Americans view participation as a means to tap and motivate unused human potential (Cole 1989).

The Swedes started with a highly centralized decision-making process because Unions in Sweden had not had the same impact as those in the U.S. Once participative management was introduced in Sweden, the Swedes stressed the change in power relationships between managers and employees at all levels. The Swedes understood workplace democracy to mean new work structures and a transformation of structural relationships. Autonomy of work groups is an end in itself. In theory, workers make their own decisions about work allocation, recruitment, planning, budgeting, quality, maintenance, and purchasing. Workers take responsibility for the organization of the work. Unlike Japanese circles, Swedish work teams are involved in personnel and budgeting issues, but the ideal is seldom realized in practice (Cole 1989).

Cultural differences may be magnified when a company from one culture attempts to change the business culture in one of their facilities located in another country. According to Imai, Komatsu Ltd. found introducing circles in overseas plants to be different from introducing them in Japanese plants. It was possible, but not always easy, to get lower-level workers to participate in circles in Japan. In many cases overseas, it was better to start with middle and lower level managers before involving workers. It was relatively easy to get workers in Southeast Asia and the Middle East to accept the concept of quality circles, but it was much more difficult to get managers involved in the U.S. and other industrialized countries because they assumed they already knew the techniques. Komatsu concluded that Japanese workers are more willing to learn and acquire new knowledge and skills, whereas workers elsewhere tend to be more interested in linking their learning with results. Another distinction noted was that Japanese workers had less turnover and less need for material recognition for making improvements than workers from other countries (Imai 1986).

There follows a brief introduction to the topics of reliability, maintainability, and availability as they are discussed in the literature. The Team was formed to improve accelerator performance in these areas, and therefore it was essential that Team members had a good understanding of the engineering principles that are the foundation for the three terms.

## Reliability, Maintainability, and Availability

Reliability, maintainability, and availability are related and quantifiable terms of singular importance to the Team because CEBAF has made a commitment to the US Department of Energy to maintain a minimum availability on an annual basis beginning in 1995. The nature of and relationships between the three terms are mathematical and are well covered in undergraduate-level text books. Reliability and Maintainability are actually probabilities, but normally for practical reasons are quantified in units of time.

For example, reliability is measured by the time between equipment failures, and maintainability is measured by the time it takes to repair a failed component or equipment. Availability is usually expressed as the percentage of the available time that equipment is actually operating usefully.

Reliability is most commonly expressed by the term mean time between failures (MTBF), and maintainability is most commonly expressed by the term mean time to repair ( MTTR). Availability is expressed in several forms, but what has become known as inherent availability (Ai) is equal to the following:

$$Ai = \frac{MTBF}{MTBF + MTTR}$$

This definition of availability equates equipment operating time to the mean time between failures, and it equates the total time available to operate as equal to the same equipment operating time plus the time on average to repair the failures. Theoretically, if an equipment can be repaired instantly, its inherent availability is one hundred percent, no matter how often it breaks down.

Taking the above discussion one step farther, reliability engineering texts make other distinctions to better identify and understand reliability data for operating equipment. For example, mean time between maintenance (MTBM) accounts for the eventuality of shutting equipment down for preventive maintenance in addition to repair maintenance. Another term, Mean Down Time (MDT), includes time for administrative delays and time spend obtaining parts, in addition to the time to actually perform preventive and repair maintenance. Operational availability (Ao) makes use of these two terms as indicated by this equation:

$$Ao = \frac{MTBM}{MTBM + MDT}$$

There are even more complex variations on this theme in reliability engineering texts. A review of the literature about reliability, maintainability, and availability is made available to the reader in Appendix 1.

## Chapter Summary

The Literature Review Chapter provides a standard for teams in the work place so that the Team can be compared with a viable reference. It also provides a set of expectations for the Team and a set of lessons learned from previous team experiences. This knowledge may be factored into the Team's practices and help improve its performance and its survivability. Finally, the chapter contains information about certain theories about team performance which can be examined through this team.

The first section in this chapter discussed the theory of small groups in the work place. This section presented a historical view of work-group theory since the turn of this century. This is a story that see-saws back and forth over time between the school of thought that says that little can be learned about groups by studying the individual and the other school of thought that says that groups are not worthy of study. The results of relatively simple experiments conducted early in this century with bicycles and a tug-of-war rope provide images of the complexities of trying to understand the behavior of individuals within a group. These experiments and others led to conflicting results; there is evidence that the presence of witnesses can enhance individual performance or detract from it. The search for the prevailing psychological variables has been intense, leading to the present perception that (1) fear of criticism interferes with the performance of complex tasks being observed and (2) anticipation of a positive evaluation improves performance of easy tasks being observed.

Group research has had periods where it barely survived because it is clearly more difficult and time consuming than individual research. Some theories about groups have won acceptance. For example, Marjorie Shaw proposed in 1932 that groups solve problems better than individuals because the members engage in checking each other's errors and eliminate incorrect answers.

More recent research reports that many myths about teams are flourishing and finding acceptance. Driskell and Salas list and discuss their findings in this regard. They point out that it is not necessarily so that highly cohesive groups are more productive than less cohesive groups, and explain that a group may be so cohesive that it develops its own goals that conflict with the larger organization's goals. Productivity, of course, is a measure of reaching the organization's goals.

Traditional group theory states that teams establish a set of normal behaviors, and one theory classifies group members as regular members, deviates, and isolates. Some researchers have unified their understanding of group processes and have developed a model of a work-place team. For example, Gray and Stark discuss two models of group behavior; the Bales model which focuses on the types of interactions that occur within a group, and the Homans model, which focuses on task accomplishment. J. R. Hackman describes his normative model as a conceptualization of group processes which depend on the organizational context, the resources available to the group, and the group design. A model named TEAM defined eight stages of team development, but a team need not go through all stages .

Much recent writing addresses improving team productivity. One suspects that this reflects the parochial interests of funding sources rather than that of researchers. Group research conducted by scholars such as Steiner, Hackman, and Morris has focused on group productivity in hopes of being able to improve it by learning what factors have a positive influence. There has been some discussion about whether laboratory-based group research results can be translated to teams in the field, and this is still in debate.

Some of the work is not enlightening; for example, Katz and Kahn show that a similar strategy will not always work for all groups and that there may be more than one path to success. Indeed! On the other hand, Pritchard developed a very complex, quantitative process called ProMES which measures group productivity so that a group's performance can be compared at various times or against other groups. In one practical application, a team of researchers measured the performance of an organization in a multi-year test and documented a notable improvement.

Japanese quality circles were the forerunners to American teams in the work place. The Literature Review Chapter gives a brief history and account of these circles. They were first started in 1962, and within twenty years numbered more than one million. About ten percent of the post-war Japanese industrial success is attributed to its quality circles. Like many successful innovations, circles went against the predominant paradigm, Taylorism. Circles were democratic, allowing the same people who made decisions to implement them and be accountable for the results. Circles promoted respect for the individual rather than the organization and self-fulfillment rather than quota fulfillment. Circles advocated participative rather than autocratic management and encouraged cooperation rather than confrontation.

The literature provides some useful statistics about the stereotypical Japanese circle: the number of members (five to eight), the method for selecting the leader (sixty percent elect their own leader), the number of annual accomplishments (three), and other data. Also, most accounts offer ideas on why circles work so well. Among the reasons offered are: members receive more training, a lot of resources are focused on just one problem at any time, and they only take on problems they believe they can solve. The literature also provides insight into identifying organizational resistance to circles, evidence that top management is supporting circles, and indicators that a circle is failing.

The American experience with teams parallels that of the Japanese with some notable differences. One definite difference that is emerging is that American teams are more focused on organizational concerns than employee concerns. J. Michael Crouch identifies four management techniques or states: inspection, fire fighting, problem solving, and prevention. Teams work well with problem solving and prevention, which should be the preferred states for an organization. Crouch supports the formation of an Action Board and a Steering Committee to oversee the work of an organization's teams.

Shilliff, Motiska, and Zenger point out some important differences between American teams in the work place and the natural work group. The discipline in a team is not imposed by a supervisor; it is self discipline and the product of peer pressure. The old management methods do not work with teams; i.e., the traditional role of a supervisor was to maintain control, but the role of a team leader is to anticipate change. Zenger also asserts that consensus decision making is fundamental for a team.

The literature is filled with many variations on the theme of teams in the work place; i.e., action teams, cross-functional teams, problem-solving teams, self-managing, pilot teams, and so on. These are artificial labels created to emphasize some differences.

One of the most insightful authors read during the research, Clay Carr, discusses at length the importance of cooperation, of empowering team members so that they can control their work, and making the work challenging. Carr also described eight desirable characteristics that are essential for a team to become successful: shared values, clear and worthwhile goals, a need for each member, commitment to the goals, specific and measurable objectives, prompt and usable feedback, rewards for the team, and solid individual and group competence.

Hackman's five trip wires (treating members as individuals rather than as a team, giving too little or too much authority, failure to give clear direction, skimping on support, and bad coaching) were a dangerous set of traps for management to avoid.

Because CEBAF has a diverse staff including citizens of many different countries, the research included an examination of the possible effects of cultural differences. The differences between Japanese and American experiences with circles and teams have been discussed already in this summary, but the writings of R. E. Cole provide further greater insight into the effects of cultural differences on team successes and failures. His position is that cultural differences can have a significant impact on team results. For one thing, we can learn from other cultures; no single culture has a monopoly on the best of everything. Cultural differences can also inhibit the learning process; for example, language differences. Cole also refutes some common myths, such as the belief that the Japanese are significantly better suited to working in groups than Americans. Cole's research with Swedish industry indicates that Swedish workers probably overemphasized the changes in power relationships when work groups were introduced, and work-group autonomy became an end in itself.

The Literature Review chapter also contained an introduction to the engineering field of reliability, maintainability, and accountability. This section also refers the reader to Appendix 1, which contains a literature review for this technical field. An understanding of these three engineering terms gave Team members the knowledge needed to determine which factors most affected availability; i.e., the importance of having spare parts for high failure-rate items and the importance of a preventive maintenance program.

The Methodology Chapter, which follows this chapter, makes the case for the legitimacy of the research, the credibility of the researcher, and the acceptability of qualitative research as valid, academic research. The legitimacy of the research is based on the lack of documented and substantiated knowledge about how teams decide which members will do what work. The Methodology Chapter will propose a method for obtaining this knowledge by studying one team in detail. The credibility of the researcher is acceptable in terms of educational background and work-experience, but his dual role of being observer and active participant may present a conflict in the minds of some readers. This will be examined closely in the Methodology Chapter. In addition, the Methodology Chapter discusses the legitimacy of the researcher using knowledge gained during the research to enhance team performance.

The need to justify qualitative research still exists, and the Methodology Chapter will present the arguments made by standard bearers for this type of research, which is more subjective and descriptive than quantitative research, as will be explained in the next chapter.

## Rationale

This chapter is ample proof that many able researchers have studied many teams doing many different things in many different settings. So why study another team in the workplace? Is there anything important left to learn about teams? Are there any interesting questions about teams that have not been answered? This chapter also provides the answer; the literature is incomplete, there is much more to learn about teams, and there are questions about teams not yet answered.

The literature just reviewed contains models of the team process, lists of policies that help teams, lists of policies that hurt teams, quantitative data about typical teams, and models for improving team performance. The literature is full of generalized concepts about teams and advice for those contemplating team formation. It provides lists of variables that directly affect team performance, and it identifies the stages a team should pass through from birth to death. The incompleteness of this body of knowledge may not be readily apparent to the reader at first exposure because of the quantity of material. However, there is incompleteness, and it stems from the macro-view the authors take of teams. The compulsion to find and report on commonality among many teams seems to result in discarding important details observed in individual teams. Time limitations may force selective sampling of team activities, and production of reliable statistics may require observation of many teams. Such constraints can lead to over reliance on second-hand accounts and interviews with team members. Research along these lines can produce excellent results when the objective is to find commonality and the general case. It is not optimized for a search for exquisite details about the inner mechanisms that make a team function effectively.

In no case, did an author admit to staying with a workplace team from start to finish. In no case, did an author admit to being a member of a workplace team at any time, much less while conducting research on the team. Given all of the recent research on teams, it seems odd that no group of researchers observing a suitable subject in the field or laboratory, simultaneously conducted meta-research on itself as a team. No record of such an interesting and readily available project was evident in the literature.

The success of this research depends on a member of the Team conducting the research and being involved throughout the life of the team. It will be a search for a level of detail that can only be discovered and understood by continuous exposure to and involvement with team activities over a long period. Such a plan will allow the researcher to discover and explain the processes team members use to accomplish their work and meet their goals. More specifically, the researcher will try to define the processes the Team uses to decide who will do what work, and will also try to determine the variables that affect this decision. Once the processes and the variables are identified, the researcher will attempt to define the logic; i.e., the "whys", behind the processes and the variables. Knowing this information should be dhelpful to members of a new team.

Defining the logic may be difficult, but the literature should be helpful in providing insight into understanding the Teams' decision-making process for assigning and apportioning the work. First, the available theories about group behavior may explain why a specific member is picked for a specific task. Second, the same theories may explain why some team members volunteer to do work. Third, the same theories may explain why a specific number of members actually work on a particular project, and whether they work together or separately.

Not only is the literature an important influence on this research, the research should be able to influence the literature. Beyond providing new information about the processes that a particular team uses to assign and apportion work and identifying the most significant variables, this research will be an opportunity to compare what is observed in the field with what is predicted in the theory, in essence a validation of the literature. It is recognized that group theory applies to many groups and not to all, but this will be an opportunity to provide constructive criticism on the body of knowledge from the field and validate or not validate what theory predicts.

Finally, some of the literature provides guidance and advice for teams and team leaders, and the researcher, will use this knowledge as a basis for comparing the Team with a norm and the range of normality that accrue in one's mind from reading extensively about teams. In addition, as an active participant, the researcher may use suggestions from the literature selectively to influence team policy and the outcomes of team projects. This aspect of the research is discussed in more detail in the next chapter.

The last section of this chapter, which follows, poses some questions which the researcher will explore and answer. The questions serve as a focus for the research and force the researcher to measure the Team and compare it with the latest understandings about team characteristics and group dynamics. This comparison should be beneficial in both directions; for the team and for the knowledge base. The questions are discussed and answered in the Analysis Chapter.

## Questions

How did the Team's ability to be self-managing vary throughout its lifetime?

To what degree did the Team conform to the model described by Gray and Stark?

Did this Team validate Gersick's observation that teams change their strategy for completing a task about half way through the task?

Did the Team demonstrate the two-track path advocated by the team evolution and maturation model (TEAM) and the "preforming through deforming" stages that are part of the TEAM model?

Which of the productivity models described most closely fits the Team?

How does the Team compare with Salas's Integrated Model?

What characteristics of the typical Japanese quality circle were shared by the Team, and which characteristics were not shared, and why?

Did the Team validate Imai's list of seven major advantages of using circles?

Did the Team use any of the TQM statistical and graphical tools ?

Did the Team more closely match an American work-team or a Japanese circle?

Of the various subspecies of American work-teams, which one best describes the Hardware Checkout and Reliability Team?

How well did the Team measure up to Carr's eight essential characteristics of successful teams.?

Did the Team experience a self-fueling spiral in the sense Hackman uses it?

Were any of Hackman's five "trip wires" present in the Team's experience?

Did Team members assume roles as specialized as Brooks' software team?

In what ways did the international culture of CEBAF affect Team performance?

# METHODOLOGY

## Introduction

\The Engineering Management field embraces the interface between the social and physical sciences. As a student in this academic field since 1985 and as an engineer practicing management since 1959, this investigator has much appreciation for and fascination with the interplay between our individual human personalities and our attempts to organize and optimize our collective efforts in the workplace. There is a drama to the story of the human species and industrialization. Humans, acting sometimes rationally and sometimes irrationally, conceive of, design, build, and operate machines of such complexity, that no one person living in the late twentieth century can even be aware of the many types and categories of machinery, much less have a detailed knowledge of their function and theory of operation. Indeed, the most common machines are little more than "black boxes" to many users, witness the automobile and the photocopy machine.

The engineering management field attempts to form a bridge of understanding between a thinking human being and objects, objects which are the products of human thought and were conceived to reduce human labor and amplify human ability. These man-made objects, ironically, are often disappointing precisely because they share some characteristics with their creators. Like people, machines wear out, suffer catastrophic failure, require maintenance, are unpredictable, and can cause injury and death. Some machines, such as computers and robotics, are made to mimic the human mechanism, making the interface between the animate and inanimate both interesting and complex.

When this investigator commanded the nuclear-powered submarine, USS Mariano G. Vallejo (SSBN 658), he was responsible for the health, welfare, and state of training of the crew of 125 people. At the same time he was responsible for the ship, its sixteen nuclear-armed missiles, its torpedoes, the nuclear reactor, and all other equipment on board. One objective for the commanding officer was to motivate the crew to take good care of the equipment, for no one person could take care of such a ship. A former commanding officer offered this new commanding officer the following advice: "If you look out for the crew, the crew will look out for the ship. If you put the ship ahead of the crew, the crew will let you look out for the ship all by yourself." This proved to be excellent advice, witness that this vessel was that last of its class of forty-one submarines to be retired and was known as a "show boat" to the end.

This background information is provided to establish the credibility of the investigator as a person with extensive and successful life experiences in management in an engineering environment. Additional biographical information is provided in the biography section, as required by university regulations for dissertations.

## Purpose

This chapter has three primary purposes. Foremost among the purposes is to establish the legitimacy of the research. A second purpose is to justify the investigator's role. A third purpose is to describe the processes used to collect and analyze the data. The chapter is not divided into three separate sections, each devoted to one of the above purposes. Rather, the three purposes are met by an integrated, interwoven discussion about the research which reveals its roots grounded in the investigator's experience and in the discipline of qualitative, evaluative, and participative research.

## The Motivation

The researcher began work at CEBAF in May, 1987, during the first year of construction. There was never any doubt that opportunities for doctoral-level research would be available in the scientific environment CEBAF presents, especially during the construction period. The problem was to find a subject that would excite the researcher, contribute something significant to the knowledge base of scholarship, and be useful to CEBAF. After several false starts on selecting a research topic, the researcher seized the opportunity to be a member of one of the first teams formed at CEBAF under the banner of Total Quality Management (TQM).

The researcher had been exposed to TQM information for several years, but had not had the opportunity to participate directly in a TQM context before this opportunity. This personal interest in TQM started while taking graduate-level courses at Old Dominion University. Courses on statistical process control and robust engineering design included discussions about Japanese management techniques. Some students in these courses worked for companies that had adopted the TQM philosophy, and they shared experiences with their classmates. The researcher held the position of Quality Assurance Officer at CEBAF from 1987 to 1992, and this experience coupled with membership in the American Society of Quality Control presented many opportunities for exposure to discussions and writings about TQM. It took a convergence of several events for CEBAF to crack the door for the new style of management. One influence that counted was pressure from the primary funding source, the U.S. Department of Energy. The other factor was the arrival of a senior scientist, A., who was a “true believer” in Deming, TQM, and especially the use of teams to solve problems. The opportunity to serve on a team and practice TQM was very exciting for this researcher, and still is.

The background reading for the literature review began about the same time as the team was formed, June 1993, and continued until November 1993, when it was time to start writing to support a December 1994, graduation. The reading of books about teams coincided with the early days on the Team, but there was no clear focus at first on what the dissertation would be about. However, the more that was read in the literature and experienced with a real team, the clearer it became to this researcher that the search for common threads that could apply to all teams had diverted other writers from very important areas. One area that really excited this researcher was the process that occurred when the Team decided who would take the responsibility to do the work on a particular project. This defining moment, when several members would say “I’ll do it,” “I’ll help you,” or “I can contribute my expertise” was in retrospect, a magic moment when all that is good about participative management, TQM, employee empowerment, and team dynamics converged. What excited this researcher was trying to unravel the factors that made such a moment happen. Why these members? Why this number? Who will do what? This mystery ignited the motivation and sustained the momentum.

## The Research

The research which is the subject of this dissertation focused on the processes used by the Hardware Checkout and Reliability (HC&R) Team at CEBAF to improve accelerator reliability. This is a case study, a study of one team among millions of teams in the workplace world-wide. Case studies are particularly useful for understanding a particular problem in great depth, and qualitative evaluation is a very useful research method for a case study (Patton 1990). The work processes which were the subject of the research included the methods used by the HC&R Team to achieve their objectives. Of particular interest was the method used to apportion the work. The team consisted normally of ten members, but much of the work did not lend itself to an equal apportionment of responsibility to all members. The members seemed quick to recognize what effort was required to meet an objective and formed a small group to do the work.

Scholarly research has been and remains interested in the ways that groups of people work together. This dissertation contributes to the knowledge base for this topic. The reader will find while proceeding through the dissertation that this topic is more complex than it seems at first consideration. For example, the Literature Review Chapter relates the very interesting history about the debate within scholarly circles about the value of group efforts with respect to individual efforts. One school of thought asserts that only individuals can perform work and group-work does not exist. The polar-opposite view maintains that group effort is real and can exceed the sum of the individual efforts, giving groups the potential for a higher efficiency than the average of the individual efficiencies. One school will be in vogue for ten or twenty years, and then the other school will dominate academic thinking.

It is not the purpose of this research to take sides in this argument. It will not prove one side right and the other side wrong. Contemporary means to quantitatively measure group productivity, as described in the Literature Review Chapter, requires resources beyond the domain of this investigator. Secondly, forming a control group of individuals who work independently to accomplish the same objectives as a group, is a most improbable occurrence in a real workplace with scarce resources. What this dissertation does have to offer is a very detailed and intimate account about a small team of scientists, engineers, and technicians which efficiently and effectively accomplished its assigned work on schedule.

Such an account offers to the literature a rich source of data points from the work-a-day world within an engineering environment. Moreover, this dissertation is more than a verbal panorama of the doings of a small group of hard-working, technical people. To provide useful insight and understanding, it attempts to identify the variables which influenced the team to divide up and accomplish the work. In addition, it relates this new-found understanding to the principal theories about small-group dynamics, decision-making patterns, and productivity, as discussed in the Literature Review Chapter.

## The Investigator as Team Member

The Heisenberg Uncertainty Principle is a basic tenet in physical science and states that an observer influences the results of an experiment, and the value of the research accrues from being able to quantify this influence and account for it. Physical and social scientists share at least one preference in their experimental strategies; that is, both try to fix all variables save the one of interest. Making controlled adjustments on one of the variables and recording the system output produces the desired data. Theoretical social-science research minimizes the role of the observer and controls the variables by a set of tactics: using a control group and an experimental group and using the "double blind" approach which shields the true purpose of the experiment from its subjects so that they will not bias the results. This brand of social research is best done in a laboratory using people with no direct interest in the results.

The Literature Review Chapter briefly discussed the advantages and disadvantages of laboratory settings for social research. The laboratory setting has its place, particularly when controlling all but one variable is essential and when it does not matter whether or not the subjects have ever met before. However, scholars, such as Driskell and Salas, argue convincingly that the laboratory environment does not duplicate the work environment, and studies about the workplace necessarily force the investigator into the workplace. This dissertation describes research in the workplace, but there is a further distinction to be made.

As Patton describes so clearly, yet in great detail, the investigator in this setting has to decide the degree to which to interact with the work force. At the most noninvolved end of the spectrum, the investigator could avoid overt exposure to the subjects of the research by such tactics as: (1) limiting the investigator to reading meeting minutes and formal documents produce by the organization. (2) observing a work setting through a one-way mirror as is found sometimes in the wall between a manager's office and the work floor. (3) observing video tapes that management has made of the work force. At the other end of the spectrum is the participative investigator who joins the work force and shares in their experiences, but at the same time observes, records, and analyzes the processes of interest. This type of research can be done overtly or covertly;

i.e., the investigator may or may not identify the true nature of his or her participation (Patton 1990).

The research for this dissertation was overt and participative. After gaining permission from top management, the investigator made known to all members of the HC&R Team that he was a doctoral student at Old Dominion University and he would be reporting on and analyzing the work processes that the Team used to achieve their goals. Most team members were familiar with the investigator; in fact, he had joined CEBAF before any of them. However, he had only worked closely with three members before, D., Rn., and S. [See Appendix 3 for a brief, professional description of the members] There had been no prior professional working contact with Al., M., B., K., Ka., and Ro.; however, these six had worked together many times installing and testing accelerator components and were at ease with each other.

The investigator did not settle for being just a witness to the Team's activity, but resolved to set an example by working diligently on Team projects and being loyal to the Team and its goals. These personal goals amounted to a bias that is stated without embarrassment. The investigator was committed to helping the Team be as successful as it could be. This commitment was manifested in a written agreement with management which stated that if this research identified a problem or flaw which could benefit from immediate attention, the investigator would notify management right away rather than keep it a secret for the benefit of the academic goal. As an employee, organizational goals had to take priority over individual goals; however, the investigator is not aware of any conflicting goals that affected the research or this dissertation.

The overt, action researcher can be faced with this troubling dilemma: "To what degree does he or she share the data, the analysis, and the conclusions with the subjects of the research, and when is this done?" Improving the accuracy of the data is a major advantage of sharing the research with the subjects, because inaccurate data can lead to false conclusions no matter how superior the analysis. A disadvantage of opening up the research to its subjects is that someone may take spirited exception to subjective arguments and opinions. Does the researcher bow to the opposition, canvas the other subjects to get a vote, or what? In addition, someone may actually manipulate the researcher and alter his or her understanding of some point or opinion. The research is no longer the effort of a single person and is "contaminated" in this sense.

For this research, the investigator shared the most objective of the chapters with team members in order to have the text checked for accuracy and to give the members an opportunity to see what was written about them. In July, 1994, after the Team was disbanded, copies of parts of the Hardware Checkout and Reliability Team Chapter and the Work Processes Chapter were sent to S., Rn., B., and Ka. They were involved in projects which did not include the investigator, and his understanding of the details of the flow of work was incomplete. Their comments about the draft text and the accompanying figures were helpful in making the report accurate. Previously, a copy of an early version of the Literature Review Chapter was made available to all members and is still positioned in a public place at CEBAF. This was done to provide members with potentially useful information. The investigator did not share the last two chapters in the dissertation, Analysis, and Summary and Conclusions, with Team members to prevent any member from influencing the outcomes of the research. Such an event might be considered reverse action research.

Participative research is open to many questions, particularly from theorists who revel in basic research which emphasizes control over the variables. There is a spectrum of research strategies between the two extremes, but for the sake of emphasis, the contrast between these two styles of research is made clearer by comparison. Basic research is theory driven and strives for rigor, exactness, and adherence to rational processes. Participative research is practice driven, strives for relevance to the real world, and offers better understanding of and leads to improvements to existing process. Basic research is pure research; knowledge for the sake of knowledge. Participative research is applied research, and is at its best when it provides new ways of improving an existing process.

The basic researcher strives to be disinterested, objective in view point, and an outsider to the process being investigated. The participative researcher is engaged, subjective in viewpoint, and an insider. Finally, the basic researcher relishes quantitative data and analysis. The participative researcher relishes quantitative data when it is available and useful, but in most if not all situations, has to make qualitative evaluations of many aspects of the research data.

Patton states the case for social research in the field as well as anyone, and he will be referred to in many of the paragraphs that follow in this chapter. But before linking this research to Patton so that it may be connected to valid academic work, a few comments on the experience of being a Team member and a Team observer are offered to help the reader conclude that the research was not impaired by the dual role played by the investigator. It is true that playing the two roles required several postures which could have been in conflict (Patton 1990). For example, being a team member requires respect, trust, understanding, and accessibility, and being an objective observer requires maintaining a certain distance to minimize opportunities for and susceptibility to the subjects of the research biasing the data collection and analysis, whether intentional or unintentional.

The investigator attempted to establish respect, trust, understanding, and accessibility by a conscious effort to participate fully in team activities. He missed only three of thirty-four regular meetings, engaged without reservation in discussions, accepted responsibility for several of the more difficult Team projects, and was spokesperson for the Team at several presentations. The length of life for the HC&R Team, eleven months, and the intensity of the Team's activities, helped the investigator fit into the work lives of the other members. The need for team loyalty, the necessary sense of cooperation, the sharing of mutual experiences, and the close contact required to work together on projects, contributed to the investigator's perception that he was fully accepted as a loyal and contributing member of the Team. But this was not a singular effort. Other members, to varying degrees, contributed wonderfully to the remarkable team spirit that developed with time. It was B. who remarked at one Team meeting about disliking all meetings, but actually looked forward to our Team meetings. This startling admission to the membership had a positive affect on Team morale.

Despite the sense of togetherness just discussed, it was important at times to the investigator to keep some distance from the other members. As Jorgensen warns, "There is a real danger that, as you become immersed in the setting and overwhelmed by what transpires there, you will find it increasingly difficult to stand back and generate a fruitful perspective on what is of interest." (Jorgensen, 1989, 33) This investigator did not want to be guilty of "going native", and several factors helped him keep an acceptable distance when that was useful. Being at least ten years older than the next oldest member, Ro, and about twice as old as M. and Ka., provided some distance because Team members displayed a "respect for your elders" that is a mark of a civilized people. At a more practical level, the investigator's office was in a building that was seldom visited by any other Team members, and no other member had an office in that building. Furthermore, the investigator only visited the Machine Control Center (MCC), where the accelerator operations center is located, about twice a week for a total of an hour of time, and thus Al., B., M., K., Ka., and Ro., who spend most if not all of their on-shift time at MCC, might only see T. at the weekly Team meeting. Finally, the research tools possessed by the investigator because of his educational experience provided some intellectual distance. Not to put too fine a point on it, but the masters and doctoral level courses on organizational behavior, cybernetics, the Viable System Model, and qualitative and quantitative research methods, provided some insights on human individual and group behavior that are not part of most people's common experience or native intuition. Not only was the investigator better equipped to recognize certain behaviors and use research tools such as surveys, but was the only member motivated to act on these capabilities. This created a distance of the mind, which was based on a different vision of what was going on collectively within the Team.

The above discussion must be considered as a subjective argument for the legitimacy of this research. It is subjective in recognition that it is opinion and is not substantiated by reference to primary sources. Evidence for its veracity exists in the body of the dissertation. What has been said here fits with the rest of the dissertation. Having said that, while leaving the reader the right to doubt and challenge anything said, it is time to bring Patton's words to the forefront to give this research a firm footing in the fertile grounds of accepted academic research.

## The Basis for Qualitative Research

"Qualitative" is just one of scores of adjectives in common usage to precede the word "research". Scientists have found many useful distinctions that may be made between this and that type of research. Within the qualitative category of research, there are many members, and those useful to this research are addressed. To prove the point, Patton asserts that evaluation research is applied research or "action science" if the findings are "useful". Applied research serves to inform, lead to action, enhance decision making, and apply knowledge to solve human and societal problems. If the evaluation "is done systematically and empirically through careful data collection and thoughtful analysis, you have evaluation research" (Patton 1984, 11-12).

Patton identifies three sources of data for evaluation research: interviews, direct observation, and written documents. This investigator used interviews to fill in information gaps or to delve deeper into an issue that was available by other means. Direct observation was the predominant source of information by virtue of attendance at nearly all Team meetings and by participation in two-person and three-person projects.

Referral to meeting minutes and other papers cited elsewhere in this dissertation attests to the great value of written documentation to this research (Patton 1990).

With regards to observational data, Patton contends that it must have both depth and detail. It must be sufficiently descriptive that the reader can understand what occurred and how it occurred, without being saturated with irrelevant numbers and trivia. The ideal is for the reader to "enter the situation under study." This imperative was a *sine quo non* for the investigator, but it remains for the reader to judge the degree to which the dissertation meets this objective (Patton 1990).

Patton lists four mandates for collecting data from humans. (1) Get close enough to the people and the situation being studied to personally understand the details. (2) Aim at capturing what actually takes place and what people actually say. (3) Qualitative data must have pure descriptions of the people's activities, interactions, and settings. (4) There must be direct quotes from people, either spoken or written. A reading of this dissertation will show that the first three mandates are met quite clearly. However, the dissertation does not contain a plethora of quotes from Team members, because opinions and impressions that they had are not central to the topic. The research focused on their behavior rather than their attitudes, for which quotes are most helpful. The members did voluntarily provide the information for the personal data in Appendix 3, and agreed to the meeting minutes, which were a rich source of material for the research. (Patton 1990)

As previously stated, this research was directed predominantly at Team processes. The data collected was focused on what Team members did and how they did it. The research did not attempt to discover why members did what they did or what they individually would rather have done. The Team culture demanded consensus, which in most cases meant everyone giving a little so that the Team could reach closure efficiently, and seldom if ever meant that the majority was forced to persuade or negotiate with the minority. The research was also interested in results, but in many cases, the long-lasting results of the Team's efforts could not be known within the life spans of the Team and the research. Consequently, Team processes were the most immediately available activity to observe, identify, and analyze.

Process evaluation is aimed at understanding and elucidating the internal dynamics of an organization such as the Hardware Checkout and Reliability Team, and it requires an intimate acquaintance with the details. This intimacy is necessary to uncover formal and informal patterns of interactions. It is necessary for uncovering the critical elements that lead to successes and failures. Patton advises the investigator to use an inductive, naturalistic approach for a process evaluation and enter the research without predetermined hypotheses. This open-ended approach lets the findings of strengths and weaknesses flow from the observations rather than from the theory. This investigator tried to follow this model, and again, the degree to which an open mind was maintained is to be judged by the reader (Patton 1990).

What Patton calls illuminative evaluation is closely related to this research. According to Parlett and Hamilton, to whom Patton refers, illuminative evaluation's primary concern is with description and interpretation rather than measurement and prediction. The parallels of illuminative evaluation and this research are many; both address what it is like to be a part of a process and both avoid introducing external controls. Likewise, both may take into account individual idiosyncrasies, uniqueness, and complex group dynamics (Patton 1990).

The analytical phase of qualitative research is different from analysis of basic; i.e., theoretical research. Patton summarizes the process and the problems of analyzing the subjective, human-based data:

> The challenge is to make sense of massive amounts of data, reduce the volume of information, identify significant patterns, and construct a framework for communicating the essence of what the data reveal. The problem is that "we have few agreed-on canons for qualitative data analysis, in the sense of shared ground rules for drawing conclusions and verifying their sturdiness"(Miles and Huberman, 1984:16). There are no formulas for determining significance. There are no ways of perfectly replicating the researcher's analytical thought processes. There are no straightforward tests for reliability and validity. In short, there are no absolute rules except to do the very best with your full intellect to fairly represent the data and communicate what the data reveal given the purpose of the study. (Patton 1984, 371-372)

> This does not mean that there are no guidelines to assist in analyzing data. But guidelines and procedural suggestions are not rules. Applying guidelines requires judgment and creativity. Because each qualitative study is unique, the analytical approach used will be unique. Because qualitative inquiry depends, at every stage, on the skills, training, insights, and capabilities of the researcher, qualitative analysis ultimately depends on the analytical intellect and style of the analyst. The human factor is the great strength and the fundamental weakness of qualitative inquiry and analysis. (Patton 1984, 372)

A prior statement in this dissertation said that inductive analysis was the preferred type of analysis for this type of research, but what is it? Inductive analysis means that the patterns, themes, and categories of analysis arise out of the data rather than being imposed prior to data collection and analysis. In simple words, the investigator enters into the situation with an open mind, looking for any and all distinctions, rather than entering into the situation looking for one or more specific distinctions. Patton advises that this involves a search for the natural variation in the processes under study, and the best place to start an inductive analysis is to seek the key terms and phrases used in the processes (Patton 1990).

With regard to terms and phrases, an investigator may use the categories articulated by the participants or may establish categories that the participants did not develop. Making this decision was not necessary during this research because the investigator was already immersed in the culture of the Team and was cognizant of nearly all of the terms and phrases that would be used. The exceptions were the highly technical terms that a member might use at a meeting when forgetting the setting and not realizing that most people outside his or her technical group would not understand the usage or meaning. The Literature Review Chapter does dwell on the different terms used to distinguish groups in the workplace, such as self-governing work team and quality circle. Some of the fine distinctions made by various authorities about the characteristics which distinguish one type of group from another are discussed in the same chapter. In some research, the investigator enters an unfamiliar culture, and as Patton asserts, the investigator must learn the language and symbols unique to that culture. In the case of this research, the investigator understood the language of the Team; however, the Team was trying something new, a Total Quality Management team effort, and the Team had to learn the terms and phrases of that new management culture (Patton 1990).

Patton points out that there is an argument that states that when the investigator constructs and makes explicit patterns that appear to exist but were not recognized by the people studied, that this is an imposition on the participants and reflects the world of the investigator more than the world of those studied. The counter to this outlook is that if the participants are confronted with the new distinction and say, “yes, I see it, it does exist,” then the distinction is valid and should be pursued (Patton 1990).

Patton (1990) credits Guba with using the word “convergence” to signify the problem of figuring out what things fit together. This is an important part of analysis, and making it fit and be coherent is a primary challenge for this investigator. Guba discusses "recurring regularities" in the data; i.e., patterns that can be sorted into categories (Patton 1990). Patton also establishes four tests to help evaluate the completeness of any set of categories. (1) Viewed internally, the individual categories are consistent. Viewed externally, the categories comprise a whole picture, or at least seem to. (2) The categories should not exclude any of the data and information; i.e., there should be no unassignable cases. If there are, then one or more categories are probably missing. (3) The set should be reproducible by another competent investigator. (4) The set should be credible to the participants (Patton 1990). This seems to be a reasonable test, and was applied during the development of the Analysis Chapter as reported therein.

Can the investigator make mistakes in selecting key terms, phrases and categories? Of course; both Type I and Type II errors are possible. The investigator may decide that something is not significant when it really is (Type I); and conversely, the investigator may decide something is significant when it has no value (Type II). Qualitative investigators do not have statistical tests to tell them when an observation or pattern is significant, and they must rely on their own intelligence, experience, and judgment. (Patton 1990)

How does the investigator know when categorization has reached closure? There are several indicators that are helpful: (1) When sources of information have been exhausted. (2) When the categories are saturated so that new sources lead to redundancy. (3) When regularities emerge, are clear, and seem to fit together. (4) When the analysis begins to go beyond the scope of the research.

Does the investigator need mental or psychological preparation before collecting the data, defining the key terms and phrases, and identifying and selecting the obvious categories? Patton (1990) credits Clark Mustaches and Bruce Douglass with a process of "phenomenological analysis" that they use. This first step in this process is known as *Epoche'*, which is a phase of self examination used to locate biases and preconceptions. From this, the investigator causes a change of attitude within so that a fresh and open viewpoint emerges. Judgment and personal opinions are suspended until all the evidence is collected (Patton 1990).

The next phase is called phenomenological reduction, during which the investigator brackets out the world and inspects the data in its pure form. After bracketing, the horizontal phase begins, and the data is spread out and grouped in meaningful clusters. Then the delimitation process begins, and overlapping and irrelevant data are eliminated. At this point, the investigator attempts to define and understand the underlying themes. The final step in the process is the development of a structural synthesis which will contain the "bones" of the experience. This type of analysis should lead to a deep look into the experience of an individual (Patton 1990).

Heuristic inquiry is a variant of the phenomenological analysis and includes five basic phases: immersion, incubation, illumination, explication, and creative synthesis. Immersion is what it sounds like; getting totally involved with the subject(s) of the research. Incubation is a period of quiet reflection where awareness, intuition, and understanding are nurtured. In the illumination phase, a new clarity of knowing about the experience in all of its parameters follows the first two phases. The explication phase features expanded understanding of the experience through focusing and reflection and results in new connections and patterns being discovered. Creative synthesis is the bringing together of the pieces of the experience, the connections and patterns, and the relationships. During this phase, the investigator captures the total experience "in a personal and creative way" (Patton 1990).

The descriptions of the two qualitative research methods just described were summarized to give credence to the methods use by this investigator to approach and direct this research effort. Inventing a new research method was not this investigator's objective; rather it was to use the best proven method(s) available to maximize the process and the product. The reader is judge.

Once the patterns and connections are identified and understood, the investigator conducting qualitative research is compelled to identify causes, consequences, and relationships. Interpretation will be necessary, and interpretation as used here means attaching significance to what was found, offering explanations, drawing conclusions, extrapolating lessons, making inferences, imposing order, and dealing with rival explanations and inconsistent data. The burden is on the investigator to make clear what is description and what is interpretation (Patton 1990).

Patton warns of the danger for evaluators of doing qualitative analysis by falling back on the linear assumptions of quantitative analysis. Trying to specify isolated variables that are mechanically linked together out of context is a great temptation. Simple statements about relationships may appear to be helpful, but if they are not real, they will cause more distortion than illumination. It is the challenge and dilemma of qualitative research to be moving back and forth between our need for linear statements of cause and effect and our interpretations of the reality of complex human activity (Patton 1990). The quintessential message from Patton regarding the distinct nature of qualitative research is as follows, in the opinion of this investigator:

> It is important to understand that the interpretive explanation of qualitative analysis does not yield knowledge in the same sense as quantitative explanation. The

> emphasis is on illumination, understanding, and extrapolation rather than causal determination, prediction, and generalization. (Patton 1984, 424)

## Theory and Practice

CEBAF is a research laboratory with a single purpose: conducting basic research on the quark structure of the atomic nucleus. The information produced at CEBAF will be compared to existing theories and hopefully will give rise to new theories. The scientific staff at CEBAF contains both theorists and experimentalists, and both categories can be divided further into accelerator physicists and nuclear physicists. There is, of necessity, a rich flow of communications between the physicists, whatever their branch. Similarly, there is a constant interaction between CEBAF and academia. Some physics professors from local universities and colleges have offices at CEBAF. Some senior physicists at CEBAF hold physics chairs at various Virginia universities. Much of the experimental equipment to be used at CEBAF was designed and built at various universities and laboratories world-wide. The larger and most expensive components, however, were built by engineering firms, both national and international. This is a project which brings theoretical scientists, experimental scientists, engineers, academicians, and industrialists together to accomplish a common goal, the discovery of new scientific information. If something practical results from CEBAF, fine, but that is not the goal.

When one reads the literature about the relationships and differences between theory and practice and between theorists and practitioners, the authors seem to give special attention to the differences. Much is made of the theorist's rigor and the practitioner's lack of rigor. This investigator is not convinced that the differences are particularly important. For one thing, whether one is a theorist or a practitioner is relative, depending on the judge's frame of reference. The reviewers of this dissertation probably view the investigator as a practitioner. The investigator considers himself a practitioner, but to the Team members, the investigator was more of a management theorist than a practitioner.

In *The Reflective Practitioner,* Donald Schon examines widening gulfs between universities and professions, research and practice, and thought and action, which he perceived at the time of publication of his book in 1983. He announces the need for inquiry into the epistemology of practice and wonders what kind of knowing it is in which practitioners engage. He asks: is this knowing different from the knowledge found in text books and journals? *The Reflective Practitioner* provides his answers to these interesting questions. His topic is important to this research because he frames as well as anyone, the central challenge for practitioners, and this challenge is quite different from those experienced by investigators in basic research. Schon characterizes theoretical research as convergent and practical research as divergent in the sense that theoretical research is more focused and has sharper boundaries. He considers practical research to be divergent in that it focuses on many things. Furthermore, Schon sees a tendency for research and practice to follow divergent paths (Schon 1983).

Schon introduces a model of professional knowledge which he calls Technical Rationality, and this model asserts that professional activity consists of instrumental problem-solving made rigorous by the application of scientific theory and technique. However, Schon also notes that within the professions there is a dichotomy between theory and practice which causes a divergence of purpose and predilection. In medical school, for example, there are two years of theoretical studies before clinical practice begins. Those doctors who enjoy the theory, spend their lives in research hospitals or teaching, and those who enjoy clinical work, pursue a private practice with real patients. This divergence leads to a lessening of communications and interaction between the two groups (Schon 1983).

In his book, Schon traces Technical Rationality back to the time when science and technology began to replace superstition and mythology and gave birth to the industrial revolution. Professions were founded to apply the new sciences to the achievement of human progress by improving man's control over nature and over the powers that weaken his body. Eventually, elitists arose to make the claim the science and theory were preeminent. For example, Thornton Veblen of the University of Chicago, in 1916, made a sharp distinction between universities and the lower colleges and professional schools. According to him, universities had the higher calling, that of knowledge and scholarship. The lesser schools were obligated to make their pupils good citizens in whatever position [economic status] they found themselves. Obviously, such an attitude widened the distance between universities and the "lesser" schools and their graduates (Schon 1983).

Schon sees that Technical Rationality is inadequate in today's complex society. Its emphasis on problem-solving is outmoded. The modern professional must do more than solve problems; the professional must define the setting of the problem before it becomes a problem. A problem setting is the process where we name the items we will consider and frame the context in which we will attend to them. A weakness of technical rationality is that it depends on agreement about ends, which must be distinct and clear. Unfortunately, in complex organizations, disorder and chaos may obscure the "playing field" and the goals. This leads to what Schon calls the dilemma of "rigor or relevance". Rigorous professional knowledge is inadequate for some of the activities professionals see as central to their practice. Artistic and imaginative ways of coping do not, in their minds, meet the criteria of being professional knowledge (Schon 1983).

Schon's message is that professionals in practice are faced with such complexity that the process of problem identification and solution is often too difficult for linear, cause-and-effect thinking and acting. He points out that professionals can not always describe or explain how they know what they know. His explanation is that professionals rely on intuition and a spontaneous application of knowledge to their decision-making. He uses "reflecting-in-action" as a term signifying the iterative process of acting and watching, acting and watching, and making corrections as you go along. This is a process of adjustment, of making changes in the process to produce improvements in the results. It is akin to a baseball pitcher adjusting his or her pitches for each batter faced. It is akin to a musical combo improvising as it develop a new song (Schon 1983).

How does this discussion about reflection in action fit into this dissertation? It is discussed in this chapter so that any reader who is far more familiar with basic and quantitative research in a scientific field will be on notice that this dissertation will not follow familiar paths. The research will be far more subjective and qualitative than the reader is accustomed to. The Hardware Checkout and Reliability Team, composed of scientists, engineers, and technicians who are the subjects of the research, interacted and reached their goals in a different way, a way that approached reflection-in-action, and made use of intuition, ambiguity, flexibility, and spontaneous action. These are unquantifiable variables which are critical factors in day-to-day operations. The Analysis Chapter in this dissertation will discuss in detail the work methods the Team used to accomplish its goals. As will be shown, these work methods are those of the practitioner, and in some cases, those of a reflective practitioner. For example, as is told in the Analysis Chapter, the Team had to make adjustments to fit particular conditions when completing the survey project. The survey was an intervention into the most sensitive aspects of the work of the functional organizations. Some of the seventeen groups involved resisted and some obscured their response. The Team had to try different tactics on different groups in order to get believable and useful answers to the survey questions.

## The Investigator as Active Participant

The investigator also had to reflex-in-action in the performance of multiple roles. On one level, he was a team member, equal to the others, and engaged in team discussions and reaching consensus. On a second level, he was a member of mini-teams engaged in collecting, analyzing, and synthesizing information before presenting it for review. On a third level, he was an observer who carefully listened and watched the activity at Team meetings, who compared the Team with what he learned from the literature, and who analyzed the processes which he considered to be taking place. On yet another level, the investigator was an active participant, who used what he had learned to steer the conversation and change the course of Team events. For example, in developing the survey, the Team would have introduced questions that had to be answered in the affirmative or the negative. Prior knowledge allowed the investigator to intervene and convince Team members that such questions yield little information and frustrate the responders. The survey that was used contained no questions that could be answered with a single word.

The four levels of participation described above did cause some tension for the investigator because of conflicting goals. Compromise was often the answer. For example, during preliminary discussions of an issue, the observer role was prudent in most cases, and let the other members proceed and follow a logical trail to reach consensus. On occasion, an opportunity would arise to actively intervene and steer in another direction. Tension resulted from suppressing the urge to enter the discussion until later to see what would happen. This was not a common experience, however, because the Team was quite capable on their own, and members were selected on the basis that they would be successful without the investigator's help.

Looking back, there were more opportunities to intervene than was actually done because in most instances the reading and the analysis took place too late to be useful. If the reading and the writing of the first draft of the Literature Review Chapter had taken place before the first meeting, the investigator could have had much more influence on the culture of the Team by providing training, recommending books to read, and generally telling members what was supposed to work and what was not supposed to work. Fortunately that did not happen, because that would have compromised the comparison made in this dissertation of the Team to the literature. By the time, the

Literature Review Chapter was written, late January 1994, the Team's culture was established, and its work was successful.

As it turned out, playing the four different roles was more interesting and more fun than difficult. The members were congenial and cooperative with one another. The investigator carried his weight work-wise, and felt fully accepted. He never overplayed the observer role by taping conversations, taking notes on a clip board, or referring to himself as an observer, researcher, student, or any other related title. The investigator's objective was to make the observer role as invisible as possible to the other members by emphasizing his role as useful member and collaborator. The observer role emerged at the word processor, at the library, and when deep in thought. The boundaries between the roles were not quite so well defined as this indicates, and some nimbleness of mind and flexibility of personality were useful when moving back and forth between the roles.

The question is raised: if another person, trained as a researcher but unfamiliar with CEBAF and its employees, had been given the opportunity to take the place of this investigator, would that person have developed the same findings and drawn the same conclusions? The safe answer is to say it depends. If this person had emphasized the observer role and had not taken part in any of the projects, the Team would have been different, and some of the results would have been different. For example, the survey would have had different questions if there even was a survey. An observer unfamiliar with CEBAF would have been faced with two handicaps: (1) the technical jargon the members used in meetings could have caused confusion and miscommunications, and (2) an outsider, especially one taking notes or tape-recording the dialogue, would have probably intimidated the members, at least at the beginning. Moreover, the members probably would have been more guarded in their talk and less likely to say something negative about hardware readiness at CEBAF. In addition, it is estimated that an outsider would have to work hard to gain the trust of the membership equivalent to that with which the actual researcher started. The members were quite familiar with the researcher, and trust was a prerequisite for conducting the action research that was accomplished. On the other hand, had a leader in the field, such as Hackman, chosen to conduct this research, he may well have detected activities of interest which eluded this first effort.

## Chapter Summary

This chapter makes the case that the research is a legitimate, academic work, explains the role of the investigator, and describes the processes used to collect the information. The research focuses on a ten-person, interdisciplinary team which was formed at CEBAF to improve the reliability and availability of accelerator systems. In this regard, top management challenged the Team with some specific goals. The investigator volunteered to be a part of this team so that he could conduct research which would examine and explain the work processes the Team used to meet its goals and deadlines. The case for legitimacy of the scholarship is based on the nearly century-old argument in academia about whether only individuals do work or whether groups can do work. This dissertation does not make the case that either side is absolutely right, but it does provide new knowledge that helps explain the complexities that lead to the uncertainty. It does this by identifying the variables which affected the Team's decision-making process concerning which member(s) would work on which project and what part the entire team would play in accomplishing each project.

The Methodology Chapter takes pains to contrast the differences between theoretical and applied research, between research in a laboratory and in the workplace, and between a non-involved investigator and an involved investigator. Clearly, this dissertation is about applied research which an involved investigator conducted in the workplace. This was participative research with the investigator purposely playing an active role on team activities. This research clearly fits Patton's criteria for participative research; it was practice driven, it was relevant to the real world, and as was described in the Work Processes chapter, it lead to improvements to existing work processes. As is usually the case in participative research, qualitative data lead to qualitative findings and conclusions. This is all in sharp contrast to theoretical or basic research which demands that quantitative data be collected and lead to quantitative results.

The investigator had several role; primarily that of team member and that of observer of the Team. These two roles could have been in conflict; for example, being a team member requires respect, trust, understanding, and accessibility, while being an observer requires maintaining enough distance from the other members to be objective. The Methodology chapter makes the case that this conflict was not insurmountable and had little or no impact on the research.

The investigator admits to desiring to see the Team succeed and a willingness to devote thought and energy to this goal. In addition, the investigator was committed by agreement with management to use whatever knowledge was progressively gained from the research for the benefit of the Team. The investigator made an obvious effort to participate fully in team projects and meetings with the intent of establishing respect, trust, and understanding while being accessible. By sharing work experiences and being loyal to the Team, the investigator was able to be accepted as an equal member. This opened up access to the unqualified comments of the members.

For the most part, the investigator followed Patton's prescriptions for evaluative research and found them helpful: (1) Collect data through interviews, direct observation, and written documents. (2) Get close enough to the people to understand the details, (3) Capture what actually takes place and what people actually say. (4) Obtain pure descriptions of people's activities, interactions, and settings. (5) Use an inductive, naturalistic approach for a process evaluation. Inductive as used here means that the findings arise out of the data rather than being imposed from the beginning. (6) Enter the research without predetermined hypotheses.

Patton provides more guidance than can be used on this one research project. The Methodology chapter discusses those classifications and distinctions of his that seemed to have the most potential for being useful during this research. For example, the guidance from Patton and Guba was very useful for evaluating patterns observed in the work processes and determining when the classification of patterns had reached closure. The phenomenological analysis credited to Mustaches and Douglass made the investigator aware that he should identify his biases and preconceptions and try to keep an open mind. Patton's explanation of heuristic inquiry led to acknowledgment of five phases to the research, one of which, quiet reflection, might have been overlooked, to the detriment of the research. Patton's urging to impose order, to deal with inconsistent data, to attach significance to what was found, and to be aware of the danger of falling back on linear assumptions and simple statements about human relationships, were useful advice.

This chapter included a discussion about theory and practice as they apply to this research, and D. Schon is referred to extensively. He asserts that theoretical research is more focused and has sharper boundaries than practical research. He concludes that research and practice are diverging, to the detriment of society, and we must get beyond mere problem solving, which, of course, is what quality circles and teams in the workplace are all about. Traditional emphasis on the primacy of rigorous professional knowledge cannot always cope with the complex issues we have today. He coins the phrase "reflecting-in-action" to mean the use of intuition, spontaneous application of knowledge, artistry, and imagination in an iterative process of acting, watching, and making corrections as you go along. Both the Team and the investigator were able to apply this approach when the linear, problem solving approach did not suffice.

The Team did not have to deal with extremely difficult problems; they were problems which took a lot of persistence, and the linear approach was adequate. Nonetheless, the Team stepped outside its defined boundaries to develop a list of isolated hardware problems that had potential for preventing operation of the accelerator. The same applies to the generation of a list of portable emergency equipment, which the Team did in anticipation of problems caused by severe weather and electrical power outages.

# HARDWARE CHECKOUT AND RELIABILITY TEAM

## Introduction

The Hardware Checkout and Reliability (HC&R) Team was formed in June, 1993, by the Accelerator Division Deputy Director for Commissioning and Operations, A. It was one of six teams A. formed at the same time. Four of the other teams were hardware or function specific (Injector, Extractor, Operability, Linac). The sixth team, the Planning Team, supervised the five other teams and coordinated their activities.

This chapter is an account of the activities, both successful and unsuccessful, of the HC&R Team, told roughly in chronological order for the period of April 1993, through May 1994. This is an objective account with only a few opinions offered here and there. Analysis of and judgments about the Team's contributions to CEBAF will be rendered in the Analysis Chapter, which comes later.

## Organization

To explain fully the importance of the formation of teams in 1993 to the success of CEBAF, a description of the organizational structure used at CEBAF prior to 1993, is useful. As would be expected, CEBAF's organizational structure evolved during its early years, and is expected to continue to evolve to meet an ever-changing environment of budgets, government restrictions, and scientific goals.

CEBAF's present functional organization includes three divisions and three offices. The Accelerator Division includes two branches: (1) Accelerator Support and (2) Commissioning and Operations. Physics Division includes the computer center, a department for each of the three experimental halls, a detector group, and a data acquisition group. Administration Division includes: Finance, Procurement, Human Resources, and Plant Engineering Departments. The Director's Office provides immediate support to the laboratory Director and includes Public Affairs. The Office of Technical Support conducts self-assessment reviews and oversees Environment, Health, and Safety lab-wide. The Project Management Office coordinates construction funding, monitors construction progress, and coordinates laboratory interface with local educational facilities.

In addition to the functional structure, CEBAF has used a project organizational structure during the construction phase and will continue to use it until construction is considered complete, which will probably occur in late 1994, or early 1995. The project management organization includes nine Work Breakdown Structure (WBS) groups:

| WBS | Area of Responsibility | Division/Office |
|---|---|---|
| 1 | Accelerating components | Accelerator Division |
| 2 | Magnets | Accelerator Division |
| 3 | Radiofrequency Power | Accelerator Division |
| 4 | DC power | Accelerator Division |
| 5 | Instrumentation and Control | Accelerator Division |
| 6 | Experimental Areas | Physics Division |
| 7 | Cryogenics | Accelerator Division |
| 8 | Plant Engineering | Administration Division |
| 9 | Project Management | Office of Project Management |

The functional and project management organizations co-existed from the beginning of construction in February 1987, to the present. Key managers hold positions of authority and responsibility in both organizations. In a sense, U.S. Department of Energy funding policies drove this organizational arrangement. Funding for the construction project supports the project management organization, and funding for operations supports the functional organization. It is a legitimate question to ask: Why establish "teams" and further complicate the organizational structure?

## Why Teams?

Several factors contributed to the decision to form teams. One reason stands out when looking at the useful lifetimes of organizational structures. The functional organization is expected to last throughout CEBAF's lifetime, an estimated 30 years. This does not mean it will not change. Already, two divisions, Engineering and Superconducting Radio Frequency, have been absorbed by the Accelerator Division, and the Office of Technical Performance was established at the five-year point. The project management organization was designed to last only as long as the construction project was operative; i.e., from 1987 through 1994. In contrast, teams are useful for shorter periods, probably no more than a year, because each has a mission that is specific, well defined, and with a clear endpoint.

Another benefit to forming teams is their special ability to facilitate communications across functional-organization lines and between the experts in interdependent equipment systems. In the early days, CEBAF top management designed the functional and project management organizations to minimize the need for communications between groups. Each group had its own budget and goals to support the design, contracting, manufacturing, assembly, and acceptance testing of the systems and equipment within its sphere of responsibility. Certainly, some intra-group communications was necessary to insure compatibility at the interface, but the desire was to minimize cross-functional meetings and keep the work force focused on the very real task of building an accelerator. This was acceptable until the time came to (1) connect all the components and convert seemingly independent equipment into a single accelerating system and (2) a single person, the operator, had to understand how the subsystems were tied together and was given operational control of the entire system.

A third factor in favor of establishing teams is this. External pressures on SURA have forced this science-centered organization to consider adopting some modern management methods, including Total Quality Management (TQM). Much of the nation's industrial base has embraced TQM at a slow but steady rate during the last ten years, and governments at federal, state, and local levels are following suit. The Secretary of Energy during the Bush Administration pushed the "continuous improvement" concept very hard during 1990-1992, and the Secretary of Energy in the Clinton Administration broadened the application of TQM within the national laboratories, including CEBAF, with emphasis on improved communications and increased trust between government and contractors. The current Secretary persuaded all of the directors of the national laboratories to meet and set quality goals. One of the goals collectively adopted by the laboratory directors was for laboratories to use the Malcolm Balderidge award criteria for quality excellence as the standard for laboratory performance. The U.S. Department of Commerce makes Balderidge awards annually to one or two companies each year in three size categories, based on their performance in regards to nationally-established standards. This competition is supposed to help create a climate where work teams may thrive.

The concept of "teams" is not foreign to a sports-minded nation like the United States, and the TQM concept of teams, which evolved from Japanese "quality circles" shares some characteristics with sports teams. The idea of every member being empowered, the importance applied to the concept that all members are free to make suggestions, and the emphasis on group goals over individual goals are examples.

Before establishing the first teams, A. prepared the organization in three ways. First, A. established a series of talks by guest speakers who had extensive experience with TQM. Then A. contracted with a local TQM consulting firm to provide twelve hours of team training for potential team members. As part of the contract, the firm was tasked to provide a facilitator for meetings when a team leader requested this support. In March 1993, A. sent two team leaders to a three-day school on team leadership, and one was S., leader of the HC&R Team. In October 1993, A. brought four team members to a Peninsula Total Quality Institute monthly meeting, to expose them to people in other organizations who could provide first-hand information about team performance.

## Formation of Teams

A. decided in early 1993 to form teams to accomplish a very difficult task, delivering a functional accelerator within eighteen months. The situation was formidable given the resource limitations that existed and the amount of work left to be done. A. believed that teams were the most efficient means for focusing the effort. Appendix 2 includes a list of milestone events and dates for 1993 and 1994, and graphically displays the tightness of the schedule and the extent of the work that remained. Using teams seemed a daring gamble at the time, and there was much doubt on the part of some participants that teams would help. What sold the concept, perhaps, was that no one had a satisfactory alternative, and many of those directly involved with completing the accelerator and getting it to work were rather sure that the functional and project organizations would not be able to meet the schedule.

Three documents marked the formal beginning of the teams. A draft memorandum from A. and dated April 29, 1993, assigned goals to the Hardware Checkout and Reliability Team. Ro. modified the goals minimally, and sent them in writing to S. on May 5, 1993. A. also sent a memorandum in late May 1993, to every person selected for a team which informed the person of the name of a particular team. An attachment listed all members of the team and the percentage of time that each person was to give to team activities. This same attachment assigned three completion dates for a requirements review, a specifications review, and the start of the commissioning process. See Appendix 2.

The documents just described were the end products of many conversations and negotiations that A. had with other managers at all levels. A. and the Planning Team had to form five teams, and each team had to have a desired mix of expertise and abilities. Each team needed a leader who could get team members to work together. In addition, they had to convince supervisors to give up a specific percentage of their staff's time and effort. R. was assigned as Program Coordinator, and S. was assigned as Team leader for the HC&R Team. The Program Coordinator, while not a member of the Team, was the member of the Planning Team responsible for the HC&R Team and had an open invitation to attend all meetings. Appendix 3 is a brief biography of Team members. Their privacy is protected by using one or two letters to distinguish them as individuals. Each person willingly provided the information listed.

## Hardware Checkout and Reliability Team

The first meeting of the Hardware Checkout and Reliability (HC&R) Team was held on June 8, 1993. At this meeting, the Team reviewed the goals and milestones developed by A. and modified by the Program Coordinator. The Team accepted the goals and milestones listed below. (Minutes June 8, 1993)

Goals:

1. Evaluate the hardware reliability during the last six month's running and identify weak or unreliable equipment. Inform the appropriate WBS groups of the results.
2. Evaluate improvements proposed by the WBS groups to ensure that the weaknesses are rectified and check out improved equipment; e.g., perform a long term run of a high power amplifier in the South Linac with additional diagnostics to investigate stability.
3. Participate in definition of the new database.

4. Establish procedures to enter hardware information into the database.
5. Check out all of the hardware through the computer with the help of the operations group and correct the database as necessary, to support the commissioning schedule.
6. Ensure that the trouble-reporting system is ready and adequate.
7. Propose and implement procedures for "burn-in" to improve reliability.

Milestones:

| | |
|---|---|
| 1. Logbook analysis of equipment performance report. | July 1, 1993 |
| 2. Written evaluation of proposed database content | July 1, 1993 |
| 3. Written evaluation of trouble-reporting system | July 1, 1993 |
| 4. Analysis of WBS responses to performance report | August 1, 1993 |
| 5. "Burn-in" procedures recommended in writing | September 1, 1993 |

Ground Rules for Meetings:

The contract consultant attended the June 25, 1993, Team meeting and acted as facilitator. The Team established this list of ground rules for future meetings:

1. Everyone reports on progress.
2. There should be time limits (start and stop times).
3. One hundred percent attendance at meetings is the goal.
4. To achieve team goals, responsibilities must be shared.
5. Time outs (on discussions) can be called by anyone when appropriate.
6. Review and modify the agenda if necessary at the beginning of the meeting.
7. Define the agenda for the next meeting and put it in the minutes of the meeting.
8. Records of the meetings should not include open discussions, but should be limited to flip charts. Do not include open and frank discussions of any problems.

The Team concluded that "The purpose of the meetings should be to share information, and it was recognized that most of the actual work will be done outside the meeting environment." (Minutes June 25, 1993, 1) The Team also recognized the importance of keeping meeting minutes. Rn. used a lap-top computer to record notes during meetings and met with S. after most meetings to compose formal minutes. S. distributed typed minutes to Team members and other interested individuals prior to the next meeting. The minutes for one meeting provided the agenda for the next meeting. The minutes were very helpful to the Team during the course of its existence and were invaluable to the research. When meeting minutes are cited as references, as done earlier in this paragraph, the date of the meetings is provided. A complete list of meeting dates is provided in Appendix 15 rather than in the Reference List, which lists all other sources.

## Requirements Document

The first project that the Team attempted collectively was in response to the requirement levied by the Planning Team on all other teams to produce a "requirements document". The contents of this document were to be supportive of the goals document without being an elaboration of the goals. The requirements for a team were to be the equivalent of the specifications for a piece of equipment. The HC&R Team worked throughout July and into August to develop and refine its requirements and presented them to the Planning Team and representatives from other teams on August 9, 1993.

At the presentation, the Team identified nine categories of requirements: metrics (the means to evaluate), problem identification, resources, hardware/software, checkout, documentation, scheduling, budget, and mechanisms for improvements. Most of the categories were broken down into subcategories and given more detailed explanations. For example, under resources, the Team listed: manpower, call-in lists, spares, tools and equipment, training, and funding. In addition, the document provided more detail for each of these categories; such as under "tools & equipment" are listed:

1. Identify weaknesses in existing tool and equipment inventories, and make recommendations for supplementing existing items with purchased, rented, or leased equipment.
2. Identify weaknesses in existing software tools and make recommendations for improvements or augmentation.

The Team also included in the Requirements Document, a copy of an availability budget approved by CEBAF management in May of 1992. The availability budget provided a percentage availability for fiscal years 1994 through 1998 (FY 94 - FY 98) for twelve major systems and an "others". A total availability was provided after the thirteenth category. The availability predicted for FY 94 was 35%. For FY 95 - 98, the availability's are, in order, 55%, 68%, 77%, and 80%. The rules used to predict and compute these percentages are explained in Appendix 1. The availability budget was included in the Requirements Document as a reminder that this budget was a promise by CEBAF to the U. S. Department of Energy, and as such it became a focal point for operational planning. Appendix 4 is a copy of the requirements document.

During the presentation and the question and answer period that followed, some members of the audience were skeptical. T. kept a hand-written record of the questions asked, which the Team discussed very thoroughly at the next meeting. From this discussion, the Team developed a list of nine issues which seemed to encapsulate the concerns of the audience.

1. What is the role of the Team in determining alarm set points, out-of-tolerance set points, and automatic restart features?
2. What should be done with the failure data from the last operating period?
3. How does the Team feed useful information back into the management system?
4. What does the Team do (other than make recommendations)?
5. What does this Team do in regards to bypassing hardware and software interlocks?

6. What about developing diagnostic procedures which help operators identify and possibly correct a failure before calling and waiting for expert help?
7. What documentation should be readily available to the Crew Chief, and what is the optimum media for storing/presenting the information ?
8. Should there be/can there be an action item tied to each requirement, and if the answers are yes/yes, what are they?
9. What is the mechanism by which the Team learns of and obtains copies of existing and in-development procedures, check lists, etc.?

Because the HC&R Team was the only team that was not responsible for specific hardware or software, there was concern by some members of the Planning Team that the HC&R Team would become another layer of management. There was a mood present among members of other teams that expressed itself by this question: If the Team had to exist [because the boss wanted it to], could it help with some of the work, like performing some of the check outs? There was concern about the type and quantity of communications between the Team and the other teams and functional groups because the pace was fast and the quantity of activity great. How would it keep up to date?

As will be shown in the sections that follow, the Team began to address most of these issues right away by working on two projects: 1. a compilation and analysis of component failures during the previous operating period, and 2. administering a survey of twenty questions to the technical groups working on hardware and software installation.

## Systems and Equipment Reliability Record

Accelerator Division operated the injector, the north linac, and more than half of the east arc of the CEBAF accelerator from October 1992 to April 1993. The operations staff, consisting of one Crew Chief and two or three Beam Operators, kept a handwritten journal of major events, including system and equipment problems. This journal, called the *Daily Summary Log,* was a primary source document for investigating hardware and software reliability. Personal examination of the Crew Chief's *Daily Summary Log* demonstrated to the researcher that in most instances, the operators recorded the initial symptoms of a problem, but failed in many cases to record amplifying information about troubleshooting, identification of the real problem, and the time and date the problem was solved. Fortunately, the responsible hardware and software groups documented failure and repair data in their records in more detail, and this allowed the HC&R Team to locate most of the missing information.

S., a qualified Crew Chief; i.e., chief operator, reviewed the *Daily Summary Log* and other records for the October 1992 - April 1993, operating period, and extracted useful information about hardware and software failures. Ka. entered this information in a computer and used a software called *Cricket* to sort the data by work group, equipment, and type of failure. The software produced histograms for equipment type and work group, which provided a graphical indication of the equipment with the highest failure rates. More than 500 failures were identified and catalogued. The appropriate log-book number and page number were also listed for every entry to assist with verification.

The collected information was useful in the first order, but no further because it was not feasible to normalize failures to hours of equipment usage; i.e., operating hours, starts and stops, or some other useful metric because that data was not recorded. S. and Ka. compiled the analytical results and distributed a draft report. Some groups submitted corrections and amplifications to the draft report, and the authors worked with them to produce a final report, which was sent by the Team to A. on September 8, 1993. Copies were sent to key individuals. The report provided each WBS with information in two formats: faults listed alphabetically by equipment name, and histograms which show the number of faults for each type of equipment.

The report had the following benefits, at a minimum: (1) It identified high failure rate items. (2) Groups that had kept good records of equipment failures were able to improve on the information gleaned from the operator's logs. (3) Groups which did not have good records of equipment failures were identified. (4) S. and K. learned first-hand the importance of keeping good records. Appendix 5 is a copy of the report.

## Work Group Survey

As you will recall, the Team identified nine issues as a result of the requirements presentation made to the Planning Team on August 9, 1993. Many of the issues addressed the information exchange process and mutual support mechanism between the Team, the hardware groups, and the operators. The Team labored over the most effective method for bringing the required information into focus. It developed conceptual responses to the nine issues (Minutes August 17, 1993), but clearly needed input from the employees who were installing and testing the equipment. Eventually the Team decided to survey the hardware and software groups with a set of questions which would address most of the requirements issues. Team members contributed questions, and the entire Team selected the questions to be used in the survey. The Team wanted the survey to:

1. Encourage thought about mid-term and far-term problems
2. Encourage thought about supporting accelerator operators
3. Confirm or deny the conventional wisdom about equipment readiness
4. Identify major hardware, software, and system problems

The survey questionnaire was distributed on August 12, 1993, to eleven Accelerator Division group leaders and the Plant Engineering Department Head, with copies to two branch heads and six department heads. The questionnaire contained twenty questions which were arranged in four groups: schedule, support for operations, maintenance, and spare parts. S., Ka., and T. supervised the collection and analysis of the data. Fifteen of a possible seventeen groups and subgroups responded in writing to the survey. The following assumptions and facts affected the outcome of the survey:

1. The Team relied on the truthfulness and completeness of the respondents.
2. Team members interviewed respondents several times to clarify responses.

3. The responses were received over a six week period.
4. Responses submitted early could be out-of-date at the end of six weeks.

The twenty questions in the survey included six which requested basic information such as, “What systems or subsystems are you responsible to have on line for the next start-up?” The other fourteen questions, such as, “What are the obstacles which you feel may hinder efforts towards meeting your obligations?”, were directed at getting at potential problems. Contrary to our concerns, this type of subjective question did not provoke answers that were too hard to evaluate. Appendix 6 is a complete list of the questions. The Team realized from the beginning of the survey project, that evaluating the responses would have to be macroscopic and settled on putting all responses into one of three categories: green, yellow, or red. A green or “1” evaluation meant that the activity seemed to be on track. A yellow or “2” evaluation meant that there was some doubt about progress, and a red or “3” evaluation meant that the response was alarming.

After evaluating about half of the responses, the Team refined the process and reevaluated the grading criteria, and established three to five criteria for each of the three categories. See Appendix 7. For example, the criteria for a “1”, was any of the following:

1. The requested data was provided and was satisfactory.
2. What needs to be done is complete and reported to be in good shape.
3. There seems to be no problem with meeting the schedule.

Because the Team received the responses to the survey over a period of six weeks, the evaluations changed for some responses because groups fixed less-than-satisfactory items. It could be that the improvements were in response to the survey, but they could have been the result of normal progress, and it was difficult to determine one way or the other. However, our attempts to look and take credit for positive results made us realize that with time, the responses for all questions should converge on green or “1”.

## Presentations

The Team distributed a memorandum which provided background information about the survey to the Planning Team on October 26, 1993, and made a presentation at its regular meeting on October 28, 1993. Appendix 8 is a copy of the memorandum. At the meeting, the Team presented:

1. The average grade for the twenty questions
2. The five questions with the worst grades
3. Information about thirteen spare parts and equipment deficiencies
4. Five conclusions and four recommendations, which are discussed below

With regards to the thirteen deficiencies, the Team recommended that the Planning Team review the information and assign action to a responsible group or individual based on their review. The Team concluded that budget constraints have restricted and discouraged development of an acceptable spare-parts program by some groups. The Team recommended that the Planning Team establish a program for critical spare-parts acquisition which includes committed funding, prioritization based on needs, and continued oversight. Also, the Team concluded that hardware groups are not investing sufficient time with the Operations Group to make the operators full partners in caring for the equipment. In addition, the Team concluded that hardware installation is taking priority over the development of supporting documentation, training, and interfacing with other groups. Another recommendation was to insist on concurrent achievement of goals for installation of hardware and software, maintenance training, development of supporting documentation, and training of operators. The final conclusion from analyzing the survey was that some groups have invested little effort towards developing a preventive maintenance program. This recommendation was to establish a coherent preventive-maintenance program which provided some standardization of methods and required technical staff to inform the Crew Chief of all overdue preventive maintenance. During the presentation, as well as later, a few corrections were made to the data. For example, one Department Head was aware of a spare injector gun that the Team had not located.

The presentation to the Planning Team raised sufficient interest that the Team was asked to give the presentation to the Accelerator Division Council on November 15, 1993. Membership on this council included the Associate Director, the two Deputy Associate Directors, and the five Department Heads (Linac, Arcs, Superconducting Radio Frequency, Operations, and Instrumentation and Controls.) This was probably the most significant event to date for the HC&R Team. Appendix 9 is a paper copy of the presentation view graphs. The message of the presentation was that certain mid and long term needs were not being addressed or were being delayed until they might became crises. The audience included the people who had the responsibility and the resources to make things happen. This was the group which would collectively set the priorities that determined the division of resources and the emphasis given to the many tasks remaining to be completed before the accelerator was fully operational.

## Software

CATER is an acronym standing for Computer Aided Trouble Entry and Reporting. It is a software program developed and provided by the Stanford Linear Accelerator Center (SLAC), an accelerator laboratory located near San Francisco, California. B. adapted CATER for use at CEBAF, and once adopted, CEBAF employees were required by Accelerator Division policy to make a CATER entry for all accelerator software and hardware problems. The software assigns a CATER number to every problem to allow tracking and easy reference. The software accommodates follow-up status reports, printouts, and completion reports. The data base is password protected, with every individual having a unique password. This first-generation failure-reporting system provides a good history of failures, but does not perform any sophisticated analysis such as computing downtimes or displaying histograms of system failures.

The CDF (collision detector at FermiLab) Downtime Logger is a software program developed by FermiLab, an accelerator laboratory located near Chicago, Illinois, and provided through the good offices of Ro., who previously had worked at FermiLab. The downtime-logger software records the time that individual components are turned on and turned off, and computes system availability. Unfortunately, the Downtime Logger required the use of a control-system software called ACNET, which CEBAF does not use. In August 1994, management selected another software, called EPICs, for its control system, and the CDF Downtime Logger was no longer an option. The lack of a downtime logger capability remains an organizational weakness.

A brief chronology of the CATER software program at CEBAF follows: In June 1993, the Stanford Linear Accelerator Center (SLAC) transmitted its CATER software program to CEBAF. On July 13, 1993, the SLAC software program was demonstrated to the Team at a computer terminal, and Al. provided Team members with two information handouts: (1) a technical note from SLAC which provided historical and factual aspects of the program as well as sample computer menus and displays, and (2) a copy of a letter from a SLAC employee which describes CATER.

Although Al. was a computer programmer and a member of the HC&R Team, the accelerator software functional organization assigned CATER development to B. in June 1994 because B. had a strong background in the VMS operating system, which CATER used, and Al. did not. B. visited the Stanford Linear Accelerator Center (SLAC) for one week in July 1993 to study CATER in use, and a computer programmer from SLAC, visited CEBAF during August 1993, to assist with implementation. On July 22, 1993, B. published a "Proposal for CATER at CEBAF" which included a description of CATER's capabilities and a schedule for its implementation. As CATER began to take shape, B. had to interface more and more with HC&R Team members. Eventually the inevitable occurred, B. joined the HC&R Team on August 11, 1993, and Al. moved to the

Extraction Team. At the August 17, 1993, Team meeting, B. distributed a three page handout which showed the current CEBAF version of screen text for CATER menus.

B. completed CATER conversion to CEBAF toward the end of September 1994, and published directions for its use on October 12, 1994. Throughout the development period, B. asked other HC&R members to test the program with fictitious entries and provide feedback, especially with regards to identification of software glitches and making the program more user friendly. Rn. was particularly helpful in this regard, and provided extensive quality-assurance monitoring of the program. Rn. and B. acted in concert to develop and prove the program. CATER was implemented for general use on November 1, 1993. Appendix 10 contains documents that describe CATER in detail.

In December 1993, Ka. and S. analyzed the CATER reports and developed a second report of equipment failures. This analysis proved to be just as tedious and time consuming as the previous analysis of failures recorded by hand in the *Daily Summary Log*. This and many other clues taken from comments by users indicate that several changes to the CATER program are essential. Appendix 11 includes histograms for the first 248 CATER failure reports.

## 1994 Projects

The 1993 holiday period and the accelerator operating period that followed reduced the opportunities for the HC&R Team to meet and slowed its momentum. A., S., and Ka. went on shift work. Equipment development and checkouts demanded the full attention of F., K., and N. Nevertheless, the Team took on three projects which were self initiated by the Team; i.e., a Team member proposed the work, and the Team accepted the task. The Team developed a cold-weather plan for the accelerator in response to one of the coldest winters on record in Hampton Roads. In conjunction with this plan, the Team developed a list of portable electric generators, portable pumps, space heaters, and portable air compressors that would be useful if utility-provided electric power were not available. Finally, the team reviewed and commented on the draft version of the top level policy document about accelerator systems and component maintenance. The highlights of each of these projects are described in the paragraphs that follow.

During the severe weather in January 1994, with zero degrees Fahrenheit reached on several nights, a sprinkler pipe froze in an unheated building, resulting in dousing some electronics cabinets when the freeze plug thawed. This event drew attention to the need for a cold-weather plan for the accelerator site. S. asked Team members to provide input from their functional groups for a severe-weather plan, to include hot and cold temperatures. T. contacted Plant Engineering for a copy of their severe-weather plan. T. collected the submissions, reviewed them, and developed a draft severe-weather plan for the accelerator site. T. submitted the plan to Team members for review and comment, and the final severe-weather plan took their comments into account. The final version was presented to the Crew Chiefs, and a copy was placed in the Crew Chief's Emergency Notebook. Appendix 12 is a copy of the plan.

The list of emergency portable equipment was coincidental with the development of the severe-weather plan. In January 1994, the power utility company threatened to off load portions of the electrical grids in what they called "rolling brownouts" because the company expected the demand for power would be greater than the available supply. While CEBAF did not experience such an outage, some rural areas in southeastern Virginia went without power for hours. This close call prompted the Team to consider compiling lists of equipment that would be useful to have during a lengthy period without electrical power. By way of note, one of the attractions of Newport News for siting CEBAF was its excellent record of reliable electrical power. In addition, the CEBAF site can be supplied from two different substations, but this is no protection against forced outages when regional demand exceeds regional supply.

The process for compiling a list of portable equipment that would be useful during lengthy power outages, included two primary stages. R. reviewed the CEBAF property management file, which is on a computer data base available to all employees. By searching for generators, pumps, space heaters, and air compressors, R compiled four lists which were turned over to T. T. developed a questionnaire for each type of equipment and sent them to the listed custodians. The replies indicated that much of the equipment listed was not portable, was installed in place, and could not be reasonably moved during an emergency. The equipment that was verified by the custodians to be portable and of potential use during an emergency was compiled and published as a list which has been placed in the CEBAF Emergency Management Manual. The Emergency Management Manager will update the list annually. Appendix 13 is a copy of the list.

Early in January, 1994, A. advised S. that he had nominated the HC&R Team and the Injector Team to give presentations to the Virginia Peninsula Total Quality Institute (VPTQI) on February 28, 1994. This organization provided a forum for the private and public organizations in Hampton, Newport News, Yorktown, James City County, and Williamsburg to share experiences and promote Total Quality Management throughout the area. After discussion, the Team developed the following agenda:

| | |
|---|---|
| Introduction | S. |
| Survey Results | T. |
| CATER | B. |
| Equipment Failure Analyses | Ka. |
| Summary | S. |

During mid preparation, VPTQI moved the conference date ahead one week, to February 18, 1994. This interfered with a vacation planned by S. Consequently, T. filled in for the introduction and summary during the conference. The speakers developed view graphs for the talks and practiced before the Team on February 15, 1994. The presentation went as planned and generated questions from the audience. There was follow-up later by an organization interested in using CATER to track their equipment failures. A copy of the presentation is attached as Appendix 14.

## Final Days

By March 1994, accelerator installation and operations and shift work frequently took priority over weekly HC&R meetings. However, the Team started two new projects: (1) selection of a software program for organizing and tracking preventive maintenance activity and (2) a survey to technical groups to ascertain their readiness for operations scheduled to begin on May 15, 1994. These initiatives were brought to a close so far as the HC&R Team was concerned when A. met with the Team on May 2, 1994 and disbanded it after thanking the members for their many accomplishments. This decision was not unexpected. The Team had completed its initial mission and had evolved into a self-governing team generating its own projects. The intense operating schedule planned for May and the rest of 1994 precluded repetition of the considerable effort that Team members were able to devote to projects during the summer of 1993 when the accelerator was shutdown for six months to allow final equipment installation in the south linac and the beam switch yard. Thus the HC&R Team became a part of CEBAF's history, but its legacy will continue when a new set of teams, including one with maintenance responsibilities, is formed within the next year.

Appendix 15 is a listing of the meetings held by the HC&R Team during its existence and lists of team training received, team products produced, important documents received, and presentations given by Team members. This appendix also serves as a list of the meeting minutes, and there is one set of minutes for every meeting listed by date.

## Chapter Summary

This chapter is a chronological account of the Team, from its formation in June 1993 until it disbanded in May 1994. The Team was one of five teams formed at this time under the supervision of a Planning Team. The use of teams on this scale to solve time-dependent problems was new for CEBAF. The accelerator was to be shutdown for the last half of 1993, and this shutdown period was to be used for installation and test of accelerator components needed for the next period of operations. The Planning Team set goals and completion dates for the five teams based on the operating schedule for 1994. The Team was assigned seven goals and five completion dates. The Team agreed to a set of eight ground rules, which became the norms for conducting meetings.

The first major project for the five teams was to develop a requirements document and give a presentation to the Planning Team. The purpose of the requirements document was to specify the expectations for the team's products and results. The Hardware Team identified nine requirement categories, some with several subcategories. The Planning Team and the audience asked many questions at the Hardware Team's presentation, primarily because the Team had far more subjective goals and requirements than the other teams. The Team documented the questions, studied them, and categorized them. From this effort, the Team developed a survey with twenty questions, which it distributed to all technical work-group leaders. The questions were placed in one of four categories: schedule, support for operations, maintenance, and spare parts. Fifteen of seventeen possible work groups responded to the survey over a six-week period. Three Team members analyzed the returns using a numerical grading criteria developed during a review of the first few returns. The Team decided that it was not useful to compare the grades of the different work groups because the returns were submitted over too long a period. They looked carefully at the five questions with the lowest averages and also looked at the seven responses which received the lowest possible grade. Team members met with the responsible line managers to alert them to the findings. Finally, a list of specific concerns developed from the many conversations and written communications that occurred while bringing the survey project to completion.

The future of the Team was in the balance at the end of the presentation of the requirements document. There were serious doubts about the Team's usefulness, but the survey dispelled these doubts and also gave Team members an improved sense of worth. The importance of the survey was that it forced technical group leaders to take a hard look at their workload, their resources, and the schedule and assess their prospects for success. It also forced them to share their assessment with someone outside their group. The answers had to be relatively honest; an overly optimistic response would set the group up for a fall later on, and too pessimistic a response would invite immediate, close attention by management. The survey was a direct intervention into the real business of the technical groups responsible for completing the accelerator on schedule.

The survey results reached management's attention in this way. The Team sent a memorandum to the Planning Team (Appendix 8) which included the questions, the grading criteria, and the results. This was followed by a presentation which resulted in serious questions and answers. This presentation was so well received that the same material was presented to the Accelerator Division Council at its next meeting.

The first of the eight goals given to the Team required the identification of equipment that was weak and unreliable during a previous operating period. This proved to be a very time-consuming project because the records of equipment failures were recorded in a log for accelerator operations. The two members collecting this information had to read half a year's worth of logs and extract the small percentage of information that was useful. Frequently, only symptoms were recorded, and there was no record of what was really wrong or what was done to fix the problem. Many interactions with work groups were required to verify the existing information and obtain what was missing. The end result of this project was a formal report (Appendix 5) with lists of equipment failures and histograms for nine major technical groups.

This last project emphasized one point that was already known and acknowledged as a problem: the collection and display of equipment failure data must be automated. Developing such a system was, in fact, one of the Team's prescribed goals, and the CATER software system proved to be the answer to the problem. CEBAF adapted

CATER from its place of origin, the Stanford Linear Accelerator Center. Exchange visits by members of both laboratories facilitated a rapid conversion of the software to meet CEBAF's needs. A complete CATER input requires detailed information about the equipment, the times of failure and repair, the symptoms observed, the parts used to make repairs, the names of the people who made the repairs, and similar details.

Every CATER entry is given an identification number, and the software compiles lists of closed and open reports for management review. An attempt to use a complementary software called Downtime Logger proved to be impossible because of control-system software incompatibilities. CATER was put into service in October 1994, and by December, there was enough data to support a second analysis of equipment failures. The same mini-team of two members reviewed the CATER reports, analyzed the results, and developed a report consisting of histograms which grouped the failures for the equipment of eleven technical groups. It is desirable that CATER be modified so that it can produce histograms for prearranged groups directly from the failure reports. Upon completion of this report, the Team had met its original set of goals, but rather than disbanding, it continued to meet to solve new problems.

The Team identified and agreed to work on the solutions to two related problems: developing a severe-weather check list for the accelerator site and compiling a list of portable, emergency equipment for all of CEBAF. Both projects were prompted by the effects of severe cold weather early in 1994. Sustained temperatures near zero had caused some unexpected difficulties on site, and the local electrical utility announced that because of excessive demand due to the cold weather, it may be forced to dump loads to keep power going to the rest of the grid. From these two events sprang the idea of compiling lists of portable equipment, such as gasoline-powered electrical generators, air compressors, water pumps, and space heaters, that could be useful in an emergency. In addition, the Team developed a severe cold-weather plan for the accelerator site and coordinated that plan with a site-wide plan compiled by the Plant Services Manager.

The final project that the Team was to undertake was to make a presentation at a regional conference about teams in the work place. The Team considered this assignment an honor and prepared a presentation about the survey, CATER, and equipment-failure history. The Team also developed a vertical display board which showed amplifying information about CEBAF and the Hardware Team. When the Team was disbanded, it was working on two projects, a search for software for scheduling preventive maintenance and a new set of survey questions for technical groups. The survey did not survive the transition, but the search for a suitable software will be the basis for a new team to be formed in late 1994.

# WORK PROCESSES

## Introduction

This chapter is an extension of the Hardware Checkout and Reliability Team Chapter, which precedes it. The Hardware Checkout and Reliability Team Chapter is an account of the Team's experience during its eleven month existence. That chapter is a factual account of team formation, team goals, team problems, team projects, and team successes and failures. This chapter, Work Processes, takes a more detailed look at the processes which the Team used to accomplish its tasks. Specifically, nine projects are examined from the viewpoint of: (1) who did the work, (2) how they did the work, and (3) why they did the work. There is some overlap of information within the two chapters, but a minimum amount was unavoidable in providing coherent accounts. In addition, the Work Processes Chapter makes frequent reference to the same appendices referred to by the Hardware Checkout and Reliability Team Chapter.

The investigator was challenged to present clear and accurate descriptions of the processes the Team used to complete their projects. The processes the Team used for doing work are the central focus of this research, and therefore it is very important that they be examined in detail, yet be presented simply so that the most important factors may be grasped without undo effort by others who want to understand what went on. The investigator had to gain an understanding of the processes first, and in the search for understanding, selected a visual means of presenting the flow of work from start to finish. This may have been personal preference because the investigator is better at comprehending information visually than by the other senses. To take advantage of this, the investigator developed a two-dimensional flow diagram, using boxes and arrows, to model each of the nine processes.

The investigator used the flow diagrams to lay out the processes step-by-step and better understand what actually happened from the time each project was conceived until it was completed. The diagrams indicate when an individual worked alone, when a mini-team functioned, and when the entire team acted together. To ensure accuracy and completeness, the investigator asked the members with principal responsibility to comment on the text and the flow diagram for their specific projects. The projects treated in this way were those for which the investigator did not contribute as a member of a mini-team. The comments of the members in these cases contributed to the accuracy of the chapter and validated the investigator's observations and understandings.

In this chapter, a separate section describes each of the nine projects, and a figure is located after the narrative section about each project. The figures provide a graphical description of the flow of work, and are structured in this way: The pages are landscaped; i.e., laid out lengthwise. The project starts at the left-hand side of the page and terminates at the right-hand side of the page. The top row of blocks are reserved for individuals and groups. The middle row of blocks are reserved for equipment and systems such as a computer. The computer was the primary tool of this team, and was an essential part of the work process and a significant contributor to productivity. The bottom row of blocks are reserved for products such as reports, view graphs, and memoranda. Arrows are used to indicate the direction of the flow of information.

## Meeting Minutes

The Hardware Checkout and Reliability Team published typed minutes for all formal meetings. Copies of the minutes were distributed to all team members and to members of the Planning Team. In general, meeting minutes serve many purposes. They are a historical record of what happened at meetings. They give all participants an opportunity to dispute what someone else thinks happened at a meeting. They formally assign action and due-dates to individuals. They provide notification of the time, date, and location of the next meeting. They inform people who did not attend, including top management, about what transpired during meetings. This section is about the process of taking notes during the meetings and producing a set of accurate minutes.

The Team settled quickly on a process for producing the minutes for the weekly meetings. Rn. was selected to be in charge of taking the minutes, and accepted this responsibility for the following reasons: (1) Ownership of a lap-top computer that would facilitate taking notes during meetings. (2) Expertise in equipment reliability techniques. (3) Confidence from prior experience in personal ability to produce excellent minutes. (4) A mutual desire with S. to work together on a project.

Rn. in fact, always brought his personal lap-top computer to the meetings and typed what seemed to him worth saving as the meeting progressed. The standard procedure after a meeting was over was for Team leader S. to go with Rn. to Rn.'s room to review, correct, smooth up, and approve the minutes. Rn. would take the disc from the lap-top computer and transfer the information via the disc to a table-top computer. Rn.. and S. reviewed the minutes on the screen, making corrections as they proceeded.

S. did not sign the minutes after approving them because this is not a requirement at CEBAF. S. initially determined the distribution list (the names of people who were to receive copies) of the minutes; however, any Team member could recommend additions to the list. S. primarily made copies of the minutes and distributed them through the internal-mail system at CEBAF. Upon receipt of the minutes, members were free to dispute the minutes and ask that something be added, deleted, or changed at the next meeting. This was rarely done. If Rn. was going to be absent, T. took the minutes. This happened three times, but T. used a more traditional process: taking notes on paper during the meeting, using the notes to type the minutes, and presenting minutes on paper to S. the next day for review, correction, approval, and distribution.

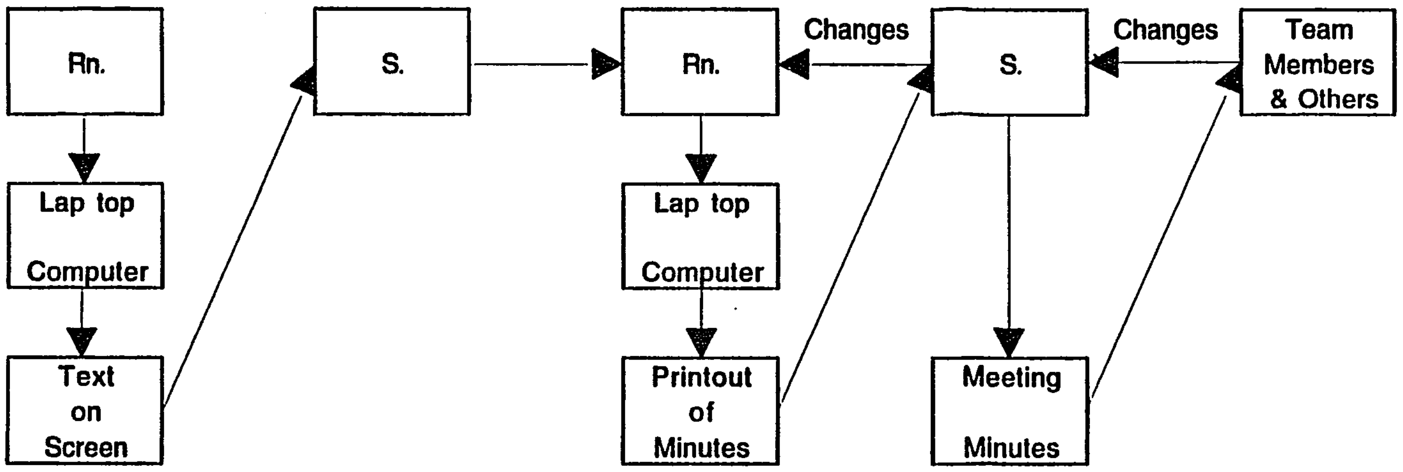


Fig. 1. Work Processes used for Producing the Minutes of the Team Meetings.

Note: The arrows indicate the sequence of work. The top row is used for people and the Team.
The middle row is used to indicate use of a computer.
The bottom row is used for products of the Team's work.

## Requirements Document

The Planning Team required all other teams to develop a requirements document which would establish the specifications for their product(s). In the case of the Injector Team, for example, the input and output specifications of the injector would be a major part of that team's requirements. Because the HC&R Team was not responsible for specific equipment, considerable uncertainty existed among Team members about what their end products would be. Discussion about these uncertainties started at the July 13, 1993, Team meeting. Also adding to the uncertainties, CEBAF management had not decided on the organization structure responsible for accelerator equipment maintenance when installation was complete and operating would be the norm.

The HC&R Team leader, S., listened to the discussion, and then asked each member to draft a personal vision of a requirements document. S. collected and reviewed these independently developed documents and wrote a single, first-draft document which he distributed to all Team members at the weekly meeting held on July 20, 1993. The Team devoted most of this meeting to a careful review of the first-draft requirements document. The Team met again the next day, July 21, 1993, to continue with developing the document. S. submitted the resultant draft document to the Planning Team for preliminary review and comment.

At the next Team meeting, on July 27, 1993, the scientist who was leader of the Operability Team was present and tried to refocus the Team's thinking about its requirements document. Later investigation indicates that the Planning Team found the Team's initial input unacceptable because of its subjectivity and because it was so different from the requirements documents the other teams presented. The other teams were responsible for equipment performance, and their requirements documents include performance specifications for their equipment and beam parameters. The Operability Team leader was persuaded that the Hardware Team's document must answer this question: What does the Team provide as deliverables to the other teams and how can the results be measured? This question promoted new discussions and discoveries.

One of the most fruitful results of this discussion was that it led to the discovery that previous to the Team's formation, CEBAF management had made numerical commitments about accelerator availability for fiscal years 1994 through 1998 to its funding agency. The report which conveyed this information was a windfall for the Team in that it was approved by the highest levels of CEBAF management and contained quantifiable goals that were at the center of the Team's purpose. However, not all information in this report were fully understood, and four Team members left this meeting with assignments to clarify and resolve the uncertainties. A copy of this availability report is the penultimate page of Appendix 4.

The Team met again on July 30, 1993, and discussed the latest organizational policy regarding machine availability and the number of weeks of operations for the next five fiscal years. In additional, the Team listed all known remaining issues for the requirements document and made recommendations for addressing the issues.

S. presented an updated requirements document to the Team at the August 3, 1993, meeting. The Team discussed each of the entries and reached consensus, and this proved to be the final review of the document by the Team before S. presented it to the Planning Team and interested members of other teams. In response to this Team meeting, S. revised the document a final time, and met with the Team in the morning on August 9, 1993, for about one hour for a strategy and motivation meeting. At this meeting, S. announced that he had distributed paper copies of the presentation view graphs to thirty-seven managers on August 6, 1993, so that the presentation three days later might go smoother. S. made the formal presentation later, on August 9, 1993.

S. accepted responsibility for leading the Team in developing the requirements document for the following reasons: it was interesting, a personal desire to work on a project which involved all members, possession of expertise in the topic, and self confidence in being able to do an excellent job.

Figure 2 is a graphical representation of the flow of work for producing the requirements document. The sequence of events is in the direction of the arrows.

The aftermath of the presentation of the requirements document to the Planning Team and members of other groups is discussed in the next section. The Team developed a set of questions to ask all technical groups and surveyed them to obtain the answers.

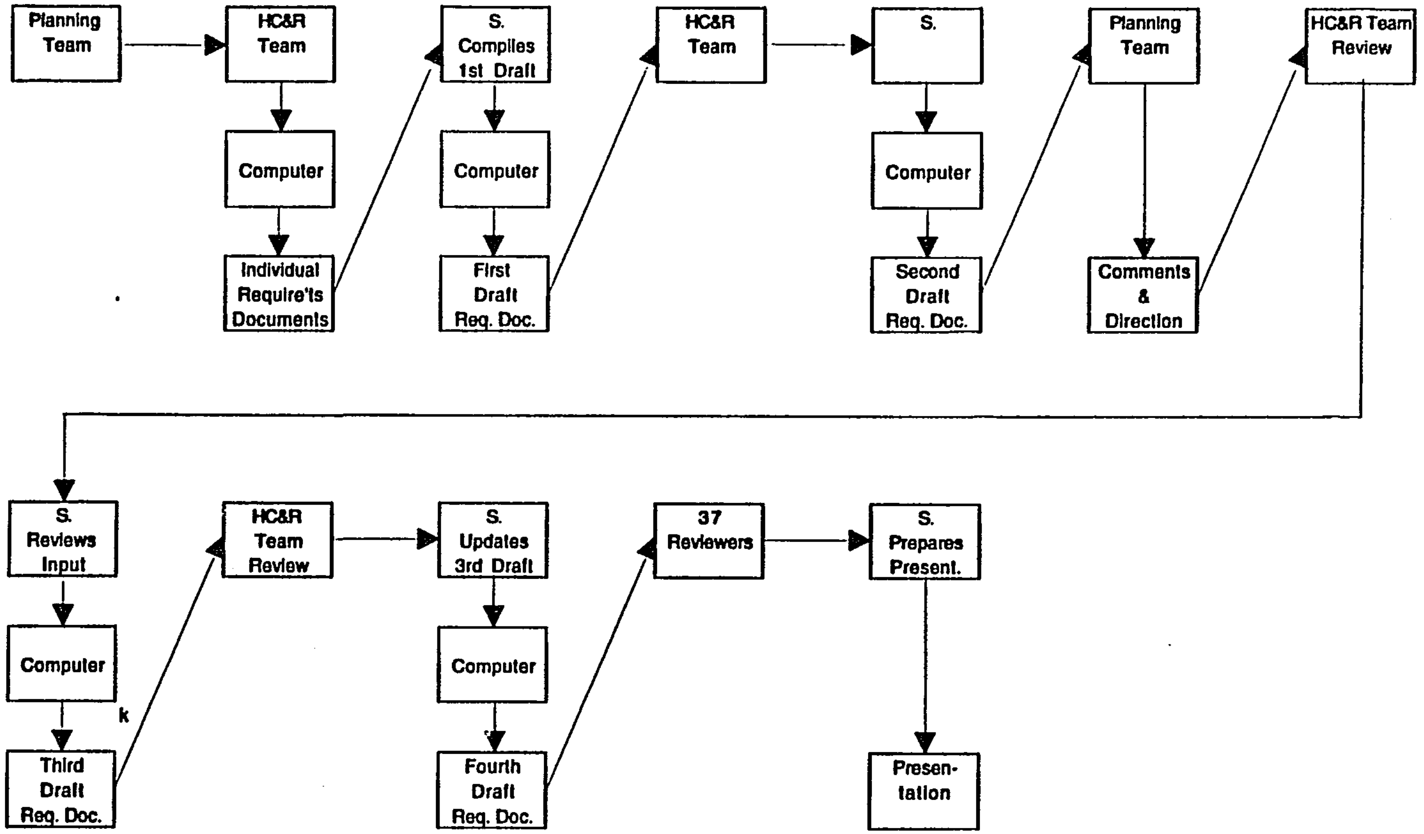


Fig. 2. Work Processes used for Producing the Requirements Document.

Note: The arrows indicate the sequence of work. The top row is used for people and the Team. The middle row is used to indicte use of a computer. The bottom row is used for products of the work.

## Survey

The survey to be discussed in this section was the direct result of the requirements document and the Team's presentation to the Planning Team. During the presentation on August 9, 1993, T. took notes on the questions made by the audience and the answers given by Team members. The Team reviewed a typed version of these notes at the next meeting, which was held the next day, August 10, 1993. The Team was able to distill the dialogue into nine questions, which are listed in the Hardware Team Chapter.

The nature of these questions was, in general, such that the Team could not answer them. Only the groups responsible for delivering installed equipment could properly respond. From this realization, the Team pondered about the optimum means for acquiring responses from the various working groups, and settled on a survey. S. asked all Team members to consider the nine questions and determine if any other questions should be asked. In addition, four Team members, D., R., K., and T., agreed to meet on August 12, 1993, to organize the survey. This involved selecting the questions, wording the questions, determining their order of appearance, and determining which groups should take the survey. These four members met the one time, met their goals, and disbanded. S. distributed the survey to twelve group leaders later the same day. The survey in its final form contained twenty questions.

The Team received responses to the survey very sporadically. One of the earliest responses was typed and signed by a department head. One of the last was barely legible and was answered by a technician. In most cases, the path to completion required an iterative dialogue between a Team member and the respondent. This was necessary to clarify answers that seemed incomplete or vague and to obtain answers to questions that were ignored. Why were some groups so slow to respond to the survey? Some were in fact extremely busy, and the pace of installing equipment was so great that there would be a significant change in some of the answers on a weekly basis until the group reached the asymptotic position. Other groups were reluctant to report an unsatisfactory condition, and in fact, the two groups farthest behind the schedule never did respond. However, these two groups were the objects of very close oversight by top management and were supplemented with extra labor and funds as necessary to get back on schedule. This was accomplished.

The process of persuading reluctant managers to document their status had elements of reflection-in-action, which was discussed in the Methodology Chapter. The Team member tasked to remind a manager of the overdue response to the survey could try an escalating series of techniques: (1) persistent, frequent reminders, (2) talking to the workers in the group to gain knowledge, then filling out the survey, and asking the manager to review it, (3) officially notifying management about all of the overdue reports, and (4) telling the manager that all answers will be given the lowest grade. The Team member engaged in such a struggle, was wise to consider which approach would work with which person. An unwise choice could result in a manager who would resist as a matter of principle. Fortunately, this did not happen, but still, it took six weeks to reach closure because some managers considered the survey to be too revealing an intervention in the work of their groups.

Evaluating the responses to a subjective survey was an interesting exercise. S., T., and Ka. met to evaluate the returns. T. collected the returns and distributed copies to S. and Ka. Several days later, the three mini-team members would meet and evaluate the responses on a "1" through "3" basis. Three meetings were needed to evaluate eight returns. An examination of the evaluations, however, indicated inconsistencies. What might have been a "2" on one day was a "3" on the next day. T. analyzed the reasons given for all of the evaluations for the first eight returned surveys, and developed a set of criteria that should lead to a grade of "1", "2", or "3". Appendix 7 is a copy of the grading criteria.

The mini-team of S., Ka., and T. reevaluated the first eight survey returns using the new grading criteria. This process proved useful; however, when there was doubt for a particular response, one member would read the criteria set, and all three would look for the best match. The reevaluation did result in a small number of changes, perhaps as much as ten percent, or two questions per survey. The process of using preestablished criteria normally led to a quick resolution. When it did not, resolution was achieved by requesting more information from the responding group. A question or two was usually all that was needed to alleviate the uncertainty.

The mini-team evaluated the surveys and developed a matrix, which is included in Appendix 9. The matrix lists the "one through three" evaluation for each group for each of the twenty questions. The matrix was presented to the Team, the Planning Team, and the Division Council. T. computed the average grade for each of the questions, and the averages were analyzed to determine which questions had the lowest grades. The Team analyzed the questions with the five lowest average number in order to look for a common theme. The Team also averaged the scores for the fifteen groups, but because the responses were received over a six week period, the Team judged that the scores for groups could not be compared fairly. The matrix was distributed to Group leaders. The Team brought yellow and red responses to their attention.

Figure 3 is a graphical representation of the flow of work for drafting the survey, taking the survey, and analyzing the results. The sequence of events is in the direction of the arrows.

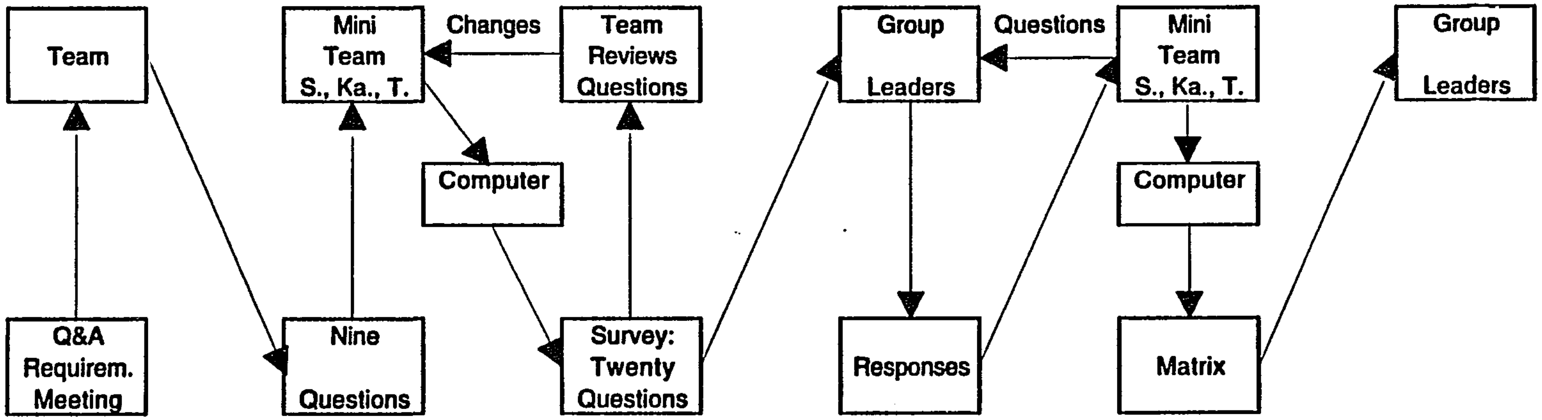


Fig. 3. Work Processes used for Producing the Survey and Analyzing the Results.

Note: The arrows indicate the sequence of work. The top row is used for people and the Team. The bottom row is used for products of the work.

## CATER

CATER was the first attempt at CEBAF to develop an integrated data base for documenting system and equipment failures. Previously, individual technical work groups had developed their own methods to track hardware and software failures. The intent for CATER was for it to be a central recording and reporting system for hardware and software failures that affect accelerator operations. A. arranged with the Stanford Linear Accelerator Facility (SLAC), the originating organization of CATER, for CEBAF to use CATER. SLAC sent the CATER software to CEBAF electronically.

B. was selected to implement CATER at CEBAF. B. loaded the software and learned how to navigate through the menus and manipulate the data base. B. visited SLAC for one week, and a computer scientist from SLAC visited CEBAF several times to assist with the details of changing the software to service CEBAF. A major task for B. was to change the SLAC data base to a CEBAF data base. The data base consists of a symbology for CEBAF equipment, equipment owners, and equipment locations. The symbology consists of up to nine alphanumeric symbols which systematically indicate the system, the equipment, sub component, and location. Once B. was satisfied with the CEBAF version of CATER, the Team began to access CATER to learn about its capabilities and to look for opportunities for improvement. Rn. was the principal Team member who took the time to learn CATER and provide useful comments to B. Rn. was able to do this because of extensive, prior computer experience. In addition, Rn. was a senior member of one of the major technical groups at CEBAF and had been responsible for failure-rate analysis for that group.

Rn. provided B. with extensive comments about what worked at a remote terminal and what did not. Rn. quickly found out that 48 lines were necessary to show CATER screens, and Rn.'s computer, a PC, was incompatible with that number of lines until a special software was loaded. Macintosh computers had a similar problem receiving CATER. As a future user of CATER, Rn. provided a much-needed perspective.

B. accepted the task of developing CATER for CEBAF in terms of being a member of the Team for the following reasons: expertise in computer programming, interest in the topic, Team leader support, and a desire to work with all Team members.

At weekly meetings, B. urged all members to log on to CATER and provide comments. There was a limited response to this request other than from Rn. B. considered CATER ready for operational use in September, 1993 and began to provide training sessions for users. In October, B. published instructions for logging onto CATER and for communicating questions and recommendations back to B.

Actual use of CATER began in October 1993. Extensive usage by many groups and individuals proved the utility of CATER. By November 1994, employees had filed over 1,600 CATER reports. With this amount of experience, both operators and staff have used every capability of the software, and have made some constructive suggestions for improving the software. The decision-making process for upgrading CATER has been defined, and an upgrade is scheduled to be conducted annually. Appendix 10 contains background information about CATER.

Figure 4 is a graphical representation of the flow of work for adapting CATER for CEBAF. The sequence of events is in the direction of the arrows.

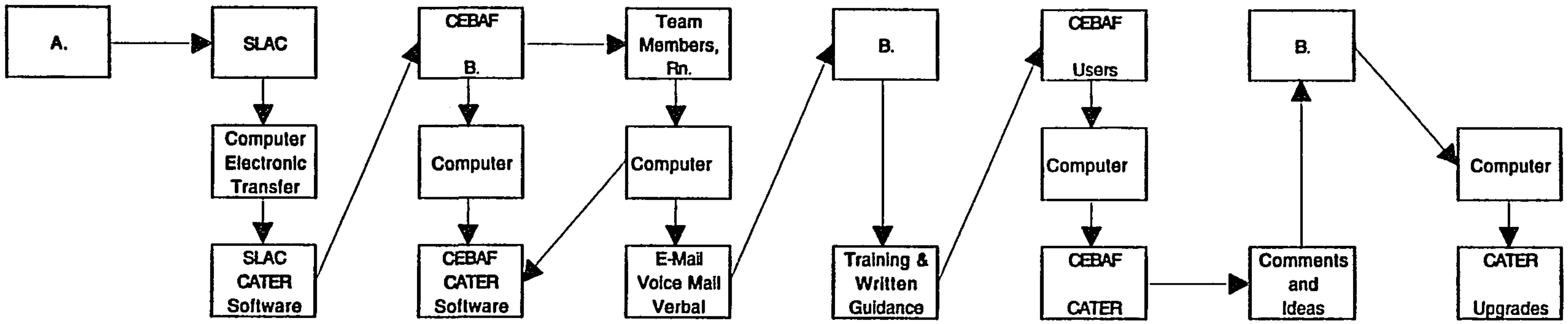


Fig. 4. Work Processes used for Adapting CATER Software to CEBAF.

Note: The arrows indicate the sequence of work. The top row is used for people and the Team. The middle row is used to indicate use of a computer. The bottom row is used for products of the work.

## Equipment History I

As previously stated, one of the seven original goals of the Team was to "evaluate hardware reliability during the last six months and identify weak or unreliable equipment, and to inform the appropriate WBS group of the results." The operation period covered by this section was from October 1992 through April 1993. Two Team members, S. and Ka., were responsible for successfully meeting this goal. This was a difficult task which took patience, attention to detail, and obtaining information from other people. This was detective work.

The object of this task was to collect information about all systems and equipment failures which affected accelerator operations. There were two primary sources of information, operations logs and group equipment records. CATER did not exist at CEBAF during this period. Potentially, the equipment records of the technical groups was the more reliable source because they should contain more detail about the cause of failure and action taken to make repairs. These documents would not necessarily be helpful in determining whether or not the fault affected accelerator operations because the records would contain accounts of all failures regardless of the impact on accelerator operations. The other choice, operations logs, contained many inaccuracies and were incomplete in many instances. The accelerator operators were reliable about recording the initial reports of problems, but were not always informed about follow-up action, changes in status, and completed corrective action.

Team leader, S., reviewed the *Daily Summary Log*, which is the log in the accelerator control room that the Crew Chief uses to record every important event affecting accelerator operations. This review covered five separate *Daily Summary Log* journal notebooks, which resulted in over 500 identified faults. In a few cases, S. obtained useful information from the *Systems Information Log,* a log for recording information about safety systems. S. passed the collected data to Ka, who used a PC to record the fault entries. The list of faults was sorted by work group; i.e., WBS, and listed in alphabetical order by equipment name. Ka. then fed this data into a PC software called *Cricket*, to produce histograms. The histograms plotted number of faults versus equipment name. Ka. returned this package of lists and histograms to S., and S. reviewed it and distributed it to the WBS leaders for their review and comment. WBS leaders have at their disposal a variety of records such as repair orders, purchase requests for parts and replacement components, and computer based tracking systems, and these records were a source of information for comparison with the data from the operation logs. They also were a source of information for filling in the blanks where the operational logs were incomplete or inaccurate.

The Team received feedback from some of the groups, and after discussion, factored that which was considered factual into a final report. S. delivered the final report to A., and it was sent to the Planning Team under a cover letter. Appendix 5 is a copy of the final report. Planning Team members then passed the report to the individual technical groups which were responsible to the project and functional organizations for the equipment. Figure 5 is a graphical representation of the work process which produced this record of accelerator equipment failures.

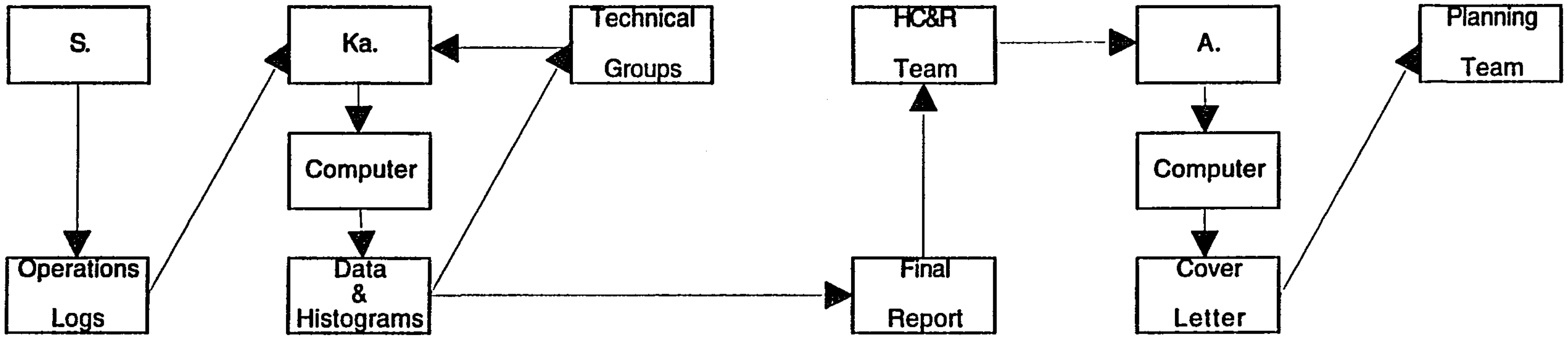


Fig. 5. Work Processes used for Producing Equipment History I.

Note: The arrows indicate the sequence of work. The top row is used for people and the Team. The middle row is used to indicate use of a computer. The bottom row is used for products of the work.

## Equipment History II

The advent of CATER provided the operations staff with an improved means for collecting information about equipment and system failures, and the CATER format specified the minimum amount of information needed for a report. Record keeping would no longer rely on busy and possibly distracted accelerator operators to record accurate and complete information in their logs. However, CATER does rely on busy equipment and technical managers to make CATER entries for failures and corrective actions. Experience indicates that technical workers are more likely to record accurate and complete information about their own equipment than operators who are not as familiar with some of the equipment. However, when operators are the only employees present, such as on weekends and night shifts, they make the initial CATER report.

After several hundred CATER reports were made, the Team decided to conduct another analysis of equipment failures to verify that CATER really was an improvement over the prior system. The Team also wanted to learn if the reliability of some equipment had improved.

Again, Ka. and S. worked together on this project. Ka. worked with paper printouts of CATER reports, but found it very difficult and time consuming to categorized the failures. CATER does not have the capability to sort by equipment name, WBS, or any other criteria; so Ka. sorted the reports manually. Because this project was self generated by the Team, and was not an assigned goal, a formal report was not required. Ka., with S. first and then the Team performing the quality assurance function, produced a set of histograms for each technical group. The histograms were informally sent to group leaders for use with their staffs. Appendix 11 is a collection of the histograms just discussed.

This second analysis of equipment and system failures produced some tangible results: (1) A comparison of the equipment failures indicated that most groups were experiencing new failures on different equipment. That is, there was little repetition of data. Whether this means the first set of problem equipment were fixed, or this was just statistical variation at work will have to wait for more data from future experience. (2) The was the first effort to use CATER reports as a source of information for analysis of data from all technical groups.

Figure 6 is a graphical representation of the work processes used to complete this project.

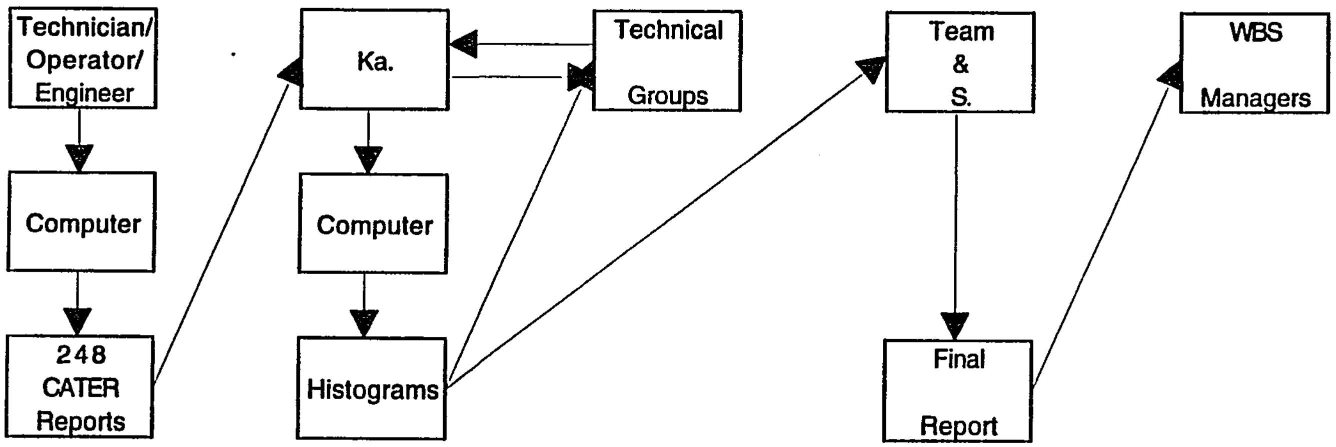


Fig. 6. Work Processes used for Producing Equipment History II.

Note: The arrows indicate the sequence of work. The top row is used for people and the Team. The middle row is used to indicate use of a computer. The bottom row is used for products of the work.

## Presentation to the Accelerator Division Council

Just as the requirements document led to the survey, the survey led to two presentations of its findings. The Team made a presentation to the Planning Team, which then asked that the presentation be made to the Accelerator Division Council, a group composed of the Division Associate Director, the two Branch Heads, and the four Department Heads. The Team understood the importance of the presentations; that they would be the only opportunity to discuss the survey findings with the senior staff members who had both the authority and resources necessary for correcting the problems.

The work processes which led to the presentation started with Ro. informing the Team that the survey results were important enough that the Planning Team needed to hear them. Ro. suggested the Team make a presentation that described the genesis of the survey as well as the results. The Team met on October 5, 1993, to develop a basic outline for the presentation. In addition to the process of developing the survey, collecting responses to the survey, and evaluating the results, the Team decided that the presentation should reveal isolated material and organizational problems which the Team discovered while the survey was in progress. At the same meeting the Team made a list of these problems, and they were listed in the meeting minutes.

The Team leader suggested that T. should give the presentation because T. had been responsible for the survey,. The Team agreed, as did T. T. developed a set of view graphs for the presentation, and S. reviewed these and recommended some changes. T. presented paper copies of the view graphs to the Team at the October 12, 1993, meeting and discussed their content with the Team, which made comments and recommendations which T. used to revise the presentation.

The urgency in preparing the presentation was reduced when higher priority organizational demands forced Planning Team meetings to be held in abeyance until November 11, 1993. T. used the delay to compose a draft memo to the Planning Team which would set the stage for the presentation. It included the grading criteria for the survey and the matrix of grades. It also summarized the findings in terms of the four survey categories: schedule, support for operations, maintenance, and spare parts. T. distributed copies of the draft memo to all Team members, and factored their recommendations into the final version, which was signed and distributed on November 1, 1993. T. distributed an updated set of view graphs to Team members at their regular meeting on November 9, 1993. At this meeting, the Team focused on the special problems list and a list of recommendations that T. had developed since their last exposure to the presentation. At Ro. 's suggestion, the Team revised the special problems list to make a distinction between those items which could shut the plant down for forty-eight hours or more and all other items. Appendix 8 is a copy of the memorandum to the Planning Team.

T. made the presentation to the Planning Team on November 11, 1993, and several Team members attended. The presentation was well received, and the Planning Team expressed a desire that the presentation be given to the Accelerator Division Council. The Planning Team suggested a few minor changes, which were adopted. A. took action to get the presentation on the Council schedule for November 15, 1993, and T. made the presentation with several Team members, including Ro. and S., attending. The presentation proved to be provocative because it "stirred the pot" by focusing the minds of these senior managers on some new and difficult problems. Appendix 9 includes paper copies of the view graphs used in the presentation. Figure 7 is a graphical representation of the work processes used to develop the memorandum and presentation for the Planning Team and the presentation for the Accelerator Division Council.

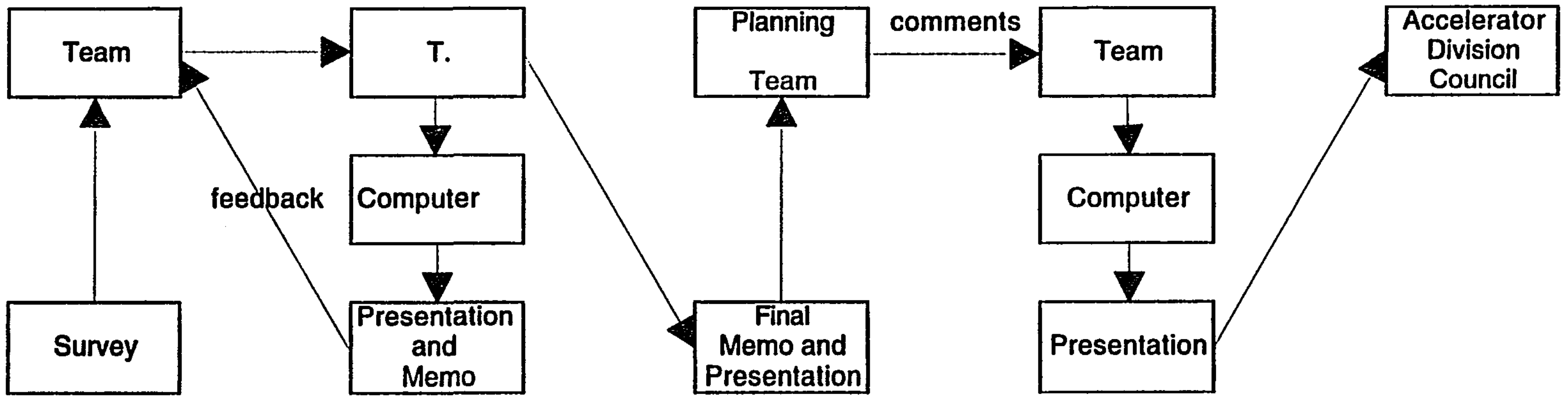


Fig. 7. Work Processes used for Producing the Presentation for the Division Council.

Note: The arrows indicate the sequence of the work. The top row is used for people and the Team.
The middle row is used to indicate use of a computer.
The bottom row is used for products of the work.

## Presentation to the Virginia Peninsula Total Quality Institute

The Virginia Peninsula Total Quality Institute (VPTQI) is an organization dedicated to the advancement of Total Quality Management (TQM) methods throughout industry and government on the lower peninsula of Virginia. Newport News Shipyard, CANON Virginia, CEBAF, and virtually all major industries and Peninsula governments are represented in this organization. The leadership of VPTQI scheduled a conference about Teams for February 1994, and A. decided that CEBAF should be represented. A. selected two CEBAF teams to give presentations, and the HC&R Team was one of them.

The Team first discussed the content of the presentation at the January 18, 1994, meeting. Eight topics were proposed and discussed, but because the presentation was expected to be limited to thirty to forty-five minutes, it was unlikely that all could receive full treatment. A small group composed of S., B., Ka., and T. agreed to get together and develop an outline for the presentation. This group met on January 20, 1994, and developed a program which listed topic, speaker, and allotted time in minutes, totaling forty minutes. The small group presented the program to the Team at the January 25, 1994, meeting, and the speakers agreed to make a practice presentation to the Team on February 9, 1994. In addition, the Team decided that it would be advantageous to display a poster board about CEBAF and the Team at the presentation. S. agreed to contact the CEBAF Public Affairs Office and request assistance with the poster board.

At the February 8, 1994, meeting, S. made three announcements: that the VPTQI conference would be on February 18 rather than 25, that he would be unable to attend due to a prior commitment, and that our presentation would be limited to fifteen minutes. The implications of this news was that there was one less week to prepare, that S. would not be able to give the introductory and concluding remarks, and that our presentation time was reduced by half. The three remaining speakers essentially had to reduce their talks by one half; i.e., to five minutes each and no more. The practice session on February 9, 1994 was productive, and the speakers gave a second practice run at the Team meeting on

February 15, 1994, just three days before the conference. On the evening before the talk, the three speakers were informed that the Team would have thirty minutes for the presentation. The speakers were ready, since they had just reduced their talk by half by removing some of their view graphs and eliminating some remarks. Now, the view graphs and remarks could be returned to the presentation.

The four Team members attended the conference for a half-day. One Team member, R., who was not a speaker, was in charge of the poster board. The posters that were displayed included aerial and ground-level photographs of CEBAF, artists drawings of future technical equipment, and copies of several view graphs to be used by the Team at the presentation. The Team's presentation was made before about forty people. Two other presentations were going on at the same time in other rooms. The Team's presentation was preceded by a presentation by a team from NASA Langley, which had improved NASA's procurement process, and was followed by a talk by a team from Newport News Shipbuilding, which had improved the fabrication process for aircraft-carrier superstructures. The Team members present benefited by listening to others who were also struggling to make large improvements in their organizations. Likewise, members of the NASA team and the shipyard team informed members of the HC&R Team that they benefited from listening to a team from CEBAF. Also, a representative from the City of Newport News Waterworks expressed interest in CATER software and later visited B. to learn more about it.

Figure 8 is a graphical representation of the work processes used to develop the presentation to the Virginia Peninsula Total Quality Institute.

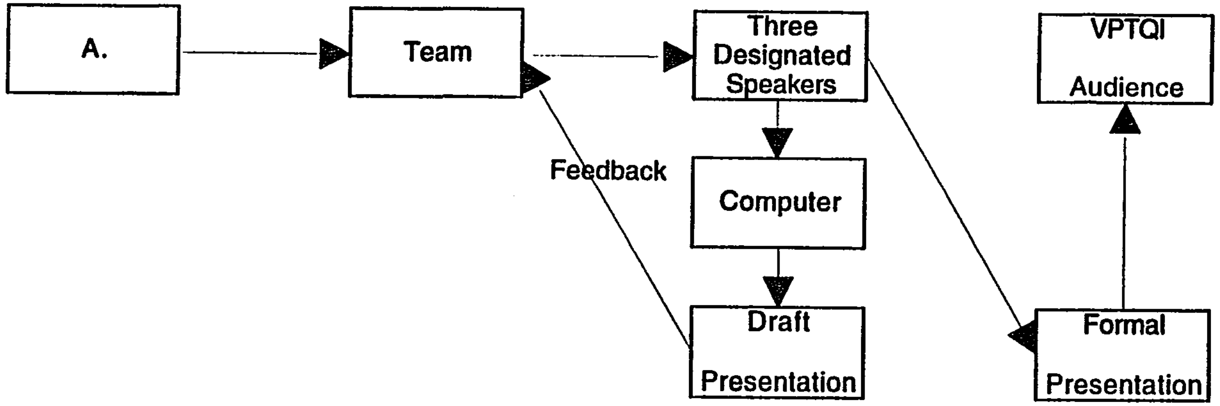


Fig. 8. Work Processes used for Producing the Presentation for the VPTQI.

Note: Arrows indicate the sequence of the work. The top row is used for people and the Team. The middle row indicates use of a computer. The bottom row is used for products of the work. VPTQI stands for the Virginia Peninsula Total Quality Institute.

## Emergency Portable Equipment

Surprisingly cold weather in January 1994 and the local power utility's plan to unload parts of the grid for several hours served to focus the Team on the impact on CEBAF of a lengthy loss of electrical power. The Team realized that a spell of extremely hot weather in the summer or a hurricane could also cause a loss of power for extensive periods of time. The Team reasoned that a list of portable emergency equipment would be a practical and useful data base to develop and maintain current. The Team initiated this task; it did not come from high management.

The Team decided that the types of portable equipment that might be useful in severe weather should include the following: electrical generators, water pumps, heaters, and air compressors. The electrical generators, which are normally powered by a gasoline engine, would provide electrical power to the other types of emergency equipment. S. asked all Team members to provide a list of the equipment that their group held. This proved to be nonproductive. At a Team meeting, R. volunteered to search the CEBAF property management file, which is a computer data base available to all employees and provides extensive information about important equipment.

R. conducted a search of the data base for “generators” and “pumps”, and the use of these two terms resulted in two lengthy printouts. Printout data included the name of the person who was supposed to be the custodian, the organizational department that paid for the equipment, the building and room number where it was supposed to be located, the manufacturer's serial number, the CEBAF property tag number, the name of the item, the manufacturer's name, and the cost of the item.

R. was able to eliminate by observation many of the items listed, but this took time. After generating two long lists by using "generator" and "pump", R. used "air compressor" rather than "compressor" and "space heater" rather than "heater" to reduce the number of useful findings for these two items. R. presented the four lists at a Team meeting, and all members were asked to review them and use their familiarity with their group's equipment to add or subtract to any list. This proved nonproductive. T. volunteered to take the lists and check with the listed custodians to determine whether the equipment was available, working, and was actually portable and useful for emergencies. In addition, T. agreed to locate quantitative input and output data about the equipment that would be useful for planners and operators, such as voltage and output. T. volunteered for this subtask for the following reasons: Locating the needed information was going to require great attention to detail and persistence, meaning that a thorough job would be very time-consuming. T. reasoned that this time needed could be justified by virtue of being CEBAF Emergency Management Manager and also by being Operations and Commissioning Branch's safety person. Both positions would be enhanced if the Team could develop an original list and sustain it. The following steps were needed to obtain all quantitative data for all equipment. T. went into the property management data base and extracted what was there. Note: The data base contains more about each piece of equipment than is available on the search printout, such as date of purchase and power requirements, and this additional information is presented by naming the individual equipment. This accounted for about half of the desired information. T. obtained another twenty-five percent of the information by sending memos to the custodians and asking for it. The final twenty-five percent of the information was obtained by personally locating the equipment, inspecting it, and reading the owner's manual.

The search for "generator" resulted in a list of 71 generators. R. reviewed the printout and was able to eliminate all but nine generators. Most of the 62 generators eliminated were electronic signal generators. T's. follow-up action resulted in a final tally of seven generators, of which two were not on the original list and were located by referral during searches for listed generators.

The search for "pump" resulted in 282 listed pumps. R. was able to eliminate all but four pumps. The 278 other pumps proved to be installed in place, vacuum pumps, pump motors, oil pumps, or some application other than being a portable water pump.

The final tally was that CEBAF owned one water pump that was portable, and this pump was on the original list compiled by R.

The search of the data base for "space heater" resulted in a list of twelve heaters, and R. was unable to eliminate any by observation. T. followed up with memorandum to custodians, searched the data base for additional information, and searched buildings. This resulted in a final list of three portable space heaters, but none of the three were on the original list. These three were located by referral during searches for listed heaters.

The search of the data base for "air compressor" resulted in a list of forty, and R. was able by observation to reduce this list to ten. T's. actions reduced this list to five air compressors, of which one was not on the original list and was located by referral during a search for a listed air compressor.

The task of compiling and verifying a list of portable equipment that could be useful in an emergency required little coordination, teamwork, or special skills. It required knowledge of the property management data base and lots of persistence to get employees to locate missing equipment and missing information. Consequently, one or more persons, working independently, but in frequent communication, could complete this task.

The completed list of portable emergency equipment was placed in the fifteen copies of the CEBAF Emergency Management Manual. The Emergency Management Manager was tasked to keep the list up to date on an annual basis.

Figure 9 is a graphical representation of the flow of work for producing the list of emergency portable equipment.

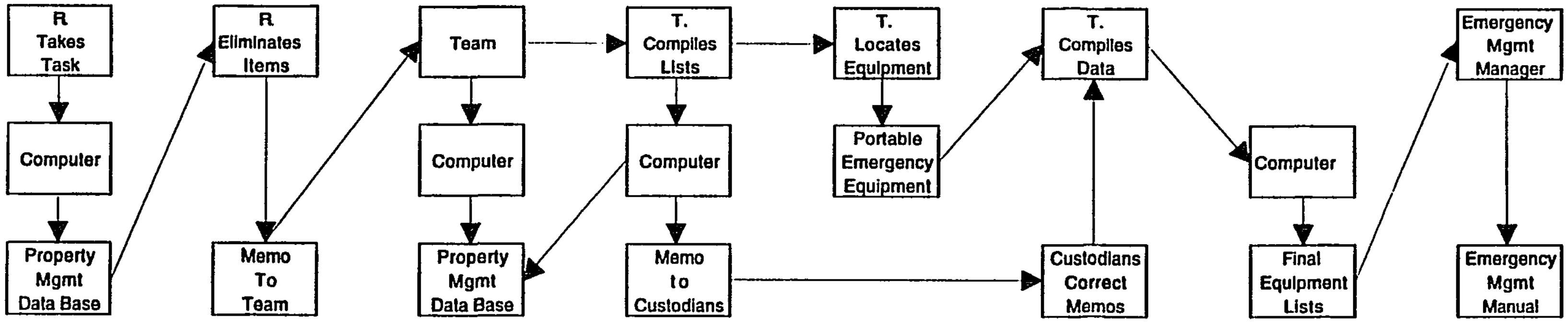


Fig. 9. Work Processes used for Producing the List of Emergency Equipment.

Note: The arrows indicate the sequence of work. The top row is used for people and the Team.
The middle row is used to indicate use of a computer. The bottom row is used for products of the work.

## Chapter Summary

This chapter took a very close look at nine of the projects the Hardware Team worked on and completed. The purpose of this aspect of the research was to look for commonalties in the way that the members decided who would do the work and in the processes by which they did the work. It addresses questions such as: was the work done individually, by small mini-teams, or by the entire team? The description of each of the nine projects is accompanied by a figure which graphically portrays the flow of work in terms of: (1) individuals and groups, (2) equipment and systems used, and (3) products, such as reports and presentations. The visual display facilitated understanding and analysis of the work processes.

The process for producing the minutes for the weekly meeting involved only two members except for final approval by the entire team. The process for the requirements document was probably the most complicated of the nine projects. The Team leader, S., was the key person in this project, but this was the only one of the nine projects in which the entire Team played an active role at the start; S. asked all members to provide an independently written, first draft for the requirements document. The Team reviewed the document after the first three drafts, the Planning Team reviewed it after the second draft, and thirty-seven reviewers were provided copies for comment before the presentation to the Planning Team. The survey project was a direct result of the presentation about the requirements document for the Planning Team. A three-person mini-team did the bulk of the work on this project, but the Team provided valuable feedback on the wording of the survey questions. Interaction with line managers proved to be necessary to obtain complete information and clarify the intent of some of the questions.

The project to develop CATER involved two persons; one person converted the software for CEBAF's purposes and the second person provided quality assurance and made recommendations to improve user-friendliness. B. encouraged the other Team members to use the first editions of the CATER software and provide comments. When

CATER was officially introduced, the many users were able to provide ideas for improvements in quantity. CATER is still in use one year after introduction.

A two-person mini-team completed before-CATER and after-CATER projects to collect and analyze equipment-failure data. The projects, called Equipment History I and Equipment History II, were presented as lists of failures and histograms for types of equipment. Technical group leaders and the Team provided quality control for the finished products. The initial set of data taken before CATER was inferior to that taken after CATER because it was taken from operating logs which were incomplete. CATER provided information significantly more complete than that taken from logs, although it seemed to take just about as long to organize and analyze the data.

The results of the survey project were revealed and explained to management by a memorandum and two presentations. This project was called "Presentation to the Accelerator Division Council" in the Work Processes Chapter. One member drafted the memorandum and made the presentations, but the Team was very active in reviewing or observing the memorandum and presentation drafts. The Team was essential in this project for coaching the presenter about the technical details that proved to be useful for answering questions raised during the presentations.

The hard work and useful results of the Team were rewarded with an invitation to make a presentation to a Virginia Peninsula Total Quality Institute conference. Four members of the Team did most of the work for this presentation, with three of them determined by the subject matter: the survey, CATER, and the two Equipment History projects. The Team selected the three people most instrumental in these three projects to make the presentations. A fourth person supervised a poster presentation about CEBAF and the Hardware Team. Again, the Team was a competent and convenient panel of reviewers with a vested interest in success.

The ninth and final project addressed was the development of lists of portable equipment of possible use during a loss of power in severe cold weather. Two members, working in series, collected and collated this information. The first investigator extracted essential information from a computer data base of CEBAF property. This information was distributed to the listed custodians for confirmation. Completion of this project required several iterations between some of the custodians and the Team as well as some serious searching to locate misplaced equipment. The end product, the list of equipment, now resides in the CEBAF Emergency Management Manual, and it will be verified annually.

The computer was a common characteristic of the projects. From the lap-top used for the minutes, to the desk-top used to write memorandum, to the mainframe used for CATER, computers were essential to the Team effort.

# ANALYSIS

## Introduction

After the Introduction Chapter, this dissertation continued with a review of current literature about the use of teams in the work place, with emphasis on the Japanese, American, and Swedish experiences. This review of the literature about teams is complemented by Appendix 1, which contains a brief summary of the principles of reliability, maintainability, and availability as presented in engineering texts. The literature review: (1) presents the reader with the base of information necessary to understand and appreciate the environment in which the Team functioned, (2) provides a baseline of work-team characteristics for comparison with the Team, and (3) provided helpful information to the researcher for influencing the Team during its existence, in the spirit of action research. The Literature Review Chapter concludes with a series of questions for answering in this chapter.

Two closely-coupled chapters about the Hardware Checkout and Reliability Team follow the literature review. The first chapter presents a historical, non-judgmental account of the Team from its inception until it was disbanded. This chapter provides the reader with: (1) the process of forming a team and establishing team norms, (2) the process of meeting externally established Team goals, and (3) the transition of the Team to becoming self-governing and establishing its own goals. Appendices 2 though 15 provide examples of Team products such as view graphs for a presentation and a memorandum to the Planning Team. The Work Processes Chapter describes the methods the Team used to distribute the work among the members for accomplishing nine of its most important activities. This chapter also includes the results of an in-depth analysis of the work processes the Team used to meets its obligations. This same chapter includes a figure for each of the nine activities, and the figure is a flow chart which illustrates: (1) the relationships between the team members involved in each activity, (2) the direction of the flow of work, and (3) the important role that the computer played in each project.

This chapter presents findings based on a comparison of the Hardware Checkout and Reliability Team with the theoretical and practical information about teams presented in the Literature Review Chapter. It does this by answering the questions at the end of the Literature Review Chapter. It also includes responses to the questions posed about reliability, maintainability, and availability at the end of Appendix 1. This chapter also presents a set of findings about work processes based on commonalties and relationships observed during the analysis of the nine activities. The chapter ends with a summary. A final chapter, which follows this chapter, ends with a set of conclusions that are developed from the findings of this chapter.

In the next section, questions taken from the end of the Literature Review Chapter and Appendix 1 are followed by a response and a finding. Both the question and the finding are underlined for easy recognition by the reader.

## Answering the Questions

How does the Team's ability to be self-managing vary throughout its lifetime? The Team was highly structured at its inception. The Planning Team selected Team members and the Team leader, as well as the Team's goals. Ro., a member of the Planning Team, attended most meetings and provided soft guidance to the Team when appropriate. However, from the start, the Team demonstrated creativity by finding innovative ways to meet its assigned goals, such as the use of a survey to learn about the operational readiness of work groups installing hardware and software. The Team encountered continuing success at solving problems while accomplishing goals, and this gave members a growing confidence in themselves and each other.

Once the Team had accomplished its initial set of goals, it began to develop new goals, goals which fell within its established boundaries of responsibility. The list of emergency portable equipment is an example. At the time of its termination, the Team was very confident in its ability to function as a Team and its ability to accomplish important objectives. The Team was working on several self-imposed tasks, such as locating a suitable, commercial software for potential use for scheduling preventive maintenance throughout CEBAF, at the time it was disbanded. The Team's ability to self-manage itself increased with time due to individual gains in confidence in each other through commonly experienced successes. This led to a decrease in oversight and direction by the Planning Team, which created opportunities for the Team to take the initiative and develop new goals and priorities.

To what degree did the Team conform to the model described by Gray and Stark? The Team had an appointed leader and regular members, but did not have deviates and isolates. An informal leader did not develop during the eleven-month existence of the Team. The Team went through the four stages of growth depicted by Gray and Stark, but in a mild sort of way. The trying-out stage may have lasted for no more than two meetings. Open discussion, a characteristic of the second stage, was quick to develop. It helped, certainly, that most of the members had worked with each other before joining the Team. Stage three, characterized by a decrease in conflict and posturing, with regular members motivated and productive, was not observed because conflict and posturing were below detection levels. This Team was in stage three from the first meeting. The Team reached stage four, when group norms control behavior and establish the social structure, within four or five meetings.

This Team was, in the researcher's opinion, too mature in age and experience to be subject to the "group think" problem that Gray and Stark described. However, the Team did exhibit a strong cohesiveness based on mutual respect, and members seemed to find the experience of being on this Team a positive experience. One member remarked that "these are the only meetings I look forward to," referring to the weekly Team meeting. The cohesiveness was not so strong that this Team was compelled to "outdo" other Teams or take on goals in conflict with CEBAF goals. The facilitator, Ro., and the Team leader, S., were able to keep the Team in balance with a minimum of effort. This Team went through Gray and Stark's four stages of growth very quickly, hardly pausing at the newest stage before going on to the next. The smoothness of the transitions from one stage to the next is attributed to the maturity and experience level of the members and complete lack of deviates and isolates. The Team did not exhibit extreme behaviors such as group think and pursuing goals which were in conflict with the organization's goals.

Did this Team validate Gersick's observation that teams change their strategy for completing a task about half way through the task? The researcher did not observe this characteristic; perhaps because nearly all projects became two or three-person efforts, rather than five to ten-person efforts. A smaller group may more readily reach consensus in response to changing circumstances than a larger group. Therefore, changes in strategy may be smaller in size and direction and be more frequently taken, and thereby are probably less noticeable when conducted by a smaller group. Please recall that the development of the requirements document was the only project which required initial input from all members, and then the inputs were developed independently.

There were several false starts for writing the requirements document, but they are attributed to the difficulty of the project and the uncertainty of what was expected, not for mysterious causes at the mid-point. When time was running out for meeting a dead line, the active members would pick up the pace of work and might alter the plan by dropping some activity or step. This could happen at the mid-point, but not necessarily so. Shifting to a higher gear when it is "crunch time" is not a trait unique to teams at work; it applies to many human activities, including writing a dissertation. For the most part, this Team did not leave its work to the last available opportunity. This Team did not change strategies at the mid-point of a project, probably because the projects were addressed by two or three-person teams which were flexible enough to make incremental changes rather than one large and very noticeable change.

Did the Team demonstrate the two-track path (technical and team skills training) advocated by the team evolution and maturation model (TEAM) and the "preforming through deforming" stages that are part of the TEAM model? It was clear that there were several aspects to the training needs of Team members. The Team received Total Quality Management training and team training prior to forming the Team. S. received team-leader training prior to joining the Team. Most members were on an equal footing at the start, having had little or no exposure to TQM methods and team skills. Some had received Myer-Briggs or comparable psychological testing to improve communications.

In regards to training for the operational and task-oriented skills, Team members, of necessity, trained each other on the job while engaged in a project. Also, members educated each other about their areas of expertise when presenting a project for Team review. For example, during the time that B. was developing CATER and demonstrating sections of it as soon as they were developed, other Team members interacted with B. and tested the CATER software. They were, in effect, being trained on the CATER software. While not proven, it is safe to say that every member learned something interesting about each other's field of expertise and about working together with people in different professional fields.

The eight phases of team development that Morgan postulated did apply to the Team's experience to a limited degree. Certainly there was a preforming period when initial TQM training took place and a forming period when the members met for the first few meetings. A storming period was not evident other than some expressions of uncertainty associated with drafting the requirements document and some disappointment with staff reaction to that document. The Team moved through the norming period swiftly and began performing very early in its life. A reforming period was noticeable only after the Christmas 1993 break, and the need to regroup had more to do with the break in time than in response to a difficulty. The termination of the Team in April 1994, clearly served as the deforming stage. The Team's experience fits rather closely the team evolution and maturation model, its two-track training, and its eight stages of team development. This model is more empirical than theoretical, and more logical than fanciful. It seems to make sense in an intuitive way. It is not surprising then, that many aspects of the model can be seen in the Team.

Which of the productivity models describe in the Literature Review Chapter most closely fits the Team? Gladstein's Task Group Effectiveness model, which has been tested with a large sample from the work environment, is very helpful in determining the Team's productivity in subjective terms. The model defines productivity in terms of terminal performance and group satisfaction. It also asserts that open communications, supportiveness, active leadership, experience, and training are variables that positively affect group satisfaction and performance. The Team gets high marks for these variables. Group satisfaction was particularly evident because members were openly proud of their team. Team performance is more difficult to evaluate, but the evidence is that the Team met its assigned goals. Then it took the initiative and solved other problems, and to its credit, it was selected to represent CEBAF at a local-area conference. This research was aimed at evaluating Team processes rather than Team performance; however, performance cannot be ignored because the success or failure of a project provides a momentum which affects the process of the next project. This Team consistently performed well on project after project, and the continued successes generated considerable satisfaction among the members. Gladstein's model was general enough that the Team easily fit its criteria.

How does the Team compare with Salas's Integrated Model? This model proposes that team performance is the result of complex coordination and communications patterns which have six variable inputs: organizational characteristics, situational characteristics, task and work characteristics, individual characteristics, and training. This model includes feedback loops and also establishes training as a special variable which interacts with the other five variables. This is a complex model, and in the most general way, the Team experience confirmed that the six mentioned variables do have an impact on a team's performance.

An organization's management controls resources and sets limits on the degree of effort that a team can devote to a project. Our members could give no more than twenty-five percent of their time to the Team. Such a constraint can be altered by the degree of cooperation other employees give Team members. Two groups, which were farthest behind the schedule, did not respond to the Team's survey, and the survey results were skewed by the absence of the two groups. Compiling the equipment history twice was very time consuming, and the two members involved could not participate in other projects while working on these two.

A task can be difficult or simple, and short or long in duration. Lengthy projects reduced the number of projects that could be undertaken. Working conditions can ease or slow progress and encourage or discourage the workers. The Team enjoyed excellent working conditions. It had a small, quiet conference room for its meetings, larger conference rooms for presentations, and easy access to modern computer services.

Individual talents and a strong desire to work have a direct effect on performance. The Team had a diverse mix of talented members that enhanced performance, and TQM training at the right time improved Team performance. The members received initial training prior to forming the Team, but after that, training was limited to on-the-job. However, it is not clear what additional training would have improved performance. It is evident that the Team validated the general theses of the Integrated Model. No attempt was made to assess the effectiveness of the feedback loops, which are part of the model.

What characteristics of the typical Japanese quality circle were shared by the Team, and which ones were not shared, and why? Many of the circle characteristics described by Gryna applied to the Team. The interactions between members were more participative than autocratic, communications increased with time, and the quieter members increased their participation in Team activities. Team membership was between the Japanese formula of three to thirteen, and management and members trusted and respected each other. The circle had a definite lifetime. Most work was done outside the weekly meeting. In agreement with Imai's observation, Team interactions were less formal and less confrontational than normal organizational interactions.

The teams at CEBAF are not connected to regional and national organizations and they are not registered with the government at any level. This Japanese practice has not evolved in the U.S. to any noticeable degree. When a Japanese circle is first formed, it is usually allowed to focus on problems of immediate value to the members. Once these problems are solved, management urges circles to solve problems of value to the company. The Team was formed to work immediately on company problems, and never addressed problems to make the work more meaningful. The 1983 survey that Cole refers to, indicates that sixty percent of Japanese circles choose their own leaders, and leadership is rotated in twenty percent of the circles. The Team's leader was appointed and remained leader for the duration of the Team's eleven-month life.

It is rare for an individual unit to share all of the predominant characteristics of the set to which it belongs. It is likely that no living person possesses all of the physical characteristics of the "average man or woman" considering the age, weight, and body dimensions of the fifty percentile. It is probably that only a few if any Japanese circles fit the norm of all circles. Therefore, the Team at CEBAF is surprisingly close to fitting the Japanese model. Some of the characteristics of the Team were beyond Team control, and some were acquired through experience or purposefully to become more efficient.

Did the Team validate Imai's list of seven major advantages of using circles? Yes! Teamwork was strengthened through the process of setting objectives and working towards their attainment. Members shared their roles and improved their ability to fill each other's roles. Communications between workers and between workers and communications improved. Management and worker relations were improved because the Team was entrusted to solve problems and was given the resources to do that. Members saw a large increase in morale. Members acquired some new skills, such as using CATER software and became more cooperative. The Team solved problems, such as compiling a list of emergency portable equipment, that probably would not have been done. Likewise, the equipment-history data probably would not have been collected and analyzed. This particular team was at the right place and at the right time to succeed with problems that no functional group could or would accomplish alone for the Accelerator Division. It is no surprise then, that the advantages of forming and sustaining this team coincide well with the primary benefits of Japanese circles cited by Imai.

Did the Team use any of the TQM statistical, management, or graphical tools? Yes! Weekly meetings were often the scene of brainstorming. Development of the requirements document probably required the most time for brainstorming because it was the most difficult project to grasp. Analysis of survey results made good use of Pareto analysis to emphasize the five questions with the least favorable results. Equipment history results were displayed in histograms, which provided easy visual comparison of the number of equipment failures for the various work groups. The Team made limited, but good use of TQM tools to improve their problem-solving ability and their ability to communicate quantitative results to other employees.

Did the Team more closely resemble the American work-team or the Japanese circle? As discussed several pages back, the Team shared many characteristics with Japanese circles. American teams do not have sufficient history to develop a highly-recognizable stereotype; however, a few characteristics seem to have developed and persist. As both Crouch and Gryna have noticed, American teams are more results oriented, and they focus on management problems rather than worker problems. The Team was formed to meet specific management-generated objectives, and worked on meeting these objects. Only when these were completed, about February 1994, did the

Team develop and solve Team-developed problems, all of which involved improving accelerator availability. The Team never worked on problems which would improve working conditions or worker welfare directly. A stereotypical American work-team is not established yet. The Team does conform to the one notable American characteristic which is different from the Japanese quality circle; that is it was oriented from the start towards achieving management's goals.

Of the various subspecies of American work-teams, which one best describes the Hardware Checkout and Reliability Team? Zenger defines (1) the intra-functional team as being within a department, (2) problem-solving teams as temporary forces assigned to a particular problem, and (3) cross-functional teams which are permanent and cross organizational lines. Ciampa defines the cross-functional analysis team as one which defines and bounds a problem and makes recommendations. If a solution is possible, a cross-functional pilot team is formed. The pilot team recommends a course of action, and another team may be formed to carry out the action. Crouch calls for an action team which investigates a specific problem, recommends solutions, and implements the solution, if it is approved by an action board.

Based on his observation of twenty-seven teams, Hackman classifies teams according to their degree of authority for self governing. So-called manager-led teams have the least authority. Those with some authority are called self-managing teams, and those with the most authority are called self-governing teams.

Carr describes an empowered, self-managing team. Such a team is challenged, the members have control, and cooperation is promoted. To be empowered, the members must be motivated and skilled. The Team closely fits Zenger's problem-solving team: it was a temporary group of employees given specific objectives to achieve, and when those objectives were met, it began to solve self-discovered problems on its own until the Team was brought to a close. The Team started out closest to being a manager-led team and clearly reached Hackman's concept of being a self-managing team. Carr's empowered, self-governing team also describes the Team well. The members were self governing and felt empowered to ask questions, seek help, take charge, or perform in some other suitable way to solve problems. The tasks were challenging, the members believed that they were in control, and cooperation was a well-developed characteristic of Team members; thus the Team most closely matched Carr's model.

Carr cites eight essential characteristics of successful teams. How well did the Team measure up these characteristics? (1) Shared values that support teamwork: team members did very well at exhibiting respect for others, commitment, competence, and trust, which are the most important values Carr cites. (2) Clear, worthwhile goals: the initial set of objectives management assigned to the Team were clear and understood. The Team was given an opportunity to discuss and challenge the goals from the start.

(3) A genuine need for each member of the Team: two members, K. and M., and to a lesser extent, R. and A., did not participate in the administrative projects. These four were the Team members most active in actual hardware installation and testing. They provided invaluable information to the other members about the status of equipment, new technical problems, and the state of morale within the technical force. They had the best understanding of whether a group would be ready for the next operating period or not. They knew where the trouble spots were. It is safe to say that every member contributed to the Team's success. (4) Genuine commitment to goals: this team did not become diverted with tangential pursuits. It stayed focused on the problems that were supposed to be solved. (5) Specific, measurable objectives: the most important goals had milestone dates, which focused the Team's priorities and energies.

(6) Direct, prompt, dependable, and usable feedback to the Team: Ro.'s presence on the Planning Team and attendance at HC&R Team meetings provided a conduit of information, requests, and responses. The Team leader, S., had frequent meetings with A., which was another avenue for feedback and guidance. (7) Rewards for the team, not just for individuals: visible, measurable rewards were scarce. The Team was selected to

represent CEBAF at a quality conference about teams. At this conference, a few "favors" were passed out to teams. The Team got together and quickly decided which individuals could make the best use of the prizes. For the most part, members got a lot of self satisfaction from their work on the Team, and this was the primary reward. (8) Solid individual and group competence: every member had competencies and expertise to contribute; in fact they were selected by management to be on the Team because of their demonstrated competence. Group competence came with time as experience and trust were gained through solving problems together. The answer to the question, it seems clear, is that the Team did quite well in meeting Carr's eight essential characteristics of a successful team.

Did the Team experience a self-fueling spiral in the sense Hackman uses it? The Team kept getting better for about six months, from July until Christmas-break in mid-December, 1993. There was no step change in performance, just a steady, evolutionary improvement. The Team gained momentum with each project, but there was no singular event which seem to provide the energy to reach "escape velocity". Two events stopped the momentum and ultimately led to the Team reaching its conclusion. All of the teams were formed and got their start during a lengthy accelerator shutdown period. All of the equipment areas were available for installation and testing. Operators were not on shift work. When operations were resumed in December 1993, the organizational focus changed. Shift work affected S., Ka., A., and M. directly, and members with technical expertise could be called in at any time or on any day to fix problems. Also, members of many of the technical groups could no longer get at their equipment because it was inside a locked area or could not be down-powered without shutting down the accelerator.

The second factor affecting momentum was that the Team had accomplished its management-generated goals, and no more goals were given to the Team except for making the presentation to the quality conference. The members wanted to go on, but the shift work and the operational focus of management brought the usefulness of the Team to a close. The answer to the question, then, is yes, the Team did experienced a positive spiral leading to its success. The spiral was not started by a singular, dramatic event, but was powered by the steady pace of Team members working hard and their commitment to making a difference.

Were any of Hackman's five "trip wires" present in the Team's experience? No! The Team was managed as a team rather than as individuals. The Team had enough authority to perform well, but not so much that it could become a problem for the organization. The presence of a member of the Planning Team at the meetings was helpful in this regard. The Team was not left entirely to its own imagination to solve problems. Frequent conversations between A. and S. kept management's expectations and the Team's intentions in concert. The Team was given work to do that was meaningful to the members and there was a sufficient flow of information to avoid doing work twice or at cross-purposes. The Team was about the right size with a good mix of expertise, and its authority and responsibility were sufficiently clear. The Team was given sufficient resources to meet its objectives; albeit a bit later than its milestone dates. Management understood the reasons for delays, and accepted the lateness. Team members were given team training before they met to become a team. The Team, with the help of management, avoided all of the problems that Hackman cited as having potential for causing a team to fail.

Did Team members assume roles as highly specialized as Brooks' team? Some Team members did develop some specialties, but not to the degree described. Brooks was trying to optimize development of an enormous software program and had just this one principal objective. The HC&R Team had multiple objectives, and the members had to be interchangeable to some degree. This is not to say there was no specialization. B. was the computer expert. T. was the principal presenter. Rn. wrote the minutes. S. was the leader. Ka., analyzed equipment failures and drew histograms. The Team specialized to some degree, but not as much as Brooks advocated for his specialized, single purpose.

In what ways did the international culture of CEBAF affect Team performance? Many cultures are represented at CEBAF, but all members of the Team were U.S. citizens and all used English as their principal language. There were three females on the Team and one African-American. Team members had to interact with foreign-born employees on a daily basis. The fact that English is the international language for physicists was helpful. The Planning Team, which was composed entirely of scientists, was more culturally diverse than the Hardware Team.

The effects of cultural differences on teams cited in the literature were not particularly germane to the Team's experience. Team members were more interested in learning something new if it had a direct relationship to their performance. Learning for the sake of learning was considered a luxury. Team members did well without much recognition, in contrast with the perception that non-Japanese teams seek relatively excessive material recognition. Unlike the Swedish model, the Team had no authority for budgeting and personnel matters. In summary, the cultural differences at CEBAF had no special significance for the Team because the differences that do exist are integrated into the normal environment and are relatively invisible. To compare the Team with teams in other countries may be useful, but a study of many American teams would be more useful research if it compared norms and determined common characteristics.

That concludes the findings from comparing the Team with the characteristics of teams discussed in the Literature Review Chapter. The next section includes responses to the questions posed at the conclusion of Appendix 1, the brief summary about reliability, maintainability, and availability. The format is the same. A question is posed and underlined. After a discussion and explanation, a finding is presented and is underlined for easy recognition.

Are the theories about reliability, maintainability, and availability too removed from the daily operation of an engineering facility to be applied usefully? Solving daily problems in such a facility does not in general require a deep understanding of reliability theory or the ability to use statistical distributions at will to analyze and understand equipment failures. However, it is important that designers, engineers, and budget analysts have a macro-level of understanding about the benefits of preventive maintenance for mechanical equipment and carrying spare parts for critical and high-failure-rate components. Without some understanding of the theory, technical staff may be less likely to look for or detect new patterns of failure and appreciate the many variables that affect overall availability. Ignorance generally has a cost, and an organization without any appreciation for what affects its availability may not even be aware of what it is missing. An engineering-based organization may survive without any appreciation for reliability theory, but there clearly are benefits for having technical staff who know the fundamentals. In some situations, having an in-house expert or hiring one is beneficial.

Should an engineering-based facility maintain an in-house capability to conduct statistical studies of equipment failure rates? If an engineering-based organization does not maintain an in-house capability to conduct statistical analyses, it may, as an alternative: (1) require equipment suppliers to provide the results of mathematical analyses of component failures, or (2) hire a competent consultant part-time to conduct the analyses. On the other hand, having such a capability in-house could be useful, especially if equipment is not performing as well as was estimated and the causes have not been identified. Much depends on the versatility of the person employed. A smart person with poor people skills may be of less use than a person who works well with hands-on technical staff, designers, contracting officials, and suppliers. Locating a problem and understanding it lacks purpose if the organization resists taking corrective action, for whatever reason. The decision to hire a reliability engineer is case specific for every organization. Among the variables that affect the decision are: the skills of the applicant, equipment performance, and the long-term need for such a person.

What use did the Team make of reliability theory and practices above and beyond what was already being done by the technical groups? Before the Team was formed, the larger organization was making good use of reliability practices in many areas. The design called for high quality components, electronic burn-in, redundancy, and a minimum of moving parts. To these good practices, the Team increased line-management's awareness of the importance of: (1) Identifying single-point failure items. (2) Budgeting for spare parts. (3) Owning some portable emergency equipment for power outages. (4) Knowing failure rates of existing equipment by producing the two studies of equipment failures. The larger organization already made good use of standard reliability practices, but the Team provided a new and more detailed understanding of areas and activities which show promise for improving accelerator availability.

What promising areas remain for the organization to explore for improving accelerator availability? (1) CATER reports continue to provide equipment failure data that is available for analyses. (2) There may be benefits for introducing a preventive maintenance software program for all technical groups to use. The Team had started to search for such a program just prior to its termination. A follow-on team may pursue this project. (3) The formation of electronic and mechanical repair teams could be useful, particularly when the work breakdown structure (WBS) groups cease to exist at the end of the construction period. At that time, the technical groups will probably be consolidated into mechanical and electronic support groups. These groups may develop fast-responding repair teams that have readily accessible repair kits containing tools, instruments, and high-usage supplies. There are several areas (equipment failure history, preventive maintenance, and repair teams) with promise for improving accelerator availability. The organization can apply limited resources in these areas and monitor closely for beneficial outcomes. Additional resources should be applied if the initial programs meet or exceed expectations.

## Findings

The close examination in the Work Processes Chapter of nine Team projects provides a base of information that leads to some important findings and conclusions about how this team accomplished its work. It was not the purpose of this paper to prove that what worked for this team could work for some other teams, much less all teams in an industrial setting. Nevertheless, if the findings and conclusions are rational and are highly acceptable to the reader, then the possibility exists that the same conclusions may apply to some, many, or even most teams. The reader is asked to keep this in mind as he or she proceeds; that is, to evaluate each finding and conclusion on its degree of generalizability to other industrial work teams. The writer believes that many of the findings and conclusions reached by this study have application to many other teams in an industrial environment. The reader is cautioned, however, to be cautious in applying any technique or concept developed by this research to a real team in the workplace.

What has been learned about a team from this detailed look at the nine processes? What are the most useful functions of the collection of people that we label a team? There are three fundamental characteristics of teams that this research reaffirms: (1) A team is a pool of people; i.e., labor, with diverse skills, knowledge, and abilities, from which to draw on to accomplish work. (2) A team is a source of ideas for building on old ideas and starting new initiatives. In this capacity, teams develop strategies, either strategies to meet established goals, or strategies to develop and accomplish new goals. (3) A team is self-correcting in that the members review and comment on the work of the other members. In this function, a team can provide quality assurance, new directions, and new energy when and where that will improve the end product.

In a sense, saying that a team provides a labor pool is stating the obvious, but there is more to it. A team is enhanced if its membership contains sufficient people to handle the work, but not so many members that they lose interest. Also, the membership must include the right mix of skills, knowledge, and abilities to accomplish the work.

Appendix 3 provides brief professional biographies of the members of the HC&R Team, and amply demonstrates the variety of education and work experiences of this particular group of people. Engineers, technicians, and computer scientists dominate the professional status of Team members, and some members are managers while others are hands-on technicians. Some have military experience and some have industrial experience. Gender and age differences added to the diversity, which was an asset.

With ten members, this Team had several members who had adequate writing skills and several who had adequate verbal skills to represent the Team well before a critical audience. Had the Team been composed of fewer members, that might not have been the case. Furthermore, having ten members allowed the Team to divide the labor into bearable portions and not overload anyone. As indicated in Appendix 3, all members save the leader were limited to giving twenty-five percent of their time to the Team. Had their been fewer members, there would have to have been a concomitant increase in the percentage of time the fewer members allocated to the Team to produce the same set of results. Also, it is important to note that five different members; S., T., Rn., B., and Ka. were in charge of at least one of the nine processes.

The Team was a source of ideas and new initiatives. When it had accomplished the goals established by A., it began to develop its own goals. For example, on its own initiative, the Team challenged itself to develop a list of all emergency portable equipment on site, which it did, as the Work Processes Chapter describes. Likewise, the initiative to analyze the first two hundred or more CATER failure reports came from the Team, as the previous chapter described . Also, the Team developed a severe cold-weather procedure for the accelerator site, which was discussed in the HC&R Team chapter, but was not included in the Work Processes Chapter.

More important, perhaps, than having the vision to conceive of new goals, Team meetings often included a repartee that was a rapid series of exchanges between members as one idea sparked another. That this was an excellent team is an opinion formed from first-hand experience and may not be deduced from an analysis of work processes nor from the meeting minutes. An experienced person, however, should gain a sense of this from a careful reading of the dissertation. A review of what this team accomplished indicates that the members seemed to be highly motivated, even excited about their work. Finally, is it not reasonable to assume that a small group of well-trained and well-educated professional people who have common objectives can have and most probably will have a synergistic affect on each other in terms of ideas and concepts?

In terms of the Team being self correcting, it acted to set strategy for its work and made adjustments as needed to reach its goals. It was involved early in all but three of the nine work processes described in the previous chapter, and those three; the Meeting Minutes, Equipment History I, and Equipment History II, were one or two-person projects with clear objectives and no need for a Team policy. In the other six projects, the Team discussed the project in depth at a meeting, and the discussion provided the person in charge of the project with a set of ideas, ground rules, and direction that provided a base on which to continue the project with confidence. Most importantly, the Team acted as final-review panel before projects went beyond the Team.

One of the clearest findings that may be drawn from this study of a Team is that the membership acted as a review panel and provided constructive comments to a member working on a project. A look at Figures 1 through 9 indicates that the Team acted as a review panel at some point in all cases. This group of people, with expertise in computers, mechanics, electronics, electrical power, physics, and management, provided a wide and ideal spectrum of expertise for reviewing Team products. Moreover, the "sense of team" that developed with time and familiarity, led to a frankness that allowed for truly honest criticism without inciting hard feelings. Furthermore, because all members were motivated for Team success, it was to their advantage during the review process, to pay more attention to details and offer better suggestions than might be expected in other circumstances. Also, project leaders frequently questioned the membership about options, impressions, and new ideas during review. In other words, a project leader could go to the membership without embarrassment and ask for help in one form or another.

The number of people who participated in actually doing the work for a particular project varied from one to the entire membership. In only one project, the requirements document, did the entire membership play an active role, and here the Team leader, S., asked everyone to draft an independent requirements document. From the submissions, S. made a first draft, which the Team reviewed and improved. Why was this the only project of the nine that needed everyone to participate actively? For the following reasons: this was probably the most subjective of the nine projects, the possibilities were endless, and no member had a monopoly on expertise. When the Team started on this project, no one knew what the end product would be. The strength inherent in numbers led to a mutual building of confidence that the Team could successfully write a requirements document if everyone contributed.

As indicated in Table 1 on the next page, two projects were completed by a single member, (Equipment History II and Presentation to the Division Council.) Four projects were completed by two members (Minutes, CATER, Equipment History I, and Emergency Portable Equipment). Finally, two projects were completed by three members. (Survey and Presentation to the Virginia Peninsula Total Quality Institute). Table 1 also indicates whether the Team was involved early, late, or throughout the process. For the cases of two or three members working on a project, Table 1 indicates whether they worked in series or parallel. Making these distinctions and understanding their implications gives better insight into how Team members worked together to meet their goals. Table 1 demonstrates the considerable variety of situations for just nine projects. No two projects listed have the same combination of entries for the four columns. Table 1 has one theme: the optimum number of people assigned to a project was a small percentage of those available.

**Table 1**

**Summary of Work Processes Data**

| Project | Members | Series/Parallel | Team Involvement | Project Leaders |
|---|---|---|---|---|
| Minutes | 2 | Series | Late | Rn. |
| Requirements Doc. | 10 | Parallel | Throughout | S. |
| Survey | 3 | Parallel | Throughout | T. |
| CATER | 2 | Series | Early | B. |
| Equipment Hist. I | 2 | Series | Late | S., Ka. |
| Equipment Hist. II | 1 | --- | Late | Ka. |
| Presentat. to ADC | 1 | --- | Throughout | T. |
| Presentat. to VPTQI | 3 | Parallel | Throughout | B., Ka., T. |
| Emergency Equip. | 2 | Series | Early | R., T. |

The two projects which were accomplished primarily by one person used the full Team membership in different ways. The presentation to the Division Council involved the Team early in its formulation. The results of the survey; i.e., the matrix that is in Appendix 9, was the starting point for developing the presentation, but the list of problem areas was equally important. The development of the list of problem areas grew out of the survey, but also benefited from specific knowledge held by members from their own work. The intimate knowledge of accelerator hardware held by members with hands-on technical jobs, D., R., and K., was crucial to developing a credible list of hardware problems that needed management attention. The Team also acted as a final review panel by observing the last practice before the presentation to the Planning Team. The other single-person project, Equipment History II, was a straightforward reduction of CATER failure reports with transformation from text to graphics. Ka. completed this project without assistance and presented the histograms to the Team for review.

There is an interesting characteristic that the four two-person projects shared; in all cases, both members essentially worked in series to complete the project. The minutes, for example, involved Rn. typing on the lap-top computer during the meeting, followed by S. reviewing and making changes after the meeting. Rn. then entered the changes and printed the minutes. S. then made copies and the distribution. Likewise the CATER project involved B. adapting the software to meet CEBAF needs and by Rn. testing and proofing the product, then providing technical ideas to B. Equipment History

I also involved two members working in series; S. extracted equipment failure reports from the records, and Ka. typed the reports using Cricket software to produce histograms. Finally, the Emergency Portable Equipment project started with R. extracting information from the CEBAF property management data base and passing the results to T. T. contacted the owners, inspected the equipment to verify the data, and published the list.

In terms of the stage of the process for involving the Team, the two-person projects yielded the following information: The minutes involved the Team late in the process; i.e., the minutes were handed out at the next meeting for acceptance or rejection by the membership. Likewise, Equipment History I involved the membership late in the process for reviewing what Ka. proposed to be the final product. There was no need for guidance by the Team early in either process because both project leaders knew what to do. In contrast, both CATER and the Emergency Portable Equipment processes involved early input from the Team. In the case of CATER, B. made a presentation of CATER in its SLAC format to the Team to win acceptance of the concept and managed to benefit from some useful comments from members. The project to develop a list of portable emergency equipment benefited from early involvement of HC&R Team members because the Team selected the types of equipment that should be tracked, and several members provided information about the location of specific pieces of equipment.

The two projects which involved three people had two similar characteristics of interest; Team involvement occurred throughout the process, from beginning to end, and the members worked in parallel rather than in series.

As has been stated several times, the survey was a response to outside questions raised in response to the requirements document. The idea of a survey occurred during the Team meeting after the requirements presentation. The Team helped develop the nine questions that were the essence of the many questions from the audience at the presentation. A four-person mini-team took the nine questions, added eleven more questions, and segregated them into four topic areas. The parallel efforts of a three-member team occurred during the grading of the responses from the fifteen technical groups to the survey. The three met together, read the responses out loud, and then reached consensus on the grades, or agreed they needed to question the respondents.

The Team developed the plan for the presentation to the Virginia Peninsula Total Quality Institute (VPTQI) during meetings and reached consensus on three topics: the survey, CATER, and Equipment Histories I and II. The project leaders for these topics were selected to make the presentations. The Team reviewed the presentations as they were developed and the final practice. The parallel effort in this project was quite different from the survey experience. In this project, the three speakers worked independently to develop and perfect their presentations. The practice presentations provided each speaker the opportunity to ensure that nothing said by one conflicted with what the others said. The opening statements and the concluding remarks for the formal presentation did require some collaboration and agreement among the three presenters and the Team, but the real work was done independently by the three, albeit within the same time frame; hence the claim of parallel effort.

## Chapter Summary

This chapter has two distinct sections: (1) Answers to sixteen questions posed at the end of the Literature Review chapter and answers to four questions about reliability, maintainability, and availability posed at the end of Appendix 1. (2) Findings from an analysis of the work processes. The sixteen questions, derived from the discussion of the literature about teams, basically ask for a comparison of the Team with some specific characteristics of teams described in one or more of the references. The questions posed in Appendix 1 ask about the usefulness of engineering theory about reliability to the Team and CEBAF. The analysis of the work processes was a search for characteristics common to most if not all of the nine processes.

The Team changed from a team with an assigned leader and assigned goals into a self-governing team which selected its own projects. In terms of the theories described in the literature, it compared favorably with many aspects of most of the models. It did fit the Team Evolution and Maturation (TEAM) model and the Task Group Effectiveness Model, whereas the strategic shift that denotes Gersick's model was not observed. The Team also compared favorably with the characteristics of the typical Japanese quality circle and validated Imai's seven major advantages of using circles. Of the different types of teams described by American authors, the Team, when mature, most closely resembled Carr's self-governing team. The evidence also supports an assertion that the Team enjoyed Hackman's self-fueling spiral in the positive direction to a limited degree and averted his five trip wires. The Team also functioned within a culturally-diverse organization, although this was not a particularly challenging experience because all Team members were U.S. citizens and English is the international language of physics.

The analysis of the nine work processes reaffirmed three fundamental characteristics of teams: a team is a pool of diverse human resources, it is a source of ideas and strategies, and it can be self correcting. The Team demonstrated a tendency to use its members effectively by selecting the smallest number of members within reason to perform the work for each project. These mini-teams consisted of two or three members. The entire team, however, acted in several critical capacities: to brainstorm new ideas and revisit old ideas, to be the first to hear a presentation, to critique draft memoranda and formal reports, and to provide encouragement.

The commitment CEBAF has made for accelerator availability makes it imperative that operators and technical staff have a good foundation in the methods of reliability engineering. Team members took good advantage of their awareness of the fundamentals of reliability engineering and focused management's attention on some spare part and maintenance shortfalls. Action in this regard is being taken to acquire some additional spare parts and to improve the organization's maintenance capabilities.

# SUMMARY AND CONCLUSIONS

## Introduction

This chapter contains four sections: a summary of the preceding material, a set of conclusions based on the findings, some ideas for research that would build on this research, and some final thoughts. The summary is intended to refresh the reader's memory of what was presented in the preceding chapters and to set the stage for the conclusions. The conclusions are the final interpretations of the analysis, and are based on the data presented, the analysis, and the informed opinions of the investigator. They are intended to fit together to present a broad and coherent picture, but like much of research, new questions are raised which could give impetus to future research. Finally, the chapter and the dissertation are closed with some final thoughts about the work processes the Hardware Checkout and Reliability Team used and how they compare with the processes teams in other settings use.

## Summary

The previous chapters end with summaries which attempt to encapsulate the important thoughts and information presented in each chapter. Rather than redistill those distillations into a meta-summary or summary of summaries, this final chapter will have a summary which is a narrative. It is the story of a journey taken by a small group of professionals. It is about their experience as a team in the workplace, and it is about the author's coincident experience with conducting research and writing a dissertation.

The author asked to serve on a team at CEBAF when first informed of the intent to establish several teams based on the Total Quality Management (TQM) concept. The motivations for volunteering were: (1) a growing interest in TQM that needed an outlet, (2) a personal desire to become involved in accelerator operations, and (3) the potential such an experience offered for conducting doctoral-level research. The benefits to CEBAF for offering membership to the author were that the author (1) would promote TQM among the members, some of whom might be skeptical, and (2) as a doctoral candidate, would be highly motivated to help see that the team would succeed and should be skilled enough to actually help.

The author, researcher, and investigator had to travel on five tracks simultaneously, not all tracks all of the time, but most of the time. The primary track was that of team member, actively engaged in working with other members on projects to accomplish the goals. The second track was that of observer; listening, watching, asking, and thinking about what was going on, where the Team was headed, and how its results would be perceived. The third track was that of reader; reading the books about teams, about reliability engineering, and about conducting participative research, and trying to classify and focus the newly discovered knowledge so that it could be put to good use. The fourth track was that of active participant; selectively taking knowledge gained from the literature and trying to apply it to real situations. The fifth track was that of author; making sense of what had been seen, heard, and read; searching for coherence, meaning, and important lessons; and crafting the text.

The experience of being on the Team from start to finish can be separated into these distinct functions: (1) attending Team meetings, (2) working on a project, (3) getting approval for the product of the work, and (4) presenting the final product. The Team worked on about a dozen distinct projects, and all proved to be worthwhile and useful. The author worked directly on the survey, the three presentations, the severe-weather plan, and the list of emergency portable equipment. Working on the survey project involved these steps: (1) crafting the questions to obtain the desired information and distributing the survey, (2) developing a set of criteria for evaluating responses, (3) evaluating the responses, (4) visiting technical group leaders to obtain original or additional information when needed, (5) developing a method of displaying the information, (6) analyzing the information, and (7) notifying those who had the authority and resources to take action.

Being observer, was almost as interesting as being a team member. There were times, no doubt, when being a member required so much emotional and mental effort, that it was easy to forget about observing. However, the weekly meetings and the time taken to read the minutes were excellent times to observe and think about observing. This was not difficult, because thinking on several levels is a human capability; however, it is a challenge when it is necessary to be highly attentive and retentive on both levels. The researcher suppressed the observer role during meetings to avoid inhibiting Team members and thereby change their behavior. Consequently, no notes were taken in the presence of others and no audio tapes were made.

The reading of the literature was time well spent. There is no lack of interesting and informative books about teams in the workplace. The literature provided a comprehensive base of information about teams in the workplace in several countries; it provided models which show the stages teams go through as they age, and it contains models of the processes that determine team productivity. One problem encountered, was knowing when enough had been read. The answer came, when the amount of new and useful material decreased significantly with each new reading.

The investigator's prior work experience and his readings about Teams and TQM provided the necessary background for potentially influencing the course of events at Team meetings. There were very few opportunities, however, where this was done to any significant degree, other than as a regular member. Is it possible to make a distinction between the author influencing the Team as member and as an action researcher? The answer lies in whether or not special knowledge is used to exert the influence. Special knowledge included eliminating questions from the survey that should be answered with just one word. Special knowledge included the use of Pareto analysis to concentrate on the few survey questions which generated the lowest average grades. No special knowledge was needed to realize the usefulness of a list of portable emergency equipment and finding a permanent location for the list. The role of the action researcher was played discretely and rarely to avoid becoming the informal leader or overtly challenging the authority of the team leader.

The writing of the dissertation was the most rewarding and the most lonely part of the journey. Most of the writing took place after the Team was disbanded; only the first drafts of the first few chapters and Appendix 1 were completed by May 1994. The requirement to follow a prescribed format, *A Manual for Writers* by Kate L. Turabian, was a help in reducing uncertainties, but was also a hindrance. A few personal writing habits acquired over a half-century had to be overridden. Nonetheless, creating order out of volumes of material, and crafting the sentences and building the paragraphs into a logical, scholarly document that would be easy to read, was a stimulating challenge for this author. There is an enormous amount of going back and forth in such a document, because when it is as long as this one and as interwoven, a single change in one place can affect many other parts. The need to rewrite and revise continually requires unusual persistence and patience. Nonetheless, the writing was the best part.

Entering into doctoral-level research requires faith that there is a way out of the maze and also faith that there is something worthwhile at the other end of the maze. At the beginning of this research, it was clear that the Team would start, it would do something, and it would be finished. It was clear that there would be a story to tell about the Team, but it was not clear that there would be a mystery to solve; that there would be something new and interesting to discover, and that there would be something complex enough to arouse the curiosity of scholarship and meet its demands for new knowledge.

The reading of the literature introduced this researcher to the argument about who does the work on a team. The accounts of relatively primitive experiments with bicycles and ropes ignited a huge interest. The on-going debate between the advocates of the individual and the advocates of groups provided the mystery. The lack of material in the literature about the processes teams use to do this work provided the opportunity for conducting this research. The experience of working on some of the Team's projects and reviewing all the other projects provided the germ of an idea and the details necessary for scholarly analysis and discovery.

This research was about a team that proved to be very similar to the typical team in the American workplace in the age of TQM. It passed through most if not all of the stages of team-life many authors predict. It was a successful team, meeting its assigned goals and doing its work well, however, its most significant contribution may be as yet unknown to its members and its managers. It revealed how a team decides who will do what work. It revealed the variables that determine this decision. And it connects back to the most basic theories: People will work harder if they are observed, providing that the work is not beyond reach. People will work harder, the fewer that are involved, providing the work is not too much for the number involved. Mini-teams of two or three members did most of the work, but all members acted as observers. Peer pressure created sufficient incentive for every member to work hard so that no one would let the others down. The ten members providing the necessary reservoir of talent and commitment to support the mini-teams and meet Team goals.

## Conclusions

The conclusions presented in this chapter are the distilled product of this research and are the author's initial contribution to the body of scientific knowledge. Many of the conclusions confirm the conventional wisdom about teams in the work place, but some challenge the general understanding. The conclusions apply only to the Team which was the subject of the research, and any application of the conclusions to other work teams is at the discretion of the reader and should be tempered with caution. The conclusions are presented in three subsections; Teams, Availability, and Work Processes; the distinctions are used to provide focus and organization.

## Teams

The Team did not fit any of the theoretical team models exactly, but compared closely with many of the models. The models are based on observations of many teams at various stages of their experience, and are not based on observation of all teams at all times, and are thereby not perfect. The Team compared closely with the stereotypical Japanese quality circle with the most notable exception being that management established it to accomplish organizational goals. Some of the eight stages of the TEAM model (forming, norming. . . .) were barely recognizable in the Team experience. Rather than going through the eight stages, the Team did go through two time-dependent stages with a gradual passage from one stage (governed by management) to the next (self-governed). The Team was under tight control of the Planning Team and an assigned leader in the first stage. It also had very specific objectives and a time-table. As the Team met its goals and gained confidence with every success, it moved into a second stage of selecting and accomplishing its own goals, setting its own priorities, and establishing its own schedule. The Team entered this stage with the full knowledge and acceptance of the Planning Team, and it continued to be an effective force. Some specific conclusions about the Team and teams follow:

The Team solved problems that the functional organization neglected or failed to do because the members focused their energies and resources on that problem to the exclusion of other problems.

Solving one-time, achievable goals in a planned, organized manner significantly increased member job satisfaction and morale.

The experience of being on a team broadened the skills, knowledge, and abilities of the members, and they returned to their functional organizations capable of being more productive in their resource-limited, competitive, and bureaucratic environments.

Many variables affect team performance, but the following variables were noted to be very useful in a Team member: technical knowledge, administrative skills, energy, verbal skills, organizational skills, informal access to employees with useful information, computer skills, persistence, cooperation, supportiveness, and enjoyment in working with other people. Team work is not enhanced by people with large egos and tendencies to talk rather than work. Fortunately, the Team had no such member, but we recognized what a threat that person would be and accepted our good fortune with grace.

The Team had excellent correlation with Carr's eight characteristics of successful teams and no correlation with Hackman's five trip wires.

Management would do well to consider the following course of action when forming a new team: (1) Discuss Imai's list of benefits for using teams. (2) Introduce Hackman's five trip wires and discuss the means of avoidance. (3) Introduce Carr's eight characteristics of a successful team and discuss their merits and any organizational difficulty with them. (4) Do not present any team-model diagrams from the literature; they are not intended to be road maps for use in the field. (5) Provide a copy of the Literature Review Chapter of this dissertation to the Team leader for reading.

## Availability

An organization with responsibilities for engineering equipment must pay attention to reliability, maintainability, and availability to remain competitive and cost-effective. An organization cannot rely just on buying the best available equipment; it must look to the future and take preventive measures. Attention to stocking spare parts for critical items and items which fail often offers potentially important improvements to availability data. Also, a preventive-maintenance program which is thought out well and provides for replacing worn components before they fail will improve availability.

Engineering staff which understands the fundamentals of reliability theory, such as the concepts of mean time between failure (MTBF) and mean time to repair (MTTR), will be more inclined to look for ways to minimize down time and minimize failures than a staff with only intuitive knowledge. Knowledge of the more detailed aspects of reliability theory is not essential in many cases. It can be useful for evaluating unusual failure patterns and during the early stages of design when redundancy and maintainability can be included in the design at least cost. The need for a full-time reliability engineer on an organization's staff is a complex issue which should be decided on a case basis, there being many variables to consider, not the least of which are the capabilities of the person to be hired.

The Team made good use of its awareness of reliability theory and practices when it advised management to budget for spares for critical items and provided equipment-failure data to all technical groups. The Team's legacy includes the desire within some of the members to acquire a preventive-maintenance software for all groups to use. Also, implementing CATER was a significant achievement with the potential for long-lasting benefits. Furthermore, the entire membership left the Team and returned to full-time work for their original groups with new knowledge about and greater appreciation for reliability, maintainability, and availability theory and practices. This greater awareness may be the most significant, long-lasting contribution the Team makes to CEBAF.

## Work Processes

Every project presented a unique situation which the Team countered with a unique set of members and processes, always trying to find the most economical solution.

The Team selected the most able member(s) to accomplish a project, but in general, the most able member(s) volunteered to take projects. Being able included having the time required to do a good job, as well as the expertise.

A small number of members, usually two or three, worked together to complete projects. This number was an optimum because a project would be too much for a single member giving no more than twenty-five percent of their time to the Team. More than three members increased the complexity of reaching consensus, made finding acceptable times to meet more difficult, and fragmented the work inefficiently. There probably is a strong correlation here to Ringlemann's research, which concluded that the fewer people on a team in a tug-of-war, the harder each person pulled.

A great value of the Team was that the members reviewed and judged the work of the two and three-person mini-teams, providing correction, additional information, and encouragement to the few who had assumed responsibility for a project. The fact that the reputation of the Team and all of its members was always at stake, provided added incentive for the members to be especially helpful and supportive. Also, the diversity of the member's experiences and expertise ensured that errors of omission and commission would be detected in nearly every case during the review process.

The figures that accompany the text in the Analysis Chapter attest to the importance of the computer to the accomplishment of projects and the meeting of Team goals. CATER was the principal use of specialized software, and greatly simplified the collection of information about equipment failures. Also, the use of table-top and lap-top computers for word processing simplified the production of memoranda, tables of data, and view graphs. Finally, the Cricket software allowed the easy production of histograms for visual representation of equipment-failure data. The conclusion is that computer literacy was essential for all Team members to be productive team players.

## Additional Research

Some research topics inspired by this research are:

- Determine if other work-place teams at CEBAF and in industry also rely on mini-teams to address most projects. Model the general case.
- Evaluate the variables affecting the optimum number of members on a mini-team.
- Define the role of the team leader in increasing morale and productivity.
- Determine what types of personalities (Myer-Briggs) make the best team members and team leaders. Determine, if possible, what types of personalities should not be on teams in the workplace.
- Design a new model showing the processes teams use to accomplish work, and design a model showing how teams decide who will do what work.
- Investigate the variables that affect whether members work in parallel or in series.

## Final Thoughts

In conversations with fellow employees, it is evident that those who have not been on a TQM team have trouble believing and understanding why a team is different than a committee. For those of us who have done both, the differences are unmistakable and clear. Committee members owe their loyalties to their parent organization, and committees go on for years. Committee members are on the committee to represent their parent organization and to see that that organization's interests are protected and nourished. In contrast, members of the Team became very loyal to each other, to a degree the author has never observed among committee members Another difference is that teams have a defined life time, which is usually less than one year, but it is the difference in loyalty that sets teams apart and makes them especially capable of rapid accomplishment and high morale. The "one for all and all for one" spirit that infected the Team provide a special energy to the members that fueled their success.

A spirit of teamwork is especially beneficial because it provides team members with a flexibility to adapt to changing circumstances, which is important because different tasks require different responses. The task itself determines more than any other variable how a team will apply its resources to complete the task. For the Team, all tasks ultimately required one, two, or three members to work alone or together to complete the work. How does this compare to other small groups with goals? In baseball, only one person has the ball at a time and only one person can bat at a time. Coordinated effort between two or more players other than pitcher and catcher, is occasionally required, such as a double steal or a pick-off play, but this occurs in only a very small percentage of time in a nine-inning game. On the other hand a chorus singing a song requires all members to sing at the same time and blend their voices. A lone singer a bit off-key can ruin the performance; the point being that all members must work together and fulfill their roles (soprano, alto, tenor, and bass) equally. Interestingly, a singer with the chorus would be expected to put more personal effort and attention to singing a solo than when singing as just another member of the chorus, as Ringlemann would predict.

The Team did not fit the baseball or chorus models, being neither so independent as a baseball team nor as interdependent as a chorus. The Team came closer to the basket-ball or soccer models of a team. In these two goal-oriented sports, only one player has the ball at any instant, but it is rare that one player single-handedly takes the ball the full length of the court or field. The norm is for several players, but not all, to pass the ball to each other as the ball is advanced toward the goal. It is rare in both sports, and particularly in soccer, for all members to touch the ball during the drive to a single goal. The basketball and soccer models closely parallel the Team's methods for accomplishing work and reaching its goals.

In closing, the author gives his utmost thanks to all of the members of the Team for their friendship, cooperation, and hard work. Being a member of this team was a happy, satisfying experience.

## REFERENCE LIST

Barlow, Richard E. and Frank Proschan with contributions by Larry C. Hunter. 1967. *Mathematical Theory of Reliability.* New York: John Wiley & Sons, Inc.

Brooks, Frederick P. 1982. *The mythical man-month essays on software engineering.* Philippines: Addison-Wesley Publishing Company, Inc., 1975; reprint, Reading, Mass.: Addison-Wesley Publishing Company, Inc.

Bunday, Brian D. 1991. *Statistical methods in reliability theory and practice.* London: Ellis Horwood Limited.

Carr, Clay. 1992. *Teampower lessons from America's top companies on putting teampower to work.* Englewood Cliffs, N.J.: Prentice-Hall.

Ciampa, Dan 1992. *Total quality a user's guide for implementation.* Reading, Mass.:Addison-Wesley Publishing Company, Inc.

Cole, Robert E. 1989. *Strategies for learning: small group activities in American, Japanese, & Swedish industry.* Berkeley: University of California Press.

Crouch, J. Michael. 1992. *An ounce of application is worth a ton of abstraction.* Greensboro, N.C.: LEADS Corporation and Piedmont Publishing Partners.

Crowder, M. J., A. C. Kimber, R. L. Smith, and T. J. Sweeting. 1991. *Statistical analysis of reliability data.* London: Chapman & Hall.

Driskell, James E. and Eduardo Salas. 1992. *Can you study real teams in contrived settings? The value of small group research to understanding teams.* Edited by Robert W. Swezey and Eduardo Salas. *Teams: their training and performance.* Norwood, N.J.: Ablex Publishing Corporation.

Fleishman, Edwin A. and Stephen J. Zaccaro. 1992. *Toward a taxonomy of team performance functions.* Edited by Robert W. Swezey and Eduardo Salas. *Teams: their training and performance.* Norwood, N.J.: Ablex Publishing Corporation.

Goldman, A. S. and T. B. Slattery. 1964. *Maintainability: a major element of system effectiveness.* New York: John Wiley & Sons, Inc.

Gray, Jerry L., and Frederick A. Starke. 1984. *Organizational behavior concepts and applications.* 3rd ed. Columbus, Ohio: Charles E. Merrill Publishing Company.

Gryna, Frank M., Jr. 1981. *Quality circles a team approach to problem solving.* New York: AMACOM, a division of the American Management Association.

Hackman, J. Richard, ed. 1991. *Groups that work (and those that don't).* San Francisco: Jossey-Bass Publishers.

Haviland, Robert P., 1964. *Engineering reliability and long life design.* Princeton: D. Van Nostrand Company, Inc.

Imai, Masaaki. 1986. *Kaizen the key to Japan's competitive success.*. New York: McGraw-Hill Publishing Company.

Jorgensen, Danny L. 1989. *Participant observation A methodology for Human Studies.* Newbury Park, Calif.: Sage Publications.

Lloyd, David K. and Myron Lipow. 1984. *Reliability: management, methods, and mathematics.* 2d ed. (seventh printing 1991) Milwaukee: The American Society for Quality Control.

Manz, Charles C. and Henry P. Sims, Jr. 1993. *Business without bosses how self-managing teams are building high performance companies.* New York: John Wiley & Sons, Inc.

Moorland, Richard L. and John M. Levine. 1991. *Problem identification by groups.* Edited by Stephen Worchel, Wendy Wood, and Jeffry A. Simpson. *Group Process and Productivity.* Newbury Park, Calif.: Sage Publications.

Patton, Michael Quinn. 1990. *Qualitative evaluation and research methods.* 2d ed. Newbury Park, Calif.: Sage Publications.

Penner, Louis A. and J. Philip Craiger. 1992. *The weakest link: the performance of individual team members.* Edited by Robert W. Swezey and Eduardo Salas. *Teams: their training and performance.* Norwood, N.J.: Ablex Publishing Corporation.

Pritchard, Robert D. and Margaret D. Watson. 1991. *Understanding and measuring group productivity.* Edited by Stephen Worchel, Wendy Wood, and Jeffry A. Simpson. *Group Process and Productivity.* Newbury Park, Calif.: Sage Publications.

Ramakumar, R. 1993. *Engineering reliability: fundamentals and applications.*. Englewood Cliffs, N.J.: Prentice Hall.

Salas, Eduardo, Terry L. Dickinson, Sharolyn A. Converse, and Scott I. Tannenbaum. 1992. *Toward an understanding of team performance and training.* Edited by Robert W. Swezey and Eduardo Salas. *Teams: their training and performance.* Norwood, N.J.: Ablex Publishing Corporation.

Samuelson, Charles D. 1991. *Small group decision making.* Edited by Stephen Worchel, Wendy Wood, and Jeffry A. Simpson. *Group Process and Productivity.* Newbury Park, Calif.: Sage Publications.

Schon, Donald A. 1983. *The reflective practitioner.* New York. Basic Books, Inc.

Shilliff, Karl A. and Paul J. Motiska. 1992. *The team approach to quality.* Milwaukee: ASQC Quality Press.

Simpson, Jeffry A. and Wendy Wood. 1991. *Introduction: where is the group in social psychology?* Edited by Robert W. Swezey and Eduardo Salas. *Teams: their training and performance.* Norwood, N.J.: Ablex Publishing Corporation.

Von Alven, William H., ed. 1964. *Reliability engineering.* Englewood Cliffs, N. J.: Prentice-Hall, Inc.

Worchel, Stephen, Dawna Coutant-Sassic, and Michele Grossman. 1991. *A developmental approach to group dynamics.* Edited by Stephen Worchel, Wendy Wood, and Jeffry A. Simpson. *Group Process and Productivity.* Newbury Park, Calif.: Sage Publications.

Zenger, John H., Ed Musselwhite, Kathleen Hurson, and Craig Perrin. 1994. *Leading teams mastering the new role.* Homewood, Ill.: Business One Irwin.

# APPENDIX 1

## Reliability, Maintainability, and Availability (RMA)

### Purpose

The appendix will focus on the field of engineering reliability and will serve both as a very brief summary of this field and as a source of practical ideas for the Hardware Checkout and Reliability Team to use at CEBAF. The reading of the literature was a search for clear explanations of the theory of engineering reliability and believable reports of improving RMA in industry. The purposes of this chapter are discussed in the four paragraphs that follow.

One purpose of the literature search was to find theoretical concepts that could be applied to the Hardware Checkout and Reliability Team's purpose at CEBAF. Theoretical concepts can include terminology, mathematical methods, statistical models, and techniques for evaluating system performance. Successful application of theoretical concepts by the Team, whether done intuitively or with knowledge of the theory, is of interest.

A second purpose of the literature search was to locate and review accounts of real organizations making an effort to improve their system reliability so that a comparison could be made between other organizations' efforts and the Team's efforts to improve communications, teamwork, and productivity.

A third purpose of the literature search was to gain an understanding of the many variables that affect RMA, both theoretical and managerial, so that a comparison can be made with the Team in its efforts to understand and improve RMA at CEBAF.

In summary, the literature search provides a baseline of information for the research and will be the reference or source material against which the Hardware Checkout and Reliability Team is compared.

## Introduction

Equipment RMA is a highly technical literary subject with a limited readership. Of the eight books on this subject which I checked out from the Old Dominion University, William and Mary College, and CEBAF libraries, I was the first borrower on three of them. Most of the books were written by reputable authors to be graduate and undergraduate text books, and their quality was quite high.

The writings about RMA can be divided into four areas of interest: (1) discussions about equipment reliability, maintainability, and availability as concepts and practical matters in industry, (2) the use of mathematics, primarily probability and statistics, to describe and estimate equipment and system reliability, (3) management methods that enhance RMA, and (4) the use of a special group of employees within an organization to monitor and report on equipment RMA.

## Key Terms

All disciplines tend to develop their own language of terms which have special meanings for those belonging to the group. Reliability engineering is no different, and some of its most significant terms, which are underlined, are defined and explained below.

Availability of a system or equipment is "the probability that it is operating satisfactorily at any point in time when used under stated conditions, where the total time considered includes operating time, active repair time, administrative time, and logistic time." (Von Alven 1964, 7)

Intrinsic (inherent) availability is the mean time between failures (MTBF) divided by mean time between failures plus mean time to repair (MTTR) (active repair time only). This excludes time spent waiting for parts and administrative delays (Von Alven 1964).

Operational availability is the mean time between maintenance (MTBM), which includes both preventive and corrective maintenance, divided by MTBM plus the mean down time (MDT), which includes the time to make repairs plus any administrative time and time spend obtaining needed parts and supplies (Blanchard and Lowery 1969).

Bunday uses the term censoring to indicated that exact data is not known, but enough data is available to estimate the reliability of a device because it is known that the device survived beyond a certain time. Type I censoring occurs when the devices are observed for a limited period of time, and the test is terminated before any devices fail. Type II censoring occurs when the test involves a larger device, which fails because of some component other than the subject of the test. Exact analysis is impossible in censoring situations, but intelligent estimates are possible. Bunday cites two techniques, the Kaplan-Meier product-limit estimate and the variance of the product-limit estimator, and he reports that the Weibull distribution can be useful with censored test results (Bunday 1991).

A coherent system is one where the individual components are in one of two states, functioning or failed. Every component is relevant, and each component's reliability affects the reliability of the system (Crowder et al. 1991).

Corrective maintenance follows in-service failures and includes repair, adjustments, and replacement of components, all done to restore the system to normal operation.

Down time is "the total time during which the system is not in an acceptable operating condition." Down time includes active repair time, logistic time, and administrative time (Von Alven 1964, 12-13).

Maintainability is "the probability that a failed system is restored to operable condition in a specified down time when maintenance is performed under stated conditions." (Von Alven 1964, 9)

Mean time to failure (MTTF) is the average lifetime of a component or device.

Mean time to repair (MTTR) is the average time to repair a component or device.

Mean time to install (MTTI) is the average time to replace a device.

Mean time between failures (MTBF) = MTTF + MTTR (Ramakumar 1993).

A path is "a physical means for accomplishing a given task." (Von Alven 1964, 198)

Repair includes the following steps or phases: preparation, malfunction verification, fault location, part procurement, repair, and final test (Von Alven, 1964).

A serial system is one in which all the components must function satisfactorily for the system to be successful. The reliability of a serial system cannot be greater than the minimum of the reliabilities of its subsystems. A product rule works for independent serial systems; the reliabilities of all of the components or subsystems are multiplied together to yield the system reliability (Lloyd and Lipow 1984).

A parallel system is one in which if one component fails, another takes its place, and the system continues to operate. A parallel system failure occurs if and only if all subsystems fail. If at least one subsystem is successful, the system is successful (Lloyd and Lipow 1984).

A partially parallel system is one in which there is a probability that the parallel components will not work rather than it being a yes-no situation. If there are eight items, and three must be successful for the system to be successful, it is a partially parallel system, and the probability depends on component probability (Lloyd and Lipow 1984).

Scheduled (preventive) maintenance is performed at constant time intervals, even if the system is still working satisfactorily. This prolongs component life, decreases the number of failures, and increases the mean time to fail of the system (Ramakumar 1993).

Variables analysis means "taking data several times and then predicting whether the system will succeed or fail at some time in the future." (Lloyd and Lipow 1984, 220)

## RMA in Theory

### The Mathematical Aspects of RMA

There is a famous saying which says: "There are lies, damned lies, and statistics", and the order in which they appear suggests that statistics are the worst of the three. The problem with statistics is that if the desired outcome is known, there may be statistical methods for making the data support that outcome. This is well known, and it may be necessary to overcome this perception when reliability engineers present their work to management.

Ramakumar identifies three steps essential for assessing system reliability: (1) construct a reliability model. (2) analyze the model and calculate the appropriate reliability indices. (3) evaluate and interpret the results. This formula suggests quantification of data and comparison of measurements with a standard, making a mathematical approach inevitable, and this is what is found in industry. A brief review of probability theory and reliability statistics is useful at this point, and it is presented in the context of what has potential utility and currency for the Hardware Checkout and Reliability Team at CEBAF (Ramakumar 1993).

Suppose that you have fifty identical items, and two have failed. The reliability is 96%. But that is also the reliability for one failure in twenty-five items and twenty failures in five hundred items. Intuition tells us that the larger the sample base, the more reliable the data, and this can be expressed mathematically as the confidence level. For example, in the case of the fifty items and two failures, statistical tables, such as those in the back of Lloyd and Lipow, indicate that there is a 90% confidence that the reliability is at least 90%. For the five hundred item case, there is a 90% confidence that the reliability is greater than 95%, confirming our intuition. However, one must be especially careful when thinking statistically. For example, if the true reliability of a device is 90%, then no amount of testing will prove it is 95%, but there is a statistical probability of observing an apparent reliability of 95% or greater. Just because a certain reliability is measured does not make it so (Lloyd and Lipow 1984).

Three types of time dependent failures have been identified and studied. If a device is turned on at t=o, it may already have failed, or it may fail soon after t=o. This is called initial failure, or "infant mortality", and is characteristic of electronic devices. In practice, a "burn-in" period is achieved by powering new electronics on a test stand before installing them for their ultimate use. This forces the failure of the defective items, and they are prevented from failing in service and potentially causing collateral failures in connected units. Following this initial burn-in period, which has an exponentially falling failure rate, there is a chance-failure period where the failure rate is essentially constant. This is characteristic of both mechanical and electronic components, and failures are caused by reason of very severe and unpredictable environmental conditions occurring during operations. The third type of time-dependent failure is the wear-out period, which is characteristic primarily of mechanical components. The failure rate increases during the wear out period. The composite of these three periods is called the "bathtub curve" because of its shape (Lloyd and Lipow 1984).

Reliability engineers have developed a set of mathematical terms and concepts which they use to understand and explain system and equipment reliability. Like many mathematical approaches to understanding, a single reading of any text on the subject does not bring instant understanding to most humans. The summary of the terms and concepts that follows is a best attempt to present the information clearly, simply, and briefly, and all are attributed to Bunday unless indicated otherwise (Bunday 1991).

The reliability function, R(t), is the probability that a system, component, or device is still functioning properly at time t. At time t=0, R(0)=1, and at t=∞, R(∞)=0.

The survivor function, S(t), is the probability that the system, component, or device survives until time t. It is equivalent to the reliability function.

The probability density function, f(t), is the negative of the first derivative with respect to time of the reliability function. As such, it is the negative of the slope of the reliability function curve.

The probability that in a random trial, the random variable is not greater than t is called the unreliability function, which is designated F(t) and is equal to the integral from minus infinity to t of f(t)dt. $F(t)=1-R(t)$ (Von Alven 1964).

The hazard function, h(t), is the age-specific failure rate. It describes the way in which the instantaneous probability of a failure for a component changes with the age of the component. The "bath tub" curve referred to earlier is in fact a plot of h(t) versus time for a particular component. The hazard function is also called the failure rate function, and it is an indicator of the "proneness to failure" of a component after time t has elapsed. An equation for the hazard function is this: $h(t)=f(t)/S(t)$ (Crowder et al. 1991).

The functions described above are interrelated, and as an example, the functions for the constant hazard section of the bath tub curve are as indicated below:

$h(t)=\lambda$, a constant. Then $R(t)=S(t)=e^{-\lambda t}$, and $f(t)=\lambda e^{-\lambda t}$.

Given any one of f, F, S, h, and H, the others may be deduced (Crowder et al. 1991).

Other interesting relationships exist which connect the mathematical to the practical. For example, the mean lifetime of a component is the integral of the survivor function, S(t)dt, from $t=0$ to $t=\infty$. (Bunday 1991) Also, the reciprocal of the hazard function for a device is its mean time to failure (MTTF).

There are two fundamental testing methods for collecting data for the study of equipment reliability: (1) The lifetime of a particular device is recorded. When it fails, it is replaced by a second device which is supposedly identical. The lifetime of the second device is recorded. This continues with a string of replacement devices. This method stretches out over a long period of time, but can indicate whether the devices are getting better, worse, or staying the same. (2) The lifetimes of *n* identical devices are recorded. The times of the first failure, the second failure, and so on until the *n*th item fails are recorded. The second method provides data on the one generation of the device with high confidence levels (Bunday 1991).

## Constructing a Model

A variety of distributions are being used to model failure data. Statisticians are candid in admitting that the reasons for using a particular form to model the aging process is more likely to be empirical than being based on a fundamental understanding of the process. (Bunday 1991) The rule of thumb seems to be "if it the curve fits, use it." A brief summary of the distributions that seem to be most used in the reliability field follows:

The negative exponential distribution is used when the components are subject to a constant hazard; that is they do not deteriorate with age, nor do they wear out. They fail due to a shock, and the shocks occur usually in a Poisson process (Bunday 1991).

The gamma distribution is similar to the negative exponential distribution, but the difference is that failure does not occur on the first shock, but on a later shock, not necessarily the second shock (Bunday 1991).

The Weibull distribution is the most popular parametric distribution and has a wide range of applications such as ball-bearing failures, composite materials, and electrical insulation failures. The hazard function can vary with time in this distribution, and the negative exponential distribution is a special case of the Weibull distribution (Bunday 1991) (Crowder et al. 1991). There was a special graph paper designed for use with the Weibull distribution, and it made graphical analysis achievable before computer statistical software programs became available (Von Alven 1964).

The Gumbel distribution has been used to model failures caused by progressive chemical corrosion. It can be used to model both parallel and series systems, and the originator used it in meteorology, flooding studies, and general engineering problems (Bunday 1991).

The Gaussian or normal distribution has some use in modeling the wearout region for mechanical devices, especially if the sample size is large (Ramakumar 1993).

The inverse Gaussian distribution has been used to model progress to the failure point of certain wear processes. It was originally used to describe Brownian motion of particles. The formulae for the density and survivor functions are quite complex, limiting its applications (Bunday 1991).

The Poisson distribution is useful when there are a large number of opportunities for an event to occur, but a small probability of any one (Lloyd and Lipow 1984). The Poisson distribution corresponds to the successive replacements of a particular device when the devices have negative exponential lifetimes (Bunday 1991). The Poisson process is valid if two assumptions are met: 1. Failures occur in disorderly time intervals and are statistically independent; and (2) the failure rate is constant, and so it does not depend on the particular time interval examined (Crowder et al. 1991).

Bunday cites the use of three models which are helpful in understanding special situations that may affect the reliability of systems (Bunday 1991).

The competing-risks model is helpful when a device has several independent failure modes. Each risk generates a random lifetime which is independent of other failure modes. The initial failure occurs at the end of the first of the lifetimes.

The accelerated-life model is used in some situations in the laboratory when it is possible to simulate the stress that the device is subject to in the field and do it under accelerated time conditions so that testing to failure can be carried out much more rapidly than would occur in actual practice.

The proportional-hazards model is used when a device is no longer subject to standard conditions. A variable, such as temperature, has changed, and this model allows the hazard function to be proportioned to fit the situation.

### Evaluating the Reliability of Complex Systems

Ramakumar presents some proven techniques for evaluation system reliability: The event-space method, the path-tracing method, the decomposition method, the minimal cut set method, minimal tie set method, the connection matrix technique, event trees, and fault trees. These are methods used in practice, and the large number in use suggests that the search for an optimum method continues. Several sentences on each provides some meaning beyond the titles. All are attributed to Ramakumar (Ramakumar 1993).

Event-space method. All possible occurrences are listed systematically, and the list is separated into favorable and unfavorable events. Reliability is obtained by summing the probabilities of occurrence of all the favorable events. For a system of N components, there is a total of $2^N$ events. This procedure is unwieldy if N is greater than six.

Path-tracing method. All possible paths of a system are traced, and the reliability of the system is the union of the favorable paths. This method is unwieldy if there are more than five favorable paths.

Decomposition method. This is a conditional probability approach in which a keystone component that appears to bind the reliability structure together is selected. System reliability is calculated on the probability of that component being successful or unsuccessful. In the case of complex structures, the decomposition process on substructures is formed after the first decomposition.

Minimal cut set method. This is a powerful technique used for network evaluation, and is accomplished on a computer. A minimal cut set is a system of components that meets the criteria for a parallel system. (See key terms.)

Minimal tie set method. A minimal tie set is a group of branches which connects the input and the output of a system, and has a series structure. This method is similar to the path tracing method and is used less frequently than the minimal cut set method.

Connection matrix technique. This method uses matrix mathematics to solve the reliability equations for transmission from input to output.

Event trees. This is a visual method of showing the component paths from input to output. This method is difficult if there are more than five components and there are more than two states (on and off, for example).

Fault trees. A fault tree symbolically represents the conditions that may cause a system to fail, and it can pinpoint system weaknesses in a visible form. The logic for this method is the reverse of the one used for event trees, which maps successes. This method starts with a particular failure and works backwards to explore all the combinations of events that can lead to this failure. Fault tree analysis recognizes three types of failures: (1) primary failures, which occur while a component is functioning properly. (2) secondary failures, which are due to excessive environmental operational stress. (3) command failures, which result from the proper operation of a component, but at the wrong time or place.

Some attempts are being made to use Baysian methods to examine reliability data. This approach is controversial and is not universally accepted. The Baysian method requires practical judgments to be made and is more subjective than the traditional statistical methods. Baysian methods are being used when the data is simply inadequate for predictions to be made by standard methods and when complicated likelihoods are expected (Crowder et al. 1991).

## RMA in Practice

Reliability is not an easy concept to define, but one rather general and subjective definition is "the probability of a successful operation of the device in the manner and under the conditions of intended customer use."(Lloyd and Lipow 1984, 20) Ramakumar defines system reliability as "the probability that the system will perform its intended function for a specified interval of time under stated conditions." (Ramakumar 1993, 3) This is a bit more specific. Maintainability is defined as the "ability of a component or unit to be retained in or restored to a state in which it can perform service under the conditions of use for which it was designed." This includes repairing a device or installing a replacement device (Ramakumar 1993, 9).

The reliability of a device is a quality of that device, but unlike many attributes, it cannot be measured directly, and we are limited to estimating it. It is one among many measures of equipment quality, but it differs from style, economy, and size in that it is not an obvious attribute. It is more abstruse and subject to interpretations and qualifications. Reliability is also a subject of study which includes a set of techniques generated from managerial concern for the effects of unreliability and an appreciation of the need to eliminate the problems leading to unreliability. Reliability is not a separate activity for an organization; rather it is integral with manufacturing, testing, engineering, and other departments. As such, it is not an obvious quality, nor is proof of its worth immediately obvious (Lloyd and Lipow 1984).

Designing for reliability is not as straight forward as it might appear. At first glance, improving reliability may seem to be a constant and worthy goal. This is not the case, however, because budgets and practicality dictate otherwise. It is unacceptable for designers and builders to order and pay for components with significantly longer estimated lifetimes than the larger system to which they belong. In areas of rapid technological advance, such as computers, actual equipment lifetime need not exceed the useful lifetime for that equipment. Experience indicates that equipment at the cutting edge of technology tends to be relatively unreliable because the technology enters production with limited opportunity to benefit from "lessons learned."

Often, there is an interesting trade-off between reliability and maintainability. If one makes a device more rugged so that it can be more reliable, the result may be that the device is difficult and costly to repair. There will be fewer repairs, but they will probably take longer to complete. Increased reliability due to increased ruggedness, such as more solid supports and casings, more bolts, thicker welds, and so forth, adds costs. Here is a good example from previous experience. The instructors at the US Naval Submarine School in the 1960's in Groton, Connecticut, were experienced in diesel-powered submarines, and the diesel engines on submarines at that time were manufactured either by General Motors Corporation or Fairbanks-Morse Company. The Fairbanks-Morse engines had a reputation for being more reliable than the "Jimmies", but they were also more difficult to disassemble and took longer to overhaul. The less reliable General Motors engines failed more often, but access to components was easier, and the technicians were well trained to conduct repairs because of the frequency of repair. Access to the cylinders and the crankcase was more difficult on the Fairbanks-Morse engines, and the more rugged parts tended to be more expensive. The crews on these submarines tended to be less skilled at making repairs because they had less opportunity to practice and opportunities were further apart. The availability percentage of the two brands tended to be about equal, but the sailors who took care of the engines tended to be loyal to one brand and wanted nothing to do with the other.

In practice, managers must balance reliability and maintainability by considering several factors simultaneously and select trade-off points for: (1) the reliability index and time duration desired. (2) the cost of an in service failure. (3) the cost of replacement before failure. (4) the most economical point in the equipment life to effect a replacement. (5) the predictability of the failure pattern of the equipment. The ideal is to replace the equipment just before it fails (Von Alven 1964).

The trade-off between reliability and maintainability is reflected in textbooks such as Ramakumar's by displaying an optimization curve which shows that as more money is put into reliability, less money is needed for operating and maintenance. By summing the two curves, a total-cost curve is shown, and it is the familiar “u” shape, with the lowest point being the optimum, cost-wise. His point of view is that one should not ask if a device is reliable, but should ask if it is reliable enough (Ramakumar 1993). There are curves available to help practitioners find the optimum point that are based on theoretical curves, such as those referred to by Ramakumar, but entry parameters include average hourly cost of the equipment, the cost of a failure, the cost of a replacement, and the probability that a new unit will last a specific lifetime (Von Alven 1964).

Given that it takes money to make a system or component more reliable, unreliability has costs too. Time wasted, the psychological effect of unscheduled shutdowns and repairs, the costs of increased labor for repairs, the changes in plans, the expense of replacement parts, all add to the bill. However, getting management to buy improved reliability can be difficult. The costs are up front for better equipment, more testing, and more planning. The pay-off for these expenses takes time and is not always demonstrable. We cannot hypothesize about what did not happen. This makes budgeting for reliability difficult; however, support for improving reliability can be gained by analyzing, demonstrating, and reducing or eliminating the causes of unreliability (Lloyd and Lipow 1993).

Redundancy is one method for improving a system's reliability, but, again, it has its costs. Redundancy can mean having built-in spare parts or alternate components; e.g., three pumps in parallel when only two are needed at any one time. Over design is another redundant technique; that is using a more powerful motor than the pump requires, meaning the motor will not be stressed and should last longer than a weaker motor operating at its limit. There is a tradeoff, and redundancy is seldom free; extra capitol costs, more maintenance, more weight, and increased labor contribute to the price paid for improving reliability by means of redundancy (Lloyd and Lipow 1984).

Component failure is often attributed to environmental causes, which can be classified into two categories: (1) those which are severe enough to cause the component to cease operations (a failure). (2) those which are mild enough so that one application is not fatal, but the cumulative effect of several or even a large number of exposures will cause the equipment to fail (Lloyd and Lipow 1984, 152).

There is a general perception that every failure has at least one cause, and identifying the cause(s) and correcting them in part or in whole will improve reliability.

Lloyd and Lipow cite as major contributing factors to equipment failures such subjective factors as human error, poor communications, complexity, budget limitations, and time constraints (Lloyd and Lipow 1984).

Human error contributes to system unreliability in complex ways. Lack of knowledge, carelessness, forgetfulness, a tendency to ignore written instructions and warnings, the pressure of time, and poor judgment cause failures. In an era of mass production, robotics, automation, and immensely large and complicated systems, the typical worker may feel that his or her contribution is unimportant. The consequence is a lack of enthusiasm which leads to carelessness, producing mistakes and sometimes failures. But as Lloyd and Lipow note, human absence, can cause more failures than the presence of an imperfect human operator. The operator can anticipate problems and compensate for changing situations (Lloyd and Lipow 1984).

Elaborating on their contention, Lloyd and Lipow assert that the more complex a system, the more complex the organization needed to run it. The more complex the organization, the more complex is the communications systems needed to function effectively. If there was time, we could learn everything useful about an item, but this does not happen. There isn't time, and devices are not perfect. They do not always act the same. Furthermore, we do not learn from other's experiences because of limits in the communications systems. Even if we do hear about someone else's experience, we may misinterpret it. We learn largely from our own experiences, but before we have time to synthesize and apply our knowledge, we are on to something else. We eliminate some mistakes, but they are replaced by new ones (Lloyd and Lipow 1984).

Poor communications is a rich source of human error. Inadequate coverage of important information, incomplete reporting of relevant data, data not reaching the appropriate person, and imperfect interpretation of the data or information all can lead to mistakes and failures (Lloyd and Lipow 1984).

Budget constraints affect every aspect of an organization and its activities, and RMA is no exception. Top management faces many tough decisions in resource allocation, and one involves balancing the apparent high cost of a reliability program and the consequences of producing a product with unsatisfactory reliability. Does the money go into better equipment, research, analysis of data, or some other useful activity which promises to improve the reliability? The answer is elusive (Lloyd and Lipow 1984).

System complexity contributes to unreliability; for example, the interaction between components such as a vibration in a pump which shakes pipe fittings loose and causes leaks. Likewise, the output of one component may be greater than the input specifications of its mate if the designer works with incomplete or incorrect information. The potential for undesired interaction leading to failures demands concurrent development to ensure component compatibility. Moreover, even if compatibility is not a problem, a successful system is dependent on the success of its components and subsystems. This interdependence introduces probability theory, which states in its simplest form that the probability of a successful operation of the system is the probability that all lesser devices within the system operate successfully. If the components are statistically independent, then the system probability is the product of the component probabilities (Lloyd and Lipow 1984).

### Preventive Maintenance

The value of preventive maintenance has long been a subject of debate. Some people believe that well-running equipment should be left alone. Others advocate strict adherence to a preventive maintenance schedule. In either event, actual practice should be based on an analytical evaluation of the performance of the specific equipment involved. In general, preventive maintenance is advantageous for systems and parts whose failure rates increase with time. Many types of batteries, lamps, motors, relays, and switches fall within this category. The purpose of preventive maintenance is to reduce operational failures, and that is sometimes lost in the argument (Von Alven 1964).

A study of hazard functions and failure rates for equipment leads to important conclusions regarding preventive maintenance. If a component has a constant hazard, its time to failure has an exponential distribution, and the probability of failure during the next time increment remains unchanged throughout its lifetime. This means it is as good as new no matter how long it has operated, and preventive maintenance is irrelevant. This applies to most electronic devices, which fail due to shocks. If a component has a decreasing hazard, it is improving as time goes on, and preventive maintenance to restore it to the new condition is actually disadvantageous (Ramakumar 1993).

Prevent maintenance is advantageous for components with an increasing hazard function, such as most mechanical devices. The important effect of periodic preventive maintenance from a mathematical view point is that it alters the failure density function from its original shape to one with an exponential character. This contributes to the widespread use of exponential distributions to model component lifetimes (Ramakumar 1993).

### Spare Parts

The availability of spare parts reduces logistic time and thereby reduces mean time to repair. The lack of a needed part, even a minor and inexpensive part, can be very expensive when logistic and administrative time required to locate, order, and deliver a part runs into days and weeks. This problem is prevalent for older equipment, especially when the manufacturer has gone out of business.

Practitioners have curves available which advise on the number of spares to carry; however, the equations used to generate the curves depend on prior knowledge of failure rates. A curve in Von Alven requires knowing the failure rate per million hours of operation and an operating time in months, from one to thirty-six. These inputs and the curves lead to a number of spares to stock with a ninety percentage confidence level. For example, with a failure rate of one thousand per million operating hours, about fifteen items should be stocked for a twelve month operating period (Von Alven 1964).

## Management Methods

Von Alven suggests that the emphasis should be placed on prevention rather than correction, and this approach points to a constructive responsibility rather than a remedial. He also supports making quantitative reliability requirements contractual responsibilities equal with other system parameters such as performance, weight, and cost. The well-meaning but ineffectual philosophy often applied to reliability - "we will do the best we can" should not be accepted (Von Alven 1964).

Management can benefit by establishing indices other than operational availability for measuring performance because they can bring correctable weaknesses into focus. One company, RCA, reportedly used the following indices to measure status: (1) the ratio of satisfactory operation time to the total required time. (2) average down time per unit of calendar time. (3) mean time to repair. (4) man-hour requirements per unit of operating time (5) total man-hour requirements per unit of calendar time. (6) waiting time per unit of calendar time. (7) material requirements per unit of time. (8) cost of support per unit of calendar time. Von Alven also cites the use of total man-hours per thousand operating hours as an index, although this is not an RCA index (Von Alven 1964).

## A Reliability Group

The authors, Lloyd and Lipow, worked as reliability engineers for TRW. Their background biases them towards promoting the benefit to an organization of having a small group focused on improving RMA. They present the best case for having such a group, and their comments and ideas should be listened to in that context.

Such a group has two different but related functions: assessing the reliability of the system and improving the reliability of the system. Lloyd and Lipow contend that a small group with their occupational survival at stake will improve reliability better then the functional organization with reliability being one of many responsibilities held by many employees. A plausible argument is made that placing reliability responsibility in the engineering division with line responsibility for the equipment has the advantage of keeping the responsibility with the people who early in a project have the major task of providing a system of high reliability. The counter argument is that the engineering group cannot be independent in its criticism. The role of the separate group is to provide independent and forceful oversight and be a reservoir of special knowledge and skills, particularly in statistics (Lloyd and Lipow 1984).

A reliability group envisioned by Lloyd and Lipow should be organizationally independent of all of the major divisions, but have the close cooperation with each of those divisions so that it can work effectively and in sufficient detail to accomplish the technical aspects of its job. The head of such a reliability group must report to top management to establish an authority that cannot be ignored. The skills, knowledge, and abilities of the members determine the group's effectiveness. It should contain systems engineers and theoretical specialists who bring significant education and experience to the job. The need for frequent interaction with line staff demands that coordination and integration are important activities that group members should be adept at. A reliability group has areas of responsibility which may not be readily distinct from that of other groups. Couple this with a human reluctance to accept advice when it is not asked for and the inherent resistance to change, and you have a potential management problem. The potential for conflict and interference definitely exists, and the group must be ever mindful that it has to be perceived as contributing to, rather than detracting from, progress if it desires to survive (Lloyd and Lipow 1984).

Lloyd and Lipow describe nine functions for the ideal reliability group (Lloyd and Lipow 1984):

1. Systems engineering and operational analysis

2. Component design
3. Specification and materials review
4. Manufacturing operations and quality control
5. Test planning and environmental materials review
6. Design and analysis of statistical experiments
7. Data collection evaluation
8. Project management and coordination
9. Mathematical and statistical probability theory

If the group understands the reliability structure of the systems; i.e., their serial and parallel nature, it can recognize the weaknesses or potential weaknesses of the system from a reliability view point and bring pressure to bear to correct the problems. This understanding provides the group with knowledge and techniques enabling them to eliminate many unreliable areas. They can compute the number of redundant components needed as back-ups to yield a system with a required level of reliability (Lloyd and Lipow 1984 ).

Von Alven, with regards to establishing a group with responsibility for reliability, recommends that the group have a charter which requires all supported groups to cooperate with the reliability group. The implication is that the group will be viewed with skepticism and will have to prove its value to the total organization. This reliability group should report to the general manager and have "dotted lines" to all divisions. There should be a reliability committee which also reports to the general manager and has representatives from all divisions. This committee assigns responsibility and monitors results of the reliability group. Von Alven's vision for the reliability group is that it will be involved in many activities such as supplier selection, production documentation, test plans, and material specifications, in addition to traditional reliability functions (Von Alven 1964).

## Conclusion

The information, concepts, and experiences presented in this appendix raise some questions which will be considered during the analysis phase of the research. Among the questions that are addressed are the following:

Are the theories about reliability, maintainability, and availability too removed from the daily running of an engineering facility to be usefully applied?

Should an engineering-based facility maintain an in-house capability to conduct statistical studies of equipment failure rates?

What use did the Team make of reliability theory and practices above and beyond what was already being done by the technical groups?

What promising areas remain for the organization to explore for improving accelerator availability?

These questions are addressed in the Analysis Chapter.

# APPENDIX 2

## Memo of May 28, 1993

CEBAF
*The Continuous Electron Beam Accelerator Facility*

**MEMORANDUM**

**To:** T.

**From:** A.

**Subject:** Team Membership

**Date:** May 28, 1993

You have been selected to participate in one of the Teams that are being created to plan and execute the commissioning of CEBAF. Your participation will obviously impact your other tasks and we felt it necessary to clearly define the percentage of your time that you should devote to the Team. The attached sheet contains the list of the members in your Team and the fraction of time that each will be spending on Team related activities.

Team membership will be an important and integral part of your job assignment from now on and your performance within the Team will be considered in your job evaluation. For this reason, this Memo is coming to you via your administrative chain of command to ensure that there can be no possibility of a misunderstanding of your duties by anyone and that you get proper credit for your efforts.

It is our intention to organize Team Member training and provide a facilitator to maximize the efficiency of the Teams. You will be contacted by your Team Leader for further information and an invitation to the Team kick-off meeting.

[This page was retyped by T. to give it the necessary left-hand margin for binding the dissertation in book form.]

xxxxxJan94Plan]MemberLetter. May 27, 1993

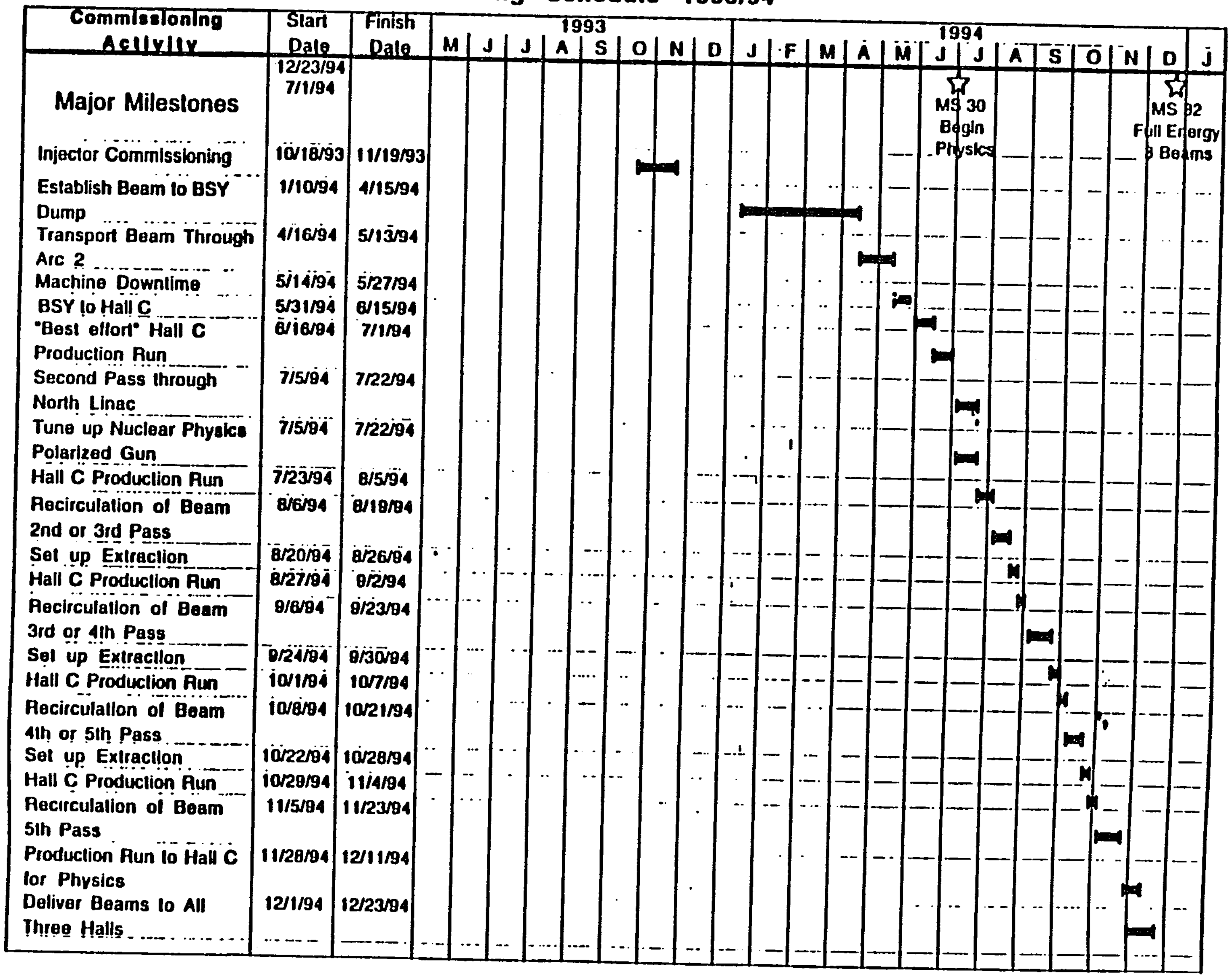
[redacted]
May 27, 1993

# Hardware Team Dates 1993/ 94

| | | |
|---|---|---|
| Requirements<br>Review<br>June 15, 93 | Specifications<br>Review<br>Aug 15, 93 | Commissioning<br>Start<br>Jan 10, 94 |

| Team Member | Work Fraction |
|---|---|
| [redacted] S. | 75% |
| [redacted] D. | 25% |
| K[redacted] | 25% |
| R[redacted] | 25% |
| T[redacted] | 25% |
| Al[redacted] | 25% |
| Ka[redacted] | 25% |
| [redacted] Rn. | 25% |
| M[redacted] | 25% |

## Commissioning Schedule 1993/94



| Commissioning Activity | Start Date | Finish Date |
|---|---|---|
| Major Milestones | 12/23/94<br>7/1/94 | |
| Injector Commissioning | 10/18/93 | 11/19/93 |
| Establish Beam to BSY Dump | 1/10/94 | 4/15/94 |
| Transport Beam Through Arc 2 | 4/16/94 | 5/13/94 |
| Machine Downtime | 5/14/94 | 5/27/94 |
| BSY to Hall C | 5/31/94 | 6/15/94 |
| "Best effort" Hall C Production Run | 6/16/94 | 7/1/94 |
| Second Pass through North Linac | 7/5/94 | 7/22/94 |
| Tune up Nuclear Physics Polarized Gun | 7/5/94 | 7/22/94 |
| Hall C Production Run | 7/23/94 | 8/5/94 |
| Recirculation of Beam 2nd or 3rd Pass | 8/6/94 | 8/19/94 |
| Set up Extraction | 8/20/94 | 8/26/94 |
| Hall C Production Run | 8/27/94 | 9/2/94 |
| Recirculation of Beam 3rd or 4th Pass | 9/6/94 | 9/23/94 |
| Set up Extraction | 9/24/94 | 9/30/94 |
| Hall C Production Run | 10/1/94 | 10/7/94 |
| Recirculation of Beam 4th or 5th Pass | 10/8/94 | 10/21/94 |
| Set up Extraction | 10/22/94 | 10/28/94 |
| Hall C Production Run | 10/29/94 | 11/4/94 |
| Recirculation of Beam 5th Pass | 11/5/94 | 11/23/94 |
| Production Run to Hall C for Physics | 11/28/94 | 12/11/94 |
| Deliver Beams to All Three Halls | 12/1/94 | 12/23/94 |

## APPENDIX 3

### Team Membership

There was a good mix of technical, administrative, and management skills on the Team, and proper use of the strengths of each member gave the Team the ability to meet its goals. A brief biography of each member follows:

A. joined CEBAF in August of 1992. A. is a senior accelerator physicist and is a native of England. Previous experience includes scientific work at several physics laboratories, most recently at the Stanford Linear Accelerator Center. At CEBAF, A. is the Deputy Associate Director for Commissioning and Operation of the Accelerator.

Al. joined CEBAF in May 1992. Education includes a BA in physics from Randolph-Macon College. Prior work experience includes being a scientific applications and graphics programmer at NASA Langley Research Center. Initial work at CEBAF consisted of being a control-system computer programmer. Al. has qualified as an accelerator operator and is currently in training to be a crew chief.

B. joined CEBAF on October 12, 1992. Education includes a BA in biology/chemistry from Seton Hill College and a MSIS (Information/Computer Science) from the University of Pittsburgh. Prior work experience includes 17 years with Kennametal, MTI, in materials research and computer support and two years at Newport News Shipbuilding. M. is currently in WBS 5 and Controls Systems Group. Current function is as a computer scientist. M. is system manager for CATER, the Computer Aided Trouble Entry and Reporting System.

D. joined CEBAF in December 1988. Education includes a BSEE from Lowell Technological Institute, Lowell, Mass. Prior work experience includes two years in electrical power distribution design and construction and 15 years in cryogenic plant design. Arenius is with the Cryogenic Group at CEBAF with responsibility for cryogenic facility instrumentation and controls and electrical power distribution.

K. joined CEBAF in March 1989. Education includes a high school diploma and completion of several U.S. Navy electronics schools. Prior work experience includes six years in the Navy, five years with Exeter Drilling and Exploration, and five years with Rockwell International. K. is with the Instrumentation & Controls Department, Diagnostics Group at CEBAF and assembles, installs, tests, and maintains hi-tech accelerator equipment such as beam viewers and beam position monitors.

Ka. joined CEBAF in September 1992. Ka. has Bachelors degrees in computer programming and industrial engineering and is enrolled in a masters program leading to a degree in administration. Prior work experience is two years as a computer programmer. Current function is as an accelerator technician. Ka. is a qualified beam operator and is in training to become a crew chief.

M. joined CEBAF in October 1991. Education includes three years at the Newport News Shipbuilding (NNSB) Apprentice School resulting in a certificate of completion as an electrician. US Air Force (USAF) Electronics School, and an Associate in Applied Science (A.A.S.) degree Electronics from Thomas Nelson Community College. Prior work experience includes five years in the USAF. M.'s primary work at CEBAF has been as an accelerator operator, with some time spent providing technical support in electronics.

R. joined CEBAF in February 1991. Educational background is an A.A.S. in Electronic Technology and additional college level management and computer programming courses. Flood's prior work experience includes 14 years at FERMILAB, a sister accelerator lab in Illinois. Four of the years at FERMILAB were with a controls group, and ten years were with an operations group. At CEBAF, Flood is a shop supervisor with the DC Power Group.

Rn. joined CEBAF on June 8, 1988. He has a BSEE. Prior work experience was in broadcast engineering, microprocessor hardware development, and software design. Nelson is with the Radio-Frequency (RF) Group at CEBAF and is an RF engineer. Nelson is deputy group leader and leads the Electro-Magnetic SubGroup.

Ro. joined CEBAF in December 1992. Education includes a B.A. in mathematics and a Ph.D. in Physics, both from U.C. Berkeley. Work experience includes two years at Maxwell Labs, four years at Lawrence Berkeley Lab, and seventeen years at FERMILAB. Ro's. was the Head of the Instrumentation and Controls Department, until April 1994 when he left for other work.

S. joined CEBAF in June 1987. Suhring has a BS in physics from Dickenson College. Prior work experience includes being a field engineer on large ($5M to $50M) construction projects. Suhring is Operations Accelerator Manager with emphasis on machine hardware issues. Suhring is leader of the HC&R Team.

T. joined CEBAF on May 18, 1987. Education includes a BS in engineering from Annapolis and a Masters Degree in Engineering Management from Old Dominion U. Prior work experience includes more than twenty years in the U.S. Navy, mostly in nuclear submarines, including submarine command. Present position at CEBAF is as Emergency Management Manager. Other duties include being Environment, Health, & Safety Officer (EH&S) for the Commissioning and Operations Branch, and writing chapters for a new EH&S Manual.

# APPENDIX 4

## Requirements Document

# Hardware Checkout & Reliability Team

"Identify issues relating to availability and make recommendations for maximization."

- **Metrics**
  - Evaluation of past performance
  - Trouble tracking and statistical analysis
- **Problem Identification**
- **Resources**
  - Manpower
  - Call-in lists
  - Spares
  - Tools & equipment
  - Training
  - Funding
- **Hardware/Software**
  - Maintenance
  - Improvement
- **Checkout**
  - Burn in
  - Integrated operability from MCC
- **Documentation**
  - Procedures
  - Sign off
- **Scheduling**
  - Maintenance & Development
- **Availability Budget**
  - Breakdown of amounts
- **Mechanisms for Improvements**
  - Identify steps to achieve improvement

August 5, 1993

# Metrics

**Evaluation of Past Performance:** *Gather and examine information from last run.*

- Analyze existing data as relates to system failures during the past run and inform the appropriate groups of the results.
- Evaluate any machine improvements during the testing and checkout phase, and during actual operation where opportunity for improvement can be identified.

**Trouble Tracking and Reporting Systems:** *Systems and procedures necessary for improving machine reliability and availability based upon an accurate current and historical compilation of problems and resolutions*

- Recommend a system for reporting system problems and disseminating that information in the form of trouble reports, repair status, and analysis of the historical data contained therein.

# Problem Identification

**Problem Identification:** *Software, hardware, and techniques used to develop a precise and detailed description of a system's performance.*

- Facilitate the development of tools and training necessary to quickly and accurately identify problems and obtain as much information as possible to enhance repair efforts.
- Verify that necessary control system and hardware troubleshooting capabilities are in place that will allow identification of problems and out of tolerance conditions.
- Familiarize personnel with systems designed to provide automatic monitoring and alerting of problems and out of tolerance conditions.

# Resources

**Manpower:** *Workers available to a particular group or required for a particular task.*

- Look at current and projected manpower needs versus manpower availability. Adequate staffing is needed to cover the required work, shifts, and call-ins.
- Work with individual groups to assure that response teams include the correct number and mix of talents and skills.

**Call in Lists:** *List of knowledgeable, on-call individuals responsible for resolving problems with specific systems.*

- Improve existing maintenance and troubleshooting call-in lists by making them easier to use;,provide quicker response, and ensure appropriate matching of individuals to the reported problems.

**Spares:** *Hardware required for maintenance, repair, and restoration of critical accelerator systems.*

- Identify critical components based on impact to machine availability, known failure rates, and availability of replacement parts.
- Collect, compare, and evaluate the lists of critical components to spare parts presently on hand. Individual responsible groups will need to support this activity by providing current spare parts lists and long term requirements.
- Identify storage problems and recommend solutions based on most appropriate methods.
- Review tracking systems required to locate components when needed, insure parts used are replenished in a timely manner, and to project future requirements.

# Resources

**Tools and Equipment:** *Items necessary to perform an operation or accomplish necessary work*

- Identify weaknesses in existing tool and equipment inventories, and make recommendations for supplementing existing items with purchased, rented, or leased equipment.
- Identify weakness in existing software tools and make recommendations for improvements or augmentation.

**Training:** *To make proficient with specialized instruction and practice.*

- Encourage training. To ensure maximum system availability, users and maintainers must be adequately trained to operate, diagnose, and maintain the systems. This will require specific training that varies with individual responsibility, and should include a formal procedure for maintenance as part of the training process.
- Encourage proficiency. Operators need to be knowledgeable, and individual groups must have backup teams and provide feedback to operators

**Funding:** *Financial resources necessary to accomplish required objectives.*

- Participate in determining funding levels required.

# Hardware/Software

**Maintenance:** *The act of preserving or keeping systems in good operating condition to maximize machine availability.*

- Recommend that individual groups verify that necessary maintenance procedures exist and are sufficiently comprehensive.
- Participate in the identification of routine maintenance activities.
- Assist in the development of maintenance activities which can be accomplished during unscheduled maintenance opportunities.
- Identify maintenance activities which cannot be fully checked until the machine is brought back to an operable state.

**Improvement:** *The act of making beneficial changes to systems*

- Improve baseline performance by feeding lessons learned back into the systems .

# Checkout

**Born in:** *Operation of systems under stressed conditions where possible with the intent of weeding out weak components or designs (infant mortalities).*

- Confirm that systems have been run as much as possible before general operation resumes.

**Integrated Operability from the MCC:** *Operation of the accelerator system and subsystems in their normal configuration using regular operational screens and controls.*

- Verify that systems are controllable and respond satisfactorily.
- Review the current integrated checkout plans and compare to available schedule and time period. Specifically, how will CEBAF assure system checkout plans are consistent with overall performance goals leading to the upcoming runs in November and February?

# Documentation

**Procedures:** *A series of steps required to accomplish a task.*

- Review policy for changing or improving existing procedures, and introducing new ones.
- Recommend that individual groups verify that necessary procedures exist and are sufficiently comprehensive.
- Solicit input for improvements to existing procedures.

# Scheduling

**Maintenance and Development:** *Time that must be reserved for restoration of systems to optimum levels, and for experiments designed to provide greater understanding of accelerator characteristics to improve performance.*

- Evaluate the effectiveness of existing scheduled maintenance plans with respect to program impact, efficient use of time, and ability to accomplish tasks in the allotted time.
- Reinforce the need to have maintenance, testing, and checkout included as part of the experimental program schedule.
- Review the ability of groups to respond to changes in the experimental program to take advantage of unscheduled downtime.

# Mechanisms for Improvements

- **Identify steps to achieve improvement.**

# Availability Budget

## ACCELERATOR SUBSYSTEM AVAILABILITY

| # | System | FY94 | FY95 | FY96 | FY97 | FY98 |
|---|---|---|---|---|---|---|
| 1 | RF system | 76.0% | 88.0% | 93.0% | 95.0% | 96.0% |
| 2 | Site power | 95.0% | 95.0% | 96.0% | 97.0% | 97.0% |
| 3 | Controls | 90.0% | 94.0% | 96.0% | 97.0% | 97.5% |
| 4 | Cryogenics | 82.0% | 93.0% | 95.0% | 97.0% | 98.0% |
| 5 | Cryomodules | 94.0% | 95.0% | 96.0% | 97.0% | 98.0% |
| 6 | Trim power supplies | 92.0% | 95.0% | 97.0% | 98.0% | 98.0% |
| 7 | Utilities (water, air, etc.) | 96.0% | 97.5% | 98.5% | 99.0% | 99.0% |
| 8 | Trim magnets | 98.0% | 98.0% | 98.5% | 99.0% | 99.0% |
| 9 | 0.5 MeV injector | 95.0% | 96.5% | 98.0% | 99.0% | 99.0% |
| 10 | Main dipoles & septums | 97.0% | 97.5% | 98.5% | 99.0% | 99.0% |
| 11 | Warm vacuum system | 95.0% | 98.0% | 98.5% | 99.0% | 99.0% |
| 12 | Main power supplies & shunts | 95.0% | 97.0% | 98.5% | 99.0% | 99.0% |
|  | Others | 97.2% | 97.6% | 98.7% | 99.2% | 99.4% |
|  | Total availability | 35.0% | 55.0% | 68.0% | 77.0% | 80.0% |

Others include:

Operator error.

CEBAF

*The Continuous Electron Beam Accelerator Facility*

[redacted]/Talks/Ops Review-5/92

28 May 1992

**Additions to availability budget table developed by** [redacted]

- Personnel safety system
- Machine protection system(s)
- Radiological equipment

August 3, 1993

Hardware Checkout & Reliability Team

# APPENDIX 5

## Analysis of Hardware Failure Frequency

CEBAF
*The Continuous Electron Beam Accelerator Facility*

**MEMORANDUM**

**Distribution:**

**To:** A.
Planning Team

**From:** Hardware Checkout and Reliability Team

**Subject:** Analysis of Hardware Failure Frequency during last run

**Date:** September 8, 1993

The attached information is for your use. The HC&RT has identified failures which caused machine downtime during the last run by collecting problems from the MCC Daily Activity Logbooks and the Safety System Logbooks as shown on the attached pages.

We recognize that this information is somewhat subjective, but taken as a whole help to identify high frequency failures which need closer attention. The attached graph(s) plot number of occurrences per item without weighing factors which as machine downtime, cost of repairs, impact to others, severity of problem, etc.

As CEBAF's trouble tracking and reporting system is developed, we hope to be able to draw out additional information.

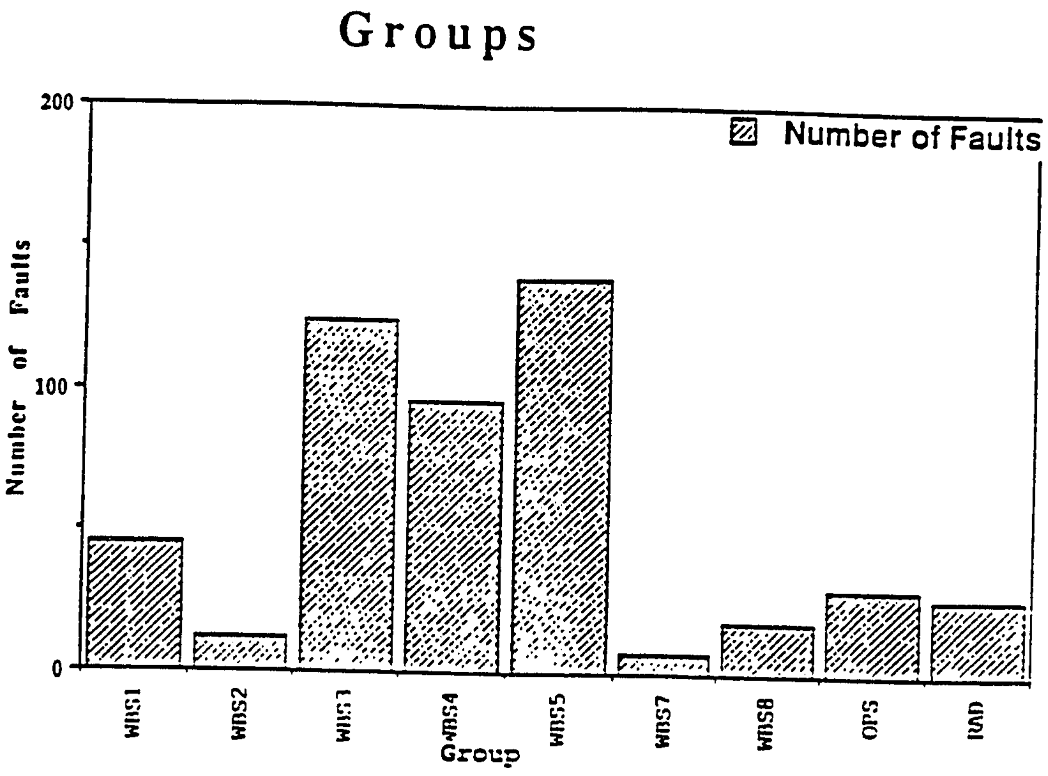
Many of the problems identified by this data have been addressed by the responsible groups in order to upgrade their equipment. Other items still need to be dealt with as soon as possible so that modifications can be made prior to our upcoming run in hope of improving both reliability and machine availability. The attached page highlights the areas of major concern and their present status.

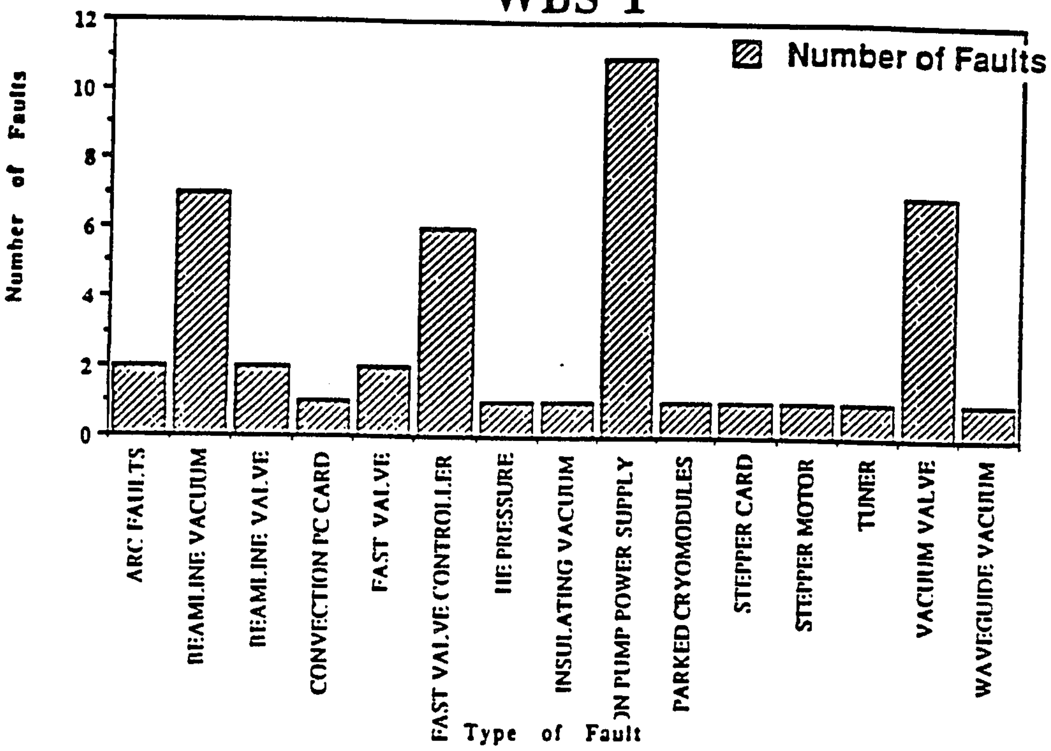
[This page was retyped by the researcher to give it sufficient left-hand margin to be bound in book form and still be readable.]

The following is a summary which highlights the major areas of concern and their present status for each subsystem.

| SUBSYSTEM | STATUS |
|---|---|
| WBS 1 | |
| Beam Line Vacuum | Unresolved. Multipler Issues. |
| Fast Valve Controller | Replaced card. No longer expected to be a problem. |
| Ion Pump Power Supply | Upgrade complete. |
| Vacuum Valves | Problem solved due to parked cryomodules and indeterminate position. |
| WBS 2 | |
| Vacuum Valves | Unresolved Indeterminate position problems. |
| WBS 3 | |
| Cables | New conformable cables. Probe cables cleaned. |
| Control Module | Numerous modifications. |
| Filament Board | Investigation revealed common mode of failure a chip of a certain date. Problems with earlier boards |
| Klystron | Nondestructive testing on poting. Results unavailable at this time. |
| Master Oscillator | Problem - crystal reference drifting. Crystal not aged enough. Redesigned & installed amplifier. |
| MOD Anode Board | Under investigation. |
| Phase Drift | Fiber Optic Reference Line to be installed in October. |
| WBS 4 | |
| Bulk Power Supply | Upgrade complete. |
| Scanner Card | Under investigation. |
| Trim Card | Initial upgrade complete; further study underway. |
| Utility Chasis | Upgrade complete. |
| WBS 5 | |
| BLM | Replace BLM heads, multiple issues corrected. |
| BPM | Arc electronics manufacturing problem corrected. Linac BPM's |

| SUBSYSTEM | STATUS |
|---|---|
| | unresolved. |
| CAMAC Crate | CAMAC power supplies. Repairs completed. |
| Computer | Multiple issues. |
| Computer Local | Multiple issues. |
| FSD | Hardware not upgraded. Software upgraded for machine in the future. Minor upgrade for injector startup. |
| Harp | Faulty PGA; noise; upgrade underway. |
| Safety System | Unresolved machine drop to power permit. |
| Star | Star crash unresolved |
| Viewer | Multiple issues. unresolved. |
| WBS 8 | |
| LCW | Mechanical upgrade under evaluation. Interlocks and alarms under review. |
| Site Power | Multiple issues. |
| Sump Pump | Unresolved float switch issue. |
| OPS | |
| 45 MEV Power Supply | Upgrade complete. |
| HPBD | Corrected interlock issues. |
| Injector Gun | Upgrade underway. |
| RAD | |
| CARMS | Unresolved machine drop to power permit. |

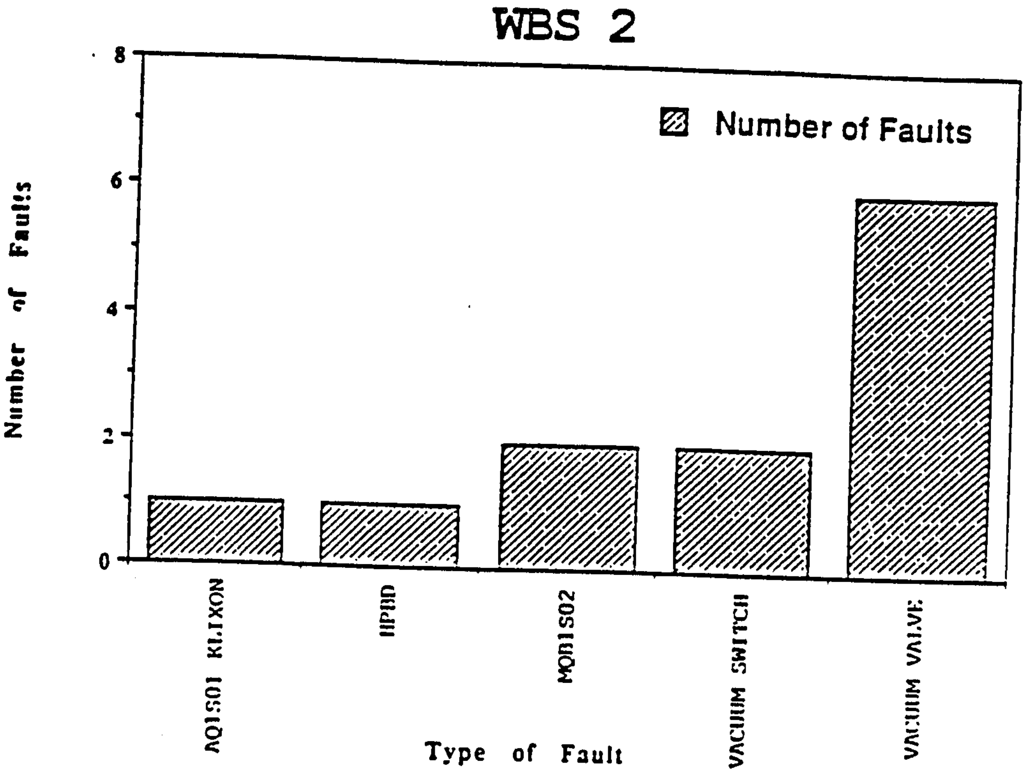

Groups
▨ Number of Faults
200
100
0
Number of Faults
WBS1
WBS2
WBS3
WBS4
WBS5
WBS7
WBS8
OPS
RAD
Group



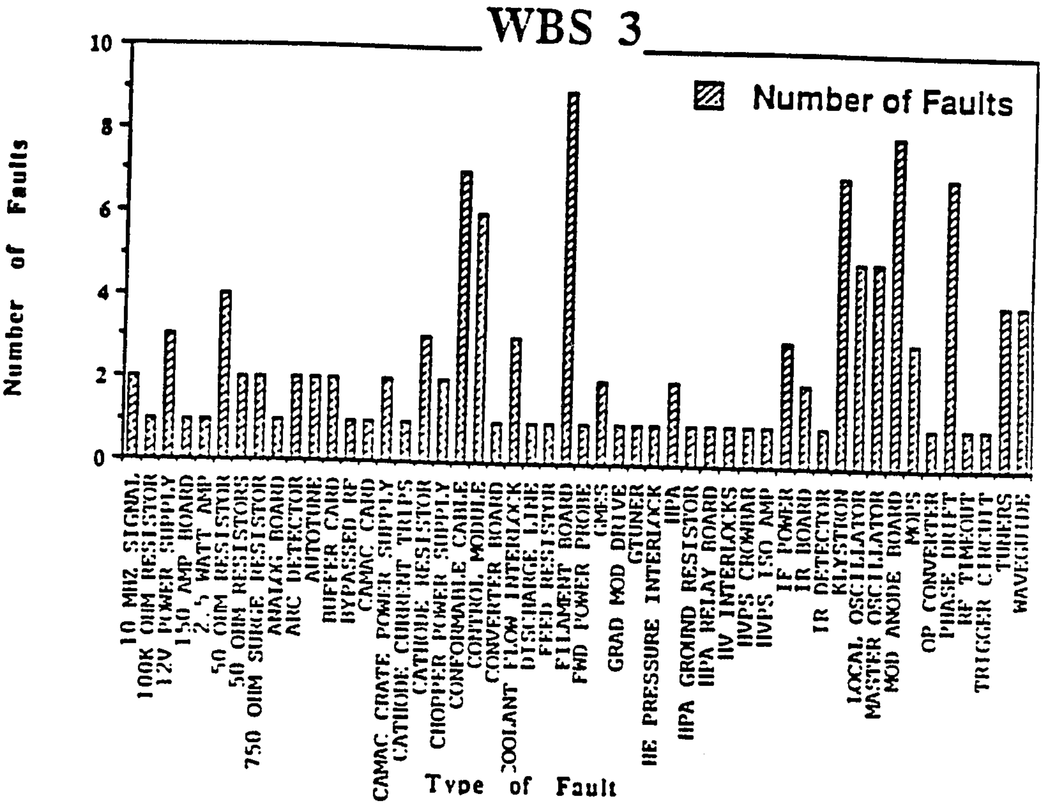
WBS 1

▨ Number of Faults
Number of Faults
0
2
4
6
8
10
12
ARC FAULTS
BEAMLINE VACUUM
BEAMLINE VALVE
CONVECTION PC CARD
FAST VALVE
FAST VALVE CONTROLLER
HE PRESSURE
INSULATING VACUUM
ON PUMP POWER SUPPLY
PARKED CRYOMODULES
STEPPER CARD
STEPPER MOTOR
TUNER
VACUUM VALVE
WAVEGUIDE VACUUM
Type of Fault

| Record# | BOOKPG | ITEM | DESCP |
|---|---|---|---|
| 8 | 12/83 | ARC FAULTS | 1L12-3 ARC FAULT |
| 9 | 12/31 | ARC FAULTS | 0L04-5,6 REPEATED ARC FAULTS |
| 10 | 13/51 | BEAMLINE VACUUM | 60PSI INTERLOCK WOULDN'T MAKE UP |
| 11 | 13/63 | BEAMLINE VACUUM | VIP0L430 RF PERMIT ICON ERROR WHEN VACUUM O.K. |
| 12 | 13/127 | BEAMLINE VALVE | VBV0103 STUCK INDETERMINANT STATE |
| 13 | 13/137 | BEAMLINE VALVE | VBV1L12A & VBV1L12B UNRESOLVED SIGNALS |
| 14 | 13/43 | BEAMLINE VACUUM | VBV1L01 WIRING PROBLEMS |
| 15 | 12/151 | CONVECTION PC CARD | RESET TRIP POINT TO AVOID CLOSING |
| 16 | 16/69 | FAST VALVE | 1L18A FAST VALVE TRIGGER FAULTY |
| 17 | 15/132 | FAST VALVE CONTROLLER | VFV1L18 FAST VALVE CONTROL CARD FAILURE |
| 18 | 13/41 | FAST VALVE CONTROLLER | NL VALVES CLOSED VPG1L09 TRIPPED |
| 19 | 12/160 | FAST VALVE CONTROLLER | BAD FAST VALVE CONTROLLER CARD |
| 20 | 12/153 | FAST VALVE CONTROLLER | 1L07810 BAD FAST VALVE CONTROLLER CARD |
| 21 | 13/57 | FAST VALVE | FAST VALVE WON'T LATCH OPEN |
| 22 | 13/48 | HE PRESSURE | 1L04 HE CIRCUIT PRESSURE TRANSDUCER FAILURE |
| 23 | 16/68 | INSULATING VACUUM | 1L03 TURBOPUMP VALVE CLOSED. INST. VACUUM DETERIORATES >HEAT LOAD |
| 24 | 12/143 | ION PUMP POWER SUPPLY | VIP1L1140 BAD |
| 25 | 15/41 | ION PUMP POWER SUPPLY | VIP1L19A TRIPPED OFF |
| 26 | 12/154 | ION PUMP POWER SUPPLY | VIP1L02A ION PUMP POWER SUPPLY FAILURE |
| 27 | 13/97 | ION PUMP POWER SUPPLY | VIP1L09B ION PUMP POWER SUPPLY FAILED |
| 28 | 15/129 | ION PUMP POWER SUPPLY | VIP1L08A ION PUMP POWER SUPPLY FAILURE |
| 29 | 15/81 | PARKED CRYOMODULES | VACUUM FAULTS AT PARKED CRYOMODULES |
| 30 | 14/119 | STEPPER CARD | IN04-3,4 STEPPER CARD FAILURE |
| 31 | 16/23 | STEPPER MOTOR | 1L03-4 STEPPER MOTOR NOT RESPONDING |
| 32 | 12/40 | TUNER | 1L7-3 TUNER RUN AWAY |
| 33 | 15/90 | BEAMLINE VACUUM | PARKED CROYOMODULES OUTGASSING TRIPS |
| 34 | 15/125 | BEAMLINE VACUUM | VIP1L07B LOST PERMIT. VALVES CLOSE. PARKED MODULE |
| 35 | 14/15 | BEAMLINE VACUUM | VACUUM LEAK (10-8TORR) AT PUMP DROP 1L19B |
| 36 | 16/6 | BEAMLINE VACUUM | PARKED MODULES CAUSING MANY VACUUM TRIPS |
| 37 | 13/53 | VACUUM VALVE | WBST VACUUM VALVES NOT OPENING. LOW INST. AIR PRESSURE |
| 38 | 16/7 | VACUUM VALVE | VFV1L18 NON-ANNUNCIATION ON VALVE SCREEN |
| 39 | 16/105 | VACUUM VALVE | VIP1L07B CLOSED. PARKED MODULE VACUUM FAULT. |
| 40 | 16/99 | VACUUM VALVE | VBV1L07A CLOSED. PARKED MODULE |
| 41 | 16/29 | VACUUM VALVE | INJ & NLINAC VACUUM VALVES CLOSED FOR NO APPARENT REASON |
| 42 | 15/111 | VACUUM VALVE | TROBLE OPENING VALVES: VFV1L18, VIP1L18A, VIP1L18B |
| 43 | 16/80 | VACUUM VALVE | 1L18 VACUUM VALVE TRIPPED |
| 44 | 12/46 | ION PUMP POWER SUPPLY | VALVES WON'T OPEN REMOTELY |
| 45 | 13/20 | FAST VALVE CONTROLLER | VFV1L02 CARD FAILURE, AGAIN |
| 46 | 13/20 | FAST VALVE CONTROLLER | VFV1L02 CARD FAILURE |
| 47 | 12/98 | ION PUMP POWER SUPPLY | BAD ION PUMP POWER SUPPLY |
| 48 | 14/34 | ION PUMP POWER SUPPLY | VIP1L0950 ION PUMP POWER SUPPLY FAILURE |
| 49 | 12/27 | ION PUMP POWER SUPPLY | ION PUMP POWER SUPPLY TRIPPED OFF |
| 50 | 12/116 | ION PUMP POWER SUPPLY | BAD ION PUMP POWER SUPPLY VIP1L0530 |
| 51 | 12/108 | ION PUMP POWER SUPPLY | WAVEGUIDE VACUUM FAULT/ ION PUMP POWER SUPPLY FUSE |
| 52 | 12/83 | WAVEGUIDE VACUUM | 1L11-1,2 WAVEGUIDE VACUUM FAULTS |


WBS 2
▨ Number of Faults
Number of Faults
0
2
4
6
8
AQ1S01 KLIXON
HPBD
MOB1S02
VACUUM SWITCH
VACUUM VALVE
Type of Fault

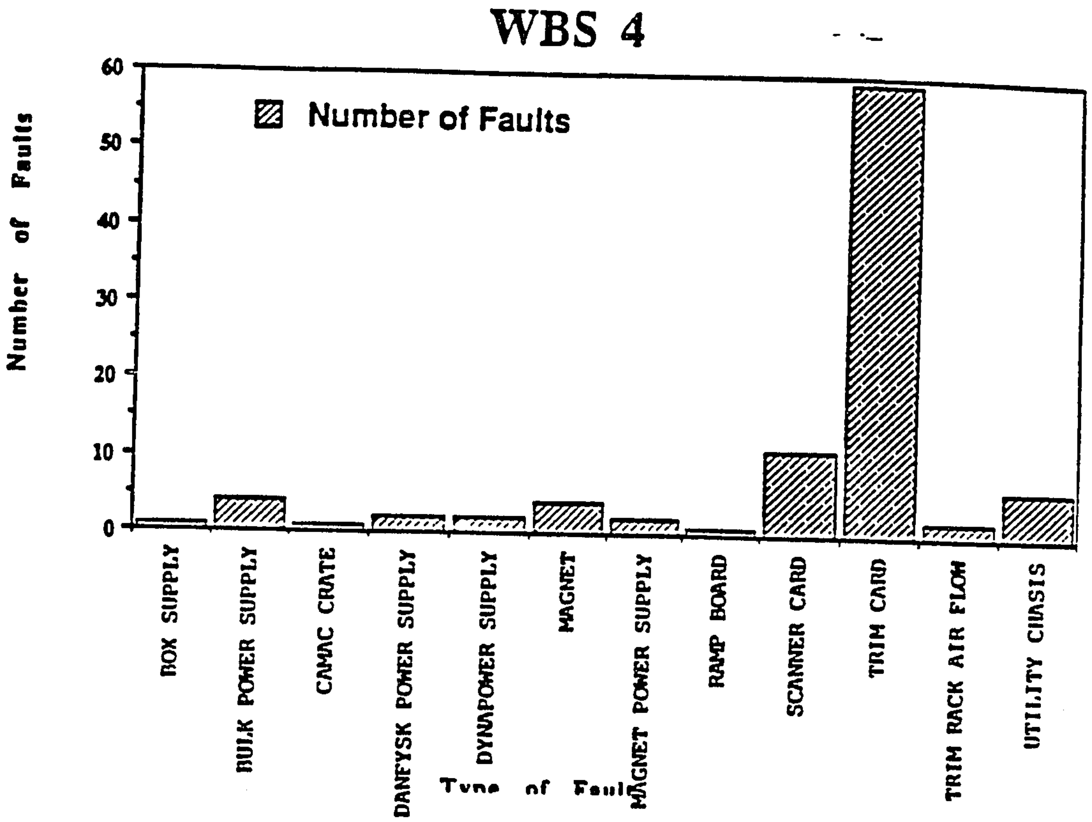
| Record# | BOOKPG | ITEM | DESCP |
|---|---|---|---|
| 53 | 14/16 | AQ1S01 KLIXON | AQ1S01 KLIXON WIRES BROKEN AND TWISTED TOGETHER |
| 54 | 13/129 | VACUUM SWITCH | VBV0103 LIMIT SWITCH FAILURE |
| 55 | 13/88 | HPBD | HIGH POWER BEAM DUMP FSD H2O CHASSIS WON'T CLEAR |
| 56 | 12/103 | MOB1S02 | PROBLEM CONTROLLING MAGNET MOB1S02 |
| 57 | 12/127 | MOB1S02 | INCORRECT POLARITY |
| 58 | 14/108 | VACUUM SWITCH | INTERMITTENT SIGNED FROM VACUUM VALVE POSITION MICROSWITCH |
| 59 | 12/96 | VACUUM VALVE | BEAMLINE VALUES AT 1A24 & 1A32 INDETERMINATE POSITION |
| 60 | 16/33 | VACUUM VALVE | VACUUM VALVES TO HPBD CLOSING W/OUT REASON |
| 61 | 16/3 | VACUUM VALVE | VBV0R07 BEAMLINE VALVE IN INDETERMINATE STATE |
| 62 | 16/51 | VACUUM VALVE | E101B02 VACUUM VALVE TRIPS/FSD |
| 63 | 12/34 | VACUUM VALVE | VALUE POSITION INDETERMINATE |
| 64 | 12/107 | VACUUM VALVE | EARC VACUUM VALUE VBV1A24T NOT PART OF FSD STRUCTURE |


WBS 3
▨ Number of Faults
Number of Faults
10
8
6
4
2
0
Type of Fault
10 MHZ SIGNAL
100K OHM RESISTOR
12V POWER SUPPLY
150 AMP BOARD
2.5 WATT AMP
50 OHM RESISTOR
50 OHM RESISTORS
750 OHM SURGE RESISTOR
ANALOG BOARD
ARC DETECTOR
AUTOTUNE
BUFFER CARD
BYPASSED RF
CAMAC CARD
CAMAC CRATE POWER SUPPLY
CATHODE CURRENT TRIPS
CATHODE RESISTOR
CHOPPER POWER SUPPLY
CONFORMABLE CABLE
CONTROL MODULE
CONVERTER BOARD
COOLANT FLOW INTERLOCK
DISCHARGE LINE
FEED RESISTOR
FILAMENT BOARD
FWD POWER PROBE
GMES
GRAD MOD DRIVE
GTUNER
HE PRESSURE INTERLOCK
HPA
HPA GROUND RESISTOR
HPA RELAY BOARD
HV INTERLOCKS
HVPS CROWBAR
HVPS ISO AMP
IF POWER
IR BOARD
IR DETECTOR
KLYSTRON
LOCAL OSCILLATOR
MASTER OSCILLATOR
MOD ANODE BOARD
MOPS
OP CONVERTER
PHASE DRIFT
RF TIMEOUT
TRIGGER CIRCUIT
TUNERS
WAVEGUIDE

| Record# | BOOKPG | | DESCP |
|---|---|---|---|
| 4 | SI 2/93 | HI. | DROPPED TO POWER PERMIT DUE TO HPA FAULT IN H. |
| 5 | SI 2/92 | HPA | DROPPED TO POWER PERMIT. THAN RESTRICTED ACCESS |
| 65 | 15/4 | 12V POWER SUPPLY | 1N03 COULD NOT BE CONTROLLED FROM MCC +,- 12V POWER SUPPLY FAILED |
| 66 | 12/132 | 12V POWER SUPPLY | 0L03 -12Volt POWER SUPPLY: NO OUTPUT VOLTAGE |
| 67 | 13/70 | PHASE DRIFT | NL 0 DRIFTS HELIAX TEMP, RF MODULE TEMP, MISMATCHED RESISTORS |
| 68 | 12/42 | PHASE DRIFT | 1L09 NOT REGULATING |
| 69 | 16/83 | 10 MHZ SIGNAL | 10 MHZ FAULT IN NLINAC. DC BLOCK MISSING |
| 70 | 16/38 | 10 MHZ SIGNAL | 1L05 10 MHZ CONNECTOR BAD |
| 71 | 16/52 | 150 AMP BOARD | 1L09 CPS VOL & I READBACK BOUNCE. RF TO IDLE. BAD 150 AMP BOARD |
| 72 | 12/39 | PHASE DRIFT | 30 DEG. 0 BOUNCE 1L04-7 |
| 73 | 12/395 | PHASE DRIFT | 30 DEG. BOUNCE 1L05-6 |
| 74 | 15/111 | 2.5 WATT AMP | |
| 75 | 14/150 | 50 OHM RESISTORS | 1L14-4 50 OHM KLYSTRON RESISTOR OPEN |
| 76 | 14/150 | 50 OHM RESISTORS | 1L12-1,7 5052 KLYSTRON RESISTORS OPEN |
| 77 | 14/143 | 750 OHM SURGE RESISTOR | 1L04,06,07 HVPS 750 OHM SURGE RESISTOR FAILED |
| 78 | 12/96 | ANALOG BOAP | 1L11-5 BAD ANALOG BOARD |
| 79 | 15/152 | ARC DETECTOR | 1L11-3 ARC FAULTS. DETECTOR & BUFFER CARD O.K. |
| 80 | 16/59 | ARC DETECTOR | 1L11-3 BAD ARC DETECTOR HEAD |
| 81 | 14/22 | AUTOTUNE | 1L02-6 TUNED OFF WHILE IN AUTOTUNE |
| 82 | 13/81 | AUTOTUNE | 1L05-2 CWL & CCWL FAULT SIMULTANEOUSLY |
| 83 | 12/149 | CONFORMABLE CABLE | 1L10-3 NO COMMUNICATION LOOSE BOARD CABLE |
| 84 | 13/50 | BUFFER CARD | NL07-3 BUFFER CARD FAILURE |
| 85 | 12/150 | BUFFER CARD | 1L03-5 BAD BUFFER CARD |
| 86 | 16/52 | BYPASSED RF | UNANNUNCIATING P1 FAULTS W/ BYPASSED CAVITIES |
| 87 | 15/3 | CAMAC CARD | 1L20, 1L21 CAMAC BUS LOCKED UP. WRONG ADDRESS CONTROLLER CARD |
| 151 | 15/151 | 100K OHM RESISTOR | 1N03-5 100K OHM LOAD RESISTOR OPEN |
| 152 | 12/20 | MASTER OSCILLATOR | 0 SHIFT DUE TO TEMPERATURE PRESSURE CHANGES |
| 153 | 15/111 | MASTER OSCILLATOR | MASTER OSCILLATOR BAD 499 MHZ P.L.L. |
| 154 | 12/25 | MASTER OSCILLATOR | UNSTABLE 10MHZ REFERENCE SIGNAL |
| 155 | 15/111 | MASTER OSCILLATOR | MASTER OSCILLATOR - HARMONICS ON 1497 MHZ |
| 156 | 12/104 | MASTER OSCILLATOR | 20 DEG 0 SHIFT IN NLINAC |
| 157 | 12/129 | MOD ANODE BOARD | 1L09-3 HIGH CATHODE CURRENT - BAD MODE ANODE BOARD |
| 158 | 15/39 | MOD ANODE BOARD | 1L02-3BURNED MOD ANODE BD.LOOSE CONNECTION ON KLYSTRON ANODE LEAD |
| 159 | 12/65 | MOD ANODE BOARD | 1L02-6 MOD ANODE BOARD FAILURE |
| 160 | 12/54 | MOD ANODE BOARD | 1L02-3 BAD MODE ANODE BOARD |
| 161 | 12/56 | MOD ANODE BOARD | 1L02-6 BAD MOD ANODE BOARD |
| 162 | 15/85 | MOD ANODE BOARD | 1L13-2 BAD MOD ANODE BOARD |
| 163 | 16/69 | MOD ANODE BOARD | 1N02-3 MOD ANODE FAILURE |
| 164 | 14/121 | MOD ANODE BOARD | 1N03-4 BAD MOD ANODE BOARD |
| 165 | 14/31 | MOPS | 1N01 5V MOPS FAILURE |
| 166 | 13/53 | MOPS | MOPS NL21 CIRCUIT BREAKER TRIPPED OFF |
| 167 | 14/93 | MOPS | 1N04 MOPS BLOWN FUSE |
| 168 | 16/98 | PHASE DRIFT | PHASE DRIFT IN NL CAUSING CW FSD TRIPS W/ BLM'S |
| 169 | 16/18 | OP CONVERTER | 1L16-8 BROKEN UPCONVERTER OUTPUT SPIGOT |
| 170 | 13/56 | 12V POWER SUPPLY | -12V POWER SUPPLY 1N03. INCORRECT OUTPUT |
| 171 | 15/64 | CONFORMABLE CABLE | 1L13-4 BAD PROBE CABLE |
| 172 | 14/106 | CONFORMABLE CABLE | 1N04-8 BAD CAVITY PROBE CABLE |
| 173 | 16/90 | CONFORMABLE CABLE | 1L04-7,8 DISCONNECTED CABLES |
| 174 | 16/90 | CONFORMABLE CABLE | 1L13-7 DISCONNECTED CABLES |
| 175 | 15/32 | CONTROL MODULE | 1N04-7,8 FAULTY RF CONTROL MODULES |
| 176 | 15/68 | CONTROL MODULE | 1L09-1RF MODULE - VACUUM FAULTS |
| 177 | 13/52 | RF TIMEOUT | RF FILAMENT TIME-OUT IN INJ TOO LONG |
| 178 | 15/68 | CONTROL MODULE | 1L09-1 RF MODULE HIGH GMOD LEVEL |
| 179 | 15/122 | TUNERS | 1L05-2,6 BLOWN STEPPER MOTOR FUSE |
| 180 | 16/80 | TUNERS | 1N04-1,2 BLOWN STEPPER FUSES |
| 181 | 14/150 | 750 OHM SURGE RESISTOR | 1L18 750 OHM SURGE RESISTOR OPEN |
| 182 | 15/109 | TRIGGER CIRCUIT | 1N04 TRIGGER CIRCUIT FAULTS |
| 183 | 16/33 | TUNERS | 1L05-4 TUNER FUSE BLOWN |
| 184 | 12/40 | TUNERS | TUNERS NOT RESPONDING. BLOWN FUSES. |
| 185 | 16/83 | WAVEGUIDE | 1N02 LOW WAVEGUIDE PRESSURE |
| 186 | 12/116 | WAVEGUIDE | LOW WAVEGUIDE PRESSURE 1L11 |
| 187 | SI 2/99 | WAVEGUIDE | WAVEGUIDE HOOK-UP CAUSED AN AIR PRESSURE FAULT |
| 188 | SI 3/2 | WAVEGUIDE | CONROL ACCESS - WAVEGUIDE REPAIR |

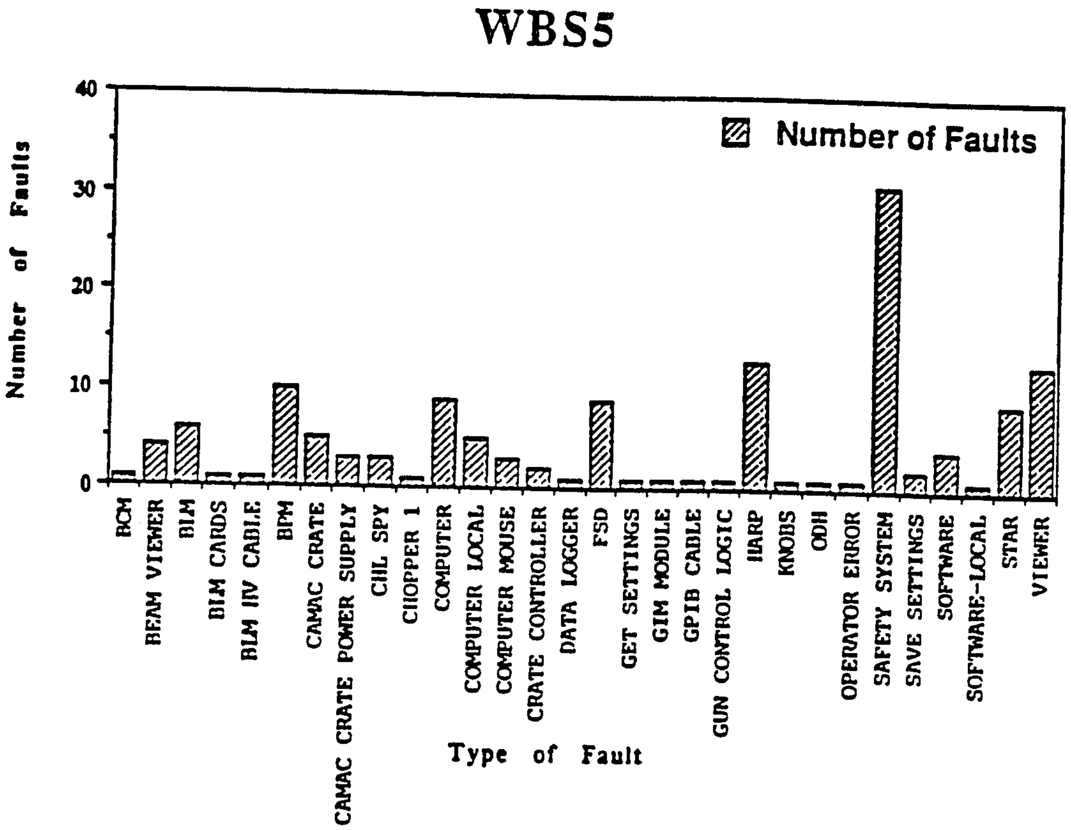
| | | | |
|---|---|---|---|
| 88 | 13/16 | AC CRATE POWER SUPPLY | 1L11-7 FAULTY. CAMAC CRATE POWER SUPPLY FAI. |
| 89 | 13/88 | CAMAC CRATE POWER SUPPLY | NL17 BAD CAMAC POWER SUPPLY |
| 90 | 13/53 | FILAMENT BOARD | CAPTURE FILAMENT VOLTAGE LOW (6.3v) |
| 91 | 12/117 | CATHODE CURRENT TRIPS | 1L09-3 CATHODE CURRENT TRIPS |
| 92 | 15/151 | CATHODE RESISTOR | 1L04-3 50 OHM CATHODE RESISTOR OPEN |
| 93 | 15/151 | CATHODE RESISTOR | 1L17-6 50 OHM CATHODE RESISTOR OPEN |
| 94 | 14/73 | CHOPPER POWER SUPPLY | CHOPPER 1 POWER SUPPLY +15V FAILURE HIGH RIPPLE |
| 95 | 16/103 | CHOPPER POWER SUPPLY | CHOPPER 2 PHASE MOD DRIVE FAULTY |
| 96 | 13/54 | CONFORMABLE CABLE | 1L10-5 KLYSTRON DRIVE INPUT CONFORMABLE CENTER PIN DAMAGED |
| 97 | 12/132 | CONFORMABLE CABLE | 1L09-5 CONFORMABLE CABLE DAMAGED |
| 98 | 12/48 | CONTROL MODULE | FAULTY CONTROL MODULE 119-6 |
| 99 | 15/50 | CONTROL MODULE | 1L12-4 NO PHASE OR AMPLITUDE LOCK. FAULTY MODULE |
| 100 | 16/53 | CONTROL MODULE | 1L09-1 HIGH (30KW) FORWARD REFLECTED POWER |
| 101 | 13/59 | CONVERTER BOARD | 1L12-1,2 50 OHM LOAD MISSING |
| 102 | 15/151 | COOLANT FLOW INTERLOCK | 1L10 COOLANT FLOW INTERLOCK FAULT |
| 103 | 12/129 | COOLANT FLOW INTERLOCK | 1L12 COOLANT FAULT - BAD PRESSURE SWITCH |
| 104 | 15/61 | COOLANT FLOW INTERLOCK | 1N04 FAULTS. NO DIAGNOSTICS |
| 105 | 15/85 | CATHODE RESISTOR | 1L13-2 OPEN CPS 50 OHM RESISTOR #2 |
| 106 | 14/150 | DISCHARGE LINE | 1L15 DISCHARGE LINE JUMPER FROM RESISTOR MISSING |
| 107 | 14/149 | FEED RESISTOR | 1L03-3 FEED RESISTOR FAILURE. CABLES MELTED |
| 108 | 13/51 | FILAMENT BOARD | 1N02-4 FILAMENT BOARD LOW FILAMENT VOLTAGE |
| 109 | 12/44 | FILAMENT BOARD | FILAMENT BOARD FAILURE |
| 110 | 12/97 | FILAMENT BOARD | 1L11-7 EXCESSIVE BODY CURRENT |
| 111 | 15/2 | FILAMENT BOARD | 1L11-1 NO FILAMENT VOLTAGE. BAD FILAMENT BOARD |
| 112 | 12/90 | FILAMENT BOARD | 1L11-1 BAD FILAMENT BOARD |
| 113 | 12/40 | FILAMENT BOARD | 1L11-5 BAD FILAMENT BOARD |
| 114 | 12/89 | FILAMENT BOARD | 1L07-1 BAD FILAMENT POWER SUPPLY BOARD |
| 115 | 13/17 | FILAMENT BOARD | 1L08-6 LOW FILAMENT VOLTAGE. BAD MOD DRIVE. BAD FILAMENT BOARD |
| 116 | 12/128 | FWD POWER PROBE | 1L02-5 FWD POWER PROBE - BENT IN |
| 117 | 12/40 | GMES | GMES NOT TRACKING |
| 118 | 12/40 | GMES | GMES NOT TRACKING |
| 119 | 12/100 | GRAD MOD DRIVE | 1L09-3 OSCILLATING GRAD MOD DRIVE |
| 120 | 13/151 | GTUNER | 1N03-3,4 TUNERS CANNOT BE STEPPED FROM MCC |
| 121 | 13/52 | HE PRESSURE INTERLOCK | INCORRECT HE PRESSURE SETPOINT 50MBAR VS 70MBAR |
| 122 | 15/151 | HPA GROUND RESISTOR | 1L08 50 OHM RESISTOR FOR HPA REAR DOOR GROUNDING POINT MISSING |
| 123 | 12/128 | HPA RELAY BOARD | 1L09 HPA RELAY BOARD FAILURE |
| 124 | 13/123 | HV INTERLOCKS | HV INTERLOCKS WON'T MAKE UP |
| 125 | 15/34 | HVPS CROWBAR | 1N04-1,4 CROWBAR FIRING. BAD CR1, SUSPECT METAL OXIDE |
| 126 | 15/16 | HVPS ISO AMP | 1N04 CROWBAR FIRING, OVERCURRENT. ISOAMP BOARD C1 C4 C7 C10 |
| 127 | 13/96 | IF POWER | NO IF IN NL |
| 128 | 12/43 | IF POWER | LOW IF POWER |
| 129 | 16/107 | IF POWER | IF POWER LOW IN NL |
| 130 | 14/34 | PHASE DRIFT | 1N01-2 MODULE. NO PHASE LOCK |
| 131 | 14/31 | PHASE DRIFT | 1N01-2 MODULE 'Y' FAILURE |
| 132 | 16/80 | IR BOARD | 1L10-5 IR TRIPS. BAD IR BOARD |
| 133 | 13/51 | IR BOARD | NL13 IR CARD MISSING |
| 134 | 16/81 | IR DETECTOR | 1N04-7,8 IR FAULTS |
| 135 | 15/151 | KLYSTRON | 1L07-4 BROKEN CATHODE GROUND CONNECTION |
| 136 | 16/69 | KLYSTRON | KLYSTRON FAILURE |
| 137 | 15/39 | KLYSTRON | 1N04-4 BAD KLYSTRON |
| 138 | 15/151 | KLYSTRON | LOOSE BULLET FOR RF INPUT TUBE |
| 139 | 16/95 | KLYSTRON | 1N03-8 MOD ANODE VOLTAGE RAILED. NO CATHODE CURRENT. BAD KLYSTRON |
| 140 | 15/24 | KLYSTRON | 1L12-4 KLYSTRON OPEN FILAMENT |
| 141 | 16/10 | KLYSTRON | 1L11-6 KLYSTRON OPEN FILAMENT |
| 142 | 13/96 | LOCAL OSCILLATOR | NO L.O. IN NLINAC |
| 143 | 15/4 | LOCAL OSCILLATOR | INJ. LOCAL OSCILLATOR MISSING L.O. AMP OFF |
| 144 | 12/65 | LOCAL OSCILLATOR | LOW L.O. POWER |
| 145 | 12/137 | LOCAL OSCILLATOR | 1L07-3 LOW LO POWER CABLE LOOSE |
| 146 | 14/143 | 50 OHM RESISTOR | 1L03-3 LOAD RESISTOR FAILURE; CATHODE POWER SUPPLY |
| 147 | 14/150 | 50 OHM RESISTOR | 1L16-6 KLYSTRON LOAD RESISTOR OPEN |
| 148 | 15/151 | 50 OHM RESISTOR | 1L04-5 100K OHM RESISTOR OPEN |
| 149 | 14/149 | 50 OHM RESISTOR | 1L10-3 FAILED KLYSTRON LOAD RESISTOR |
| 150 | 12/33 | LOCAL OSCILLATOR | LOCAL OSCILLATOR IN NLINAC POWER OSCILLATIONS |

| Record# | BOOKPG | ITEM | DESCP |
|---|---|---|---|
| 189 | 13/54 | BOX SUPPLY | FAULTY COMMUNICATION MCC TO SAB |
| 190 | 12/137 | BULK POWER SUPPLY | E301B13 - BULK SUPPLY ERROR INDICATION |
| 191 | 12/43 | BULK POWER SUPPLY | BAUD BULK POWER SUPPLY E301B12 |
| 192 | 15/16 | BULK POWER SUPPLY | E3B13 - BULK POWER SUPPLY FAILED |
| 193 | 13/96 | BULK POWER SUPPLY | E3B13 BAD - BULK POWER SUPPLY |
| 194 | 16/64 | CAMAC CRATE | 1L01 MAGNET CAMAC CRATE HUNG UP |
| 195 | 14/22 | DANFYSK POWER SUPPLY | DANFYSIC POWER SUPPLY CONTROL CARD FAILURE |
| 196 | 13/16 | DANFYSK POWER SUPPLY | FAULTY DOUBLE EPROM |
| 197 | 12/133 | DYNAPOWER SUPPLY | BROKEN WIRE ON LOCAL/REMOTE SWITCH |
| 198 | 14/4 | DYNAPOWER SUPPLY | NL SPECTOMETER DYNAPOWER SUPPLY TRIPPING OFF |
| 199 | 13/54 | MAGNET | MOB1L14 - NO MEASURED CURRENT |
| 200 | 13/74 | MAGNET | MB11L16H INTERMITTENT CABLE SPLICE |
| 201 | 15/41 | MAGNET | MB10502H NOCONTINUITY IN LOADS TO MAGNET |
| 202 | 16/2 | MAGNET | MANY RESETABLE FAULTS |
| 203 | 14/20 | MAGNET POWER SUPPLY | ME101B11, ME101B12 POWER SUPPLY NOT FUNCTIONING |
| 204 | 13/58 | MAGNET POWER SUPPLY | DYNAPOWER POWER SUPPLY 1L26 NOT RESPONDING |
| 205 | 12/31 | TRIM CARD | MAGNET NOT AFFECTING BEAM - POSSIBLE SHORT |
| 206 | 12/98 | TRIM CARD | MAGNET CURRENT SETTING CHANGED |
| 207 | 14/127 | RAMP BOARD | NL27B19 RAMP BOARD INTERMITTENT FAILURE |
| 208 | 15/5 | SCANNER CARD | E-2 BLDG SCANNER BOARD WOULD NOT RESET |
| 209 | 12/132 | SCANNER CARD | E1 RACK 11 BAD SCANNER CARD |
| 210 | 16/89 | SCANNER CARD | IN04B10-19 MAGNETS FAULTING |
| 211 | 13/62 | SCANNER CARD | NL27B19,20,21 MAGNETS UNRESPONSIVE |
| 276 | 12/43 | TRIM CARD | TRIM CARDS OVERHEATING |
| 277 | 13/25 | TRIM RACK AIR FLOW | E201B12 TRIM RACK AIR FLOW FAULT |
| 278 | 13/25 | TRIM RACK AIR FLOW | E201B09 TRIM RACK AIR FLOW FAULT |
| 279 | 16/89 | UTILITY CHASIS | IN04B10 BAD UTILITY CHASIS +5V |
| 280 | 15/5 | UTILITY CHASIS | 1L09B10 +5V FAILED |
| 281 | 15/16 | UTILITY CHASIS | UTILITY CHASIS FAILED |
| 282 | 14/112 | UTILITY CHASIS | NL27B19 UTILITY CHASIS +5V FAILURE |
| 283 | 15/5 | UTILITY CHASIS | 1E101B11 +24V FAILED |
| 284 | 14/4 | UTILITY CHASIS | NL27B19 BAD UTILITY CHASSIS |


WBS 4
Number of Faults
Number of Faults
60
50
40
30
20
10
0
BOX SUPPLY
BULK POWER SUPPLY
CAMAC CRATE
DANFYSK POWER SUPPLY
DYNAPOWER SUPPLY
MAGNET
MAGNET POWER SUPPLY
RAMP BOARD
SCANNER CARD
TRIM CARD
TRIM RACK AIR FLOW
UTILITY CHASIS
Type of Fault

| Record# | BOOKPG | ITEM | DESCP |
|---|---|---|---|
| 189 | 13/54 | BOX SUPPLY | FAULTY COMMINICATION MCC TO SAR |
| 190 | 12/137 | BULK POWER SUPPLY | E301B13 - BULK SUPPLY ERROR INDICATION |
| 191 | 12/43 | BULK POWER SUPPLY | BAID BULK POWER SUPPLY E301812 |
| 192 | 15/16 | BULK POWER SUPPLY | E3B13 - BULK POWER SUPPLY FAILED |
| 193 | 13/96 | BULK POWER SUPPLY | E3B13 BAD - BULK POWER SUPPLY |
| 194 | 16/64 | CAMAC CRATE | 1L01 MAGNET CAMAC CRATE HUNG UP |
| 195 | 14/22 | DANFYSK POWER SUPPLY | DANFYSIC POWER SUPPLY CONTROL CARD FAILURE |
| 196 | 13/16 | DANFYSK POWER SUPPLY | FAULTY DOUBLE EPROM |
| 197 | 12/133 | DYNAPOWER SUPPLY | BROKEN WIRE ON LOCAL/REMOTE SWITCH |
| 198 | 14/4 | DYNAPOWER SUPPLY | NL SPECTOMETER DYNAPOWER SUPPLY TRIPPING OFF |
| 199 | 13/54 | MAGNET | MQ81L14 - NO MEASURED CURRENT |
| 200 | 13/74 | MAGNET | MB11L16H INTERMITTENT CABLE SPLICE |
| 201 | 15/41 | MAGNET | MB10502H NOCONTINUITY IN LOADS TO MAGNET |
| 202 | 16/2 | MAGNET | MANY RESETABLE FAULTS |
| 203 | 14/20 | MAGNET POWER SUPPLY | ME101B11, ME101B12 POWER SUPPLY NOT FUNCTIONING |
| 204 | 13/58 | MAGNET POWER SUPPLY | DYNAPOWER POWER SUPPLY 1L26 NOT RESPONDING |
| 205 | 12/31 | TRIM CARD | MAGNET NOT AFFECTING BEAM - POSSIBLE SHORT |
| 206 | 12/98 | TRIM CARD | MAGNET CURRENT SETTING CHANGED |
| 207 | 14/127 | RAMP BOARD | ML27819 RAMP BOARD INTERMITTENT FAILURE |
| 208 | 15/5 | SCANNER CARD | E-2 BLDG SCANNER BOARD WOULD NOT RESET |
| 209 | 12/132 | SCANNER CARD | E1 RACK 11 BAD SCANNER CARD |
| 210 | 16/89 | SCANNER CARD | IN04810-19 MAGNETS FAULTING |
| 211 | 13/62 | SCANNER CARD | NL27819,20,21 MAGNETS UNRESPONSIVE |
| 276 | 12/43 | TRIM CARD | TRIM CARDS OVERHEATING |
| 277 | 13/25 | TRIM RACK AIR FLOW | E201812 TRIM RACK AIR FLOW FAULT |
| 278 | 13/25 | TRIM RACK AIR FLOW | E201809 TRIM RACK AIR FLOW FAULT |
| 279 | 16/89 | UTILITY CHASIS | IN04810 BAD UTILITY CHASIS +5V |
| 280 | 15/5 | UTILITY CHASIS | 1L09810 +5V FAILED |
| 281 | 15/16 | UTILITY CHASIS | UTILITY CHASIS FAILED |
| 282 | 14/112 | UTILITY CHASIS | NL27819 UTILITY CHASIS +5V FAILURE |
| 283 | 15/5 | UTILITY CHASIS | 1E101811 +24V FAILED |
| 284 | 14/4 | UTILITY CHASIS | NL27819 BAD UTILITY CHASSIS |

| | | | |
|---|---|---|---|
| 212 | 12/72 | SCANNER CARD | SCANNER CARD FAILURE E201812 |
| 213 | 15/108 | SCANNER CARD | E101811 SCANNER MODULE BIRA 200 FAILED |
| 214 | 14/22 | SCANNER CARD | FAULTY BIRA SCANNER MODULE 1L27 |
| 215 | 15/17 | SCANNER CARD | 1L19809 SCANNER BOARD COMMUNICATION FAULTS |
| 216 | 15/20 | SCANNER CARD | E4811 TRIM SYSTEM SCANNER MODULE FAULTY |
| 217 | 15/119 | SCANNER CARD | 1L19810 SCANNER MODULE FAILURE |
| 218 | 15/16 | SCANNER CARD | E1811 SCANNER MODULE FOR TRIM SYSTEM FAILED |
| 220 | 15/35 | TRIM CARD | 1L27819-18 FAULTY NO RESPONSE |
| 221 | 15/35 | TRIM CARD | 1L19809-1 FAULTY NO RESPONSE |
| 222 | 15/5 | TRIM CARD | 1L27820-18 FAILED |
| 223 | 15/35 | TRIM CARD | E101811-5 FAULTY NO RESPONSE |
| 224 | 15/5 | TRIM CARD | 1L27821-29 FAILED |
| 225 | 15/5 | TRIM CARD | 1L27819-24 FAILED |
| 226 | 15/5 | TRIM CARD | 1L27821-23 FAILED |
| 227 | 15/5 | TRIM CARD | 1L19809-9 FAILED |
| 228 | 15/5 | TRIM CARD | E401812-18 FAILED |
| 229 | 15/83 | TRIM CARD | E101812-2 BOARD OVERHEAT |
| 230 | 15/59 | TRIM CARD | E201809-24 FAULTY |
| 231 | 15/5 | TRIM CARD | 1L27821 FAILED |
| 232 | 15/5 | TRIM CARD | 1L01 801-21 FAILED |
| 233 | 15/5 | TRIM CARD | 1L27819-7 FAILED |
| 234 | 13/42 | TRIM CARD | M865507V TRIM CARD FAILED FULL ON. ME101811 Ch.8 |
| 235 | 15/87 | TRIM CARD | MQ81S09 |
| 236 | 14/36 | TRIM CARD | NL27819 SLOT 15 BLOCK OVERHEATED |
| 237 | 13/96 | TRIM CARD | NL27819 CH15 BAD CARD |
| 238 | 15/108 | TRIM CARD | E101811-20 NO RESETABILITY |
| 239 | 15/87 | TRIM CARD | MQ81S10 |
| 240 | 13/54 | TRIM CARD | NL09810 SLOT 9 BOARD OVERHEAT #1775 |
| 241 | 15/108 | TRIM CARD | 1L27820-18 BOARD OVERHEAT |
| 242 | 13/74 | TRIM CARD | NL19809 CH3, MBT1L15V ANALOG BLOCK FAILURE |
| 243 | 15/112 | TRIM CARD | QB81S10 FAILED |
| 244 | 15/68 | TRIM CARD | E101811-25 FAILED MQ81S07 |
| 245 | 13/25 | TRIM CARD | E101812 SLOT 8 MQ81S10 TRIM CARD FAILURE |
| 246 | 15/108 | TRIM CARD | E101811-1 ERRATIC STATUS ERRORS |
| 247 | 15/122 | TRIM CARD | 1L27819-26 RESET READY FAULT BLOWN FUSE |
| 248 | 15/108 | TRIM CARD | E101812-8 NO POWER SET |
| 249 | 12/117 | TRIM CARD | BAD TRIM CARD FOR MQ81S07 |
| 250 | 12/52 | TRIM CARD | MAGNET FAULT. MBT1L25N |
| 251 | 16/21 | TRIM CARD | IN04810-25 FAILURE |
| 252 | 13/17 | TRIM CARD | 1L09810 SLOT 23. MBT1L12V TRIM CARD FAILURE |
| 253 | 16/21 | TRIM CARD | IN04810-27 FAILURE |
| 254 | 12/46 | TRIM CARD | MAGNET FAULT QB1S02 |
| 255 | 12/132 | TRIM CARD | E1 Slot 17 BAD TRIM CARD |
| 256 | 12/49 | TRIM CARD | FAULTY TRIM CARD NL27821 Ch26. KILLED COMMUNICATION |
| 257 | 12/128 | TRIM CARD | QB1A24 TRIM CARD WOULON'T PROGRAM |
| 258 | 13/1 | TRIM CARD | E301812 SLOT 12 TRIM CARD FAILURE |
| 259 | 12/146 | TRIM CARD | E 301 813 Slot 24 (MOA9A11) TRIM CARD FAILURE |
| 260 | 16/89 | TRIM CARD | IN04810-4 TRIM CARD FAULTY |
| 261 | 16/89 | TRIM CARD | IN04810-30 TRIM CARD FAULTY |
| 262 | 16/89 | TRIM CARD | IN04810-5 TRIM CARD FAULTY |
| 263 | 13/62 | TRIM CARD | NL19809 CH7; MBT1L16N TRIM CARD FAILURE |
| 264 | 16/89 | TRIM CARD | IN04810-25 TRIM CARD FAULTY |
| 265 | 12/93 | TRIM CARD | BAD TRIM CARD E301813 CH12 |
| 266 | 12/154 | TRIM CARD | E501811 SLOT 30 TRIM CARD FAILURE |
| 267 | 16/89 | TRIM CARD | IN04810-12 TRIM CARD FAULTY |
| 268 | 16/89 | TRIM CARD | IN04810-21 TRIM CARD FAULTY |
| 269 | 16/89 | TRIM CARD | IN04810-23 TRIM CARD FAULTY |
| 270 | 16/89 | TRIM CARD | IN04810-31 TRIM CARD FAULTY |
| 271 | 16/89 | TRIM CARD | IN04810-24 TRIM CARD FAULTY |
| 272 | 12/136 | TRIM CARD | 1L27820 SLOT 25 BAD TRIM CARD |
| 273 | 14/106 | TRIM CARD | MBT1L07V WON'T RESPOND |
| 274 | 12/146 | TRIM CARD | 1L27820 Slot 30 MQ19S01 TRIM CARD FAILURE |
| 275 | 16/89 | TRIM CARD | IN04810-6 TRIM CARD FAULTY |


WBS5
Number of Faults
▨ Number of Faults
40
30
20
10
0
BCM
BEAM VIEWER
BLM
BLM CARDS
BLM HV CABLE
BPM
CAMAC CRATE
CAMAC CRATE POWER SUPPLY
CHL SPY
CHOPPER 1
COMPUTER
COMPUTER LOCAL
COMPUTER MOUSE
CRATE CONTROLLER
DATA LOGGER
FSD
GET SETTINGS
GIM MODULE
GPIB CABLE
GUN CONTROL LOGIC
HARP
KNOBS
ODH
OPERATOR ERROR
SAFETY SYSTEM
SAVE SETTINGS
SOFTWARE
SOFTWARE-LOCAL
STAR
VIEWER
Type of Fault

| Record# | BOOKPG | ITEM | DESCP |
|---|---|---|---|
| 1 | SL2/90 | BLM | REPLACED BLM HEAD |
| 2 | SL2/80 | BPM | BPM ELECTRONICS REPLACEMENT |
| 3 | SL2/81 | CAMAC CRATE | SERVICED A CAMAC CRATE IN ZONE NL02 |
| 7 | SL2/74 | OPERATOR ERROR | WEST ARC GATE #2 OPEN. |
| 285 | 15/137 | BCM | MISLABLE IN03B06 BCC INPUT 2 TO IN03B07 |
| 286 | 13/48 | BEAM VIEWER | ITV1L20 NO TARGET (FLAG) CAMERA O.K. |
| 287 | 14/10 | BEAM VIEWER | ITV1L25 & ITV1L26 VIEWER BRIGHT & OBSCURED |
| 288 | 14/31 | BEAM VIEWER | IST01062 (AFTER CAPTURE) NO VIEWER LIGHT |
| 289 | 14/4 | BEAM VIEWER | ITV1L021 LIGHT BURNED OUT |
| 290 | 15/79 | BLM | BLM 1600 FAILED HEAD |
| 291 | 13/14 | BLM | 1L10 SHV CONNECTORS - RECESSED CONDUCTORS |
| 292 | 16/38 | BLM | BLM 24 CONSTANTLY FAULTING |
| 293 | 16/83 | BLM | BLM # 22, 23, 57 SPONTANEOUS TRIP. NO BEAM. |
| 294 | 13/137 | BLM CARDS | E5 BLM CARDS OVERVOLTAGE CAUSING DAC FAILURE |
| 295 | 12/128 | BLM | Bad BLM Head - ARC OVER AT 900V |
| 296 | 12/128 | BLM HV CABLE | BLM STATION 1668 BAD HV CABLE |
| 297 | 12/128 | BPM | BPM ELECTRONICS FAILURE 1BPM 1S03 1S07 1A05 1A06 1A10 1A13 1A14 |
| 298 | 16/69 | BPM | 45MEV SPECTROMETER BPM. AUTOCAL LEVEL SIGNAL PROBLEM |
| 299 | 12/37 | BPM | 60HZ NOISE ON BPM SIGNALS. POSSIBLY FLUORESCENT LIGHTS. |
| 300 | 15/09 | BPM | IPM1A24 BAD B0007 BOARD |
| 301 | 14/32 | BPM | X+X- TUNNEL ELECTRONICS REVERSED X,Y OUTPUTS REVERSED |
| 302 | 16/115 | BPM | IPM1S01 NOT UPDATING. BEAM SYNC. DISCONNECTED |
| 303 | 15/68 | BPM | BPM NO OP 1S01 1S02 1S05 1E02 1A03, 01, 08, 07, 14, 18, 19, 26,28 |
| 304 | 13/59 | BPM | IPMOL082 INJ.BPM CAMAC CONFIGURATION ERROR |
| 305 | 12/67 | CAMAC CRATE | 1L02 CRATE OVERHEAT |
| 306 | 12/85 | CAMAC CRATE | 1L02-B12 FAULTY CRATE NO 6V |
| 307 | 16/36 | CAMAC CRATE | IN02B05 CAMAC CRATE FAILURE |
| 308 | 12/145 | CAMAC CRATE | IN03B05 CRATE CONTROLLER BAD |
| 309 | 13/135 | CAMAC CRATE POWER SUPPLY | E501B05-29 +12V CAMAC POWER SUPPLY FAILED +23.8V |
| 310 | 14/69 | CAMAC CRATE POWER SUPPLY | BAD CRATE CONTROLLER POWER SUPPLY E4 BPM ADDRESS #12 |
| 311 | 14/129 | CAMAC CRATE POWER SUPPLY | E201B05 ADDRESS 12. BAD CRATE POWER SUPPLY |
| 312 | 13/54 | CHL SPY | CHL Gaurd SCREEN NOT UPDATING |
| 313 | 16/13 | CHOPPER 1 | CHOPPER 1 GRADIENT SET CONNECTED TO KNOB 1 ON BLM SCREEN |
| 314 | 16/65 | COMPUTER | FSDEA UNRESOLVED |
| 315 | 16/83 | COMPUTER | MC02 CRASHED |
| 316 | 16/110 | COMPUTER | TURING SELF CLOSES AND RESTARTS |
| 317 | 16/126 | COMPUTER | TURING LAN CARD |
| 318 | 16/90 | COMPUTER | TURING AUTOMATICALLY REBOOTS |
| 319 | 16/31 | COMPUTER | TURRING CRASHED |
| 320 | 16/110 | COMPUTER LOCAL | LOCAL COMPUTER E01 LOCKED UP |
| 321 | 16/1 | COMPUTER LOCAL | 1L06 UNRESOLVED SIGNALS |
| 322 | 16/65 | COMPUTER MOUSE | TURING MOUSE HUNG UP |
| 323 | 16/30 | COMPUTER MOUSE | HOPPER MOUSE LOST |
| 324 | 16/99 | COMPUTER LOCAL | NL6 HUNG UP |
| 325 | 15/132 | COMPUTER | MAJOR COMPUTER CRASH. MAY HAVE BEEN RESULT OF UPS SYSTEM |
| 326 | 15/133 | COMPUTER | NL21, NL15, NL139 UNRESOLVED SIGNALS |
| 327 | 14/97 | COMPUTER | POWER FAILURE LOAD TO TEST OF UPS - LASTED 10 MIN |
| 328 | 14/22 | CRATE CONTROLLER | E5 BPM CRATE CONTROLLER FAILED |
| 329 | 15/79 | CRATE CONTROLLER | E201B05-29-21 CHANNELS 1 & 3 CONSTANT 5.7 V |
| 330 | 13/80 | DATA LOGGER | DATA LOGGER NOT RECORDING. RF FAULTS |
| 331 | 12/52 | BPM | ELECTRONICS FAULTY IPM1E02 |
| 332 | 15/135 | FSD | FSD UNANNOUNCED FSD FAULTS |

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333  13/48      .                      NL07B12 FSD MASK PROBLEM.  MASKS DROPPING .
334  13/63     FSD                     IN01B12/IN03B06 INPUT FAULT PROBLEMS. POSSIBLE CAMAC SHORT
335  13/57     FSD                     FSD SYSTEM BEHAVED UNPREDICTABLY
336  13/53     FSD                     FSD MASK CONTROL NOT RESOLVING
337  13/48     FSD                     NL07B12 FSD MASKS WOULD NOT SET. DATAWAY O.K.
338  13/87     FSD                     NL16B12 & NL17B12 MODES UNRESOLVED
339  13/88     FSD                     E201B06 BAD FSD CARD
340  16/35     FSD                     INCORRECT LABEL ON FSDEA RASTER MAGNET
341  13/52     GET SETTINGS            GET SETTINGS WOULD NOT WORK. NEW NET ADDRESS
342  16/89     GIM MODULE              GUN HIGH VOLTAGE LOST
343  14/18     GPIB CABLE              EA05 LOCAL WOULD NOT START. bAD GPIB CABLE
344  15/136    GUN CONTROL LOGIC       UNTESTED GUNCNTRL LOGIC INDEFAULT DIRECTORY
345  14/152    HARP                    IHA1A33 SIGNAL NOISE
346  5/2       HARP                    45MEV HARP CONNECTOR BROKEN PINS ON POT
347  15/39     HARP                    IHA1A31, IHA1A33 NOISE
348  13/56   . HARP                    PROGRAMMABLE GAIN AMP AT 135DEG HARP CONSTANT OUTPUT 14V
349  16/70     HARP                    IHPOL021 NOISY PGA FAILED
350  16/87     HARP                    IHA EAST ARC PGA NONRESPONSIVE
351  16/79     HARP                    PULSE WIDTH CHANGED AFTER CYCLING HARP
352  16/62     HARP                    IN03A HARP NO SIGNAL BAD PGA OR TRANSIENT DIGITIZER
353  5/2       HARP                    IHA1A35. FAILED PGA
354  13/106    HARP                    HARP AT 135 DEG PGA FAILED
355  12/136    HARP                    BAD PRE-AMP IHA1A04
356  12/154    HARP                    IHA6D01 at 135 DEG DUMP NOT OPERATIONAL. BROKEN WIRE STEP MOTOR
357  12/26     VIEWER                  VIEWER LIGHT OUT
358  12/104    VIEWER                  BEAM VIEWER ITV1A11 NOT WORKING
359  13/4      VIEWER                  E3 24V POWER TO ITV1A111 - ITV1A221 FAILED
360  13/8      VIEWER                  BURNED OUT LIGHT
361  12/48     VIEWER                  ITV1S04 WOULD NOT INSERT
362  12/133    VIEWER                  MALFUNCTIONING IN LIMIT SWITCH ITV502b
363  12/87     VIEWER                  VIEWER IN INTERMEDIATE STATE. ITVD502B
364  12/108    KNOBS                   KNOBS ATTATCHED ON EZCIPBM WHEN NONE INDICATED
365  15/88     COMPUTER LOCAL          NL07 LOCAL COMPUTER FAULT
366  12/114    COMPUTER LOCAL          Logic died NL01A
367  13/56     COMPUTER MOUSE          MOUSE ON KNUTH LOCKED UP
368  16/121    ODH                     MONITOR #32 BAD ODH CELL
369  16/36     HARP                    PROGRAMMERABLE GAIN AMPLIFIFER FAILURE
370  SL2/113   SAFETY SYSTEM           DROPPED TO POWER PERMIT
371  SL2/115   SAFETY SYSTEM           SAFETY SYSTEM CRASHED TO ERROR STATE
372  SL2/114   SAFETY SYSTEM           DROPPED TO POWER PERMIT
373  SL2/77    SAFETY SYSTEM           DROPPED TO POWER PERMIT
374  SL2/112   SAFETY SYSTEM           DROPPED TO POWER PERMIT
375  SL2/111   SAFETY SYSTEM           DROPPED TO POWER PERMIT
376  SL2/113   SAFETY SYSTEM           DROPPED TO POWER PERMIT
377  SL2/115   SAFETY SYSTEM           DROPPED TO POWER PERMIT
378  SL2/106   SAFETY SYSTEM           DROPPED TO POWER PERMIT
379  SL2/108   SAFETY SYSTEM           DROPPED TO POWER PERMIT
380  SL2/78    SAFETY SYSTEM           DROPPED TO POWER PERMIT THAN RESTRICTED ACCESS.
381  SL2/107   SAFETY SYSTEM           DROPPED TO POWER PERMIT
382  SL2/106   SAFETY SYSTEM           DROPPED TO POWER PERMIT
383  SL2       SAFETY SYSTEM           ATTEMPTED A CONTROLLED ACCESS DROPPED TO RESTRICTED ACCESS
384  SL2/103   SAFETY SYSTEM           TUNNEL DROPPED TO POWER PERMIT
385  SL2/77    SAFETY SYSTEM           DROPPED TO RESTRICTED ACCESS. FAULT NL12 B CHAIN
386  SL2/102   SAFETY SYSTEM           DROPPED TO POWER PERMIT
387  SL2/83    SAFETY SYSTEM           DROPPED TO POWER PERMIT
388  SL2/75    SAFETY SYSTEM           DROPPED TO POWER PERMIT. CYCLED KEY DROPPED TO RESTRICTED ACCESS
389  SL2/102   SAFETY SYSTEM           DROPPED TO POWER PERMIT
390  SL2/101   SAFETY SYSTEM           TUNNEL DROPPED TO POWER PERMIT
391  SL2/107   SAFETY SYSTEM           MACHINE TO POWER PERMIT
392  SL2/80    SAFETY SYSTEM           DROPPED TO POWER PERMIT. FAULT ON LOGIC A MAGNET - MG02SA01
393  16/3      SAFETY SYSTEM           IN07B30 - UPS BATTERY BACKUP FAILURE. SAFETY SYSTEM
394  SL2/84    SAFETY SYSTEM           DROPPED TO POWER PERMIT
395  SL3/2     SAFETY SYSTEM           DROPPED TO RESTRICTED ACCESS WHEN SWITCHED TO CONTROLLED ACCESS
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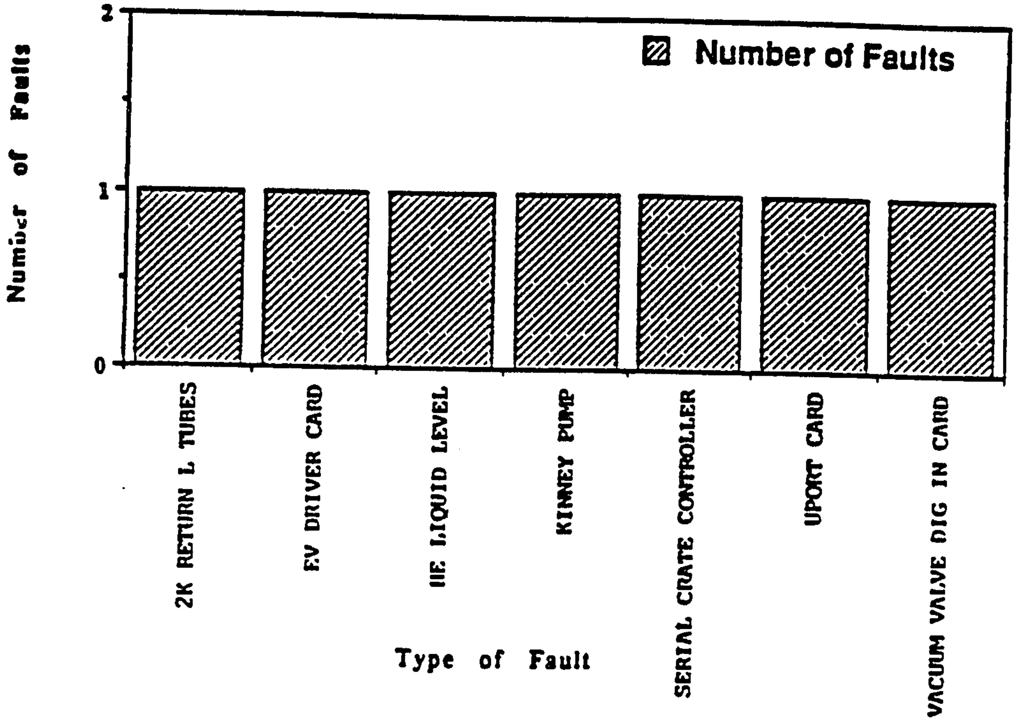
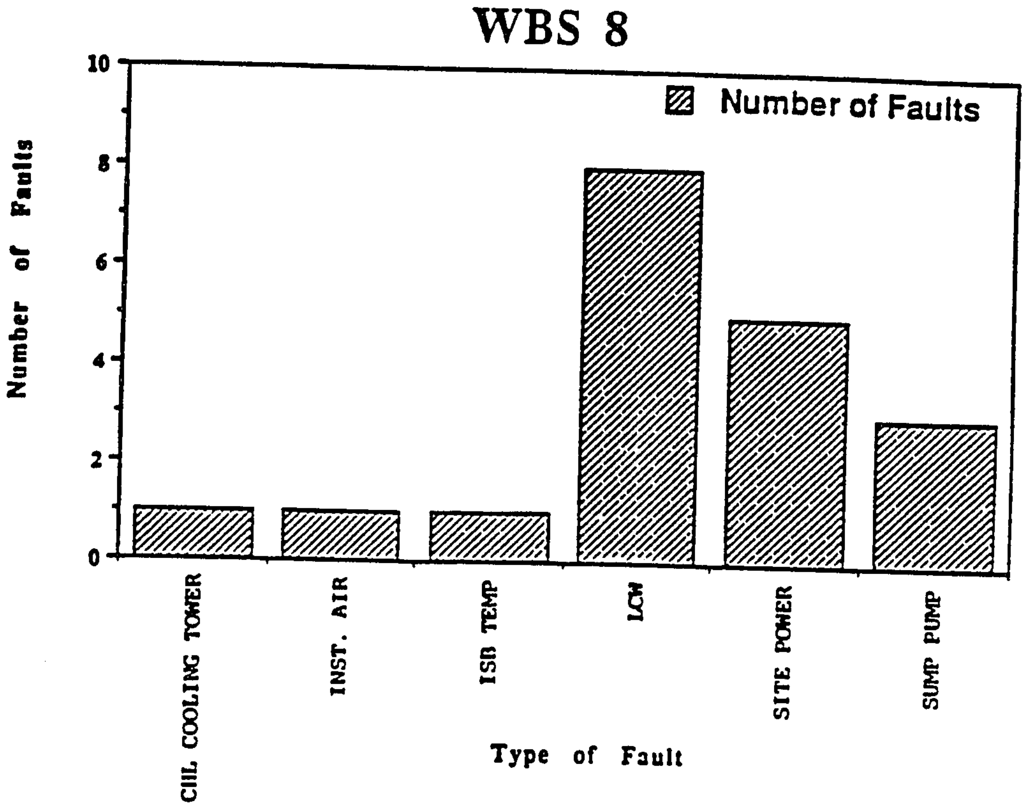
# WBS 7


Number of Faults
2
1
0
▨ Number of Faults
2K RETURN L TUBES
EV DRIVER CARD
HE LIQUID LEVEL
KINNEY PUMP
SERIAL CRATE CONTROLLER
UPORT CARD
VACUUM VALVE DIG IN CARD
Type of Fault

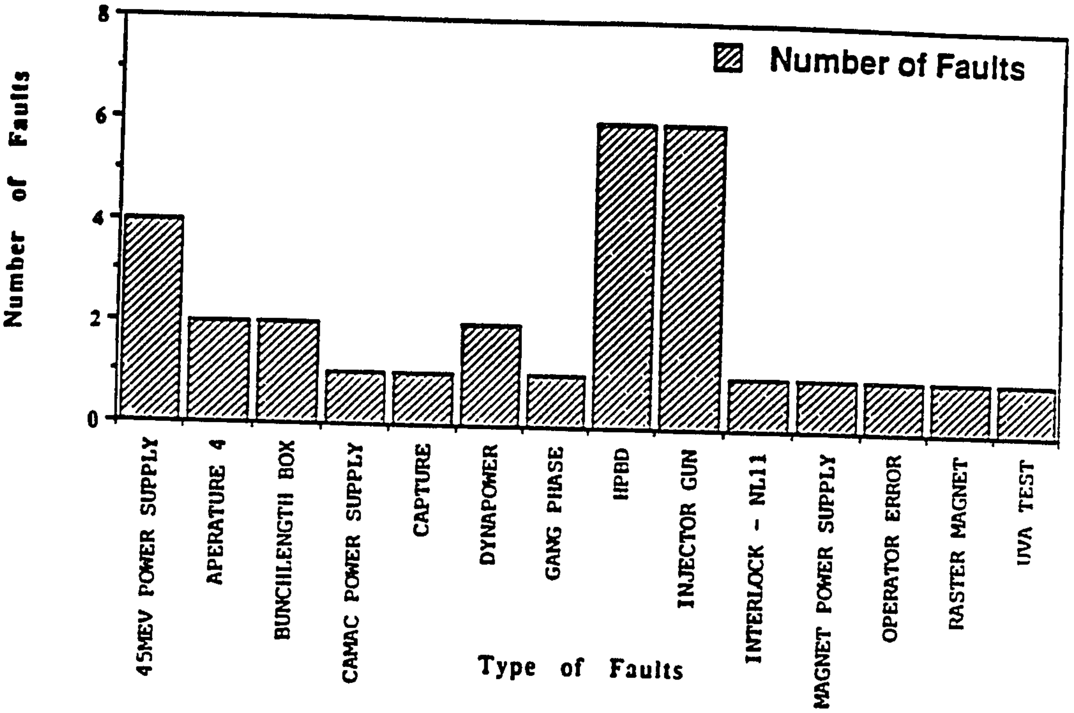
| | | | |
|---|---|---|---|
| 396 | SL2/79 | SAFETY SYSTEM | DROPPED TO POWER PERMIT THAN RESTRICTED ACCESS. |
| 397 | SL2/82 | SAFETY SYSTEM | DROPPED TO POWER PERMIT |
| 398 | SL2/85 | SAFETY SYSTEM | DROPPED TO POWER PERMIT |
| 399 | SL3/5 | SAFETY SYSTEM | DROPPED TO POWER PERMIT |
| 400 | SL2/77 | SAFETY SYSTEM | DROPPED TO POWER PERMIT |
| 401 | 16/79 | SAVE SETTINGS | INCORRECT DEFAULT VALVES FOR CHOPPER 1 SAVE SETTINGS |
| 402 | 13/69 | SAVE SETTINGS | RECALL SETTINGS FOR CHOPPER 1 & 2 ATTENUATORS DIDN'T RESTORE |
| 403 | 16/10 | SOFTWARE | EXTRACT 0 H V CORRECTOR ICONS REVERSED |
| 404 | SL2/81 | SOFTWARE | LOGIC PLC B'S CONT ACCESS, BEAM,POWER PERMIT CHANGE NETWORK PAGES |
| 405 | 12/23 | SOFTWARE | IN02 LOGIC SET UPDATE FOR CAPTURE SECTION FAULTY |
| 406 | SL2/106 | SOFTWARE | GINCTRL SOFTWARE WORK |
| 407 | 16/4 | CHL SPY | CHL COMMUNICATION FAULT ZERO LIQUID LEVEL |
| 408 | 15/113 | CHL SPY | SPY FAILURE |
| 409 | 12/63 | STAR | STAR CRASH |
| 410 | 13/135 | STAR | UNRESOLVED SIGNALS |
| 411 | 13/73 | STAR | STAR CRASH |
| 412 | 13/58 | STAR | UNABLE TO CLEAR FSD FAULTS - STAR TIMEOUT PROBLEM |
| 413 | 15/133 | STAR | LOSS OF STAR CONTACT MCO2 300 SERIES COMPUTER |
| 414 | 15/133 | STAR | UNABLE TO OPEN/CLOSE VACUUM VALVES FROM MCC |
| 415 | 16/123 | STAR | STAR PROBLEMS. SLOW UPDATE. SCREEN FLICKER. |
| 416 | 13/46 | STAR | STAR FAILURE; LOCALS DOWN |
| 417 | 16/107 | STAR | STAR CRASH: SCREEN LOCK, MOUSE LOCK, SCREEN FLICKER 3 1/2 HOURS |
| 418 | 16/64 | VIEWER | IIVIL08, IIVIL1B STUCK IN INTERMEDIATE STATE |
| 419 | 14/20 | VIEWER | IIVIL27 VIEWER WILL NOT INSERT |
| 420 | 15/68 | VIEWER | IIVIS04 FAILED |
| 421 | 15/38 | VIEWER | 1L27A CRATE FAULT. STOPPED SCANNING |
| 422 | 12/34 | VIEWER | VIEWER LIMITED |
| 423 | 13/102 | VIEWER | NO VIEWERS FROM 1L27. FIBER CABLE DAMAGED |
| 472 | 13/68 | SOFTWARE-LOCAL | INJ GUN HV READBACK FAULTING |

| Record# | BOOKPG | ITEM | DESCP |
|---|---|---|---|
| 424 | 14/10 | 2K RETURN L TUBES | 1L17, 1L19 HE LEAK 2K RETURN L-TUBES |
| 425 | 13/128 | EV DRIVER CARD | FAULTY EV DRIVER CARD SLOT 4 CRATE 10 INJ S.B. |
| 426 | 12/28 | HE LIQUID LEVEL | MOMENTARY LOSS OF LIQUID LEVEL SIGNAL CAUSING RF TO TURN OFF |
| 427 | 16/124 | KINNEY PUMP | KINNEY PUMP DOWN - BLOWER SHAFT HOUSING |
| 428 | 15/17 | SERIAL CRATE CONTROLLER | CHL LIQUID LEVEL FAULTS. 1L26 SERIAL CRATE CONTROLLER FAULTY |
| 429 | 14/129 | UPORT CARD | CRATE FAULT HL 20 UPORT CARD |
| 430 | 15/141 | VACUUM VALVE DIG IN CARD | VBVOL06B WOULD NOT OPERATE. SHORTED DIGITAL INPUT LEVEL |


WBS 8
Number of Faults
10
8
6
4
2
0
Number of Faults
CHL COOLING TOWER
INST. AIR
ISB TEMP
LCW
SITE POWER
SUMP PUMP
Type of Fault

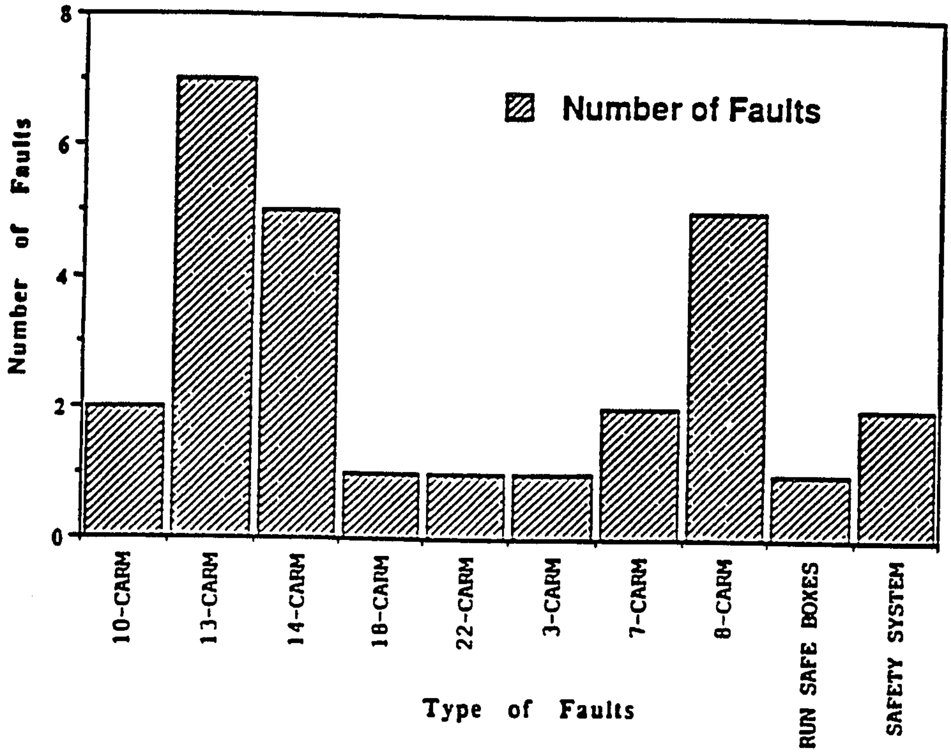
| Record# | BOLK.U | ITEM | DESCP |
|---|---|---|---|
| 219 | 12/60 | SITE POWER | POWER GLITCH DROPPING RF AND VACUUM VALUES |
| 431 | 13/42 | LCW | LCW OFF . NO WBS LCW DIAGNOSTICS TO MCC. |
| 432 | 13/123 | CHL COOLING TOWER | CHL COOLING TOWER PUMP #2 FAILED. CHL POWER OUTAGE RESULTS |
| 433 | 16/3 | INST. AIR | INST AIR PRESSURE LOW |
| 434 | 15/6 | ISB TEMP | ISB > 90DEG F CAUSING RF SYSTEM CROWBAR FAULT |
| 435 | 13/43 | LCW | LEAK STATION 360 |
| 436 | 13119 | LCW | CLOGGED FLOWMETERS INJECTOR |
| 437 | 12/20 | LCW | INJ FLOWMETER CLOGGED WITH METAL DEPOSITS |
| 438 | 14/132 | LCW | LCW DIFFERENTIAL PRESSURE LOW |
| 439 | 16/39 | LCW | LCW PIPE BREAK SLSB 3/4 PIPE |
| 440 | 16/52 | LCW | LCW AT SAB OFF |
| 441 | 12/81 | LCW | LEAKING GASKET NAB RM108 VALUE PC2G |
| 442 | 16/121 | SITE POWER | HL16 P2 PANEL CIRCUIT BREAKER PP4/8 NO RESET |
| 443 | 16/125 | SITE POWER | POWER GLITCH AT CHL SHUTTING DOWN 7 COMPRESSORS |
| 444 | SL3/1 | SITE POWER | DROPPED TO RESTRICTED ACCESS DUE TO POWER OUTAGE |
| 445 | 14/12 | SITE POWER | MEDIUM VOLTAGE CABLE TERMINATION FAULT TO GROUND H3A |
| 446 | 16/125 | SUMP PUMP | INJECTOR SUMP PUMP FLOAT SWITCH HUNG UP |
| 447 | 16/127 | SUMP PUMP | EXIT STAIR 4 FLOAT SWITCH HUNG UP |
| 448 | 14/18 | SUMP PUMP | LEAKING VALVE AT INJECTOR STORAGE TANK |

# OPS


▨ Number of Faults
Number of Faults
Type of Faults
0
2
4
6
8
45MEV POWER SUPPLY
APERATURE 4
BUNCHLENGTH BOX
CAMAC POWER SUPPLY
CAPTURE
DYNAPOWER
GANG PHASE
HPBD
INJECTOR GUN
INTERLOCK - NL11
MAGNET POWER SUPPLY
OPERATOR ERROR
RASTER MAGNET
UVA TEST

| Record | OKPG | ITEM | DESCP |
|---|---|---|---|
| 6 | ..2/107 | INTERLOCK | DROPPED TO POWER PERMIT. INTERLOC. ..ULT NL11 |
| 449 | 13/142 | INJECTOR GUN | 100KEV GUN POWER SUPPLY TRIPPED OFF TWICE |
| 450 | 13/42 | 45 MEV POWER SUPPLY | 45MEV SPECT DIPOLE LEFT ON NO LCW, OVERHEAT. NEED TO FIX CONTROLS |
| 451 | 13/97 | 45 MEV POWER SUPPLY | 45MEV SPECT POWER SUPPLY - NO READ BACK OR REMOTE CONTROL |
| 452 | 12/39 | 45 MEV POWER SUPPLY | UNABLE TO CONTROL MAGNET FROM CONTROL ROOM |
| 453 | 15/6 | APERATURE 4 | A4GROUNDED TO BELLOWS COVER |
| 454 | 12/25 | APERATURE 4 | NO SIGNAL SHORTED TO BEAM PIPE |
| 455 | 16/31 | BUNCHLENGTH BOX | FAULTY DIGITIZER |
| 456 | 16/65 | BUNCHLENGTH BOX | VERY NOISY BUNCH LENGTH SIGNAL |
| 457 | 15/65 | CAMAC POWER SUPPLY | IN03807 CAMAC POWER SUPPLY FAILED |
| 458 | 12/24 | CAPTURE | INOPERABLE CONTROL VALUE. CAPTURE SECTION. |
| 459 | 15/191 | 45MEV POWER SUPPLY | FAULTY COMMUNICATIONS CARD IN DANFYSIK POWER SUPPLY |
| 460 | 12/79 | DYNAPOWER | LCW LINES REVERSED |
| 461 | 15/65 | DYNAPOWER | 45MEV SPECTOMETER DYNAPOWER POWER SUPPLY LOCKED UP |
| 462 | 15/66 | GANG PHASE | GANG PHASE OF NL DRIFTED @ 20 DEG |
| 463 | 14/18 | INJECTOR GUN | NO BEAM SYNC. GUN INTERFACE MODULE |
| 464 | 16/64 | INJECTOR GUN | GUN WON'T GO TO HIGH VOLTAGE |
| 465 | 14/92 | INJECTOR GUN | PEAK CURRENT SAG. |
| 466 | 15/3 | HPBD | FLOWMETER SST #2 FAILED |
| 467 | 15/49 | HPBD | HPBD COPPER SKID FLOW METER FAULTY CLOGGED W/ TEFLON TAPE |
| 468 | 15/1 | HPBD | TURBINE FLOW METER - NO OUTPUT - ALUMINUM #1 (TOP) |
| 469 | 5/2 | HPBD | GROUND LOOP PROBLEMS WITH FLOW METER CIRCUITS |
| 470 | 5/1 | HPBD | LOW PRESSURE SENSOR SST SKID NOT OPERATIONAL |
| 471 | 5/1 | HPBD | MOISTURE SENSOR NOT OPERATIONAL |
| 473 | 13/119 | INJECTOR GUN | OPEN INJECTOR GUN FILAMENT |
| 474 | 14/12 | INJECTOR GUN | INJ GUN H.V. CABLE SHORTED OUT |
| 475 | 15/111 | MAGNET POWER SUPPLY | MAGNET POWER SUPPLY USED TO POWER SKEW QUAD |
| 476 | 16/31 | RASTER MAGNET | RASTER MAGNET HOOKED UP IMPROPERLY |
| 477 | SL2/96 | OPERATOR ERROR | TUNNEL DROPPED TO SWEEP IN PROGRESS DUE TO OPERATOR ERROR |
| 478 | 14/127 | UVA TEST | NON-RESETTABLE INTERLOCKS. REQUIRED CONTROLLED ACCESS |

**RAD**


Number of Faults
8
6
4
2
0
▨ Number of Faults
10-CARM
13-CARM
14-CARM
18-CARM
22-CARM
3-CARM
7-CARM
8-CARM
RUN SAFE BOXES
SAFETY SYSTEM
Type of Faults

| Record# | ..JKPG | ITEM | DESCP |
|---|---|---|---|
| 479 | SL2/113 | 10-CARM | DROPPED TO POWER PERMIT. RAD MONITOR #10 TRIP |
| 480 | SL2/111 | 10-CARM | DROPPED TO POWER PERMIT. RAD MONITOR #10 |
| 481 | SL2/111 | 13-CARM | DROPPED TO POWER PERMIT. RAD MONITOR #13 |
| 482 | SL2/116 | 13-CARM | DROPPED TO POWER PERMIT. CARM #13 |
| 483 | 15/75 | 13-CARM | ALARM, NEUTRON CHANNEL |
| 484 | 16/57 | 13-CARM | CARM #13 NEUTRON TRIP AGAIN |
| 485 | 15/25 | 13-CARM | CARM #13 ALARM NO HIGH LEVELS INDICATED |
| 486 | 16/57 | 13-CARM | CARM #13 NEUTRON TRIP |
| 487 | SL3/3 | 13-CARM | DROPPED TO POWER PERMIT. CARM #13 |
| 488 | 15/75 | 14-CARM | CARM #14 |
| 489 | SL2/111 | 14-CARM | DROPPED TO POWER PERMIT. RAD MONITOR #14 |
| 490 | SL2/108 | 14-CARM | DROPPED TO POWER PERMIT. RAD MONITOR #14 |
| 491 | SL2/112 | 14-CARM | DROPPED TO POWER PERMIT. RAD MONITOR #14 |
| 492 | SL2/108 | 14-CARM | DROPPED TO POWER PERMIT. RAD MONITOR #14 |
| 493 | SL2/108 | 18-CARM | DROPPED TO POWER PERMIT. RAD MONITOR #8 |
| 494 | 15/6 | 22-CARM | CARM #22 SOUTH LINAC S.B. WARNING ALARM |
| 495 | SL2/114 | 3-CARM | DROPPED TO POWER PERMIT. CARM #3 |
| 496 | 15/89 | 7-CARM | CARM #7 ALARM |
| 497 | SL2/84 | 7-CARM | DROPPED TO POWER PERMIT. FAILED PROBE ON UNIT #7. |
| 498 | SL2/89 | 8-CARM | RAD MONITOR #8 EXIT STAIR #1 BROUGHT MACHINE TO POWER PERMIT |
| 499 | SL2/95 | 8-CARM | DROPPED TO POWER PERMIT. RADIATION ALARM. CARM IN EXIT STAIR #1 |
| 500 | SL2/89 | 8-CARM | DROPPED TO POWER PERMIT. FAULT AT RAD MONITOR #8 EXIT STAIR #1 |
| 501 | SL2/114 | 8-CARM | DROPPED TO POWER PERMIT. CARM #8 |
| 502 | 13/145 | 8-CARM | CARM #8 FAULTED TO ALARM. NO APPERENT REASON. |
| 503 | SL2/74 | RUN SAFE BOXES | RADAITION ALARM ON 12 & 13 CAUSED RS28, 29, 30 NOT TO ALARM SAFE |
| 504 | SL2/85 | SAFETY SYSTEM | DROPPED TO POWER PERMIT. 1ST FAULT READ MONITOR #2(RAD) INJ HATCH |
| 505 | SL2/85 | SAFETY SYSTEM | DROPPED TO POWER PERMIT. 1ST FAULT INJ. HATCH |

# APPENDIX 6

## Survey Questions

### Schedule

1. What systems or sub-systems are you responsible to have on line for the next start-up?
2. Provide a brief outline or schedule of the equipment installation or tasks which your group is planning to support.
3. Provide a schedule of anticipated pre-commissioning start dates and duration for:
   Installation -
   Checkout -
   Burn-in -
4. To whom and how often do you provide periodic "status" and "impact on schedule" reports?
5. What checkout verification documentation can you make available to the Hardware Checkout & Reliability Team Leader as checkout is completed?
6. What are the obstacles which you feel may hinder efforts towards meeting your obligations?
7. What are the work-arounds/fall-back plans to ensure meeting the schedule goals?

### Support for Operations Group

8. What are your plans for providing support for verification of system operability from the MCC with the Operations Group?
9. For normal operating conditions, what documentation, instructions, flow charts, and check lists do you plan to provide the Operations Group?
10. For abnormal operating conditions, what documentation, instructions, flow charts, and check lists do you plan to provide the Operations Group?
11. What instructions and diagnostic tools do you plan to provide Operations Group to facilitate identification and correction of faults?
12. Do you have an emergency call-in list of personnel to support repair of your equipment?

### Maintenance

13. Describe your existing preventive maintenance system.
14. Do you have a repair maintenance tracking system with regards to spares inventory control, labor, procedures, and tool requirements, and if not, what are your plans?
15. What specific training is needed for your group/subgroup to help bring the machine up as quickly as possible after a component failure?
16. Describe your procedure for responding to unscheduled repairs.
17. During the course of installation, commissioning, or maintenance of your equipment, which subsystem procedures call for masking/buggering and why?

### Spare Parts

18. What are your shortfalls in stock of critical spare parts to support operations?
19. Where are your critical spare parts stored?
20. What is the procedure for accessing your critical spare parts after normal working hours?

# APPENDIX 7

## Grading Criteria

1 **A warm, fuzzy feeling.**

A. The requested data is provided, or
B. What needs to be done is complete and reported to be in good shape, or
C. There seems to be no problem with meeting the schedule.

2 **Struggling to survive. No one said it would be easy.**

A. Data is partially reported, or
B. What needs to be done is partially done, or
C. We know what needs to be done, but have not done it, or
D. It is possible, even probable that the schedule will be met, or
E. On hold until another group reaches a specific point in their work.

3 **Help! Help!**

A. Does not know what to do, or
B. Does not have the resources to do what must be done, or
C. Very unlikely to meet the schedule, or
D. Behind in quantity or quality or both, or
E. None in place.

N/A = Not Applicable

# APPENDIX 8

## Memorandum to the Planning Team

CEBAF
*The Continuous Electron Beam Accelerator Facility*

**MEMORANDUM**

**To:** Planning Team

**From:** Hardware Checkout and Reliability Team

**Subject:** Survey Results

**Date:** November 1, 1993

The Hardware Checkout and Reliability Team distributed a survey in mid-August 1993 to Group Leaders and WBS Cost Account Managers who were directly involved in preparations for accelerator operations. The Team's intent for the survey was threefold: (1) to collect information from all groups which have immediate impact on the success or failure of the accelerator so that the Team could evaluate present and future readiness for reliable operations, (2) to provoke thought about some topics that probably are not considered a high priority now, but will be later on, and (3) to factor the conclusions reached back into operations, maintenance, and support in a process of continuous improvement.

The survey consisted of twenty questions divided into four groups: schedule, support for Operations Group, maintenance, and spare parts. Attachment 1 is a copy of the survey questions. The Team has received fifteen completed surveys. The Team has analyzed and evaluated the responses, and even though most of the questions were subjective, the Team was able to quantify the evaluation macroscopically. The evaluation assigned a 1, 2, or 3 to each question's response, with 1 being the most favorable and 3 the most worrisome. One can think of a 1 as a green status, a 2 as a yellow status, and a 3 as a red status.

The following assumptions and facts affected the outcome of this survey:

- The Team relied on the truthfulness and completeness of the respondents.
- Team members went back to some respondents two or more times to clarify responses.
- The responses were received over a six week period, and were "snapshots" taken at different times.
- Some responses received in August/early September have changed, and the matrix is being updated as changes are reported.

Attachment 2 is the grading system used to assign a 1, 2, or 3 to all the responses. In some cases, a responder reported that a question did not apply to a group, and then an "N/A" was assigned. Attachment 3 is the tabulation of the grades assigned. You will note that Attachment 3 provides the average value for every question.

The most important conclusions reached through analysis and evaluation are:

tah[Cover Ltr-Survey Results 11/1/93]HCR

## Schedule

- The intense pressure on all hardware and software groups to meet the installation schedule has caused many groups to defer their development of operator guides, checkout and debug procedures, maintenance programs, and training programs. Installing the hardware and developing the software have taken priority, but waiting until everything is in place and tested before compiling the necessary documentation is short sighted. In most cases, too little time is left over to do it right. The solution is to establish and require a schedule for the production of support items that fits with the hardware installation and software development schedules.

## Support for Operations Group

- Those who are responsible for hardware are not sufficiently appreciative of the payoff for providing operators with user friendly tools for operating and maintaining the equipment. Well trained and equipped operators can detect something just beginning to fail and thereby prevent catastrophic failure. They also can miss clues and make mistakes, possibly contributing to equipment abuse. As a general rule, the more attention and care a hardware group gives to the operators, the more attention and care the operators will be capable of giving the equipment.

## Maintenance

- There is no evidence of a consistent preventive (also called scheduled or periodic) maintenance program for all accelerator systems. Examples of undone maintenance abound.
    - There is no contract in the works for taking care of the LCW system, and no one is providing necessary maintenance. This is a system which can destroy klystrons and magnets and concentrates radioactivity in a resin bed.
    - The UPS system at MCC acted up and was bypassed because it was less reliable than normal power. Investigation several months later showed that the batteries were more than two years beyond replacement age. The batteries were replaced, and the UPS is on line.
- The will to allocate the resources needed to develop a modern and effective preventive maintenance program is not evident. We are in a "run it until it breaks" mode, which means that the machinery is in charge of the schedule.

## Spare Parts

- Most groups attribute shortages of critical spares to past budget constraints. If one hour of beam time is "worth" several tens of thousands of dollars, direct comparisons of costs and benefits can be made. The lack of a particular spare part can have a major negative impact on beam availability and research, both of which are major contributors to our reputation and budget stability. Given the lead times for obtaining some critical spare parts, it is time to review the entire critical spares issue and take action to order what makes sense.

## HARDWARE CHECKOUT AND RELIABILITY TEAM SURVEY - AUGUST 13, 1993

## QUESTIONS

### Schedule

1. What systems or sub-systems are you responsible to have on line for the next start-up?
2. Provide a brief outline or schedule of the equipment installation or tasks which your group is planning to support.
3. Provide a schedule of anticipated pre-commissioning start dates and duration for:
   Installation -
   Checkout -
   Burn-in -
4. To whom and how often do you provide periodic "status" and "impact on schedule" reports?
5. What checkout verification documentation can you make available to the Hardware Checkout & Reliability Team Leader as checkout is completed?
6. What are the obstacles which you feel may hinder efforts towards meeting your obligations?
7. What are the work-arounds/fall-back plans to ensure meeting the schedule goals?

### Support for Operations Group

8. What are your plans for providing support for verification of system operability from the MCC with the Operations Group?
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10. For abnormal operating conditions, what documentation, instructions, flow charts, and check lists do you plan to provide the Operations Group?
11. What instructions and diagnostic tools do you plan to provide Operations Group to facilitate identification and correction of faults?
12. Do you have an emergency call-in list of personnel to support repair of your equipment?

### Maintenance

13. Describe your existing preventive maintenance system.
14. Do you have a repair maintenance tracking system with regards to spares inventory control, labor, procedures, and tool requirements, and if not, what are your plans?
15. What specific training is needed for your group/subgroup to help bring the machine up as quickly as possible after a component failure?
16. Describe your procedure for responding to unscheduled repairs.
17. During the course of installation, commissioning, or maintenance of your equipment, which subsystem procedures call for masking/buggering and why?

### Spare Parts

18. What are your shortfalls in stock of critical spare parts to support operations?
19. Where are your critical spare parts stored?
20. What is the procedure for accessing your critical spare parts after normal working hours?

# HC&R Team Survey

## Grading Criteria

1 **A warm, fuzzy feeling.**

A. The requested data is provided, or
B. What needs to be done is complete and reported to be in good shape, or
C. There seems to be no problem with meeting the schedule.

2 **Struggling to survive. No one said it would be easy.**

A. Data is partially reported, or
B. What needs to be done is partially done, or
C. We know what needs to be done, but have not done it, or
D. It is possible, even probable that the schedule will be met, or
E. On hold until another group reaches a specific point in their work.

3 **Help! Help!**

A. Does not know what to do, or
B. Does not have the resources to do what must be done, or
C. Very unlikely to meet the schedule, or
D. Behind in quantity or quality or both, or
E. None in place.

N/A = Not Applicable

tah|Survey #1 Grading System|HCR

| Question Number | Description | WBS 1 | WBS 2 | WBS 3 | WBS 4 | WBS 5 PSS/MPS | WBS 5 Beam Diagnostics (Mechanical) | WBS 5 Applications | Operations Inj Interlocks | Operations Inj Software | Operations Inj Magnets | Operations Inj Gun | Operations Control System | WBS 5 Systems Interface | WBS 7 | WBS 8 | AVERAGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Sys. Responsibility | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1.00 |
| 2 | Inst. Sched Plan | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1.13 |
| 3 | Injector Sched. | 1 | N/A | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | N/A | 1 | N/A | 1 | 1.15 |
| 4 | Status | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1.00 |
| 5 | Documentation | 1 | N/A | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | N/A | N/A | 1 | 1 | 1.08 |
| 6 | I.D. Obstacles | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 1.87 |
| 7 | Work Arounds | 1 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1.47 |
| 8 | Oper. From MCC | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | N/A | 2 | 1.14 |
| 9 | Flow Charts-Normal | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | N/A | 2 | 1 | 2 | 1 | 1 | 2 | 1.36 |
| 10 | Flow Charts-Abnormal | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | N/A | 2 | 1 | 2 | 1 | 1 | 3 | 1.43 |
| 11 | Fault ID | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | N/A | 2 | N/A | 1 | 2 | 1 | 3 | 1.47 |
| 12 | Call In List | 1 | 2 | 1 | 1 | 1 | 2 | 1 | N/A | 1 | N/A | N/A | 1 | 1 | 1 | 1 | 1.17 |
| 13 | Maint Sys | 2 | 3 | 2 | 1 | 1 | 2 | 1 | N/A | N/A | N/A | 1 | 1 | 2 | 1 | 2 | 1.58 |
| 14 | Maint Training | 1 | 2 | 2 | 1 | 2 | 3 | N/A | N/A | N/A | N/A | N/A | 1 | 1 | 1 | 2 | 2.10 |
| 15 | Training | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1.33 |
| 16 | Unsched. Repair | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | N/A | N/A | N/A | 1 | 1 | 1 | 3 | 1.25 |
| 17 | Buggers | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | N/A | 1 | 1 | 1 | 1.00 |
| 18 | Spares | 1 | 1 | 2 | 1 | 2 | 1 | N/A | N/A | 1 | 1 | 1 | 3 | 1 | 2 | 1 | 1.38 |
| 19 | Spare Storage | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | N/A | 1 | N/A | N/A | 2 | 1 | 1 | 1.08 |
| 20 | Spare Access | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | N/A | 1 | 1 | 1 | 2 | 1 | 1 | 1.14 |

Harware Checkout and Reliability Team Survey #1

# APPENDIX 9

## Presentation to the Division Council

# HARDWARE CHECKOUT AND RELIABILITY TEAM

## Presentation for the Accelerator Division Council
## November 15, 1993

CEBAF
*The Continuous Electron Beam Accelerator Facility*

Hrdwre Chkout & Rel. Team 15 November 1993

# HARDWARE CHECKOUT AND RELIABILITY TEAM

| | |
|---|---|
| Ro. | Coordinator |
| S. | Team Leader/Operations |
| D. | Cryogenics/WBS 7 |
| K. | Beam Instrumentation/WBS 5 |
| R. | AC/DC Power/WBS 4 |
| T. | EH&S |
| B. | Control Systems/WBS 5 |
| Ka. | Operations |
| Rn. | RF/WBS 3 |
| M. | Operations |

## SURVEY PURPOSE

- To encourage thought about mid-term and far-term problems
- To encourage thought about supporting the Crew Chiefs
- To confirm or deny the conventional wisdom about readiness
- To identify major hardware, software, and system problems

## SURVEY QUESTIONS

Schedule

1. What systems or sub-systems are you responsible to have on line for the next start-up?
2. Provide a brief outline or schedule of the equipment installation or tasks which your group is planning to support.
3. Provide a schedule of anticipated pre-commissioning start dates and duration for:

   Installation -

   Checkout -

   Burn-in -
4. To whom and how often do you provide periodic "status" and "impact on schedule" reports?
5. What checkout verification documentation can you make available to the Hardware Checkout & Reliability Team Leader as checkout is completed?
6. What are the obstacles which you feel may hinder efforts towards meeting your obligations?
7. What are the work-arounds/fall-back plans to ensure meeting the schedule goals?

# SURVEY QUESTIONS

<u>Support for Operations Group</u>

8. What are your plans for providing support for verification of system operability from the MCC with the Operations Group?
9. For normal operating conditions, what documentation, instructions, flow charts, and check lists do you plan to provide the Operations Group?
10. For abnormal operating conditions, what documentation, instructions, flow charts, and check lists do you plan to provide the Operations Group?
11. What instructions and diagnostic tools do you plan to provide Operations Group to facilitate identification and correction of faults?
12. Do you have an emergency call-in list of personnel to support repair of your equipment?

## SURVEY QUESTIONS

Maintenance

13. Describe your existing preventive maintenance system.
14. Do you have a repair maintenance tracking system with regards to spares inventory control, labor, procedures, and tool requirements, and if not, what are your plans?
15. What specific training is needed for your group/subgroup to help bring the machine up as quickly as possible after a component failure?
16. Describe your procedure for responding to unscheduled repairs.
17. During the course of installation, commissioning, or maintenance of your equipment, which subsystem procedures call for masking/buggering and why?

## SURVEY QUESTIONS

Spare Parts

18. What are your shortfalls in stock of critical spare parts to support operations?
19. Where are your critical spare parts stored?
20. What is the procedure for accessing your critical spare parts after normal working hours?

# SURVEY RESULTS

- Based on written responses of technical staff
- 88% of responses received to date
- Responses graded depending on
    - A “1” just for a complete answer (1, 2, 3, 4, 5 and 17)
    - A “1, 2, or 3” depending on content (all other questions)

## SURVEY GRADING CRITERIA

1. A warm, fuzzy feeling
   - The requested data is provided, or
   - What needs to be done is complete and reported to be in good shape, or
   - There seems to be no problem with meeting the schedule.
2. Struggling to survive.  No one said it would be easy.
   - Data is partially reported, or
   - What needs to be done is partially done, or
   - We know what needs to be done, but have not done it, or
   - It is possible, even probable that the schedule will be met, or
   - On hold until another group reaches a specific point in their work.
3. Help! Help!
   - Does not know what to do, or
   - Does not have the resources to do what must be done, or
   - Very unlikely to meet the schedule, or
   - Behind in quantity or quality or both, or
   - None in place.

- N/A = Not Applicable according to responder

| Question Number | Description | WBS 1 | WBS 2 | WBS 3 | WBS 4 | WBS 5 PSS/MPS | WBS 5 Beam Diagnostics (Mechanical) | WBS 5 Applications | Operations Inj. Interlocks | Operations Inj. Software | Operations Inj. Magnets | Operations Inj. Gun | Operations Control System | WBS 5 Systems Interface | WBS 7 | WBS 8 | AVERAGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Sys. Responsibility | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1.00 |
| 2 | Inst. Sched. Plan | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1.13 |
| 3 | Injector Sched. | 1 | N/A | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | N/A | 1 | N/A | 1 | 1.15 |
| 4 | Status | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1.00 |
| 5 | Documentation | 1 | N/A | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | N/A | N/A | 1 | 1 | 1.08 |
| 6 | I.D. Obstacles | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 1.87 |
| 7 | Work Arounds | 1 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1.47 |
| 8 | Oper. From MCC | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | N/A | 2 | 1.14 |
| 9 | Flow Charts-Normal | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | N/A | 2 | 1 | 2 | 1 | 1 | 2 | 1.36 |
| 10 | Flow Charts-Abnormal | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | N/A | 2 | 1 | 2 | 1 | 1 | 3 | 1.43 |
| 11 | Fault ID | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | N/A | 2 | N/A | 1 | 2 | 1 | 3 | 1.47 |
| 12 | Call In List | 1 | 2 | 1 | 1 | 1 | 2 | 1 | N/A | 1 | N/A | N/A | 1 | 1 | 1 | 1 | 1.17 |
| 13 | Maint. Sys | 2 | 3 | 2 | 1 | 1 | 2 | 1 | N/A | N/A | N/A | 1 | 1 | 2 | 1 | 2 | 1.58 |
| 14 | Maint. Training | 1 | 2 | 2 | 1 | 2 | 3 | N/A | N/A | N/A | N/A | N/A | 1 | 1 | 1 | 2 | 2.10 |
| 15 | Training | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1.33 |
| 16 | Unsched. Repair | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | N/A | N/A | N/A | 1 | 1 | 1 | 3 | 1.25 |
| 17 | Buggers | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | N/A | 1 | 1 | 1 | 1.00 |
| 18 | Spares | 1 | 1 | 2 | 1 | 2 | 1 | N/A | N/A | 1 | 1 | 1 | 3 | 1 | 2 | 1 | 1.38 |
| 19 | Spare Storage | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | N/A | 1 | N/A | N/A | 2 | 1 | 1 | 1.08 |
| 20 | Spare Access | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | N/A | 1 | 1 | 1 | 2 | 1 | 1 | 1.14 |

Harware Checkout and Reliability Team Survey #1

# PARETO ANALYSIS # 1

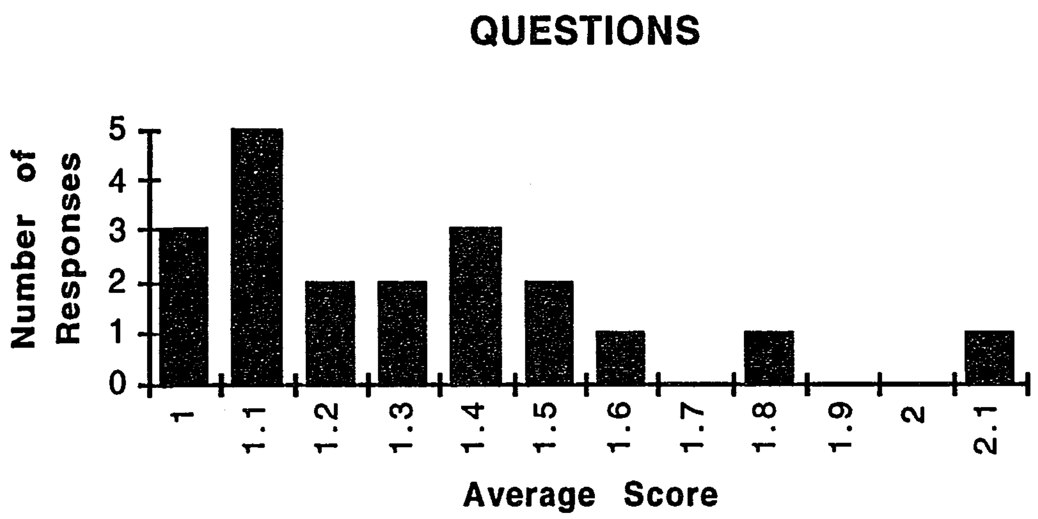
"Twenty percent of the items will cause eighty percent of the problems"

300 Total blocks
-30 N/A blocks
270 Quantified blocks

60 blocks = 2
+7 blocks = 3
67 blocks not 1

$$\frac{67}{270} = .248$$

# QUESTIONS



CEBAF
*The Continuous Electron Beam Accelerator Facility*

Hrdwre Chkout & Rel. Team

15 November 1993

## PARETO ANALYSIS # 2

Questions

| Question | Topic | Average |
|---|---|---|
| 14 | Describe your repair maintenance tracking system. | 2.10 |
| 6 | What are the obstacles hindering your efforts? | 1.80 |
| 13 | Describe your existing preventive maintenance plan. | 1.58 |
| 7 | What are your work-around/fall-back plans? | 1.47 |
| 11 | What tools will you provide the OPS Group for fault detection/correction? | 1.46 |

# CONCLUSIONS

| | |
|---|---|
| Schedule | Hardware installation takes priority over development of supporting documentation, training, interfacing, etc. |
| Support for Operations Group | Hardware Groups are not investing sufficient time with Operations Group to make them full partners in caring for the equipment. |
| Maintenance | Some Groups have invested little effort towards development of preventive (scheduled) maintenance programs. |
| Spare Parts | Budget constraints restrict and discourage development of an acceptable spare parts program by some groups. |
| Survey | It raised other questions which the Team is following up on.  Based on analysis of results, the Team developed a list of concerns. |

# SPECIFIC CONCERNS

| WBS | Spares | $/Time |
|---|---|---|
| Ops | HV gun, ceramic piece (no spare) | 3 months $80-120k |
| WBS7 | motor spares (no redundancy) (for compressors) | $37-42k each<br>12 wks new /<br>12 days rebuild |
| WBS7 | 2K° cold compressor cartridges (no spares anywhere) | 6-8 months turbines |
|  | **Maintenance** |  |
| WBS8 | CHL Cooling water system (maintenance & spares) |  |
| WBS8 | LCW (maintenance & spares) |  |
|  | **Reliability** |  |
| WBS7<br>WBS8 | reliability of 480 VAC power system (ground faults) | $20-75k CHL only<br>$.25M site wide |
| WBS7 | adequacy of LN2 storage capacity & delivery (daily delivery required) | $30-40k / month |
| WBS3 | M.O. amplifier (reliability - have one spare) (transistor discontinued) | 4 months, $20k |

CEBAF
*The Continuous Electron Beam Accelerator Facility*

Hrdwre Chkout & Rel. Team

15 November 1993

# APPENDIX 10

## CATER Documents

[redacted] 28H

# CATER: AN ONLINE PROBLEM TRACKING FACILITY FOR SLC*

[redacted]

*Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309 USA*

*Abstract*

An online facility has been developed for SLC to organize and simplify the management of all problems encountered in the operation of the accelerator. CATER (Computer Aided Trouble Entry and Reporting) may be used to make the initial entry of a problem, to enter one or more solutions to a problem, to modify or closeout a problem, to generate a variety of pre-defined reports giving status and statistical summaries, and to allow anyone to browse the database. All phases of CATER can take place on the operator console, workstations, or on any ANSI compatible terminal. The user interface is designed around a menu driven windowed environment with a large amount of context sensitive help information to alleviate the need for consulting user documentation. Currently, the CATER database contains information on more than 30,000 problems entered since it went online in January of 1986. The features of the software and some implementation details will be presented.

## INTRODUCTION

In the early days of SLC operation, hardware and software problems were reported and tracked by the "yellow-sticky" and other paper-based methods. It was apparent early on that some more reliable method of tracking the many machine problems was needed. The initial attempt to implement a problem tracking software system failed mostly because of a lack of user acceptance. For the second attempt, it became clear that like a good business, the system had to cater to the needs of the users first if it was to be accepted. CATER was thus designed with the following general requirements:

1. Above all it had to be easy to use with a minimum of instruction and keystrokes.
2. It had to run on any of the terminals then in use at SLAC.
3. It had to keep all problems in a database for historical analysis.
4. It had to be fairly easy to modify so it could adapt to changes in the physical accelerator and management structure.

## GENERAL FEATURES

At any point, a given problem is either Unsolved (*has no solution*), Solved (*has one or more solutions*) or Closed (*solved and a supervisor agrees that it's fixed*). Thus from the main menu there are separate CATER functions to report, solve and close a given problem. Also from the main menu are additional *functions to modify existing* unclosed problems or solutions, generate canned reports and browse the database.

For consistency, the operation of all screens in CATER is as similar as possible. Figure 1 shows the hardware problem report screen as it appears when reporting a new problem which we'll use to show the operations common to all screens.

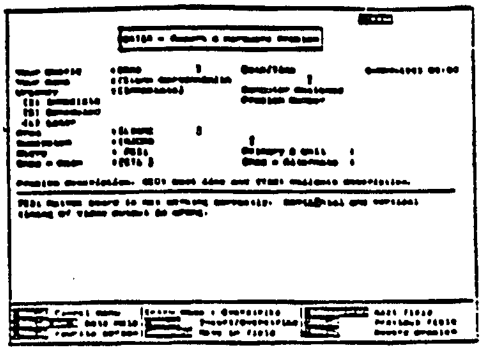


Figure 1. Hardware problem report screen

1. All allowable control options are highlighted at the bottom of the screen. Control key sequences are used for most control options because there is little overlap in function key mappings between the various terminals and emulators on which CATER can be run.
2. Online help is available for every field. This help information includes any validation which is performed. If the field is limited to a set of specific entries, the help lists them and the minimum keystrokes required for each entry.
3. Within a field the user can edit the text using the arrow keys and switching the entry mode to insert or overstrike.
4. The user can move back and forth to the next or previous field as many times as desired until all data is entered satisfactorily. Until the user enters CTRL-Z to execute the function, the cancel option (CTRL-C) is always available which returns to the previous menu without making any database changes.

## PROBLEM REPORTING

Again refer to Figure 1, the hardware problem report screen. The software screen is similar but with different fields after "Urgency". For the problem and solution entry forms there are some additional items of note:

1. Required fields are enclosed in brackets. CATER insists that you make a valid entry in these fields.
2. Initial default values are entered. For the hardware problem report this includes the users id, name and problem priority.
3. Both the problem report and solution forms have a 10 line free form description field used to describe the problem or solution. As in single line fields, the arrow keys and entry mode can be used to do simple editing. For this multi-line field, carriage-return goes to the next line as you would expect. The TAB or CTRL-B must be used to go to the next or previous field respectively.

---

* Work supported by Department of Energy contract DE-AC03-76SF00515.

An interesting historical anecdote reveals how important it is for any widely used system to adapt to the user's needs. The initial system had two lists of supervisors; one for hardware problems and one for software. After a problem was entered, it was mailed to the appropriate list. It turned out that the hardware people were usually in the field and rarely read electronic mail and so their problems were just stacking up! While the specific printer details have evolved over the years, we automatically print new hardware problems, email software ones and everybody's happy.

Except for the distribution list, the email of software problems has remained unchanged since CATER's initial release. Hardware problem distribution on the other hand, has been modified several times, reflecting organizational and personnel changes. At the present time a hardware problem is assigned to a default shop based on several problem criteria. The reporter can change the default if desired and when the problem is entered it is immediately printed on that shop's printer. This has served to expedite the solution of hardware problems since most problems go directly to those responsible for fixing them without the necessity of logging in to the computer system.

### SOLVING A PROBLEM

Once a problem has been completely or partially fixed, the solver enters a solution into the database. Any number of solutions can be entered for a given problem. Figure 2 shows the solution entry of a previously solved hardware problem. As with the problem entry, there are a set of required fields and some default values are supplied.

In this case there have been previous attempts to solve the problem and while entering yet another solution you have immediate access to the initial problem entry and all solutions to date. By using the PF1 and PF2 keys as indicated, you can expose the buried problem and solution windows and scroll through all previous solutions. If this is the first solution entry to a previously unsolved problem, the problem status automatically changes from Unsolved to Solved.

### MODIFYING PROBLEMS AND SOLUTIONS

It is frequently useful to modify the fields of an existing problem or solution. Additionally, not all fields in a problem description (such as who is assigned to fix it) are available to the initial reporter. The modify function allows supervisors to change any field in an existing, Unclosed problem. Typical reasons for modifications include.

- Add to the problem description.
- Change the person or shop to which the problem is assigned.
- Change the problem's urgency

When the modified problem is entered into the database, the modifier has the option of re-distributing the modified problem in the same way as if it were initially entered. This again allows the immediate notification of maintenance personnel of any change in a problem's status.

### CLOSING PROBLEMS

When a problem has been solved to everyone's satisfaction, a supervisor is responsible for officially closing it. Figure 3 shows the closeout screen.

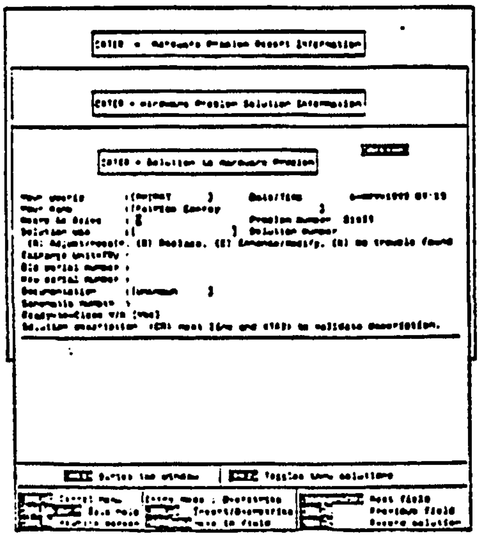


Figure 2. Hardware problem solution entry screen

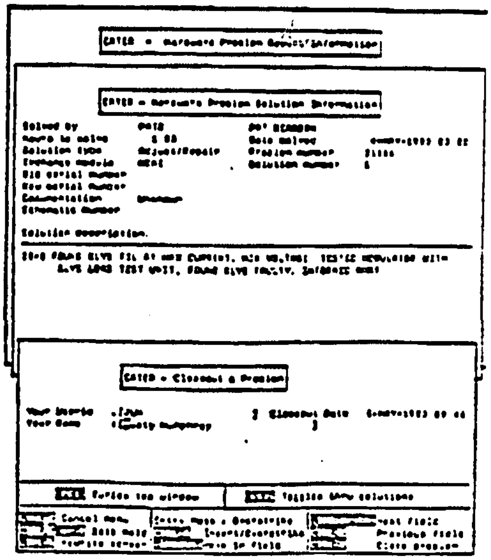


Figure 3. Problem closeout screen

As before, the report and all solutions are available for immediate review by burying windows and scrolling through multiple solutions. The user's id and name are filled in and validated against a list of authorised closers before the status of the problem is officially changed to Closed in the database.

### REPORTS & DATABASE BROWSING

Figure 4 shows the first level report screen.

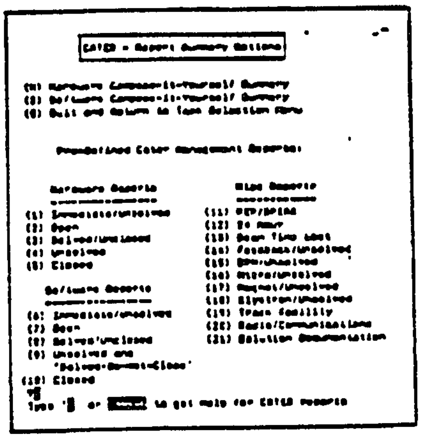


Figure 4. First level report screen

If you enter one of the numbers, CATER generates the appropriate pre-defined report on a printer of your choice. This is submitted as a batch job and returns immediately so you can do other CATER work while it's printing. If you enter 'H' or 'S', you get a "compose-it-yourself" screen for browsing the database. Figure 5 shows the hardware browsing screen. There are several things to note about this screen:

1. You can direct the output to a printer, have it displayed on your screen or written to a file for disposition as you choose.
2. The output format can be an abbreviated one liner for each selected problem, a full display of the problem and all solutions or the data can be written to a file in an 'export' format, suitable for incorporation into a PC spreadsheet or database.
3. You can enter selection criteria for any of the problem or solution fields augmented with the operators listed at the bottom of the screen. This allows almost unlimited read access to the database in a simple manner.

### IMPLEMENTATION

CATER was implemented in late 1987 before workstations and GUI interfaces were available or popular at SLAC. Indeed, many of the CATER users still use VTXXX compatible terminals or emulators which are located throughout the accelerator to access the system. The basic tools used to construct CATER were:

1. SMG, a set of screen management routines.

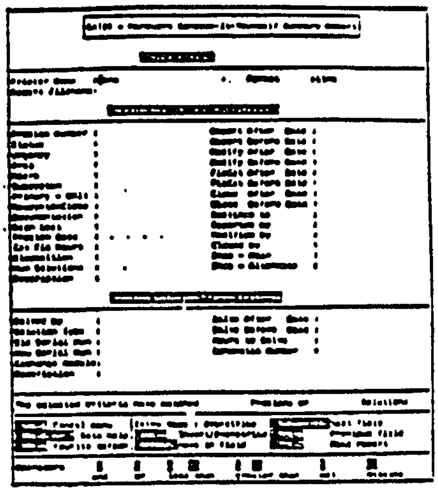


Figure 5. Hardware browsing screen

2. Rdb, DEC's relational database and associated tools, precompilers etc..
3. VAX "C" programming language.

The SMG routines are fairly low level so the CATER program has a set of data structures which define the screen layouts, fields and their validation. This means that the screens are decoupled from the database so when new database fields are added, they must also be manually added to the appropriate screens. This is the most tedious and error prone aspect of CATER software maintenance. We considered migrating to Oracle a few years ago to make maintenance easier. We ultimately decided against this approach since it would have substantially changed CATER's "look-and-feel" and some of the fine control we exercise over the screen was difficult to reproduce under Oracle. *

In general, Rdb has been satisfactory for our purposes. It offers a precompiler for executing fixed queries like we use for problem & solution entry or modification. For the browsing screens, we compose a query "on-the-fly" from the fields and operators entered and pass that to Rdb for interpretation. This is somewhat slower but gives us complete freedom to formulate queries at run time.

Retrieval performance for the browsing screens has been a bit of a problem as the database has grown. The indexes are defined around the set of fields most often referred to when scanning open (Unsolved or Solved) problems and with a little care, retrieval performance is generally satisfactory averaging 1-10 seconds depending on the complexity of the query. At the present time, of the more than 30000 problems in the database, only about 1% are open so historical queries which look at a large number of closed problems can take a minute or more. For this reason, those people compiling historical statistics usually export a large selection of records into a PC tool and do the analysis there.

To date our reliability has been excellent; we have not lost a single problem or solution in CATER's operating history.

* [illegible]

9 July 1993

To: [redacted]

From: [redacted] JLB

Subj.: What is CATER Used For?

In principle, operators write up a CATER record for (1) every time they dispatch a maintenance shop (AMW, Maintenance Mechanics, etc.) to follow up on a problem; (2) every time they discover a hardware problem which can be dealt with later; and (3) every time a hardware failure causes more than 0.1 hours of lost machine time. In fact, operators generally only make up CATER's for problems in class (2). Operators make up about 30% of the class (3) problem reports, and Wayne Linebarger or I make up the rest. Class (1) problems often don't get made out, unless they happen to be class (3) as well. Nevertheless, even with this incomplete recording, we have now amassed 32000 CATER records, most of which are for hardware problems. The value of this data base lies in its size, the fact that it spans several years, and that it is "safe" (i.e., the software is robust and the files are backed up). One deficiency is that it is not particularly easy or quick to make tailored reports from this database. One work-around is to extract a set of records using very generous search criteria which are sure to include all the problems of interest, and then to export that data to a Macintosh or PC where it can be imported into a database or spreadsheet program for more tailored reports.

The first use of CATER is by maintenance groups simply to track work outstanding. It is not intended to serve as a maintenance work control system, but it does serve as one mechanism for capturing data about malfunctioning equipment.

There is a field in CATER called "Urgency", which can have (among other values) "ROD" (for "Repair Opportunity Day") and "Downtime" (for long scheduled outages). When making up worklists for ROD's or downtimes, the CATER database can be searched for records with these values, and entries made on appropriate schedules. This has been done for several months now.

In somewhat the same vein, monthly reports are issued to the various support groups based on the CATER's which are not yet closed--this typically totals 400 or so at any given time. These are intended just to be nags to try to keep the maintenance backlog down.

Monthly reports are also issued summarizing machine downtime by various subsystems, by machine area, and so forth. These can then be looked at over time to spot trends where problems seem to be getting worse, or to flag areas where improvements have paid off.

Although the CATER system is not linked directly to the SLC control system, there is one "administrative" linkage. The control system includes a "status display system" which shows all devices which are out of tolerance or not in the proper state; since there are tens of thousands of devices in SLC this search and display has to be automated. Needless to say some of the so-called "red" problems are not necessarily serious at the moment, so they can be "acknowledged" or "deferred". The facility for performing these actions includes a feature for entering the CATER number of the record associated with the deferred or acknowledged problem.

The CATER database can be used to answer "what if" questions. Recent examples of this include: What would be the availability of the linac if used as an injector to the B-factory? What would happen if we didn't have electrician coverage on swing shift? What would happen if we didn't have instrument tech coverage on owl shift? The answers to these questions start from looking at the machine down-time figures in the CATER database, and then extrapolating them to the situation that is proposed.

Another class of question which CATER helps to answer is the retrospective specific question. Examples of these are: How many accelerator water pumps have we replaced in the past year, and do their locations appear to be statistically independent? Have we experienced more pulsed magnet high voltage cable failures this year than last, and, if so, do they appear to have a common cause? How much machine time have we lost in the past year due to entries into the machine housing to investigate false fire alarms?

Although CATER was originally intended as a replacement for yellow Post-it's reminding us to follow up on maintenance requests, it now has value as an historical database which can be used for performance analysis, work scheduling, evaluation of options, and the like.

July 22, 1993

# Proposal for CATER at CEBAF

[redacted], Controls Systems Group, Accelerator Division

## 1 Introduction:

1.1 CATER (Computer Aided Trouble Entry and Reporting) was developed at the Stanford Linear Accelertor Center to simplify the management of all problems encountered in the operation of an accelerator. It is not tied to a specific control system and runs on hardware currently available at CEBAF. All CATER functions can be performed on operator consoles workstations or on any ANSI terminal.

1.2 CATER can be used to report hardware or software problems, and in each case the system guides the user to enter sufficient information to facilitate locating and correcting the problem. The user interface is consistent throughout. Records can be modified if further information becomes available.

1.3 Statistics on the accelerator operation and downtime can be generated using CATER reports and loading the data into a PC spreadsheet such as EXCEL.

## 2 Purpose:

2.1 Provide the hardware group with an equipment performance tracking utility. This will be helpful in commissioning the accelerator and also in the day-to-day operation, in spotting recurring problems.

2.2 Generate hard copies of descriptions of equipment failures.

2.3 Provide the software group with a means of identifying and tracking control system problems. This will be especially critical with the EPICS project, since it untested in operating an accelerator. The CATER database will provide useful information to future users of the EPICS control software.

2.4 Provide the operators with an easy method of reporting problems.

2.5 Provide a method of tracking patterns in accelerator problems, and generating statistics on accelerator performance.

## 3 Hardware/Software/Manpower Requirements:

3.1 The CATER software can be imported at no cost from SLAC

3.2 The customization for CEBAF is estimated at 3 person-months with input from other Control Systems staff members.

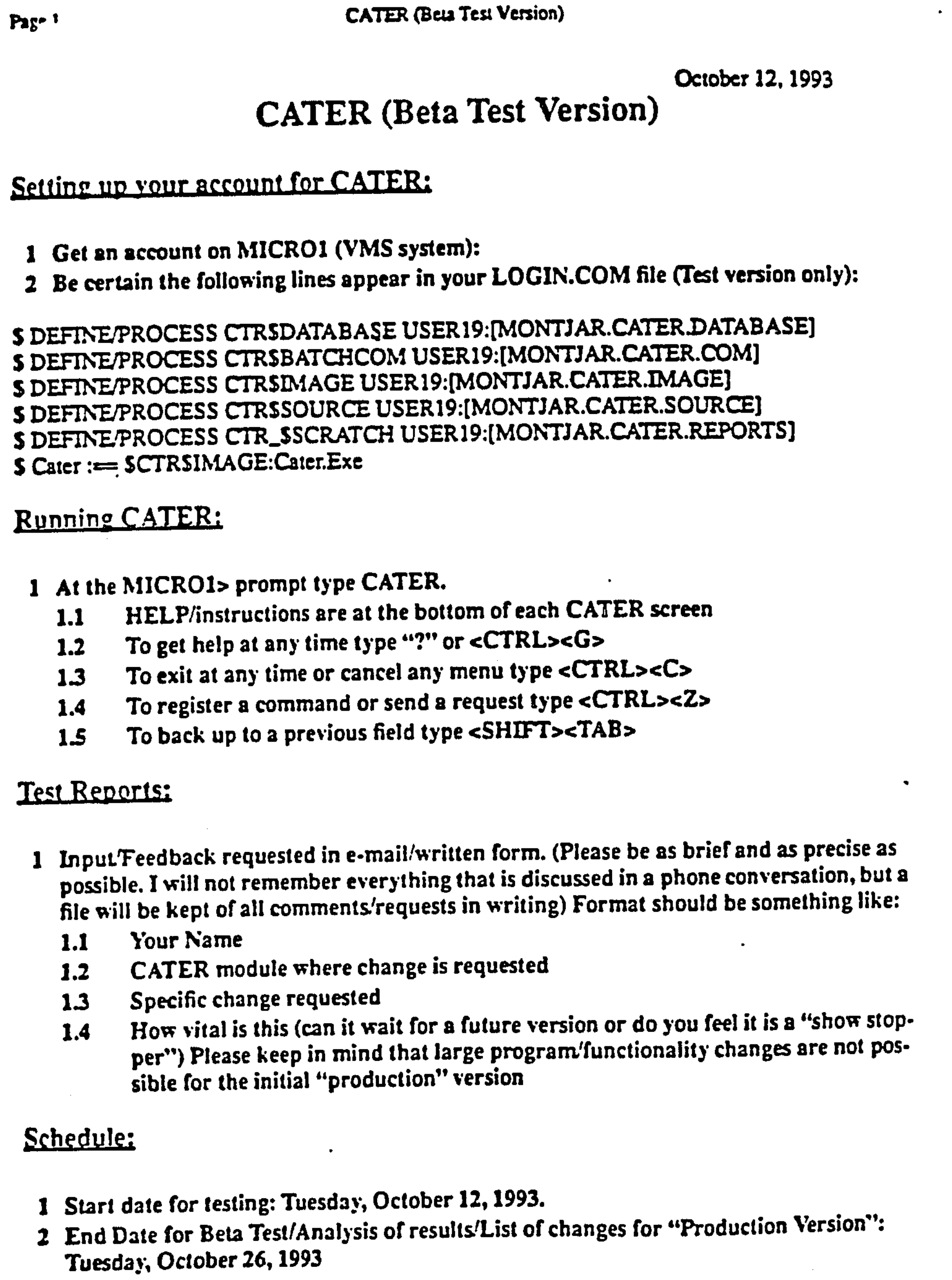
3.3 SLAC is willing to assist in the customization project. They will help to get a CEBAF CATER version running at SLAC and then assist in getting the software over to CEBAF.

3.4 **Hardware:**

- 3.4.1 VAX or VAXStation with at least a 10-user VMS Version 5.5 License (This already exists on one of the CEBAF Center machines).

3.5 **Other Software**

- 3.5.1 DEC/VAX RDB, relational database software, full development version @$3751.00



October 12, 1993

# CATER (Beta Test Version)

## Setting up your account for CATER:

1 Get an account on MICRO1 (VMS system):
2 Be certain the following lines appear in your LOGIN.COM file (Test version only):

```
$ DEFINE/PROCESS CTR$DATABASE USER19:[MONTJAR.CATER.DATABASE]
$ DEFINE/PROCESS CTR$BATCHCOM USER19:[MONTJAR.CATER.COM]
$ DEFINE/PROCESS CTR$IMAGE USER19:[MONTJAR.CATER.IMAGE]
$ DEFINE/PROCESS CTR$SOURCE USER19:[MONTJAR.CATER.SOURCE]
$ DEFINE/PROCESS CTR_$SCRATCH USER19:[MONTJAR.CATER.REPORTS]
$ Cater :== $CTR$IMAGE:Cater.Exe
```

## Running CATER:

1 At the MICRO1> prompt type CATER.
  1.1 HELP/instructions are at the bottom of each CATER screen
  1.2 To get help at any time type "?" or <CTRL><G>
  1.3 To exit at any time or cancel any menu type <CTRL><C>
  1.4 To register a command or send a request type <CTRL><Z>
  1.5 To back up to a previous field type <SHIFT><TAB>

## Test Reports:

1 Input/Feedback requested in e-mail/written form. (Please be as brief and as precise as possible. I will not remember everything that is discussed in a phone conversation, but a file will be kept of all comments/requests in writing) Format should be something like:
  1.1 Your Name
  1.2 CATER module where change is requested
  1.3 Specific change requested
  1.4 How vital is this (can it wait for a future version or do you feel it is a "show stopper") Please keep in mind that large program/functionality changes are not possible for the initial "production" version

## Schedule:

1 Start date for testing: Tuesday, October 12, 1993.
2 End Date for Beta Test/Analysis of results/List of changes for "Production Version": Tuesday, October 26, 1993

July 22, 1993

# Schedule for CATER at CEBAF

1 June 25 - July 9 ****
1.1 Source code examination
1.1.1 Purpose: To determine where any modifications need to be made to CATER to adapt it to the CEBAF environment, and make it useful to the customers of the Controls Systems Group.
2 July 12 - 16 ****
2.1 Visit - [redacted] from SLAC
2.1.1 Purpose: Speak to appropriate staff members about the use of CATER at SLAC and the advantages to CEBAF

3 July 19 - August 6 ***
3.1 Examination of the software by CEBAF groups.
3.1.1 Purpose: To determine what CEBAF specific text needs to be added to adapt the program to our environment
3.1.2 Determine reports that are needed from the system.

4 August 9 - 13 ***
4.1 Software Specification for CATER at CEBAF
4.2 Begin adaptation of SLAC user guide for use at CEBAF

5 August 16 - 20
5.1 Review of Software Specification for CATER at CEBAF (Probably optimistic)

6 August 23 - 27
6.1 B. [redacted] at SLAC to work with software engineers and database specialists.

7 August 30 - September 30
7.1 Code changes to CATER for CEBAF
7.2 Hold training sessions for users who will test the software
7.3 Test software with selected group of users. make any changes necessitated by the test.
7.4 Begin training process for all users

8 October 1
8.1 Begin controlled release of CATER into atmosphere...
8.2 Distribute production version of User Guide

**** Steps already completed
*** Steps in process

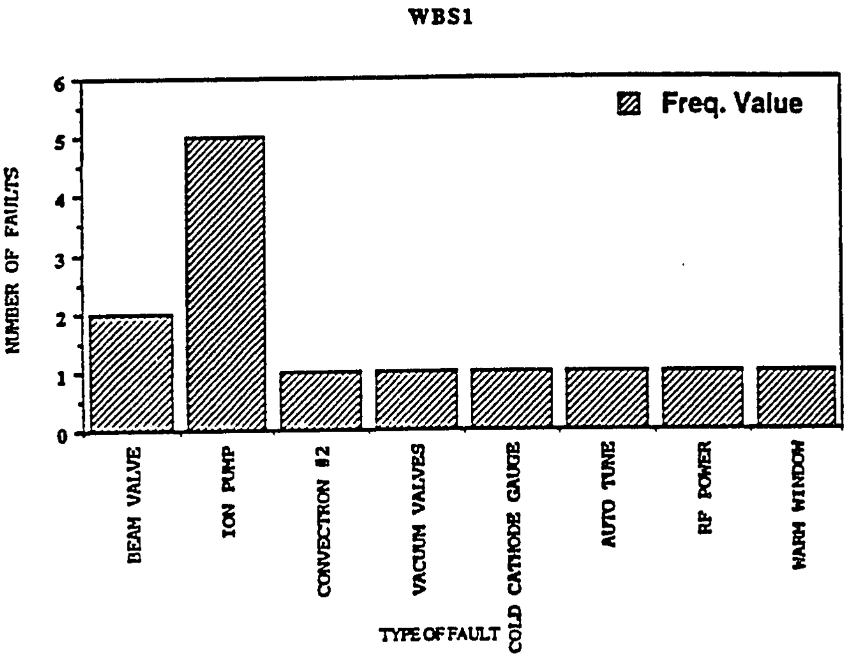
**3 Proposed Date for implementation in Control Room: Monday, November 1, 1993.**

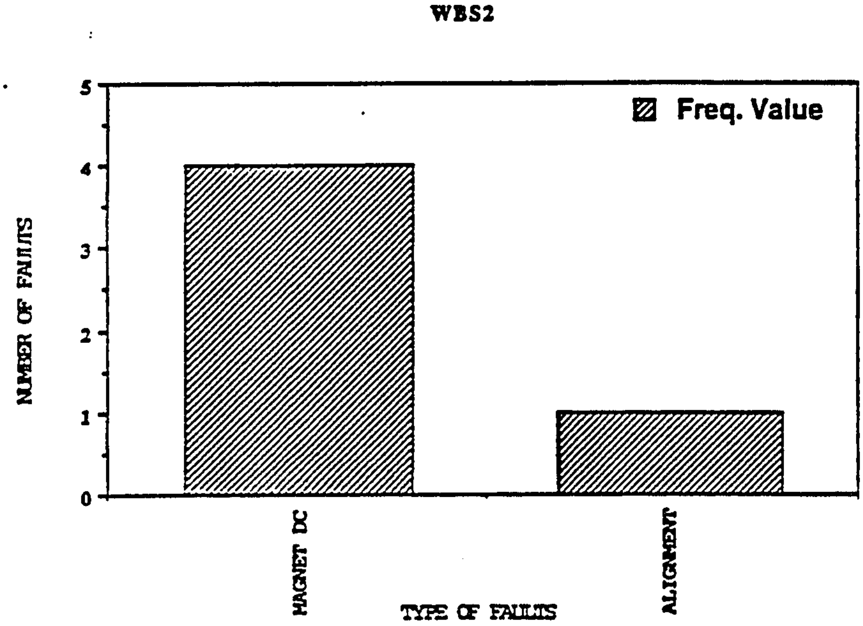
NOTE: There are now two executable versions of CATER - one for me to work on, and one for you to test. As I get features worked out on the development version, I will transfer them to the test version with notes to all of you participating in the test.

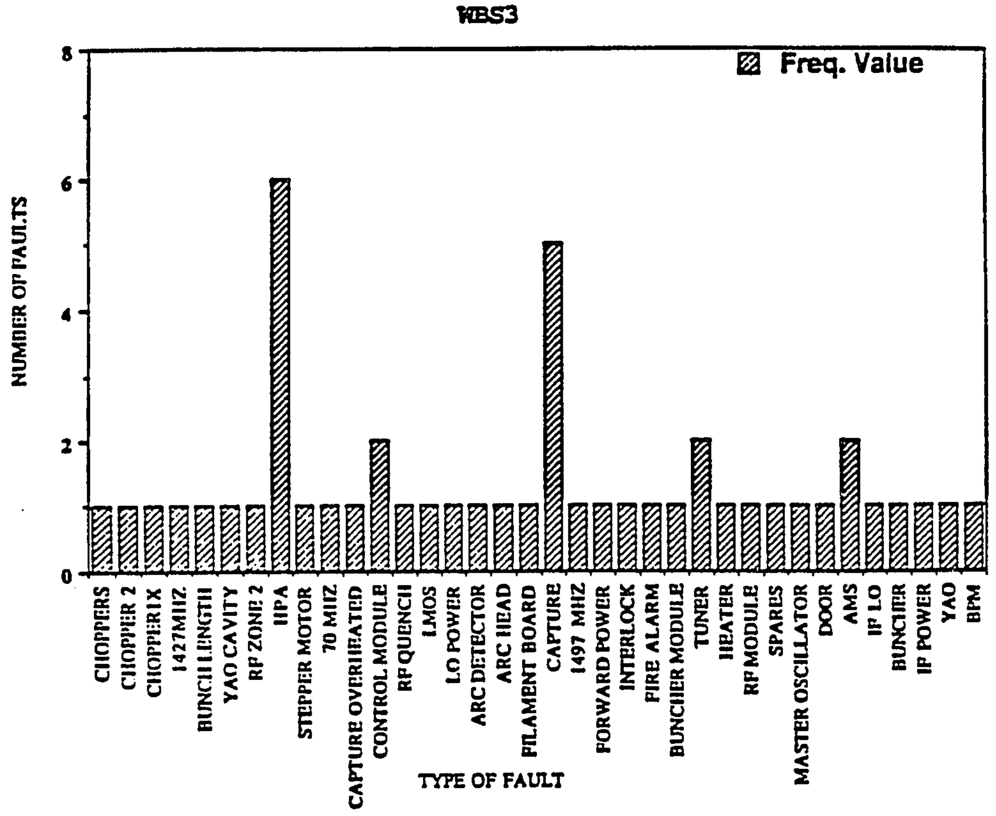
# APPENDIX 11

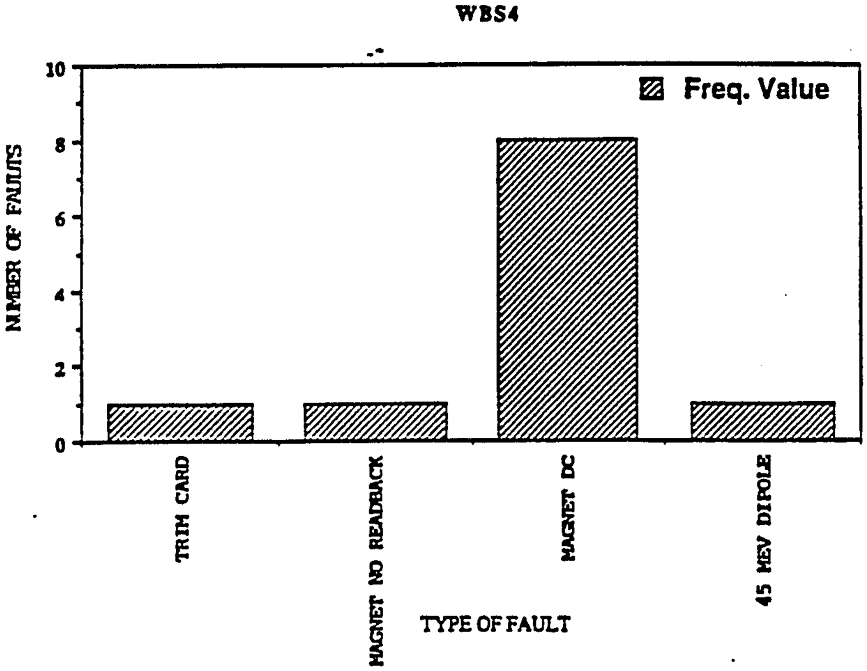
## Equipment Failures II

This appendix contains histograms for the first 248 equipment faults reported using the CATER system. Histograms were developed for each work group. The histograms plot number of faults against the type of fault. The type of fault is usually listed as a piece of equipment, but if that equipment experienced several modes of failure, then each mode is listed and described in a word or two.

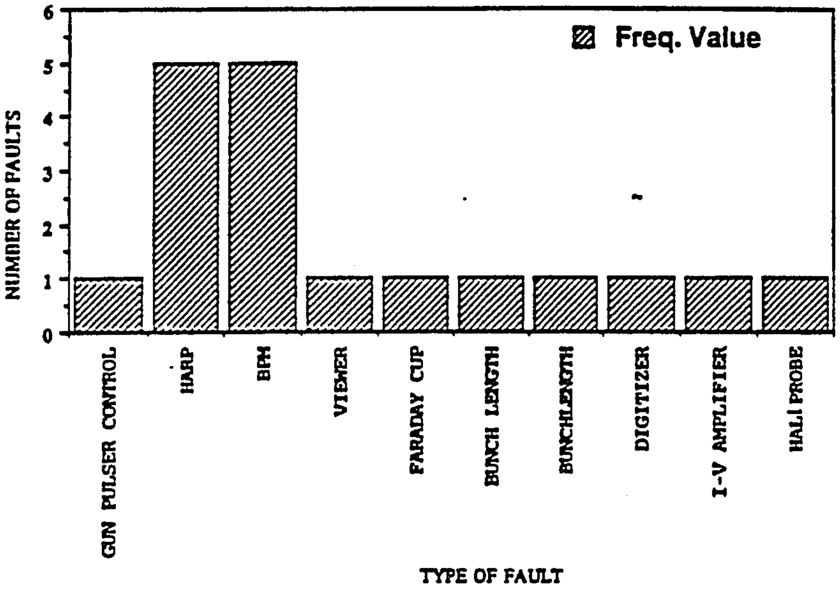

WBS1
Freq. Value
NUMBER OF FAULTS
0
1
2
3
4
5
6
BEAM VALVE
ION PUMP
CONVECTRON #2
VACUUM VALVES
COLD CATHODE GAUGE
AUTO TUNE
RF POWER
WARM WINDOW
TYPE OF FAULT

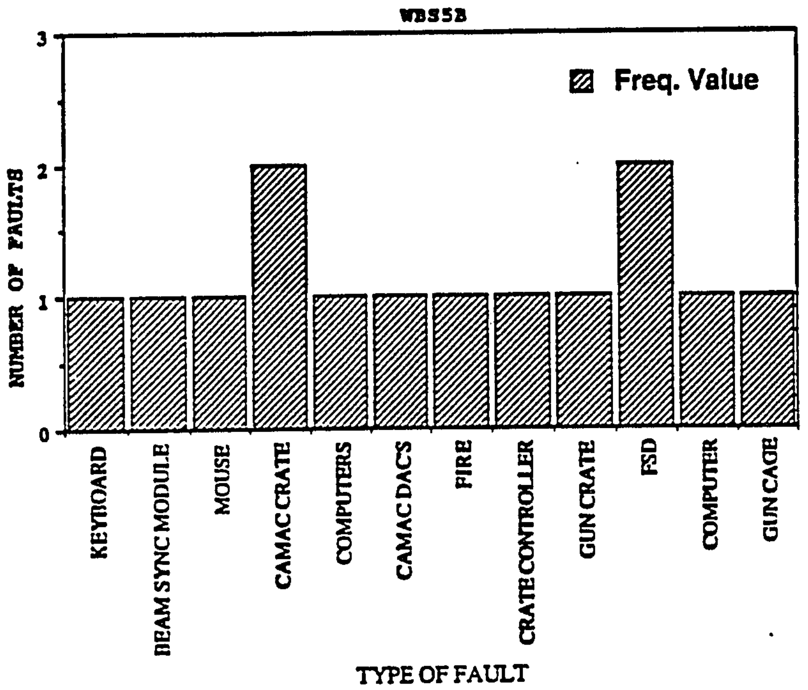

WBS2
▨ Freq. Value
NUMBER OF FAULTS
TYPE OF FAULTS
MAGNET DC
ALIGNMENT
0
1
2
3
4
5

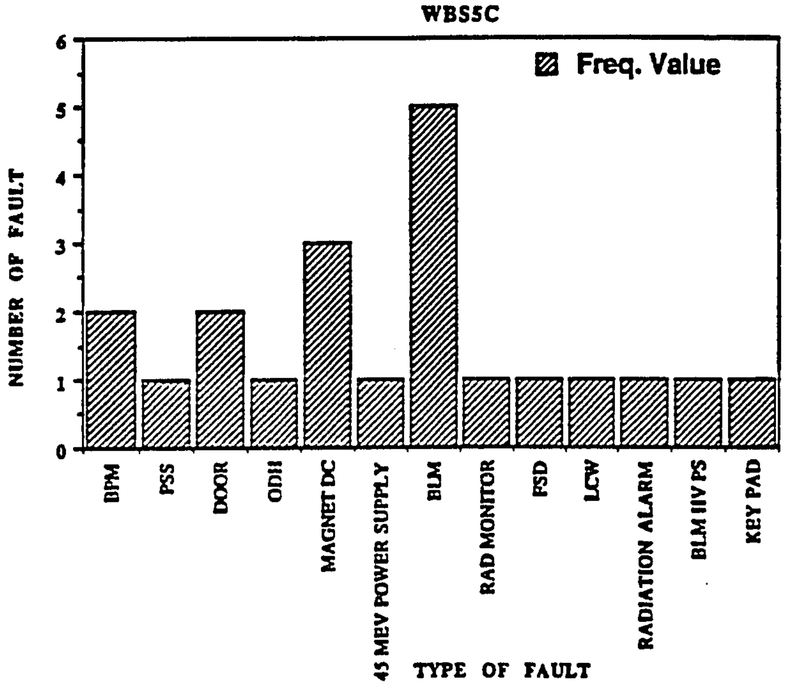

WBS3
▨ Freq. Value
NUMBER OF FAULTS
0
2
4
6
8
TYPE OF FAULT
CHOPPERS
CHOPPER 2
CHOPPER1X
1427MHZ
BUNCH LENGTH
YAO CAVITY
RF ZONE 2
HPA
STEPPER MOTOR
70 MHZ
CAPTURE OVERHEATED
CONTROL MODULE
RF QUENCH
LMOS
LO POWER
ARC DETECTOR
ARC HEAD
FILAMENT BOARD
CAPTURE
1497 MHZ
FORWARD POWER
INTERLOCK
FIRE ALARM
BUNCHER MODULE
TUNER
HEATER
RF MODULE
SPARES
MASTER OSCILLATOR
DOOR
AMS
IF LO
BUNCHER
IF POWER
YAO
BPM

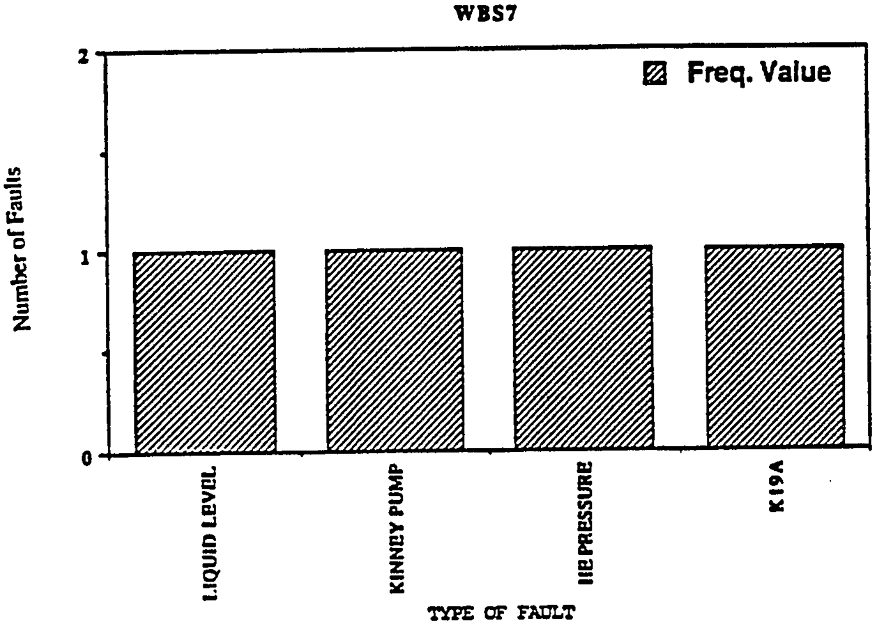

WBS4
▨ Freq. Value
NUMBER OF FAULTS
0
2
4
6
8
10
TRIM CARD
MAGNET NO READBACK
MAGNET DC
45 MEV DIPOLE
TYPE OF FAULT

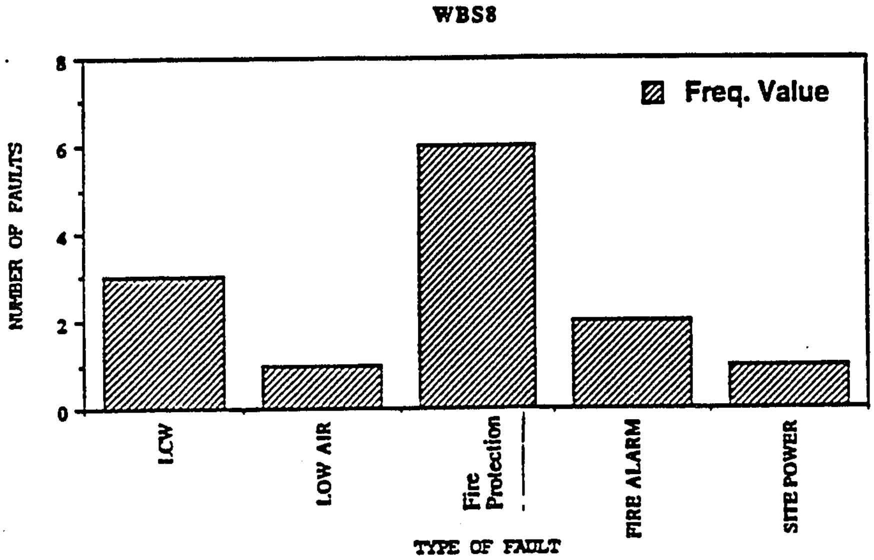
WBS5A

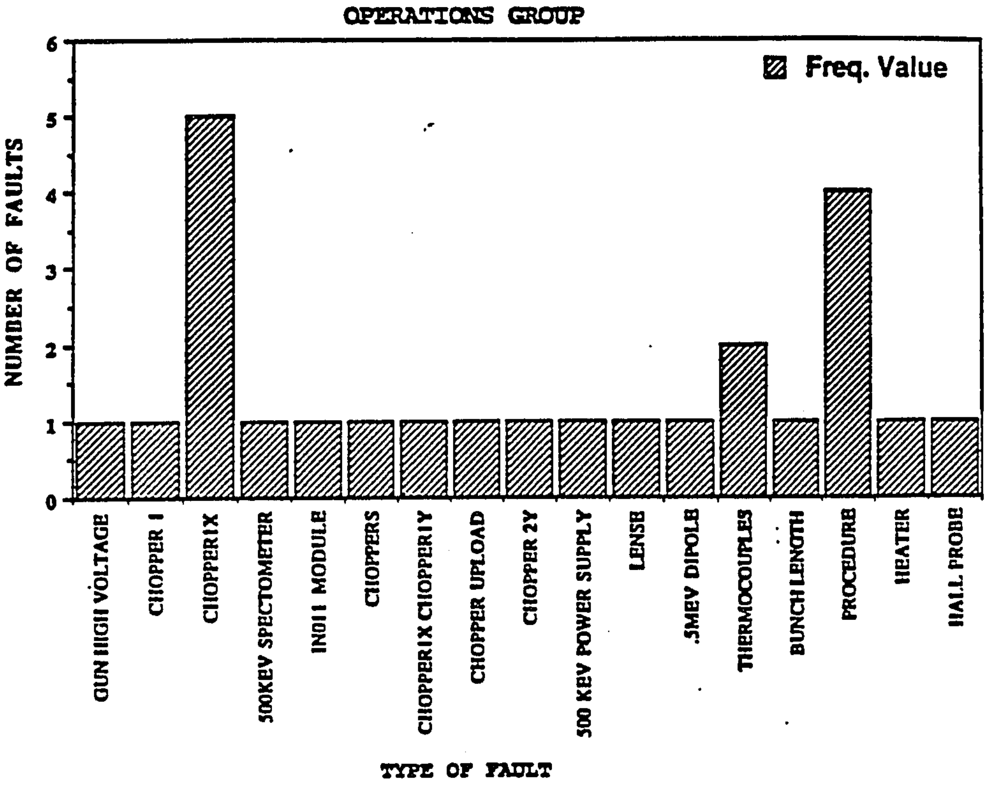

▨ Freq. Value
NUMBER OF FAULTS
0
1
2
3
4
5
6
GUN PULSER CONTROL
HARP
BPM
VIEWER
FARADAY CUP
BUNCH LENGTH
BUNCHLENGTH
DIGITIZER
I-V AMPLIFIER
HALL PROBE
TYPE OF FAULT


WBS5B
▨ Freq. Value
NUMBER OF FAULTS
0
1
2
3
KEYBOARD
BEAM SYNC MODULE
MOUSE
CAMAC CRATE
COMPUTERS
CAMAC DAC'S
FIRE
CRATE CONTROLLER
GUN CRATE
FSD
COMPUTER
GUN CAGE
TYPE OF FAULT

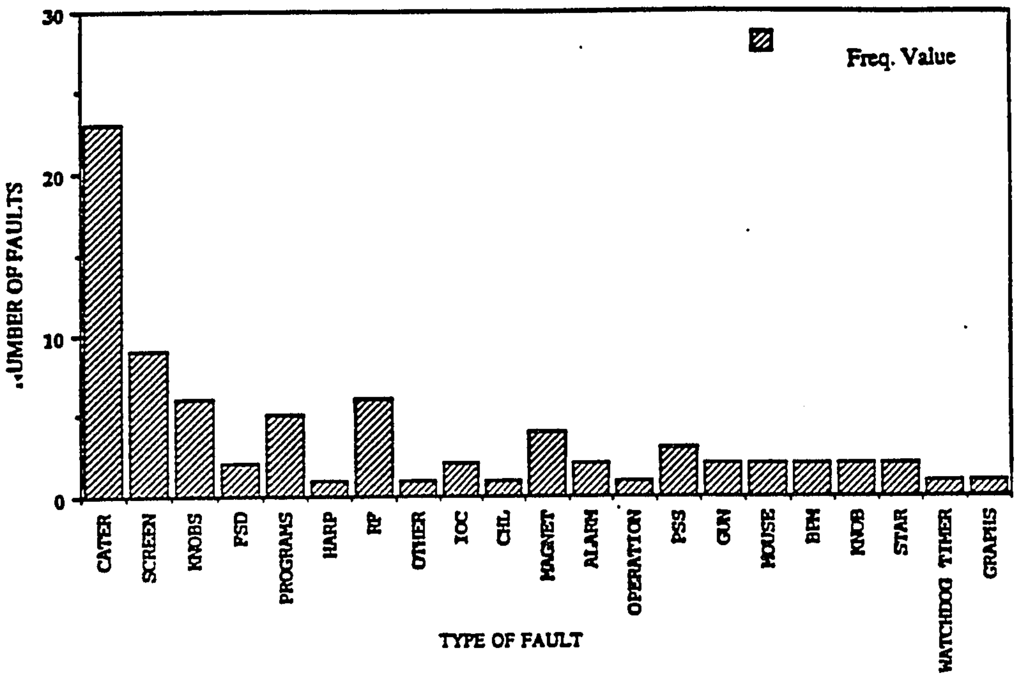

WBS5C
▨ Freq. Value
NUMBER OF FAULT
0
1
2
3
4
5
6
BPM
PSS
DOOR
ODH
MAGNET DC
45 MEV POWER SUPPLY
BLM
RAD MONITOR
FSD
LCW
RADIATION ALARM
BLM HV PS
KEY PAD
TYPE OF FAULT


WBS7
Freq. Value
Number of Faults
2
1
0
LIQUID LEVEL
KINNEY PUMP
HE PRESSURE
K19A
TYPE OF FAULT


WBS8
▨ Freq. Value
NUMBER OF FAULTS
0
2
4
6
8
LCW
LOW AIR
Fire Protection
FIRE ALARM
SITE POWER
TYPE OF FAULT


OPERATIONS GROUP
▨ Freq. Value
NUMBER OF FAULTS
0
1
2
3
4
5
6
GUN HIGH VOLTAGE
CHOPPER 1
CHOPPER1X
500KEV SPECTOMETER
IN011 MODULE
CHOPPERS
CHOPPER1X CHOPPER1Y
CHOPPER UPLOAD
CHOPPER 2Y
500 KEV POWER SUPPLY
LENSE
.5MEV DIPOLE
THERMOCOUPLES
BUNCH LENGTH
PROCEDURE
HEATER
HALL PROBE
TYPE OF FAULT

**CONTROL SYSTEMS**



# APPENDIX 12

## Accelerator Site Cold Weather Plan

From the CEBAF Cold Weather Plan:

The Emergency Management Manager or designee will recommend to the Facility Manager that cold weather plans be implemented site wide when severe cold weather or a cold weather storm is predicted by the National Weather Service. Any one of the following criteria are probably adequate reasons for making this recommendation:

1. An ice storm or a snowfall of five or more inches.
2. Sustained day time temperatures below freezing.
3. Temperatures below $32^o$ F. with sustained loss of electrical power.

The Facility Manager will take this recommendation under consideration and make a decision. If the decision is made to implement cold weather plans, The Emergency Management Manager will notify all Associate Directors and request that they implement their cold weather plans.

Nothing in this plan precludes an Associate Director from starting implementation of divisional plans early in anticipation of site wide implementation.

Accelerator Cold Weather Plan

Crew Chief

Upon receiving direction to implement the Accelerator Site Cold Weather Plan, the Crew Chief will ensure that the Operations Department Head and the Program Director are aware of the decision.

1. Notify essential workers (designated by the Associate Director) of the time of implementing this plan.

2. Coordinate conduct of scheduled operations with the Program Director and experimental groups leaders.

3. Contact Plant Services and coordinate implementation of Plant Service's Cold Weather Plan with the accelerator site. Specifically, determine necessary protection for the following systems from freezing:

    a. Cooling towers
    b. Low conductivity water (LCW) Systems
    c. Sprinkler Systems
    d. Potable water systems

4. Contact all maintenance groups and direct them to implement their cold weather plans.

5. Verify availability of emergency equipment:

    a Emergency generator(s)
    b. Water pumps
    c. Portable heaters
    d. Air compressor(s)
    e. Radio telephones

6. Control all work being conducted outside or in unheated buildings to include:*

    a. Know location and type of work.
    b. Record names of all individuals.
    c. Record start and stop times of work.
    d. Equip work team leader with a 2-way radio and conduct periodic radio checks.

7. If electrical power is lost, review possible courses of action with the Operations Department Head:

    a. Position heaters in service buildings.
    b. Drain or blow down certain water systems.
    c. Maintain a flow in some water systems.
    d. Provide emergency power to selected loads.

# APPENDIX 13

## Emergency Portable Equipment

## EMERGENCY PORTABLE EQUIPMENT

**Electrical Generators**

| Name | Serial # | Prop. Tag | Manufact. | Building | Room | Specs |
|---|---|---|---|---|---|---|
| 1 | 1092863 | F25288 | Briggs&Strat. | 98 | Main | 120VAC/4KW/3 choices amps and phase. |
| 2 | None | F217178 | Honda | 13 | NA | 120/240VAC/6.0KVA/1 phase |
| 3 | ALQ1072 | F25527 | Honda | Tunnel | NA | 12VDC@8.3A/120 VAC, 900VA, 1 phase |
| 4 | 2215936 | F25435 | Honda | 58 | 140 | 120VAC/1.4KVA/gasoline |
| 5 | EA4-1101232 | F25265 | Honda | 58 | A8A | 120VAC/1KW/110VAC/gasoline |
| 6 | ALQ0949 | F25266 | Honda | 13 | NA | 120VAC/900 VA/12VDC/8.3A |
| 7 | 113526 | F22855 | Kawasaki | 58 | 124 | 120/240VAC 1 phase/12VDC/3KW |

**Air Compressors**

| Name | Serial # | Prop. Tag | Rating | Building | Room | Specs |
|---|---|---|---|---|---|---|
| 8 | 082687L-008133 | F21376 | 1 HP* | 8 or 98 | Various | 200psi/120-230 VAC |
| 9 | 07179L/519262 | F25264 | 2 HP | 90 | 102 | 125psi/5-7cfm/120V/15A |
| 10 | 1290 | F25201 | 1 HP | 58 | Mezzanine | 100psi/120Vac |
| 11 | none | F25342 | 1 HP | 90 | 118 | 110psig/2.2 ft$^3$/hr/120VAC |
| 12 | 062189L009577 | F27116 | 2 HP | WBS3 transportainer |  | 200 psi Speedair brand |

**Space Heaters**

| Name | Serial # | Prop. Tag | Rating | Building | Room | Power Requirements |
|---|---|---|---|---|---|---|
| 13 | 1022081 | F217230 | 150,000 BTU | 13 | NA | 120 VAC/4.5A |
| 24 | 1018568 | F217231 | 150,000 BTU | 13 | NA | 120 VAC/4.5A |
| 15 | None | F25463 | 15KW | WBS4 Transptnr |  | 480VAC |

**Portable Water Pumps**

| Name | Serial # | Prop. Tag | Manufact. | Building/Room | Rating (GPM) |
|---|---|---|---|---|---|
| 16 | 739659 | F216200 | Grindex | 28/61 | 480V/3 phase/centrifugal |

Numbers are used in this appendix rather than names to protect privacy.

# APPENDIX 14

## Presentation to the Quality Institute

# INTRODUCTION

## Continuous Electron Beam Accelerator Facility

## Hardware Checkout and Reliability Team

**Introduction:** T
**Cater:** B
**Failure Analysis:** Ka

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# TEAM INFORMATION

| | |
|---|---|
| What: | Hardware Checkout and Reliability Team |
| Who: | Ten members: Scientist, Operators, Engineers, Technicians, Computer Scientist |
| When: | Established in June 1993 |
| Where: | CEBAF Accelerator System |
| How: | Meets weekly for two hours<br>Established group norms<br>Subgroups (2 or 3) work on projects |

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# GOALS AND MILESTONES

- Evaluate hardware reliability during the last six months of operations. Logbook analysis of equipment performance to be reported by July 1, 1993. Identify unreliable equipment. Inform all groups. Analysis of group responses by August 1, 1993.
- Evaluate improvements made by groups. Perform long term check of high power amplifier in the south linac.
- Participate in definition of the new database. Evaluate and report on proposed database content by July 1, 1993.
- Establish procedures to enter hardware into the database.
- With operations group, check out hardware through the computer and correct the database.
- Ensure the trouble reporting system is ready and adequate. Evaluate and report on the trouble reporting system by July 1, 1993.
- Propose and implement "burn-in" procedures to improve reliability. Provide "burn-in" procedures document by September 1, 1993.

# SURVEY PURPOSE

- To encourage thought about mid-term and far-term problems
- To encourage thought abut supporting operations
- To confirm or deny the conventional wisdom about readiness
- To identify major hardware and system problems

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d[redacted]|Tidewater Quality Counsel 18 February 1994

# SURVEY QUESTIONS

| | |
|---|---|
| Schedule | 7 |
| Operational Support | 5 |
| Maintenance | 5 |
| Spare Parts | 3 |
| TOTAL | 20 |

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djv [redacted] Tidewater Quality Counsel

18 February 1994

# GRADING CRITERIA

| | |
|---|---|
| **Six Objective Questions** | |
| Satisfactory Response | 1 |
| Unsatisfactory Response | 2 |
| **Fourteen Subjective Questions** | |
| In Good Shape | 1 |
| Situation Doubtful | 2 |
| In Trouble | 3 |

| Question Number | Description | WBS 1 | WBS 2 | WBS 3 | WBS 4 | WBS 5 PSSMPS | WBS 5 Beam Diagnostics (Mechanical) | WBS 5 Applications | Operations Inj. Interlocks | Operations Inj. Software | Operations Inj. Magnets | Operations Inj. Gun | Operations Control System | WBS 5 Systems Interface | WBS 7 | WBS 8 | AVERAGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Sys. Responsibility | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1.00 |
| 2 | Inst. Sched. Plan | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1.13 |
| 3 | Injector Sched. | 1 | N/A | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | N/A | 1 | N/A | 1 | 1.15 |
| 4 | Status | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1.00 |
| 5 | Documentation | 1 | N/A | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | N/A | N/A | 1 | 1 | 1.08 |
| 6 | I.D. Obstacles | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 1.87 |
| 7 | Work Arounds | 1 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1.47 |
| 8 | Oper. From MCC | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | N/A | 2 | 1.14 |
| 9 | Flow Charts-Normal | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | N/A | 2 | 1 | 2 | 1 | 1 | 2 | 1.36 |
| 10 | Flow Charts-Abnormal | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | N/A | 2 | 1 | 2 | 1 | 1 | 3 | 1.43 |
| 11 | Fault ID | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | N/A | 2 | N/A | 1 | 2 | 1 | 3 | 1.47 |
| 12 | Call In List | 1 | 2 | 1 | 1 | 1 | 2 | 1 | N/A | 1 | N/A | N/A | 1 | 1 | 1 | 1 | 1.17 |
| 13 | Maint. Sys. | 2 | 3 | 2 | 1 | 1 | 2 | 1 | N/A | N/A | N/A | 1 | 1 | 2 | 1 | 2 | 1.58 |
| 14 | Maint. Training | 1 | 2 | 2 | 1 | 2 | 3 | N/A | N/A | N/A | N/A | N/A | 1 | 1 | 1 | 2 | 2.10 |
| 15 | Training | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1.33 |
| 16 | Unsched. Repair | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | N/A | N/A | N/A | 1 | 1 | 1 | 3 | 1.25 |
| 17 | Buggers | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | N/A | 1 | 1 | 1 | 1.00 |
| 18 | Spares | 1 | 1 | 2 | 1 | 2 | 1 | N/A | N/A | 1 | 1 | 1 | 3 | 1 | 2 | 1 | 1.38 |
| 19 | Spare Storage | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | N/A | 1 | N/A | N/A | 2 | 1 | 1 | 1.08 |
| 20 | Spare Access | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | N/A | 1 | 1 | 1 | 2 | 1 | 1 | 1.14 |

Harware Checkout and Reliability Team Survey #1

# PARETO ANALYSIS # 1

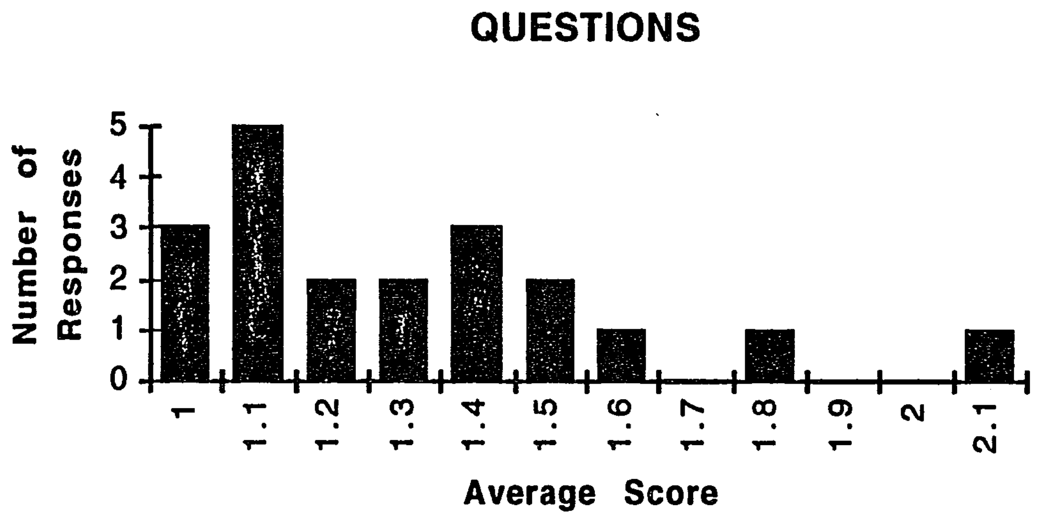
"Twenty percent of the items will cause eighty percent of the problems"

300 Total blocks
-30 N/A blocks
270 Quantified blocks

60 blocks = 2
+7 blocks = 3
67 blocks not 1

$$\frac{67}{270} = .248$$

# QUESTIONS



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Hrdwre Chkout & Rel. Team 15 November 1993

# PARETO ANALYSIS # 2

## Questions

| Question | Topic | Average |
|---|---|---|
| 14 | Describe your repair maintenance tracking system. | 2.10 |
| 6 | What are the obstacles hindering your efforts? | 1.80 |
| 13 | Describe your existing preventive maintenance plan. | 1.58 |
| 7 | What are your work-around/fall-back plans? | 1.47 |
| 11 | What tools will you provide the OPS Group for fault detection/correction? | 1.46 |

# SPECIFIC CONCERNS

| | | |
|---|---|---|
| Spares | | 2 |
| Maintenance | | 2 |
| Reliability | | 3 |
| | TOTAL | 7 |

# THE FUTURE

- Increase CATER capability
- Improve preventive maintenance program
- Develop spares database
- Develop "downtime logger"
- Identify high failure rate items
- Identify high maintenance items

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# WHY CATER?

- Already operational, well tested
- SLAC willing to work with us to transfer the software
- Provides unbiased, non-confrontational method for reporting and solving problems
- Rapid notification to responsible groups
- Highlights situations that could become problems
- Data can be used for reports, statistics, trend analysis
- Unexpected benefits

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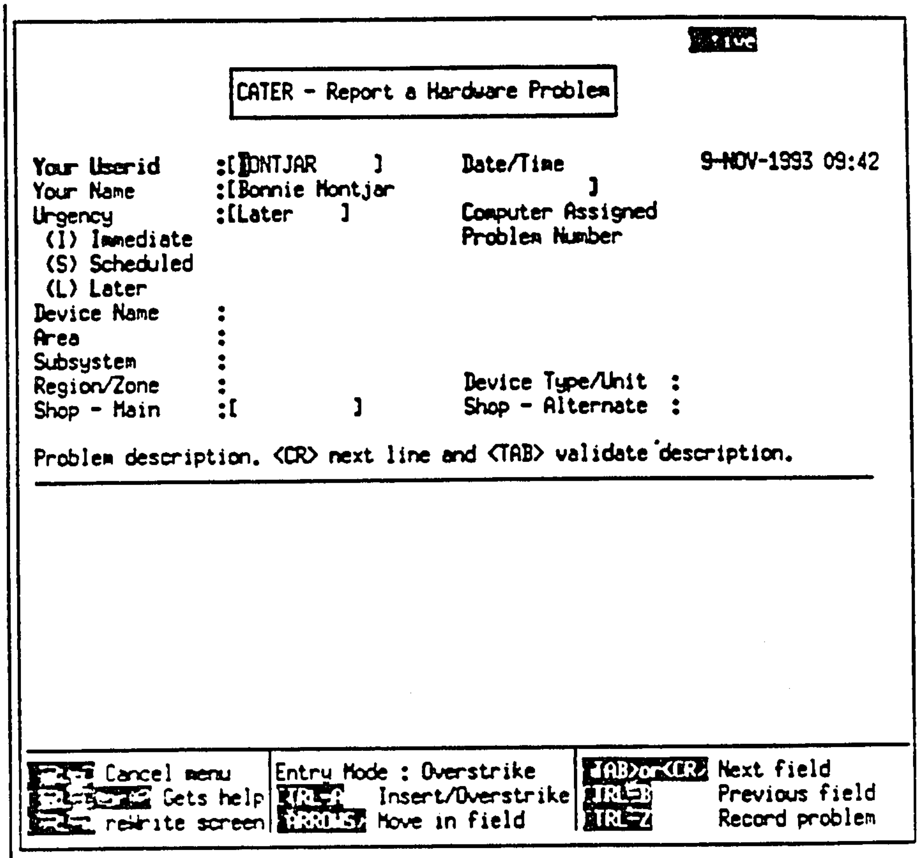
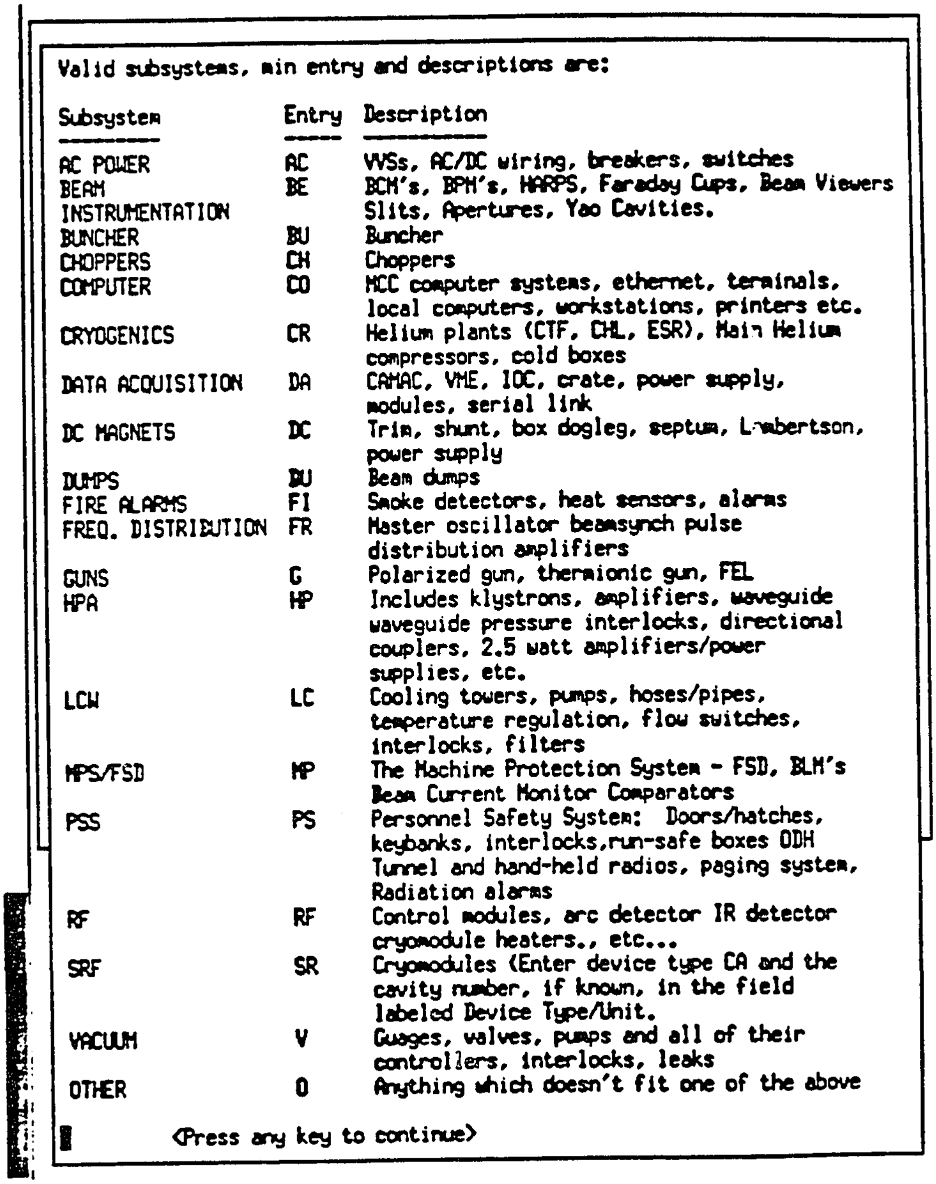
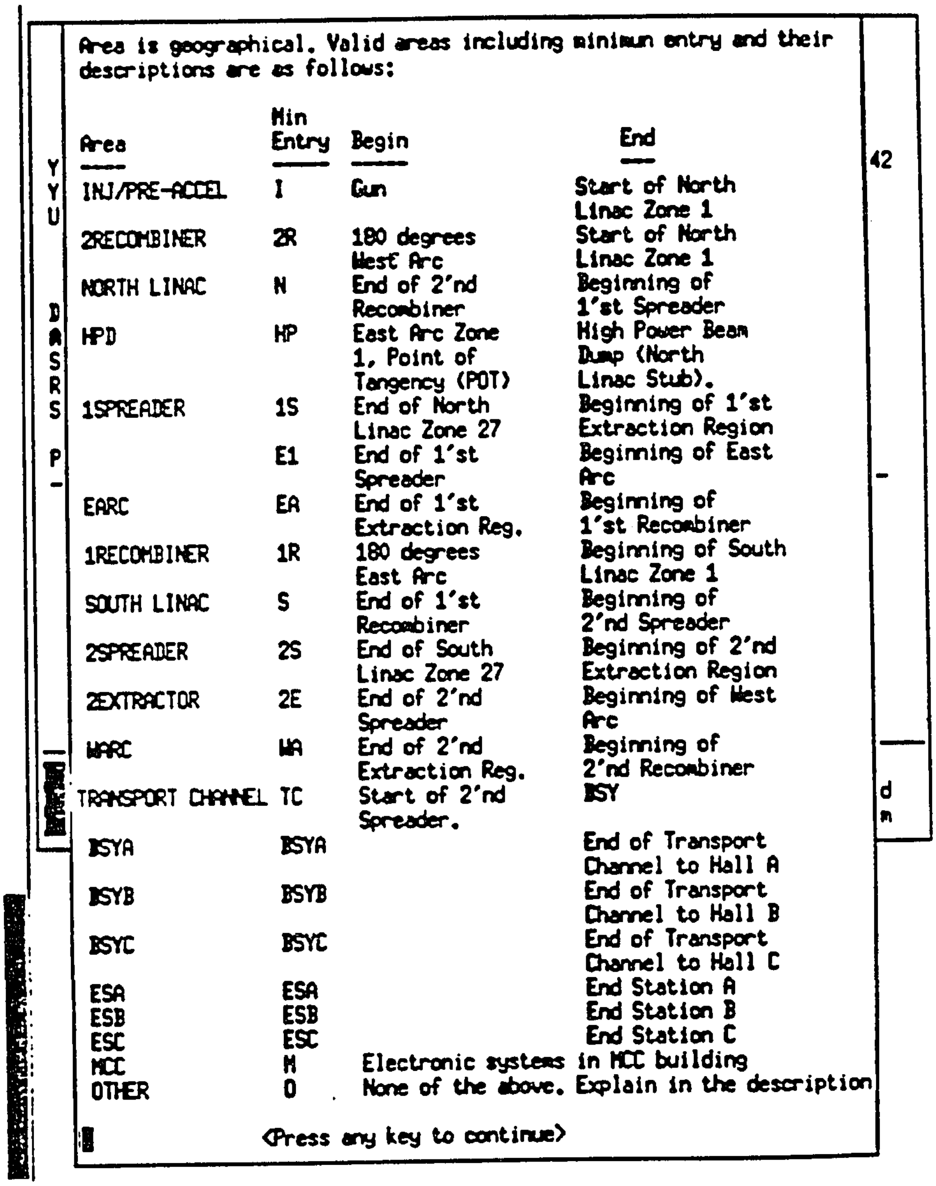


```
                    CATER - Report a Hardware Problem

Your Userid    :[█ONTJAR    ]       Date/Time             9-NOV-1993 09:42
Your Name      :[Bonnie Montjar                 ]
Urgency        :[Later   ]          Computer Assigned
 (I) Immediate                      Problem Number
 (S) Scheduled
 (L) Later
Device Name    :
Area           :
Subsystem      :
Region/Zone    :                    Device Type/Unit  :
Shop - Main    :[          ]        Shop - Alternate  :

Problem description. <CR> next line and <TAB> validate description.
______________________________________________________________________

[illegible] Cancel menu     | Entry Mode : Overstrike     | TAB>or<CR> Next field
[illegible] Gets help       | CTRL-A   Insert/Overstrike  | CTRL-B     Previous field
[illegible] rewrite screen  | ARROWS   Move in field      | CTRL-Z     Record problem
```

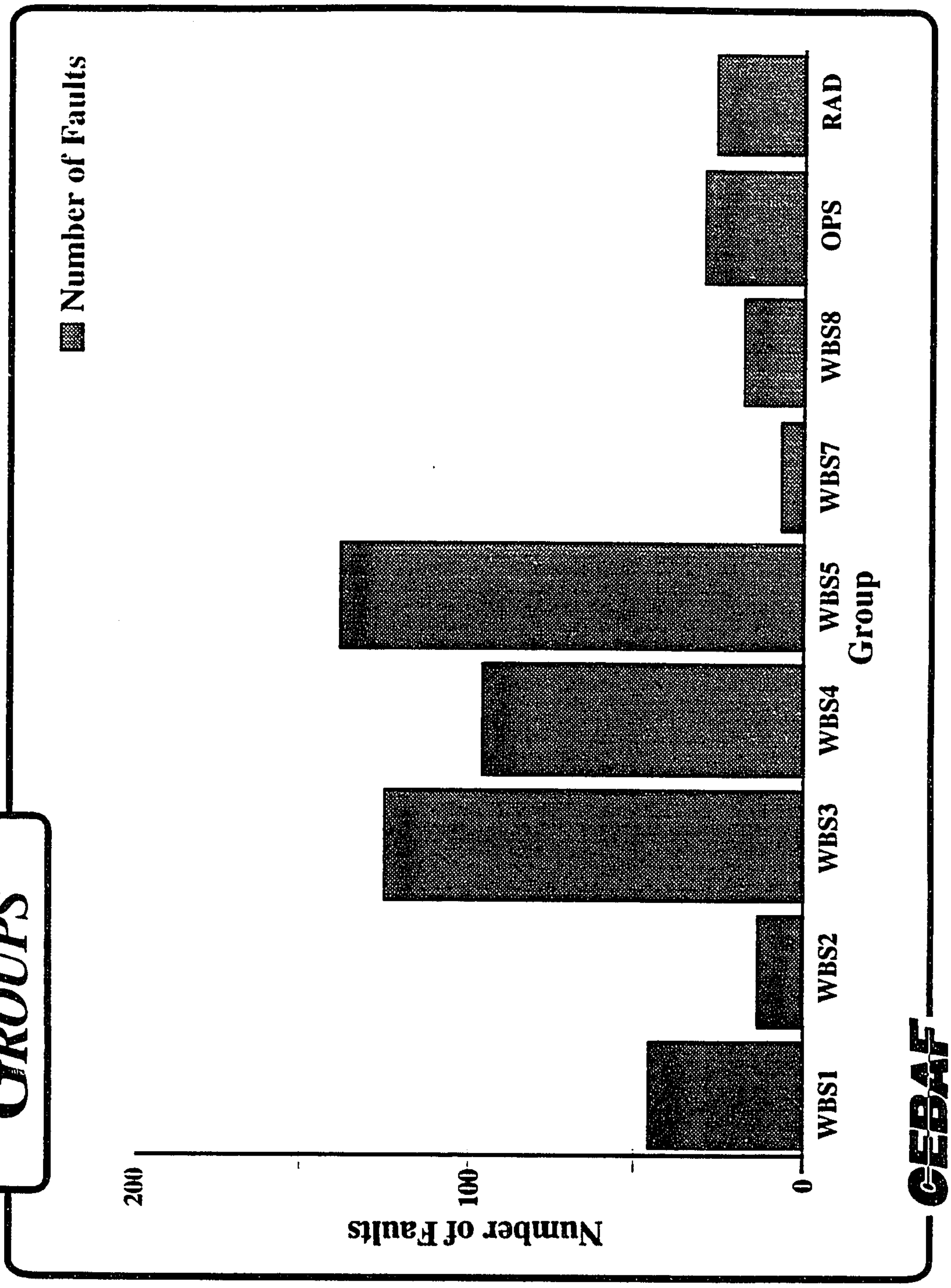


```
Valid subsystems, min entry and descriptions are:

Subsystem            Entry  Description
---------            -----  -----------
AC POWER             AC     VVSs, AC/DC wiring, breakers, switches
BEAM                 BE     BCM's, BPM's, HARPS, Faraday Cups, Beam Viewers
INSTRUMENTATION             Slits, Apertures, Yao Cavities.
BUNCHER              BU     Buncher
CHOPPERS             CH     Choppers
COMPUTER             CO     MCC computer systems, ethernet, terminals,
                            local computers, workstations, printers etc.
CRYOGENICS           CR     Helium plants (CTF, CHL, ESR), Main Helium
                            compressors, cold boxes
DATA ACQUISITION     DA     CAMAC, VME, IOC, crate, power supply,
                            modules, serial link
DC MAGNETS           DC     Trim, shunt, box dogleg, septum, Lambertson,
                            power supply
DUMPS                DU     Beam dumps
FIRE ALARMS          FI     Smoke detectors, heat sensors, alarms
FREQ. DISTRIBUTION   FR     Master oscillator beamsynch pulse
                            distribution amplifiers
GUNS                 G      Polarized gun, thermionic gun, FEL
HPA                  HP     Includes klystrons, amplifiers, waveguide
                            waveguide pressure interlocks, directional
                            couplers, 2.5 watt amplifiers/power
                            supplies, etc.
LCW                  LC     Cooling towers, pumps, hoses/pipes,
                            temperature regulation, flow switches,
                            interlocks, filters
MPS/FSD              MP     The Machine Protection System - FSD, BLM's
                            Beam Current Monitor Comparators
PSS                  PS     Personnel Safety System:  Doors/hatches,
                            keybanks, interlocks,run-safe boxes ODH
                            Tunnel and hand-held radios, paging system,
                            Radiation alarms
RF                   RF     Control modules, arc detector IR detector
                            cryomodule heaters., etc...
SRF                  SR     Cryomodules (Enter device type CA and the
                            cavity number, if known, in the field
                            labeled Device Type/Unit.
VACUUM               V      Guages, valves, pumps and all of their
                            controllers, interlocks, leaks
OTHER                O      Anything which doesn't fit one of the above

█          <Press any key to continue>
```



```
Area is geographical. Valid areas including minimum entry and their
descriptions are as follows:

                  Min
Area              Entry  Begin               End
----              -----  -----               ---
INJ/PRE-ACCEL     I      Gun                 Start of North
                                             Linac Zone 1
2RECOMBINER       2R     180 degrees         Start of North
                         West Arc            Linac Zone 1
NORTH LINAC       N      End of 2'nd         Beginning of
                         Recombiner          1'st Spreader
HPD               HP     East Arc Zone       High Power Beam
                         1, Point of         Dump (North
                         Tangency (POT)      Linac Stub).
1SPREADER         1S     End of North        Beginning of 1'st
                         Linac Zone 27       Extraction Region
                  E1     End of 1'st         Beginning of East
                         Spreader            Arc
EARC              EA     End of 1'st         Beginning of
                         Extraction Reg.     1'st Recombiner
1RECOMBINER       1R     180 degrees         Beginning of South
                         East Arc            Linac Zone 1
SOUTH LINAC       S      End of 1'st         Beginning of
                         Recombiner          2'nd Spreader
2SPREADER         2S     End of South        Beginning of 2'nd
                         Linac Zone 27       Extraction Region
2EXTRACTOR        2E     End of 2'nd         Beginning of West
                         Spreader            Arc
WARC              WA     End of 2'nd         Beginning of
                         Extraction Reg.     2'nd Recombiner
TRANSPORT CHANNEL TC     Start of 2'nd       BSY
                         Spreader.
BSYA              BSYA                       End of Transport
                                             Channel to Hall A
BSYB              BSYB                       End of Transport
                                             Channel to Hall B
BSYC              BSYC                       End of Transport
                                             Channel to Hall C
ESA               ESA                        End Station A
ESB               ESB                        End Station B
ESC               ESC                        End Station C
MCC               M      Electronic systems in MCC building
OTHER             O      None of the above. Explain in the description

                   <Press any key to continue>
```

# GROUPS



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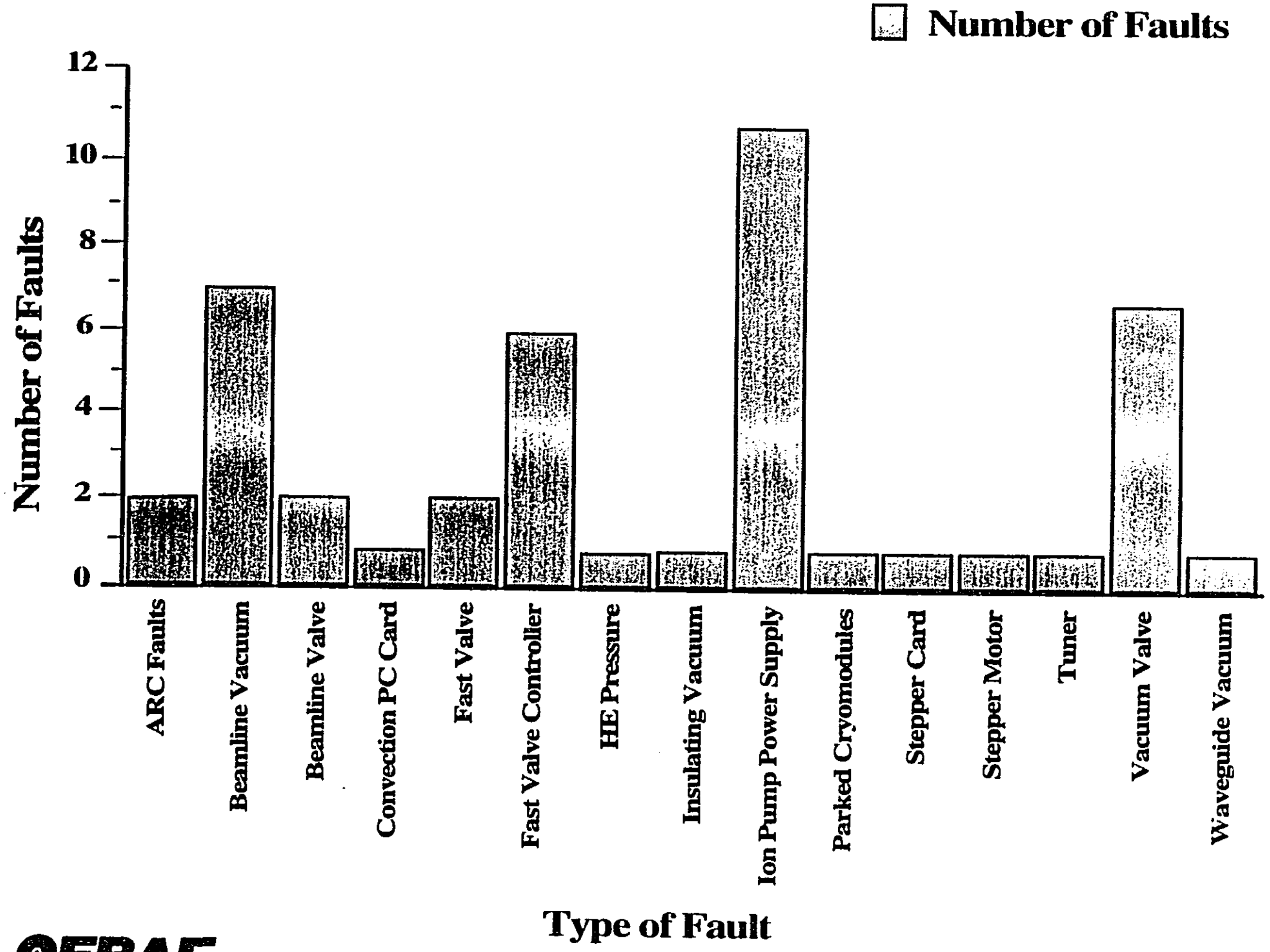
# WBS 1



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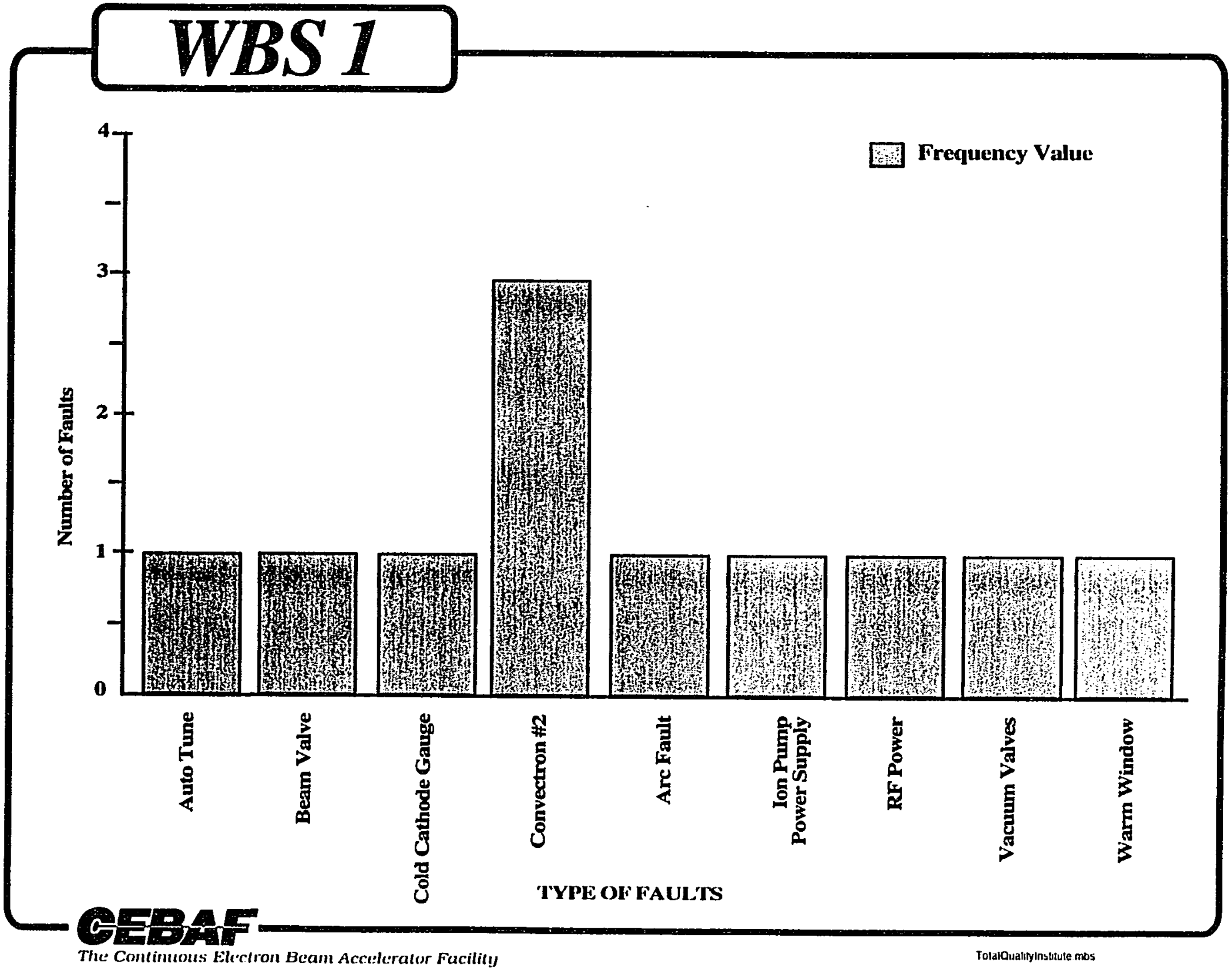
TotalQualityInstitute.mbs


WBS 1
Frequency Value
Number of Faults
0
1
2
3
4
Auto Tune
Beam Valve
Cold Cathode Gauge
Convectron #2
Arc Fault
Ion Pump Power Supply
RF Power
Vacuum Valves
Warm Window
TYPE OF FAULTS
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TotalQualityInstitute mbs

## RECOMMENDATIONS

- **Coordinate progress milestones for maintenance training, operator training, and documentation with milestones for hardware installation**
- **Establish a coordinated preventive maintenance program**
- **Establish a critical spare parts acquisition program**
- **Evaluate the list of specific concerns and take action as appropriate**

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## APPENDIX 15

### Team Chronology

| 1993 Meetings | Main Topics |
|---|---|
| June 8. | Get acquainted. Ops schedule. Hardware problems. |
| June 25 | Developed team rules. |
| June 29 | Brainstormed trouble reporting system. |
| July 8 | Failures last run presentations by WBSs 5,3,and 4. |
| July 13 | Downtime logger discussed. Tutorial on reliability.math. |
| July 21 | First draft requirements document |
| July 30 | J., visitor. helps us get requirements together |
| August 9 | Planned our presentation to the Planning Team. |
| August 10 | A. leaves and B. joins. Develop 9 issues. Develop survey. |
| August 17 | Worked on answers to 8 issues. |
| August 24 | Developed answers to 8 issues from Requirements Meeting |
| August 31 | R. raises LCW interlock issue. |
| September 7 | B. was at SLAC for a week. |
| September 14 | Ro. distributes Pre-commissiioning and Commissioning d. |
| September 21 | B. is modifying CATER for CEBAF use. |
| September 28 | Ka. handed out copies of failure analysis report. |
| October 5 | CATER is available for team members to access |
| October 12 | We listed problem equipment and concerns for each. |
| October 26 | Klystron failure analysis. Power supply upgrade. |
| November 9 | Previewed presentation and letter to planning team. |
| November 16 | B. demonstrated CATER on a computer. |
| November 30 | Nomenclature. CATER reports distributed. |
| December 7 | M. leaves team. D. reports on Motorola U. course. |

| 1994 Meetings | Main Topics |
|---|---|
| January 11 | CATER analysis last run. Operability Team goals list. |
| January 18 | Preeze protection. CATER update. Plan VPTQI present. |
| January 25 | Accelerator severe weather plan. Spares budget |
| February 1 | R. provides emergency equipment holdings. Budget. |
| February 8 | Plan presentation for VPTQI. Discuss equipment problems. |
| February 15 | Dry runs for presentation. |
| February 22 | Emergency equipment survey results. Future team projects. |
| March 1 | Downtime logger. CATER. Pass out maintenance chapter. |
| March 8 | Reviewed maintenance chapter. Comments to S. |
| April 12 | Team status. Develop survey for supporting May 15 ops. |
| May 2 | Final Meeting. A. evaluates team performance. |

| Training Dates | Subject | Who |
|---|---|---|
| March, 1993 | Team Leadership - sixteen hours | S. |
| June 15, 1993 | Total Quality Management - four hours | Team |
| June 22, 1993 | Team Training - eight hours | Team |
| June 29, 1993 | Team Training - eight hours | Team |
| November 1993 | Motorola U.- thirty-two hours | D., Ro., Rn. |
| March 3-4, 1994 | Facilitator Training - sixteen hours | T. |

| Team Products | |
|---|---|
| July 13, 1993 | List of failures from last run. |
| July 22, 1993 | Proposal for and schedule for CATER at CEBAF |
| September 8, 1993 | Analysis of Hardware Failures letter |
| September 17, 1993. | Precommissioning and Commissioning Plans |
| October 5, 1993 | Survey Results to Planning Team |
| November 15, 1993. | Getting Started with CATER |
| January 1994 | List of Equipment Failures |
| January 26, 1994 | Accelerator Site Severe Weather Plan |
| March 1, 1994 | List of Emergency Equipment |

| Documents Received | |
|---|---|
| June 10, 1993 | CATER Software and Instructions |
| July 30, 1993 | Physics Div. and PAC Schedule for Beam Time |
| August 8, 1993 | CDF Downtime logger from Ro. |
| August 19, 1993 | Memo from Planning Team. Pre and Commissioning Plan. |
| August 26, 1993 | Memo from Claus on LCW Interlocks. |
| January 11 | Operability Team Goals List. |
| January 24, 1994 | Plant Services Freeze Protection Plan |
| March 1, 1994 | Maintenance Chapter of Accelerator Operations Directives |

| Presentations | |
|---|---|
| August 9, 1993 | HC&R Team Requirements to the other teams. |
| November 11, 1993 | Survey Results to the Planning Team |
| November 15, 1993 | Survey Results to the Division Council |
| February 18, 1994 | Team Performance to Peninsula Total Quality Institute |

# BIOGRAPHY

## Thomas Andrew Hassler

Birth: Born in Brown City, Michigan, on January 8, 1937, in the home of his maternal grandfather, the town veterinarian.

Raised: primarily in Arlington, Virginia

Education:
- Duke University - 1954-1955 - Chemistry major
- Annapolis - 1955-1959 - B.S. with distinction (19th of ~800 graduates)
- Old Dominion University - 1988 - MEM - Phi Kappa Phi

Positions Held in the U.S. Navy:
USS Henley (DD762) - Antisubmarine Warfare Officer (1.2 y)
USS Shark (SSN 591) (3 years on board) - Supply Officer (1 y), Main Propulsion Assistant (2 y), Weapons Officer (2 y)
USS Barb (SSN 596) - Engineer Officer (3 y)
USS Daniel Webster (SSBN 626 Blue) - Executive Officer (3 y)
USS Mariano G. Vallejo (SSBN 658 Gold) - Commanding Officer (3 y)
Submarine R&D Manager, Naval Ship Systems Command (3 y)
Submarine Element Coordinator (1 y)
Submarine Force Weapons Officer (1 y)
Training Officer, Submarine Squadrons 8 and 6 (2.5 y)
Cruise Missile Officer, U.S. Atlantic Command (1.5 y)

Positions Held at the Continuous Electron Beam Accelerator Facility:
Quality Assurance and Safety Officer ( 3.5 y)
Quality Assurance Officer (2 y)
Emergency Management Manager (7.5 y)
Commissioning and Operations Branch Environment, Health, and Safety Officer (2y)