ESD-TR-69-302

SYSTEMS MANAGEMENT APPLIED TO LARGE COMPUTER PROGRAMS IN BUIC III; REVIEW OF EXPERIENCE

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June 1969

AIR WEAPONS SURVEILLANCE AND CONTROL SPO
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts

(Prepared under Contract No. F19628-67-C-0026 by System Development Corporation, 2500 Colorado Avenue, Santa Monica, California 90406.)

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FOREWORD

This report is the result of a special study which was carried out at the System Development Corporation offices in Santa Monica, California. The study was a portion of the contract work for the BUIC III System Program during the period of July 1968 to June 1969. The purpose of the study was to provide a documentary record of the contractor's experiences in applying Air Force systems management techniques to the BUIC III computer program acquisition.

Material contained in this report represents a revision of material originally reported in the SDC Technical Memorandum TM-4223, "Systems Management Applied to Information Processing Elements in BUIC III; Review of Experience," dated 25 February 1969. The content is based on information which was collected, organized, and interpreted by the contractor; it does not reflect official information provided by the 416M System Program Office (SPO) nor technical participation by SPO personnel.

Administrative monitoring of the task was accomplished by Major Harvey B. Blanton and Captain James E. Puffer, Office Symbol ESSGB, of the Air Weapons Surveillance and Control System Program Office (416M/P/418L), Electronic Systems Division, Air Force Systems Command, Laurence G. Hanscom Field, Bedford, Massachusetts.

Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

Lionel C. Allard

LIONEL C. ALLARD, JR., Colonel USAF
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ABSTRACT

This report is a review and analysis of experience with the application of Air Force systems management techniques to the acquisition of information processing elements in the 416M (BUIC III) system program. The report includes a background review of the systems management concepts and trends in relation to practices which had been employed in L-system programs preceding BUIC III. Novel requirements introduced in BUIC III are identified in the areas of computer program configuration management, standard documentation, design reviews, and Category I testing; and a summary is presented of the milestones associated with these requirements as they actually occurred during the program. Finally, the experience in specific areas is discussed and evaluated with respect to implications for future modification and use of the management techniques.

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CHAPTER I

INTRODUCTION

A. SCOPE AND OBJECTIVES

This report is concerned with the problem of the integration of a new type of technology and the management process in the military realm. The technology is that of computer-based command and control systems. The particular focus of this report is upon the computer programs and associated products. Management, in this context, refers to the process whereby electronic command and control systems are acquired by a procurement agency for a using command. The system on which we shall focus is known as BUIC III (416M), the back-up interceptor control system for the SAGE (416L) system of air defense.

The procurement agency in this example of the system acquisition process is the Electronic Systems Division (ESD) of the Air Force Systems Command (AFSC) while the Air* Defense Command (ADC) is the user. Two non-military, not-for-profit organizations of critical concern in this report are the MITRE Corporation, which was the General Systems Engineering/Technical Direction Contractor (GSE/TDC) in BUIC III, and the System Development Corporation (SDC), which was responsible for the BUIC III operational computer program system segment. Other non-military organizations, of course, also played important roles in the development of BUIC III. Foremost among these is the Burroughs Corporation, which designed and manufactured the system equipment. However, since the focus of attention in this report is on the acquisition of computer programs, the roles of these other organizations will be dealt with only insofar as they impinge upon the main areas of concern.

In the BUIC III system project, several management techniques based on the AFSCM 375-series and associated systems management principles were applied on a broad scale for the first time to the acquisition of information processing elements of a command and control system. While some of the techniques have now been adopted as formal Air Force requirements for general use, BUIC III represents a first and significant case of actual experience with their systematic application in a major system project. Because of the increasing importance of information processing elements in Air Force systems, that experience constitutes an invaluable source of potential guidance for future applications, as well as for continued expansion, modification, and refinement of the techniques. It is therefore a primary objective of this report to document the history of the program in such a way as to make the lessons learned available for early dissemination and use.

* Now Aerospace Defense Command.

B. METHODS

Two main types of sources were used to gather the information upon which this report is based: (1) documents of various types, and (2) interviews with SDC personnel who participated in the BUIC III system program.

The documents used to reconstruct the history of the BUIC III acquisition effort and the problems encountered by SDC during the course of that effort were derived primarily from SDC sources. These included: historical reports on SAGE, BUIC II, and BUIC III written by SDC personnel; letters, notes, and memoranda obtained from SDC personnel who participated in a variety of capacities in the BUIC III effort; similar types of documents obtained from SDC's BUIC Management File; the BUIC III/SDC Configuration Index, SDC's BUIC Monthly Management Report going back to July, 1964, SDC's Technical Objective and Plan series, SDC's Air Defense Division's annual Activities Report, SDC's Lexington Liaison Office Activity Reports and a variety of technical documents (SDs, TMs, FNs, Notes). Important sources of information were letters, notes, and memoranda prepared by SDC personnel who gathered these documents while investigating a particular problem at the request of an SDC manager. Additionally, extensive use was made of the files of SDC's System Management Project, which has provided continuing support to ESD during the past 5-6 years in developing the computer program acquisition guidelines, and whose members have also conducted special studies associated with the BUIC II and BUIC III programs.

In addition to the document sources, much information in this report has been supplied by SDCers who participated in the BUIC III program and provided first-hand data on the application of the 375-series to the design and development of the operational computer program system segment. Material for Chapter VI, Discussion and Evaluation, was initially gathered in a series of interviews and group meetings with SDC technical and managerial personnel in the Military System Division. Their number was too large to permit listing of all of their names. These people not only provided essential basic information but also contributed useful comments and corrections as the writing progressed through several drafts. Helpful factual comments were also supplied by several members of MITRE Corporation.

In working with this material and benefitting from the many comments and suggestions received, the three authors wish to make it plain that the interpretations and viewpoints expressed in the report are their own.

CHAPTER II

BACKGROUND OF SYSTEMS MANAGEMENT FOR COMMAND AND CONTROL SYSTEMS

A. THE PROGRAM DEFINITION PHASE

On 14 January 1963, the Office of the Secretary of Defense issued a draft instruction entitled "Program Definition." The concept of "program definition" was based upon the experience of AFSC's Ballistic Systems Division (BSD). The formal presentation of the concept appeared in BSD Exhibit 62-101, System Analysis: Procedures for System Definition, published in June, 1962, for the Mobile Mid-range Ballistic Missile (MMRBM) program. BSD exhibits had previously been forerunners of military management procedures with Air Force-wide applicability and this proved to be the case in this instance. The BSD exhibit proposed a new "system definition" phase, Phase I, to cover the first four months of the Acquisition Phase. The Department of Defense instruction required such a phase for all large-scale military system development programs, not merely those within BSD or the Air Force.

The new phase was defined as follows in the draft DOD instruction:*

> "Program Definition is the formal process whereby preliminary engineering and management planning are accomplished in order to arrive at definite performance specifications and refined cost and schedule estimates for the project under consideration. It is a funded effort by one or more contractors, working in close collaboration with the government, having as essential objectives the achievement of best technical approaches, the identification of high risk areas, and the development of an adequate basis for firm fixed price or incentive contracting of the main body of a major development project."

Headquarters USAF responded quickly to the DOD draft instruction and then turned the matter over to the Air Force Systems Command for detailed study. Headquarters AFSC arranged for a Command-wide meeting to be held at Andrews AFB on 6 and 7 February 1963 to review the impact of the new concept on existing management policies and procedures. Representatives of the Department of Defense as well as the Army and the Navy also attended and participated.

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*The expression "Program Definition" was changed to "Project Definition" and subsequently to "Contract Definition" in successive revisions to the original draft instruction, which were issued in February 1964 and July 1965 as DOD Directive 3200.9.

It is evident in the report of the Command-wide meeting that the cost concerns of the Department of Defense were a primary factor in the publication of the draft instruction on Program Definition. It was closely related to the experimentation then going on throughout the aerospace industry with a new management tool known as Program Evaluation Reporting Technique (PERT). A variation of PERT called PERT/Cost was clearly exciting to DOD personnel since it provided "a single system for collating the three things that one has to manage in a program...the work to be accomplished, the time schedule...and the cost...."* Mr. Robert S. Tucker, Assistant Director for Engineering Management in Department of Defense Research and Engineering (DDR&E), who presented this interpretation of the DOD position, went on to say that PERT/Cost seemed to be a powerful tool for managing large development programs of the type represented by TITAN III, then under development. At this point it is worth quoting a later section of the report on PERT/Cost in full:**

> "About two years ago (1961) when people really began to worry about bad cost estimates and the spiralling cost of weapon systems, the discussions always centered about the very beginning of the program. It was stated that most of our problems were caused because we hadn't had a good cost estimate to start with. Everybody seemed to agree that this was so. They further agreed that you couldn't get a good cost estimate unless you had a good statement of work to define the job clearly. We began by thinking along the lines of how we could get a better statement of work at the beginning of a program and, therefore get a better cost estimate."

The objective of the Program Definition Phase, then, was to obtain accurate cost estimates, and the procedure for achieving this was by associating costs, not with some "combination of functions and hardware" but by analyzing the system into subsystems and then into specific pieces. These pieces are identified as "hardware end-items" and, on the basis of these end-items, PERT networks are created. This approach was applied during the TITAN III program in the belief that it would provide "a firm basis for negotiation of definitive contracts with the contractors when they were selected."*** In this way, the contractor's cost estimates would be related to explicitly defined items of work instead of an amorphous work statement. Phase I of the Acquisition Phase required competition among contractors for the award of development contracts. It was believed that PERT/Cost would provide a basis for evaluating competing proposals from industry.

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* The Program Definition Phase, Report of a Command-wide Conference held at Hq. AFSC, Andrews AFB, 6 and 7 February 1963, p. 6.

** Ibid., pp. 51-52.

*** Ibid., p. 7.

The use of PERT/Cost approach in the TITAN III program was regarded as very successful by the Department of Defense and it asked for a similar approach to the development of BSD's Mobile Mid-range Ballistic Missile (MMRBM) program then just getting underway. In this case, DOD referred to the period of system definition as the "Program Definition Phase" and that, according to Mr. Tucker, is how the name came into being.

In essence, the value of the Program Definition Phase, according to the Department of Defense, was that it would make possible the identification of the components of a large-scale program before it was undertaken, rather than after it was contracted for, and it would provide a means for controlling the program, especially costs, after it was begun.

B. IMPACT OF PROGRAM DEFINITION CONCEPT ON ESD

Prior to the publication of the DOD draft instruction on Program Definition and the AFSC-sponsored Command-wide meeting in February, 1963, the Electronic Systems Division had initiated efforts to improve the procurement procedures for large-scale, computer-based, command and control systems. In August, 1962, personnel representing ESD, MITRE Corporation, and System Development Corporation met at Headquarters, ESD, and established a Task Group to examine the problems associated with the acquisition of the L-systems which were ESD's responsibility. MITRE and SDC were not for profit organizations providing ESD with technical support--MITRE for over-all system engineering and SDC for computer programs and associated products, a "package" referred to at that time by the generic term "software."

The reasons for the creation of the Task Group may be briefly summarized: (1) pressure from the DOD and USAF for tighter and more effective control over the procurement process; (2) ESD's concern over the adequacy of its own management process; and (3) concern by the ESD SPOs about managing a procurement process for "software" aspects of military systems, aspects which were relatively unfamiliar to them and which had been managed up to that time by the contractors.

The ESD/MITRE/SDC Task Group was composed of a Steering Committee and, over a period of time, a number of ad hoc Working Groups. The Steering Committee was composed of senior representatives from the three participating organizations. Responsibilities of the Committee were to identify problem areas that needed investigation, to define specific tasks for the Working Groups, to provide the groups with guidance, and to review their work.

The first Working Group, composed like the Steering Committee of representatives from ESD, MITRE, and SDC, and under the chairmanship of then Lt. Col. S. G. Morgan of ESD, studied the acquisition histories of 465L, 473L, 425L, 416L, and 412L to attempt to identify the typical problems encountered in their management and to assess the adequacy of the management techniques used to deal with them. The Working Group reported the results of its investigation in October 1962. The following areas were described as major sources of problems in need of additional study and improvement:

- Management tools and techniques, i.e., specifications, contract work statements, concurrence documents, etc., for acquiring computer programs, associated products, and related technical data.

- User relationships to development agencies and user participation throughout the system development process.

- Capabilities of ESD military personnel in the fields of system design and computer programming.

- The philosophy and concepts of system design.

A second Working Group was created to address itself to the problem areas identified by its predecessor with a particular focus on the first area, management tools and techniques. The task assigned to the Group was to "prepare drafts or outlines of ESD Exhibits which would serve as guidance and illustration in the use or applicability of specific documentation, procedural steps, processes and definitions for the uniform conduct of management of computer program design and acquisition ...." The results of this Working Group's efforts were published on 18 February 1963 as a MITRE document, TM-3551, Computer Program Acquisition Study. This document constituted a good beginning, despite some deficiencies, in what was to become a long-range task of detailed definition of the procurement process for computerized systems. It identified the major problems associated with the acquisition of computer programs and it recommended possible solutions to them.

Meanwhile, significant events were also taking place elsewhere in Systems Command. Following the Command-wide meeting at Headquarters AFSC in February, 1963, General Schriever established a system Definition Task Force (SDTF) on 4 March 1963. The "charter" for the SDTF made it clear that the AFSC Commander considered the work of the Task Force to be of the utmost importance and to merit top priority support from all AFSC divisions. The first meeting of the SDTF was held a week later at Headquarters BSD, which had been made the lead division for the task at hand. An interdivisional team was formed as a result of this meeting and it began full time work at Norton AFB, California, on 1 April 1963. Lt. Col. S. G. Morgan was the ESD representative.

The immediate objective of the Task Force was to incorporate a Definition Phase into the typical system life cycle, in compliance with General Schriever's directive to implement the DOD instruction on that concept, and to revise existing Air Force systems management documentation accordingly. However, after studying the problem, the SDTF undertook the reorganization and consolidation of the entire systems management framework. This task took the form of initiating the development of a guidance manual for general use by the System Program Offices throughout AFSC, which would contain uniform procedures covering all phases of the system life cycle and all major aspects of systems management. This manual (which eventually became AFSCM 375-4) would presumably be applicable to electronic command and control systems as well as to jet aircraft, missiles, and space vehicles.

While these events were transpiring at the Command level, the activities of the ESD/MITRE/SDC Task Group were interrupted by the receipt of a letter from AFSC, dated 20 March 1963, requesting the Division's comments on the DOD draft instruction on Program Definition and the BSD Exhibit 62-101 on the same subject. Senior ESD, MITRE, and SDC representatives met to consider how to reply.

Various staff groups were asked to review the DOD instruction and BSD exhibit. The consensus was that, although there was no question about the desirability of a "program definition" phase to precede acquisition, the proposed procedures were based upon experience with weapons systems and were not suitable for command and control systems. Both MITRE and SDC recommended to ESD that it resist any attempt to establish a single type of program definition procedure for all Air Force system programs.

One of the products of the Definition Phase identified by the DOD was a detailed PERT/Cost network "for the development of all items contained in the system or portion thereof on which he (the contractor) was asked to bid." A list of all end items was to be included and, for each end item, performance specifications, cost estimates, and foreseeable technical problems were to be presented. In retrospect, the dismayed reactions of the MITRE and SDC staffs to these demands upon their technical virtuosity are not difficult to understand. Detailed end items had never before been systematically identified in advance of development for the then current crop of L-systems. Disagreement was rampant over the kinds of products which should be included under the rubric "software." Did it, for example, include "system training," "human engineering," "system evaluation," etc.? No reliable cost estimates for computer programming tasks in military command and control systems existed. SDC personnel could not see how computer program end items could be identified sufficiently at this early phase in the system life cycle to provide a basis for cost estimates accurate enough for fixed price or incentive contracts--the basic objective of the DOD instruction.

Considering the computer programming state-of-the-art, the requirement to identify "foreseeable technical problems" during Phase 1B, was regarded by experienced programmers as an unrealistic one. In the early 1960s, computer programmers regarded a large part of what they did in military systems as research or exploratory development. The DOD requirements implied a more highly developed technology. In Phase 1B, for example, it was stated that the contractors' approach "should be such that the system development to follow can be accomplished essentially as an engineering task requiring little or no further exploratory investigation." In general, the feeling at ESD was that the DOD concept of the system life cycle had the phases in a reverse order of emphasis insofar as L-systems were concerned. For L-system development, more time should be devoted to system design and relatively less to acquisition. They saw the basic problem as "the proper phasing of software with hardware design and development." Past experience indicated that requirements for the computer programs were usually underemphasized during the early stages of a system program. Prior to 1963, for example, it was common for computer equipment, displays, and operator consoles to be contracted for before the writing of performance-level specifications for computer programs was initiated.

In spite of such questions, however, the obvious importance of the general problem motivated ESD and its supporting not-for-profits to take immediate action.

The ESD/MITRE/SDC Steering Committee established the third Working Group at this point to provide technical support to ESD in preparing its response to AFSC, and to provide limited support to the interdivisional team which was already in session during the first week in April. Known as the System Acquisition Working Group (SAWG) this group led an active and productive existence for a period of about six months. Its primary objective was to define an acquisition process which would take into account the unique needs of electronic system development as viewed in the ESD management framework. The personnel associated with SAWG continued to provide occasional support to the interdivisional task force during that period. However, the factors of remote geography, disparities of initial orientations, and inherent complexity of the problems prevented the SAWG efforts from being materially influenced by the command-wide concepts being evolved at Norton, which subsequently resulted in the 375-series manuals.

The SAWG resulted in two published reports which, although issued separately by MITRE and SDC, represented complementary treatments of the total system problem as viewed at that time in the ESD context. These were: SDC TM-(L)-LX-74/000/00 (Draft), Command Control Software Subsystem Development During the Conceptual, Program Definition, and Acquisition Phases, 14 August 1963; and MITRE TM-69, The Electronic Systems Acquisition Process, 31 October 1963.

Both reports, in different ways, were something less than finished products. TM-69 defined a general process at the total system level, in terms of the four subsystems which had been chosen as typical of an electronic system -- namely, hardware, software, testware, and facilities. While the intent was to amplify processes subsequently for the subsystems (except software, which was amplified in the SDC report), this intent was never realized. The SDC document was published only in draft form. Like TM-69, it contained a variety of management concepts and assumptions which later proved to be incompatible with the Command-wide 375-series philosophy. However, it did provide, for the first time, a comprehensive description of the technical processes involved in "software" development which both reflected a breadth of L-system experience and established valuable precedents for subsequent work.

C. DEVELOPMENT OF CURRENT CONCEPTS AND PROCEDURES

The SAWG activities terminated in late 1963. However, the Command-wide efforts which were destined to result in the 375-series manuals continued, with increasingly active participation by ESD. During the early part of 1964, the attention of aerospace industry and defense agencies was drawn to the newly-revised issue of AFSCM 375-1, which had begun to expand the scope and importance of configuration management. Although the immediate impact of the manual was on systems and items of equipment, a decision had already been reached by Systems Command that the principles of configuration management should be extended to cover computer programs. In effect, this was a decision that computer programs are a class of system components which should be managed like items of equipment -- as opposed, specifically, to items of data.

The decision to classify computer programs with equipment for purposes of management was not altogether novel. However, appearing as it did in the context of the emerging 375-series concepts, it provided a new set of criteria and guidelines for approaching questions of computer program acquisition which had not been present in the earlier ESD studies. Further studies were clearly needed, since it was recognized that the equipment procedures were of questionable applicability to computer programs in many areas, not only within configuration management but throughout the systems management structure. As a result, and because of ESD's primary interest in computer-based systems, ESD was designated the lead division for Systems Command to resolve the associated problems.

Since that time, the tasks undertaken have been concerned with developing the necessary adaptations of requirements and procedures in the areas of configuration management, data management, testing, and system engineering, using the established manuals covering those areas as points of departure. This process actually began in late 1963, as a result of a tentative proposal made by the 416M SPO to apply the ANA Bulletin No. 445 to SDC's contract for the BUIC II computer programs. Problems posed by the bulletin's equipment-oriented language and procedures stimulated SDC to undertake, by way of a counter proposal, to develop a special exhibit which would apply to managing computer program changes. A series of drafts of the exhibit, initiated in December, 1963, evolved into a final exhibit which was attached to the BUIC II contract in June 1964.

In the interim, SDC had also been invited by the Technical Requirements and Standards Office of ESD to comment on the revised AFSCM 375-1 which was issued in draft form in January 1964. Through interest in the general problem, SDC initiated a staff study, expanding the BUIC II exhibit effort, which both influenced the content of the BUIC II exhibit along lines suggested by 375-1 and also resulted in a report (SDC TM-1918, 1 June 1964) containing a proposed approach to computer program configuration management for general application.

In January 1965, the Technical Requirements and Standards Office took steps to initiate continued studies on a more formal basis. A Software Management Committee, composed of representatives from a number of ESD offices, was formed to coordinate and direct the efforts, and arrangements were made for contract support by SDC. At SDC, the contract work was carried out by a small group of the personnel who had been associated with the earlier work in SAWG and configuration management.* The contract for the first six-months period was sponsored by the 416M SPO, with specific objectives to (1) develop a set of AFLC/AFSC Forms 9 covering the information processing data items for a typical system program, to fill a vacuum which existed in that area in the 310-1 manual, and (2) to expand and refine the requirements for computer program configuration management. Requirements incorporated in the BUIC III contract, which are the subject of this report, were largely products of that effort.

Continued work by the ESD/SDC team during the next few years was devoted to refining those early products, expanding the coverage of 375-series areas, and coordinating products with other agencies. Figure 2-1 summarizes the events which have been described, and also indicates a number of relevant events which have occurred since. The principal documents shown on the chart beyond those already discussed are identified and explained briefly below.

<u>ESD 416M-34</u> -- The BUIC III configuration management exhibit was issued before the general exhibit, EST-1, became available. It was based on materials resulting from the project described above (SDC TM-1918/01), but with a few revisions which (1) had been made in the course of subsequent Air Force/industry coordination and (2) were indicated for the specific BUIC III applications.

<u>EST-1</u> -- The ESD Exhibit EST-1 was first issued in May 1966. Based on TM-1918/01, it was reorganized into the form of change pages and additional exhibits to AFSCM 375-1.

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* This group became the SDC System Management Project, which has been in existence since that time, usually at a level of 2-4 members. Current members are the authors of this report.

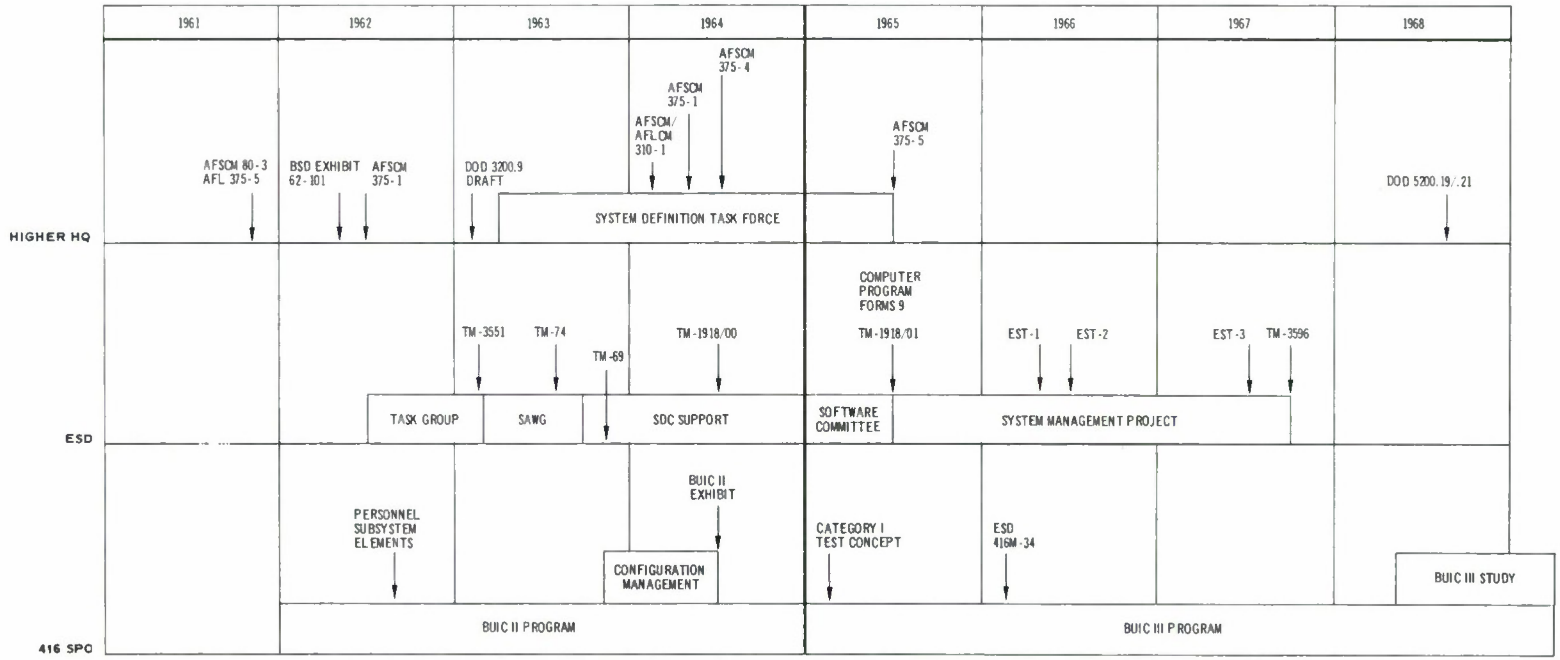

Figure 2-1

Evolution of Systems Management Documentation

EST-2 -- ESD Exhibit EST-2 was directed towards the "parent" manual of the 375-series, AFSCM 375-4. The exhibit contained some minor additions to the 375-4 flow charts of events for a system life cycle and a set of supplementary narratives, keyed to the narratives of 375-4, to clarify application of the manual to ESD systems. The exhibit was revised and reissued the following year (1967) in the form of ESD Supplement 1 to AFSCM 375-4.

EST-3 -- ESD Exhibit EST-3, "Instructions for Conducting Formal Technical Reviews, Inspections, and Demonstrations," was written by personnel of the Technical Requirements and Standards Office to clarify the subject topics for the benefit of the program offices. It covers those requirements as they pertain to systems and equipment, as well as to computer programs.

TM-3596 -- This document, entitled "System Engineering Guide for Computer Programs," was initially issued in September 1967 as an SDC Technical Memorandum. It was subsequently reissued as ESD-TR-68-1, in March 1968. As the title suggests, it was directed towards the areas covered by AFSCM 375-5. However, it was written in informational rather than directive form, to provide a basis for further study in relation to the applicability of 375-5 requirements.

DOD 5010.19/.21 -- The DOD Directive 5010.19 and Instruction 5010.21 were issued in July and August of 1968, providing authority for the subsequent issuance of military standards 480 and 490 containing uniform configuration management requirements for use by all defense agencies. These events have caused the Air Force to initiate revisions of 375-series AFSC manuals to comply with the new standards, and will result in some variations in procedures and terminology from those described during later chapters herein. The conversion has not yet been accomplished at the time this report is published.

CHAPTER III

ORIGINS AND DESCRIPTION OF THE BUIC III AIR DEFENSE SYSTEM

A. INTRODUCTION

The history of the BUIC system program is treated in two parts in this and the following chapter. This chapter reviews the evolution of BUIC as an air defense system out of its predecessor systems: the Manual Air Defense System and the Semi-Automatic Ground Environment System (SAGE). The major reasons for the creation of the BUIC III system are reviewed and the nature of the system--its operation and organization--are described. Chapter IV reviews the history of SAGE and BUIC II in terms of their acquisition as <u>system programs</u> managed by an ESD SPO.

B. MANUAL AIR DEFENSE SYSTEM

The defense of the continental United States against air attack was not regarded by the military services as a serious problem until after World War II. Two events altered military thinking about the need for an effective continental air defense: the successful explosion of an atomic device by the U.S.S.R. in 1949 and the outbreak of the Korean War in 1950 which raised the possibility of an attack directly against the United States mainland by manned Soviet intercontinental bombers.

The defense of the continental United States against air attack in the early 1950s was the responsibility of the Air Defense Command (ADC) of USAF. ADC operated an Aircraft Control and Warning (AC&W) network composed of a few hundred radar stations in the United States and Alaska.*

Responding to the pressures of the cold war, ADC's manual AC&W network gradually expanded. In cooperation with Canada, radar coverage was extended outside of the United States to include the so-called Pine Tree Line, the Mid-Canada Line, and the Distant Early Warning (DEW) Line. Radar picket ships and early warning and control (radar) aircraft patrolled the approaches to the east and west coasts of the United States, thereby extending continuous radar coverage hundreds of miles out to sea. The Greenland-Iceland-United Kingdom (GIUK) Line, also composed of airborne radars, extended radar coverage across the north Atlantic. The Ballistic Missile Early Warning System (BMEWS) was added to provide warning against a possible U.S.S.R. ballistic missile threat.

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* A USAF plan in 1947 called for the construction of 411 radar stations at a cost of about $4,000,000.

The primary functions of air defense were to detect, identify, intercept, and destroy the elements of an enemy air attack. The operations required to detect and identify aircraft and to control interceptors were carried out in Air Defense Direction Centers, the basic units of the AC&W network. These Direction Centers (DCs) were located at the surveillance radar stations where air traffic was kept under constant observation.

The basic operations within the DC may be briefly described. Operators watched displays of radar echoes on radar scopes for signs of movement indicating the flight of aircraft. After detecting an aircraft, the operators would pass its range, azimuth, and estimated speed to plotters who marked its position relative to local geography of the DC on a large, vertical, Plexiglass board. Other plotters maintained the current status of interceptor squadrons, status of winds aloft, and status of the air defense system as a whole. The radar operators kept the plotters informed of the movements of an aircraft, referred to by an assigned track number, as it flew over the DC's geographical area of responsibility. Each track was quickly identified from available flight plans or was declared unknown if no match with a flight plan could be made. Information on tracks was passed laterally to adjacent DCs and vertically to higher headquarters known as Control Centers (CCs), each of which had jurisdiction over several DCs.

If it became necessary to identify an unknown track visually or to intercept a potentially hostile aircraft, the Control Center issued scramble orders to a selected interceptor base and then assigned control of the interceptor to the DC best located to direct the interception. By following the flight of the unknown aircraft and the interceptor on his radar scope and by passing verbal instructions to the interceptor pilot via radio, a weapons director guided the fighter pilot to a point where visual identification of the unknown aircraft could be made, or, if the unknown was determined to be a hostile track, into a position to intercept and destroy it.

Organizationally, each DC was identified as an AC&W Squadron. The commanding CC and its several assigned AC&W squadrons comprised an Air Defense Division. The several Divisions into which the United States was divided reported to North American Air Defense Command (NORAD) headquarters at Colorado Springs, Colorado. In 1956, the continental United States was organized into twelve Divisions grouped into three Air Defense Forces.

The Manual Air Defense System suffered from two basic weaknesses: inadequate radar coverage and an inability to process with sufficient speed and accuracy the large amounts of data which could be expected to accompany any reasonably large-scale air attack. The Ground Observer Corps was utilized to attempt to fill in the gaps in radar coverage. In response to the problem of data processing requirements beyond the system's capabilities, USAF requested the assistance of the Massachusetts Institute of Technology. In 1951, a special study known as Project Charles was instituted by MIT. Recommendations stemming from Project Charles led to the creation of the Lincoln Laboratory which investigated the feasibility of using an electronic digital computer for processing radar data. It was this investigation and other similar studies which led to the concept of a Semi-Automatic Ground Environment system or SAGE.

Throughout the growth and development of SAGE, selected elements of the manual system have continued to provide a back-up capability for the air defense network.

C. THE SAGE SYSTEM

SAGE was the first real-time, computerized air defense system in the operational inventory of the Air Defense Command. Headquarters, USAF approved its acquisition in 1953 and the first site attained operational status in 1958. The rationale for the replacement of the Manual Air Defense System by SAGE is reviewed in these words:*

> "In early 1950, the military concluded that the manual air-defense system in use at that time could not adequately co-ordinate use of our improved hardware against the growing enemy threat. The capacity of the system was too low; the speed with which enemy aircraft could be detected, tracked, and intercepted was too slow; and the area over which an air battle could be closely coordinated was too small. The problem was one of inadequate, nation-wide, data-handling capability: facilities for communication, filtering, storage, control, and display were inadequate. A system was required which would 1) maintain a complete, up-to-date picture of the air and ground situations over wide areas of the country, 2) control modern weapons rapidly and accurately, and 3) present filtered pictures of the air and weapons situations to the Air Force personnel who conduct the battle."

SAGE performs essentially the same operational air defense functions as did its manual predecessor: surveillance, identification, and weapons control. SAGE is different in one basic respect--it employs electronic digital computers, in addition to human operators, to accomplish selected air defense functions. While Air Force personnel carry out such tasks as the initiation, identification, and monitoring of tracks, the computer programs plot, correlate, and display surveillance data. The assignment and commitment of weapons are made by weapons

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* See R. R. Everett, _et al_., p. 148, in the bibliography

directors, but the central computer continuously tracks the position of interceptors and makes the calculations necessary to guide a weapon to its target. Man-computer communications flow is shown in Figure 3-1. A key characteristic of SAGE, deliberately built into the system, is its semi-automatic operations: human operators have the capability to intervene at practically any point in automatic processes. All major decisions are made by Air Force personnel.

The SAGE DC contains over 100 console positions, although actual manning at any given time varies with traffic load and the military situation. The operations of the DC are conducted in several rooms, each responsible for a basic air defense function: the Surveillance Room, where radar returns and tracks are monitored; the Weapons Room, where interceptors and missiles are assigned to targets and controlled; the Identification Room, which processes flight plans; the Manual Inputs Room, where data received by voice and teletype are inserted into the computer; the Command Post, where the Battle Staff may observe the course of the air situation or battle on a large wall display; and the Training Battle Staff Room, where training and simulation activities are conducted.

The SAGE Direction Center (DC) is the basic operating unit of the system, modeled after its manual DC prototype. However, communications laterally with adjacent DCs and vertically to the Combat Centers are primarily digitalized. The elements linked to the SAGE DC by both automatic and manual information processing capabilities are shown in Figure 3-2. These elements include the command element, the SAGE CC; adjacent SAGE and manual DCs; the Army Air Defense Command Post with its complement of Nike guided missiles; interceptor bases; weather stations; the Air Route Traffic Control Center, which through its Air Movements Information Section (AMIS) provides the SAGE DC with flight plan information; long range and gap filler radars; radio transmitters linking the DC by voice and digital data to interceptor pilots; BOMARC guided missiles; and, at various times in the past, Navy radar picket ships and Air Force early warning and control aircraft.

The SAGE system, in 1966, consisted of 14 DCs under the command of 5 CCs, one of which (Ottawa) was a combination CC/DC.

Each SAGE DC contains duplexed IBM digital computers, designated the AN/FSQ-7. The two components ensure round-the-clock operations. The following description of the computer system and computer programs as of 1966 is quoted from H. Sackman.*

> "The computer system consists of the central computer, the computer programs, magnetic drum buffer storage, six magnetic

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* See H. Sackman, pp. 109-111, in the bibliography. Changes to SAGE have, of course, occurred since this description was written.

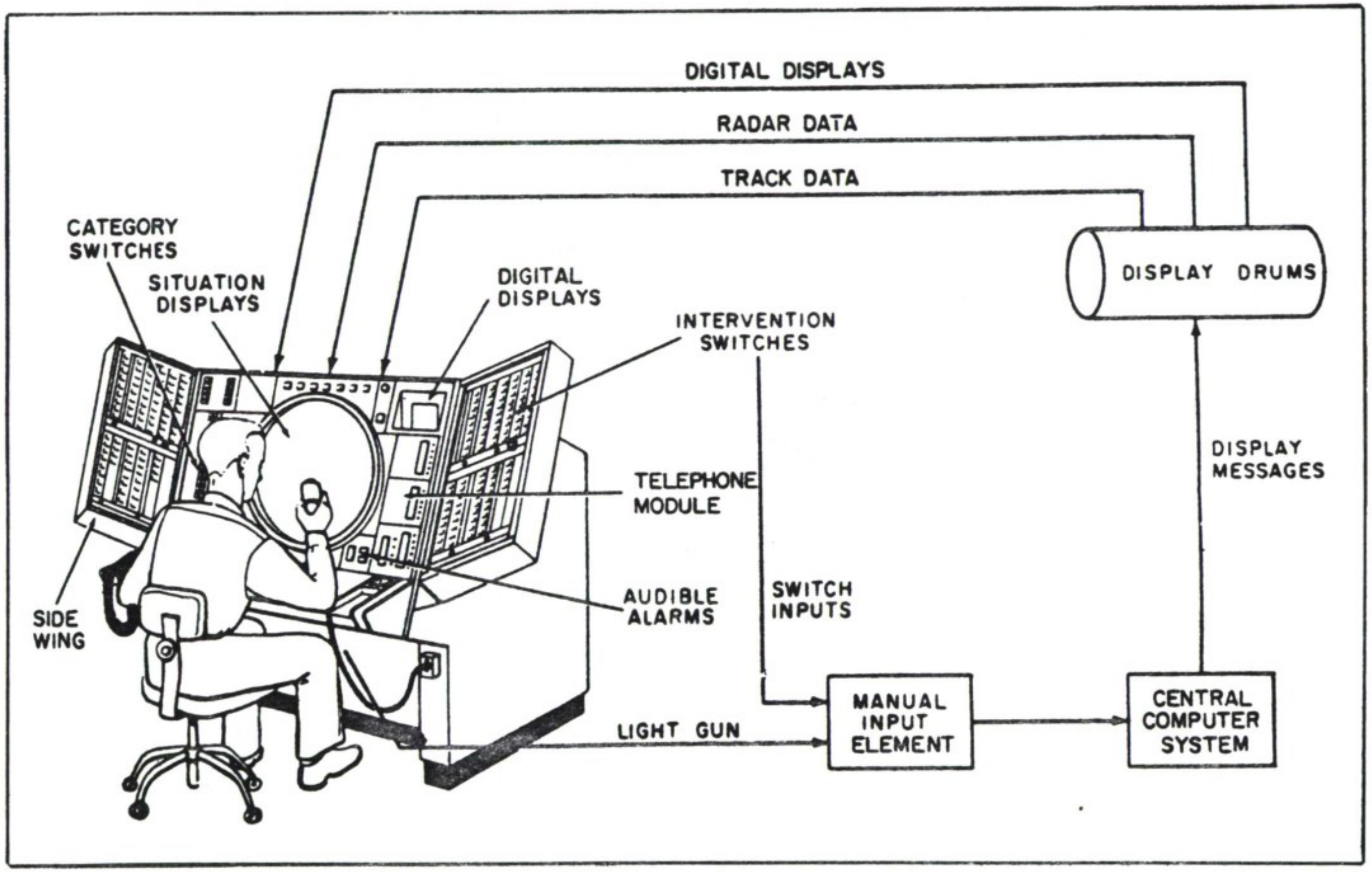

Figure 3-1. Man-Computer Communication Flow in SAGE

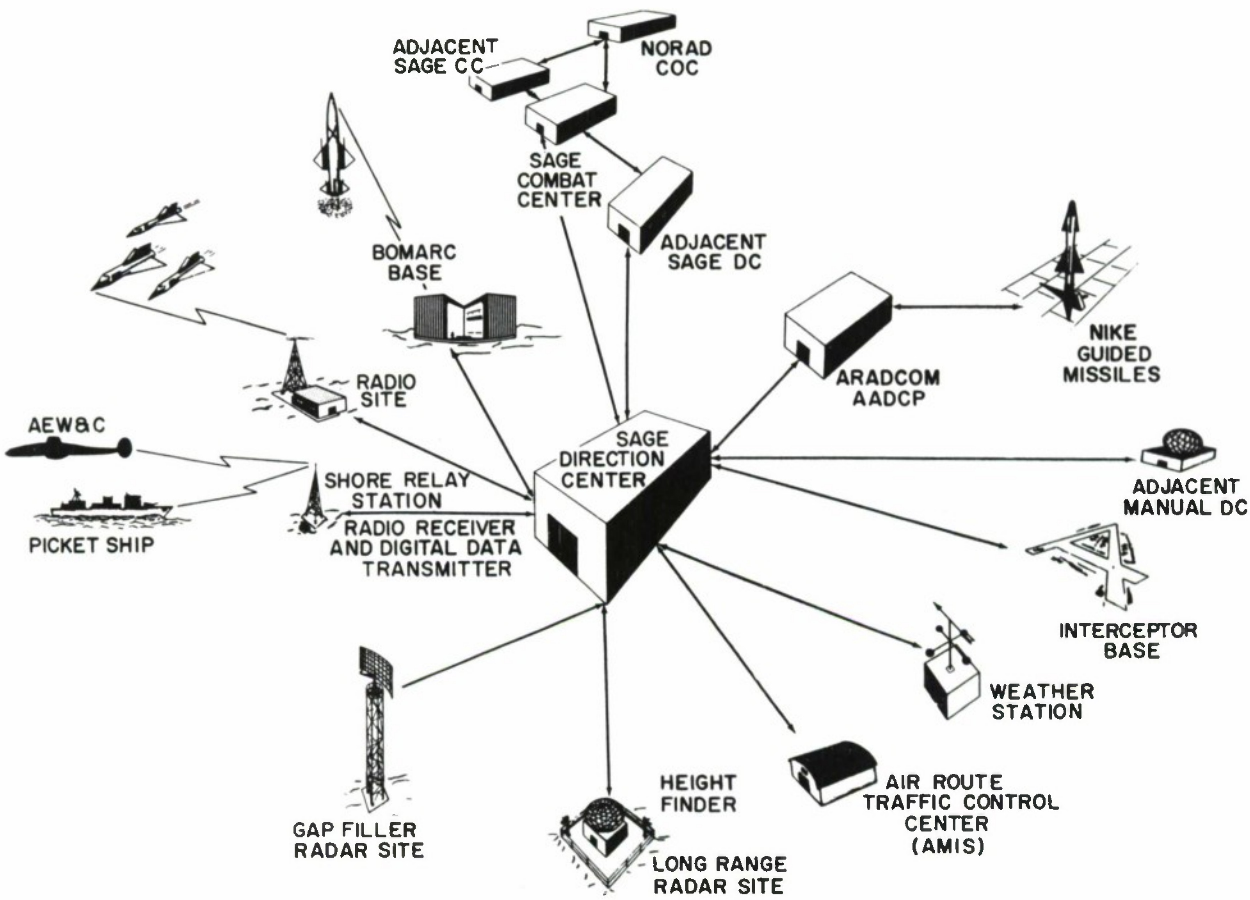

Figure 3-2. SAGE Data Flow

tape units on each side,* and a real-time clock. The central computer is a general-purpose,** binary, parallel, single-address machine with a 32-bit word length. The magnetic core memory originally included 8,000 registers, later expanded to 69,000. Memory cycle time is 6 microseconds, and average instruction operating time is close to 10 microseconds, permitting up to 100,000 dynamic instructions to be executed per second."

"There are 12 magnetic drums, each with 12,288 32-bit words, for a total capacity of some 150,000 words. The magnetic drums are used for storage of the operational program, system status information, and for in/out buffer data. A break feature permits central computer operations to continue while data are transferred from core memory to a terminal device. For example, although 325 microseconds are required to transfer a word from core to tape, only six microseconds of central computer time are used during this period for the instruction that initiates the transfer. This feature is most important for a real-time computing system since considerable time is consumed in input/output searching, waiting and transfers. Separate read-write heads permit in/out operations between external sources and buffer storage to occur independently of central computer operation. This frees the central computer from routine service activities and permits it to do more complex jobs more closely tied to air defense operations."

"The operational or real-time program system for the SAGE Direction Center contains about 100,000 instructions. It is partitioned into some 40 sub-programs to handle specific functional areas. Roughly speaking, the operational program is approximately equally divided in size between four general areas: input/output operations, man-computer communications, tracking and weapons control, and miscellaneous areas including bookkeeping (updating tables) and simulation. The various Q-7 support programs involve over half a million instructions. They include utility, assembly, recording, data reduction, simulation, site production, and JOVIAL compiler programs."

* Four tape units were standard at SAGE sites.

** The AN/FSQ-7 was actually designed to incorporate special-purpose features for air defense application.

"There are additional operational and support programs for the AN/FSQ-8* (Q-8 for short) used at higher headquarters at SAGE Combat Centers. The Q-8 computer is physically identical with the Q-7 computer as it was originally designed with an 8,000 word core memory. A broader definition of the computer program system might reasonably include contractor activities in direct support of SAGE training and operations, activities requiring the use of SAGE and other computers and associated support programs. Under this broader definition, the grand total of SAGE-related programs incorporates more than one million computer instructions."

The SAGE system suffered from one very critical flaw -- it was extremely vulnerable in an age of thermonuclear missiles. As so frequently happens in the race between offensive and defensive weapons development, USAF had committed itself to SAGE before the advent of the ICBM. In addition to the question of SAGE survivability, USAF was concerned over what it regarded as unexpectedly high operational and maintenance costs. Numerous studies were conducted in the 1959-1961 period in an attempt to find solutions to SAGE inadequacies.

In the 1959-1960 period, Super Combat Centers were proposed and evaluated in an effort to reduce SAGE vulnerability. The SCCs were conceived as hardened, underground sites. However, the SCC concept did not resolve the problem of the high cost of air defense. Rather than build expensive underground Combat Centers, USAF turned in 1961 to an alternative concept -- a decentralized dispersed, less vulnerable and less expensive system which would provide a back-up capability in the event SAGE facilities were destroyed.

The Back-Up Interceptor Control or BUIC system was a natural outgrowth of SAGE modes of operation. In Mode I, normal air defense operations are conducted by the SAGE DCs. If the active computer failed, the standby computer assumed operational responsibility. In the event a SAGE DC was completely disabled, Mode II operations began. In this mode, adjacent DCs expanded their geographical areas of responsibility to cover the disabled sector. Mode III referred to an operational situation in which manual or back-up sites assumed the task of air defense when their SAGE DCs were inoperative.

D. THE BUIC CONCEPT

In 1961, a Task Group at Headquarters, USAF developed the concept of an

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* The Q-8s have since been phased out.

austere interceptor control system as a back-up to SAGE and submitted their plans to NORAD, ESD, and ADC. The cost of the system was not to exceed $100 million, using off-the-shelf equipment, available communications, and was to be acquired in the shortest possible time.* The USAF planners believed that the BUIC concept would make a SAGE reconfiguration possible in which the most vulnerable DCs would be eliminated and, as a result, USAF would realize significant savings in operations and maintenance costs. In January 1962, ADC published an operational plan for BUIC and a month later ESD published a document dealing with BUIC functional design and performance requirements. These early documents recommended the creation of back-up control centers, called NORAD Control Centers (NCCs), which would take over the air defense responsibilities in the event SAGE control capabilities were lost. The assumption that the NCCs would have a higher probability of surviving a missile attack than SAGE DCs was based on the fact that they were to be collected with selected long-range radar sites which were not near expected ICBM targets.

The BUIC system implementation was divided into three phases. BUIC I was conceived as an interim system consisting of 27 manual NCCs. This system provided an immediate manual back-up control capability comparable to the earlier Manual Air Defense System. While some of these BUIC I NCCs will remain part of the air defense system, most will be either phased out or converted into semi-automatic NCCs. BUIC II was originally planned to have 34 NCCs; however budget limitations and other factors reduced that number to 13 computerized NCCs capable of assuming the SAGE air defense functions. The BUIC NCCs do not have the same data processing capabilities as SAGE DCs, but perform basically the same air defense operations in a similar, computer-assisted manner. BUIC II is currently operational.** The BUIC II system with improved and expanded capabilities, roughly twice that of BUIC II, is gradually replacing it.

E. THE BUIC III SYSTEM***

BUIC III is a command control system composed of semi-automatic NCCs located at selected long-rage radar sites. One, two, or three NCCs are installed in an Air Defense Division to serve as a backup to the SAGE DC (see Figure 3-3).

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* See W. S. Melahn, p. 1, in the bibliography

** A description of the BUIC II system may be found in a System Development Corporation document, BUIC II Interface Exercise Manual, TM-2329/000/02, 4 April 1966.

*** The information on BUIC III in this section, with the exception of Figure 3-3, is taken in its entirety from a System Development Corporation document, Introduction to BUIC III and SETE, TM-3000/100/02, 1 February 1968.

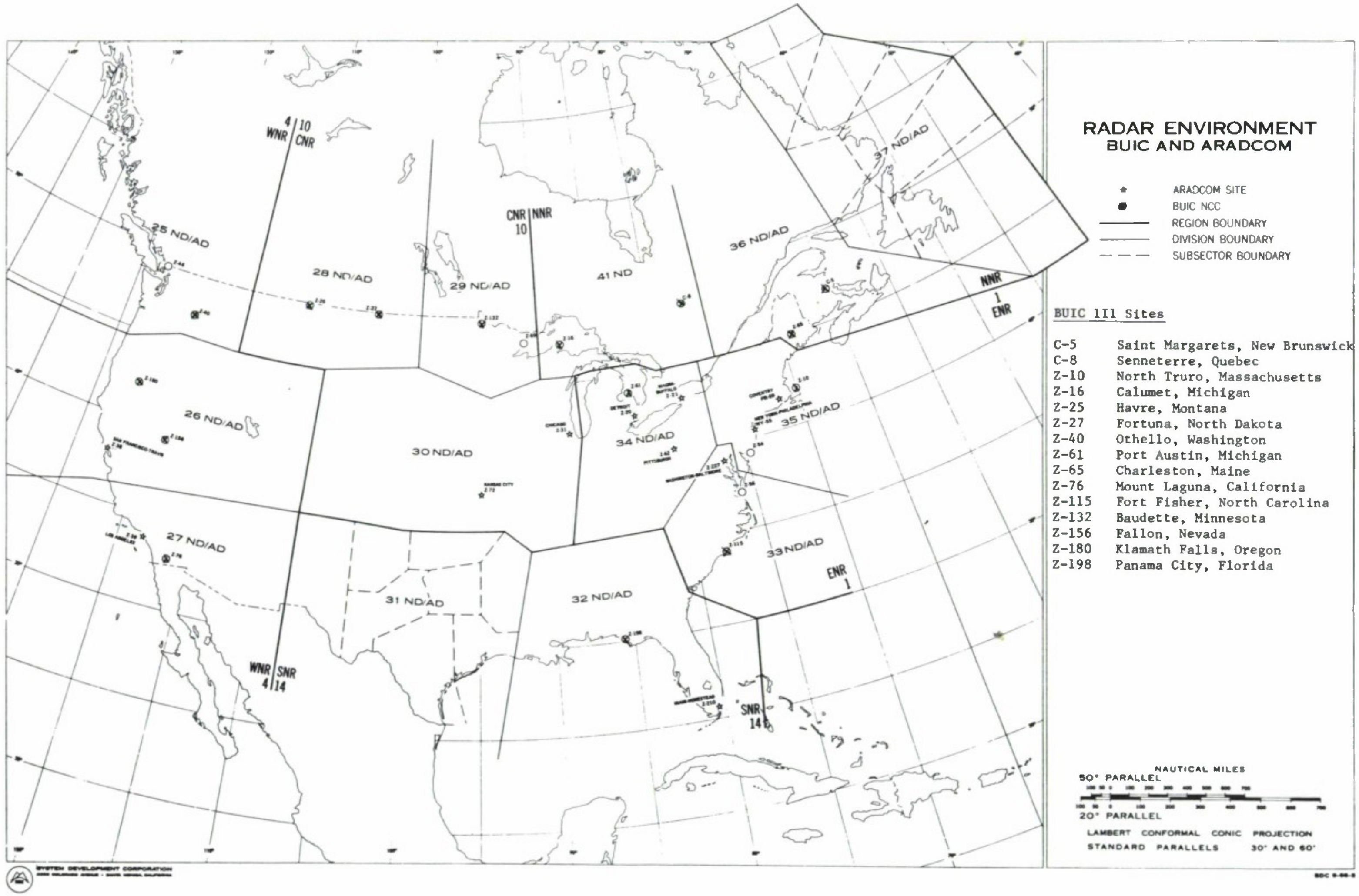

Figure 3-3

BUIC III Sites

When the DC in a Division is operating, the NCCs in that Division monitor the air defense situation to be able to assume air defense responsibility quickly in case the DC becomes inoperative. This operational mode, called the Monitor mode, is the normal operating state of NCCs. If a SAGE DC becomes inoperative, the NCCs in that Division change to an Active mode of operation and assume responsibility for air defense operations within the Division. At the NCC, BUIC III operators receive displays of filtered and processed data and enter instructions at display consoles connected to the BUIC computer.

A digital, teletype, and voice communications network interconnects NCCs and other air defense system elements. Most of the data entering the NCC are in digital form and are entered directly into the computer. Other data received by voice or teletype may be entered into the computer manually by card inputs. The NCC, in either a Monitor or an Active mode, receives a continuous flow of data which must be processed and displayed to support its air defense role. There is also a continuous flow of data out of the NCC, but the volume of outputs is much less in the Monitor mode than in the Active mode when the NCC has active control of air defense elements in its area of responsibility. The major elements that a typical NCC interfaces with are depicted in Figure 3-4.

In the Monitor mode, an NCC maintains a current air picture by means of radar data received directly from radar sites and track data received from its parent DC (the DC in its Division) or from associate NCCs (other NCCs in the same Division). Radar data come from the same network of radars used by the SAGE system. This network includes long-range radars (LRRs), gap-filler radars (GFRs)* and airborne long-range radar inputs (ALRIs). These data are processed and displayed at the NCC in the same manner in either the Monitor or the Active mode. An NCC in the Monitor mode, however, has no control over the operations at the radar sites. In the Monitor mode, the track data from the DC are automatically updated by the BUIC computer program by means of radar inputs. This helps to ensure the continuity of tracks in the system in the event the NCC has to take over the air defense function. While in the Monitor mode, an NCC does not initiate tracks, request height, or identify live tracks, nor does it commit weapons.

When the parent DC becomes inoperative, the NCCs in the Division take over the functions of the DC. The Active mode NCCs expand their interfaces and each assumes control of a predesignated portion of the Division. External defense elements are informed by voice that the NCC is assuming control and circuits are established for the flow of information. An NCC replaces its parent DC in the lateraltell network of DC communications. One NCC in the Division becomes interconnected with the SAGE Combat Center (CC) which is responsible

* All but one of the GFRs have been phase out.

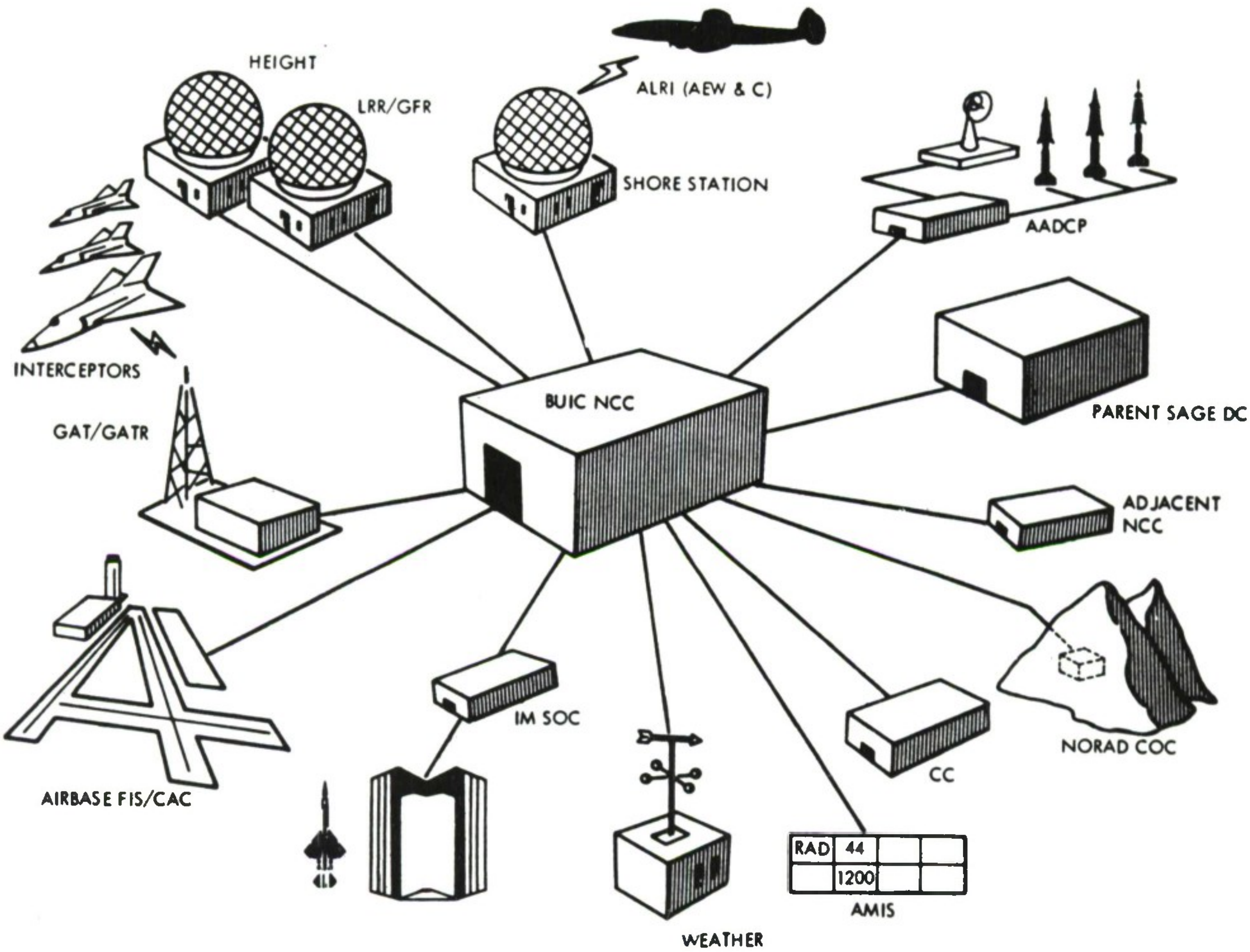

Figure 3-4. Typical BUIC NCC Interfaces

for the direction and coordination of air defense functions in the Region. The NCC transmits track data and weapons status information to the CC via data link. By voice, the CC provides the Active NCC with early warning information, nuclear detonation reports, and information on adjacent Region activity. If the CC becomes inoperative, and no DC in the Region remains in operation, the Battle Commander in a designated NCC establishes voice communications with the NORAD Combat Operations Center (COC) in order to transmit Region status data, battle damage, and track information to the COC and to receive threat information, nuclear hazard data, intelligence data, and battle direction.

An Active NCC is responsible for all air surveillance and weapons control functions in its area of responsibility. Close coordination with radar site personnel is needed to maintain the best possible surveillance radar data. Height finding radars at these sites are also controlled. Tracks are initiated and monitored by air surveillance personnel at the NCC. Identification responsibilities are assumed. Flight plan information received from the Air Movements Information Section (AMIS) via teletype is inserted into the computer by card input for manual and automatic identification processing. Weapons personnel commit manned Interceptors or BOMARC missiles against tracks identified as Hostile or the tracks are passed to Army Air Defense Command Post (AADCPs) for engagement by ADA fire units. Manned interceptors are scrambled by means of voice communications between NCC weapons personnel and personnel at the Combat Alert Center (CAC) at an airbase. Control of the aircraft is ordinarily by means of data link transmitted via Time Division Data Link (TDDL) but two-way voice communications are provided by ground-to-air voice radio sites. BOMARC control is always via TDDL.

In the remainder of this chapter, MCC equipment, computer programs, and personnel are described briefly.

1. Equipment

Data processing and display equipment are installed at each BUIC II NCC to support the NCC air defense role. As an integrated group this equipment, the AN/GSA-51A Radar Course Directing Group, is capable of performing the calculations and data manipulations required by computer programs; accepting and transmitting information via digital data circuits; displaying information to operators; accepting and processing manually inserted information, operator requests and commands; and storing information for subsequent processing.

a. Data Processing Equipment

The BUIC III data processor consists of solid state computers, core memories, and input/output modules. Their functions and the functions of related peripheral equipment are described below.

Digital data computers. Two digital data computer modules interpret and execute program instructions. They operate independently and each is capable of controlling the operation of a stored program.

Core memories. Eight core memory modules provide a high-speed random access storage of a total of 32,768 words.

Controller-comparators. Four controller-comparators or input/output control modules control the transfer of data between the core memories and peripheral devices.

Magnetic drums. Three magnetic drums are used for the storage of computer programs, large blocks of data, and information to be displayed. Each drum provides 65,536 words of storage. Three magnetic drum controller-converter enable the transfer of data from a display drum to a data display console.

Message processors. Two message processors receive digital data from external sources, store the data, and send them to a controller-comparator. They also store output messages from the controller-comparators prior to transmission over the output circuits.

Magnetic tape units. Four magnetic tape units or recorder-reproducers are used to record data and store computer programs and simulated data. They are made compatible with the controller-comparator modules by means of a recorder-reproducer controller.

Teleprinter set. An on-line teleprinter produces permanent records of selected data. This high-speed device can print 120 characters per line in quadruplicate at a rate of 600 lines per minute.

Keypunch. A keypunch machine is used to punch and verify data on 80-column cards.

Punch card reader. An on-line punch card reader is used for the manual insertion of information to be used by the computer program.

Teletypewriters. Teletypewriters (teletypes) are used to receive flight plan data, winds aloft data, and weather information. They output information in both punched paper tape and printed form.

047 Tape-to-card converter. This device converts the punched tape output by the teletype to punched cards which are ready for entry into the card reader.

Typewriter-punch reader. An on-line typewriter-punch reader provides a means of communication between the data processor and maintenance personnel.

Status display console. A status display console is provided in the data processing area for use by maintenance personnel in controlling and monitoring all central and peripheral data processing equipment.

Simulator group. The simulator group consists of two manual input keyboards located in the data display area and one compatibility unit in the data processing area. This equipment can be used to generate and control simulated interceptors and to simulate pilot response during a training exercise.

b. Data Display Equipment

Data display consoles provide operators with the computer-generated displays they need to perform their assigned tasks, a means of selecting the information to be presented, and a means of inserting requests and commands into the computer. Eleven data display consoles are provided in those NCCs having an Air Defense Artillery responsibility. All other NCCs have ten. All consoles are logically and electrically identical, but they may be assigned to different functions by means of manual input card messages. A typical configuration of display equipment and assignments is shown in Figure 3-5. The minimum and maximum number of consoles that may be assigned to various functions is as follows:

Console Function	Min.	Max.
Senior Director	1	1
Weapons Director(s)	0	6
Air Defense Artillery Director(s)	0	2
Radar Inputs and Countermeasures Officer/Air Surveillance Officer	1	1
Air Surveillance Operator(s)	1	7
Identification Operator (s)	0	2
Simulation Supervisor	0	1
Flight Path Simulator(s)	0	3
Target Monitor	0	1

Situation Display. The data display console contains a cathode ray tube for the display of information concerning the air defense situation. It has a

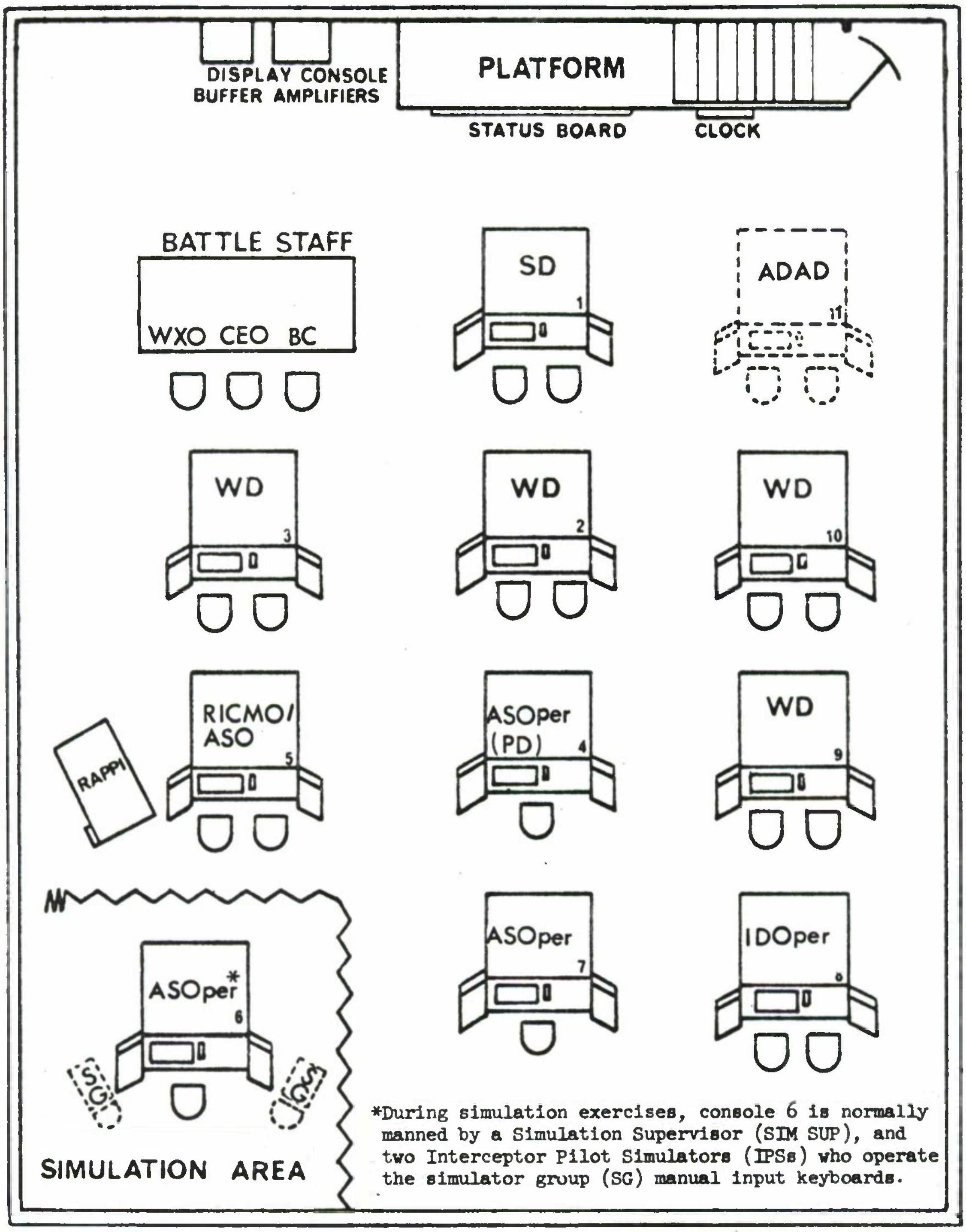

Figure 3-5. Typical BUIC III Display Area

viewing area 12 5/8 inches square. Symbols and vectors are used to display such information as radar data, track information, alarms, intercept points, the location of air defense facilities, and geographic boundaries. By pushbutton action an operator may select display expansion levels of two, four, or eight in addition to the basic display which covers an area 1500 nautical miles square.

The classes or categories of data displayed on a situation display may be selected to be appropriate to the function being performed at each individual console. Forty three-position category selection switches are provided on the left side of the situation display viewing surface for this purpose.

Tabular display. A separate cathode ray tube is provided on the data display console for the display of data in a tabular format. It has a viewing area 3 3/6 inches square. Within this area a maximum of 17 columns and 16 rows of symbols may be displayed.

Computer alarms. One visual and one audible computer alarm are provided at each console. Activation and resetting of the alarms are under the control of the computer program but the audible alarm may also be reset manually by the console operator.

Manual intervention. By means of pushbuttons or switches, an operator may enter and transmit information from the display console to the data processor. The switch panel on the console contains a twelve-column pushbutton keyboard, a rotary heading switch for the insertion of heading information, and an activate pushbutton/indicator to transmit information to the data processor.

Light sensor. Operators are provided with light sensor devices similar to the SAGE light guns to initiate requests or commands to the data processor. This device is activated by positioning it over a displayed symbol or vector by means of a projected circle of light.

Coordinate data monitor. A coordinate data monitor console is provided for the monitoring of radar inputs. This equipment is also called a Random Access Plan Position Indicator (RAPPI).

2. Computer Programs

The computer programs provided for BUIC III were identified and developed as four separate computer program contract end items (CPCEIs), distinguished on the basis of system functions as follows: (a) operational functions, (b) system exercising functions, (c) utility functions, and (d) computer maintenance-diagnostic functions.

a. Air Defense Computer Program (ADP)

The ADP performs the calculations and data manipulations required for air defense operations. It provides the capability for tracking and identifying aircraft, for the scrambling and control of interceptors, and for the transfer of information to adjacent facilities or higher echelons. In addition, a capability is provided for periodically recording operations data for later analysis. For training operations crews, a means of simulating certain inputs to an NCC is included in the program.

b. System Exercise Computer Program (SEP)

The SEP provides the capability to generate simulated data on magnetic tapes to be used as inputs to ADP during air defense exercises and during the testing of ADP. It also provides a means for analysis of data recorded during exercise and training missions. Summary information may be provided on individual operator performance as well as on the performance of groups of operators or of the system as a whole.

c. Utility Computer Program (UCP)

The UCP is the system used for the production and maintenance of ADP and SEP. It is also capable of maintaining itself. In producing a coded system, information is accepted by the program, assembled into a machine language and placed on a magnetic tape for later use. These tapes may be changed via the UCP to correct errors or to incorporate required changes to the system.

d. Maintenance Computer Program (MCP)*

The maintenance computer program is made up of two parts: the backup confidence-diagnostic (BCDP), and the active confidence-diagnostic (ACDP). BCDP consists of confidence checking and diagnostic testing programs which exercise and operate in the backup equipments. This program operates in parallel with ACDP or ADP. ACDP operates in the active equipment modules when ADP is not running. It provides executive control for parallel BCDP/ACDP operation, diagnostic testing, and error analysis. The MCP provides the BUIC III system with early malfunction detection and fault isolation to minimize the effect of equipment failures on overall system performance. The computer operators are kept informed of equipment failures through audible alarms, visible displays, or printed output on the typewriter-punch reader or the teleprinter.

3. <u>Personnel</u>

Operations and maintenance personnel are stationed at each NCC for the performance of air defense operations. They are divided into functionally oriented

* MCP is a Burroughs Corporation computer program.

groups consisting of a Supervisory Team, an Air Surveillance Team, a Weapons Direction Team, a Manual Data Team, a Maintenance Team, and several other support teams. The authorized positions which constitute these teams are outlined in the following paragraphs, but the number of operational positions which will be manned at any given time will depend on the NCC status and the Division air defense conditions.

a. Supervisory Team

The Supervisory Team is composed of the Battle Commander (BC), a Senior Director (SD), and a Senior Director Technician (SDT). The BC is responsible for the NCC operation and coordinates with higher echelons of command. The BC's position is at a table in the display area adjacent to the SD. He does not have a display console, but he may share the SD's console. The SD is responsible for air defense functions being performed within the NCC and coordinates defense operations with other NCCs. The BC is supported by the Weather Officer (WXO) and the Communications-Electronic Staff Officer (CEO), who are located at the same table as the BC.

b. Air Surveillance Team

The Air Surveillance Team is responsible for radar input data control, tracking, height finding, track identification and coordination with other control centers. The team's supervisor is responsible for dual functions. As the Radar Inputs and Countermeasures Officer/Air Surveillance Officer (RICMO/ASO), he supervises the action of the air surveillance function, monitors radar input data, and coordinates ECCM activities in an ECM environment. He also supervises the manual inputs function. The Air Surveillance Technician (AST) assists him in these duties. Other team positions include Air Surveillance Operators (ASOs) who initiate and drop non-Interceptor tracks, monitor active tracing, initiate height requests, and monitor passive tracking; and Identification Operators (IDOs) who identify tracks and coordinate flight plan information with input agencies.

c. Weapons Team

The Weapons Team is responsible for directing and controlling air defense weapons and coordinating activities with other control centers and AADCPs. The team consists of Weapons Directors (WDs) and their technicians, and an Air Defense Artillery Director (ADAD) and his technician. Army personnel are stationed at the NCC to perform ADA functions.

d. Manual Data Team

The Manual Data Team is responsible for handling data received by voice or teletype from external sources and entering it into the NCC data processor. Normally, the team is composed of three Manual Inputs Operators (MIOs) and a Manual Status Clerk (MSC). The duties of the MSC include the maintenance of current status data on a vertical plotting board in the display area. Other than this task, the functions of the Manual Data Team are performed in the Manual Data/Weather area, which is a 9' by 12' space partitioned within the data processing area. This team has no data display console.

e. Weather Team

The Weather Team provides weather information to operations personnel in the NCC. Weather staff support is given to the Battle Commander. Nuclear fallout patterns are developed, and weather forecasts and winds aloft data are prepared for the Manual Data Team to enter into the data processor. The Weather Team consists of a Weather Officer (WXO) whose normal position is at the BC's table in the front of the display area and a Weather Observer (WXOB) who is located in the Manual Data/Weather room in the data processing area.

f. Maintenance Team

The Maintenance Team is under the direction of the Electronic Computer Maintenance Office (ECMO) who normally supports the SD in the display area. The Computer Maintenance Supervisor (CMS) and the Facility Maintenance Monitor (FMM) have over-all responsibility for the maintenance and operation of the data processing and display equipment. They are assisted by Computer Maintenance Technicians (CMTs) and Display/Input-Output Technicians (D/IOTs). A Computer Program Maintenance Team (CPMT) is responsible for monitoring the operation of the NCC computer programs and making on-site modifications and corrections as necessary.

g. Target Monitoring Team

The Target Monitoring Team consists of an Exercise Director and a Target Monitor. They are responsible for controlling exercise target aircraft and for ensuring the safety of all aircraft during air defense exercises using live aircraft. These are not full-time positions but will be filled by qualified operations personnel as a supplement to their normal duties.

h. Simulation Team

The Simulation Team is responsible for the generation of the simulation environment and performance evaluation during a training mission. The only full time position is the Training Technician (TT). Other positions are manned as required by available NCC personnel.

CHAPTER IV

INFORMATION PROCESSING ELEMENTS OF THE SAGE/BUIC II SYSTEM PROGRAMS

A. INTRODUCTION

Whereas the preceding chapter presented an outline description of the SAGE/BUIC systems, the purpose of this chapter is to review those aspects of the earlier system programs which are relevant to an appreciation of the BUIC III experience. As in other portions of the report, the focus of interest is on the elments of contractor responsibility which were once known as "software" and are presently referred to as the computer program, or information processing, system segment.

The distinction is being made herein between a system, on the one hand, and a system program on the other. By system program we refer to the management structure and organizational activities which are involved in the process of creating, delivering, and sustaining an operable and supportable system (cf. AFR 375-1). The system itself is the collection of equipment, computer programs, facilities, procedural data, and personnel which is provided to a user for operational employment. Thus, in brief, the system is the product, while the program is the set of time-phased work elements which bring the product into being. The point of making this distinction is that the program is basically a set of R&D activities, and encompasses many products which are not parts of the delivered system. Also, the complete operational system may involve elements which were not acquired under a given system program; for example, neither of the two BUIC systems could operate without the radar, communications, and other elements which were acquired as parts of other air defense programs.

BUIC II and BUIC III were closely related not only as systems but also as system programs. BUIC II provided the direct precedent for defining the scope of contractor responsibilities associated with computer program development in BUIC III; and BUIC II, in turn, was an outgrowth of the developmental history of SAGE. Relevant aspects of those earlier programs are therefore reviewed briefly in the following sections of this chapter, to provide a basis for understanding the new elements which were introduced in BUIC III.

B. SAGE

As the first big computer-based system to be developed at the Hanscom complex (now ESD), SAGE established procedents which have influenced most, if not all, of the later L-System programs. Beginning as an R&D project at the MIT Lincoln

Laboratory in 1951, it merged into the Experimental SAGE Sector (ESS) in 1953, became operational at its first site (McGuire AFB) in 1958, and has continued to grow and change to the present time. Thus, its history covers the time span during which the data processing arts have had their growth, essentially from a state of infancy, to their current and rapidly expanding roles of importance as elements of military system programs. SAGE was directly responsible for much of the growth; in the late 1950s, more than half of the nation's computer programmers were still associated with the program.

It was a natural result of its close association with the evolving state-of-the-art in data processing that SAGE was adopted as a "model" for command and control system development. Constant changes in configuration were its most distinguishing characteristic. Factors leading to the changes included the advent of new weapons, equipment, and tactical/strategic doctrines, as well as improved computer programming techniques. The concept of "evolutionary development" was derived from that experience and generalized as a guiding principle for command and control system programs. This principle has a variety of facets which are closely in conflict with current objectives to procure systems as items having pre-defined performance, schedules, and costs. Hence, it provided some of the basis of early resistance at ESD to the new systems management philosophy (see Chapter II) and the feasibility of developing computer programs, in particular, under conditions of fixed performance, cost, and schedule requirements has continued to be a matter of debate.

The evolution of SAGE computer programs occurred in a variety of forms, but notably through the development of a series of "SAGE Models". The first operational model, which was installed at the New York Air Defense Sector at McGuire AFB in 1958, was based on the Model Zero that had resulted from the experimental developments at Lincoln Laboratory. Subsequent models incorporated various computer program improvements, but were mainly in response to requirements for new capabilities or to changes in system/equipment configuration and interfacing weapons. By the time the BUIC II program was initiated in 1962, Model 9 was operational and a next was in the planning stages. The last model was never implemented, although new "versions" incorporating extensive changes have continued to appear at the rate of 3 or 4 per year since that time.

Each new model or version represents a complete re-cycling of the computer program acquisition process through its 6 phases of analysis, design, development, testing, installation, and maintenance. The process naturally emphasizes the added or altered operational capabilities, but it also typically involves altering other parts of the "basic" computer programs to avoid exceeding fixed storage constraints and compensate for interactions. The analysis phase involves conducting studies of feasibility and trade-offs, and defining firm requirements to be incorporated in the new model or version. The design phase consists of both (1) "operational design", which results in the precise formulation of performance-level requirements, and (2) design of the computer program changes to meet the requirements. Development encompasses the coding, testing, and debugging of individual computer programs, while the test phase is devoted to assembly testing of functionally-related elements, checkout of the integrated computer program system at an operational site, and the performance of tests under live conditions. During installation, site-specific adaptation data are incorporated and the new version is checked for operation at each site. Once operational, a maintenance* phase begins and continues for the life of that model or version, which consists of (1) malfunction diagnosis and error correction and (2) incorporating minor or emergency modifications on-site, pending appearance of the next complete new version.

Involvement in SAGE computer programming by the organizational unit of RAND Corporation which eventually became SDC was an outgrowth of earlier work in the field of operational readiness training for personnel of the manual air defense system. The capability known as the Manual System Training Program (MSTP) had been developed and put into operational use in the manual air defense system during the period of 1954 to 1957. This capability consisted of a complex set of simulation equipment, materials, and procedures which could be used at the operational sites, permitting personnel manning the air defense network to conduct realistic exercises against simulated air attacks. Following the introduction and use of MSTP, requirements were established for a similar capability to be provided in SAGE. The result was the SAGE System Training Program (SSTP), which was developed and implemented concurrently with other SAGE elements. And like the other elements, SSTP underwent a continuing series of evolutionary refinements and changes.

The close association of computer programming and training was a natural result of their mutual technical concern with and dependence on the detailed procedures involved in air defense operations. Also, in SAGE, special computer programs emerged as important elements of the on-site SSTP capability; and still others were developed to generate the synthetic input data, aids, and materials for distribution to the sites.

As integral parts of the computer program and training development activities, extensive documentation was associated with the SAGE models and SSTP problems. These documents included reports of special studies and analyses, operational specifications for the computer programs, positional handbooks for the SAGE

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* Use of the term "maintenance" for these activities is commonly accepted, although some other term might be preferable in the interest of avoiding confusion with equipment usage; for example, "modification" is closer to the point, since the indicated action in cases of malfunctions or other deficiencies is always to alter the original configuration, rather than to restore or maintain it.

operational personnel, SAGE System Description, adaptation data, and positional guides, manuals, and other materials for SSTP.

C. BUIC II

The conceptual studies leading to the choice of a system configuration for BUIC II were carried out principally during 1961. The document which served as a system specification, entitled BUIC System Functional Design and Performance Requirements, was issued as ESD Document No. 416L-1 in February 1962. There followed a period of negotiations, resulting in the award of contracts to two associate contractors prior to mid-1962. These were: Burroughs Corporation, for system computer and associated equipment; and System Development Corporation, for computer programs.

Although the initiation of BUIC II thus preceded the appearance of the DoD Draft Instruction on Program Definition by about a year, pressures for firm planning of costs and schedules were in evidence from the outset of the program. The equipment contract was negotiated on a fixed-price basis; and the equipment schedules and constraints soon became the pacing factors in the program as a whole. At that time, ESD studies which led to the MITRE TM-3551 (see Chapter II) were just beginning, and little or no guidance was available to the SPO for planning the management of computer program acquisition, other than that which could be supplied by MITRE and SDC as the program progressed.

At SDC, SAGE experience provided a ready basis for defining the major technical products. However, in SAGE, those products had come into being gradually, through the "evolutionary" processes of experimental developmental and successive modifications based on use under operational conditions. Such factors as the brief and fixed timing of acquisition, concurrency of equipment development, close schedules, and the general austerity of funding which characterized BUIC II throughout its course were novelties. Hence, the scope and content of work elements for the computer program contractor had to be worked out for the first time in BUIC II under conditions which were significantly closer to those of current system programs than had been true earlier. The resulting elements are outlined briefly below.

Operational Design

As it has been defined traditionally in SAGE and BUIC, this is the set of activities which results in completed "operational specifications" for the computer programs. As a level of technical work, it is comparable in a general way to the system engineering effort which a contractor would carry out to produce Part I specifications for contract end items, although with some discrepancies. It encompasses such component elements as: analysis of user requirements; study of alternative solutions and trade-offs; development of detailed operating descriptions of computer functions, controls, and displays; derivation and selection of mathematical formulas and equations; specification of interconnections between console switches and computer (Variable Display Equipment); and writing of the operational specifications.

Computer Program Design, Development, and Test

Although not known as contract end items at that time, elements of the BUIC II computer program system were separately identified as: operational; utility and support systems, including an automatic adaptation capability; Field Site Production System (FSPS) for on-site generation of Problem Input (PI) tapes used in system exercising; and the BUIC Data Reduction System (BUDR) for a variety of uses in testing, checkout, system exercising, and operational data reduction. The development process for each of these elements was divided into a series of phases, which were identified in one BUIC II work statement as follows:

a. Program Design: allocation of functions to subprograms; allocation of drum and core storage; design of control and timing subprograms.

b. Program Costing: determination of machine instructions, display slots, and programming personnel requirements.

c. Subprogram Design and Coding: determination of logic, design of internal and external communications, and refinement of storage allocation.

d. Simulation Testing: initially, testing of subprograms (parameter testing) to verify conformance with subprogram design; subsequently, testing at successively higher levels of assembly to verify conformance with operational specifications, using simulated inputs.

e. Documentation: preparation of technical documents describing design, data structure, testing accomplished, and other information for using and modifying the computer programs.

f. Retrofit: incorporation of changes to meet new requirements.

g. Program Maintenance and Error Correction: diagnosis of malfunctions and correction of errors; maintaining correspondence of computer programs at different locations; maintaining technical documentation.

Program System Testing (PST)

Following the installation of system equipment at an operationally configured facility, the computer programs resulting from in-plant development were installed and subjected to extensive testing, using both simulated and live inputs. In BUIC II, this PST activity was initiated at the BUIC Evaluation Facility (BEF), located at Hanscom Field, and was later continued at the first operational site at North Truro, Massachusetts. Category II tests were also accomplished, to some degree concurrently, at those same locations.

Data Collection and Processing

This activity encompassed the collection of geographic, unique-to-site, and weapons characteristics data, as well as processing, verifying, publishing, and maintaining the data.

Personnel Subsystem (PS)

BUIC II was the first system program at ESD to be materially affected by the concept of the personnel subsystem, which had become established as Air Force-wide policy through the issuance of AFL 375-5, Planning and Programming for System Personnel, in October 1961.* The spectrum of PS requirements defined in AFL 375-5 was set forth in the BUIC II specification issued in February 1962, although stated at a very general level. They posed a variety of problems which were new in the ESD system context and which were also somewhat foreign to the PS concept itself because of the fact that PS, like other systems management elements which were yet to appear, had originated with aircraft and missiles. There ensued a period of study to define implementing methods which would be suitable to the requirements of an information system, and to identify workable allocations of responsibilities to the SPO, MITRE, and the two associate contractors. As a result, BUIC II preceded BUIC III as a "test bed" for the requirements in this area as they relate to computer program acquisition. Elements assigned to SDC as PS contract activities are summarized briefly below.**

a. Personnel-Equipment Data (PED). PED was only partially implemented in BUIC II because of the general austerity of funding. Information was compiled and maintained by each contractor for internal purposes only, at the level of whole documents rather than as individual data elements.

b. Human Engineering, Detailed task analyses for operating system personnel were required as a basis for design of

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* The Air Force letter was later superseded by AFR 30-8.

** An expanded description of the PS adaptations arrived at in BUIC II is contained in SDC TM-1494, The Personnel Subsystem Program for an Information System, dated 23 September 1963.

display format/content, switch functions, and special computer program functions, and to provide the basic data for positional handbooks and QQPRI.

c. Qualitative and Quantitative Personnel Requirements Information (QQPRI). Position description information was prepared for the operator, simulation/exercising, and computer programming support (Blue Suit) personnel, for input to the system QQPRI report which contained similar information for equipment maintenance and other personnel supplied by the hardware contractor.

d. Personnel Subsystem Test and Evaluation (PSTE). Contractor support was provided to develop plans and assist in conducting PSTE during Category II system testing.

e. System Exercising for Training and Evaluation (SETE). Although not included as a recognized element of the general PS structure, SETE was so classified in BUIC because of its emphasis on training. Development of the SETE capability in BUIC II was based on the SAGE model, SSTP, but with the addition of requirements pertaining to use for evaluating system functions and subfunctions as well as training and evaluating personnel. Tasks required to accomplish the development included the following variety of elements:

   (1) analyses of training and evaluation requirements;

   (2) specification of exercising modes and configurations;

   (3) identification of performance/design requirements for special equipment for problem generation, simulation, communications, and recording;

   (4) specification of computer programs for data reduction and recording;

   (5) development of computer programs for on-site generation of simulated aircraft tracks;

   (6) development of problems for system-wide exercises, together with associated aids and materials;

   (7) development of manuals and guides covering the organization, planning, and conduct of system exercises.

Configuration Management

The circumstances under which configuration management was introduced in BUIC II were mentioned earlier, in Chapter II of this report. At the time the configuration management exhibit was placed on contract (June 1964), the documentation to be controlled either was already completed or was in advanced stages of development. Hence, the exhibit merely identified the specific documents which constituted the baselines, in terms of their contractor document numbers, titles, and dates, rather than specifying their format and content. The baselines identified were (1) operational specifications which had been written for the operational field-site problem generation (FSPS), and data reduction (BUDR) computer programs, and (2) a series of user manuals which was in process of being completed for the utility and support elements. Also, as compared with subsequent exhibits, there was no attempt to identify a FACI or establish product configuration baselines. In other respects, the control and document maintenance procedures were closely similar to those which were later adopted for general use, although with a number of minor differences in the names and formats of control and maintenance forms. In June 1964, the contract identified the following specific activities under a task entitled "Configuration Management":

a. Prepare Change Proposal (CP) forms for all proposed changes to the established computer program baselines.

b. Prepare Change Recommendation (CR) forms for any system item, when considered necessary because of conditions affecting the computer program developments.

c. Provide summary cost estimates for each Class I CP.

d. Publish, maintain, and revise the Configuration Index.

e. Publish and update the Configuration Management Status Report.

CHAPTER V

BUIC III PROGRAM REQUIREMENTS AND EVENTS

A. INTRODUCTION

The Air Force was authorized by the Defense Department to proceed with the BUIC III program in November 1964. This event had been preceded by a variety of studies involving ADC, ESD, MITRE, SDC, Rand, and others, as a result of which the BUIC III concept had been selected from among several alternatives.

As a fundamental aspect of the BUIC III concept, the program was initiated as a major "modification" of the BUIC II system, rather than as a completely new system program, and prior to the time that BUIC II was scheduled to be completely operational. Thus, it readily became an extended and modified effort of the same agencies, including the same principal contractors (Burroughs and SDC) who had been involved in the development of BUIC II. A Definition Phase was not required since estimated costs were below the stated DOD thresholds. The draft system specification was developed during the first half of 1965 by ESD/MITRE, with some support by the contractors, following which formal contract work initiating system acquisition began at the outset of FY 1966 (July 1965).

The BUIC III system specification was the first to be produced at ESD which attempted to conform to the guidance established in Exhibit I of AFSCM 375-1, which had been issued in essentially its present form* and coordinated among the AFSC divisions during the preceding year. The specification defined performance/design and test requirements for the system, including requirements for the system exercising capability**,and allocated requirements among

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* The January 1964 draft, which was issued for official use in June 1964, was a major expansion and revision of an earlier version of AFSCM 375-1 which had appeared in June 1962.

** The label carried by this capability in both BUIC II and BUIC III is System Exercising for Training and Evaluation (SETE). Although often thought of as part of the computer program system segment because of SDC's responsibility for its extensive computer programming, problem generation, and personnel subsystem aspects, the capability is more properly treated -- as it was in the BUIC III System Specification -- as a system-level set of requirements. Its impact on the system includes, for example, additional capacity of the operational computer, as well as special consoles, communications, simulation equipment, and personnel.

the five system segments:

Data Processing and Display System Segment
Maintenance Computer Program System Segment
Operational Computer Program System Segment
Building and Facilities System Segment
Communication System Segment

Major developmental work to be performed by the two associates system contractors was defined by the first three of these segments. The equipment and maintenance computer program segments were assigned to Burroughs, while activities associated with the operational computer program were assigned to SDC.

To provide a basis for discussing experience with the systems management techniques, the following two sections are devoted to outlining the elements of work which comprised SDC's system segment, and describing the ways in which these were influenced by the new management procedures and requirements. Subsequently, in the final section of this chapter, an attempt will be made to present a factual summary of events as they actually occurred during the program.

B. THE OPERATIONAL COMPUTER PROGRAM SYSTEM SEGMENT

The basic items to be developed and delivered under the contract were three computer program contract end items (CPCEIs), which were identified as:

ADP -- Air Defense Computer Program
SEP -- System Exercise Computer Program
UCP -- Utility Computer Program

It has been mentioned earlier (Chapter IV) that these correspond closely, with regard to general computer program types and functions, with the computer programs which had been required in both SAGE and BUIC II.

In addition to the CPCEIs, important items of deliverable data included the computer program specifications, positional handbooks, user manuals, exercising manuals and guides, and system exercise problem inputs and materials. For the most part, these items had precedents in BUIC II (cf. preceding chapter).

The technical activities were also similar to those which had been carried out under the BUIC II program, except for the pervasive influence of BUIC III management innovations. These included: operational design; computer program design, development, and testing; development of system exercising problems, aids, guides, and materials; and performance of associated personnel subsystem tasks. In addition, SDC became responsible eventually for the management and conduct of the Category II test program.

However, essentially all of these activities were affected in varying degrees by the procedures and guidelines which had been developed by the SDC Systems Management Project during the first six months of FY 1965 (see Chapter II). That effort had been funded by the 416M SPO, with the explicit intent to acquire products which could be applied and tested in the BUIC III program. Also, the SPO was actively represented* in the ESD Software Management Committee which reviewed and coordinated the effort during that phase of the project. As a result, it is of note that some of the specific new requirements were influenced by known characteristics of the BUIC III system. This was considered to be a desirable circumstance by the committee members, who regarded the development of generalized L-System procedures to be the primary objective, but felt at the same time that the realism of concepts would be materially enhanced to the degree that they could be related to the particulars of an actual program. Thus, BUIC III became a "test bed" for guiding the initial formulation of many of the concepts, as well as for subsequently evaluating the experience with their application.

The procedures applied in BUIC III consisted of adaptations to computer programs of established Systems Command procedures, principally in the areas of data management (AFSCM/AFLCM 310-1), configuration management (AFSCM 375-1), and testing (AFSCM 375-4; AFR 80-14). Except for formal design reviews, the program was not specifically influenced by the concepts and requirements of system engineering management as set forth in AFSCM 375-5. The specific documents which governed the application of these requirements in BUIC III were: (1) AFSCM/AFLCM 310-1, together with AFLC/AFSC Forms 9 which were then largely ESD-unique, (2) the BUIC III configuration management exhibit, ESD-416M-43**, and (3) the contract statement of work, which incorporated certain requirements in the computer program testing area, in particular, which were not covered elsewhere. During the first year of this contract, a few of the Forms 9 were published in 310-1, and such other documents as ESD Exhibit EST-2 (later superseded by ESD Supplement 1 to AFSCM 375-4) and ESDP 375-10 (subsequently ESD Exhibit EST-3) appeared.

The following subsections describe the requirements which were introduced in BUIC III. Most of these were novel, in the sense that they did not exist

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* By Lt. B. Capehart

** The exhibit was based upon the same materials which were issued a few weeks later as ESD Exhibit EST-1. Except for being a self-contained document (whereas EST-1 is in the form of change pages to AFSCM 375-1), differences in content as compared with EST-1 are negligible.

in the same form in BUIC II. For convenience, Table 5-1 presents a summary list which identifies the particular aspects of novelty as compared with earlier practice.

C. SYSTEMS MANAGEMENT INNOVATIONS

Data Management

The use of a Contractor Data Requirement List (CDRL: DD Form 1423) was initiated in BUIC III, together with the application of Forms 9 governing the preparation of identified data items. The applicable Forms 9 included a set which had been developed under the Systems Management Project to cover items which were judged to be of typical interest in ESD systems, but which had not previously existed in AFSCM/AFLCM 310-1. As listed below, these items were initially ESD-unique; nearly all have since been published in Volume II of 310-1:

Positional Handbook--Information System Operational Personnel (ESD 178) (H-109*)

Contract End Item Detail Specification (Computer Program), Part I (ESD 236) (C-132*)

Contract End Item Detail Specification (Computer Program) Part II (ESD 237) (C-133*)

Category I Test Plan (Computer Program), (ESD 261) (T-103-1*)

Category I Test Procedures (Computer Program), (ESD 262) (T-103-1*)

Category I Test Report (Computer Program), (ESD 263) (T-118-1*)

Exercise Conduct Manual (ESD 281) (Q-125-1*)

Synthetic Inputs Operator Guide (ESD 282) (Q-123-1*)

Evaluation Manual (Information System Exercising Personnel), (ESD 283) (Q-124-1*)

Human Operator Task Analysis for Information Systems (Q-]5-18.0) (Q-118-1*)

Training Needs/Exercise Requirements Analysis (Q-26-18.0) (Q-119-1*)

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* Refers to the data item number (DD Form 1664) in Volume II of AFSCM/AFLCM 310-1 as of 30 August 1968.

Table 5-1. Summary of Computer Program Management Requirements Introduced in BUIC III.

	ITEM	PRECEDENTS	NOVEL ELEMENTS
DATA MGMT	AFSCM/AFLCM 310-1 Requirements	Some Data Items	Use of CDRL Specified Format/Content Some Items
CONFIGURATION MANAGEMENT	Part I Specification	Ops Specs	Quality Ass.; Interfaces Utility Coverage Spec. Conventions
	Part II Specification	TM-1333 User Manuals (U)	Comprehensive Coverage Up-to-date Accuracy
	Control & Accounting	CP CP (II) CR Conf. Index Status Rpt. } Part I Only	ECP CR SCN SCL EICC Conf. Index Ch St Rpt V.D. Doc } Part I & Part II
	FACI	----	Formal Audit Reissue PCB
DESIGN REVIEWS	PDR	Informal	Formal Review Minutes
	CDR	----	Formal Review Incremental (w/PQTs) Minutes
CATEGORY I TEST	Part I Spec (Sec 4)	----	Required (ESD 236)
	Cat I Test Plan	----	Required (ESD 261)
	Cat I Test Proc.	----	Required (ESD 262)
	Cat I Test Reports	----	Required (ESD 263)
	PQTs	----	Required
	FQT	----	Required
	CPT&E	P&A Testing PST	(no change)

Evaluation Needs/Exercise Requirements Analysis
(Q-24-18.0) (Q-117-1*)

Exercising Capability Implementation Plan
(Q-27-29.0) (Q-120-1*)

Minutes of Formal Reviews and Inspections
(ESD 289) (C-131*)

Users Manual (Computer Program), (ESD 290) (H-110*)

Version Description Document (Computer Program)
(ESD 291) (C-135*)

Configuration Index (Computer Program)
(ESD 293) (C-136*)

Change Status Report (Computer Program)
(ESD 293) (C-137*)

System Exercising Problem Package
(Q-28-56.0) (Q-121-1*)

System Exercising Problem Agreements Document
(ESD 295)

It was indicated earlier that most of the above items, as well as others listed in the CDRL which were not unique, had precedents among deliverable items of data which had been prepared in BUIC II. However, the CDRL procedures as such, a few of the data items (notably, in the test area), and a number of specific format/content requirements were introduced for the first time in BUIC III.

Specifications

The Forms 9 for CPCEI Detail Specifications, both Parts I and II, were derived from studies which had attempted to take into account a complex of considerations posed by (1) the general characteristics of uniform specifications as embodied, e.g., in Exhibit II of AFSCM 375-1, (2) previous practices in documenting computer program developments, as exemplified in such systems as 416L, 416M, 465L and 473L, and (3) the similarities and differences between computer programs and equipment which relate to purposes of configuration management. Hence, they involved a number of novel elements in BUIC III, as

* Refers to the data item number (DD Form 1664) in Volume II of AFSCM/AFLCM 310-1 as of 30 August 1968.

compared with the "specifications" which had been written previously for BUIC II. The major differences may be summarized as follows:

1. The Part I Specification is basically a performance-level specification, as were the earlier "operational specifications (ops specs)" which had been in use for SAGE and BUIC II. However:

   a. Ops specs had previously been written and provided to the user only for operational and support, but not for utility, computer programs. Hence, the requirements to write a performance-level specification for utility elements (including the compiler) was completely new.

   b. The ops specs had not contained a quality assurance section comparable to Section 4 of the Part I specification.

   c. Interfaces and, in general, the specific identification of detailed inputs and outputs for each functional element of the CPCEI, had not been systematically included in ops specs. Equipment interfaces, as well as personnel operating procedures, had been included in the ops specs, however, often in the form of detailed narrative descriptions of system operational sequences and conditions. In addition, a separate set of documents known as "Variable Display Equipment Specifications (VDE specs)" had been written, defining functions and labels of console switches and detailing the recommended wiring of console switches to computer storage locations.

2. Essentially all of the computer program documentation requirements contained in the Form 9 for the Part II specifications were based upon elements which had previously existed in some form, and for some computer programs. However, the requirement had not previously existed to provide all of those elements for each CPCEI, and at one point in time. Some of the elements, e.g., flow charts, had been prepared at early phases of the development process, but had not been prepared at detailed levels for all components of each computer program. Nor had the design description material generated during developmental phases, including flow charts, been revised and updated on a continuing basis to reflect actual design decisions resulting from the processes of coding, testing, and ongoing changes. Thus, the requirement to prepare the type of comprehensive description described in the Form 9 for a Part II CPCEI specification, which would be accurate in all respects at

the time of FACI for each CPCEI, represented a major new element in the BUIC III effort.

Configuration Management

Most of the procedures and standard forms used for computer program configuration control and accounting had been developed during the period of 1963-1964, and had been used in BUIC II. Only a few changes of a minor nature were made in the forms used in BUIC III, which conformed in all essential respects to those currently described in ESD Exhibit EST-1. These were: Engineering Change Proposal; a Change Report form for reporting Class II changes; Specification Change Notice; Specification Change Log; End Item Configuration Chart; Configuration Index; Change Status Report; and Version Description Document.

In BUIC II, traditional operational specifications (ops specs) comprised the baselines, which were established and formally maintained only at that level -- i.e., of performance, rather than at the level of detail design. In fact, the controls adopted in BUIC II were largely based on controls which had been exercised by ADC to govern performance-level changes in the SAGE system for some years previously.* Format and content requirements for the ops specs had not been contractually specified. These were replaced in BUIC III by the Part I specifications, with new format/content elements as described above, which became approved and controlled as Design Requirements Baseline documents. In addition, the Part II specifications were also required as deliverable items under the contract, and were scheduled to be established as Product Configuration Baselines as a result of First Article Configuration Inspection (FACI).

Thus, while configuration control at the performance level had been introduced earlier, configuration management procedures were expanded in BUIC III to encompass uniform computer program specifications, FACI, and control of baselines at the product configuration level.

Design Reviews

The Preliminary Design Review (PDR) and the Critical Design Review (CDR) involved formal meetings and reviews of computer program design data which had no direct precedents in earlier systems. Although specific design questions had occasionally been matters of interest to the SPO's GSE/TDC, MITRE, during

* ADCM 55-32, Processing Adaptation Data, Computer Program, and Related Equipment Changes in SAGE, which has been updated a number of times since, was issued as early as January 1961.

BUIC II, the ESD SPOs had not, in general, been able to acquire and maintain the capability to monitor contractor computer programming efforts at the technical design level. At SDC, the entire processes of computer program design, coding, and testing had been carried out, of necessity, as "in-house" contractor responsibilities. Thus, the objectives, functions, and conduct of PDRs and CDRs became matters with which both the SPO and contractor personnel gained their first actual experience in BUIC III. The PDR was scheduled as a single review of each CPCEI (with minor variations noted in a later section of this chapter), concerned with the design approach to the CPCEI as a whole. The CDR for each CPCEI was planned to be carried out in increments, concurrently with Preliminary Qualification Tests (PQTs), as a review of the completed design of CPCEI components undergoing PQT.

> Note: ESD Exhibits EST-1 and EST-3 emphasize CDR as a review to be conducted at the time when detailed flow charts are available for the computer program components, prior to the start of coding. However, EST-1 also allows for the variation chosen for BUIC III, in which the review was conducted after coding of the component undergoing review was completed.

Category I Testing

Prior to BUIC III, computer program testing associated with the earlier air defense systems had been accomplished by the contractor without formal involvement by the SPO. The test process included in-plant testing of components as a normal adjunct to coding and assembly operations at SDC. In addition, it also involved the conduct of a comprehensive checkout of the computer program at the Category II test site following installation of equipment and computer programs and prior to the formal beginning of Category II tests. This checkout operation was known as "Program System Testing (PST)". It is considered to be an important and necessary extension of the development process for operational computer programs, in particular, since the Category II site normally provides the first opportunity to exercise the complete set of computer programs in the operational equipment configuration.

The Category I test program formulated for BUIC III consisted of the elements which are now described elsewhere, in varying degrees of detail, in such documents as ESD Exhibit EST-1, ESD Supplement 1 to AFSCM 375-4, SDC TMs 3361 and 3596, ESD-TR-68-1, and associated Forms 9 in the Test Category of AFSCM/AFLCM 310-1, Vol. II. The major elements are summarized briefly below:

1. Category I Test Plan. A test plan was required for each of the

three CPCEIs. These plans were based on the Form 9 (ESD 261), but were also influenced by a variety of specific circumstances and agreements reached with the SPO, relating to both structure and content.

2. Classes of Testing. By analogy with the types of Category I testing which have been established for equipment CEIs, requirements were formulated under the following three categories:

   a. Computer Program Test and Evaluation (CPT&E). In general, CPT&E encompasses the testing which a contractor normally conducts as an integral part of his design and development effort. Thus, this category subsumes essentially all of testing which had been typical of the preceding systems, as described above. Major requirements formally recognized by the SPO with respect to CPT&E pertain to in-plant use of GFE computing equipment, and to utilization of the Category II test site for computer program installation and checkout (formerly PST; cf. above).

   b. Preliminary Qualification Test (PQT). PQTs are conceived as interim tests which are intended to serve the primary purpose of demonstrating contractor progress towards meeting design objectives for a computer program CEI. As expressed in current guidance documents (e.g., ESD Exhibit EST-1), they are oriented towards verifying portions of the CPCEI prior to formal qualification, but are not expected to accomplish the qualification as such. This concept was introduced for the first time in BUIC III, without benefit of either amplifying guidance or experience on the part of the SPO or contractor. As a result, PQTs were required and performed in BUIC III with somewhat greater emphasis (and difficulty) than might normally be expected. PQTs were scheduled to test/demonstrate essentially all reactions within each function of the ADP and SEP CEIs, prior to formal qualification tests. Each PQT was combined with an incremental CDR of design data pertaining to the tested components. No FQT (Formal Qualification Test) and PQTs only for two of its many functions were conducted on the utility computer program (UCP). To save time and cost, complete Category I testing was not required for UCP, which could reasonably be considered qualified through its extensive use during the program in developing ADP and SEP.

c. Formal Qualification Test (FQT). FQTs were required for the ADP and SEP, and were scheduled for performance at the Category II test site following computer program installation and checkout, prior to FACI and the beginning of Category II testing. Successful completion of FQT was planned as the primary testing basis for acceptance of the CPCEI.

3. Test Procedures and Reports. Procedures and reports were required for both PQTs and FQTs, in conformance with ESD 262 and 263 (currently contained in Vol. II of AFSCM/AFLCM 310-1 as T-103 and T-118). Test Procedures documents for PQTs were required for SPO review 30 days in advance of scheduled PQTs. In the case of FQTs, the Test Procedures document was required 90 days in advance, for SPO review and approval and to accomplish necessary changes.

In summary, the Category I test program applied to BUIC III CPCEIs, other than utility, covered the full range of documentation and formal testing procedures which have since become incorporated in general guidance for 375-series applications to computer programs. The novel elements, as compared with previous SDC/416M SPO experience, were the preliminary and formal qualification tests and their associated test plans, procedures and reports.

D. PROGRAM MILESTONES

1. General

A summary of major events as they actually occurred during the program is presented graphically in Figure 5-1, which portrays significant dates relating to specifications, design reviews and FACI, test plans, and tests, principally for the three computer program contract end items (CPCEIs) in question. Dates on which the system specification was issued and the Category II testing was conducted are also included, however, for orientation to the system program as a whole.

To distinguish among the three CPCEIs, different symbols are used for the Air Defense Program (ADP), the System Exercise Program (SEP), and the Utility Computer Program (UCP); these are triangles, circles, and squares, respectively. Symbols are drawn as solids for actual past events, and in outline only for scheduled future events which had not occurred at the time the chart was drawn (February 1969). As stated, the chart represents the timing of actual occurrence, prior to February 1969. It is not based on the initial program schedule, nor on periodic revisions which occurred as the program progressed.

Some of the events are depicted in the figure in a somewhat oversimplified manner, in the interests of avoiding clutter. However, more precise data, together with some amplification of their meaning in terms of related events and circumstances, are provided in the narrative below. In this section, emphasis is placed on descriptive and factual data regarding the program events. Discussions of problem areas and evaluative comments will be reserved for the following chapter.

2. System Specification

The system specification for BUIC III was initially issued as a formal document, designated SS-ES416M-65-1A, on 1 June 1965. It had been developed during the first six months of 1965 by the MITRE Corporation, principally, but with significant inputs from the two associate contractors, SDC and Burroughs Corporation.

A major revision, designated SS-ES416M-65-1B, was issued exactly one year later, on 1 June 1966. The revision contained significant changes and expansions resulting from contractor efforts in developing Part I specifications for the system contract end items.

These two events are depicted by star symbols in the top row of Figure 5-1.

3. Part I Specifications

The dates of Part I specifications which are shown in Figure 5-1 for the three computer program CEIs represent, in general, the principal dates of basic issue -- i.e., of the first issues in accepted forms which constituted initial baselines for the items. In all cases, basic issues were preceded by one or more drafts for SPO review and approval. Hence, except for formally processed subsequent changes, the dates attempt to represent times at which the Part I specification developments were completed. Certain deviations and other amplifying information are noted below, separately for each of the CPCEIs.

AIR DEFENSE PROGRAM (ADP)

Because of its complexity and bulk (in excess of 2000 pages, total) the ADP Part I specification was structured into a set of 11 volumes, corresponding generally to a breakdown of the ADP into major functional groupings. This multi-volume structure was also adopted for most of the other principal computer program documents, as will be explained subsequently for each.

The date indicated in Figure 5-1 actually represents completion of only the first 10 of these volumes; the 11th, "Message Formats", was delayed for an additional six months by the need to resolve interfaces with other systems

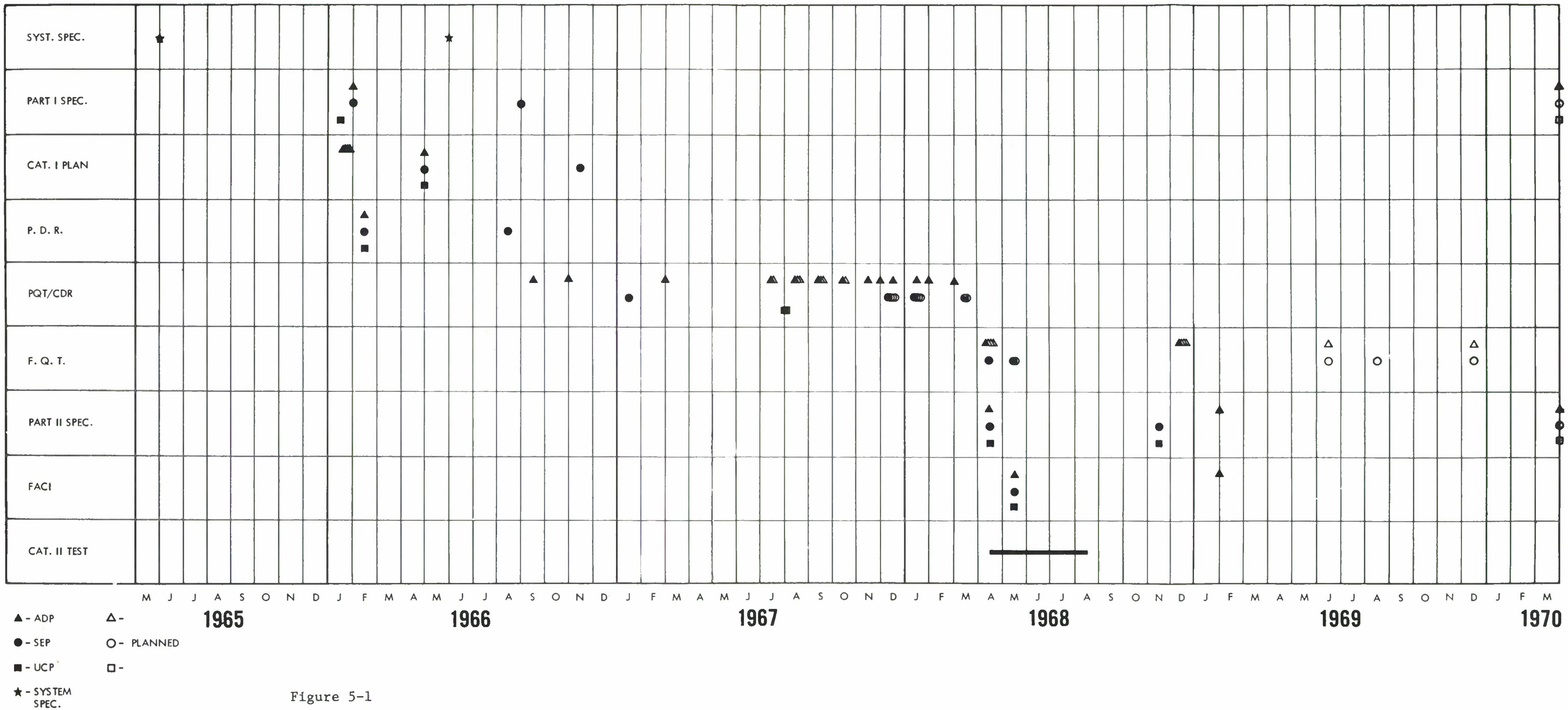

Figure 5-1

BUIC III Program Milestones:
Operational Computer Program System Segment

(SAGE, BUIC II). A list of actual dates for all volumes, together with their numbers, titles, and functional elements covered under each, is presented in Table 5-2. For convenience, the table combines the Part I specification data with similar data relating to Category I Test Plans, which will be discussed in a later subsection.

SYSTEM EXERCISE PROGRAM (SEP)

The Part I specification for SEP was written in four volumes. The first two, "General" and "BUIC Exercise Preparation System (BEPS)," were issued on 21 January 1966 and the second two, "BUIC Analysis and Reduction System (BARS)" and a "Classified Supplement," were issued on 1 September 1966. Table 5-3 lists these volumes, their titles, the functional elements comprising individual chapters under each, and the dates of basic issue. As in the case of ADP above, the table also includes Category I Test Plan data which will be discussed separately.

The widely-separated dates of their Part I specification volumes reflects, in part, the fact that BEPS and BARS were relatively independent part of the SEP. A similar separation with respect to major milestones tended to be characteristic throughout the program. However, the late initial dates of BARS Part I specifications were largely a result of new requirements associated with the System Test Reduction Processor, the Subsystem Test Processor, and modification to the Test Data Analysis Processor. The new requirements, which were introduced shortly prior to the original completion date, added about 40% to the size and occasioned a realignment of contractor manpower and schedule.

UTILITY COMPUTER PROGRAM (UCP)

The UCP Part I specification consisted of four volumes, all of which were issued on 10 January 1966 as indicated in Figure 5-1, three weeks earlier than the ADP and SEP specifications. The left-hand column of Table 5-4 shows the volume numbers and titles of the UCP Part I specification. The second column in the table lists the functional elements which comprise individual chapters in the various volumes. Note, as indicated in Table 5-4, that one function, "Timing," was added to Volume 3 on 5 November 1968. This addition was the result of ECP 120-2, "Addition of a Timing Program to ADP/UCP," which provided for a timing tool to facilitate estimating the operating time of ADP programs or portions thereof. The third column in the table shows the dates of issue of the UCP volumes and the Timing function document. The last two columns contain data pertaining to Category I Test Plans, which are discussed in the following section.

4. Category I Test Plan

The Category I Test Plans for BUIC III CPCEIs, like the Part I specifications, were also structured into volumes, corresponding roughly to functional elements

Table 5-2. Volume Structure of Part I Specification and Category I Test Plan for the Air Defense Program (ADP)

Part I Specification		Functional Elements	Dates	Cat. I Plan	
Vol.	Title			Vol.	Dates
1	General		31 Jan 66	1	1 May 66
2	Air Surveillance		31 Jan 66		
		Radar Inputs		2.	1 May 66
		Active Tracking		3	1 May 66
		Passive Tracking		4	28 Jan 66
		Height		5	21 Jan 66
		Positive Target Control		6	1 May 66
		Identification		7	1 May 66
3	Weapons		31 Jan 66		
		Weapons Assignment and Commitment		8	25 Jan 66
		Weapons Direction/ Communication		9	25 Jan 66
		Air Defense Artillery		10	25 Jan 66
4	Information Transfer and Manual Inputs		31 Jan 66		
		Information Transfer		11	24 Jan 66
		Manual Inputs		12	1 May 66
5	Startover, Control, Recording, and Real-Time Simulation		31 Jan 66		
		Startover		13	1 May 66
		Control		14	1 May 66
		Recording		15	1 May 66
		Real-Time Simulation		16	1 May 66
6	Adaptation		31 Jan 66		
7	Variable Display Equipment		31 Jan 66		
8	Displays		31 Jan 66	17	1 May 66
		Display Specification Situation Displays Tabular Displays Abbreviations and Definitions			
9	Switch Actions		31 Jan 66		
10	Classified Supplement		31 Jan 66		
11	Message Formats		1 Aug 66		

Table 5-3. Volume Structure of Part I Specification and Category I Test Plan for the System Exercise Program (SEP)

Part I Specification				Cat. I Plan	
Vol.	Title	Functional Elements	Dates	Vol.	Dates
1	General		31 Jan. 66	1	
		Control Data Base Maintenance Octal Correction			
2	Exercise Preparation (BEPS)		31 Jan. 66	1	1 May 66
		Exercise Tape Generation		1	
		Exercise Tape Description		1	
		Exercise Tape Modification		1	
3	Analysis and Reduction System (BARS)		1 Sept. 66		
		Exercise Processor		2	15 Nov.66
		Operational Processor		3	15 Nov.66
		Test Data Analysis Processor		4	15 Nov.66
		System Test Reduction Processor		5	15 Nov.66
		Subsystem Test Processor		6	15 Nov.66
4	Classified Supplement		1 Sept. 66		

Table 5-4. Volume Structure of Part I Specification and Category I Test Plan for the Utility Computer Program (UCP)

Part I Specification				Cat. I Plan	
Vol.	Title	Functional Elements	Dates	Vol.	Dates
1	General		10 Jan. 66		
2	Assembly Analysis		10 Jan. 66		
		Machine Language Assembler JOVIAL Compiler Assemble Compool Assemble Geography Binary Data Insertion Tape Load		1	1 May 66
		Set/Use Indirect Address and BAR Table Reference Adaptation Calculation Parameter Test Tool		2	1 May 66
3	Facility System		10 Jan. 66		
		Facility Control Pre-Recording Dynamite Symbolic Relative Corrector			
		Timing	(added 5 Nov. 68)		
4	General Utility		10 Jan. 66		
		Tape File Maintenance Binary Read Load Octals on Tape Tag Reference Symbolic Corrector Loader Input/Output Computer Utility and Support System Executive Dump Function			

of the computer program. In general, basic issues of test plan volumes were preceded by drafts for SPO review and approval. While they are not directly subject to configuration management, the plans were also maintained on a continuing basis during Acquisition to reflect approved changes to the Part I specifications. Accordingly, they were frequently updated by means of change pages or revision, following their dates of basic issue.

In Figure 5-1, symbols are located at points which represent the basic issue dates for groups of volumes. Additional explanation is provided below for each of the three computer program items.

AIR DEFENSE PROGRAM (ADP)

The Category I Test Plan for ADP was written in a total of 17 volumes. One of these (Vol. 1, General) emphasized planning of formal qualification (FQT) for the CPCEI as a whole. The other 16 were devoted individually to detailed planning of PQTs for the computer program functional elements identified in various volumes of the Part I specification, primarily, but also included planning pertinent to FQT.

Symbols shown in Figure 5-1 are located at two different dates for ADP, indicating that 6 volumes were issued in January and the remaining 11 volumes in May of 1966. The volume numbers, titles (corresponding to the Part I specification titles shown), and dates of issue are listed in the preceding Table 5-2. It may be noted that the table shows an absence of test plan volumes corresponding to switch actions and message formats. These were necessarily included as essential aspects in the testing of other functional elements.

SYSTEM EXERCISE PROGRAM (SEP)

The two points shown in Figure 5-1 for the SEP Category I Test Plan also indicate two separate dates of issue for the test plan volumes, in May and November 1966. The volumes, dates, and correspondence of test plan breakdown with elements of the Part I specification are identified in the preceding Table 5-3. The discrepancy of 6 1/2 months in publication dates reflects, basically, the lag in BARS portions of SEP which had been initiated by the earlier delay in completing BARS volumes of the Part I specification.

UTILITY COMPUTER PROGRAM (UCP)

An early decision had been reached that utility computer programs, except for two designated elements, would be qualified through their use in developing the ADP and SEP. As a result, the test plan for UCP was confined to one volume each for the two designated elements, the JOVIAL Compiler and BUIC Adaptation

Calculation (BAC). These are listed in the preceding Table 5-4. In Figure 5-1, the symbol represents the date on which both volumes were published.

5. Preliminary Design Reviews (PDRs)

PDRs for the three CPCEIs were held on the following dates: for ADP, on 14-15 February 1966; for parts of SEP, on 15-16 February 1966; for UCP on 16 February 1966; and for remaining parts of SEP, on 23 August 1966. The two increments of PDR for SEP basically followed the discrepancy between BEPS and BARS which had been generated earlier by the delay in the BARS Part I specification. However, the February PDR, for BEPS, also covered the BARS Test Data Analysis Processor. The later increment was devoted to the BARS Exercise Processor, Operational Processor, System Test Reduction Processor, and Subsystem Test Processor.

The review in each case was concerned with preliminary design of the CPCEI as a whole, with respect to levels of design information which would subsequently comprise a general volume (Vol. 1) of each Part II specification. These included attention to interfaces, allocation of functions to computer program components (CPCs), control and sequencing of CPC operations, and storage allocations. The preliminary design information to be reviewed was documented and delivered to the SPO for advance examination, prior to each PDR. Results of the reviews were subsequently incorporated in PDR Minutes, which were prepared by the contractor and approved by the SPO.

6. Critical Design Reviews (CDR)

The basic approach adopted in BUIC III was to conduct CDR incrementally in association with PQTs.* For this reason, the chart in Figure 5-1 shows a single row of combined PQT/CDR events for each CPCEI. The precise dates and numbers are discussed further under PQTs, in the next subsection.

However, in the case of SEP, some elements underwent CDRs which were not associated with PQTs. These were cases in which combined PQT/CDRs had been planned initially, but for which PQT requirements were subsequently waived.

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* ESD Exhibit EST-1 (Sec. H; Exh. XIV) defines CDR for CPCEIs as basically a review at the level of logical design of individual CPCs, prior to coding and testing. However, it also permits "flexible application" in the case of CPCEIs whose development follows an incremental pattern during Acquisition, suggesting that the CDR may be held in corresponding increments and may be combined with PQTs.

The SEP portions affected, and the dates of their CDRs, are listed below:

BEPS	
Exercise Tape Generator	
Exercise Tape Description	15 January 1968
Exercise Tape Modification	
BARS	
Test Data Analysis Processor	1 February 1967

Where PQTs were held, material reviewed at CDR was the available Part II specification material for the elements undergoing PQT. Hence, it was at the level, in essence, of completed design. It is reported that items specifically reviewed included, for each given CPC or combination of CPCs, the following: CPC name(s), functions, size, and interfaces; emphasis was placed on CPC sizes, noting comparisons with BUIC II and deviations from PDR estimates. It has also been reported that questions of timing were raised with increasing interest as the program progressed towards later phases.

7. Preliminary Qualification Tests (PQTs)

As indicated in Figure 5-1, PQTs occurred in large numbers for the ADP and SEP CPCEIs. Initial planning of PQTs was based on the philosophy that preliminary qualification testing was required for each and every element of the computer program. Accordingly, they were so defined and scheduled in the ADP and SEP Category I Test Plans.

As was noted in the preceding subsection, each PQT was initially planned to occur in combination with an incremental CDR of the element(s) being PQT'd. Detailed data relating to these events as they actually occurred are set forth below, separately for each of the CPCEIs.

AIR DEFENSE PROGRAM (ADP)

The record shows that a total of 35 PQTs were held for the ADP, of which 32 were combined with CDRs. Listed below are the dates of occurrence, and following each the number of PQT/CDRs held on that date. The last three dates listed are the occasions on which PQTs were not accompanied by CDRs.

19 September 1966 (2)	26 July 1967 (2)	13 September 1967 (2)
1 November 1966	22 August 1967	14 September 1967 (3)
7 March 1967 (4)	23 August 1967	10 October 1967
25 July 1967	24 August 1967	11 October 1967 (3)
25-26 July 1967	12 September 1967	21 November 1967 (3)

5 December 1967 (3)	16 January 1968	26 February 1968
15 December 1967 (2)	30 January 1968	

In some cases, a single PQT/CDR was held for an entire CPC (see Table 5-5). For selected components of ADP, CDRs were conducted in increments as the design and testing of pieces of a CPC progressed. In the case of incremental CDRs, areas of a computer program which did not have a PQT at the first CDR for that computer program had a PQT at a subsequent CDR. Thus some CPCs underwent as many as three CDRs. Table 5-5 shows the number of CDRs held for each CPC in the ADP CEI and in the order they occurred. The Minutes for each CDR list the subroutines and "functional areas" of the CPC which, at a particular time, did or did not have a PQT and which did or did not undergo a CDR.

Table 5-5. PQTs/CDRs for ADP CPCs

		No. of CDRs			No. of CDRs			No. of CDRs
1.	MIN -	2	11.	TRK -	1	21.	SIG -	1
2.	BIT -	1	12.	RAC -	3	22.	TAR -	1
3.	BOB -	3	13.	MID -	1	23.	SET -	0
4.	AAD -	3	14.	KAW -	1	24.	CIO -	*
5.	BIP -	2	15.	RAP -	2	25.	KAS -	*
6.	OCS -	1	16.	COP -	1	26.	SRT -	*
7.	REC -	1	17.	SID -	1	27.	ART -	*
8.	BID -	1	18.	TAC -	1	28.	SQR -	*
9.	TOP -	1	19.	TAG -	1	29.	TNC -	*
10.	BIO -	2	20.	BOK -	1	30.	WND -	*

It should be noted, as shown in Table 5-5, that one CPC, SET, in the ADP CPCEI did not have a CDR, and seven CPCs (CIO, KAS, SRT, ATR, SQR, TNC, and WND)

* These CPCs underwent CDRs as parts of other CPCs.

Table 5-6. Numbers of ADP PQT Procedures and Reports by Functions and CPCs

Function or CPCs	Procedures	Reports
1. Radar Inputs	2	3
2. Active Tracking	1	3
3. Passive Tracking	2	4
4. Height	2	3
5. Positive Target Control	3	3
6. Identification	3	5
7. BOMARC Guidance	4	4
8. Manned Interceptor Guidance	4	4
9. BOMARC Prelaunch	2	2
10. TDLL	1	1
11. Air Defense Artillery	2	6
12. Information Transfer	6	6
13. Manual Inputs	2	2
14. Startover	1	0
15. Control	1	1
16. Recording	1	1
17. Simulation Information and Tape Read	3	3
18. Tabulation and Situation Displays	4	4
19. Weapons Assignment and Commitment	4	4
20. Weapons Illegal Switch Action	1	2
21. Surveillance Illegal Switch Action	1	2
22. Illegal Switch Actions	2	0
Totals	52	63

underwent a CDR and testing as parts of the CPCs utilizing them. A total of 32 CDRs were conducted. Those PQTs conducted in January, February, and March 1968 for CPCs which had previously undergone CDRs did not have CDRs a second time.

Although participants report that the CDR discussions did result in a number of actions, including design changes, essentially no actions are recorded in the CDR minutes. This circumstance is apparently a function of the fact that minutes were prepared only once, after the 18-month series of CDR increments was completed. One can guess that the record of actual events would have been better had the minutes also been prepared in corresponding increments.

For the ADP CPCEI, a total of 53 PQT Procedures documents and 63 Test Reports were published. The General PQT Procedures document was issued on 23 June 1966, with the balance issued during the remainder of 1966 and throughout 1967 and 1968. The earliest Test Reports were issued in October and November 1966, with the balance of the reports widely distributed throughout 1967 and the months of January, February, and March 1968.

The large number of Procedures documents (52) is due to the fact that for some functions several PQT procedures were prepared, as shown in Table 5-6. The table shows the number of Procedures documents issued for each function identified in the Part I specification. It should be noted that the Procedures and Test Reports do not match the functions in the Part I specification on a one-to-one basis in many cases, but are also related to CPCs. The table also shows the number of Test Reports (63) for the same functions or CPCs. In some cases there are more Reports than Procedures as a result of test re-runs.

SYSTEM EXERCISE PROGRAM (SEP)

According to the formal CDR Minutes for the BARS portion of SEP, PQTs/CDRs were conducted on the dates listed below. The number in parentheses shows the number of CPCs for which PQTs/CDRs were held on that date.

System Test Reduction Processor

11 December 1967 (3)	16 January 1968 (3)
12 December 1967 (4)	17 January 1968
13 December 1967	13 March 1968

Operational Processor

11 December 1967 (5)	13 March 1968
14 December 1967	14 March 1968
18 January 1968 (2)	

Exercise Processor

14 March 1968

Various materials were made available for use as necessary in accomplishing the CDR for each CPC. These included the Part I specification, a list of ADP items and tables used, and drafts of the Part II specification including programs listings, and users manuals. The list of items and tables used for each computer program or functional area was usually part of the PQT Procedures document.

For the SEP CPCEI, a total of 30 Procedures documents and 27 Test Reports were published. The General PQT Procedures document was issued on 23 November 1966. Others were issued over a six-month period from October 1967 to March 1968. The Test Reports were published in June, September, and December 1967, and in January and March 1968.

UTILITY COMPUTER PROGRAM (UCP)

For the UCP CPCEI, Table 5-7 shows the dates for the conduct of PQTs/CDRs, and the dates of issue of the PQT Procedures and Test Reports.* The SPO did not send representatives to the CDRs conducted in conjunction with the PQTs on 1 August and 30 July 1967.

Table 5-7. Dates of UCP PQTs and Basic Issues of Procedures and Reports

Functions	Procedures	PQTs/CDRs	Reports
JOVIAL	1 July 1967	1 Aug. 1967	1 Sept 1967
Adaptation Calculation (BAC)	30 June 1967	30 July 1967	30 Aug. 1967

* Out of a total of 67 UCP CPCs, only 8 underwent a PQT. These include 7 CPCs for the Compiler and 1 CPC for BAC.

8. Formal Qualification Test (FQTs)

As indicated in Figure 5-1, FQTs were performed only for the ADP and SEP contract end items. In both cases, FQTs were conducted in a number of separate parts, as identified in the list below. A separate FQT Procedures document and Test Report were written for each part.

AIR DEFENSE PROGRAM (ADP)

- Simulation Mode Test
- Interface Test
- Live Mode Test
- System Load Test

SYSTEM EXERCISE PROGRAM (SEP)

BEPS: Exercise Preparation System

BARS:
- Exercise Processor
- Operational Processor
- System Test Reduction Processor
- Subsystem Test Processor

The initial FQTs for all parts were conducted at the Category II site (BUIC Evaluation Facility (BEF), located at Hanscom Field, Massachusetts) during the period 2 April through 16 April 1968, with the exception that the Subsystem Test Processor had been FQT'd at the contractor's plant on 12-14 September 1967.

Because of a major deficiency relating to cycle time of the ADP, which had been known to exist at an earlier date but had not been overcome by the time of the April FQT, a complete re-run of the ADP FQT was scheduled and performed in December 1968 to verify corrections which had been accomplished by that time. The symbol shown for that month for ADP in Figure 5-1 represents this re-run.

Scheduled additional FQTs at future dates may also be noted in the chart. These represent (a) a major new version of ADP, with corresponding changes reflected in SEP components, to incorporate new operational capabilities beyond those for which requirements had been established earlier in Acquisition and (b) a scheduled updating of CPCEIs associated with turnover of BUIC III to the user.

9. Part II Specification

The Part II specification for each of the three CPCEIs was subdivided into an extensive set of volumes. Each had a first, General volume describing the design and structure of the CPCEI as a whole. Additional volumes were devoted to individual computer program components (CPCs), for the most part, although a few dealt with data or other special items such as the Compool Description, Constants, Adaptation, and Library.

The 30 CPCs of the ADP are listed in Table 5-8 as an example. The ADP specification contained 38 volumes in all, while there were 141 volumes for SEP and 66 for UCP. As a complete set, the Part II specifications for the three CPCEIs contain approximately 40,000 pages of computer program design documentation. Drafts of some volumes of the Part II specifications were issued as early as February 1967. Many of the drafts were revised and reissued as many as 3 or 4 times prior to the date of 15 April 1968, when all volumes for the three CPCEIs were delivered for review prior to FACI. The 15 April date, as shown in Figure 5-1, therefore represents the first "completion" date for the Part II specifications. However, they were still pre-FACI drafts at that time, rather than basic issues.

Potential problems of Part II specification timing in relation to FQT, FACI, and Category II testing had been recognized early in the program. In reaching a solution to these problems, account was also taken of the additional factors introduced by the on-going processing of changes. The solution adopted is outlined briefly below.

An artificial "freeze" of the computer program was instituted to reflect completion of the Part II specification drafts, shortly prior to their issue date of 15 April. This configuration represented Version 1 of each CPCEI, which was the version to be FACI'd. Subsequently, the drafts would be re-published as basic issues of the Part II specification--constituting the initial baselines, but would contain no updating or corrections other than those resulting from SPO comments at FACI. As time passed and the intervening events occurred, these basic issues were eventually completed (for ADP) in February 1969. Except for a few volumes, they had continued to reflect Version 1 in its frozen configuration.

However, changes continued to occur, in actuality, throughout that period. ECPs had been in process at the time of the freeze, and more changes resulted from FQT, Category II testing, and other causes. One major set of changes was introduced to overcome the cycle time problem (see next chapter) in ADP; and Version 7 of ADP underwent a second FQT to test those changes in December 1968. All changes through Version 7 were formally processed and issued, simultaneously with the basic issue, as product configuration baseline changes in February 1969. Thus, in effect, the initial product configuration baseline was established with the issuance of pre-FACI drafts.

Beyond the date of pre-FACI drafts, additional events depicted in Figure 5-1 represent: (a) completion of basic issues for SEP and UCP late in 1968; (b) the major updating of ADP in February 1969; and (c) a projected complete revision of all Part II specifications at the time of turnover to the user in April 1970.

10. First Article Configuration Inspection (FACI)

The first FACI events shown in Figure 5-1 represent the FACI which was accomplished on 20-24 May 1968, approximately a month following delivery of pre-FACI drafts of the Part II specifications, for all three CPCEIs. One element of SEP, the Subsystem Test Processor, which had previously undergone an in-plant FQT, had also passed an in-plant FACI in September 1967. FACI was completed at that time for all other elements of the CPCEIs, except for 5 volumes of the ADP specification dealing with CPCs which were undergoing known major changes associated with the cycle time problem. As a result, these were reserved for a subsequent FACI "increment" which was held following delivery of Version 7 (the Timing Version) of ADP in February 1969.

11. Category II Testing

The Category II tests for BUIC III were conducted at the BUIC Evaluation Facility (BEF), located at Hanscom Field, Massachusetts, during the 4-month period of 15 April to 15 August 1968. The BEF, which was created as an ESD/MITRE test facility at Hanscom, was configured as an operational BUIC III site. Following Category II tests, it was closed on 16 August, but was later re-opened for additional testing associated with BUIC III. This additional testing included the repetition, in December, of the Timing Version FQT for the ADP, except for the Live Mode Test which was conducted at operational site Z-10, North Truro, Massachusetts.

CHAPTER VI

DISCUSSION AND EVALUATION

A. GENERAL

1. Qualifying Factors

BUIC III has been referred to as a "test bed," in which the novel elements described in Section C of the preceding chapter are thought of as the experimental variables whose effects on the system program are being identified and evaluated. From that point of view, it is one purpose of this report to assess the degrees of success and failure associated with the BUIC III applications of those management techniques, and to evaluate them accordingly. However, it should be recognized that the mere presence of the requirements did not automatically insure that they all became effective influences in the program. In fact, there were circumstances and constraints operating throughout to preclude simple interpretations in terms of success or failure as judged against the stated requirements.

The very novelty of the requirements meant that many of their complex implications for planning and implementation were not readily understood and appreciated. Supplemental guidance, interpretations, and explanations to accompany the formal statements of the requirements were minimal or nonexistent; and there was a corresponding absence of experience upon which to base realistic planning. The detailed implementing solutions were worked out as the program progressed, with the net result that some of the requirements were actually implemented in much the way that might be expected; some tasks were relatively unaffected; and others managed to reflect varying degrees of compromise with tradition, or to take unique and unexpected forms.

The Category I Test Plans were outstanding products of that initial inexperience and confusion, as the first to be contended with among the many novel elements associated with Category I testing. The writers of the plans attempted to define the spectrum of requirements and planning factors for the computer program CEIs in fine detail. The Part I specification Sections 4 were written from the plans, rather than the reverse. Functions of the plan were not distinguished from those of PQT and FQT Procedures documents to follow; planning centered around functional elements of the Part I specifications was not clearly relatable to structural components of the computer programs; and the planning often tried to encompass the entire gamut of computer program test activities without regard to distinctions between internal development and formal testing aspects. The resulting bulk, detail, and misconceptions incorporated in these plans (for ADP and SEP) set the stage for many troubles which ensued in carrying out the Category I testing efforts (see Section E below).

The fact that BUIC III was a modification of BUIC II, rather than a new system, was a further factor which interfered with adopting some of the new techniques in their intended form. It was a general requirement in the program to utilize existing BUIC II content and materials as much as possible. Conceptual phase studies were limited, for the most part, to the new features; and there was no formal Definition phase. Additionally, it should be noted that the areas in which the new techniques were introduced -- namely, configuration management, data management and testing -- did not include system engineering management techniques drawn from AFSCM 375-5, with the relatively minor exception of design reviews. Yet, within the general framework of 375-series concepts, system engineering is recognized as the fundamental process upon which other techniques depend for their substantive content and execution.

At the time this report is written, various problems associated with adapting the 375-5 principles to data processing elements of systems still remain to be explored and resolved. In BUIC III, the system engineering accomplished was necessarily of an ad hoc and traditional nature -- which meant that it was a combination of systematic analysis, trial-and-error explorations, and previous experience, with the technical emphasis naturally devoted to areas which had proved to be important or troublesome in earlier systems.

The problems encountered with cycle time of the operational computer program (see Section F below) can be largely attributed to the combined effects of these various factors -- i.e., limited Conceptual phase, no Definition phase, dependence on BUIC II precedent, and associated absence of system engineering analyses which were sufficiently comprehensive to detect a potential timing problem at early points in the system life-cycle. In fact, the effects of these factors were noticeable throughout the Part I specifications. Organization, style, and content of the BUIC III Part I specifications were basically patterned after their "ops spec" predecessors, even though they carried the new titles and formats dictated by the Form 9.

2. Program Overview

Discussions of the specifications, testing, configuration control, and other individual topics are to be provided in subsequent sections of this chapter. Before discussing those topics individually, however, attention is directed briefly in this section to the series of events as a whole, based on their sequencing during the Acquisition phase as depicted in Figure 5-1 of the preceding chapter.

Certain general impressions of the total program can be gained by examining the actual BUIC III sequence of milestones in the light of expectations based on 375-series systems management concepts. The chart may be compared, in particular, with the model "road maps" contained in ESD TR 68-1 for the computer program system segment, as they were adapted from such sources as AFSCM 375-4 and 375-5.

The timing of events during the first year of Acquisition appears to fit fairly well the pattern one might expect from a system program having no Definition phase. That is, ignoring a few delays in particular parts of the items, (a) the System Specification initiated both the development of Part I specifications and preliminary design of the CEIs, (b) the Category I Test Plans were closely related in time to the Part I specifications, (c) the PDRs were held at the completion of preliminary designs, and (d) the System Specification underwent a major update and expansion as a result of the Part I specification development efforts.

One would not normally expect to see PQTs held on so many occasions as they were for both the ADP and SEP CEIs. In BUIC III, the time and effort expended on PQTs were not only greater than expected, but were also far more costly than the results justified. The problems generated by this abnormal (one hopes) PQT program are discussed at length in section E below.

The timing of FQTs, at their first appearance immediately preceding the initiation of Category II tests, may be considered normal for operational computer programs, although it would be later than normal for equipment items. However, the continued appearance of FQTs over a time span of one and one-half years after the completion of Category II testing is a surprising circumstance for any type of contract end item. These continuations are identified as arising from two types of causes: (a) the necessity to re-run FQT as a result of deficiencies in meeting the original requirements; and (b) the need to verify follow-on versions of the original CEIs, containing changes to meet extensive new requirements. Again, the questions associated with this and other aspects of the Category I test program are discussed further in Section E below.

The timing of Part II specifications and FACI occurred largely as planned in relation to the initial FQT and Category II test events, except for (a) a change package containing major revisions of the Part II specifications for ADP associated with the deficiency noted above, and (b) a delayed "increment" of FACI for ADP associated with the same deficiency. The chart also depicts a planned future revision and reissue of the specifications, occasioned by turnover of the system to the using command.

At the most general level, it seems worthy of some note that the events shown were actually incorporated in the program and accomplished. While they may now be taken for granted in the light of the past few years' experience, it may be remembered that not one of the subsystem-level milestones listed in the chart had appeared in information processing system programs prior to BUIC III. Collectively, they reflect a significant trend towards increased visibility of elements in the computer programming process, in the direction of permitting SPOs to assume increasingly active roles in the management of computer program acquisitions.

B. SPECIFICATIONS

1. Part I Specifications

The influence of some of the factors mentioned in the preceding section, affecting the degree to which formal requirements were actually implemented in BUIC III, was most noticeable in items produced at early points in the program. Thus, while a considerable effort was devoted at a later time to developing Part II specifications which would conform to the full intent of the Form 9, the Part I specifications retained the flavor and much of the content of their BUIC II predecessors, the operational specifications.

The operational specifications had relied heavily on narrative description of system organization and operations. Much of their content was informational, rather than being written in the mandatory language of a "design-to" specification. In some ways they were as much reports of the analysis/definition process as they were specifications in a legal sense. For example, they contained "scenarios" of system data processing operations which often included human operator actions. While such scenarios are useful system engineering devices associated with the process of analyzing and identifying functional detail, and constitute levels of description which are readily understood by a user, they do not tend to provide unequivocal definitions of the computer program CEI requirements.

In effect, the BUIC III Part I specifications were transitional documents. They contained new sections/subparagraphs conforming to the Form 9 in such areas as interfaces, inputs and outputs, data base, human performance, and quality assurance, although not to the extent of resolving a variety of questions regarding the ways in which some of those topics should be treated. The comments below indicate types of problems which have been encountered in the course of developing Part I specifications for other systems, e.g., SEEK DAWN, as well as in BUIC III.

a. The level of information to be specified in the Part I is relatively well defined by the Form 9 (ESD 236) in some areas, e.g., input and output messages, but is subject to a wide range of interpretation in others. The inclusion in any Part I specifications of many mathematical formulas and equations has been questioned specifically, where they might be regarded as being design solutions rather than performance requirements as such. The BUIC III Part I's contained many of these, most of them being solutions which were known as a result of BUIC II design or because BUIC III design was being carried out concurrently with the writing of the Part I specification. Many were necessarily incorporated as design requirements, since they had been previously spelled out at that level in the System Specification, also because of known BUIC II design. Otherwise, and with reservations noted elsewhere, the level of detail represented in BUIC III is considered appropriate and necessary for adequate definition of CPCEI performance characteristics -- that is, for the Part I specifications in their completed form. Generally, much of the required information would not be available for completing the specifications at that level by the end of a Contract Definition Phase effort.

b. Information called for under paragraph 3.1.3, "Data Base Requirements," in the Form 9 is relatively clear as regards level of detail, but the types of data to be specified have proved to be continuing matters of debate. The ADP specification in BUIC III confined its coverage to adaptation data, which are specifically called out in the Form 9. Many other types of data were specified, but under the various functional elements rather than under the data base paragraph. They included computational constants, weather data, radar inputs, weapons characteristics, and others, some representing data resulting at intermediate stages of processing. Different solutions have been proposed in various subsequent cases, ranging from the limited treatment exemplified by BUIC III to the extreme position, as in the SEEK DAWN/818, that the data base paragraph should encompass all items in the computer which contain data values as distinct from computer instructions. However, the merits of these different solutions seem to involve a variety of technical and management considerations which need to be further explored. The general problem is apparently more complicated in the real-time air defense context than it would be for some other types of systems, e.g., 473L, in which the computer programs function principally to retrieve information from a massive data base.

c. Questions have also been raised as to whether the Part I specification should be structured to permit, or require, the computer program to be designed with components (CPCs) having a one-to-one correspondence with the Part I functional elements. Currently, one-to-one correspondence is not a requirement, for the reason that it would likely in many cases restrict the freedom to strive for maximum efficiencies in computer program design. However, the absence of correspondence also creates some problems. In BUIC III, the most noticeable difficulties were in the testing area. In cases where CPCs, or groups of CPCs, were not directly identified with given elements of the Part I specification, complications were met in the planning, technical preparation, and conduct of performance testing. In writing the Part I specification for SEEK DAWN/818, a related problem was encountered in specifying inputs and outputs for the functional elements, as required under 3.1.2.1. Inputs and outputs of the CPCEI as a whole are necessarily the same at the Part I and II levels, but the internal inputs and outputs are another matter. The task of defining all of those is a formidable one, in itself, and it can prove to be of dubious value where the functional elements undergo rearrangements in the course of computer program design. While a matrix can be constructed (as it normally is) to depict the allocation of functional elements to CPCs, a similar matrix relating internal inputs and outputs as between the Part I and Part II levels becomes far more complex. To illustrate, using the BUIC III ADP numbers of 15 functional elements and 30 CPCs, there can be 105* <u>sets</u> of input-output relations among functional elements to keep track of. To the degree that re-structuring occurs, many of these would not be included within the 435 sets (i.e., maximum possible) of inter-CPC inputs and outputs, since some number of functional element inputs/outputs would be contained inside CPCs. Hence, many are lost, many are scrambled, and many more new inputs and outputs appear which are not identified as such at the Part I level. In the real case, considerable complications are added by such factors as variability of inputs and interactions among components. The net result is to pose problems of design and development which may not be clearly soluble, as well as to complicate the testing of individual functional elements. Testing of the integrated

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* That is, for <u>K</u> elements in general, there can be as many as K (K-1)/2 non-duplicated sets of input/output interface relations.

CPCEI should not be affected, however, since the identities of external inputs and outputs are presumably maintained intact.

d. The proper content to include under the human performance paragraph 3.1.4 has also been a subject of frequent discussion. A "model" treatment of this topic has not yet appeared among the Part I specifications for BUIC III and the Southeast Asia systems. A deliberate attempt which was made in SEEK DAWN/818 did result in a few examples of appropriate material. The examples were necessarily limited and to some degree artificial, however, as a result of having to be formulated after the designs of both computer program and equipment operating stations were completed. It has been observed that the proper content of the human performance paragraph in a computer program Part I specification is not directly analogous to what it would be for equipment items. In the case of equipment, it consists largely of requirements, e.g., as set forth in MIL-STD-803, which govern subsequent engineering design with respect to workspace layouts, noise and illumination factors, and display/control elements. For computer programs, the relevant display, control, and functional requirements associated with efficient man-machine design must be incorporated into the detail contained within the Part I specification itself; the computer programmer has no freedom later to affect those solutions. Thus, if the necessary human engineering design is to be accomplished at all, it must be done as an integral part of the system engineering effort leading to the Part I specification. As yet, in the systems referred to, there have been no structured Conceptual and Definition phases which might have provided opportunities for that kind of systematic development; and much of the process, which one might expect to be analogous to the AFSCM 375-5 model except for significant modifications appropriate to the data processing context, remains to be explored in a realistic setting. The new system programs which do have Definition phases should provide additional experience in this area.

2. <u>Part II Specifications</u>

Requisite information to be contained in the Part II specifications for the BUIC III CPCEIs was identified by the Form 9, ESD 237, together with back-up sheets. SDC, early in the development effort of the BUIC III computer programs prepared and submitted to the SPO an example Part II volume portraying the level of information that was planned. The example served as the basis for arriving at mutual agreement with regard to the volume structure and level of information content of the Part IIs. The agreements, however, did not prevent difficulties which subsequently arose. The following discussion treats the significant aspects of the Part IIs based on SDC's experience. The discussion concentrates on the Part II volumes for ADP since differences peculiar to the Part IIs for SEP and UCP are not regarded as being of sufficient significance to warrant explicit treatment.

The Form 9 permits structuring the Part II specifications into multiple volumes. This was done for BUIC III and done quite satisfactorily. Volumes 1 through 8 contain information essential to programming tasks performed following initial program development (e.g., effecting program changes, adapting the computer program to unique environments). This phase is normally referred to as the program maintenance phase. No unusual difficulty has been noted in reference to these volumes.

By contrast, the content of the computer program component-oriented Part II volumes has provoked some discussion and concern. Most significant are the following:

a. Description

b. Flow Charts

c. Interface

d. Limitations

e. CPC Data Organization

In this context, it should be noted that the format and content of these CPC-oriented Part II volumes are intended to satisfy the requirements established by paragraph 3.2.1 of the Form 9. The requirements demand a brief abstract of the functions of the CPC, the languages in which it is written, and its major interfaces; additionally, the requirement states that the CPC shall be described in detail in subparagraphs. It is this last requirement that bears discussion with regard to Chapter 1, Description, and Chapter 2, Flow Chart, of the CPC Part IIs which correspond to subparagraphs 3.2.1.1 and 3.2.1.2 of the Form 9.

An examination of Part II volumes reveals that the presentation of descriptive detail contained in Chapter 1, Description, varies from one volume to another. This is to be expected considering the varying complexity of the CPCs and the varying ability of the programmers to describe the CPCs in narrative prose.

However, the point to be made here is simply that the value of much of the detail was sufficiently diminished by poor writing that the presumed purpose of the description was not satisfied. That is, that the primary subsequent function of the description is to convey an understanding of the operations performed by the subject CPC to a programmer who has responsibility for effecting changes and corrections to the CPC in the maintenance phase.

A similar comment applies to the level of detail presented in Chapter 2, Flow Chart. It is suggested that this information should also be at a level of detail describing the operations performed by the CPC, the sequence in which they are performed, and graphically portray the CPC in sufficient detail to enable a programmer to ascertain which region of the CPC performs which operationa. Thus, the flow chart should provide the programmer with an entree into the program as given in the CPC listing.

Although substantial opinion favors flow charts with gross detail, or no flow charts at all, carefully conceived requirements may demand detailed flow charts. If such is the case, alternative means of obtaining or satisfying the requirement should be examined. The possibility of obtaining the flow charts by means of an automated flow chart system (i.e., a special purpose computer program) is certainly worth considering. Another possibility could be the substitution of a form of logic flow table instead of flow charts. The significant advantages of either of these approaches must lie in the ease and resultant economy with which they may be employed both in the initial preparation of the flow charts (or substitute) and their subsequent modification or updating.

An automatic flow charting capability was considered in the BUIC III development. However, because of development costs and other factors including the detail of flow charts, the proposed capability was not deemed to have significant advantages over manual preparation and it was therefore rejected. This does not invalidate the concept as a potential approach for other computer program systems; it remains a possibility worth considering. In essence, each CPC is described three times within the Part II CPC volume: 1) prose; 2) flow chart; 3) listing.

The reason for concern with regard to the level of detail presented in the CPC prose description and flow chart is not only the effort necessary to initially prepare the prose and flows, but the effort that must be expended to keep them current. A typical schedule for initial Part IIs might be as follows:

1) 60 days devoted to preparation of prose and flow charts by programmers

2) 30 days for final typing, publication and delivery to SPO

3) 30 days for SPO examination preparatory to FACI.

Program development consisting of coding and testing is normally underway concurrent with the preparation of the Part IIs. Moreover, both tasks are performed by the same programmers. Consequently, the level of detail presented in the prose and flows can be of considerable significance since programmers often do not firm the fine details of program design until coding and initial testing has been done. If the fine detail must be firmed 120 days prior to FACI, it may impose undue constraints on the program development process continuing to FACI. It is recognized that this argument is not always true; difficulties can be minimized if sufficient allowance is made in the schedule for this task, but fine detail can be costly. Furthermore, experience has shown that command and control systems typically undergo considerable change after initial development. The changes may be necessitated to correct program errors, remedy design deficiencies, or to implement new requirements. Consequently, the greater the detail in the prose and flows, the more likely they will need to be changed to maintain identity with the computer program as the computer program undergoes change. Obviously, the cost must be evaluated against the benefits to be derived.

Accordingly, the prose can describe in normal English such information as the operational tasks of the CPC, timing considerations, spares considerations, and unique or unusual aspects of the CPC design; the flow chart can identify the region of the CPC that performs each operational task; and lastly, the listing represents the actual configuration of the CPC accurately, identically, and completely. The prose and the flow chart then complement one another and provide a means of informing a programmer of the unique algorithms implemented by the computer program as well as where in the listing he should look for detailed information. Ultimately, it is the listing to which a programmer must look in order to find exact information of how the CPC performs its operations in terms of actual machine instructions.

The chapter on interfaces in the BUIC III Part II CPC-oriented volumes, corresponds to subparagraph 3.2.1.3 of the Form 9. These chapters did not, by themselves, satisfy the interface requirements. Since this was a subject pursued at some length in the FACI meeting conducted in May 1968, it is evident that mutual understanding by all responsible parties had not been previously attained. The question was essentially whether or not the interface requirements had to be treated in detail within each CPC volume such that each volume would be self-contained, or if the interface requirements could be satisfied by reference to other Part II volumes containing the desired information. The former approach would have included all interface information relevant to each CPC in the individual CPC volumes. This would have entailed extensive duplication of information in the Part IIs as a whole which would not have particularly enhanced their value. Final resolution of this question was obtained by agreement that references would suffice. That is, the desired information was contained in Part II volumes such as Volume 4, Compool and Layout, Volume 3, Compool Description, and Volume 7, System Item Set/Use Matrix; additionally, other CPC volumes describing subroutines are referenced as necessary.

The approach taken in resolution of the question appears to be very satisfactory and reasonable. The required interface information is contained in the Part II specification in a form that can be readily understood by competent programmers. It had been suggested that inclusion of the interface detail in the CPC volumes would have benefitted inexperienced programmers charged with the responsibility of program maintenance. This argument is not necessarily valid; in the case of BUIC III even inexperienced programmers will need to know how to use Compool Description (Volume 3), set/use listings, and the like in order to fulfill their responsibilities. Thus, the interface requirements were satisfied by the special purpose volumes in conjunction with the CPC volumes.

Of greatest significance with respect to the BUIC III Part II specifications is the question, "How much of what was prepared is necessary and useful?". It was the consensus of contractor personnel that the net result of following Form 9 requirements to the letter was a level of detail below that which would be useful, and that subsequent specification maintenance at that level would prove to be impractical.

This experience points up the need for good judgment in determing a proper level of detail to be required for the Part II specification. In general the two important objectives to be kept in mind are (a) its function as an instrument for configuration control and (b) its use by computer programmers as an aid in diagnosing malfunctions and designing modifications. Since configuration control needs are met most directly by the actual listings, the prose and flow chart requirements should be directed towards attaining that level of description which will be adequate to convey an understanding of the design rationale, nature of design solutions, and the flow of information.

The appropriate level of detail can be expected to vary for different computer programs and systems, as a function of such factors as computer program nature and complexity, expected frequency and magnitude of later design changes, and provisions for operational phase computer programming support and specification maintenance. In the usual case, it is believed that the minimum detail required to accomplish the purposes outlined above should also be viewed as a desirable maximum, since the expense of not only producing the specification initially, but of maintaining it later, increases significantly as additional detail is incorporated, particularly in the flow diagrams.

C. SPECIFICATION CHANGES

It was pointed out in the preceding chapter that procedures for controlling changes to the specifications had been developed and applied during the earlier SAGE and BUIC II programs. As regards visibility by the SPO Configuration Control Board (CCB), the earlier procedures had not involved formal processing of changes at the Part II level, but had been confined to the Part I (former "ops spec") level. However, experience with the earlier procedures had created a sufficiently firm base that the BUIC III configuration control and specification maintenance processes were handled efficiently, with relatively minor difficulties.

Changes were initiated by issuance of a Preliminary Engineering Change Proposal (PECP) to the CPCEI specification(s) involved. In cases where the System Specification was affected, a PECP was accompanied by a Specification Change Notice (SCN) to the System Specification, but not by SCNs containing proposed word changes to the CPCEI specification(s). Instead, the PECP described the change in sufficient detail to provide a basis for SPO review, approval, and contractual authorization. Following approval, the precise word and/or data changes were then developed and incorporated into specification change pages which were subsequently issued with covering SCN and formal ECP.* The volume of change pages was such that they were normally issued periodically in packages, each package reflecting changes resulting from a number of ECPs and CRs (Change Reports, for Class II changes).

Following the history of their predecessors in SAGE and BUIC II, the BUIC III computer programs were controlled primarily in terms of changes which were processed at the design requirements level, both before and after establishing product configuration baselines. Class I changes to the Part II specification only were limited to a few instances in which formal changes were processed to cover recompiling of the computer program instructions.

BUIC III also followed well-established precedent in being characterized by frequent and extensive changes to the computer programs throughout Acquisition.

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* The process described here represents a basic aspect of configuration control for computer programs as embodied in ESD Exhibit EST-1, which departs significantly from the accepted change processing practice for items of equipment. Contractual authorization is necessary prior to the issuance of SCNs for the reason that the costs associated with computer program changes are totally matters of R&D, unaffected by such factors as production and logistic support. Costs of issuing exact changes to the Part I specification are normally appreciable; once the product baseline has been established, the total cost of implementing the change must have been incurred by the time all specification changes are completed.

Tables 6-1 and 6-2 below list the numbers of Class I and Class II changes, respectively, which occurred in the Part I specifications during the period March 1966 through December 1968. Changes affecting the Part II specifications only, which occurred after product configuration baselines were established (effectively, April 1968), are summarized in Table 6-3.

Change page packages to the Part I specifications were issued at average intervals of about 6 weeks between May 1966 and November 1968. Figures indicating the volume of changes pages for two of the CPCEIs, ADP and SEP, during that period are listed in Table 6-4. For comparison, the table also lists the initial and ending (November 1968) numbers of pages contained in the specifications. Data relating to how much of the material on the pages was changed, or on what per cent of the pages were actually affected, are not available. However, it may be noted that the new raw numbers are large enough that each of the original specification pages might have been replaced more than twice, during Acquisition.

The reasons for changes were naturally many and varied. Also, the requirements for changes originated from a number of sources other than the contractor. While the information is not complete, sources are often identified in the "ECP Detailed Status Summary Forms" which were contained in periodic configuration management reports, giving descriptions and detailed status summaries for each ECP. These included NORAD, ADC, MITRE, Burroughs, and the SPO. In all, nearly 50% were positively identified as originating from such sources, largely based on needs arising from changes in interfacing equipment and systems.

Table 6-1. ECPs to the Part I Specifications

Computer Program	1966	1967	1968
ADP	46	6	17
SEP	26	2	1
UCP	15	2	1
Totals	87	10	19 = 116

Table 6-2. Change Reports (CRs) for the Part I Specifications

Computer Program	1966	1967	1968
ADP	37	42	42
SEP	24	63	15
UCP	5	9	2
Totals	66	114	59 = 239

Table 6-3. Part II Specification Change - 1968

Computer Program	ECPs	CRs
ADP	1	305
SEP	2	167
UCP	1	46
Totals	4	518

Table 6-4. ADP and SEP Part I Specifications:
Number of Pages vs. Change Pages

Computer Program	1966	1968	Change Pages
ADP	2192	2046	5762
SEP	898	866	2682

D. DESIGN REVIEWS AND FACI

1. Preliminary Design Review

The Preliminary Design Reviews for the three BUIC III CPCEIs, ADP, SEP, and UCP, are most noteworthy in that the meetings did achieve their purpose; a formal technical review of the proposed basic design approach was satisfactorily accomplished. For each CPCEI, the documented preliminary design presented information necessary to the conduct of the formal review. The information included a brief review of the interfaces identified in the Part I Specifications, a discussion of timing, a concise description of the CPCs, storage allocation, and other information pertinent to the computer program design. This was essentially in accordance with system management guidelines contained in EST-1 and, more recently, EST-3.

The ADP PDR was significant in that it led to the subsequent cycle time analysis. The expected cycle time given in the preliminary design exceeded the minimum specified in the Part I Specification. Since the input/output table size was predicated on the specified minimum time, a determination was made that the I/O table design should be reconsidered to make more efficient utilization of the output capabilities. The ensuing analysis revealed the cycle time problem.

Also of interest is the fact that, contrary to the understanding obtained at the ADP PDR, JOVIAL was not used as projected for the development of ADP. It was intended that new CPCs or rewritten BUIC II CPCs be written in the JOVIAL computer program language. Subsequent efforts revealed that the expansion factor prohibited the use of JOVIAL; code written in JOVIAL could not remain within the storage constraints. Consequently, a decision was made to forego JOVIAL for ADP and use machine language instead.

Thus, it is evident that the PDR served as the stage for involving the SPO/MITRE monitors in the decision-making process with respect to significant aspects of CPCEI program design. The design agreed to at the PDRs facilitated mutual understanding by SDC and SPO/MITRE of the problems and their solutions in the computer program development that followed the PDR.

2. Critical Design Review (CDR)

As described at an earlier point (Chapter V), CDRs were scheduled and held incrementally, and for the most part in conjunction with preliminary qualification testing. While there were some discrepancies associated with the functional emphasis of PQTs as opposed to the computer program component (CPC) emphasis of CDRs, the reviews were generally concerned with design documentation for the elements undergoing test. Hence, the reviews were held at the level of completed design for those elements.

Despite their close association with PQTs, however, and in contrast with the PQT experience (see Section F below), there is a notable absence of reports of difficulty, resulting changes, or other action items related to the conduct of CDRs. In general, the CDRs occasioned very little concern or comment.

On the whole, these BUIC III CDRs did not appear to involve elements which were particularly novel as compared with prior practice. They were often attended by SPO representatives, and typically included presentations of the design, functions, timing, size, and interface characteristics of the CPC(s) being reviewed. However, beyond the point of providing visibility of technical progress, the purposes apparently did not extend to reaching significant decisions with regard to the development cycle of the computer programs involved. This is perhaps not an unexpected circumstance, considering that the designs were already complete at the time of reviews.

In Exhibits EST-1 and EST-3, the emphasis is placed on CDRs which are held "at the level of flow charts or computer program logical design prior to coding and testing." At that level, the stated formal objective is to identify the design documentation which will be released for coding and testing. Experience on computer program CDRs in that category is not available from BUIC III or other system programs with which the authors have been associated. However, computer programmers have volunteered firm opinions to the effect that it would not have been feasible to accomplish the stated objectives of a CDR at that level for a CPCEI as complex as the ADP. Comments are made that: the design which initiates coding must remain flexible during the coding process; exact interfaces among CPCs are not visible for review on an incremental basis; and the ability to conduct such reviews in a meaningful and adequate fashion would require significantly greater technical resources than the SPOs have typically had at their disposal.

While the interim design level (i.e., at flow charts) is given the primary emphasis, it is to be noted that EST-1 does provide a range of options which is broad enough to cover the BUIC III application.* Judging from the comments which have been made, and the fact that they did not contribute additional problems, it may be fortunate that the CDRs were handled as they were, in BUIC III.

3. First Article Configuration Inspection (FACI)

The first Article Configuration Inspection of the three CPCEIs was essentially accomplished in May 1968. The FACI was noteworthy in that there was very little precedent for conducting such an inspection for computer program items in accordance with recognized system management concepts.** While the FACI

* ESD Exhibit EST-1, Section H, p. 40-13.

** As noted elsewhere, one element of SEP had been FACI'd in September of the preceding year.

did not proceed without some problems, the nature of the problems did not pose severe obstacles and they were resolved to the mutual satisfaction of the participants. The objectives of the FACI were achieved; the Part II specifications were audited and approved with the qualification that revisions based on SPO comments be incorporated in the basic issues of the Part IIs which were due to be published by 1 February 1969. With SPO approval, the Part IIs were recognized as the instruments defining the product configuration baseline for the respective CPCEIs. For practical purposes, however, the baseline had been established in the preceding month, April, at the onset of Formal Qualification Tests. Formal control was maintained of all changes to the draft Part II specifications which had been issued describing those FQT configurations.

FACI was preceded by FQT and followed by Category II testing. This relative timing is reasonable and conforms to established concepts. However, certain deviations did occur as a result of the known cycle time deficiency in ADP. Although an approach to correct the deficiency had been agreed upon and approved, its implementation had not been completed prior to FQT and FACI. Since the corrections entailed extensive changes and recompilation of five computer program components, SDC and SPO/MITRE agreed to defer the FACI audit of the Part II volumes for those five CPCs. The audit of those five CPC volumes was then performed in February 1969 after implementation of the cycle time changes, thus concluding the FACI. An unusual aspect of those five volumes is that the basic issues include Specification Change Notices for ECPs and CRs that were processed against previous draft Part II volumes of the five subject CPCs.

The contrast of the approach taken to the FACI meetings for BUIC III and SEEK DAWN Interface Computer Program (SDICP) is interesting. In both cases, draft copies of the Part II specifications were delivered to the SPO in advance of the FACI meetings; BUIC III drafts were delivered approximately 30 days before FACI; SDICP drafts were delivered approximately 90 days before FACI. Whereas the detailed review of the BUIC III Part IIs was performed at the FACI meeting, the review of SDICP Part IIs was essentially done prior to the meeting. In the latter case, SPO/MITRE comments were sent to SDC so that mutual agreement had been substantially obtained before the FACI meeting. The meeting thus served to confirm understandings that had already been reached and to resolve those few questions that had not been completely resolved earlier.

The difference in approach is of interest since the one week FACI meeting for BUIC III (disregarding the second meeting for the five deferred CPCs) permitted only a superficial examination of the Part II specifications. It is highly likely that a more comprehensive examination of the BUIC III Part IIs would have revealed many more discrepancies among the CPC descriptions, flow charts, and listings. Depending on the bulk of the Part II specifications, available SPO technical resources, and other relevant factors, the SDICP approach may be the more desirable one in conducting FACI on other CPCEIs.

The prospect of a FACI, and resulting formal control at the level of product configuration, was viewed in advance with some apprehension. While procedures for computer program control and accounting had been in effect for systems preceding BUIC III, they were developed and used internally by the contractor, had been largely confined to control of computer program listings, and had not been carried out under the formal label of configuration management. However, with minor exceptions, anticipated difficulties did not materialize.

There were two areas of potential difficulty which deserve mention. The first related to detailed flow charts for CPCs. which proved to be expensive and time-consuming to maintain in the draft Part II specifications during a period of some months preceding FACI. The possible continuing impact of this problem was avoided, following FACI, by a SPO-approved change which eliminated the CPC-level flow charts from the specification.

A temporary problem arose in the course of Category II testing, relating to a proposed requirement for a new Version Description Document to cover each daily change made in connection with the test activities. The question of what constitutes a "new version" is not unequivocally defined, and disagreements occurred on the point among personnel of the SPO, contractor, and test team. It developed that the real issue was more a matter of test philosophy than of control procedures, and working solutions were reached following a week or two of discussion.

However, the BUIC III experience as a whole has provided clear evidence that the configuration control and accounting procedures which had been adapted for computer programs were remarkably efficient. Some data relating to rates of changes were presented in the preceding section of this chapter. Following FACI, control was extended to cover the computer programs and Part II specifications, and was maintained routinely under complex circumstances. In practice, situations arose in which as many as three versions of the Air Defense Program were in existence or under development at one time, each differing significantly from the others with respect to incorporation of approved changes and scheduled introduction into test or operational use. The process included, for example, accounting for Class II error corrections made to a given version which were either applicable to succeeding versions or not applicable because of superseding Class I changes, and also involved keeping track of change relations with other computer programs, support documentation as well as specifications, and items of system equipment. Under these conditions, control was maintained at all times and with relatively minor difficulties. Considering the frequency and volume of changes implemented, it seems clear that the BUIC III experience has also demonstrated that post-FACI control need not seriously impair the flexibility with which computer programs can be altered to accomplish desired changes in system functions.

E. CATEGORY I TEST PROGRAM

When the Category I test requirements were introduced at the outset of the BUIC III program, they were generally viewed as innovations which would have the primary effect of merely formalizing various aspects of the "normal" test process. Computer program test and evaluation (CPT&E), although introduced for the first time as a new term, was readily recognized as an inherent and familiar part of computer program development. It was not immediately obvious in advance that the addition of a few preliminary and formal qualification test sessions would significantly affect the total computer program acquisition job to be accomplished. Nevertheless, Category I testing proved to be an expensive and troublesome area throughout the BUIC III effort, in essentially all of its various aspects.

The record indicates, as reviewed in the preceding chapter, that the Category I test milestones--in the form of PQTs and FQTs and their various associated documents--were actually accomplished during the program. This achievement now seems a remarkable one, at face value, although it is conceded to have been made possible only by the fact that the system schedule slipped appreciably, for independent reasons, during the critical periods. Throughout, difficulties and complexities were faced by SPO and contractor personnel in interpreting, coordinating, and implementing the many requirements. In fact, the effect of resulting confusions and misinterpretations among personnel involved in the program was so pervasive that an unbiased and factual account of the problem is difficult to reconstruct on the basis of available records and verbal reports.

Preliminary qualification testing of the ADP is the specific area in which troubles are universally reported as being most important and acute. As outlined earlier, a total of 35 PQT sessions were conducted on 19 different dates during the 15-month period of September 1966 to February 1968. Associated with these 35 PQTs were 53 PQT Procedures documents and 63 Test Reports. Although the reasons for these discrepancies are not all accounted for, it appears that some PQTs had multiple objectives for which separate procedures were written, some PQTs failed and had to be re-run, some of the reports had to be re-written, and a few scheduled PQTs were never accomplished.

The objective established for PQTs in the Category I Test Plan was to verify approximately 2500 "reactions" of the computer program in conformance with detailed requirements which had been set forth in the Part I specification. PQTs were planned, as a complete set, to provide comprehensive coverage of nearly the whole of the Section 3 requirements for the ADP CEI. As later described by contractor participants, some (i.e., most) of the PQT sessions were planned, rehearsed in advance, and then conducted as "demonstrations," in effect, for the benefit of visiting SPO personnel. These were generally successfull, but were also time-consuming and more costly in manpower than had been anticipated. Others were prepared but not rehearsed, and were actually run in conformance with the written procedures for the first time during the formal PQT meeting. These were more in the nature of true "tests" but they often failed and had to be re-run at subsequent times. The program as a whole is reported to have caused cost overruns and difficulties in meeting schedules, as well as significant morale problems among many computer programmers, who came to regard the PQT requirements as monstrous and artificial barriers to their progress towards completing the ADP development task.

The 35 PQTs which were carried out did manage, in one way or another, to result nevertheless in formal verification of all but 450 of the original 2500 reactions prior to the beginning of FQT and Category II testing. Of those, all but 110 were subsequently verified at the Category II site, and the remaining few were eventually waived.

Essentially the same problems were encountered in PQTs for the system exercising CPCEI (SEP), although the totals of events and documents were slightly less numerous: 24 PQTs, 30 Procedures documents, and 27 Test Reports. In the utility area (UCP), qualification testing for the entire CPCEI was confined to one "PQT" for each of two (out of a total of 25) of the elements: except for these two tests, the entire CPCEI was qualified in relatively painless fashion through its use in supporting the Acquisition phase development of ADP and SEP.

The formal qualification tests (FQTs) for ADP and SEP were held, as noted earlier, in a number of separate test sessions in each case. For SEP, the FQT was "incremental," in the sense that the total consisted of separate test sessions for each of the major elements of the CPCEI, each having a separate associated plan, procedures, and report. This arrangement was made possible by the fact that those major elements of the CPCEI represent capabilities which can operate independently. In the case of ADP, four separate FQT sessions were run to examine separate aspects of the performance of the integrated CPCEI.*

The Procedures documents for FQTs posed additional difficulties which had not been typical of PQTs. Whereas PQT Procedures had been delivered only for SPO review, normally about 30 days in advance of a scheduled test, the FQT Procedures were required a minimum of 90 days in advance for review, approval, and revision based on SPO comments. The records indicate that initial drafts of some of the FQT Procedures for ADP were revised and reissued as often as five times before being accepted, because of various problems involving conformance to the Form 9, the style of presentation, and technical adequacy. This, as in the conduct of PQTs, was an area in which the project personnel encountered an unexpectedly firm insistence by the SPO on rigorous adherence to the requirements, and in which inevitable difficulties resulted from a

* For both ADP and SEP, all test sessions were run on an identical configuration of the CPCEI.

general absence of adequate guidance and experience. However, the necessary experience was acquired in the course of this troublesome process, to the degree that a subsequent FQT (see below) was documented and accomplished with significantly fewer perturbations.

The FQT for the first version of the ADP was accomplished immediately prior to Category II testing, at the Category II site. This timing and location had been anticipated from the outset of the program, based on a variety of considerations which have been recognized as being generally pertinent to the qualification of such complex operational computer programs as the ADP.* However, as was noted in the preceding chapter, a second FQT was performed (the Timing Version) approximately four months following the completion of Category II testing, and a third and fourth are planned for additional follow-on versions which are under development and scheduled for delivery at future dates. The initial version of ADP which underwent FQT prior to Category II testing contained a cycle-time deficiency. Interim corrections were devised for Category II use, and the deficiency was removed fully in the Timing Version, for which FQT was then repeated. Thus, one might assume that qualification of the CPCEI had been accomplished by that point in time. Yet, future FQTs are being planned for the follow-on versions.**

While the continued repetition of FQTs is apparently not regarded with any particular concern by either the SPO or contractor, it does suggest that there are certain questions regarding the philosophy of qualification as applied to computer program contract end items which remain to be clarified. Judging from SAGE/BUIC II precedents, the ADP can be expected to undergo continuing changes which will probably occasion periodic new versions at the rate of three or four per year, each containing additional, altered, and/or deleted capabilities as compared with the version being replaced. In SAGE, each new version is subjected to formal tests which are comparable in scope and level to the "FQTs" planned for follow-on Acquisition phase versions of the BUIC III ADP. These SAGE tests, however, which are actually conducted by the using command prior to introducing each new version into operational use, are known as "acceptance" tests. One might question the application of either term, acceptance or qualification, to such tests -- considering that "qualification" is normally confined to an initial article, while "acceptance testing" is firmly associated with individual units of a CEI undergoing quantity production.

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* The considerations are mentioned and discussed more fully in ESD Exhibit EST-1, ESD Supplement 1 to AFSCM 375-4, and ESD-TR-68-1.

** It is being suggested here only that this situation poses some novel questions relating to the general concepts of qualification and acceptance testing, not that the repetition of FQTs was in any sense "wrong"; in fact, it was clearly an effective and appropriate procedure for the circumstances.

This appears to be an area in which the type of computer program represented by ADP may call for some new testing concepts which are not readily derived from established practice with equipment items.

It was mentioned above that the objective of PQTs was to verify some 2500 reactions of the computer program, covering the spectrum of detailed requirements set forth in Section 3 of the Part I specification. While it is to be assumed that the computer program must be designed to meet those detailed requirements, and must "work" in the operational system, the sheer number of reactions alone suggests that the task of formal verification can be one of considerable magnitude. Many of the reactions are interdependent; they should occur under variable combinations of input and operating conditions, and many can be verified only through intricate analysis. This much was evident in varying degrees to both SPO and contractor people who were involved in planning the Category I testing at the outset of the BUIC III program. It was also obvious at that time that the total job could not be accomplished during a limited period of formal qualification testing at the Category II site. Based on the ground rule that the comprehensive formal verification had to be done, however, it was decided to place the burden of verifying detailed reactions onto the PQTs, and to limit FQT objectives to the testing of higher-level characteristics of the integrated CPCEI operating under system conditions. This decision was reached early enough to influence the writing of the Category I Test Plans for ADP and SEP. Together with some lack of understanding of the test plan functions in relation to Section 4 of the Part I specification on the one hand, and to the subsequent Procedures documents on the other, it accounts for much of the bulk and detail in the Category I Test Plans.

Thus, the groundwork was laid for the troublesome experience which ensued in trying to carry out the total of 57 PQTs for ADP and SEP. It became recognized early in the process by both SPO and contractor, although for different reasons, that the attempt to accomplish formal qualification by means of PQTs was unsound -- to the contractor because the magnitude of the task has not been appreciated and reflected in planning manpower and schedules, and to the SPO because of an emerging realization that such testing accomplished during intermediate stages of evolving those complex and massive CPCEIs would provide, at best, a weak basis for guaranteeing the presence of specified reactions in the "final" product. However, the contractual commitments reflected in the test plans were enforced, except for the few reactions which were eventually waived after Category II testing and two FQTs for each of the major CPCEIs had been completed.

The test process was also obviously affected by the continuing flow of Part I specification changes throughout the period during which PQTs were being conducted, as well as by coding changes in PQT'd elements as they were assembled and made to work with other elements of the computer program. The desirability of baselining PQT'd elements at the instruction level was considered briefly at an early point, in the context of qualifying via PQTs, but was discarded as being an impractical requirement to implement. The record does not show how many PQTs, or tests of individual reactions, were vitiated by subsequent Part I specification changes, or how many were added as new requirements, although it may be inferred from the number of Category I Test Plan changes listed in the Configuration Index -- as well as from the voluminous flow of Part I specification change pages resulting from ECPs -- that the numbers were substantial. These changes were known and clearly recognized during the program. Also, in some manner which was never readily visible to an outside observer, the contractor was able to implement the changes and maintain an updated test effort which was at least adequate at a practical level; internally, similar change rates in SAGE and BUIC II had become a way of life. However, there is evidence now that an overt recognition of this "fluid" nature of the computer programs in question was conspicuously missing at the time the PQTs -- and the FQTs too, for that matter -- were initially being planned in BUIC III. In retrospect, it appears that the testing approach adopted would have been more fitting for CEIs having less complex performance requirements, which had more stable definitions at the outset in terms of Acquisition phase end objectives, and which could be expected to have relatively longer operational lives in their FACI'd configurations.

One may assume, as most of the BUIC III personnel actually did, that the trials and tribulations of Category I testing were caused by application of the new 375-series requirements. This was undoubtedly true in a sense, although a step-by-step study of the requirements -- i.e., of the Forms 9 and exhibits -- fails to reveal any significant errors or unsound provisions which can be pointed to as being responsible for the troubles. In fact, it seems clear that the major difficulties were a direct result, not of their application, but of their misapplication. PQTs, for example, should never have been planned in the first place as formal tests which would actually qualify the CPCEIs with respect to the full ranges of requirements contained in their Part I specifications.

However, the BUIC III experience makes it equally clear that the existing requirements are inadequate, in and of themselves at least, to guide a successful Category I testing program for such CPCEIs as the ADP and SEP. As mentioned earlier, requirements were formulated and communicated in the legal language of Forms 9 and contractual exhibits, with a minimum of explanatory material or other guidance to their specific interpretation as applied to the CPCEIs in question. By and large, the requirements are sufficiently general in wording to cover many other types of computer programs, including those which would be far less complex and would remain relatively stable during both Acquisition and Operational phases of their existence. By virtue of this very generality, however, they are deficient in both guidance and specific coverage for the classes of computer programs represented by ADP and SEP. Although it is beyond the purpose of this report to construct a detailed analysis and propose specific changes, the points discussed briefly below will attempt to identify the problem areas more directly, and to suggest better interpretations which might have been made to the requirements as they now stand.

1. The degree to which formal verification of performance requirements must be accomplished during Category I testing is a matter which poses special problems in the case of many CPCEIs. Existing guidance tends to imply that all requirements of Section 3 in the Part I specification must be satisfied. Yet it can be shown that for the ADP, for example, if one takes into account the numbers of defined characteristics and their countless potential interactions during operating conditions, complete verification would be virtually impossible to achieve, even if no changes were permitted for the life of the item. Hence, a contractor cannot reasonably commit himself to the task of proving complete verification. At the same time, a SPO obviously needs assurance that the computer program does meet its requirements, at least well enought to permit successful operation of the system. This dilemma was not clearly recognized in BUIC III, and many of the difficulties can be traced to the supposition that complete verification could actually be accomplished. Pending the development of better guidelines in this area, the problem seems to indicate a need for good judgment in the SPO-contractor relationship to assure that qualification requirements are established on a practical and cost-effective, rather than perfectionist, basis, taking account of both the CPCEI's inherent complexity and its anticipated degree of stability as an element of the operational system.

2. The meaning and purposes of preliminary qualification testing were interpreted in varied ways by personnel associated with BUIC III. Some of the confusion might be ascribed to the term itself, which implies qualification as a purpose; and the available guidance is sufficiently scant that it has to be analyzed carefully to derive the intent that PQTs are really preliminary <u>to</u> qualification. Beyond this bare interpretation, official documents presently provide only meager amplification -- although there are some isolated references which might be used as starting points. For example, the following statement is contained in ESD Exhibit EST-1, Section H:*

> "Since the total process [i.e., of computer program development] is typically lengthy ..., and represents the major expense of computer program acquisition for the system, it should normally include preliminary qualification tests/demonstrations at appropriate stages for formal review by the procuring agency. Requirements for such tests are established in Section 4 of the

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* Section H is a portion of EST-1 which did not appear in the BUIC III configuration management exhibit.

> Part I specification and are amplified in the contractor's Category I Test Plan. While the tests are preliminary in nature (they do not imply acceptance, or formal qualification), they can serve the necessary purposes of providing check points for monitoring the contractor's progress towards meeting design objectives and of verifying detailed performance characteristics which, because of sheer numbers and complexity, may not be feasible to prove in their entirety during a limited period of formal qualification testing."

Elsewhere, an ESD technical report* presents the concept that PQTs can be related to successive stages of assembly of CPCEI components during the development process. The authors illustrate a "building block" approach to CPCEI development, in which each new CPC is envisaged as being assembled to the existing piece(s) of the CPCEI and each assembly stage is preceded by a CDR (prior to coding the CPC) and accompanied by a PQT. In the authors' words: "As each computer program component is added and each PQT conducted, increased confidence develops in the CPCEI being tested."

Such sources provide a basis for regarding PQTs as having primarily a "confidence-building," rather than qualification, purpose. It is suggested that the concept might be further amplified along the following lines:

a. PQTs should be planned as formal events which will enable the SPO to verify contractor progress in developing a computer program CEI, prior to its formal qualification.

b. A PQT should be regarded as a demonstration, rather than a true "test," since it is presumed that the contractor will have accomplished the necessary assembly testing for the components in question as part of his CPT&E effort. However, sessions could be arranged to provide SPO observers the opportunity to verify additional detailed requirements where indicated, perhaps on a sampling basis.

c. Scheduling should be based on the contractor's CPCEI development plan, such that PQTs are timed to coincide with stages at which key components, or assemblies of components, are due to be completed

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* Piligian, M. S. and Pokorney, J. L., Air Force Concepts for the Technical Control and Design Verification of Computer Programs. Electronic Systems Division Technical Report, ESD-TR-67-67, April 1967.

at an operable level. Scheduling should be spaced, to provide visibility of progress at early, intermediate, and later points during Acquisition.

d. There should be no necessary requirement to subject all components of a complex CPCEI to PQTs. Emphasis should be placed on components and assemblies which are critical and/or which will provide adequate indices of contractor progress in meeting the CPCEI schedule and design objectives. Considering time and cost, it is suggested that 3 or 4 judiciously spaced PQTs would have accomplished the purpose for the BUIC III ADP, instead of the 35 which were actually held.

3. As noted above, the emphasis on PQTs in BUIC III resulted from an initial recognition that the FQT, which was planned (for ADP) to be held during a short period between the installation/checkout of computer programs at the Category II site and the beginning of Category II tests, would not be adequate to accomplish the full qualification objectives. The question of how those objectives can be met, other than by shifting the burden to PQTs, does not have answers which are altogether obvious. Consideration has to be given to the wide variations among CPCEIs which can exist with respect to such characteristics as size and complexity, stability of configuration once developed and criticality of performance characteristics during operational employment.

Generalized requirements should therefore permit appropriate solutions to be formulated on a case-by-case basis. However, for computer programs like ADP and SEP, it is believed that better solutions could have been reached within the framework of provisions which now exist, e.g., in ESD Exhibit EST-1 and elsewhere. It should be recognized that the initial burden of arriving at feasible and adequate solutions for a given CPCEI falls on the contractor, who must propose the solutions in the process of formulating test requirements to be contained in Section 4 of the Part I specification. Alternatives which might have been considered, but were not tried in BUIC III, include the following:

a. The contractor is responsible for comprehensive testing against each and every performance requirement of the computer program, as part of CPT&E. If the development/testing process is properly managed, it should be possible to utilize CPT&E as a source of data for qualifying much of the detail, in particular, which can be time-consuming and expensive to repeat during formal test/demonstrations. To exploit this possibility, the contractor should be required to demonstrate the effectiveness of internal management controls, as well as to furnish data and/or other appropriate evidence that individual requirements are satisfied. Direct verification by the SPO of detailed requirements in selected areas could be carried out on a limited sampling basis during PQTs and FQT.

b. An FQT which is held at the Category II site is necessarily limited. Appropriately, as in the case of ADP, it should emphasize testing of major requirements for the integrated CPCEI performing in operationally configured equipment with live inputs. However, there is reason to believe that it should have been feasible to accomplish some of the objectives for ADP earlier. For example, much of the interface testing with the maintenance-diagnostic computer program, and the simulation mode test, would have been possible to accomplish in-plant, with proper advance planning. Such objectives as Live Mode and System Load definitely required the Category II facilities. However, to the degree that valid tests are made possible by available simulation, equipment, and other relevant factors, they should be accomplished by FQTs held in-plant.

F. BUIC III CYCLE TIME PROBLEM

1. Statement of the Problem

The BUIC III "cycle time problem" is most simply described as excessive operating time of the BUIC III Air Defense Computer Program (ADP). During ADP program development, analysis and testing revealed two significant aspects of the problem: (1) radar inputs processing; and (2) operating time of the computer program components that perform control, guidance, and display makeup.

The System Specification, SS-ES 416M 65-1B, describes timing by alluding to it in the performance allocation requirements for radar inputs. In this context, a correlation period is specified in seconds; two correlation periods equal one radar scan. Operating time was specified in the Part I Specification, CGTM2385A, Volume 1, as seconds minimum to seconds maximum per cycle, and seconds minimum to seconds maximum per bicycle. The minimum value was an estimate based on the subframe time of SAGE; the maximum was an arbitrary value. It was assumed that if the maximum value were exceeded, an equipment or program malfunction had occurred such that the BUIC Confidence Diagnostic Program (BCDP) should operate. These values had been previously established for BUIC II and were then applied to BUIC III.

Estimated cycle time of the BUIC III operational program was initially derived by adding increments for the differences between BUIC II and BUIC III features to the cycle time of BUIC II which had been determined in a timely study employing reasonably high load conditions. The differences were identified principally in input/output and computer program size.

This information was documented in TM-2385/000/00, Preliminary Design of BUIC III Air Defense Program, and submitted at the Preliminary Design Review (PDR) held January 1966. At the time of the PDR, no difficulty was anticipated in meeting the cycle time constraints; however, input/output table size had been predicated on minimum cycle time. This table design made inefficient utilization of output lines with the possibility of system degradation due to loss or delay of information to be transmitted to interceptors and other facilities. It was determined that input/output table size should be based on projected cycle time. Accordingly, SDC was committed to a study of cycle time projections considering I/O time, compression of input data to one word format, and the effect on I/O table structure.

In the months that followed the PDR, SDC did perform a study which led to a new prediction of cycle time. The study was performed using a load based on a moderate threat situation which entailed a given number of radar returns/cycle, interceptor capacity, and 20 less than full track capacity. The resultant prediction as of the end of May 1966 was substantially greater than the earlier estimate submitted at the PDR. At this point, it was clear that the possibility of adverse effects on system performances was sufficient to justify continued scrutiny and evaluation.

Radar Inputs Processing

The continuing study ascertained that the operation of the radar inputs processing program (RIP) consumed a relatively large amount of time. RIP's operating time is a function of the number of radar returns processed, number of returns correlated, and other factors. As a necessary part of this study, the possible effects of high cycle time were determined and are briefly summarized here:

a. The operation of ADP would be interrupted in each cycle exceeding a specified threshold number of seconds since ADP would assume a malfunction and initiate BCDP to investigate.

b. Degradation of active and passive tracking functions could occur since tracking parameters had been optimized based on specified minimum cycle time.

c. Height reply rate could be less than required to delay in sending out height requirements.

d. Response to operator switch actions could be delayed.

e. Duration of forced displays would vary, thus possibly causing operator confusion.

f. Guidance calculations for interception could be in error.

Concurrently with the SDC study, MITRE engaged in a parallel study which also identified radar return processing as taking a large amount of operating time. Since both SDC and MITRE agreed, further study and analysis concentrated upon radar inputs processing. A solution was recommended to the SPO and approved that entailed a redesign of the radar inputs computer program components such that the average processing time for each radar return was reduced; additionally, a new program system design was developed that provided for operating some functions less frequently than every cycle and also presented a new data limiting scheme. This change was implemented as ECP 54-1 and was included in the computer program when Program System Test (PST) began.

Control

PST of ADP was performed at the BUIC Evaluation Facility, Hanscom Field, Massachusetts, using live inputs to the computer program. The testing revealed that the cycle time problem had not been fully resolved; the earlier prediction of operating time for non-radar processing programs was not valid. It was determined that the underestimation was principally in the amount of time the control program (COP) and the CPCs performing guidance and display makeup took to operate.*

BUIC II hardware had an output interrupt every 70 ms. that allowed the control program to transfer output messages as well as read the message processor. BUIC III hardware has an additional interrupt every 30 ms. for processing inputs from the message processor. The high operating time of COP was a result of the high frequency of interrupts being processed by inefficient interrupt processing logic. The logic of COP included use of an executive loop which, when entered, would check indicators and items to determine the need to service any terminal device, the need to start any I/O operations, the need for action due to completion of an I/O operation or the need to process a

* Since this problem is treated fully in TM-4153/001/00, Final Report of BUIC III Timing Analysis, 12/15/68, no attempt is made here to address the problem in its entirety. The discussion does address COP because of its unique aspects and significance.

clock interrupt or an external request interrupt. When any interrupt except an equipment failure interrupt occurred, the indication of the interrupt was set and the executive loop was entered. If, as in the case of message processor service, multiple I/O was required, several passes through the loop would be performed. Because of the large amount of code operated in this loop and the frequency of messages processor interrupts (one every 21 ms. in COP), the control program required about 15/21 of ADP operating time for message processor servicing.

This problem was resolved by an extensive redesign of COP to make it more efficient and by changes to the message processor servicing interval (ECP 108) to reduce the frequency of interrupts. To reduce the amount of time required for interrupt processing the following changes were made in the control program design: Interrupts as much as possible are no longer queued, but are completely processed when they occur. This reduces the amount of code operated when an interrupt is processed. Secondly, the number of interrupts per unit time is reduced. The program now services a clock interrupt at a fixed frequency of once every 30 milliseconds with message processor servicing performed on every other clock interrupt. The routines with high frequency of operation were designed and coded with time efficiency the main concern. This ECP was included in the Timing Version subjected to Formal Qualification Testing at the BEF 2 December - 13 December. The FQT indicated that the Timing Version conforms to specification.

2. Conclusion

The cycle time problem insofar as radar inputs processing was concerned was identified early in the development of ADP and resolved within a reasonable time; of greater concern is the late realization that a cycle time problem still existed that had its origin in the control program (COP). That the latter should remain undetected until PST must be regarded as a deficiency in the activities preceding PST. Testing during CPT&E of COP did not sufficiently approximate its exercise in a live environment, the difference being principally in the lack of live inputs that would actuate the processing routines of COP. Hindsight indicates that CPT&E should include a full exercise with attention to the timing of the control program, as well as the other CPCs comprising the CPCEI, in a manner equivalent to employment live. This means that special purpose program tools must be designed and developed to facilitate such testing. Timing tools that were used in the control program study, redesign, and testing are described in Table 6-5.

Experience has shown that two critical factors must be considered in program design: timing and storage. Furthermore, each must be considered in relation to the other. Although operate time is basically a direct function of program size, an inverse relation may also exist. For example, if operate time had

Table 6-5. Timing Tools Description

1. Ratio of COP to NON COP Time. (COP + non COP = total ADP). This tool was developed to monitor the item N005 in COP. This item is greater than 0 whenever COP is operating. The software routine that was utilized operated in the non-ADP computer and generated counts of when ADP was in COP and out of COP.

2. Ratio of Message Processor Time Consumption to Total ADP. Real time Clock interrupts were blocked and a program loop was placed in the Manual Inputs Program (MIN). The item N005 in COP was again monitored for a value greater than 7 to determine the percentage of time required for message processor servicing. The software routine that was developed operated in the non-ADP computer.

3. Interrupt Count and Frequency Recorder. Two tools were developed to determine the frequency and interrupt mix in ADP. Both tools utilized were developed by octally modifying the control program to generate counts per cycle or to save the index register setting (XIR). The XIR was saved for an interrupt mix and sequence analysis.

4. Increases in Cyclic ADP Due to Interrupts. A timed loop was placed in the Telling Program (BIT). As additional interrupts were allowed to occur the operating time of BIT was recorded by a TIMER program in the non-ADP computer. The difference between the expected operating time of BIT (that of the timed loop) and that actually recorded indicated the time increases due to interrupt processing.

5. (Word counts of) Message Processor Input Operations. A routine was generated that recorded the result descriptor of message processor inputs. The differences between the maximum message processor word count and that of the actual result descriptor defined how many words were actually transferred.

no ceiling, a computer program could be devised that uses little storage but has an extremely high operate time; conversely, if storage had no ceiling, a computer program could be devised that uses little operate time but requires large storage. Realistically, of course, a constraint must exist for both timing and storage. An optimum balance of the two must be determined consistent with other system constraints.

The fact that the full scope of the cycle time problem was not evident until PST can be attributed in part to the emphasis placed on meeting the computer program storage constraint. Difficulty was experienced in confining ADP to the available storage. Although computer program storage allocation was carefully reviewed at the Critical Design Reviews held for the CPCs, little attention or concern was expressed with regard to operate time. Some questions were asked but they were not meaningfully pursued. Another factor that may have tempered the frame of mind of those engaged in the development of ADP is the previous experience of SAGE. High operate times were known to occur, but little had been done to ascertain what adverse consequences had resulted. A sort of mental euphoria had set in such that the potential of a further timing problem was assumed to be inconsequential

Frame time in SAGE is the equivalent to bicycle time in BUIC III. Under normal conditions, SAGE has a frame time of 15.7 seconds but instances of frame time in the range of 20 to 30 seconds have been experienced without any apparent effects, and are not uncommon. Concern has been expressed by personnel newly assigned to SAGE with regard to high frame time; however, experienced personnel have learned to cope with it (e.g., reduce amount of radar data processed by manual switch intervention). Moreover, much of the high frame time in SAGE has been experienced while the simulation and recording functions were operating, both of which increase frame time. Neither of these functions would be operated during a hostile attack. This analogy between SAGE frame time and BUIC bicycle time serves to illustrate that the relation of operate time to system performance may be complex and equivocal.

3. Recommendations

When discussing how this type of problem may be prevented or at least detected earlier in the future, the following should be considered:

a. System engineering analyses and studies preceding program development should carefully consider system requirements in terms of response time desired for specified actions and situations, the frequency of functions, required data retention and allowable data loss, and similar requirements that influence computer program operate time. However, the emphasis should be on the basic requirements, not on operate time per se which is derived in satisfying the requirements.

The studies should consider alternatives and determine potential consequences of less than optimum performance.

b. Specification of computer program requirements should include a description of specific load conditions that influence operate time for each computer program function. Actual values should be specified and related explicitly to the expected response of the CPCEI.

c. The proposed program design presented at the time of Preliminary Design Review should include a description of the expected operate time of each CPC and the CPCEI as a whole under the varying load conditions specified.

d. Personnel engaged in the management review process should examine and evaluate information based on test data regarding operate time of the CPCs during program development. Preliminary Qualification Tests can serve as the vehicle for this purpose.

e. Provision should be made for the development and use of computer program test tools that clock the operate time of sets of code. Other special purpose timing tools may also be desired.

f. Following the initial testing of the CPCs (parameter and assembly) typically performed by the programmers who did the original coding, testing should be performed by an independent group of programmers to offset the natural bias of the original programmers.

g. It is evident that some problems by their nature are not readily detected in a simulated environment; therefore, it is desirable to exercise the CPCEI in a live environment at the earliest reasonable time.

CHAPTER VII

SUMMARY AND RECOMMENDATIONS

A. INTRODUCTION

Systems management techniques based on 375-series principles were adapted and applied comprehensively for the first time, in BUIC III, to the acquisition of system information processing elements. The first part of this report is devoted to a review of the background of those techniques in terms of Air Force systems management concepts and trends, and relating them to earlier practice at ESD in the system programs which preceded BUIC III. A second part of the report is devoted to describing the elements of contractor effort, identifying the novel management requirements, and summarizing the milestones associated with the requirements as they actually occurred during the course of the BUIC III acquisition. Finally, discussions are presented of the contractor successes and difficulties in implementing the requirements, in the attempt to identify and record aspects of the BUIC III experience that can be usefully related to future system acquisitions.

This chapter briefly summarizes selected highlights of the findings, primarily in terms of comments and recommendations concerning the formally documented management techniques. Emphasis is placed on the formal requirements, not only because they were indeed the focal topic of the study, but because they provide the most direct vehicle by which results of experience can be brought to bear on future practice. At the time this report is being written, some of the contractual exhibits and supporting data items are in process of being revised to conform with recently promulgated Defense Department standards for configuration management. Similar revisions will have to be made in the related 375-series manuals and other documents. Based on current information, it appears that many of the familiar Air Force terms -- e.g., names of baselines, specifications, inspections -- will be replaced by the standard DOD terminology, but that the existing Air Force practices may otherwise be retained essentially intact. Hence, it is assumed that lessons learned from the application of systems management techniques as discussed herein will continue to be pertinent following translation into the new framework of manuals and exhibits.

B. CONFIGURATION MANAGEMENT

Configuration management requirements in BUIC III were contractually specified by a special BUIC III exhibit which was equivalent in all essential respects to ESD Exhibit EST-1 and applicable portions of AFSCM 375-1. Basic procedures relating to control of changes, specification maintenance, and accounting were similar to those which had been developed and used prior to BUIC III except for differences in standard forms and the fact that control had not previously been applied at the product configuration baseline level. In general -- i.e., as regards configuration management aspects other than the content of specifications -- the procedures were applied to effectively control and process a large volume of changes during the course of the program, with relatively minor difficulties. Recommendations below are based on applications of EST-1 to other systems as well as on the BUIC III experience.

1. Having all configuration management requirements which apply to computer programs in a self-contained document, as was true in BUIC III, is desirable. Although it is presently a separate document in its interim form as an ESD Exhibit, EST-1 is formated as change pages to AFSCM 375-1 and is more difficult for people concerned solely with CPCEIs to use. If and when EST-1 and 375-1 (or their successors) are combined into a single document covering all types of system items, the difficulty may be increased, particularly for those contractors who do not have a backlog of experience in distinguishing the applicable principles and practice as between computer program and equipment items. A separate and self-contained manual for computer programs, containing explanations and examples in addition to the bare definitions of legal requirements, would facilitate contractual application and use by both SPO and contractor personnel.

2. The use of a common, standard format for certain forms -- e.g., Engineering Change Proposal -- is now required for both equipment and computer program items. There is no advantage to this particular standardization; in fact, it encourages expectations of similarities which do not exist. It is recommended that separate forms appropriate to the purpose be devised and used, in the interests of improving efficiency and avoiding misinterpretations.

C. SPECIFICATIONS

Requirements for the two-part CPCEI specification imposed in BUIC III were essentially those which are currently described in EST-1 and associated Forms 9 (now DD 1664s), and for which supplementary experience is also available from their use in other programs. Based on these experiences certain recommended lines of improvement are suggested in Chapter VI preceding, and below. However, to maintain perspective, the problems identified should be construed as indicating only that there are specific areas needing further study and refinement, not that basic changes are being proposed. It is believed that the two-part specification has been demonstrated to be the key element in developing an effective framework for managing computer program acquisition, and that the existing structure of requirements is superior to various proposed alternatives.

The types and levels of information to be supplied in the Part I specification are generally appropriate and necessary in order for the Part I to accomplish its various functions, namely: of governing the computer program design, development, and testing; controlling interfaces of the CPCEI with other items; and serving as the primary baseline for CPCEI configuration management. The Part II meets the important needs of providing comprehensive documentation which can be used by computer programmers for diagnosing malfunctions and designing changes, as well as providing a precise technical definition of the CPCEI for configuration management at the product baseline level. However, problems needing further study and clarification include:

1. The degree to which considerations of computer program design are incorporated into the content and structure of the Part I specification should be determined. Questions exist, on the one hand, whether mathematical formulas and equations representing design solutions, which may conflict with requirements expressed purely in performance terms, should be called for in the Part I except where their firm intent is to establish design constraints. On the other hand, the question has also been raised whether the overall computer program design structure should not be anticipated, verified, and established in a corresponding structure of Part I functional elements, to provide an improved basis both for managing the computer program development and for testing.

2. The scope of intended coverage under Data Base Requirements (3.1.3) in the Part I specification should be determined, and a number of terms should be defined. Questions needing resolution relate to data which are input prior to computer program operation vs. variable values input during the course of operation, computational constants vs. data to be processed, input/output vs. intermediate data, and others. The term "data base" is subject to a variety of interpretations with respect to these considerations. Also, a number of terms, e.g., "adaptation," "parameter," etc., need to be defined and supported by explanations of their significance in terms of functions served by the specification.

3. The level of descriptive detail contained in the Part II specifications should be examined. Experience has indicated that the Form 9 (DD 1664) for the Part II specification is comprehensive and technically sound. However, as is true of Forms 9 in general, its application should be carefully tailored to the given CPCEI, taking into account the intended uses and maintenance of the document following its acceptance. The value of detailed prose and flow chart materials at the CPC level, in particular, which are expensive to produce and maintain, should be examined critically, and the required detail reduced to a minimum level which is consistent with the needs of the given application.

4. Implied functions of the Part II specification as a contractual requirements instrument should be clarified. The Part II computer program specification is recognized in EST-1 to be an "as-built" technical description of the

CPCEI configuration. However, the wording and content of certain sections in the Form 9 are not fully consistent with that role, e.g., as contrasted with functions which an equipment Part II specification would normally serve in governing production, acceptance, and delivery, following the first article. Recommended changes which might help to avoid confusion and misinterpretations include: under Section 1, "SCOPE", eliminate emphasis on units subsequent to the FACI'd article and on CPCEI serial numbers; as a title for Section 3, substitute "TECHNICAL DESCRIPTION" for "REQUIREMENTS"; eliminate Sections 4 and 5 completely, as types of requirements which should be contractually specified independently of the Part II CPCEI specification, prior to delivery of the first article.

D. DESIGN REVIEWS

A Preliminary Design Review (PDR) was held for each of the three major BUIC III CPCEIs, essentially in accordance with the guidelines set forth in ESD Exhibits EST-1 and EST-3. These were conducted successfully and were regarded as being useful and productive sessions by representatives of both the SPO and contractor.

Critical Design Reviews (CDRs) were conducted incrementally in combination with Preliminary Qualification Tests, at the level of completed design for the components undergoing review. These provided opportunities for review and comment by representatives of the SPO, and were considered useful. Although some of the discussions are reported to have resulted in minor changes, the CDRs were not associated with formal actions.

As a general matter, questions continue to be raised regarding objectives, in terms of formal actions, which the computer program CDR is intended to accomplish. Established objectives for equipment -- e.g., release of design for production and as a basis for support items -- do not apply. Available guidance in EST-1 and EST-3 indicates that the only analogous purpose for CPCEIs is to identify documentation which will be "released for coding and testing", a purpose which can only exist when CDRs are held at the flow chart level. At that stage the development is only partially complete and no testing can have been accomplished; implications relating to formal approval/disapproval, and applicability of configuration controls, have become matters of debate. The problem deserves further attention. In the interim, it is suggested that in the case of computer programs, CDRs should be regarded frankly as monitoring events only, at a level between PDR and FACI, having the primary purpose of providing visibility of the development. A change in the name would be a helpful step towards alleviating the prevalent confusion with accepted practices associated with CDRs for equipment items.

E. CATEGORY I TESTING

Requirements for Category I testing of CPCEIs encompassed: identification of test requirements in the Part I CPCEI specifications; preparation of Category I Test Plans; preparation of PQT/FQT Test Procedures and Reports; and conduct of the formal test sessions. As a whole, these represented elements of contractor effort which were novel in BUIC III as compared with practice in earlier systems. Difficulties were encountered in carrying out the test program which are attributed to absence of previous contractor experience with the concepts and procedures, as well as to certain ambiguities in the requirements as they were formulated at the time of contractual application.

The principal difficulties were associated with PQTs, which were carried out in a total of 57 testing sessions for two of the CPCEIs (ADP and SEP) and were designed to provide comprehensive verification of performance relating to detailed characteristics specified in the Part I specifications. The PQTs proved to be costly in time and effort to conduct and were not particularly satisfactory in meeting their objectives.

In the case of FQTs, the principal objective was to demonstrate compliance with major performance requirements of the computer programs during integrated system operation. Although some problems were encountered with documentation and test conduct, particularly during early attempts, the FQTs were comparatively successful. In contrast with the PQTs, they were readily recognized by the contractor personnel involved as being formal tests which serve useful and necessary purposes, as well as being feasible to accomplish.

Comments and recommendations based on discussions contained in the preceding chapter are summarized briefly below.

1. A number of factors can be identified as contributing to the severe problems experienced in carrying out the BUIC III PQTs. In some part these were matters of contractor management and technical practices which had not been geared to meeting the complex requirements of formal Category I testing, and which did not receive the vigorous attention they needed until late in the program. However, the authors believe that the initial approach which the SPO and contractor devised jointly at an early point was basically unsound. The PQTs planned were far too many and attempted to be too comprehensive in their coverage; they should have been regarded and planned as interim demonstrations of contractor progress towards accomplishing the development, not as means of qualification.

2. To be realistic, qualification requirements must be tailored to individual cases. The degree to which comprehensive formal verification is feasible, and justifies its cost, should be recognized as a variable which depends on such considerations as size and complexity of the CPCEI, frequency and extent of changes, and criticality of perfect performance in initial operational use.

3. The contractor should be required to demonstrate internal management procedures which insure that Part I specification requirements, including approved changes, are incorporated into the computer program design and tested routinely during CPT&E. Where conditions permit, documented CPT&E procedures and results should be utilized as a source of data for qualifying detailed performance/design characteristics of the computer program components.

4. Where feasible, it is desirable to conduct FQTs using the integrated CPCEI in the system environment. To the degree that adequate simulation is available, FQTs or partial FQTs should be performed at the contractor's facility.

F. CONCLUSION

As a major summary result, this study has indicated that the principles and content of the management requirements are not only sound but represent necessary and substantial improvements over previous practice. Their application in BUIC III occasioned problems, principally in the areas of documentation and testing, which are discussed at length in the preceding chapter. In general, however, the problems can be related most directly to the fact that the procedures were novel, rather than unsound, and the BUIC III personnel were inexperienced with their use. The original intent was to initiate the adoption of standards which would enable computer programming to be managed in a uniform manner, consistently with the management of equipment and other elements in a system program. The matters of uniformity and continuity in documentation and procedures are the key elements which make it possible for both SPO and contractor to benefit from experience, from system to system. In the authors' opinion, these advantages have become more evident as the procedures have become better understood and established, particularly through continued use in other system programs.

By the same token, BUIC III clearly demonstrated that the initial acquisition of contractor capability to implement the requirements adequately can be difficult and time-consuming. In part, some of the problems can be ascribed to the fact that the total 375-series framework was a novelty to the contractor at the time BUIC III began, and many of its implications for internal management were not appreciated until late in the program. There is evidence that difficulties could have been avoided by better initial guidance, e.g., in interpreting the formal test requirements, and by systematic training of personnel in relevant documentation and procedures. Misinterpretations and absence of common understanding of objectives and requirements were frequent, both internally among contractor personnel and in relations with the SPO. In general, as is indicated in comments and recommendations made above, problems can be traced to a variety of sources. However, it is believed that training of personnel, based on adequate uniform guidance, will continue to be a fruitful area for increased future attention.

APPENDIX A

GLOSSARY OF ABBREVIATIONS

AC&W - Aircraft Control and Warning
ADC - Aerospace Defense Command (formerly Air Defense Command)
ADP - Air Defense (Computer) Program
AFL - Air Force Letter
AFLC - Air Force Logistics Command
AFR - Air Force Regulation
AFS - Air Force Specialty
AFSC - Air Force Specialty Code
AFSC - Air Force Systems Command
AFSCM - Air Force Systems Command Manual
AGE - Aerospace Ground Equipment
AI&C - Adaptation, Installation, and Checkout
APASTO - Air Defense Computer Program and System Training Office
ARDC - Air Research and Development Command (predecessor of AFSC)
ASPR - Armed Services Procurement Regulation
ATC - Air Training Command

BARS - BUIC Analysis and Reduction System
BCDP - Backup Confidence Diagnostic Computer Program
BEF - BUIC Evaluation Facility
BEPS - BUIC Exercise Preparation System
BMF - BUIC Management File
BSAO - Burroughs Site Activation Office
BSD - Ballistic Systems Division
BUDR - BUIC Data Reduction
BUIC - Backup Interceptor Control

CCB - Configuration Control Board
CCBD - Configuration Change Board Directive
CCDSO - ADC Command and Control Defense Systems Office
CDP - Contract Definition Phase
CDR - Critical Design Review
CDRL - Contract Data Requirements List
CEI - Contract End Item
CMO - Configuration Management Office
CC - Control Center
CP - Change Proposal
CPC - Computer Program Component
CPCEI - Computer Program Contract End Item
CPT&E - Computer Program Test and Evaluation
CR - Change Report (In BUIC III, reporting a Class II change)
CR - Change Recommendation (In BUIC II, a recommended change to any system element, prepared by any participating agency)

DC	-	Direction Center
DOD	-	Department of Defense
ECP	-	Engineering Change Proposal
ERP	-	Error Recovery Program
ESD	-	Electronic Systems Division
ESS	-	Experimental SAGE Sector
FACI	-	First Article Configuration Inspection
FQT	-	Formal Qualification Test
FSPS	-	Field Site Production System
GEEIA	-	Ground Electronics Engineering and Installation Agency
GFP	-	Government-Furnished Property
GSE/TDC	-	General Systems Engineering/Technical Direction Contractor
HE	-	Human Engineering
IAC	-	Integrating and Assembly Contractor
LET	-	Live Environment Testing
LLO	-	Lexington Liaison Office
LS	-	Life Support
MSTP	-	Manual System Training Program
NCC	-	NORAD Control Center
NORAD	-	North American Air Defense Command
NRD	-	National Range Division
OR	-	Operational Requirement
PAGE	-	Primary Air Ground Environment
PCB	-	Product Configuration Baseline
PDR	-	Preliminary Design Review
PECP	-	Preliminary Engineering Change Proposal
PED	-	Personnel-Equipment Data
PERT	-	Program Evaluation and Review Technique
PQT	-	Preliminary Qualification Test
PS	-	Personnel Subsystem
PSTE	-	Personnel Subsystem Test and Evaluation
PSPP	-	Proposed System Package Plan
PST	-	Program System Test
PTDP	-	Preliminary Technical Development Plan
QQPRI	-	Qualitative and Quantitative Personnel Requirements Information

RDT&E	-	Research, Development, Test and Evaluation
RFP	-	Request for Proposal
SAC	-	Strategic Air Command
SAC	-	Site Activation Contractor
SAGE	-	Semi-Automatic Ground Environment (System)
SAWG	-	System Acquisition Working Group
SCL	-	Specification Change Log
SCN	-	Specification Change Notice
SATAF	-	Site Activation Task Force
SDC	-	System Development Corporation
SDR	-	System Design Review
SEP	-	System Exercise (Computer) Program
SETE	-	System Exercising for Training and Evaluation
SOW	-	Statement of Work
SPD	-	System Program Director
SPO	-	System Program Office
SPP	-	System Package Program
SSTP	-	SAGE System Training Program
TAC	-	Tactical Air Command
TC	-	Training Concept
TED	-	Training Equipment Development
TEPI	-	Training Equipment Planning Information
TM	-	Technical Memorandum
TP	-	Training Plan
UCP	-	Utility Computer Program
USAF	-	United States Air Force
USCN		Uniform Specification Change Notice
USP	-	Uniform Specification Program
VDE	-	Variable Display Equipment

APPENDIX B

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13. ABSTRACT

This report is a review and analysis of experience with the application of Air Force systems management techniques to the acquisition of information processing elements in the 416M (BUIC III) system program. The report includes a background review of the systems management concepts and trends in relation to practices which had been employed in L-system programs preceding BUIC III. Novel requirements introduced in BUIC III are identified in the areas of computer program configuration management, standard documentation, design reviews, and Category I testing, and a summary is presented of the milestones associated with these requirements as they actually occurred during the program. Finally, the experience in specific areas is discussed and evaluated with respect to implications for future modification and use of the management techniques.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Computer Program Management Systems Management Configuration Management Computer Program Category I Testing Computer Program Design Reviews Computer Program Documentation Computer Program Specifications BUIC III Experience Software Design Process Integration of Hardware and Software Engineering Management of Computer Programs Computer Program Acquisition System Engineering of Computer Programs						