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FBI Fingerprint Identification Automation Study: AIDS III Evaluation Report

Volume II: Technical Feasibility

August 15, 1980

Prepared for
U.S. Department of Justice
Federal Bureau of Investigation
Through an agreement with
National Aeronautics and Space Administration
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ABSTRACT

This volume, Technical Feasibility, assesses the feasibility of those technologies that are intended for use by AIDS III. The results of this effort are presented in a manner for use by both the AIDS III Operational and Economic Feasibility subtasks as well as the Development of Alternative subtask. The approach taken in this evaluation was to identify the major functions that appear in AIDS III, and then to determine which technologies would be needed for support. The technologies were then examined from the point of view of reliability, throughput, security, availability, cost, and possible future trends. Whenever possible, graphs are given to indicate projected costs of rapidly changing technologies. For a synopsis of this entire report see the Executive Summary in the Compendium (Volume I).

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SECTION I

INTRODUCTION

This document presents the findings of the Current Technology Evaluation subtask for the FBI Fingerprint Identification Automation Study. The major objectives are (1) to perform a technical feasibility study of the areas related to automating the Identification Division, (2) to forecast the advance of technology, and (3) to provide information for the AIDS III Operational Feasibility, Economic Feasibility, and Design of Alternatives subtasks.

The essential elements of analysis consisted of answering such questions as whether the technologies required by AIDS III would be commercially available, under development, or only conceptually designed. In addition, risk assessments were made for those technologies appearing to be marginal or inadequate. The issue of technical obsolescence was examined so that the Economic Feasibility subtask could evaluate the cost-effectiveness of rapidly changing technologies such as fiber optics and computer memory, as well as the future costs associated with aging fingerprint readers.

SECTION II

SUMMARY

This is the second of three volumes documenting the results of the Current Technology Evaluation subtask of the FBI Fingerprint Identification Automation Study. This volume contains a technical feasibility study of the areas required by the AIDS III evaluation. A later report will deal with alternate system concepts and applicable future technologies. Specifically these will include, but are not limited to data compression/error protection of files, latent fingerprint processing using finite state machines, and Automatic Fingerprint Reader System (AFRS) alternatives.

The term technical feasibility needs to be distinguished from operational feasibility. The former is used when the technology exists today, or when it is still being developed. Where development is still required, the status and associated risks are discussed. The latter addresses such issues as system design, process control, and system performance. This is documented in Volume III, Operational Feasibility.

The methodology used was to survey current applicable technology, assess technical feasibility, project technology trends, and compare competing technologies and assess risks.

Table 2-1 summarizes the technologies that needed to be evaluated, along with the functions they support, as well as which technologies were actually evaluated. (In certain cases insufficient information precluded performing an evaluation.) Also contained in Table 2-1 are brief remarks excerpted from the main text.

The overall conclusions of the Current Technology Evaluation subtask are that the required technologies are generally well established. However, the lack of specificity of the data base management systems is a cause of considerable concern. Additionally, the omission of a software methodology design is also considered to be a serious oversight. Finally, the automated image retrieval and automated card transport systems designs have several major flaws which need correction.

Table 2-1. Current Technology Evaluation Subtask Summary

Technology	Functions Supported	Evaluated	If Not, Why Not	Remarks		
				Favorable	Unfavorable	Neutral
Optical character recognition	Process control number (PCN) printers (see IV-1)	Yes				2000 cards/ hr rate
	Hand-held wands (see IV-2)	Yes			Low reliability of connecting cable	
Terminals/ displays (see IV-3)	Wandout	Yes		Off-the-shelf hardware available		Human engineering must be considered
	Data entry (DENT)	Yes				
	Verify dent (VDENT)	Yes				DENT and VDENT use existing "Four Phase" equipment
	Classification	Yes				
	Classification check	Yes				
	Search review	Yes				
	Automated correspondence	Yes				
	Semiautomatic reader	Yes				

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Table 2-1. Current Technology Evaluation Subtask Summary (Continuation 1)

Technology	Functions Supported	Evaluated	If Not, Why Not	Remarks		
				Favorable	Unfavorable	Neutral
Automatic Fingerprint Reader System (AFRS) (see IV-4)	f/p card reading Minutiae extraction	Yes		Clean binary ridge-valley image generated	Card jamming Card hopper failure Flying spot scanner prone to misadjustments Output not useful for automatic classification f/p image not recorded	
M41 Matcher (see IV-5)	Compare sets of fingerprints based on minutiae	Yes		95% true drop rate with physical description data 0.3% false drop rate	Poor performance on latent prints	

Table 2-1. Current Technology Evaluation Subtask Summary (Continuation 2)

Technology	Functions Supported	Evaluated	If Not, Why Not	Remarks		
				Favorable	Unfavorable	Neutral
Computer hardware (see IV-6)	Computer-based systems			Today's superminis will suffice		
	System Supervisor	Yes				
	PCN and image capture	Yes				
	Subject search and response generation	Yes				
	Image comparison	Yes				
	Technical search	Yes	Characteristics not reported to JPL			
	Semiautomatic reader	No				
	Data entry	Yes				
	Search review	Yes				
Fiber optics (see IV-7)	Inter-computer communication	Yes		Immunity to interference Large bandwidth Light weight	Lack of standardization High cost	

Table 2-1. Current Technology Evaluation Subtask Summary (Continuation 3)

Technology	Functions Supported	Evaluated	If Not, Why Not	Remarks		
				Favorable	Unfavorable	Neutral
Chemical analysis (See IV-8)	Microfilm, disk and tape archival	Yes				Temperature below 24°C and relative humidity below 40% recommended
	Microfilm image removal	Yes				Hot water and dull scraper will work

Table 2-1. Current Technology Evaluation Subtask Summary (Continuation 4)

Technology	Functions Supported	Evaluated	If Not, Why Not	Remarks		
				Favorable	Unfavorable	Neutral
Automated image retrieval (See IV-11)	Image capture	Yes			No data base management scheme Severe bottleneck potential	Satisfactory
	Image storage	Yes				
	Image retrieval	Yes				
	Image display for comparison	Yes				
Automated card transport (See IV-12)	Card transport between work stations	Yes		Conveyor system expected to be trouble-free	Unacceptable card buffer station design	
Software development methodology	Computer-based subsystems	No	Not specified			

SECTION III

METHODOLOGY

The approach taken in Current Technology Evaluation was first to examine the proposed system to determine what functions were being performed, and then to investigate the technologies required to support these functions. A team, consisting of JPL personnel and outside consultants, was formed to investigate the technologies within their specializations. This team included a chemist, a mathematician, and experts in robotics, artificial intelligence, computer science, electrical engineering, spacecraft computer memory, and other engineering disciplines. Trips were taken to Rockwell International, in Anaheim, California, to FBI headquarters, and to NBS for technical discussions. Whenever possible, actual maintenance information was used to evaluate existing equipment; otherwise engineering judgment was used to evaluate the reliability and risk of a particular technology.

The process of predicting the future is never easy. The methods that were used to predict future technological developments consisted of searching the literature for reasonable projections, if available, and otherwise extrapolating from known historical data. The effects of the environment on the aging of microfilm and disk were determined by a rigorous chemical analysis.

SECTION IV

TECHNOLOGY ASSESSMENTS

A. INTRODUCTION

The technology assessments contained in this section were performed with the aim of providing information to the AIDS III Evaluation and Development of Alternatives subtasks. In this regard it should be noted that if a technology is found to be mature and reliable, it still must be properly applied in a future situation; the tools are no better than the skill of the craftsman. Also in some cases, prototypes or the actual hardware intended for use in AIDS III are available for technical evaluations. In these cases, it should be kept in mind that operational performance and experimental results can be quite different due to equipment failures, queueing problems, etc. Consequently, while positive results from the Current Technology Evaluation are necessary for the succesful implementation of a particular technology, they alone are not sufficient.

B. AIDS III TECHNOLOGIES

1. Process Control Number Printer

The Process Control Number (PCN) printers were investigated from the standpoint of reliability and throughput since they are currently being used for the AIDS II file conversion. The information was obtained by examining the PCN operator's manual and maintenance logs and by discussing the performance of the printers with J. Burgard of Rockwell International.

The manufacturer says that the throughput of a PCN printer is 3000 cards/hour. A more realistic throughput rate appears to be 2000 cards/hour, primarily due to card jamming problems. The card jamming problem should subside in the future since the PCN printers are processing well-worn cards in the current conversion process instead of the new cards that the AIDS III system will process. Because card jams are detected at several points in the machine, multi-card catastrophes are prevented.

The read-after-write capability to verify proper printing is satisfactory. It appears that most printing errors are due either to a worn ribbon or to a worn or damaged printer "daisy" wheel. Proper preventive maintenance should ensure that these problems are avoided.

The PCN printers spend about 0.6 hours in repair for electro-mechanical problems (as opposed to card jamming) for each 160 hours of operation. The printer ribbon needs to be changed after every four hours of continuous operation; the daisy wheel must be replaced after 200,000 cards have been printed. The input hoppers hold about 1000 cards, so they should be loaded every half-hour. In the event of a power outage, a battery prevents the loss of data stored in the microprocessor memory.

2. Optical Character Recognition

Optical character recognition (OCR) is used by the PCN printers, the hand-held wands, and in the microfilm handling. In each case, the technology is the same since only PCN's are recognized.

The OCR equipment operates much faster than is needed. However, other aspects of the station (such as an overloaded communications interface) can cause the OCR equipment to perform in a sub-optimal manner.

The mean time between failure (MTBF) and the mean time to repair (MTTR) for OCR equipment are 1500 hours and one hour respectively.[1] It is interesting to note that the primary failure mode of the hand-held wands is not in the OCR electronics, but in the connecting cable. Rockwell and the supplier (Recognition Equipment, Inc.) are attempting to strengthen the cable to increase the reliability of the hand-held wands. Another possibility is to use a stationary wand.

3. Terminals/Displays

The current technology in this area is fast enough to keep pace with an operator's typing. A good display will quickly convey the necessary information to the operator and will avoid causing operator fatigue. A good keyboard layout is needed to enhance the operator's typing ability. The MTBF and MTTR of this equipment are about 7000 hours and 30 minutes respectively.[1]

4. Automatic Fingerprint Reader System

The Automatic Fingerprint Reader System (AFRS) consists of a card handler, a scanner, a special purpose processor, and a control computer.

a. Card Handler. The card handler is the mechanism by which the loaded cards are transported via a motor driven belt and positioned under the scanner. The positioning and card movement are computer controlled. At each position, a pair of fingerprints is presented to the scanner. After all the desired pairs are scanned, the fingerprint card is returned to the operator by a sliding belt mechanism.

There are operational concerns about the time required for the card handler to recover from a temporary malfunction and about the

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[1] Manufacturers' data transmitted by J. Burgard of Rockwell International.

frequency of malfunctions. Two malfunctions that were identified are card jamming and the failure of the card hopper.

Card jamming is generally due to poor physical condition of the card. The card holder dejamming procedure described on page 2-218 of the Calspan manual (Reference 1) is complex and time-consuming. The procedure has been substantially modified in the Rockwell-designed production AFRS.

The malfunction of the card hopper is usually caused by accumulated paper dust. This problem can be avoided by routinely vacuum cleaning the card hopper. Finally, there are serious questions as to whether the five AFRS stations can average 210 cards/hour in an operational setting as is indicated on page 4-23 of the January 1980 AIDS III System Concept Report published by Rockwell (Reference 2).

b. Scanner. Imaging in the AFRS is done by a flying-spot scanner. The flying-spot scanner consists of a high precision X-Y controlled cathode-ray tube (CRT) light source, an objective lens for a 1:1 spatial transfer of the intensity distribution from the CRT to the plane of the fingerprint card, and a system of six photomultiplier tubes (PMT's) to collect light reflected from the fingerprint card as well as incident light from the CRT. The light source is programmed in a raster scan fashion. The reflected light sent from each position in the fingerprint card is calibrated by the incident light sent from the CRT and converted to a 4-bit value. The geometric resolution of the system is 0.002 inches, and this corresponds to a 750 x 750 (pixel) fingerprint image size. The linearity, repeatability, drift, and jitter characteristics of the flying-spot scanner are within the acceptable range for fingerprint imaging.

Since the flying-spot scanner is a delicate and highly tuned system, it must be maintained accordingly. Its long-term continuous use makes it prone to misadjustments that should be corrected as needed. The positioning of the lens with respect to the CRT is essential to obtain a 1:1 magnification. To keep a consistent resolution the lens must be positioned with an accuracy of 0.003 inches. Excessive vibrations in the system may cause misalignments in the optical adjustments and may also cause damage to the delicate elements in the CRT. Changes in the adjustments of the CRT (which do gradually occur) will directly affect the image repeatability. The effort required to incorporate an optical feedback loop to solve the instabilities of the flying-spot scanner is equal to that required to replace the scanner by a solid state camera.

Another concern is that dust can settle in the optical system resulting in unwanted variations of light intensity. Also, when the PMT's are powered, an excessive light intensity on them may cause permanent damage. Excessive light means a light intensity greater than the one that the CRT provides, such as the room ambient light intensity. Rockwell International has stated (with no documentation) that a locking mechanism exists when the power is on to prevent the PMT's from such an exposure. However, if the PMT's are exposed to light when the power is off, they may not be damaged but they will be affected with a dark current build up. This dark current may remain permanently or decay gradually after the tube has returned to normal operating conditions, depending on the history of operation. Additionally, the dark current will result in biased measurements as long as it persists.

c. Processor. The processing function of the AFRS consists of several steps. At first the ridge-valley filter (RVF) converts the 4-bit gray scale image of the fingerprint into a binary image representing ridges and valleys (ones for ridges and zeroes for valleys). A two-pass algorithm is used. Both passes scan the image accessing several pixels in parallel. During the first pass the ridge or valley decision is made by comparing the gray level of each pixel to the average gray level of a surrounding 25 x 25 window. The second pass, which operates on the output of the first pass, removes the small breaks that can result from skin pore structure, improper inking, or other minute imperfections in the inked fingerprint. This two-pass algorithm performs very well and generates a clean binary ridge-valley image.

Next, the pre-editor deletes areas in the binary ridge-valley image corresponding to heavily or poorly inked regions. The resulting image is then processed for ridge direction and minutiae extraction. There are two types of minutiae, ridge endings and bifurcations. Only ridge endings are detected directly; bifurcations are detected by complementing the image and searching for ridge endings. Finally, a post-editor deletes some of the spurious minutiae.

Ridge directions extracted by the present AFRS are too coarse to be useful for automatic classification. This is an important flaw of the processor and the reason for abandoning its ridge-direction output for use in automatic classification.

Unfortunately, there was not sufficient information available either from conversations with AFRS users or from the relevant documents to permit an evaluation of the quality of the minutiae data produced by the AFRS. The only statistic determined is that the AFRS detects from 5% to 50% spurious minutiae depending on the quality of the fingerprint. At this time, it is not possible to assess the AIDS III system impact of this statistic.

In conclusion, the performance of the AFRS is difficult to evaluate; the quoted availability from the FBI is 96.5%. Meaningful MTTR and MTBF statistics could not be provided.

d. AFRS Aging. The aging characteristics of the AFRS are not easily predicted due to the various subsystems and technologies, including electro-mechanical, electronic, and optical subsystems.

Table 4-1 summarizes the problems that may arise through long term usage of the AFRS. The effects of aging on the major subsystems as well as possible solutions to aging are indicated. The possible operational effects are also contained in the table.

5. M41 Matcher

The purpose of the model M41 matcher is to compare a set of fingerprints with others on the basis of identifying characteristics. The FBI has selected fingerprint minutiae as the fundamental data type to be used in an automated fingerprint identification system. The AFRS extracts the minutiae information from the fingerprint for subsequent processing by the matcher.

The M41 matcher differs from its predecessor, the M40 matcher, in that it not only considers the degree of similarity between the search and file prints, but it also considers the degree of dissimilarity as well. The M40 matching algorithm was implemented as a special purpose digital pipeline processor, except for a software scoring routine.

Standard model SN7400 series transistor-transistor logic (TTL) has been used throughout and, where required, Schottky clamped logic is used to assure adequate delay margins through critical paths. All logic transitions occur on the trailing edge of the clock to allow maximum settling time and uniformity throughout the matcher system.

Besides the formatter board, each matcher has a set of eight wire-wrap boards, four of which are memory boards for searching minutiae data, filing minutiae data, and scoring. This matcher hardware unit operates as a peripheral device to the PDP-11/50 computer.

The M41 prototype matcher system has operated for several years since its installation. Data collected during its operation have been analyzed by the FBI and the results are presented here.

The M41 prototype matcher currently operates at a rate of 70 card matches per second or equivalently 252,000 card matches per hour. The number of matches required for each subject card is projected to be an average of 100, and a maximum of 250. Thus each subject card should be processed by the matcher in 1.4 to 3.6 seconds. The FBI has experienced two hardware failures in the hardware matcher unit. One resulted from a first-in-first-out (FIFO) memory chip failure and the other was caused by the failure of a power supply unit. Both failures were corrected by replacing each unit with a similar unit of a different brand. So far no recurrence of the same failures has appeared, and the unit has been free of trouble for more than a year. The hardware matcher unit has an empirical MTBF of about 3000 hours and an MTTR of about one hour. However, these reliability data need qualification. The MTBF and MTTR figures as given above were derived from only a few samples of data. While they may prove

Table 4-1. ARFS Aging

Subsystem	Affected Component	Symptoms of Aging	Solutions	Operational Effects
Card Handler	Card feeder	Frequent card jams with good cards	Periodic vacuuming Adjustment Replacement	Reduced throughput
Scanner				
Programmable Light Source	CRT	Inconsistent geometric images	Adjustment Replacement	Deterioration of minutiae data
Lens and Optics	Lens displacement	Change in image scale and true resolution	Adjustment	Reduced minutiae data quality
	Internal dust	Poor contrast in grey level	Cleaning	Missing minutiae data
Sensing	Dark current in photomultiplier tubes	Poor image intensity and contrast	Replacement	Missing minutiae data

helpful in understanding the hardware matcher performance, some considerations should be placed on the merit of its applicability to the AIDS III system study. For example, the failures that occurred in the hardware matcher unit might have been the ones that would normally happen during the "infant mortality" phase. If this is the case, the expected MTBF will be higher when operating in the "useful life" phase. The MTTR depends on the maintenance strategy and the availability of built-in self-diagnostics. The MTTR figure as shown reflects the effect of the current operation environment. Should there be any change in the maintenance strategy or any inclusion of certain self-diagnostic features, the resulting MTTR would noticeably change.

The performance of the matcher is measured by two quantities: false drop rate and true drop rate. The false drop rate is the probability that an incorrect file subject is returned by the technical search subsystem. Currently, the false drop rate is 0.3 per search. On the other hand, the true drop rate is the probability that the subsystem correctly returns the file subject who is the search subject, assuming that the search subject is in the file. The true drop rate has been measured under three scenarios. First, if eight prints and the descriptor data are used, then the true drop rate is 0.95; i.e., about 5% of the time the search subject is in the file and is not identified. If the descriptor data are dropped and only the eight prints are used, then the true drop rate is 0.85. Finally, the true drop rate for single (latent) fingerprints is between 0.25 and 0.5. Thus the subsystem's performance can be as high as 0.95 with complete descriptor information and as low as 0.25 with only a latent print as input.

The hardware technology needed to build an operational M41 matcher is adequate, especially if TTL is used. However if emitter coupled logic (ECL) is used, then since it operates about three times faster than TTL, timing controls may pose non-trivial design challenges. If these challenges are overcome, then the matcher should be able to perform more than 140 card matches per second instead of 70 per second. Finally, there does not appear to be an appropriate, present application of very large scale integration (VLSI) technology to the M41 matcher.

6. Computer Hardware

Today's computing hardware is sufficiently mature to support the needs of AIDS III. For example, in the International Business Machines (IBM) 4300 series of current superminis, the 4341 processor replaces the 370/138 with a system having twice the power at half the cost. It is capable of performing between 500,000 and one million instructions per second and has 2 megabytes (Mbytes) of main memory. The 3370 disk contains 570 Mbytes per drive, and has a 20 millisecond average access time and 1.859 Mbyte/second transfer rate.

Thus it appears that the computing requirements that have been specified in the AIDS III study can be satisfied by using a system of computers in the IBM 4300 class.

7. Data Storage Technologies

Large computer system designers have available a variety of memory types and technologies for incorporation into a system. Performance capabilities of these memories vary over several orders of magnitude and so does cost. It is the task of the system designer to devise a memory hierarchy which will achieve the required performance capability at the lowest possible cost and highest reliability. Cost is often defined in a very complex manner involving weighted averages of several cost factors, such as hardware acquisition cost, maintenance cost, expected equipment life, impact on software cost, etc. Computer system designers must know the present and anticipated future cost of all types of memories applicable to the system. Cost and performance trends for the near and intermediate terms are very important in order to avoid designing a system that will be obsolete shortly after its installation and could not be further expanded in the same manner as conceived. Figure 4-1 shows a memory hierarchy chart for some of the most common memory types. This hierarchy will change in time and for 1985 might be similar to that shown in the figure. Long-range predictions are difficult to make because of the rapid advancement of data storage technology. Figure 4-1 shows an attempt to visualize how the memory market might be in 1994. This attempt does not take into account any new data storage technologies which might be invented during this time period.

Memory cost is not the only consideration in selecting the types of memory for a computer system. There are several important performance criteria, such as access time, transfer rate, volatility, static/dynamic behavior and power consumption. Access time is the time required to locate a memory address and prepare for reading or writing. Generally, a number of bits are stored at one memory address, in which case the data transfer rate becomes important too. This is the bit rate at which a memory content can be read out or data written into the memory after its address had been accessed. Total read-out time for a memory address is the sum of access time and data transfer time. For very fast operation, data transfer time for certain types of memories can be made very short compared to the access time. For example, semiconductor random access memories can be written or read in parallel. This requires more hardware than serial data transfer along a single wire.

Volatility is another important memory characteristic which denotes the inability to retain its content if power to the memory is turned off. Volatile memory will lose the stored data content if power is lost even for a short time. Accidental power losses can have disastrous effects on volatile memory. This is a concern for computer operators and has led to the development of quasi-nonvoltaile memories, which are volatile memories with batteries connected to their power input lines. The batteries are kept fully charged at all times and are sized large enough to keep the memory powered until external power can be restored. The batteries and associated circuits represent a small cost item compared to the memory itself, and it might appear that this is a perfect solution for the volatility problem. In reality, it is not accepted as widely as one would expect. Since the length of time of power outages and the reliability and life time of batteries are not always easy to predict, quasi-nonvolatile memories are not considered equals to the truly non-volatile memories. Many computer operators, depending on their particular needs, are willing to pay substantial cost premiums for non-volatile memory of otherwise equal performance.

Volatile memories are subdivided into static and dynamic memories. Static memories keep their stored data content intact as long as power is properly applied to the memory devices. Dynamic memories, however, can store data only for very short periods of time, usually in the millisecond range. In order to store data longer, data content within the storage devices must either be constantly circulated or be refreshed within certain time intervals. This is done automatically within the memory subsystem by special logic and timing circuits and the users need not be concerned with it. Nevertheless, memory cycling and refreshing interferes with normal memory operation and results in longer access and transfer times and higher power consumption. The advantage of the dynamic memories is their low cost which is the reason for their popularity as low-performance random access memories.

Figure 4-1 shows that the random access memories are the most expensive types. Their existence is justified by a short access time in the nano- and microsecond range. On the other end of the cost spectrum are the large movable-head disk memories with very long access times of up to a second and more. In between are the fixed head disk memories, including the floppy disks and such novel technologies as charge-coupled device (CCD) and bubble memories. The CCD memories are dynamic and, therefore, volatile. They would be competing with non-volatile bubble memories and fixed-head disks. Because of their volatility, they are not expected to have a bright future despite their high data transfer rates and low cost. They are not further considered in this report.

The following is an assessment of the data storage technologies which are considered applicable to automated fingerprint processing. Current status as well as the anticipated evolution of each technology over the next 15 years is described.

a. Semiconductor Memory. This is a class of memory consisting of a number of different technologies with certain common features such as random access capability, volatility, high speed, high cost, and fabrication from "Large Scale Integrated" (LSI) circuit components or "Very Large Scale Integrated" (VLSI) circuit components. They range from the very expensive and very fast bipolar devices, used primarily for scratch pad and cache type memories to the less expensive and slower Negative Metal Oxide Semiconductor (NMOS) and Positive Metal Oxide Semiconductor (PMOS) devices, used for large capacity random access memories. The largest devices now available in sample quantities can store 64 kbits, which will permit the development of memory systems in the tens of megabyte range with the capacity limits being determined by cost, reliability and heat removal considerations. Access time for small bipolar memories can be as low as 10 nanoseconds, but more commonly is in the several hundred nanosecond range for larger memories.

Semiconductor memory technology has advanced rapidly over the past several years with, for example, cost being halved every three years. However, this rate of progress cannot be maintained indefinitely. Overall, the cost of memory systems on a per bit basis will probably be halved again in the next four to five years. After that, the rate of the cost decrease will be slower as the presently used technologies reach maturity. Nevertheless, some momentum will probably be maintained until basic physical limitations are approached because new semiconductor memory technologies will emerge.

Figures 4-1 shows the anticipated cost decrease until 1995. These cost reductions on a per bit basis would allow the construction of affordable Random Access Memory (RAM) with storage capacities of 10^{10} bits, but this will not occur because of competitive pressures from bubble memories and perhaps other technologies. Instead, RAM's will be supplemented by less expensive bubble memories which will limit RAM systems to perhaps 10^8 bits capacity.

Parallel to the decrease of RAM costs, their speed will be increased, but less dramatically. While access times of ten nanoseconds might be quite common by 1985, a further reduction to one nanosecond should not be expected soon.

b. Core Memory. This is a mature technology which is no longer cost competitive with semiconductor memories. However, core memories are non-volatile which is an important advantage over semiconductor memories. In fact, core is now the predominant technology for non-volatile random access memories with insignificant competition from other non-volatile technologies, such as NMOS or plated wire memories. Therefore, core memories can be expected to remain for several more years but at virtually static cost and performance capabilities. In time, competitive pressure from non-volatile block accessed memories with short access times, such as bubble memories, and quasi-volatile random access memories, such as battery backed CMOS memories, will eliminate the more expensive core memories.

c. Disk Memory. Disk memories are inexpensive, non-volatile memories with relatively long access times (between 35 ms to 80 ms). Because of the long access time, random access to individual words is not practical. Instead, access is to blocks of words, which are usually transferred to the random access main memory for processing. Disk memories are also a mature technology but progress is still being made, especially in recording density and cost per bit. There are several types of disk memories, sealed units with high-density recording and those with removable recording medium. Also, there are fixed-head disks and movable-head disks. Sealed units with movable heads can store close to 10^{10} bits per spindle while those with removable disks store much less data. Nevertheless, removable disks have important advantages, especially if off-line storage is used. In

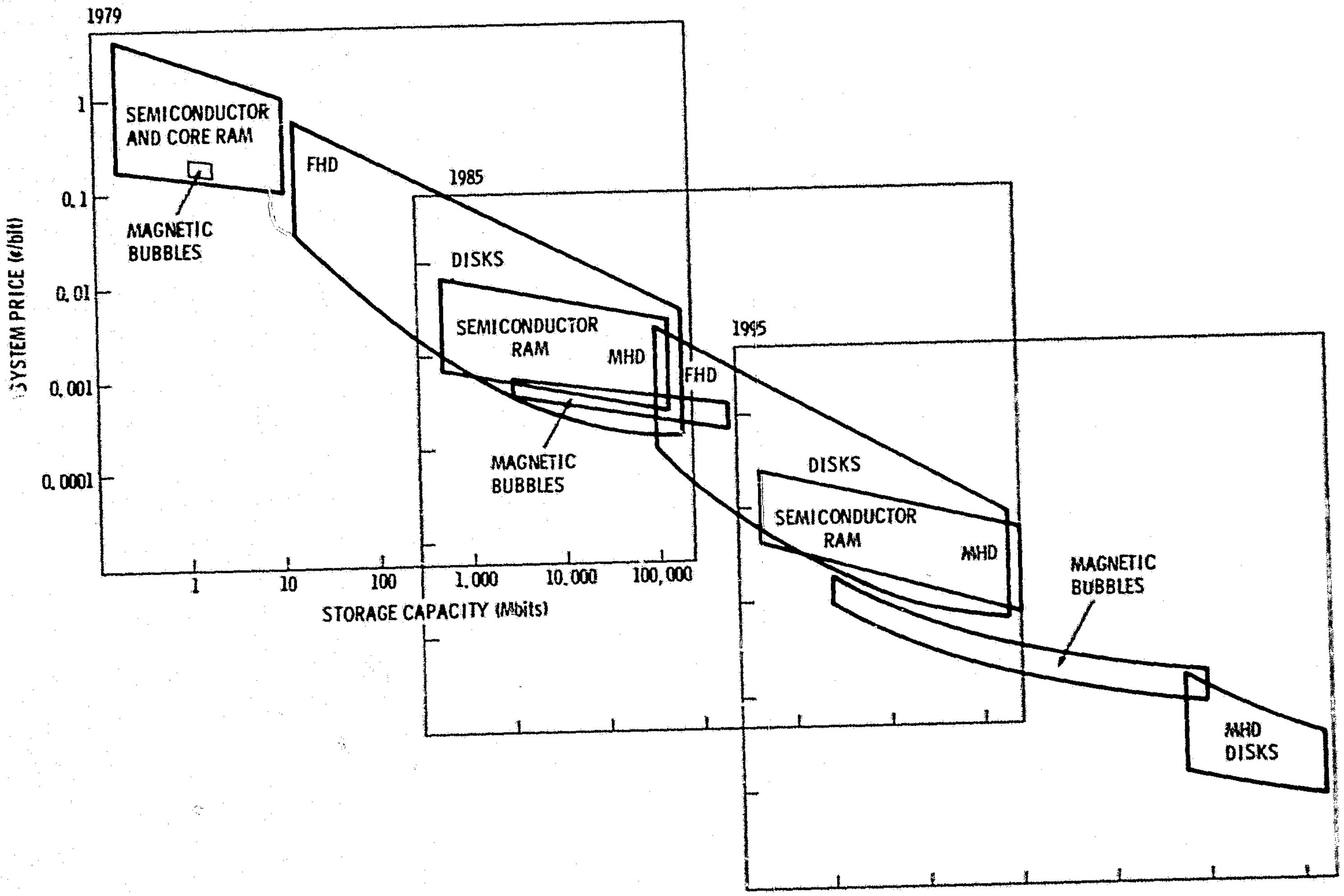

Figure 4-1. Project Costs of Mass Storage Devices

this case, cost per bit is derived from the cost of the disk or cartridge rather than the cost of the machine.

Small disk memories will see competition from bubble memories in a few years, but large disk memories have no real competition in the foreseeable future. They will be improved at a slow, but steady pace with an ultimate upper limit for the storage capacity per spindle around 10^{11} bits. Small disk memories will also see improvements in storage density and cost, but can be expected to be gradually phased out as bubble memories become cost competitive.

d. Bubble Memory. This is a new technology with initial devices in small-scale production by several manufacturers. Bubble memories will compete directly with disk memories because they are functionally similar. Their main advantages are much shorter access time, high reliability and long service intervals because of the absence of mechanical devices. At a later time, they are also expected to achieve lower cost, smaller size and weight, and require less power. The technology appears to be well-suited for automated mass production and also appears to have a large potential for technological improvement which should result in a sustained evolution for the next 10 to 15 years. The thrust of the development is directed towards increased storage density and lower cost. On the other hand, bubble memories represent a difficult technology and demand large investments for research, product development and production facilities. These expenditures will tend to slow the rate of cost decreases for bubble memories. Since manufacturers of disk memories will also reduce their costs, there will be a long struggle between these two technologies for economic survival. Small disk memories are most vulnerable to being replaced by bubble memories because of the superior performance and lower projected costs of bubble devices. Larger disk memories will feel competitive pressures much later, and the very large disk memories may perhaps never be seriously challenged. Both, fixed-disk and removable-disk memories will feel similar competitive pressures because bubble memories can also be designed with removable storage medium, called bubble devices.

As of November 1979, there was only one bubble memory device in significant quantity production and also available off-the-shelf, with a 92 kbit device from Texas Instruments. The same company is also shipping 256 kbit devices and is understood to be gearing up for quantity production. Rockwell International is shipping 256 kbit devices which are very similar to those from TI and is also gearing up for quantity production. The largest capacity device currently on the market is a one megabit device from Intel Magnetics Corp., but this is not yet in quantity production. Both, Rockwell International and Texas Instruments are expected to announce megabit memory devices soon. It is characteristic of the current status of this technology that the next generation devices are already available in sample quantities by the time production lines for the previous generation devices get on stream. On the other hand, the size of the market for 92 kbit and 256 kbit devices is uncertain and perhaps not large enough to justify the large expenditures for mass production facilities. It may require mass-produced megabit bubble devices to open a significant segment of the memory market. Naturally, manufacturers are cautious in committing to the high cost of large capacity production facilities. There is little doubt, however, that bubble memory devices will be in large scale production soon. Afterward, storage capacity per device will probably double every two years until the end of the decade (Ref. 1).

The development of memory devices with ever increasing storage capacity is only one aspect of this technology. An equally important aspect is the development of support circuits in integrated circuit form to reduce cost and improve system reliability. Both, Texas Instruments and Intel plan to have a complete memory system built with custom integrated circuits by the end of 1979. With every device of these memory systems fabricated on automated high yield production lines, system cost should come close to the cost of small disk systems by 1981. The superior performance characteristics of bubble memories should open to them a significant segment of the memory market currently dominated by small disk memories. With a steady stream of new bubble devices of increasing storage capacity reaching the market in subsequent years, supported by increasingly powerful integrated circuits, the market share of bubble memories can be expected to increase gradually for the next 15 years, partly at the expense of disk memories.

e. Tape Recorders. Tape recorders have many similarities with disk memories. Both record data by writing magnetic patterns on suitable surfaces. Tape recorders use magnetic tape which is wound on reels. This tape is inexpensive and offers much larger surfaces than disks. However, access to blocks of recorded information is difficult and time consuming. Also, tape handling is much less precise than disk handling and less data can be packed per square inch of recording surface compared to disks. Because of the difficulty of accessing recorded data blocks, most tape recorders are built with removable reels and used for off-line storage.

Tape recording is a mature technology. Its main competitors are disk memories which have shorter access times but higher cost per bit. Tape recorders are the least expensive data storage devices and cover the whole capacity range from small cartridge recorders for desk top calculators to the large machines for main frame computer systems. At the present time, a large tape reel can store up to 160 Mbytes or 1.3×10^9 bits, not counting the parity bits also recorded on tape. There is room for significant technological advancement which should result in much higher storage density for future systems. Tape recorders are not limited to the presently used magnetic recording techniques. Several optical methods have been explored. The simplest method is based on the burning of micron-sized holes with laser beams in metallized mylar tape. However, this is non-erasable and only useful for special applications. A more promising method of high-density tape recording magnetizes micron-sized areas on tape plated with a Manganese-Bismuth alloy by local heating with a laser beam above the Curie temperature and cooling in the presence of a magnetic field. This method allows erasing and recording over previously recorded tape, but is not easy and requires complex and expensive equipment. Much of the future progress of advanced tape recording concepts will depend on the marketability of such expensive tape recording systems. A reasonable upper limit for the storage capacity of a one-inch wide reel of Manganese-Bismuth plated tape is 5×10^{11} bits, including parity bits. This storage capacity, however, should not be assumed to be commercially available by 1994 because of insufficient demand for the storage of such massive amounts of data. More likely, the storage density on conventional recording tape will be increased to achieve perhaps 5×10^{9} bits per tape reel.

8. Fiber Optics

The technological feasibility of fiber optic communication has been demonstrated through field trials in the past few years. The advantages of sending data over fiber optic transmission links have been verified numerous times in systems both in the United States and abroad (Reference 3). In comparison with conventional cable such as coaxial and twisted-wire, optical fiber cables exhibit many favorable features for a data transmission link. The primary and most outstanding advantages of fiber optics are:

(1) Immunity to electromagnetic interference (EMI), radio frequency interference (RFI), cross talk, and ground loop problems.

(2) Large bandwidths.

Other advantages of fiber optics include:

(3) Small size, light weight, and flexibility.

(4) High tensile strength/weight ratio.

(5) Low transmission loss.

(6) Relatively secure data transmission.

(7) Higher temperature tolerance.

(8) Potential low cost due to abundance of basic material.

(9) No short circuits.

a. <u>EMI and Bandwidth</u>. In an environment like the AIDS III system where communication between the system supervisor and control subsystems is necessary, the use of a noninductive transmission line is particularly important to minimize EMI, RFI, and cross talk problems from various surrounding sources and to reduce bit error rates (BER). Table 4-2 compares the test results of the effect of EMI on optical fiber and double-shielded wire (Reference 4). The maximum transmission distance in the test system configuration was less than 10 meters. When high volume communications between different subsystems in the AIDS III system are necessary, it is essential to use a cable with large transmission bandwidth. A typical multimode optical fiber has a bandwidth of hundreds of Mbits-kilometer (km)/second.

Table 4-2. Summary of Bit Error Rate Test Results

	Data Transmission Time Interval (Min)	Data Transmitted (Number of Bits)	Error Induced (Number of Errors)	BER Error/Bit
Fiber optics exposed to EMI	20	2.6×10^7	0	3.9×10^{-8}
Wire exposed to EMI	1.67	2.1×10^6	42	2.0×10^{-5}
No EMI exposure	52	6.7×10^7	0	1.5×10^{-8}

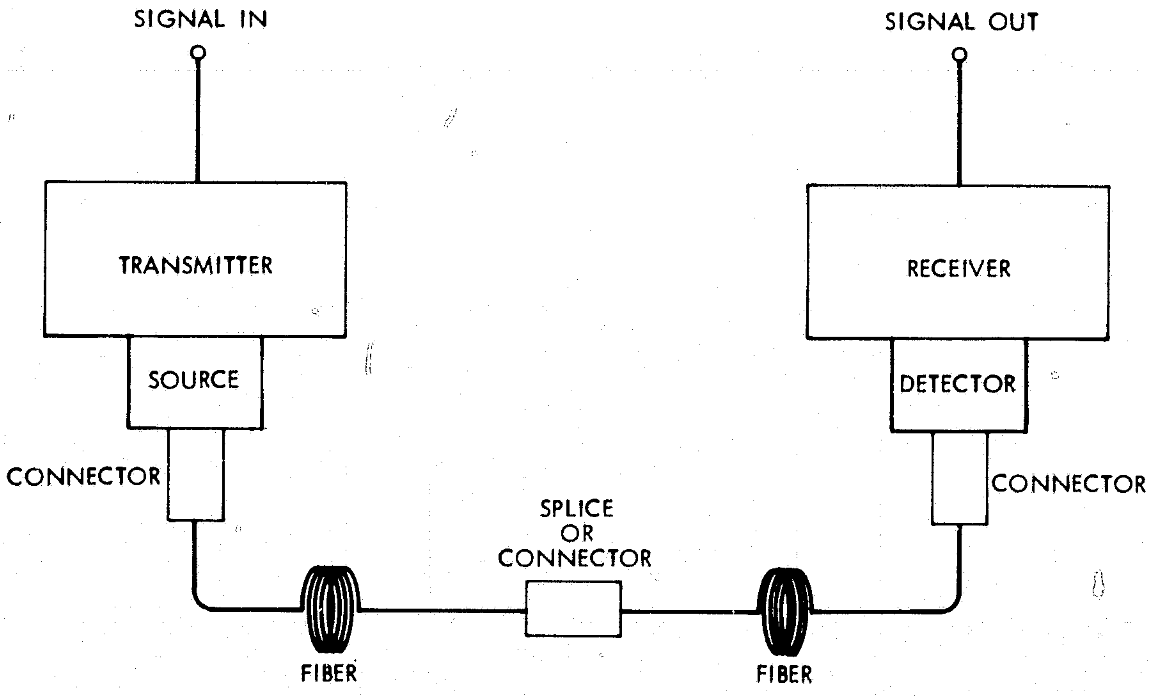

Figure 4-2. A Basic Fiber Optics Data Link Schematic

b. <u>A Basic System Schematic and Fiber Optic Components</u>. Figure 4-2 shows a schematic diagram for applying the fiber optic link to the AIDS III system with the necessary fiber optic components.

At the transmitter end, encoded signals drive the source, which in turn emits modulated pulses of light that are coupled into the optical fiber cable by a connecting device. The light pulses are detected and then decoded at the receiving end into the appropriate data format. The connector in the fiber indicates a possible interconnection between fibers.

Due to the lack of standards for optical fibers, there are different configurations of cables, fiber optic connectors, light sources, and detectors.

The outer diameter of an optical fiber may range from 110 micrometers (μm) to 400 μm. The fibers are usually protected and strengthened by various kinds of materials to form cables. Fiber cable configurations vary among manufacturers. Depending on the nature of the application of optical fibers, there is a wide variety of transmission loss ranges from less than 4 decibel (dB)/km to about 6000 dB/km for light at wavelengths near 0.9 μm among various kinds of optical fibers. A system that will not be able to tolerate high BER and uses a medium-long fiber (e.g., hundreds of meters), like the AIDS III system, should use low-loss fiber (less than 10 dB/km) for the data link. Various kinds of fiber cables in different sizes, attenuations, bandwidths, lengths, and channel numbers are available readily from more than 20 manufacturers (Reference 5).

Interconnections between fibers, fiber and source, and fiber and detector are a crucial part of a data transmission link. There are two types of interconnections between fibers. One type is obtained by splicing two fibers into a permanent connection. Splicing machines are available from some of the fiber optics and fiber optic connector manufacturers listed in References 5 and 6. Their prices range from about \$1000 to \$5000. The connection loss for each splice is about 0.2 dB to 0.5 dB.

The mountable and demountable connectors form the second type of interconnections. Different designs and configurations adaptable to different designs of cables from about 20 manufacturers (Reference 6) are available to users. Depending on the design of the connector, the loss for each connector varies from 1 dB to about 4 dB. Connectors for multi-fiber cables are also available for multi-channel communication purposes.

The interconnections mentioned above are for point-to-point connections. However, in a distributed system, a fiber optic coupler can be used to interconnect a number of terminals to one terminal. Optical couplers such as tee, access, and star are available from some manufacturers listed in References 5 and 6. The insertion loss ranges from 3 dB to 6 dB for each connection.

A variety of sources such as solid state AlGaAs LED (aluminum gallium arsenide light emitting diode) and lasers are commercially available. They are for operation near the wavelength $\lambda = 0.86\ \mu m$. While some of these devices have an average operation time of 106 hours without failure, others have performance degradations after several hundred hours of operation. Detectors such as silicon PIN and avalanche photodiodes are also commercially available for application around the $0.8\ \mu m$ to $0.9\ \mu m$ wavelength region.

c. Commercial Computer Systems. Computer systems are off to a fast start in fiber optics use. Data system designers such as DEC, Hewlett-Packard, IBM, Honeywell, UNIVAC, and others have been developing prototype links. According to J. Montgomery (Reference 7), the use of fiber optic systems in commercial computer systems should expand from \$2.1 million in 1978, to \$27 million in 1984, to \$75 million in 1990. Unfortunately, there is no unified approach to computer system fiber optics. Consequently this lack of standardization causes a high level of proprietary concern among computer system fiber optic designers. For example, there is the plastic fiber vs glass fiber controversy, flat cable vs round cable, as well as a lack of connector standards. This lack of standardization further complicates the task of evaluating various optical communication system designs. The users, according to R. Gallawa (Reference 3), are caught in a difficult situation. Those who have purchased a turnkey operation report that handing the design problem to a system vendor makes subsequent engineering and specification problems more difficult. On the other hand, those users who chose to design and install their own systems report difficulty in finding suitable measurement equipment.

d. Cost Trend. Despite the high price of fiber optic components due to small quantity production, the prices for fiber optic systems have decreased significantly in the past few years. Figure 4-3 shows the downward trend of the cost in dollars per meter of a single channel optical fiber. Although the curve is for a typical low-loss fiber with an outer diameter of about 125 μm, the relative cost trend also applies to other kinds of fiber. This trend will continue as the demand and the production of fiber optics increase in the future (Reference 7). Similarly, other fiber optic components such as connectors, sources, detectors, etc., will follow the same trend. For example, the price of a single channel connector has dropped about 50% over the past two years.

e. Conclusion. Despite the advantages of fiber optic cable over conventional transmissions, there are still factors that prevent the explosive spread of fiber optic technology. The problems are high cost and nonstandardization of fiber optic components. Besides this, there is a retarding factor for designers to try new technology. Nevertheless, fiber optic systems will expand considerably in the next decade.

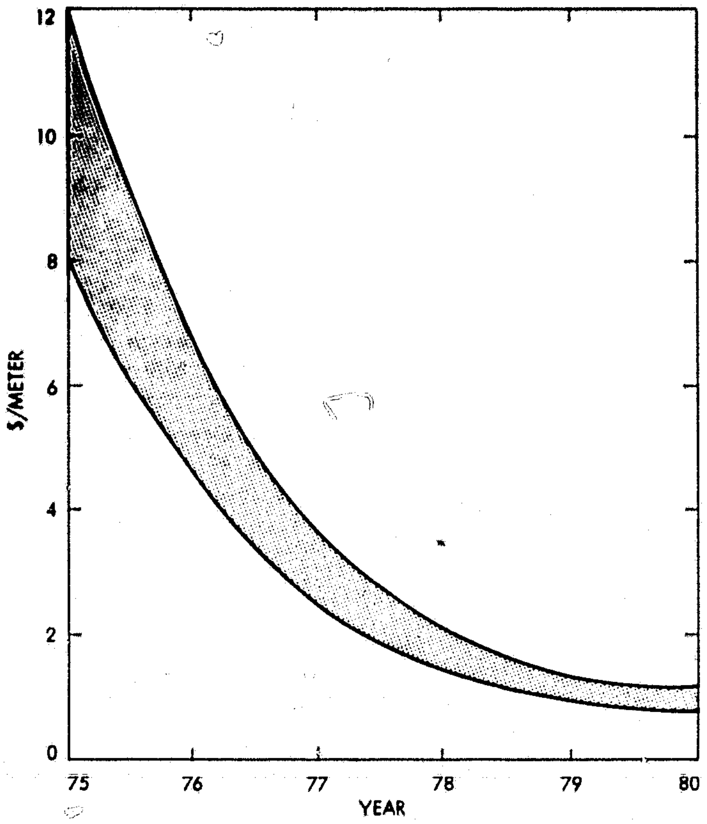

Figure 4-3. Cost Trend of a Single Channel Optical Fiber

9. Chemical Analysis of Microfilm, Tape, and Disk Media

The materials-of-construction of anti-halation underlayer (AHU) microfilm and a magnetic recording disk were identified by chemical analysis. The results of this investigation as well as previous studies of the chemistry of tape are included along with archival storage recommendations.

a. AHU Microfilm Storage. The construction of the AHU microfilm consists of a cellulose acetate film substrate, with an image-developable coating on one side and an anti-halation coating on the other side. The anti-halation coating reduces or eliminates the occurrence of light fogging or halo patterns due to internal reflection of light. The anti-halation coating is virtually removed during film development, having purpose only when the film is exposed during picture taking.

The image-developable coating consists essentially of silver salts (e.g., silver bromide) dispersed in a gelatinous protein binder. After development, elemental silver is dispersed throughout the gelatinous protein binder in graded concentrations that visually display the photographed subject.

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All three of the component materials identified so far, elemental silver, gelatinous protein, and cellulose acetate, have the potential for chemical and physical interactions with the environment, which could impact on use and storage. However, the successful use and storage of immeasurable footage of developed and undeveloped microfilm attest to the efficiency of the packaging and the care and caution exercised by users with regard to environmental exposure. Warning labels on film boxes particularly instruct the user to store film in a "cool and dry place."

Cellulose acetate is very hygroscopic, readily absorbing and desorbing atmospheric water vapor. The material has a high coefficient of hygroscopic expansion, and, in an unbalanced laminate construction, can cup or warp. When used as a substrate for magnetic recording tape, high humidity cupping can sometimes prevent the tape from being flat on magnetic recording heads, thus causing recording distortion. Almost all magnetic recording tape made today has replaced cellulose acetate with polyester film (e.g., Mylar™). For microfilm application, hygroscopic expansion and the potential of cupping or warp may not be a problem, or its occurrence has gone unnoticed. The intent of this paragraph and those that follow is not to artificially create concerns or problems, but to highlight environmental behavior characteristics of the materials.

Elemental silver is basically inert or unreactive, and as a dispersion within a binder, it must be fairly stable as attested by storage life up to 20 years. There are, of course, chemical vapors that are quite reactive with elemental silver, namely ammonia and hydrogen sulfide. Thus film should not be stored near ammonia cleaning solutions, ammonia refrigerator lines (due to possible leaks), or garbage dumps (a souce of hydrogen sulfide).

Gelatinous protein is probably the weak link in the chain of microfilm materials. Biological in origin, it should be susceptible to fungus growth; being protein, it would be expected to be highly susceptible to hydrolysis; and being gelatinous, it probably has temperature limitations relative to mechanical softening and development of an adhesively sticky surface. Cool, dry storage is clearly mandated for archival preservation.

Eastman Kodak[2] recommended to JPL in 1975 that microfilm be stored at 24°C and 40% relative humidity (RH). At JPL, developed film has been in continuous storage up to 20 years at 30% RH and room temperature without visual evidence of deterioration in the quality of the image.

Eastman points out that the life of the image will be shortened as storage temperature and humidity increase above 24°C and 40% RH. This could occur for two reasons, either separately or in combination.

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[2] Letter from L. H. Bassage, Technical Services Specialist, Eastman Kodak, to Dennis Muhlstein, Jet Propulsion Laboratory, July 16, 1975.

The first is hydrolysis, chemical breakdown of the binder from chemical reaction with atmospheric water vapor. This is the same mechanism that breaks down the binders of flexible magnetic recording tape. The second is physical softening of the binder with temperature, increasing to the point where binder creep or viscous flow can occur, causing interior movement and redistribution of the elemental silver; i.e., loss of picture sharpness, distortion, fuzziness, etc.

Eastman also notes that other physical damage effects will occur as RH exceeds 70%. Assuming the temperature to be 24°C, the damaging effect of sticking is interpreted to be caused by hydrolysis. It is a striking coincidence that hydrolysis-induced sticking of magnetic recording tapes occurs as RH equals and exceeds 70% at 24°C. (See Figure 4-4 on page 4-25.)

Hydrolysis, as for tapes, requires access to and chemical consumption of atmospheric water vapor. Any storage practice that isolates the spools of microfilm from direct atmospheric exposure will stop hydrolysis, independent of the RH and temperature of the exterior environment. Sealing film spools in metal cans or metal foil wrappers accomplishes isolation from atmospheric water vapor, as well as from ammonia and hydrogen sulfide vapors, if they are present. (Note that film manufacturers package undeveloped film in sealed metal foil wrappers.)

Even with atmospheric barrier packaging for storage, high temperature alone could cause image distortion through creep or viscous flow of the binder. A safe upper limit for temperature was not determined in this study. This may be a problem in the future if energy conservation goals lead to increases in the temperature of film storage areas.

In conclusion, there is real experience demonstrating that developed microfilm can be archivally stored as long as the environment is "cool and dry"; i.e., 24°C and 40% RH or less. There are also storage considerations that can be followed for film preservation, such as barrier packaging, assuming the environment of the storage area cannot be environmentally controlled. For the latter, the upper temperature limit is unknown.

b. Microfilm Image Removal. The ability to remove fingerprint card images from the photographic files is necessary due to possible court-ordered expungements. The technique described below is feasible only if the stored photographic images are large enough and/or separated enough so that adjacent images will not be damaged by the expungement process. An investigation was undertaken to find harmless chemical techniques that could permanently remove the developed image from microfilm. Since the image is achieved by gradations of elemental silver within a protein binder, and not within or on the substrate itself, it seemed reasonable to identify a chemical that could rapidly break down the protein or loosen the protein binder from the substrate.

Hot water, at a temperature of 60°C or more, will within about one minute loosen the image coating to the point where it can be easily scraped off the substrate with a Teflon-on-metal scraper.

On a flat surface, experience indicates that drops of hot water will not spontaneously spread over the image surface and must be mechanically spread over the image area that is to be removed. This is a good feature, as the hot water can then be localized. In about one minute, the image area is easily removed with the edge of a dull scraper (no need for razor blades).

Following this operation, it is recommended that the cleared area and the feathered edges be washed with cotton-tipped swabs dipped in ordinary rubbing alcohol, isopropanol. This solvent is harmless. Its function is to facilitate removal of loose debris and residual absorbed water. An optional final washing and area cleaning may be done with Freon.

The basis for this approach and the specific sequence of solvents (the order is important) emerged from a JPL need to prepare clear areas on magnetic recording tape without damaging the substrate. The tapes were used on spacecraft flight tape recorders, and life and reliability were prime considerations for whatever removal technique that was employed. JPL has never had a tape failure, either on the ground in simulated testing or in flight.

c. Microfilm Aging. The method for analyzing the aging characteristics of microfilm was suggested by examining the chemistry of tape. The primary aging mechanism of magnetic recording tape is hydrolysis, which results in a chemical breakdown of the polymeric binder. The extent of environmental aging can be quantitatively monitored by solvent extraction of the hydrolysis products. For tape, acetone is the best extracting solvent. Increases in the quantity of acetone-extractable material are associated with increases in the extent of environmental aging.

Accepting that hydrolysis of the protein binder of AHU microfilm is the primary mechanism of environmental aging, water appears to be the best extracting solvent.

Water extractions were carried out on fresh AHU microfilm and on three pieces of microfilm that had been stored for various numbers of years by the FBI. The results are:

Year	% Water Extraction
1960	0.40
1970	0.22
1979	0.21
Fresh	0.19

If the hydrolysis hypothesis is correct, the extraction data suggest an aging trend. However, what is not known for AHU microfilm is the threshold amount of water-extractable matter necessary for the potential manifestations of such problems as stickiness, image distortion, etc.

d. Magnetic Recording Disk and Tape. A magnetic recording disk was chemically analyzed to determine its composition. It consists essentially of a thin, magnetic oxide layer on an aluminum substrate. The oxide layer is a dispersion of γ-ferric oxide (magnetite) in an alkyd polyester resin. The oxide layer composition is approximately 85% by weight oxide and 15% by weight alkyd resin. Adhesion of the oxide layer to the aluminum substrate is extremely tenacious.

A lubricant has been detected in the oxide coating and identified by chemical analysis to be a metal sterate. This is a common lubricant system found in most commercial magnetic recording tapes. Typically, the metallic counter-ion is lead.

The metallic content of the oxide coating was analyzed by emission spectroscopy. The metallic elements of significance identified in the coating were iron, chromium, and lead. The active magnetic oxides are therefore ferric oxide and chromium oxide. This hybrid oxide system is in common usage in current tapes. Lead is assigned to the sterate lubricant.

Of the identified materials, substrate, oxide, and binder, only the binder would have the potential for environmental deterioration at ambient temperatures and humidities. The primary mechanism of deterioration is through hydrolysis, a chemical reaction between the polyester alkyd and atmospheric water vapor. Excessive hydrolysis of the polyester binder can result in mechanical break down, loss of binder qualities, release of oxide particles and flakes of binder/oxide material, and perhaps generation of sticky and resinous degradation products.

The hydrolysis of polyester binders used on flexible magnetic recording tapes has been studied at JPL. From these studies, safe conditions of temperature and humidity for long-term flexible tape use and storage have been defined. This is detailed in Figure 4-3.

It should be noted that the polyester binder used on the magnetic disk is higher in modulus and more rigid than binders used on flexible tape. Generally, the hydrolysis sensitivity of polyesters decreases with increasing modulus, and therefore it might be anticipated that a magnetic disk might survive use and storage exposures to higher levels of temperature and humidity than flexible magnetic tape.

Although this has not been experimentally investigated for disks, no technical reason is seen for rigid disk binders to be more sensitive to hydrolysis than flexible tape binders. Accordingly, the conditions of temperature and humidity defined by the recommended zone in Figure 4-4 should function as conservative recommendations for long-term storage and use of magnetic disks.

It is important to be aware that hydrolysis requires access to and chemical consumption of atmospheric water vapor. Any use or storage practice (such as barrier packaging) that isolates the disk from access to atmospheric water vapor stops hydrolysis, no matter what the exterior atmospheric conditions. The recommended zone in Figure 4-4 relates to unprotected magnetic tape having direct access to atmospheric water vapor.

Lubricants are used on flexible magnetic recording tapes to reduce sliding friction and drag as the tape passes over the recording head. As the lubricant is depleted below a critical concentration (windshield-wiper effect), tape friction and drag increase, wear of head and tape surfaces increases, and recording and playback quality becomes progressively worse. For some tapes, the lubricants are surprisingly volatile and by the nature of their chemistry more rapidly evaporate at relative humidities below 15%. The role of lubricants in magnetic disks and any relation to disk life is not known. The point is to be mindful of flexible tape experience if the disks are to be routinely and repeatedly accessed for storage and retrieval.

With respect to adhesive bonding of the oxide layer to the substrate, only two debonding problems are encountered with flexible tape. The first and most dominant is defective manufacturing, and the tendency for oxide layer debonding is revealed almost immediately upon the first use of the tape. The tape is then generally discarded. The second is hydrolysis, which, in addition to breaking down the binder, also breaks down the interfacial bond. But other hydrolysis problems precede debonding, and usually the tape is discarded before the user observes debonding. Once successfully past the first use, it is unlikely that there will be any debonding problems for flexible magnetic recorder tape. Similar behavior is expected for magnetic disks.

10. File Protection

The most prevalent cause of magnetic disk failures is the scarring of the recording sufaces due to head crashes. On the outer tracks, the media speed averages about 2000 inches per second (114 miles per hour). The flying height of the heads average 25 microinches. Therefore even small dust particles can cause severe impacts between the record playback heads and the recording media. Thus it is imperative that periodic dumps of the disks onto backup media take place. Additionally, a record of all transactions since the last dump should be retained, so that the contents of the recording surface can be reconstructed in the event of a head crash.

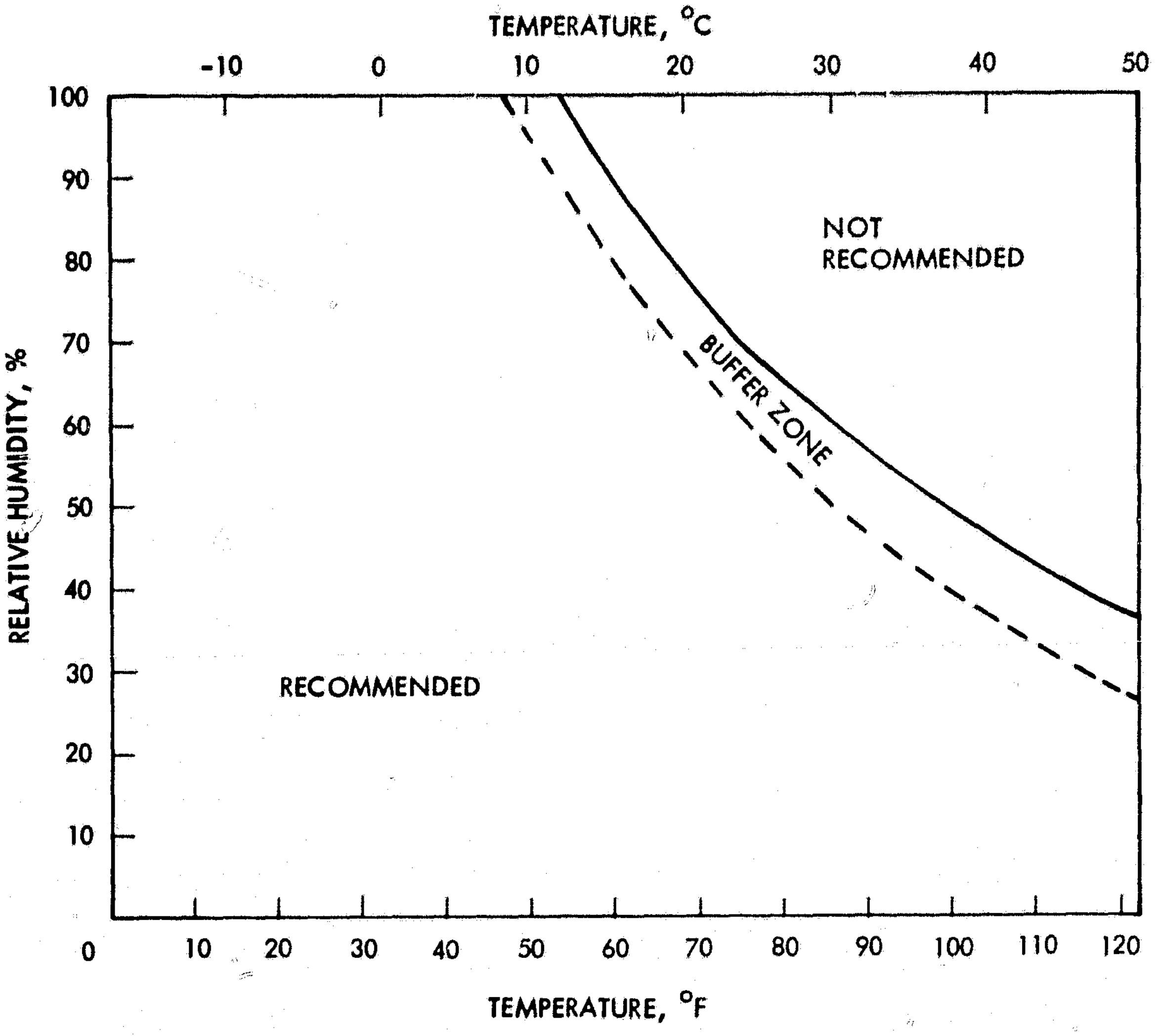

Figure 4-4. Storage and Use Environment for Unprotected Magnetic Recording Tape

There are several schemes that can be used to transfer the amounts of data required in a timely manner.

a. Standard Tape Recorders. The standard vacuum driven computer tape recorders are expensive to purchase as well as to maintain. In addition, they were designed for fast acceleration and deceleration to accomodate bursts of reading and writing. On the other hand, the reading and dumping of files is continuous, and can perform in a much faster manner as discussed next.

b. Duplicate Disks. Duplicate disks are quite expensive unless removable cartridge disks are used. The Lark cartridge disks made by Control Data Corporation are removable, but can only store 8 Mbytes of data, which is insufficient for AIDS III application.

c. Streaming Tape Recorders. The new streaming tape recorders were designed to record and play back long, continuous streams of data at high rates. A typical ½ inch streaming tape recorder can write about 100 Mbytes per reel. Moreover these recorders are far less expensive than conventional recorders. IBM and Cipher Data in San Diego currently market inexpensive ½ inch streaming tape recorders.

d. Streaming Cartridges. Data Electronics Incorporated in San Diego is marketing an inexpensive streaming cartridge tape recorder for use with 3-M tape cartridges. Cartridges have the desirable property that the recording medium is not directly handled by the operator.

11. Automated Image Retrieval

References 10 and 11 were examined to evaluate the proposed automated image retrieval subsystem. The design of this subsystem appears to mimic a manual system in the way process control is performed. Moreover the documentation is very poor; issues of file security and file indexing are omitted, and References 10 and 11 have inconsistent workstation projections. A possible alternative is presented in this section.

a. Subsystem Design. The subsystem design approach described in Section 1 of Reference 10 seems to be more concerned with equipment specification than file management. The apparent hierarchy of design tasks (from highest to lowest) is:

i) Media selection

ii) Manual vs remote viewing

iii) Image capture equipment

In contrast, it is felt that a truly top-down approach would arrange the design tasks in this order:

i) Media selection

ii) Image file organization

iii) Indexing of image file

iv) Equipment considerations

b. Workstation Projections. According to page 96 of Reference 10, 26 file segments will be needed for image comparison. On page 43 of Reference 10 it is stated that, "Each segment will have a minimum of one workstation and as many more as are required to handle the work load." Thus it appears that at least 26 workstations are needed. However Figure 4-1 of Reference 11 shows only 19 image comparison workstations. Hence there is an apparent discrepancy in the design.

c. Process Control. The design as indicated by References 10 and 11 has the potential of creating severe bottlenecks, since the distribution of the work load to the workstations is unpredictable. Another disadvantage to the design is that in the case of multuple candidates, several teams of examiners may have to analyze the same inquiry card, creating an efficiency problem. As stated on page 96 of Reference 10:

"In the least efficient procedure for screening multiple candidates, the comparison of the inquiry card to each of the candidates occurs at different times and places and is done by different people. In this case, the inquiry card must be examined once for each candidate card. Such a system results if the images are filed randomly, then divided evenly among enough workstations to handle the throughput. This type of system can be implemented using commercially available equipment. However, its efficiency would be poor for those inquiries having more than one candidate. Efficient use of the examiner's time is important because anything that adds one second to the processing of each inquiry card also adds one examiner to the required staff."

d. Interim Files. Another area of poor design is the necessity for interim files described on pages 97-98 of Reference 10. The use of interim files creates a file maintenance problem, since each of the magazines (corresponding to the 26 file segments) containing the images must be purged and updated on a daily basis. Also each time a magazine is updated, all the interim indices must correspondingly be updated to reflect their permanent status.

e. File Security. Reference 10 does discuss how files are to be protected against the loss of data due to natural disasters or internal sabotage. Either a back-up image file is needed and must be maintained, or else the original films from which the fiches were created must be stored and maintained. It would be desirable to keep the original photographic images in an area which is inaccessible to the system personnel, and then to transmit the images to the examiners to reduce the possibility of sabotage.

f. File Indexing. There is no discussion in Reference 10 regarding the data base management techniques which will be used to access the files. Such a discussion is necessary before intelligent decisions can be made about equipment.

g. Holographic Tape Recordings. Holographic tape recording media are not discussed in Section 1.1 of Reference 10. Plessey Corporation in England has developed holographic storage and retrieval devices using nitro-stilbene as the information carrier. This technology increases the linear recording density by a factor of several hundred over magnetic tape.

h. Photographic Media. Reference 13 contains an analysis of the advantages and disadvantages of using digital magnetic media, analog magnetic media, and photographic media as a carrier for the fingerprint card images. The conclusion was that photographic media would be the best choice. (This agrees with the position taken on Page 7 of Reference 10.) However, the issue of quality control should not be ignored. Some type of inspection procedure is needed to verify that the filming has been successful. Otherwise, there might be a substantial amount of additional effort required downstream.

i. Proposed Image File Alternative. If all existing and future fingerprint information is converted to a sequential, chronological, photographic file indexed by a sequence number, then problems of segmented, interim, and temporary files vanish. Also work load distribution and bottleneck problems are mitigated, leaving a smoothly flowing system. The proposed alternate procedure is as follows:

Step 1. Assign PCN to inquiry card.

Step 2. Encode each inquiry card.

Step 3. Perform candidate search to obtain the sequence numbers of the candidates.

Step 4. Create a "request for retrieval" record consisting of the sequence address of the candidate and the PCN of the inquiry.

Step 5. Sort the inquiries by sequence number so that the retrieval process is a batch process, minimizing film motion.

Step 6. Retrieve a copy of each candidate from the films.

Step 7. Print the PCN of the inquiry onto the copies.

Step 8. Sort the copies by PCN and merge the inquiries into this batch. (Now for each inquiry card, all the candidates are directly behind it.)

Step 9. Distribute the batches to smooth the work load of the examiners.

12. Automated Card Transport

The conveyor system as described in Sections 8.1.2 and 8.2 of Reference 12 should enjoy trouble-free operation. On the other hand, the chances of reliable operation of a card buffer station, such as proposed in Figure 8-1 of Reference 12, are not good. In the case of a nearly empty hopper, the cards would free-fall through more than 36 inches, in the manner of tree leaves in the autumn wind. Their landing patterns would be unpredictable, with some cards landing face-up, some face-down, and some on an edge. Cards landing on edges would buckle and perhaps be permanently damaged under the weight of up to 3600 cards (over 20 pounds) landing on them. The result would be card jams, which would be difficult to clear due to the weight of the card stack.

The task of separating exactly one card at any time from the bottom of a heavy card supply is oversimplified in Reference 12. The classical approach of the "pickerknife and throat" as was used in IBM and Remington-Rand-Powers punched card equipment does not seem promising in this application because of the lack of materials standards. Thickness variations of different cards are to be expected in addition to many well-worn cards. The use of vacuum suction for increased friction between the bottom card and the picker mechanism would allow some bending of the bottom card to enhance positive separation from the stack. Reference 12 does not discuss the problem of feeding the last cards from the stack, when there is almost no weight on the bottom card. This problem deserves consideration. Finally, there is concern that the process of removing the bottom card from a 36-inch stack might smear the fingerprint ink and blur the image.

There are a few alternative approaches that are worth studying. Delivery mechanisms with controlled drop altitude should be examined, where the hopper feed belt can be raised or lowered. Hopper shaking was used in IBM equipment to align the cards in the stack. Another suggestion is to remove the cards from the hopper in a last-in-first-out fashion, instead of first-in-first-out as indicated in Figure 8-1 of Reference 12. This could be easily accomplished by spring-loading the hopper bottom, keeping the top of the stack at a constant level.

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APPENDIX A

ACRONYMS

ACS	Automated Classification System
AFRS	Automated Fingerprint Reader System
AHU	Anti-Halation Underlayer
AIDS	Automated Identification Division System
ANS	Automated Name Search
ATS	Automated Technical Search
ATSPS	Automated Technical Search Pilot System
AUTOCOR	Automated Correspondence Station (part of AIDS)
AUTORESP	Automated Response Generation (part of AIDS)
A&R	Automation and Research Section of Identification Division
BER	Bit Error Rates
BLO	Blocking Out
CCA	Computerized Contributor Abbreviated Name
CCH	Computerized Criminal History (part of NCIC)
CCN	Computerized Criminal Name
CCNR	Computerized Criminal Name and Record (part of AIDS)
CCR	Computerized Criminal (Arrest) Record (part of AIDS)
CIR	Computerized Ident Response File (part of AIDS)
CLASS-A	Classification-A
CLASS-B	Classification-B
CLASS-C	Classification-C
CLCK	Classification Check
CNR	Computerized Non-Ident Response File
COA	Cutoff Age
CPU	Central Processing Unit

CRS	Computerized Record Sent File (part of AIDS)
CRT	Cathode Ray Tube
CSORT	Centerline Sort
DATE STP	Date Stamp, Count and Log
DBMS	Data Base Management System
DEDS	Data Entry and Display Subsystem (part of AIDS III)
DENT	Data Entry
DENT-A	Data Entry-Cards
DENT-B	Data Entry-Documents
DOA	Date of Arrest (on f/p card)
DOB	Date of Birth (on f/p card)
ECL	Emitter Coupled Logic
EMI	Electromagnetic Interference
ENC	Encode Input Data-Cards
ENCDOC	Encode Input Data-Documents
ENCK	Encode Check-Cards
ENDOCK	Encode Check-Documents
ERR	Update Error File
EYE	Color of Eyes (on f/p card)
FBI	Federal Bureau of Investigation
FEP	Front End Processor
FIFO	First-In-First-Out
FLAB	Film Lab Processing/Computer
FLOAD	Film Load
FPC	Fingerprint Classification
FPCS	Fingerprint Correspondence Section of the Identification Division
f/p	Fingerprint

GDBMS	General Purpose Data Base Management System
GEO	Geographic Location (on f/p card)
GPSS	General Purpose Simulation System
HAI	Color of Hair (on f/p card)
HGT	Height (on f/p card)
IBM	International Business Machines Corporation
ICI	Image Comparison Identification
ICRQ	Image Comparison Request
ICS	Image Comparison Subsystem (part of AIDS III, actually used for image retrieval for manual comparison)
ICV	Image Comparison Verification
ID, I.D.	Identification Division
IDENT	Identification
JPL	Jet Propulsion Laboratory
KIPS	Thousands of Instructions per Second (as executed by a computer)
LEAA	Law Enforcement Assistance Agency
MAIL	Open Mail and Sort
MFILM	Image Capture Microfilm
MIPS	Millions of Instructions per Second (as executed by a computer)
MMF	Minutiae Master File
MOE	Measures of Effectiveness
MTBF	Mean Time Between Failures
MTR	Master Transaction Record
MTTR	Mean Time to Repair
NAM	Name (on f/p card)
NASA	National Aeronautics and Space Administration
NCIC	National Crime Information Center

NCR	National Cash Register Company
OCA	Local Identification Number (on f/p card)
OCR	Optical Character Recognition
OMB	Office of Management and Budget
ORI	Originating Agency Identification Number (on f/p card)
PCN	Process Control Number
PICS	PCN and Image Capture Subsystem (part of AIDS III)
PMT	Photomultiplier Tubes
POB	Place of Birth (on f/p card)
QC	Quality Control
QUERY	On-Line Query
RAC	Race (on f/p card)
READ	Quality Control Check, Read, Annotate
RFI	Radio Frequency Interference
RH	Relative Humidity
RVF	Ridge Valley Filter
SACS	Semi-Automatic Classification System
SAR	Semi-Automatic Fingerprint Reader
SEAR	Search Review
SEX	Reported Sex of a Subject (on f/p card)
SID	State Identification Number
SKN	Skin Tone (on f/p card)
SOC	Social Security Number (on f/p card)
SPM	Search Processor Module
SS	System Supervisor Subsystem (part of AIDS III)
SSM	Subject Search Module
SSRG	Subject Search and Response Generation Subsystem (part of AIDS III)

TDFA	Top Down Functional Analysis
TFC	Technical File Conversion
TR	Transaction Record
TRC	Transaction Control File
TSS	Technical Search Subsystem (part of AIDS III)
TTL	Transistor - Transistor Logic
VDENT-A	Verify Data Entry-Cards
VDENT-B	Verify Data Entry-Documents
VLSI	Very Large Scale Integration
WAND	Wand Out of System

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16. Abstract

This volume, Technical Feasibility, assesses the feasibility of those technologies that are intended for use by AIDS III. The results of this effort are presented in a manner for use by both the AIDS III Operational and Economic Feasibility subtasks as well as the Development of Alternative subtask. The approach taken in this evaluation was to identify the major functions that appear in AIDS III, and then to determine which technologies would be needed for support. The technologies were then examined from the point of view of reliability, throughput, security, availability, cost, and possible future trends. Whenever possible, graphs are given to indicate projected costs of rapidly changing technologies. For a synopsis of this entire report see the Executive Summary in the Compendium (Volume I).

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