COMPUTERIZED PATIENT INFORMATION SYSTEM

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ABSTRACT

Handling of patient data in a medical care facility creates major problems. The magnitude of the problems, the causes and effects are investigated. Solution for improved handling of information in terms of efficiency, accuracy and speed of communication is offered by the introduction of automated data processing in patient care. The state of the art technology and the particular requirements of a computer based patient information system, such as a large data base, continuous real-time operation and the requirement for an extensive information network of interactive terminals, are described. The conceptual and functional design and operation of such a system is outlined.

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I. INTRODUCTION

In many areas, in commerce, government and industry the handling of information has been revolutionized by the computer during the last two decades. Yet few of these advanced technologies made their way into the health care area, in particular into the hospitals. Most information used by hospitals in patient care is written, often in illegible script on multipart forms. The same information is delivered to different areas of the hospital by multiple slips of paper or a number of telephone calls. One can retrieve most information only by shuffling through the medical records - a collection of physician notes, nurses observations, test results and records of therapeutic procedures.

However, the hospitals have undergone dramatic changes during the past twenty years. The difference today is that they must handle more data due to the increased demand for health care services and availability of automated medical instrumentation. The increased demand can be illustrated by the increase of annual hospital admissions. (1)

Year	1940	1955	1974
Hospital Admissions (in millions)	10	21	35

In addition to the significant growth in patient population there is a broadened scope to medical treatment, born of advances in drug therapy, operative procedures, and medical technology, greatly increased paper work required from doctors and health institutions, increased record keeping and reporting requirements for quality-care assurance and public health purposes and detailed documentation of procedures to prove that the quality of patient care provided is adequate. All of these functions create an ever increasing data handling operation.

The limitations of the manual, clerically intensive information systems result in major duplication of tasks, increased opportunities for error (2) and difficult accessibility to important information at a constantly rising cost.

Total hospital cost increased even sharper during the same period of time: (3)

Year	1940	1955	1974
Hospital Cost (in millions)	\$ 1,500	5,500	41,000

A recent analysis (4) of the trend in hospital cost identifies the following major contributors:

High prices per unit service
Increase in per capita consumption of unit service
Introduction of more sophisticated equipment
Increase in practicing defensive medicine
Introduction of new tests and procedures
Rise in the proportion of elderly population

Of the total hospital cost, the clinical laboratory is one of the more costly in terms of capital investment and personnel (5). In the United States, over 5 billion tests are performed annually (6). However, the clinical laboratory tests are crucial to the delivery of health care because of their importance in the decision making process of the physician. It has been estimated that on the average, the clinical laboratory test provides nearly 50% of the information used by the physician in making his decision on diagnosis and treatment. Demands are growing, not only in terms of increased number of tests, but for expanding information content and medical utility of laboratory reports. (7, 8).

The proper accurate and timely handling of patient information not only became an overwhelming task, but one of the major components of the escalating hospital cost. A detailed study shows that 25% of the hospital budget is spent on information handling (9).

To help to solve the patient information handling problems, an increasing number of hospitals are developing and employing automated data processing facilities. In 1970, 19.2% of the over 7000 hospitals in the United States had in-house computer facilities. Based on the more recent survey, in 1974 the percentage increased to 24.4%. (10).

Mount Sinai Medical Center

The Mount Sinai Medical Center was founded in 1852 and incorporates professional education, research and patient care. The Institution is located in Upper Manhattan and extends northward from 98th. to 102nd. Streets between Fifth and Madison Avenues. It is comprised of a number of buildings which house a Medical School, a 1250 bed Hospital and an Outpatient Department consisting of over 120 clinics. The Medical Center is one of the oldest and largest voluntary hospital's in the country and draws patients nationwide as well as from many foreign countries. The Medical staff includes over 500 In-house and approximately 1200 attending physicians.

The total number of patients being treated annually exceeds 30,000 in patients, and the number of visits to the clinics and Emergency Room is about 300,000 per year.

In the Mount Sinai Hospital there are seven major laboratory departments; Chemistry, Clinical Microscopy, Hematology, Microbiology, Blood Bank, Clinical Pathology and Endocrinology.

Total number of tests performed by the Laboratories and Radiology in 1978 exceeded five million. Following is the distribution of tests in the laboratory services:

Chemistry	2,830,927
Clinical Microscopy	1,370,778
Hematology	384,011
Microbiology	154,707
Radiology	136,584
Pathology	53,228
E.K.G.	51,123
Rehab. Med.	22,057
Radiotheraphy	16,886
Nuclear Med.	10,169
CT Scan	3,376
Cardiac Cath	767

Clinical Laboratory Information Center

The clinical laboratory is a complex dynamic operation serving many medical needs for which accuracy, timeliness and reliability are of paramount consideration. In manual operation a patient information system already exists. (11, 12). The objective to implement computerization in the clinical laboratory is not merely to replace manual data handling operations with an automated one but to introduce discipline, precision, quality, speed and accuracy to an extent not feasible with manual systems (13). A properly designed and utilized computer system will provide realtime monitoring of all facets of the laboratory operation, will control the fate of all tests requested and automatically update patients location.

In response to the present and future patient Information needs in the Hospital and particularly in the Clinical Laboratories, the Department of Clinical Laboratory Information Center was established at Mount Sinai Medical Center in 1974.

One of the major objectives, encompassing all areas involved with patient data handling, is the reduction of errors. It is imperative to good health care delivery that the possibility of error be minimized. To ensure accuracy in the acquisition, transmission and storage of data for subsequent use, a computerized information system can establish consistent standards and continuously monitor all transactions. All entries that require verification can be immediately printed at the entry terminal and verified by the user, thereby providing positive confirmation of the data. A printed record of the transaction is then available for future reference.

A major advantage of computerization is in the improvement effected by the systematic organization of medical functions and patient information in an accessible data base. An information system establishes specialized files containing data on various functional activities. The data is available throughout the system for appropriate users. The data base is constantly being updated during daily operation.

Implementation of a computerized information system requires a disciplined, rigorous and explicit formulation of the problems and formulation of any intended application in great detail. The definition of the data base needed to provide the information required to solve a particular problem has been very beneficial. The exploration of the cost effectiveness of computer based solutions as contrasted to a manual one has provided critical insight. These fringe effects of applying computer techniques have, therefore, combined to induce a problem solving orientation in hospitals. Meaningful questions must be raised to which the answers will facilitate planning of programs. Translating thoughts into computer programs forces the translation from vague indication to precise description.

Cost reducing technological developments achieved by automation, provision of timely and accurate information are independent and co-existent factors influencing the reliability and utility of hospital computer applications.

The elements for a common data base in a hospital are so widely dispersed in different areas that they are practically unconnectable. Therefore, one of the principle objectives of a computer based patient information system is to use available mechanism to aggregate this data and gain greater efficiency. Computer data base manipulation, for communication purposes or for data analysis for information, provide direct means to control decisions and actions in patient care delivery. (14, 15). Timely information will assist more accurate deployment or development of service delivery capacity. Thus, indirectly, such applications can influence availability of hospital resources. The data elements, covering the details of the patients encounter with the hospital should be utilized for both, administrative and medical needs, viewing the data from different aspects.

The information system itself must be flexible by being easily adopted to changing conditions. It must respond to the dynamics of the hospital as they are implemented.

II. COMPUTER BASED INFORMATION SYSTEM

System Approach

The system approach to problems focuses on systems taken as a whole not on their parts taken separately. Such an approach is concerned with total system performance even when a change in only one or a few of its part is contemplated because there are some properties of systems that can only be treated adequately from a holistic point of view. These properties derive from the relationships between parts of systems; how the parts interact and fit together. In an imperfectly organized system, even if every part performs as well as possible relative to its own objectives, the total system will often not perform as well as possible relative to its objectives. Or restate it by the seemingly paradox composition law of the general system theory: "The whole is more than the sum of its parts" (16).

The law certainly applies to the patient information system. The modern hospital is in fact not a single homogeneous activity but rather a conglomeration of activities; that from a functional point of view are seemingly unrelated. Optimization within each component is a necessary but not sufficient requirement for overall system optimization. Many of the deficiencies, delays in the manual data handling process are most critically felt across operating interfaces, rather than within particular service components.

Solving system problems that occur across the interface between functionally different yet interrelated subsystem, can be achieved by utilizing the computer as an effective integrator. Elements of the common data base in the hospital are so widely dispersed that to aggregate this data requires a major integration.

A system is, by definition, a set of interrelated elements. Thus a system is an entity which is composed of at least two elements and a relation that holds between each of its element and at least one other element in the set. Each of a system's element is connected to every other element, directly or indirectly. Furthermore, no subset of elements is unrelated to any other subset. For example major subsets in a patient information system are:

Patient
Physician
Nursing Service
Admitting Office
Financial Office
Medical Records
Laboratories
Pharmacy
Dietary
Housekeeping Service

A dynamic system is one to which events happen, whose state changes over time. If its elements react or respond only to each other it is a closed system. If external elements, or the environment which are not part of the system, can produce a change in the system, it is an open system.

The information system serves to provide the different functions within an organization with information necessary for rational decisions.

Therefore, the information system has to be designed to handle such functions as collecting, classifying, storing, processing and displaying of data. An analysis of an information system will help to define the information needed, its volume, the time intervals at which it is required, and that at which is available, the data from which it can be produced, and the process needed for its production, and the form for presentation of the results. Only after such an analysis has been made is it appropriate to consider computer implementation. Once the analysis has been made, also with respect to the general properties of available computer systems, should one evaluate the suitability of different specific hardware systems and their effect upon the overall organization of the system of information. Evaluation methods were developed (17) which can be applied to optimize system design. Particular attention must be given to the decision hierarchy which constrain later activities. For example:

- Selecting a hardware configuration constrains everything that follows to what can be accomplished with the selected hardware.
- Selecting the size of the main memory, number and type of input and output units, and auxiliary memory constrains, still further the overall system capacity.
- Selecting an operating system determines which processing organization is possible.

To cope with an environment of increasing complexity, user, has had to analyze and correlate vast amounts of data. In so doing, it has become sensitive to the need for accurate, consistent, and easily available information. Since the computer assumes a large share of the burden of correlating and combining data, it is no surprise that attention has focused primarily on machine-readable information, leading to a search for a more efficient way to store and use data. This search, in turn, has led to the data base approach.

In an ideal database system, the user department is no longer constrained by batch processing requirements. No longer does the user feel that he is not fully in control of the situation because some data needed for planning or operations is known only to the computer and is available only after an unacceptable delay. No longer must data be associated in certain limited ways to meet the requirements of the computer. The ultimate aim of a database management system is to enable the computer to model completely the natural data relationships and requirements of the environment without imposing any unwanted restriction on the use and communication of data.

SOFTWARE

Data Base Management System

Data Base Management System is the software that support a database. To utilize its full benefits, the database must demonstrate the following characteristics: (18)

An organized, integrated collection of data
A natural, logical representation of the data
Capable of use by all relevent applications without duplication of data

The Data Base Management System of itself does not produce output of direct value to the user, rather it is a tool by which output can be produced more readily. It does not include application programs that translate stored data into information, however, it is to form the basis of an efficient information System.

The Data Base Management System can provide:

- The controlled integration of data, so as to avoid the inefficiency and inconsistency of duplicated data.
- The separation of physical data storage from the logic of the applications using the data, to aid flexibility and ease of change in a dynamic environment.
- A single control of all data, permitting controlled concurrent use by a number of independent on-line users.
- Provision for complex file structures and access paths, such that relevant relationships between data units can be readily expressed and data can be retrieved most efficiently for a variety of applications.
- Generalized facilities for the rapid storage, modification, reorganization, analysis and retrieval of data, so that the use of a database system imposes no restrictions upon the user.
- Privacy controls to prevent unauthorized access to specific units of data, types of data or combinations of data.
- Integrity controls to prevent misuses or corruption of stored data, and facilities to provide complete reconstruction in the event of hardware or software failure.
- Compatibility with major programming languages, existing source programs, a variety of hardware systems and operating systems, and data external to the database.

Data Base Approach

A data base is a collection of units of information organized to permit sharing among different applications and different users. The purpose of using a data base is to consolidate existing data into a single repository, to eliminate redundant data as much as possible, and to disassociate the data from specific application programs. Thus, the use of a data base implies:

- The definition of each element or unit of information only once in the system
- The consolidation of all the definitions in a data definition dictionary describing the total information needs of the system
- The use of efficient special-purpose tools, such as data languages and data base management systems, to implement a physical representation satisfying the needs of multiple applications.

In general, a data base system is data oriented while the traditional file system is function oriented. Therefore, the data base approach is more than a different technique involving the storage of data and the use of additional generalized software. It involves a new approach to design and operate information systems having far reaching effect, beyond the data processing department. It regards data as a shared resource, to be available to a variety of applications and users. All basic data would be input to the data base by each department responsible, and retrieved by those departments needing access to it.

In a traditional file management the data in one file and for one set of programs are generally not available to other programs. This does not mean that such data are not usable, but that it is usually necessary to process the files of one system into a different form or format for use in another system. Consequently, common data in various files lead to considerable data redundancy. In addition, each new problem starts from its own data, otherwise utility programs for preprocessing data in existing files are required. There is a linear relationship between program and data which implies that the program derives the dissociated files. Growth should only occur in terms of data volume and is always associated with the particular application for which the system was organized.

In contrast, the data base system, is an information resource to be drawn upon by all users in the system's environment.

The four major elements of a data base system are:

The data base
Inquiry
File Organization
Data Management Functions

The data base represents the set of all information of interest to the system's user. It is a highly structured collection of data that must be addressed or referenced in order to be useful. The basic element of the data base is the record. A record consists of a number of fields which may be fixed or variable length. The three general categories of data within the record are:

1. Content - Content is the information of the data base that has been encoded as data.
2. Index data - Index data distinguishes one record, or several records, from all others in the data base (Identifier).
3. Structure data - Structure data provides the means for expressing relationships among information represented in the record as content. (Pointers, links, chains).

There are two types of structured data:

1. Physical structured data; garauntees the existence of an associated record and designates its exact location.
2. Logical structured data; implies the existence of associated records and designates the means for finding them if they exist.

Inquiry

Inquiry or user programs provide the means of creating references to the data base. The needs of the user require a definite form in order to result in the inquiry.

First, there must be a user oriented program which translates the inquiry to the system. This language is also used to call a set of programs for loading and execution. These are the inquiry programs. During their execution, they create the necessary references structured according to the design of the data management functions. These in turn translate the inquiry into access points in the data base. The result of system operation is the physical and the logical record. Selected data element of the logical record are then returned to the inquiry Program, which formulates a response to the user and delivers it to him.

With regard to the program selection and loading functions that provide the inquiry programs for execution, it is necessary that an inquiry be prepared and operated in the context of an operating system. For economic reasons, parallel access by a multiplicity of inquiries is fundamental to the large scale data base system. Therefore, an operating system is fundamental to its success. Program selection and loading are proper functions of the operating system. The associated allocation and program to program reference functions which deliver the inquiry parameters to the required data management programs are also part of the operating system.

Whatever the language, the inquiry programs resulting from the translation of this user reference must accomplish several basic functions. The keys and key values of the inquiry must be identified. A key may be considered as the name of a field within a record of the data base. A key value is a specific data value which a record must possess in this key field in order to satisfy the inquiry.

File organization

It is important to distinguish between physical and logical files and records. A physical file is a physical unit such as a reel of magnetic tape. A logical file is a complete set of records for a specific area or purpose that may occupy a fraction or all of a physical file, or that may require more than one physical file.

Similarly, a logical record consists of those fields or data item chosen to describe some entity. A logical record may extend over part or all of a physical record, and may require two or more physical records.

Data also can be viewed at various levels, from that of the storage media to that of the logical connections.

File organization within the data base system provides for expedient retrieval of specific data or a group of related data.

Data Management Functions

The following data management functions are common in all general purpose data base systems:

Data Base and File creation
Data Base and File updating
Data retrieval
Logical and Arithmetic processing
Sorting of records
Merging of records
Report generation

All above functions are involved and controlled by parameters applied to the system by the user. The user, for instance, tells the system, by means of parameters, what information he wants printed out and in what form when the reporting function is activated.

Advantages of Data Base System

Among the advantages which may be derived from using a data base, with a data base management system are the reduction of maintenance and development costs, and the timely availability of online data. The advantages result from the following:

- Data layouts and definitions may change without causing modifications to programs not functionally impacted by the changes.
- The application programmer, freed from concerns such as file organization, access methods, and program interfaces, may increase productivity.
- Less coding and, subsequently, less maintenance activity may be required because the data management system functions need be provided only once, instead of being duplicated in each of the applications. There may no longer be a need to have each application development group devote a substantial part of its resources to producing data management support.
- A data base system can respond to new requests for information. Special requests, made by management for information based on currently maintained data, may be satisfied quickly.
- New applications may use the already defined and maintained data. A data definition dictionary permits the user to recognize whether or not the data exists in the system. If the data does exist, the data definition dictionary shows where it is used.

<u>Comparison of Traditional and Data Base Organization</u>

Traditional Organization	Data Base Organization
Each application typically has its own master file, which contains data duplicated in files of related systems.	The Data Base System creates and maintains interfile access paths automatically so that the same data may be used by multiple applications.
Each physical file containing the data to be updated must be processed separately. This is usually done at different times causing discrepancies in various reports.	A program updates data in a single shared data base. The new data are immediately available for all applications.
Changes in record definition or expansion of record sizes must be reflected in every program accessing the data.	Data description is segregated from application programs. Only those programs actually referring to the changed data type need be modified.

Traditional Organization	Data Base Organization
Most traditional file systems support a single access path so that additional retrieval requirements must be satisfied by search and sort procedures.	Data Base Systems provide automatic generation and maintenance of interfile linkage and indexes, which allows tailoring of access to meet the requirements of application systems.
Application programmers often supply their own data names.	For many access operations, the applications programmer must use names known to the Data Base Management System. Central data definitions are often maintained in a data dictionary system.
Coding of security systems is an independent task.	Control blocks are generated that specify which data elements an individual application program can access. Control information and undesignated data are not available to the program.
No automatic facility is provided: therefore, each application system must program its own recovery procedures. Standardized recovery procedures are difficult to define and implement.	Recoverability is an automatic feature of Data Base Management Systems. Once processing errors are detected, the system can restore the data base files to the last intact file copy. All transactions against the data base are logged on tape, from which quick file restoration is possible.

Operating System

In applications, where continuous update of the data base is required, the computer based information system must be real-time, on-line system.

> A real-time system controls its environment by receiving data, processing them, and returning the results sufficiently quickly to affect the environment at that time.

> An on-line system is one which accepts input directly from the area where it is created. It is also a system in which the output, or results of computation, are returned directly to the area where they are required.

It follows from the definitions above, that a real-time system is always on-line, however the on-line system does not have to operate in real-time, but can function in batch process mode.

Multiprogramming

In a multi-user, multi-source environment where the single processor is subjected to unpredictable and random demands, for the system to perform must have multiprogramming capability. Multiprogramming is the concurrent execution of two or more programs simultaneously resident in the systems main memory (19, 20).

Since the central processor can execute only one instruction at a time, it cannot simultaneously execute instructions from two or more programs. However, it can execute instructions from one program, then from a second program, and then from the first program again. This type of processing is referred to a concurrent execution.

Concurrent execution of programs is desirable because input - output operations are much slower than internal processing. If only one program is processed, the processor is often idle, waiting for an input - output operation to be completed. In a multiprogramming environment the processor can execute one program while a second program is waiting for input - output operations.

In multiprogramming, areas of main storage are allocated for each program to be executed concurrently. These areas are referred to as partitions. Partitions provide two major functions: storage protection and priority. The storage protection feature is required so that a program in one partition cannot write over and destroy instructions in another partition. To accomplish this function, each program is assigned a range of memory locations, and the program cannot modify storage locations outside of this range.

Priority in multiprogramming is established by loading the programs in specific partitions. High priority partitions are called foreground partitions. Low priority partitions are called background partitions. Programs loaded into this area are called background partitions.

Programs that have high input - output requirements but relatively low processing requirements are normally located in the foreground partition. Conversely, programs that have comparatively large processing requirements are treated as background programs. The reason for this arrangement is that when a foreground program is waiting for input - output operations, the processor will execute background programs that have relatively high processing requirements.

Precise execution of the multiprogramming tasks is supervised by the executive programs of the operating system.

Executive

The principal control program in an operating system is referred to as executive. The executive controls and coordinates all the processing in the computer system. Specifically, following are the major functions performed by most executives.

- Loads processing programs into computer main memory from the system library or from input device.
- Schedules and controls input - output operations based on priority assignments.
- Handles interrupts, or signals the processor when the previously busy input - output device is now available for use.
- Opens and closes files and handles error situations encountered during input - output operations.

Some of the executive functions are required by every program processed by the computer and consequently they reside permanently in the main memory.

The problem of synchronizing the central processor and the peripheral devices after the completion of input - output operations, was solved by the interrupt concept. An Interrupt is a timing signal set by a peripheral device in a register connected to a central processor. It is examined by the central processor after the execution of each instruction. When an interrupt occurs, the central processor suspends the execution of its current program and releases the system to the operating system. When the operating system has responded properly to the device signal, it can either resume the execution of the interrupted program or start a higher priority program. This technique made concurrent operation of a central processor and its peripheral devices possible. The same technique can be used to simulate concurrent execution of several user programs on a single processor.

Interrupt facilities range from single to complex. The simplest method is to inclusively OR all interface flags together. If any one flag is asserted, the program interrupt is initiated when no other higher priority operations are pending in the processor. Once the processor acknowledges the interrupt, program execution must be directed to check all interface flags, to determine which interface or interfaces caused the interrupt.

A more efficient method of handling interrupts is to have the interrupting device identify itself to the Input - Output System. Identification is usually made by having the interface transmit a unique character to the Input - Output hardware. This method has the advantage of decreasing the time between the interrupt request and the start of the service routine, since flag identification is automatic.

When several interfaces request interrupt service simultaneously, the decision is made on the basis of priority. Priority is defined by the order in which the interfaces are connected to the Input Output bus. The closer the interface to the Central Processor, the higher the priority. When the Input - Output hardware recognizes that some, yet undetermined devices want to interrupt, it sends a signal down the bus. This signal is passed on from interface to interface along the bus. Interfaces with their flags raised stop this signal from passing to the next device.

If the operating program is able also to assign a priority to the processor, then the Input - Output facility will permit interrupts only on lines with priority greater then processor priority. This has much application in real-time systems, where it is necessary to hold pending lower priority tasks until more critical tasks are completed.

<u>Queuing</u>

All finite systems, which are service providers, are subject to queues. In the computer based information system transactions must wait in line to be processed.

Queuing is determined by two basic entities: (21)

- The service facility
- Demands placed against the system

The behavior of both entities always relates to time.

In theory, a system can be designed to service any level of demand in practically any time frame. Economics will not permit such a system, however, as a result, the system must be designed to give reasonable service. Acceptable design criteria must be specified, for example; probability that the response time will be five seconds or less must be 99 percent.

The economics in designing a real-time system are such that decreasing response time increases cost. Response time includes waiting and processing time. By using more powerful computer and high speed data transmission channels, response time can be decreased under the same input conditions.

In many applications, a mix of services are provided. There is also a mix of related priorities associated with these services. Higher priorities for service relate to the higher importance of faster response. A system designed to give equal response in all services does not take into account that some things are more important than others. Such system must cost more than they need to, since every function they carry out is geared to the faster response requirements of the most important services. Proper design should recognize service priorities.

Priority levels, as reflected in the design are not usually serviced progressively to the exclusion of all other subordinate levels. Therefore, a high priority input cannot seize the system full time. The priority scheme gives lower priority input recognition less often. The Queue discipline, places messages in their proper priority stack as they are received and it also stacks outgoing messages.

The usual service sequence within a given priority level is generally first in, first out. Depending on the number of distinct priority levels, the system may be designed to scan the queue stack to identify high priority messages for high priority processing.

In advanced real-time systems, the rules pertaining to the processing of queues can get quite complex. Priorities, for example, may be set dynamically, so that the equipment can be more fully used and better overall service provided. For example, if the highest priority transaction, in the system cannot be processed because the configuration resources it needs are momentarily tied up, the system will look for something else to do in the interim. In some applications, it may be advantageous to hold and requeue messages to provide more efficient search and retrieval of information from on-line data bases.

An advanced real-time system, can partly process a transaction to the point, where a needed resource is found to be occupied, then do something else, and later return to complete the processing. Since a number of transactions may be in various stages of completion at any one time, it is necessary that processing programs not depend on finishing part or total processing of a message.

There are the following common types of queues:

Input Queue
Channel waiting Queue
Process Queue
Output Queue

Designing the queuing structure of a system, the size of the various queues must be calculated. It can be estimated, in close approximation, from the number of transactions the system must handle at its peak time. That will have an effect on basic decisions such as how large core-memory the compurer requires or, given a fixed size memory, how the queues will be programmed.

Computer

One of the largest area of growth in computer applications is information storage and retrieval associated with ever increasing data base. Considerable effort is being devoted to the development of a new, Data Base Computer (22, 23) which is optimized for these applications. The present, high performance computers have been of relatively conventional design because electronic computing had its origin in scientific computing. It was brought to life for calculating ballistic tables and solving systems of linear equations.

However, these computers are not as well suited for information storage and retrieval. This is because information storage and retrieval applications require addressing by content, while conventional computers are designed for referencing by physical address. This mismatch between conventional computer architecture and application requirements for information retrieval introduces inefficiencies in both the processor and storage areas, such that data access can become computerbound and tables required to locate data can consume more storage than the data itself.

The usual way to access a data base, from the user standpoint, is by content. But the conventional computer architecture provides access by address only, not content, Therefore, until a Data Base Computer architecture becomes available, the conventional computer is employed, which can only obtain access to the data base through the use of pointers. Pointers, in general, represent an essential part in any composite data structure for linking components of the record. It is also used to connect one composite record to another. The pointer therefore substitutes for the address by pointing to the location of the data, identified by content.

Direct Memory Access

The processing power and usefulness of a computer depend largely upon the range of peripherals that can be connected to it. The purpose of peripheral equipment is to perform services that the central processor cannot do by itself: to sense stimuli from signal sources, (analog-digital converters) to provide stimuli to external equipment, (digital-analog converters) to receive data, (key boards, card readers) to provide hard-copy reports, (printers) to generate displays (CRT's) or to store large amounts of information (disk, magnetic tape). These components are connected by interface.

In a direct-memory-access transfer, the device interface transfers the unit of information directly between core memory and the peripheral in an operation that is completely transparent to the central processor. Operation of the processor is temporaly suspended for approximately one memory cycle while the transfer is taking place. When the transfer is finished, normal program execution resumes, with all processor registers intact. Direct memory access is usually used to transfer large blocks of data between memory and the peripheral device at high rates.

Different method is used, when direct memory access transfer is a moderately high data rate. Instead of the interface containing word-count and current-address registers, core memory locations are used for these functions. The interface need only to specify where in memory these locations are. The Input - Output system takes on the additional functions. This facility could be termed a multi-cycle direct memory access, since memory must be accessed three times: once to examine and update the current address, once to update the word count and detect the end of a block of information and once to access the unit of information itself.

A large data base requires a large storage facility. In a real-time operation high speed, random access of data, is an essential requirement. Overall system performance primarily depends on the time required to access data called seek time. Seek time can vary by as much as a factor of ten, determined by the type of storage device.

Device type	Seek time (milliseconds)
Fixed Head Disk	20 - 40
Disk pack	30 - 60
Movable Head Disk	180 - 250

Data Communications Facility

A data communication system is defined as an electrical transmission system for the moving of encoded information. The system must include input devices, transmission media and output devices. In real-time data communication systems, it is very important that a buffer storage is provided. Its capacity must match with other components of the system, otherwise the terminal performance can be affected, to the extent that real-time operation may not be attained.

Synchronization circuitry provides additional signals that are transmitted with the data to indicate the start and end of each character, or it provides timing pulses to hold the sending and receiving equipment in step for each message. The first is called asynchronous transmission, the later is the synchronous one. Asynchronous transmission requires that each character, rather than each message, be put in step. Since synchronous transmission does not require the extra bits on each character, it can transmit information faster. For data transmission at speeds higher than 75 bits per second, the carrier technique is used (25, 26) which requires an interface between each end of the communication facilities and the rest of the terminal equipment. The device on the sending end is the modulator, the one on the receiving end is the demodulator or commonly referred to as modems.

In the carrier technique, the DC pulse is generated by the input device, is fed to the modulator circuits of the modem where it is caused to modulate a carrier-transmission frequency that has been generated in the modem.

Depending on the bandwidth of the communications facility, the modem may be one that generates a single transmission frequency for serial transmission or it may be one that generates several transmission frequencies for parallel transmission (24). In serial transmission, the characters making up the data are re-sent on their way bit by bit. In parallel transmission, all the bits representing each character are sent simultaneously. Parallel transmission therefore requires a communications facility of correspondingly wider bandwith.

Communication channels can be arranged for operation in one or more of the three basic modes:

1. Simplex: Transmission is in one direction only
2. Half Duplex: Provision is made for transmission in both directions but not at the same time.
3. Full Duplex: Transmission can be made in both directions simultaneously.

Rate of transmission is expressed in units of baud. In serial transmission a baud is equivalent to one bit per second. In parallel (broad band) transmission a baud is equivalent to a bit set (character) per second.

Error Detection

In transmitting data over a communications facility that may include wire lines, cables, microwave radio links, error can be expected as a result of the nature of the communication facility itself. This is due to noise, fading, and phase delay, which distort the transmitted signal. There are numerous techniques (most common is the check digit) for applying error detection codes to the data at the sending end for detecting errors introduced during transmission. Error detecting equipment at the receiving end will indicate error or if more sophisticated it automatically will request retransmission.

Information integrity is concerned primarily with the accuracy and validity of information flowing between information sources and destination. Commonly used technique for the detection of errors in communication networks is achieved by the employment of parity bit. The bit is chosen to be zero or one, as necessary to keep the total number of digits in the binary word, odd or even according to prior agreement. In even parity, if the information bits of the character had an even number of one bits, the parity bit is set to a "zero", thus maintaining the even parity. The total number of one bits, including the parity bit in an even parity character, is always an even number. For odd parity schemes, the reverse is true, with the total number of one bits, including the parity bit, always an odd number. Source devices then generate characters of even or odd parity. Receiving devices check each incoming character for the appropriate parity condition. If the receiving device is receiving an odd parity character set and one character appears with even parity, an appropriate signal is produced, indicating that an error has occured somewhere between the transmission.

The parity generation and detection functions may be performed entirely by the hardware or by the software or by a combination of both.

III. CLINICAL LABORATORY INFORMATION SYSTEM

Objectives

The clinical laboratory is an integral component of the patient care process. Its primary function is to provide pertinent diagnostic and therapeutic information about the patient for the medical staff. (27, 28) Consequently the clinical laboratory is a major information subsystem of the total patient information system. The value of the information provided by the laboratories depends not only on the numerical accuracy but also on the timeliness of its delivery to the responsible physician. The limited organizational and physical boundries, in which the clinical laboratories operate, must be extended and integrated with all of the other activities in the hospital, involved with patient data handling. In order to achieve a smooth and efficient flow of patient information, both the interdepartmental and intradepartmental data handling must be automated and integrated.

To implement a computerized information system for the clinical laboratories the system approach was taken. This approach basically is the systematic review of the causes of the problem or the factors bearing on that problem and then a determination of possible solutions and the trade offs in selecting those solutions. The total system is composed of many subsystems. When the evolution of the total system is by piecemeal, and fragmented subsystems are added on, the efficiency, reliability and speed that can be derived only from an integrity of total system design, are usually lost. Much duplication is required and to interface parts of the system, and to achieve proper interaction among the various fragments might create an overwhelming problem.

Function of the laboratory consist of a series of tasks, each consisting of a number of tests carried out in a predescribed sequence. The flow chart in appendix 1 outlines the major steps. Data handling portion of the laboratory tasks include:

- Specimen accessioning
- Linking the specimen with the request form
- Preparing the master work list
- Preparing the individual work list
- Recording the raw test data
- Calculating the results
- Checking the quality of results
- Linking results with the request form
- Transcribing the results on the request form
- Sorting a copy of the request form for mailing
- Filing a copy of request form form for records
- Generate lab statistics
- Generate billing information

With the greater application of new technology to medicine, the care of patients increasingly relies on laboratory investigations. The increased speed of laboratory analysis obtainable from automation, highlighted the importance of automation of data processing. Often tests can now be performed in less time than it takes to prepare the report (29). Without automated data processing much of the advantage of automated analytical procedures will be lost. Data processing is becoming the bottleneck of the clinical laboratory (30).

By implementing computer based information system, it should be possible to automate nearly all the steps comprising laboratory data processing, thereby reducing clerical work, eliminating a large proportion of errors, and effecting a rapid and informative reporting. Much more comprehensive quality control and more extensive verifying procedures become feasible and this leads to a raising of the standard of performance in the laboratory and enhances the quality of patient care. (31).

As initial goals and objectives, the computer based information processing had to include the following:

Patient Reports:

- Reduction of the time interval between ordering a test and receiving the report
- All reports printed in standard, concise format
- All values sensitive to age and sex differences reported with normal range appropriate to patient
- All abnormal values flagged to direct attention of physician to abberant results
- Medically dangerous values automatically called to attention at earliest possible time in the testing process for immediate communication to the physician.
- All verified results in computer system to facilitate inquiry by medical and nursing staffs.
- Cummulative reports including all lab procedures in chronologic order by test types. Facilitates physician evaluation of trends in laboratory data.
- Support of laboratory test panels designed to target clinical disorders e. g. cardiac enzyme panel, liver profile
- Individually tailored physician reports of latest lab data for each patient managed by the physician. Printed in structured format reflecting spatial distribution of patients in hospital to facilitate daily rounds.
- Continuous update of patient census to assure that report is sent to the patient present location
- Inquiry by name of the patient. If the physician calls from outside the hospital does not have the patient serial number

Laboratory Reports:

- Entry of all test requests and specimens received into system in order to assure timely and appropriate processing in each instance. Remote and centralized accessioning capability. Accession numbers automatically assigned by system.
- Direct, on line interface for the automated instrumentation: SMA 6 SMAC, COULTER, AMES, LARC
- Automatic billing for tests to be performed upon entry to system acknowledging receipt of an appropriate and adequate specimen.
- Time audit of appropriate intervals for emergency test processing in order to provide immediate correction of faulty procedure (e. g. time from order to collection of specimen, time from order to accessioning, time from accessioning to reporting).
- Collection instructions and prepared specimen labels to facilitate correct use of various type containers, procedures, and ensure correct identification of patient and specimens obtained.
- Work lists to facilitate organization of samples for testing.
- Data entry devices permitting efficient function by laboratory technologist. Desirable to provide system feed back on-line for certain procedures in which technologist function might be extended due to nature of data entered.
- Inquiry capability by specimen number for all lab data by technologist to assist in evaluation of current test data prior to verification.
- Statistical functions available to assist in evaluation of current test data prior to verification, and laboratory utilization.
- Unfinished test report to facilitate tracking of incomplete test and relocate technologist based on the distribution of incomplete tests.
- Abnormal trend report to indicate drastic change in patients condition.
- Quality control report to monitor the performance of the laboratory.

Reliable patient identification is a fundamental prerequisite of any laboratory data processing system, and, as laboratory practice relates patients to specimens, the problem of identifying specimens is equally important. An unique number, called patients Serial Number, is allocated to each patient at admission. The number is computer generated and as to serve as a positive identifier the last digit is a check digit. The scheme to create and validate the check digit is shown in appendix 2. Each time a patient file is accessed, it is possible only through the Serial Number. The Serial Number appears on the patient identification card, on all request slips from ancillary services, the patient chart and other documents. This number is a temporary number with a new number being issued each time the patient is being admitted. A second, permanent medical number is the Unit Number.

Unit Number is included in all chart reports to aid the medical record department in the filing of the various documents.

Since the computer assigns the specimen number to a specific test service for each individual patient, the possibility to assign the same number to more than one specimen is eliminated and a complete and continuous correlation between specimen number and patient is assured.

Management Objectives:

- Capturing charge information and the timely entering of the correct laboratory ;charge against the right patient.
- Provide direct access to patient data base for the medical and nursing staff and other users.
- Provide long term storage of laboratory data in computer readible form for research and education.
- Maintain data base to generate the necessary documentation as required by federal, state or local governments. (32).

Systems Configuration

The system is built around the Diversified Numeric Application, Type MED/16 Multiprocessor. It is a general purpose, medium scale, single address digital computer, having the following features:

16 Bit word length - Single Address
1.1 Microsecond Full Cycle Time
Fully Partitioned Core Memory
Addressing: Direct, Indirect, Indexed direct and Indexed Indirect
Word and Byte Manipulation Instructions
Hardware Multiply and Divide
3 Hardware Index Registers
8 Priority Hardware Interrupts
6 High Speed Selector Input - Output Channels
32 Multiplexor, Input - Output Channels
Realtime Clock and Power Failure Protect
16 K Random Access ferrite magnetic core
89 Unique and Separate Instructions

Speed:	Add/Subtract	2.2 micros.
	Multiply	14.3 micros.
	Divide	17.6 micros.
	Compare	2.2 micros.
	Multiplex I/O Transfers	1.1 micros.
	Selector I/O Transfers	1.1 micros.

The system utilizes four fixed head rotating mass memory for the storage of programs, data files. The mass memory control and storage unit operate in the direct memory access (selector channel) data transfer mode, and is connected directly to core memory. The mass memory control and storage units have the following characteristics:

Average Access Time: 17 milliseconds
Block Transfer of 512 words
Transfer Rate: 2,746.800 bits/second
Capacity: 64 Tracks, 80 sectors per track, 5120 words per track
Number of disks in system: 4

Master Console

The master console is located in close proximity to the processor and permits a simple two-way interaction between operator and the central processor. It is utilized to trigger, via keyboard, the generation of reports.

Analog-Digital converter.

The high speed A/D converter is for continuous, on-line, high speed data acquisition from interfaced laboratory instruments. It has a 12 bit resolution, providing resolution to $\pm$ 1 part in 2048.

High Speed Paper Tape Reader

The paper tape reader converts information punched on the paper tape to electrical signals at a rate of 400 characters per second. It is used for program loading.

Line Printer

The line printer is an electromechanical device for printing of reports. The line printer has the following specifications:

Printing speed:	450 lines per minute
Line Width:	128 columns
Characters per column:	64
Print spacing:	10 columns per inch
Line spacing:	6 lines per inch

Communication Controller

The 32 full duplex communication channels transfer 12-bit information to and from the computer. Eight of the 12-bits are data bits and the remaining four are status bits.

Magnetic Tape Transport

For long term storage of patient data daily information is copied on magnetic tape and stored externally. Periodic copying of the system is performed routinely, every few hours, to serve as back up.

Card Reader

Laboratory test file is prepared on punch card and entered into the system by high speed (200 words/minute) card reader.

Other peripheral devices

The large number of communication terminals can be functionally divided into the following groups:

Request Entry Terminals
Result Entry Terminals
Control Terminals, for on-line instruments
Inquiry Terminals.

The terminals are specilly designed to simplify data entry in fixed format. They must be operational 24 hours a day and are handled by many users. Users consist of a heterogenous group with various skills and expertise, physicians, nurses, unit clerks, technologists. Therefore, it is very important that terminal operations involve:

- minimum number of key strokes
- minimum of training
- simplified procedures

System configuration is shown in the following appendices:
Appendix 3: Computer Center
Appendix 4: Terminal Network in Laboratories
Appendix 5: Terminal Network in Patient Areas

PDP 11/10 Minicomputer

This minicomputer is dedicated to provide continuous updates in patient census. It is a communication link between admission office and the patient information system.

Software Description

The System consists of an Executive, a number of applications programs, and a Data Base. The Executive is responsible for the overall system performance. It receives requests for services from a variety of sources - the console operator, terminal stations, online and offline instrumentation, applications and system functions - and dynamically allocates the system resources (processor, output devices, mass storage, tape drive) to these various requests. The Applications Programs are used for such diverse purposes as data collection, processing, statistical analysis, report generation, etc... The Data Base contains up to date information on all the patients currently in the system (e.g. patient identification and location, test results and requests), as well as on the hospital configuration (e.g. room allocation per ward, test specifications).

The Executive is an interrupt and request driven processor designed to make good utilization of all system resources in order to perform all processes as quickly and efficiently as possible. Each task - either system or applications - is assigned one of eight available levels of multiprogramming, known as a queue level. Each queue level is allocated a portion of system resources (core and disk storage). Memory allocation is shown in appendix 6. Appendix 7 shows allocation on disk. Processing of tasks within a queue level is on a first-in, first-out basis. Once a task begins execution on the processor it normally relinquishes control only at a voluntary input - output or process request. Asynchronous input - output interrupts will momentarily grab control away from the current task, but control is eventually returned to it. Once a voluntary input - output or process request is issued, the Executive will either initiate the request; or move to the next queue level and start processing that queue. Thus, a steady flow of data throughput is maintained on each queue level.

The main components of the Executive can be identified as:

The Interrupt Handler
QIN - Filling queues
QOT - Emptying queues
IOCON - Input - Output Control
RQIO - Request Input - Output

The interrupt handler is responsible for the initial processing associated with each of the 8 classes of interrupts (multiplexer and selector channel interrupts, clock, power failure), after which control passes back to the interrupted task.

QIN is responsible for the filling of queues. Whenever a new task is to be performed (such as calling a program or subroutine) a call to QIN must be issued. The argument list in the call is used to specify the required task. QIN deciphers the desired queue level and passes the argument list to that queue.

QOT (emptying the queues) is the heart of the Executive. Its function is to move from level to level, giving work (from the queues) to those levels that are idle and allocating CPU time to those levels that are active. Once a task on any queue level becomes active it obtains exclusive control over the processor (except for normal interrupt handling activities) until the task voluntarily relinquishes control either by an input - output request, a request for another task (subroutine or program call) or normal task termination. Upon relinquishing the processor, QOT regains control and moves to the next queue level.

The input - output control (IOCON) controls the initiation, monitoring and completion of all input - output activities. It is invoked in one of two ways: by QOT when it recognizes that a given queue level requires input - output activities, or by RQIO to start an input - output request.

RQIO (request input -output is that portion of the Executive that is responsible for the initial handling of all voluntary input - output requests. It deciphers the nature of the input - output request and passes control to IOCON, the input - output controller.

The MED/16 Multiprocessor on which System resides has a number of characteristics which a programmer must take into account when writing programs or modifications to existing programs. All programs are written in machine language. One of the characteristics is the addressing modes of the processor. The memory is divided into 2048 word long pages (byte addressing is also available). A memory reference is made up of a 5-bit page code combined with an 11-bit local displacement. References outside the current page (automatically set by each instruction fetch as a function of the page address of the stored instruction) can be made by momentarily forcing the current page address to a new value. This is further complicated by indexed instructions in which either all 16 bits of the index register are meant to participate in the formation of an address (global mode) or only 11 bits plus the current page address (local mode).

Another characteristic of the MED/16 is the nature of input-output instructions. Two types of channels are available - multiplexer channels, for slow devices (teletypes, line printer) and selector channels for high speed devices (disk, tape). Each type of channel requires different kinds of input - output instructions. The multiplexer channels communicate with the processor via the accumulator register on a single 16 -bit word basis per transfer. The selector channels operate on a different set of rules. The desired channel command words are first stored in a fixed portion of the memory dedicated to this purpose and the channel is activated via an Activated Selector Channel Command. The channel command words specify the type of input - output transfer, the device dependent information and the core address where transfer is to take place, as well as a word count. The core address is forced to a 64 word boundary by the nature of the input - output channel commands.

The Data Base (saved on mass storage) consists of a number of separate "files", each file with a fixed designation. It can be viewed as consisting of three major components:

- The HOSPITAL DATA BASE contains all the information that defines a given site (room number file, ward director, canned messages, test file, etc...)
- The PATIENT DATA BASE contains an updated "profile" of all patients currently in the system. Each patient is fully identified (name, hospital ID, location in ward, etc...), and all recent test results (up to 28 days old) and unanswered requests for tests are kept.
- The TEMPORARY STORAGE area is used for holding data for up to 1 day. System queues, instrumentation output and other daily hospital information (purge file, billing file) are saved here.

These three subdivisions are structurally interrelated in that the HOSPITAL DATA BASE provides a meaning to the various quantities in the other two sections. For example, a patient result saved in the Purge File (TEMPORARY STORAGE) has a meaning which is defined by various quantities in the Test File (HOSPITAL DATA BASE). System throughput, accessing the files is shown in appendix 8.

The PATIENT DATA BASE consists of six files whose relationship among themselves as well as with the HOSPITAL DATA BASE may be expressed in the following:

Patient Data Base	Hospital Data Base
Patient Header File	
Patient Locator File	Ward Directory
Patient Name File	Room Number File
Result File	Test File
Patient Number File	
Specimen Number File	

The Patient Header File provides the starting information to get at any or all of the other patient data files. All other Patient Data Files "point back" to the Patient Header File - either directly, as in the case of the Patient Name and Patient Number files for which a one to one relationship exists with respect to each Patient Header - or indirectly, as in the Result, Patient Location and Specimen files which point back by means of the Patient Header index (known as the IPN or Internal Patient Number).

Input - Output Processing

Inputs may be either requested or spontaneous. The spontaneous input occur in the areas of terminal inputs and binary inputs. These spontaneous inputs are processed by the appropriate interrupt handling routine. The data is stored in holding buffers until a complete message is received. In the case of the terminals, a complete message is usually delineated by a line feed prefix and a carriage return suffix. Terminals which do not always follow this concept (Master Console) have special input processing routines. When a complete message has been received, it is fed into the system by the REQUE function via QIN. The binary inputs are stored in 64 word buffers along with the analog inputs. This data is written onto drum buffers and further processed. Requested inputs, and all outputs, follow the initiator/continuator concept of input - output. The initiator is a portion of the input - output program which processes the input - output function just enough so that an interrupt will be generated. The continuator is the portion of the input - output program which processes the interrupt.

The system identifies the various input - output devices as LUN's, which stands for logical unit number, but is mostly a physical unit assignment. It provides an Output Format capability which is used to transfer various types of data into 72 character ASCII lines suitable for output to any of the system devices. Extended Output Format acts as a buffer between the 72 character ASCII output lines and the terminal driver. Since it takes up to 7.2 seconds to output a complete line to a 110 baud terminal, Output Format cannot pass another line to the terminal driver for that terminal. To prevent a general slowdown of system response, these 72 character lines are buffered on the drum. Thus Output Format is only held up for the time of a single drum transfer (e.g. 16 ms).

Functional Description

Patient Admissions

There are a variety of ways in which patients can be admitted to the clinical laboratory system. This information can be typed in on the Master Console, the CRT Display Terminal, the Request/Inquiry Terminal, through the Card Reader, terminals located in the admitting office, magnetic tape, or directly from another computer. The information that has to be transferred consists of patient number, name, ward, room, bed, age, sex, doctor's name. This information is passed from the communications buffer to the proper queue level and the admission programs are read in. After verification of the check digit in the serial number, the first check that is made is to determine if the patient was previously admitted to the system, and if this condition exists, an alarm message will be generated. If the patient is not in the file, he will then be placed into the next available position in file and an internal patient number or index will be calculated. The format of the patient's name will be checked and his room number will be validated to insure that it is indeed a legitimate available room. Other information such as age, sex, doctor's name will also be checked. If the format of the input data is correct, the patient will be admitted to the system and will replace the existing data in the assigned header file. The admission programs will also place the patient's internal patient number in the locator file in the proper sequence. Admission information (and discharge and transfer) of in-patient is received on-line. A dedicated minicomputer (PDP 11/10) handles the communication between admission office and laboratory system.

Test Requests

Test requests can also be made in different ways, either through the Request/Inquiry Terminal, Mark Sense cards, punched cards, or directly from nursing stations. When a request is input to the system, the basic information that is transmitted consists of patient number and test code number. Typically, this information is transmitted to the Central Processor via the communications controller. The complete input message will be transferred from the communications buffer to queue 0 and the application program will be called. This program will check the format for the input message and analyze the request to see that it has the correct number of digits.

The patient number file will be accessed to determine that the patient number is valid. The request program will then be called to determine that the test number is valid which is accomplished by accessing the test number file. Having determined the validity of both the patient number and test code number, a message will be output to the operator on the Request terminal through the use of a program called output format. Data Flow in the laboratory system starting with request entry, is shown in appendix 9. If the test request is correct, a specimen number will immediately be assigned and a specimen label generated. The open specimen number will then be placed into the individual's patient header file which establishes that the request has been made. The patient's internal patient number (index) is also placed in the specimen number file in the location that corresponds to the accession number assigned. Using this technique a cross-check can easily be made and response time optimized since the open request appears in both places.

Worksheets

Worksheets are printed for the individual tests and the worksheet program sorts through the header files of the various patients looking for the particular test by test code number. The worksheets, that are printed on demand, will contain the test code number, the specimen number, the name of patient, and his serial number.

Data Entry

Data can be entered into the system either directly from an automated instrument that is interfaced to the system, or through data entry terminals. In general, data that is input to the system will contain a specimen number, test code number and results. This information will be placed on the terminal and the complete message buffered to the system via the communications controller. The message will be transferred from the communications buffers to queue 0 with proper application program which checks the format. If the format is correct, processing program will be called to handle the entry of numeric results from terminals. This program will check to see that the specimen number is valid and has been assigned by accessing the specimen number file. If the specimen number has been assigned to someone, then that individual's header file is read in using the internal patient number (index) to see that the test was indeed requested for the individual patient. The system will accept test data only for individuals that have previously had a request made. Flow chart, in appendix 10, outlines the result entry process.

The data entry technique insures the integrity of the data that is entered into the system. Data is always entered in two steps. The first one being referred to as the enter function, and the second step as verify. By employing a dual transmission technique in conjuction with extensive format checking, communications problems are eliminated. As a part of the enter function, the test data is checked to see that it falls within predefined limits. These set of limits are typically referred to as the normal range and reject limits. The limits for normal range can be age/sex dependent with 8 sets of limits for each sex and for each test. If the data entry falls outside of the normal range, the system will immediately flag the data entry as being out of limits by the use of an asterisk. If the data entry falls outside of the reject limits, the data entry will immediately be rejected and an alarm message will be printed for the technologist. On the enter procedure, a message will be printed for the technologist that indicates the data that has been received in the system. If this information is correct, the technologist will verify the data entry, and the above procedure will again be duplicated. System will only write data on the mass memory of the entry that has been verified. The verify program checks to see that the data being verified corresponds directly to the data that was previously entered. If an error occurs at this step, the message "not verified" will be printed for the technologist, indicating that the message was not accepted. A comprehensive flowchard including result entry from on-line instruments, is shown on appendex 11.

Patient Inquiries

The system is designed to handle a number of different types of inquiries. The trend inquiry, lists all test results for a specific test type so that one can determine whether an abnormal trend is developing. The second type of inquiry lists all test results which have not yet been printed on an individual's chart report. The third type of inquiry lists not only the test results which have to be reported, but also includes all unfinished work that has been requested for the patient. Inquiries are usually initiated from one of the terminals such as the CRT Display, and the information that is transmitted includes the patient number and test number. The message will enter the system through communications core buffer and will be transferred to queue 0 and application program is called. This program will check the format of the inquiry and call the request program. This program will check to see that the patient is in the file by accessing the patient number file. If the individual is in the system, a call will be placed on the inquiry program. The inquiry program operates in several different modes depending on the type of information that was requested. If a specific test type was asked for, the inquiry program will immediately read in the header file and then the result blocks that have been assigned to that specific patient. This program will then look through every block searching for the specific test type that was requested. Every time the system locates a result for that specific test series it will output the data and indicate the date that the test was performed. In this manner a trend for a specific test series will be formed. A copy of various type of inquiries is shown in appendix 12. For all inquiries the specimen number can be substituted for patient Serial number. If the patient serial number is not available for inquiry, the terminal operator has to type in the patients name and call for the search program. Appendix 13 illustrates the systems capability to find the correct patient and output the patients serial number and to verify patients identity also the location.

Ward Report

The ward report is typically the first document that is printed that contains the results of the day's tests. This report is called through the master console and the message that initiates this transaction is a queue 0 program. The verification and validation of the request for the generation of the ward report is performed. If the request is valid, a queue call will be made to bring in the ward report program into queue 2. The ward report program uses the patient locator file and goes through the entire patient census one at a time reading in header files for each patient in the hospital. Having read in the header file, the results are then brought in from the result file -- file 3. This program will printout on the line printer every result that has not been previously charted. This report is called an interim report, and it is used primarily to get vital information to the doctors making rounds as soon as possible. As the illustration in appendix 14 shows, the format of this report is one or more pages per ward, with each patient's test grouped together. It contains all results obtained since the previous chart report. For incomplete tests, the name of the tests are listed, and the data and time when request was received also given.

Chart Report

The chart report is one of the major system reports that is produced. This document is requested in a manner very similar to the ward report through the Master Console. There are two different versions of the chart report, the daily chart report, and the 7th day chart report. The daily chart report is a document that shows all test data, one or more pages per patient, on a cumulative basis. The 7th day report is a permanent document that is produced for patients in the hospital on the 7th day and subsequent seven days. The 7th day report is never discarded and is usually printed on a different color paper to signify to medical records that it should be retained. Appendix 15 and appendix 16 illustrate the format of the daily chart report and Seven Day Chart Report, respectively. The chart reports are produced in a manner very similar to the ward report in that the program accesses the patient locator file, the header file, and the patient's data files to obtain the results to be printed. The major difference between the ward report and the cumulative chart report is that this document includes all test results for the individual, not just today's results. The cumulative chart report program also sets a number of different report flags so that other programs can determine that data has been produced on a permanent document.

Abnormal Result Report

The Abnormal Result Reports lists all patient's results that fall outside of the normal range. In addition to abnormal results, abnormal trends are indicated. The abnormal results are automatically compared with the previous test result of that patient, and if the change is greater than a pre-programmed percentage, (Delta check) it is considered an abnormal trend. The result is flagged with an asterisk and the old result is also printed.

This report is arranged by nursing units and lists the patients by room number. All patient information is included and the name of the patient's physician is also printed. Flow chart for the abnormal result report generation is shown in appendix 17.

Laboratory Usage Report

The report prints, the total number of completed tests since the last laboratory usage report.

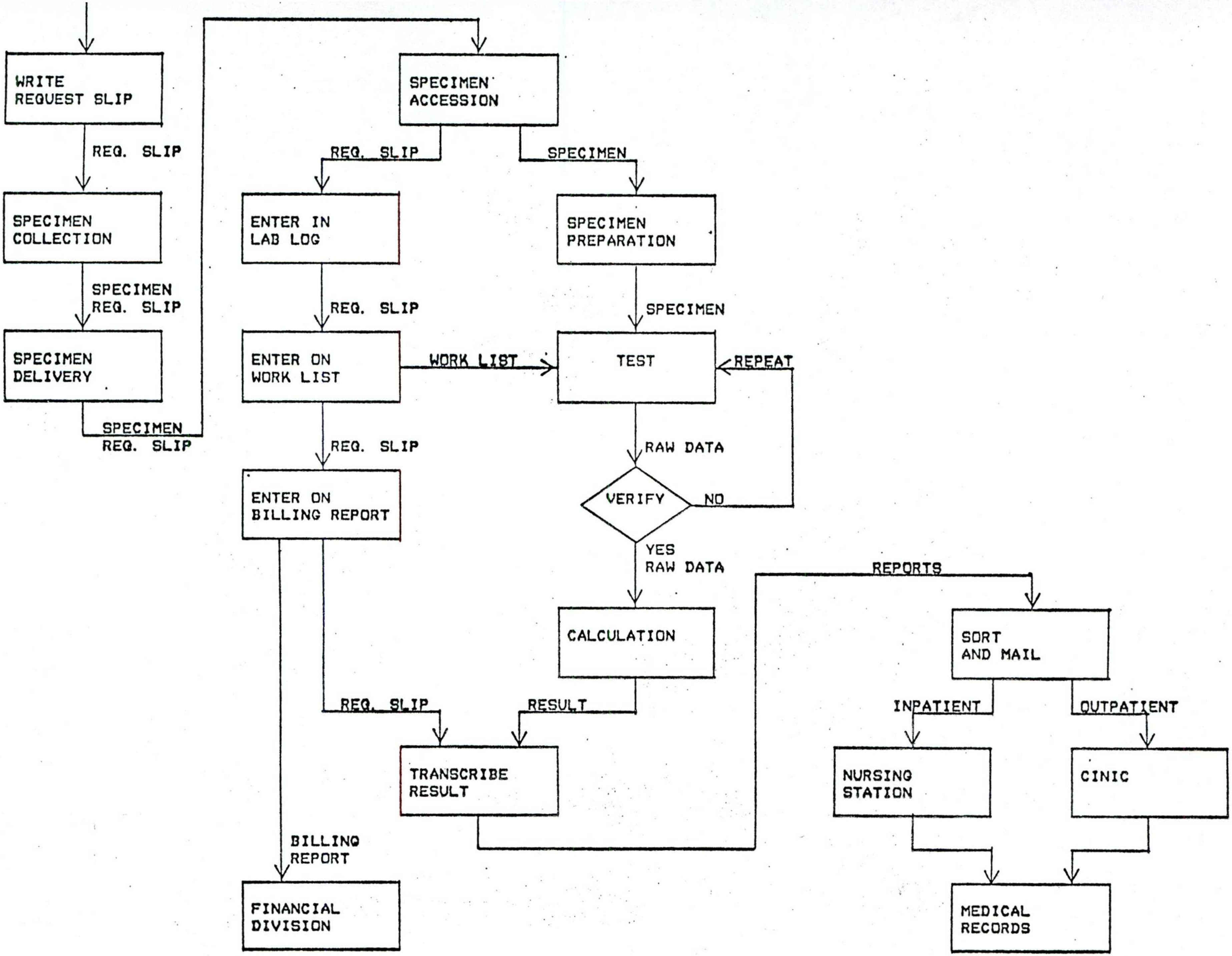
Unfinished Test Report

This report lists all tests which, at the time of printing, have not been completed.

Billing Report

The report provides billing information for each patient in a hard copy printout and on magnetic tape. Financial division receives and processes the information on the magnetic tape, daily.

IV. APPENDIX


WRITE REQUEST SLIP
REQ. SLIP
SPECIMEN COLLECTION
SPECIMEN
REQ. SLIP
SPECIMEN DELIVERY
SPECIMEN
REQ. SLIP
SPECIMEN ACCESSION
REQ. SLIP
SPECIMEN
ENTER IN LAB LOG
SPECIMEN PREPARATION
REQ. SLIP
SPECIMEN
ENTER ON WORK LIST
WORK LIST
TEST
REPEAT
REQ. SLIP
RAW DATA
ENTER ON BILLING REPORT
VERIFY
NO
YES
RAW DATA
REPORTS
CALCULATION
SORT AND MAIL
REQ. SLIP
RESULT
INPATIENT
OUTPATIENT
TRANSCRIBE RESULT
NURSING STATION
CINIC
BILLING REPORT
FINANCIAL DIVISION
MEDICAL RECORDS

APPENDIX 2

CALCULATION OF CHECK DIGIT FOR PATIENT SERIAL NUMBER

Assume that the patient serial number is 123456

Including the low-order (rightmost) digit create a multiplicand consisting of every other digit. The multiplicand in this case is 246

Multiply the multiplicand by 2. The result is now 492

Add the digits of the result -- 4 + 9 + 2 = 15

Add the unused digits of the patient Serial Number 1 + 3 + 5 = 9

Add both results together; 15 + 9 = 24

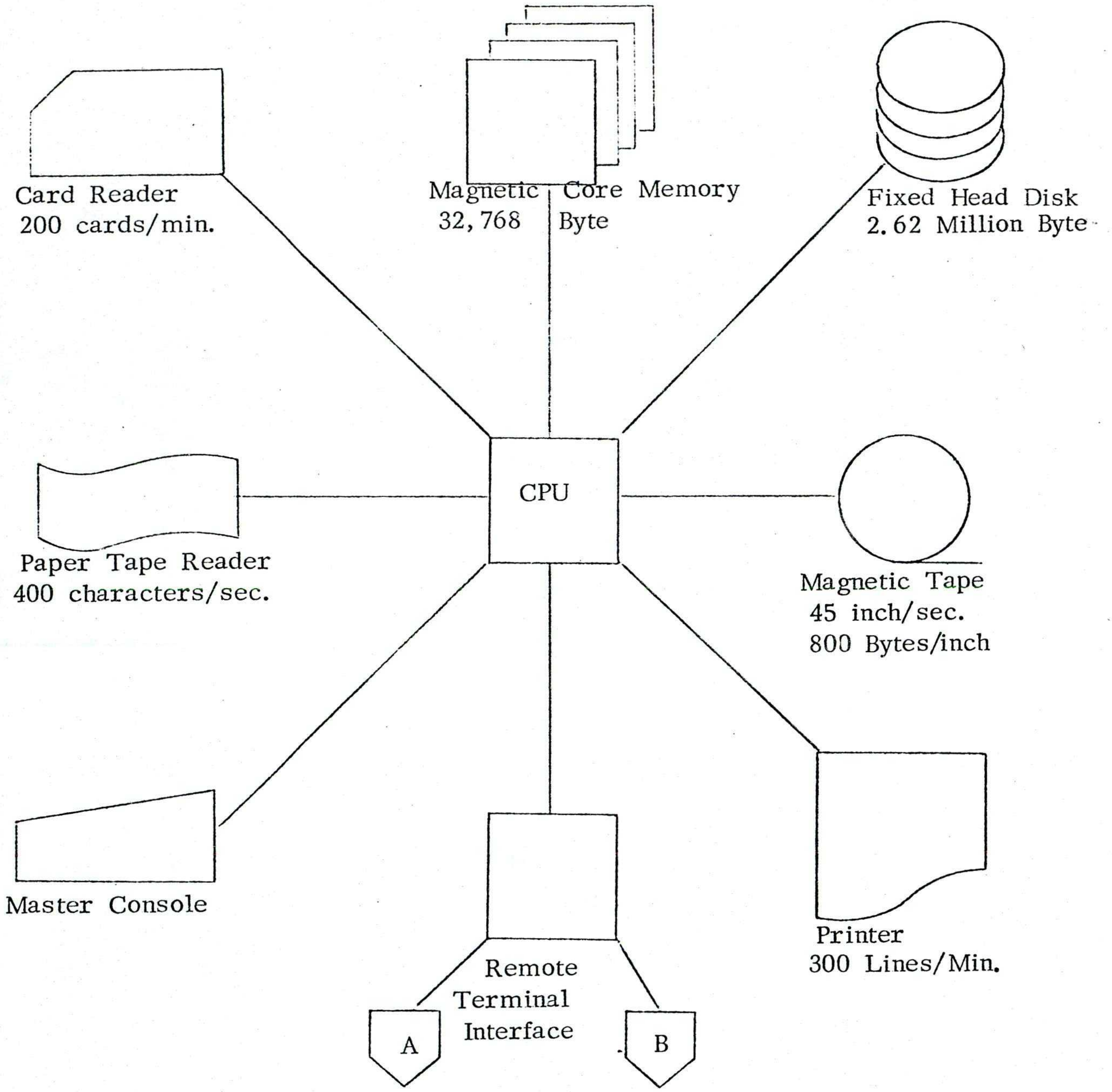
Subtract the sum of both results from 90; 90 - 24 = 66

The low order (rightmost) digit is the Check Digit

The patient Serial Number with Check Digit is now 1234566

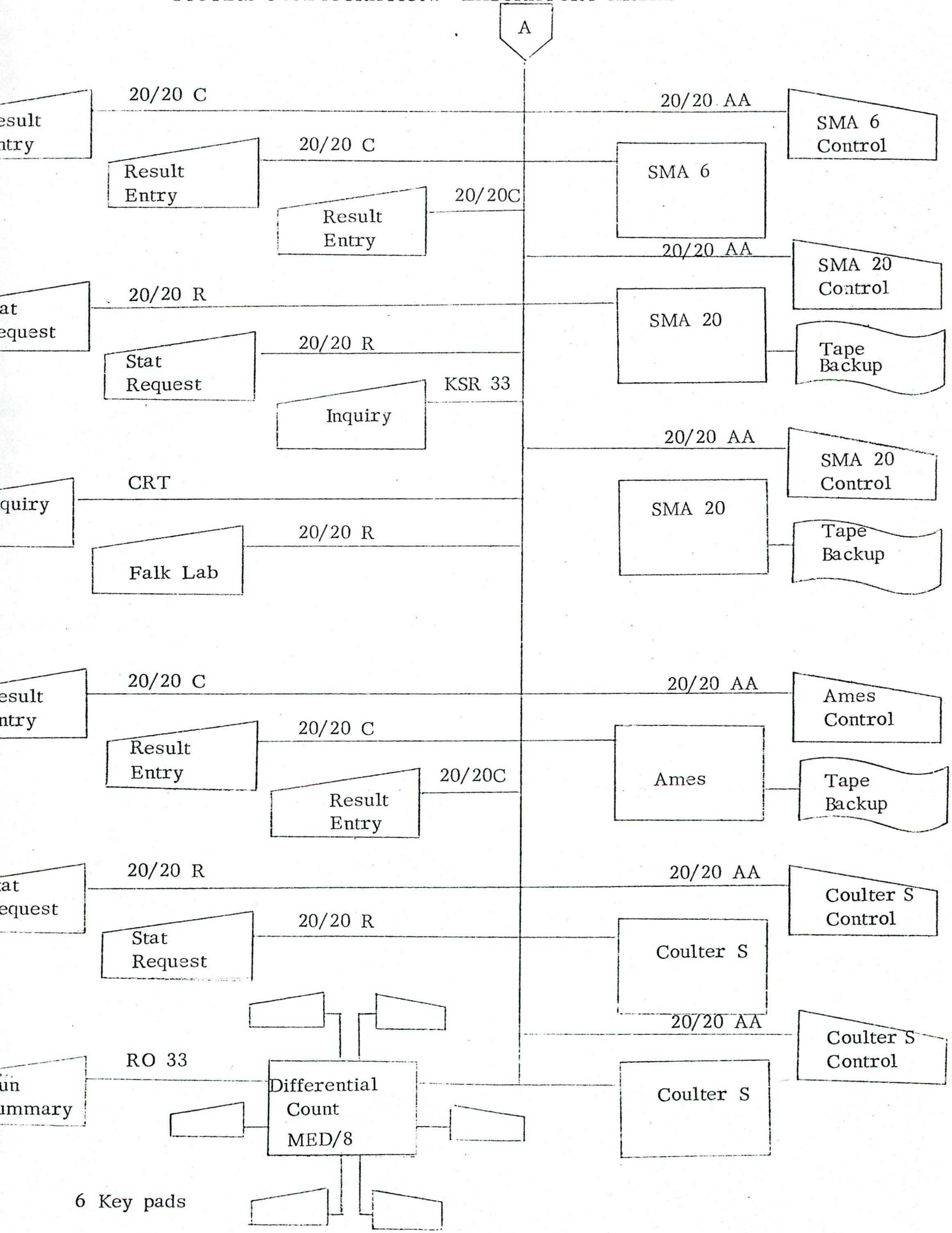
APPENDIX 3

SYSTEM CONFIGURATION : COMPUTER CENTER

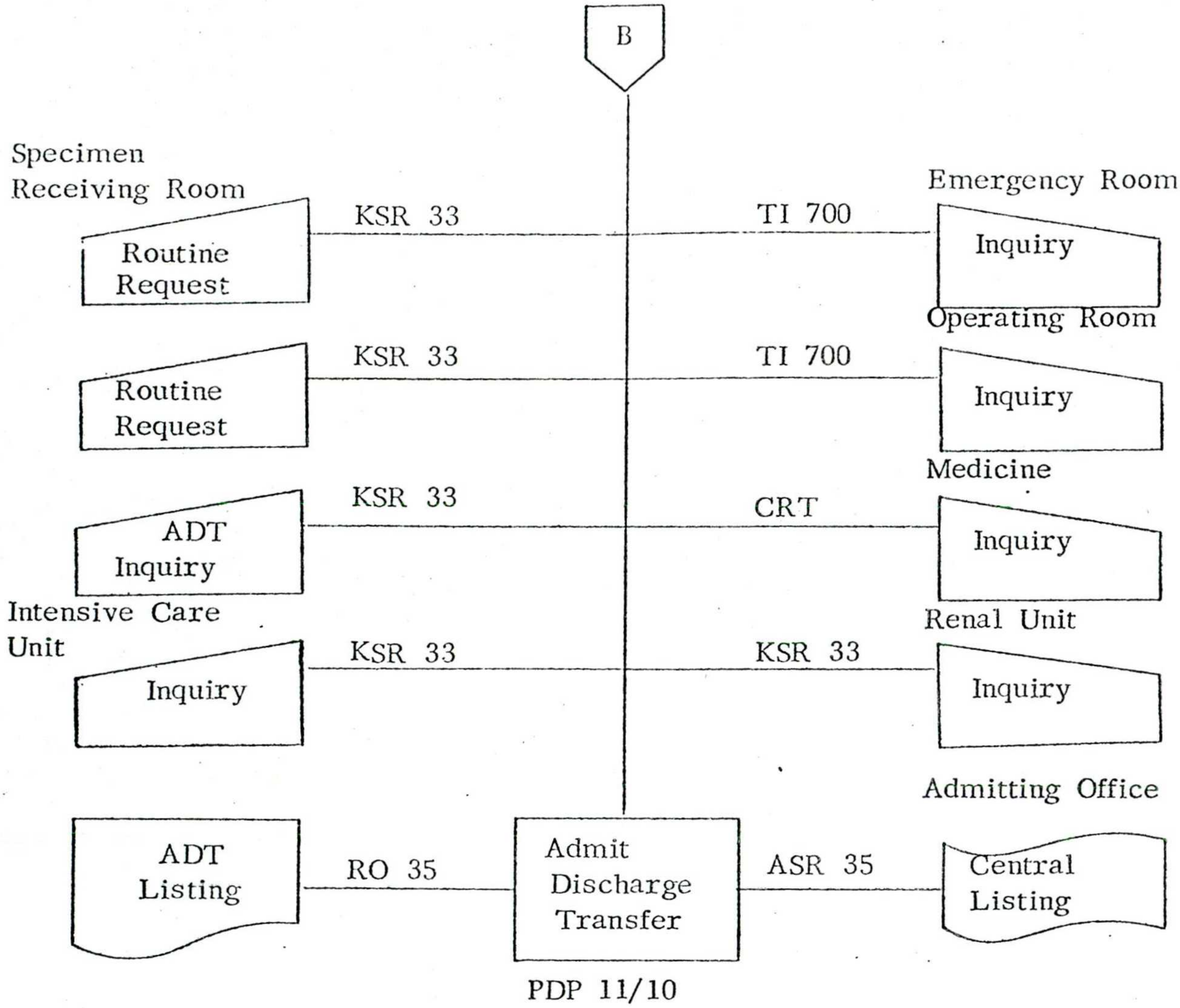


APPENDIX 4

SYSTEM CONFIGURATION: LABORATORY AREAS



APPENDIX 5
SYSTEM CONFIGURATION: PATIENT AREAS



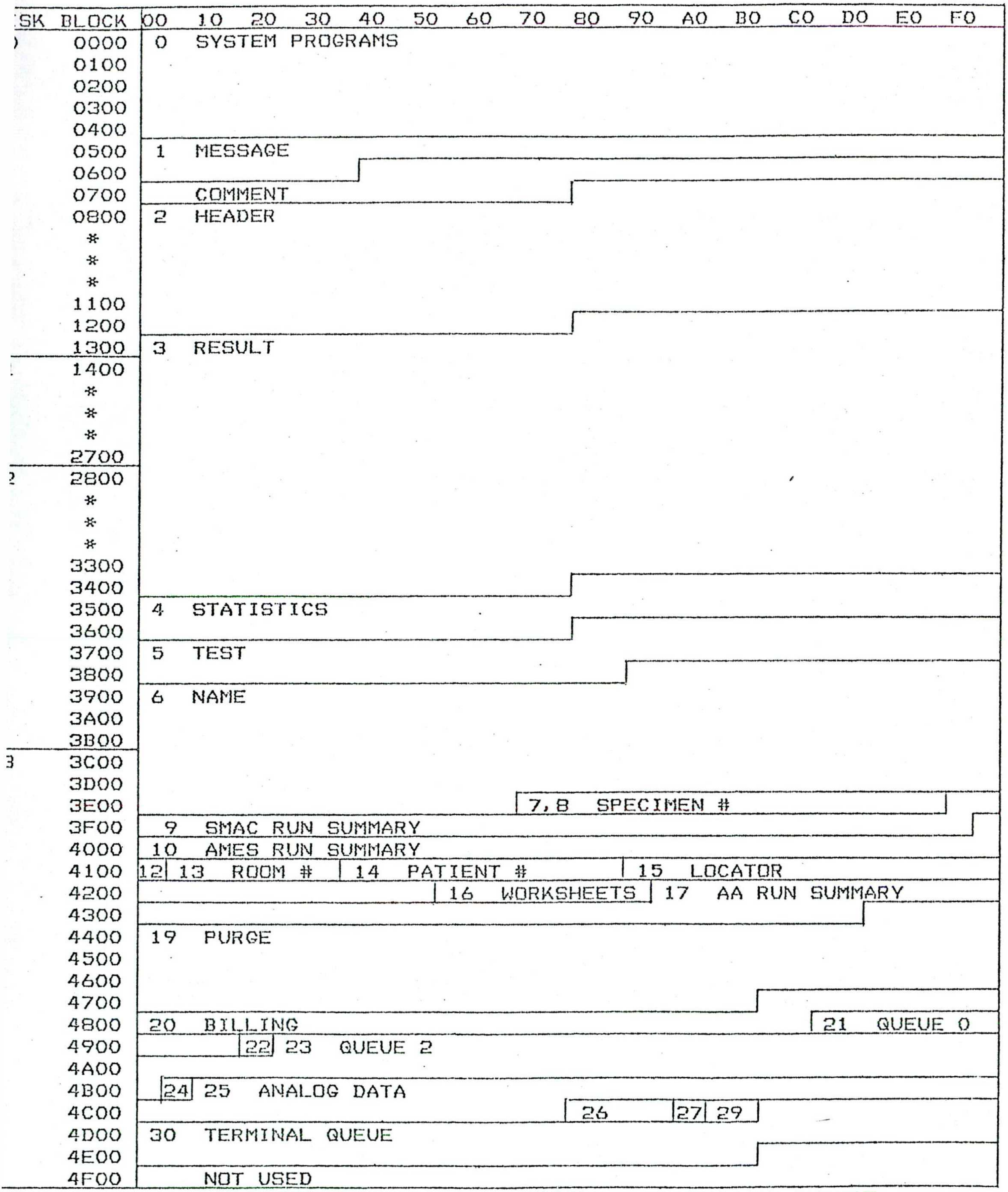
APPENDIX 6

MEMORY ALLOCATION

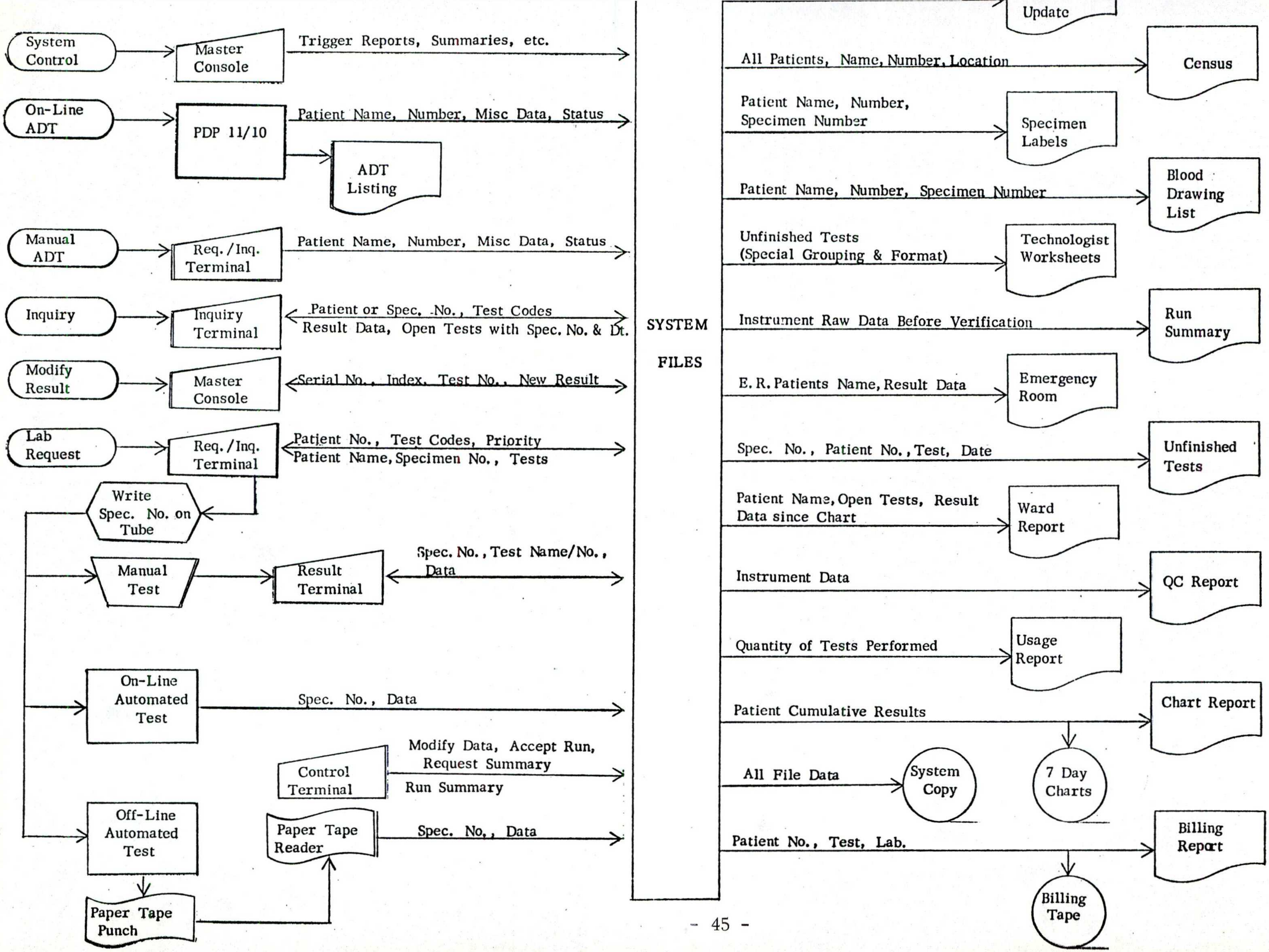
MEMORY ADDRESS	PROGRAM # / BUFFER NAME	FUNCTION
0000	P000	EXECUTIVE PROGRAM
0200	P001	& DATA BASE
0400	P002	
0600	P003	
0800		QUEUE 0 PROGRAM AREA
0C00		QUEUE 2 PROGRAM AREA
1000	P004	OUTPUT FORMAT, CLOCK, MOVE
1200	P005	
1400	P006	
1600	P007	EXTENDED OUTPUT FORMAT
1800		QUEUE 0 WORK AREA
1A00		QUEUE 2 WORK AREA
1C00	P030	ANALOG/BINARY INPUTS
1E00		NON-RESIDENT DMA DRIVERS
2000	P150	2707 MASTER CONSOLE
2200	P151	
2400	RTBUF	REMOTE TERMINAL BUFFERS
2800	P180	INTERACTIVE TERMINALS
2A00	P181	
2C00	P182	
2E00	P183	
3000	CBUF6 / CBUF3	CORE QUEUE BUFFERS
3200	CBUF4	
3400	CBUF1	
3600	CBUF2	
3800	CBUF5	
3A00	CBUF7	
3C00		
3E00		
4000		

APPENDIX 7

SYSTEM FILES

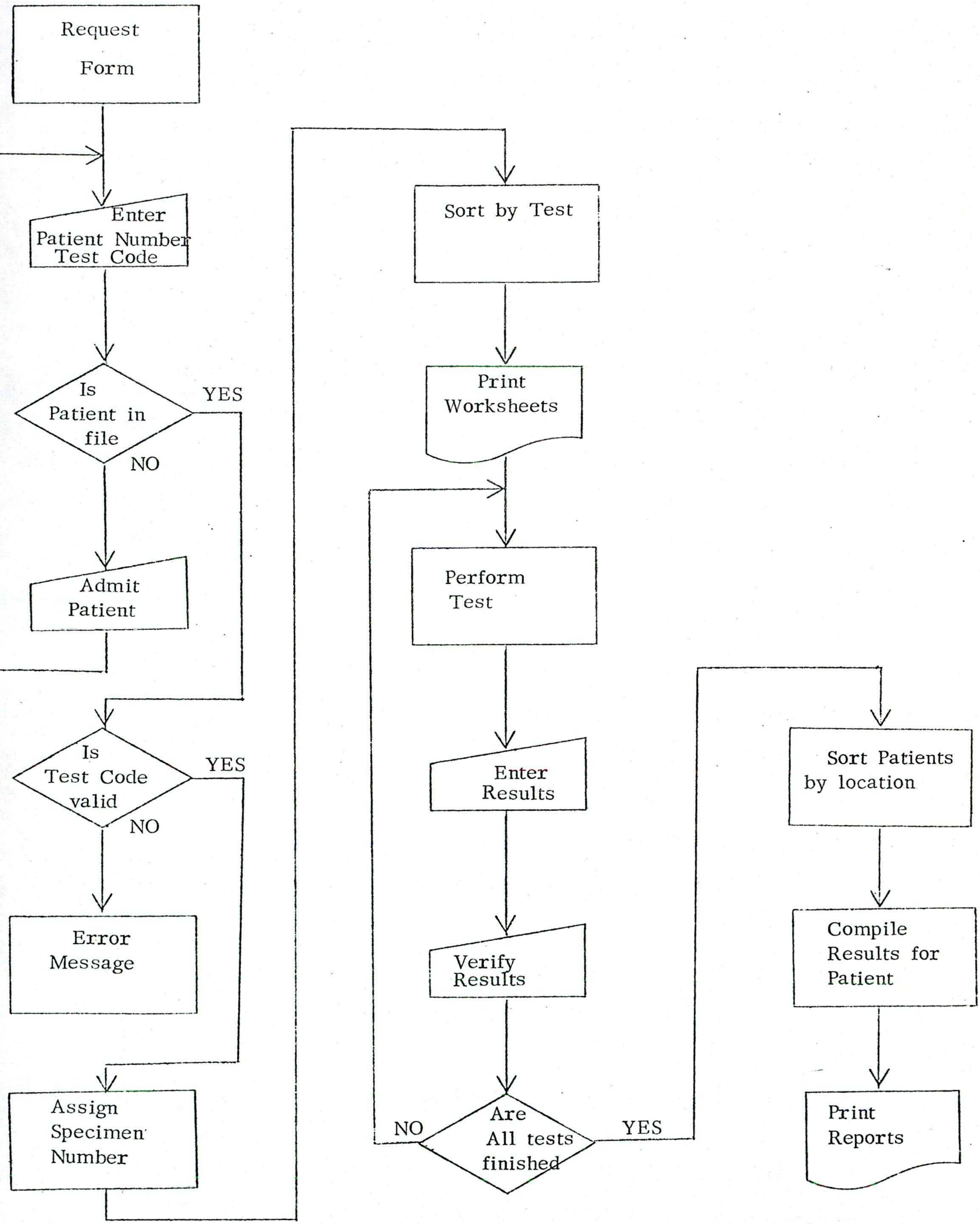


12	DB SAVE	24	QUEUE 3	27	CARD FORMAT
22	QUEUE 1	26	SUBHEADERS	29	CHART FORMAT


System Control
Master Console
Trigger Reports, Summaries, etc.
On-Line ADT
PDP 11/10
Patient Name, Number, Misc Data, Status
ADT Listing
Manual ADT
Req./Inq. Terminal
Patient Name, Number, Misc Data, Status
Inquiry
Inquiry Terminal
Patient or Spec. No., Test Codes
Result Data, Open Tests with Spec. No. & Dt.
Modify Result
Master Console
Serial No., Index, Test No., New Result
Lab Request
Req./Inq. Terminal
Patient No., Test Codes, Priority
Patient Name, Specimen No., Tests
Write Spec. No. on Tube
Manual Test
Result Terminal
Spec. No., Test Name/No., Data
On-Line Automated Test
Spec. No., Data
Control Terminal
Modify Data, Accept Run, Request Summary
Run Summary
Off-Line Automated Test
Paper Tape Punch
Paper Tape Reader
Spec. No., Data
SYSTEM FILES
Update
All Patients, Name, Number, Location
Census
Patient Name, Number, Specimen Number
Specimen Labels
Patient Name, Number, Specimen Number
Blood Drawing List
Unfinished Tests (Special Grouping & Format)
Technologist Worksheets
Instrument Raw Data Before Verification
Run Summary
E.R. Patients Name, Result Data
Emergency Room
Spec. No., Patient No., Test, Date
Unfinished Tests
Patient Name, Open Tests, Result Data since Chart
Ward Report
Instrument Data
QC Report
Quantity of Tests Performed
Usage Report
Patient Cumulative Results
Chart Report
7 Day Charts
All File Data
System Copy
Patient No., Test, Lab.
Billing Report
Billing Tape

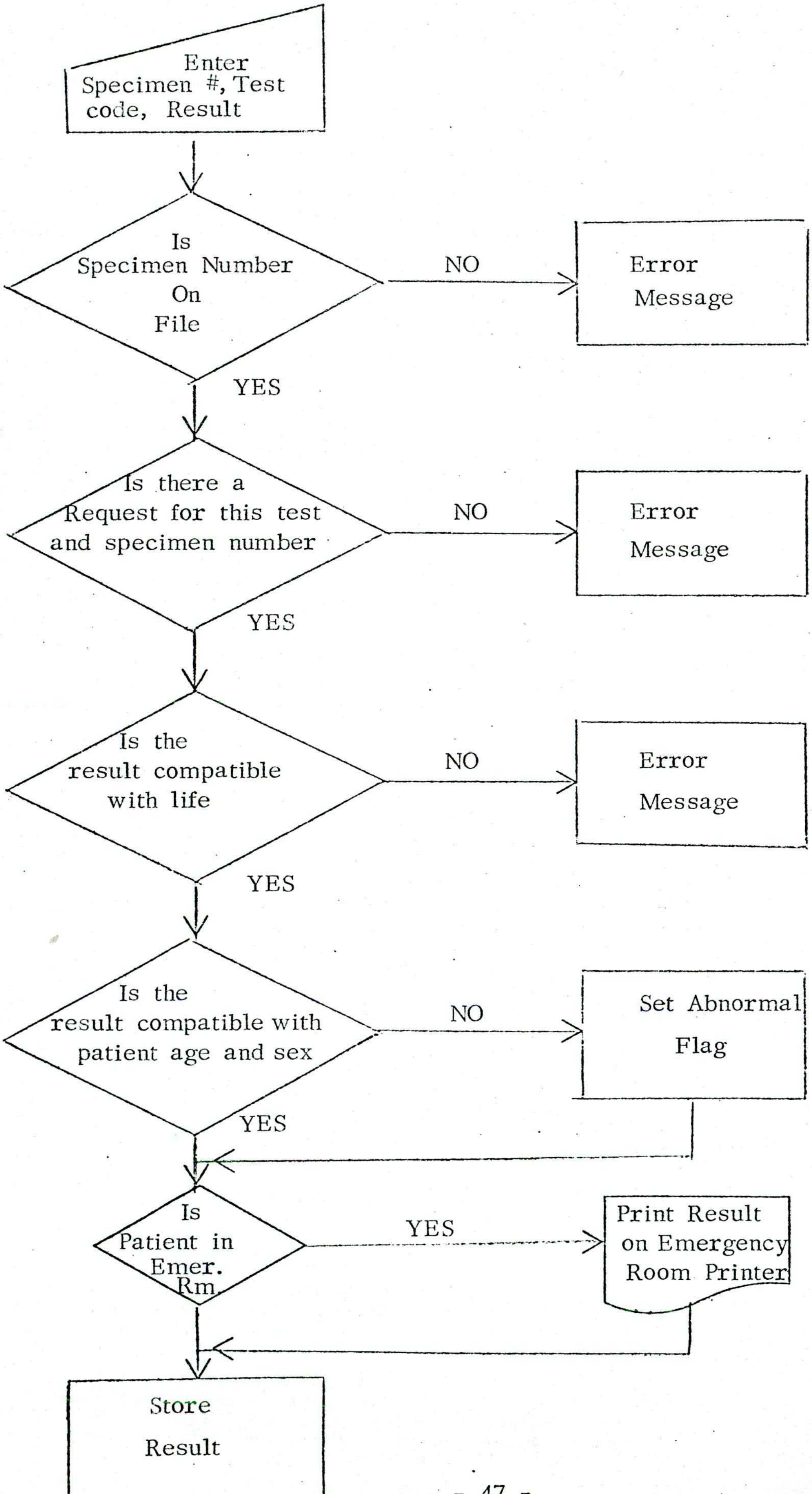
APPENDIX 9

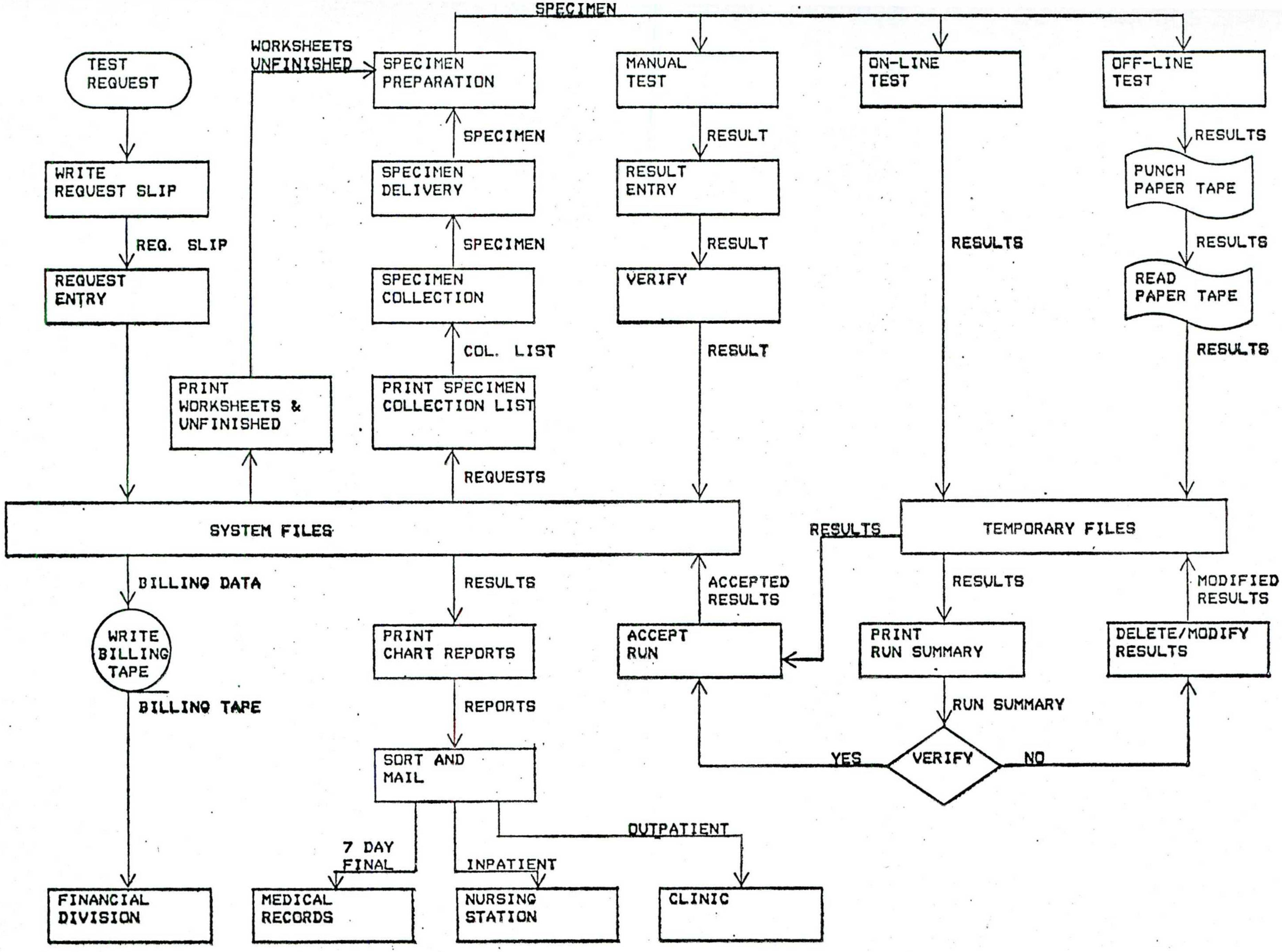
DATA FLOW IN THE CLINICAL LABORATORY



APPENDIX 10

RESULT ENTRY




SPECIMEN
TEST REQUEST
WRITE REQUEST SLIP
REQ. SLIP
REQUEST ENTRY
WORKSHEETS UNFINISHED
SPECIMEN PREPARATION
SPECIMEN
SPECIMEN DELIVERY
SPECIMEN
SPECIMEN COLLECTION
COL. LIST
PRINT WORKSHEETS & UNFINISHED
PRINT SPECIMEN COLLECTION LIST
REQUESTS
MANUAL TEST
RESULT
RESULT ENTRY
RESULT
VERIFY
RESULT
ON-LINE TEST
RESULTS
OFF-LINE TEST
RESULTS
PUNCH PAPER TAPE
RESULTS
READ PAPER TAPE
RESULTS
SYSTEM FILES
RESULTS
TEMPORARY FILES
BILLING DATA
WRITE BILLING TAPE
BILLING TAPE
RESULTS
PRINT CHART REPORTS
REPORTS
SORT AND MAIL
ACCEPTED RESULTS
ACCEPT RUN
RESULTS
PRINT RUN SUMMARY
RUN SUMMARY
MODIFIED RESULTS
DELETE/MODIFY RESULTS
YES
VERIFY
NO
7 DAY FINAL
INPATIENT
OUTPATIENT
FINANCIAL DIVISION
MEDICAL RECORDS
NURSING STATION
CLINIC

APPENDIX 12
Modes of Inquiry
(Command I)

1. For patient location and unfinished test

```
 3281912
4:02 INQUIRY              3281912 GASNICK RUTH .              C309-B 01/22/74
      2515    113 BL CHEM SMA6                               01/22/74   10:15
```

2. Last test results, and unfinished test

```
 3281912 000
4:03 INQUIRY              3281912 GASNICK RUTH .              C309-B 01/22/74
      CHLORIDE MEQ/L         104                             01/21/74   17:30
      CO2 MEQ/L               29                             01/21/74   17:30
      POTASSIUM MEQ/L        5.6*                            01/21/74   17:30
      SODIUM MEQ/L           145                             01/21/74   17:30
      BUN MG%                 18                             01/21/74   17:30
      GLUCOSE MG%            351*                            01/21/74   17:30
      2515    113 BL CHEM SMA6                               01/22/74   10:15
```

3. All previous results of a given test

```
 3281912 113
4:04 INQUIRY              3281912 GASNICK RUTH .              C309-B 01/22/74
      CHLORIDE MEQ/L         102                             01/09/74   16:45
      CHLORIDE MEQ/L         100                             01/10/74   09:45
      CHLORIDE MEQ/L          99                             01/10/74   17:00
      CHLORIDE MEQ/L         102                             01/12/74   16:30
      CHLORIDE MEQ/L          94*                            01/13/74   16:30
      CHLORIDE MEQ/L         102                             01/14/74   18:15
      CHLORIDE MEQ/L         101                             01/15/74   09:45
      CHLORIDE MEQ/L         102                             01/16/74   18:00
      CHLORIDE MEQ/L          96                             01/17/74   00:00
      CHLORIDE MEQ/L         101                             01/17/74   09:45
      CHLORIDE MEQ/L         101                             01/17/74   18:00
      CHLORIDE MEQ/L         102                             01/18/74   10:00
      CHLORIDE MEQ/L          96                             01/18/74   18:30
      CHLORIDE MEQ/L         100                             01/20/74   17:45
      CHLORIDE MEQ/L         104                             01/21/74   17:30
```

4. Inquiry by Specimen Number

```
 2515
4:17 INQUIRY              3281912 GASNICK RUTH .              C309-B 01/22/74
      2515    113 BL CHEM SMA6                               01/22/74   10:15
```

Search for patient
Serial Number and Location
(Command S)

1. By Last Name

```
S LEVINE
LEVINE DORIS .          3259736    H277A
LEVINE SADIE .          3260494    C508C
LEVINE EVE .            9630160    C3S
LEVINE MARILYN .        3322690    G252
LEVINE WILLIAM .        3309838    FICU
LEVINE MOLLY .          3322740    S5
LEVINE ERIC .           8587500    OPC2
LEVINE EVE .            3286176    C301-B
LEVINE BARNETT .        0000000    K636
LEVINE RASHELLE .       3314622    G452
LEVINE ZELDA .          3318383    H7
LEVINE ERIC .           0000000    OPC3
```

2. By Full Name

```
S LEVINE DORIS
LEVINE DORIS .          3259736    H277A
```

3. By mispelled Last Name

```
S LUINE DORIS
LEVINE DORIS .          3259736    H277A
```

4. By mispelled Last Name without First Name

```
S LUINE
LEVINE DORIS .          3259736    H277A
LURIA HILDA .           3304409    H6
LEWIS ANNETTE .         3322377    K334-B
LEWIS BB .              3323060    K3
LAURIE IRVING .         3275054    G470
LEVINE SADIE .          3260494    C508C
LILIEN ROBIN .          3300464    H6
LEVINE EVE .            9630160    C3S
LUBEL MORRIS .          3286713    S495D
LEWIS LILLIAN .         9546370    OPC183
LEONE FRANCESCA .       3322583    H476-D
LEVINE MARILYN .        3322690    G252
LEVINE WILLIAM .        3309838    FICU
LEVINE MOLLY .          3322740    S5
LEVINE ERIC .           8587500    OPC2
LINDER IRA .            3312519    S491-A
LEWIS JOHN .            3315686    FICU
LORIN LIONEL .          3238474    C2S
LEWIS FLORA .           3317336    G463-B
LEWIS NAME .          3283603    K743
LEMUS BB .              3317393    K3
LOGUEN MARIE .          3302122    C209-B
LEVINE EVE .            3286176    C301-B
LEVINE BARNETT .        0000000    K636
LEVINE RASHELLE .       3314622    G452
LEVINE ZELDA .          3318383    H7
LEVINE ERIC .           0000000    OPC3
LEONG MARILYN .         0000000    OPC135
```

.R. INTERIM REPORT 05/10/79 13:14 PAGE 1

BLISS LILLIAN . S: 1188706

BL CHEM SMA12	REQUEST RECEIVED	05/10/79	12:00
BL CHEM SMA6	REQUEST RECEIVED	05/10/79	12:00

TESTPATIENT 11 . S: 9999911

GLUCOSE MG%	94	05/10/79	08:15
CO2 MEQ/L	20	05/10/79	08:15
CHLORIDE MEQ/L	104	05/10/79	08:15
SODIUM MEQ/L	141	05/10/79	08:15
POTASSIUM MEQ/L	4.4	05/10/79	08:15
CREATININE MG%	1.3	05/10/79	08:15
URIC ACID MG%	5.1	05/10/79	08:15
CALCIUM MG%	9.9	05/10/79	08:15
PHOSPHORUS MG%	3.4	05/10/79	08:15
ALK PHOS MU/ML	120*	05/10/79	08:15
T BILIRUBIN MG%	1.6*	05/10/79	08:15
CHOLESTEROL MG%	129*	05/10/79	08:15
SGPT MU/ML	40	05/10/79	08:15
SGOT MU/ML	20	05/10/79	08:15
CPK MU/ML	102	05/10/79	08:15
LDH MU/ML	212	05/10/79	08:15
TRIGLYC. MG%	47	05/10/79	08:15
PROTEIN G%	4.8*	05/10/79	08:15
ALBUMIN G%	2.9*	05/10/79	08:15
BL CHEM SMA6	REQUEST RECEIVED	05/10/79	08:15

TESTPATIENT 13 . S: 9999913

GLUCOSE MG%	99	05/10/79	08:15
CO2 MEQ/L	20	05/10/79	08:15
CHLORIDE MEQ/L	104	05/10/79	08:15
SODIUM MEQ/L	143	05/10/79	08:15
POTASSIUM MEQ/L	4.5	05/10/79	08:15
BUN MG%	21*	05/10/79	08:15
CREATININE MG%	1.4	05/10/79	08:15
URIC ACID MG%	5.3	05/10/79	08:15
CALCIUM MG%	10.2	05/10/79	08:15
PHOSPHORUS MG%	3.5	05/10/79	08:15
ALK PHOS MU/ML	120*	05/10/79	08:15
T BILIRUBIN MG%	1.7*	05/10/79	08:15
CHOLESTEROL MG%	132*	05/10/79	08:15
SGPT MU/ML	44	05/10/79	08:15
SGOT MU/ML	31	05/10/79	08:15

NT SINAI HOSPITAL LABORATORY CHART REPORT

: G7 O.R. DAILY CHART REPORT PAGE 1

E: TESTPATIENT 11 . S: 9999911 UNIT NUMBER: 99999911

M: AMB DR: 13:20 05/10/79

T	LIMITS	05/07 08:00	05/08 08:15	05/09 08:00	05/10 08:15
CHEM BLOOD:**					
COSE MG%	65-110	96	95	102	94
MEQ/L	18-32	21	21	21	20
ORIDE MEQ/L	95-105	103	100	101	104
IUM MEQ/L	135-145	143	140	142	141
ASSIUM MEQ/L	3.5-5	4.5	4.5	4.4	4.4
MG%	10-20	21*	22*	23*	
ATININE MG%	0.7-1.4	1.2	1.4	1.5*	1.3
C ACID MG%	2.5-8	5.1	4.7	5.1	5.1
CIUM MG%	8.5-11	10.0	9.8	10.0	9.9
SPHORUS MG%	2.5-4.5	3.4	3.4	3.4	3.4
PHOS MU/ML	30-85	116*	112*	124*	120*
ILIRUBIN MG%	0.1-1.2	1.6*	1.7*	1.6*	1.6*
LESTEROL MG%	150-300	125*	124*	124*	129*
T MU/ML	1-53	38	39	36	40
T MU/ML	1-40	23	29	24	20
MU/ML	1-145	105	111	104	102
MU/ML	100-225	218	227*	222	212
GLYC. MG%	30-135	47	46	50	47
TEIN G%	6-8.6	4.9*	4.8*	5.0*	4.8*
UMIN G%	3.2-6	3.0*	2.9*	2.9*	2.9*

MOORE BUSINESS FORMS, INC.

IT SINAI HOSPITAL LABORATORY CHART REPORT

S KCC-C3N 7-DAY CHART REPORT PAGE 1

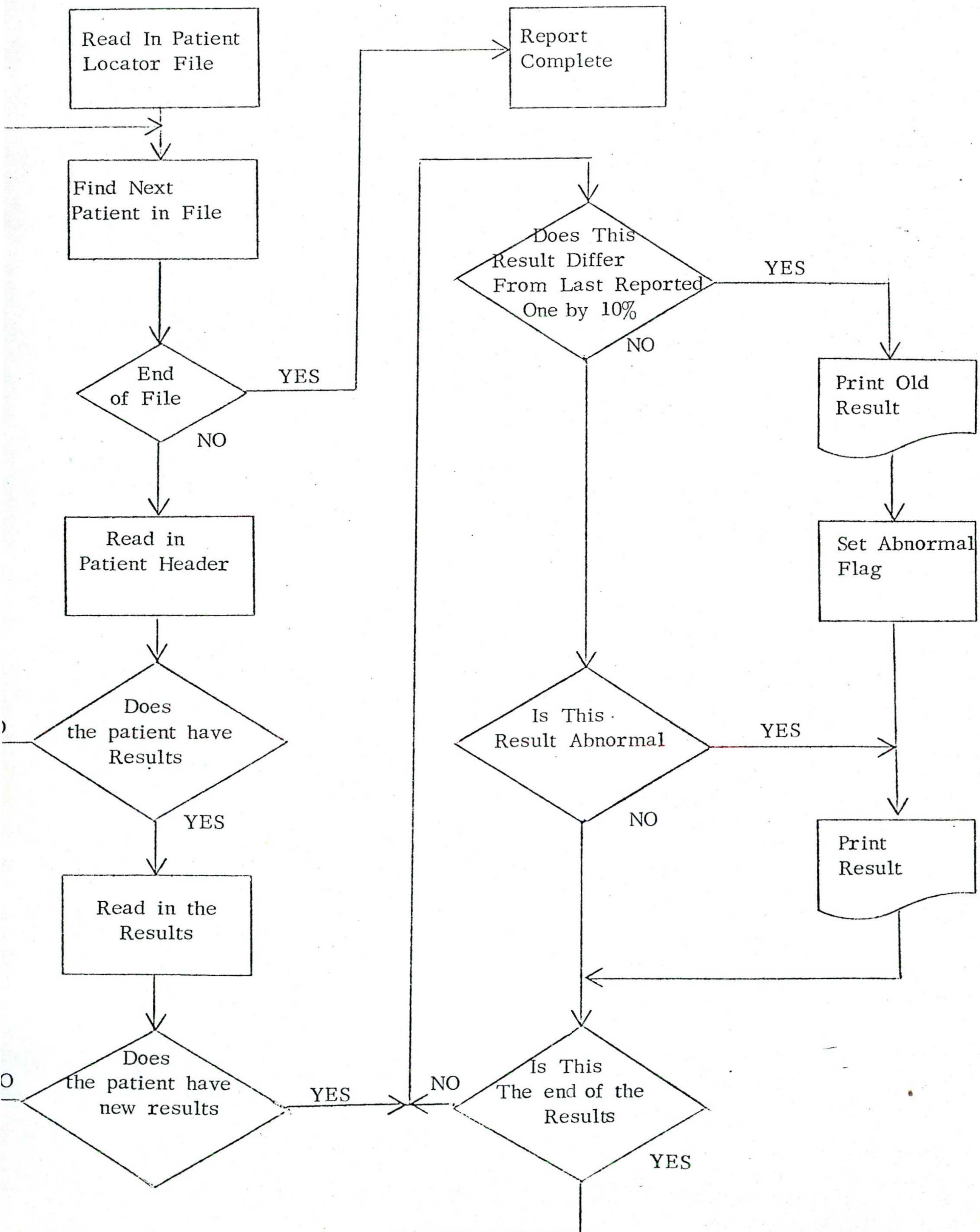
E: TESTPATIENT 47 . S: 5450747 UNIT NUMBER: 1188182

M: C314A 65 M DR: REGENBOGEN,HO/SH 16:35 05/10/79

T	LIMITS	05/04 18:15	05/07 20:45	05/08 10:30	05/08 13:30	05/08 16:00	05/09 09:00	05/10 09:30
HEM BLOOD:**								
COSE MG%	60-120	106	149*	101			119	132*
			7.48			7.53		
2 MM/HG			33.8			35.2		
MM/HG			58			59		
E EXCES-MEQ/L			2.2			6.2		
			POS					
MA GTP UNITS	4-28			1060*			1140*	
MEQ/L	24-32	29	30	28			29	29
RIDE MEQ/L	95-105	96	91*	96			94*	94*
IUM MEQ/L	135-145	138	134*	139			130*	131*
ASSIUM MEQ/L	3.5-5	4.9	5.2*	3.9			3.8	3.2*
MG%	10-30	23	30	27			22	13
ATININE MG%	0.7-1.7	1.2	1.3	1.4			1.0	0.9
C ACID MG%	4-9	7.6		7.7			6.0	4.8
CIUM MG%	8.5-11	11.0	9.6	9.0			8.6	8.7
SPHORUS MG%	2.4-4.7	4.4		3.8			3.4	3.7
PHOS MU/ML	30-90	1280*		1055*			1250*	1170*
D PHOS U	0-0.8				0.7			
ILIRUBIN MG%	0.1-1.2	1.9*		2.0*			1.8*	3.1*
ILIRUBIN MG%	0-0.8			1.4*			1.3*	
LESTEROL MG%	160-330	211		173			154*	161
T MU/ML	1-53	186*		119*			202*	206*
T MU/ML	1-50	212*		149*			324*	286*
MU/ML	1-145	188*		212*			242*	161*
MU/ML	100-22005/08		10:30	OVER 4,000 GN.S. FOR DIL				
LASE U	45-200			70				
TEIN G%	6-8.3	6.7		5.0*			4.7*	4.5*
MIN G%	3.5-4.9	3.5		2.8*			2.6*	2.4*

APPENDIX 17

ABNORMAL - DELTA REPORT



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