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UCRL-52052

A FEASIBILITY STUDY FOR THE COMPUTERIZED AUTOMATION OF THE ANNAPOLIS FIELD OFFICE OF EPA REGION III

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August 1976

Prepared for U.S. Energy Research & Development
Administration under contract No. W-7405-Eng-48

Prepared under Interagency Agreement EPA-IAG-D6-0321 by the General Chemistry
Division of the Chemistry and Materials Science Department of Lawrence Livermore
Laboratory.

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Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price Printed Copy \$. Microfiche \$2.25

<u>Page Range</u>	<u>Domestic Price</u>	<u>Page Range</u>	<u>Domestic Price</u>
001-025	\$ 3.50	326-350	10.00
026-050	4.00	351-375	10.50
051-075	4.50	376-400	10.75
076-100	5.00	401-425	11.00
101-125	5.50	426-450	11.25
126-150	6.00	451-475	12.00
151-175	6.75	476-500	12.50
176-200	7.50	501-525	12.75
201-225	75	526-550	13.00
226-250	.00	551-575	13.50
251-275	4.00	576-600	13.75
276-300	9.25	601 up	*
301-325	9.75		

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UCRL-52032

A FEASIBILITY STUDY FOR THE COMPUTERIZED AUTOMATION OF THE ANNAPOLIS FIELD OFFICE OF EPA REGION III

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MS. date: August 1976

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A FEASIBILITY STUDY FOR THE COMPUTERIZED AUTOMATION OF THE ANNAPOLIS FIELD OFFICE OF EPA REGION III

Abstract

This report describes a feasibility study for computerized automation of the Annapolis Field Office (AFO) of EPA's Region III. The AFO laboratory provides analytical support for a number of EPA divisions; its primary function at present is analysis of water samples from rivers, estuaries, and the ocean in the Chesapeake Bay area. Automation of the AFO laboratory is found to be not only feasible but also highly desirable. An automation system is proposed which will give major improvements in analytical capacity, quality control, sample management, and reporting capabilities. This system is similar to the LLL-developed automation systems already installed at other EPA laboratories, with modifications specific to the needs of the AFO laboratory and the addition of sample file control. It is estimated that the initial cost of the system, nearly \$300,000, would be recouped in about three years by virtue of the increased capacity and efficiency of operation.

1. Introduction

The Environmental Protection Agency (EPA) has recognized for some time that its laboratories would benefit from computerized automation, and since 1971 the EPA and Lawrence Livermore Laboratory (LLL) have been working jointly on automation plans. The approach has been to make individual studies of a few typical laboratories and develop automation systems for them that could be reproduced, with only minor modifications, to serve for other similar laboratories. This effort, conducted under Interagency Agreement No. EPA-IAC-D6-0321, has become known as the Pilot Laboratory Automation Project. Members of the LLL Chemistry and Materials Science Department with broad experience in computer automation of laboratory operations have been assigned to the project. Automation systems have already been designed and put into operation at three EPA laboratories: two laboratories of the Environmental Research Center at Cincinnati, and The Central Regional Laboratory, Region V, at Chicago. The fourth laboratory studied for automation is the Region III Annapolis Field

Office (AFO). This report describes the AFO study and the automation system proposed as a result.

There are five major objectives accomplished by automating the EPA's sample analysis laboratories:

1. Increased instrument capacity. The computer helps to maximize instrument capacity in several ways. Concentrations are calculated immediately and quality control checks are made on stream. On fully automatic instruments, the operator is notified immediately if something goes wrong with a run so that it can be corrected. On semimanual operations, the computer saves time between samples by relieving the operator of the need to read and calculate concentrations.

2. Improved accuracy and precision of analytical results. Digital reading of the instruments by a computer is inherently more precise than visual reading and covers a broader dynamic range. In addition, accuracy is improved by using some of the increased sample capacity that the computer provides to run more standards, spikes, and duplicates.

Computer automation provides two important kinds of quality control (QC). The first kind of QC is passive; it results from the fact that the flow of information is always under computer supervision, with no hand transcription of data once it is entered into the system. If the system makes a mistake, it is almost invariably the kind of mistake that humans find preposterous. Such errors are easy to spot.

The second kind of QC provided by computer automation is active. The arithmetic power of the computer permits easy implementation of analysis algorithms and statistical tests which are very laborious to do by hand or even with a modern calculator. Additional operator effort is required, but it is minimal. The analyst must pipet duplicate samples and standards, and spike a certain fraction of samples.

Together, these two kinds of QC, passive and active, alert the operator to trends in system behavior and permit him to take corrective action before, or as soon as, false results are produced.

3. Analysts' time saved, tedium reduced. The computer easily handles the tedious, repetitive work that operators have done in the past and frees them for tasks that better utilize their talents. There are several major ways the computer helps the analyst. It reads all the data and calculates the concentration of samples and the curves for standards. It keeps track of work

that needs to be done and work that has been done and creates tables of output data. It retrieves stored data to help with dilutions and provide compliance limits.

4. Reduced clerical time and errors. The computer saves clerical time and reduces clerical errors because it eliminates all hand transcription of information and data after the initial sample-identifying information has been entered. It will print reports suitable for filing or distribution and will maintain an inventory logbook.

5. Improved access to the analytical data. At least one month's accumulation of analysis data can be stored in computer system files. With the proper software, known here as sample file control, the information can be made available in a variety of formats that can be used in preparing reports. It can also be used for looking at trends of instrumental behavior (e.g., calibration drift), checking quality control parameters, and preparing work accountability reports.

In Section 2 of this report we describe the Annapolis Field Office and the analytical systems to be automated. Section 3 gives the features we consider important in a laboratory automation system. Section 4 describes the automation system we propose for the AFO laboratory, Section 5 compares the proposed system with alternative approaches, and Section 6 discusses the impact of the proposed system on AFO laboratory operations. Details of the analyses used in the evaluations are given in the appendices.

2. Description of the Annapolis Field Office (AFO) Laboratory

LABORATORY OPERATIONS

The Annapolis Field Office (AFO) provides analytical support for a number of EPA divisions, including Surveillance and Analysis, Enforcement, and Air and Water and Hazardous Materials Control. Currently the primary function of AFO is analysis of water samples from rivers, estuaries, and the ocean in the Chesapeake Bay area. These samples are usually obtained by teams from the particular office involved.

Some of the other duties of the AFO laboratory include bottom sediment analysis, biological identification, and analysis of material being dumped in the ocean. Laboratory personnel analyze all air bubbler samples taken in Region III as a part of the National Air Surveillance Network. They monitor

plant effluent to see that standards are being complied with, a task that will become increasingly important.

Every six months the laboratory and engineering staff plan the next six months' work load. The engineering staff picks the surveys. A description of each task is written by the engineers and sent to the laboratory. Jointly, a weekly schedule is issued showing the expected sampling.

All liquid samples for nutrient analysis arrive at AFO refrigerated. They are arranged according to parameters requested, and an analysis request form is supplied with each sample. The samples are stored in a custody room. Laboratory personnel then take these samples for indicated analyses according to established priority.

The work required to prepare sample workbooks and outgoing analysis reports and correlate sample identifications with data is a major clerical burden. More important, the analysts spend much of their time correlating strip-chart data with sample identifications and making quantitative calculations. Sample identifications and data are manually transcribed several times for each constituent determined.

Up to 40 different parameters may be measured on a sample. These parameters include about 20 trace metals; several nutrients, such as various forms of nitrogen and phosphorus; anions such as chloride, sulfate, cyanide, and fluoride; and tests for such characteristics as total organic carbon and chemical oxygen demand.

ANALYTICAL SYSTEMS TO BE AUTOMATED

Atomic Absorption Spectrometry

Trace metals are determined by measuring the amount of light absorbed by atoms at discrete wavelengths of light. A hollow-cathode lamp is used to generate a light of discrete wavelength characteristic of the metal of interest. Part of the sample is transferred to a flame or furnace in a reproducible manner. The flame converts part of the sample to atoms in the unexcited state, which can absorb the light from the hollow cathode and change the amount of light striking a detector. The detector generates an electrical signal which is converted to a voltage proportional to the amount of light absorbed by the metal atoms in the flame. The voltage is recorded and the amount of that particular metal in the test solution is calculated by comparison with a standard solution containing a known amount of the metal.

Two atomic absorption instruments together with one automatic sampler would be automated. The detector output signal would be conditioned and interfaced for computer reading. The sampler would be interfaced so that the computer would control the rotation of the turntable and the raising and lowering of the aspirator used in flame analysis. A computer analysis algorithm would automatically time the positioning of the sampler, reading of the signal, and correlation of the signal with the sample identification number.

Technicon AutoAnalyzers*

The species of interest is converted to a colored solution by a series of precisely controlled chemical reactions that take place in a continuously flowing stream in which a known proportion of sample and reagent solutions are drawn into the system and moved through it by a peristaltic pump. Processes for different constituents require different steps in the chemical procedure, such as filtration, digestion in hot concentrated acids, reduction, and time delays to allow each step to reach equilibrium. Finally, the colored solution flows through a colorimeter cell and absorbs light in the wavelength band of the colorimeter. The amount of light absorbed is detected by a photodetector and recorded as an output voltage on a strip-chart recorder, and the amount of the chemical species of interest is calculated by comparing the recorded voltage with that for a standard solution containing a known amount of the determined species.

A maximum of 15 channels of Technicon AutoAnalyzers together with their automatic samplers would be automated. This would consist of six channels of the Technicon CSM-6, five channels of Technicon AutoAnalyzer I, and four channels of AutoAnalyzer II. The detector output signal of each colorimeter would be conditioned and interfaced for computer reading. Separate computer-analysis algorithms would be provided for each colorimeter, and they would automatically time the signal reading and correlate signals with sample identification numbers.

Total Organic Carbon Analyzers

Total organic carbon is determined by combustion of organic matter to convert the carbon to carbon dioxide, which is detected as it passes through

* Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Energy Research & Development Administration to the exclusion of others that may be suitable.

an infrared analyzer. A measured volume of the test solution is injected into a combustion furnace and swept through by a continuously flowing stream of oxygen, converting the sample liquid to water vapor and carbon dioxide. The water vapor is condensed and trapped out as the gases are carried out of the furnace, and the carbon dioxide is carried through the infrared detector and released to the exhaust. The infrared detector generates an electrical signal which is converted to a voltage proportional to the amount of carbon dioxide passing through the detector. The voltage is recorded on a strip-chart recorder, and the amount of organic carbon present in the injected solution is calculated by comparing the recorded voltage with that for a standard solution containing a known amount of organic carbon.

The Beckman 915 Total Organic Carbon Analyzer would be automated. The detector output signal would be conditioned and interfaced for computer reading. A computer-analysis algorithm would automatically time the signal reading and correlate the signal with the sample identification numbers.

Existing Data-Processing Procedures

Most of the samples are water samples. When these samples are taken in the field the salinity, temperature, and other parameters are measured and recorded on a field card, which accompanies the samples back to the laboratory. Samples for dissolved oxygen are delivered in a special bottle with the bottle number already attached to it. With each sample is a sample station number and a parameter code that the field engineer enters on the card describing the sample. There are several types of field cards being used; the most common are a white and a yellow card. The white card is used for entering field data for survey-type analyses. The yellow card is used for compliance monitoring: in other words, checking to see if an industry or a municipality is exceeding its licensed amount of discharge. This card has the usual field data entered by engineers, and in addition it has a witnessed chain of custody with dates and times. On the reverse side is space for entering the results of all the desired analyses.

When the sample arrives at the laboratory an eight-digit sample number is assigned to it. The first six digits of this number are the year, month, and day the sample was taken. The last two digits are the sample number, 1 through 99. If more than 99 samples come in on any one day, the excess samples are handled by incrementing the date and starting over again with the number sequence 1-99, since normally batches of samples do not arrive daily.

The eight-digit sample number is then written on the side of the sample container, which is a cubical polyethylene bottle called a Cubitainer. These samples come in ice chests, and an attempt is made to complete all nutrient analyses within 24 hours after the samples arrive at the laboratory. Metal analyses are completed without this constraint.

The secretary keeps a series of lab books, one lab book for each different type of determination that is done, such as organic carbon, silicon, total phosphate, nitrite, nitrate, etc. The analyst picks up the lab book from the secretary and enters the results of the determinations for that day. The lab book is then returned, and the laboratory results for each sample are compiled by the secretary.

A considerable amount of both clerical and analytical time is spent writing up sample work sheets and reports, and a major portion of the analyst's time is required to correlate strip-chart recordings with sample identification numbers and to calculate values for each constituent determined.

A sample file control for sample logging and report writing should be part of the automation system. This system would control and document each sample's progress from the time it reaches the sample acceptance station until the data derived from it is printed in a final report to the requester.

3. Features Required to Meet the Automation Objectives

In this section we itemize the features required in a laboratory automation system to achieve the automation objectives listed in Section 1. Related material is given in Appendix 1, in the form of guidelines followed in evaluating various proposed automation systems for the AFO laboratory. Some of these features require or are enhanced by sample file control (SFC).

- Operating of the instruments. The system must be able to take readings from the output of the instrument at the time a sample signal is present, and to sense and control the insertion of new samples.
- Quality control for each parameter. A set of standards, replicates, and spikes must be used to assure the correct result for a parameter.
- Analyst's work-session plan. Given the samples before him, the analyst should be able to arrange the running sequence in a pattern with check standards or rerun samples in an order that minimizes interference between samples. (Enhanced by SFC.)

- Local record of sample activity. The summary of samples completed, partly done, or still to be done should be available at every work station. (SFC required.)
- Calculation of results. Arithmetic algorithms to calculate results from standard values, the volume taken, etc., and standard deviations should be included.
- Ease of instrument add-ons. The computer system should be able to accommodate additional instruments and perform additional automatic functions. The need for outside help should be minimized.
- Off-line data manipulation. This important feature, which allows an operator to use the computer as an extremely powerful calculator, should be built into the system.
- Ease of reprogramming. The user himself must be able to make necessary changes when new information, procedures, and operations are instituted.
- Logbook entries. Logbook entries must identify the samples, date them for entry, and specify the requested work.
- Analyst's workload selection. The computer must be able to select a batch of samples for a particular test from the many in storage. (SFC required.)
- Storage of results. The analytical results must be associated with all else that is known about the sample. (SFC required.)
- Storage of legal/AQC data. The record of custody and records of assurance that the proper procedures were followed are of use in quality control. The attorneys need evidence that acceptable procedures were followed and that the results are valid. (SFC required.)
- Backlog requests. The supervisor must be able to trace work in progress and plan laboratory efforts. (SFC required.)
- Standard and interim reports. A final hard-copy report of results should be readily available, as well as interim reports such as the supervisor may need to determine the progress before all work on requested parameters is complete. (Enhanced by SFC.)
- Interparameter quality control. Related parameter results should be self-consistent. An example is the sum of inorganic and organic nitrogen, which must equal total nitrogen. (Simplified by SFC.)

- Analysts' needs for at least one month's worth of data. The system should be able to store at least one month's back data for effective operation. For example, results of previous work on similar samples are needed for estimation of dilution factors, and trends in the calibration curves give warning of maintenance that needs to be done. (SFC required.)

4. The Automation System Proposed for the AFO Laboratory

The hardware and software proposed for the Annapolis Field Office are very similar to those already installed in three other EPA facilities (two at Cincinnati and one at Chicago). The differences are due mainly to improvements by the supplier, Data General Corporation, and the need for increased capabilities to improve upon the present systems. The changes do not affect transportability of software between facilities.

This description is broken into two major sections, hardware and software. The software is broken into two options: the present programs without change, and the present programs with modifications specific to the needs of the Annapolis Field Office.

HARDWARE

The proposed computer system is designed around a Data General Eclipse C/300 computer as shown in Fig. 1. A list of the major components and their cost is given in Appendix 2 (Table 2-1).

This is a maximum configuration which allows the maximum reasonable capability of the system when the ultimate number of instruments are interfaced. Some of these items do not have to be procured at first, but can be retrofitted to the system in the future if expansion is warranted. Such items are indicated in the following description of the individual components.

1. Main frame (computer). The computer main frame is the latest generation produced by Data General Corporation, the Eclipse C/300. It is similar to the Nova 840 computers, which are used in the other EPA facilities. The Eclipse computer is almost twice as fast as the Nova. It uses the same operating system as the Nova, MRDOS, so that most software is transportable.

Twice as much core memory is proposed for the maximum AFO system as in the existing systems. This additional core may be used as a swapping area

Fig. 1. Schematic of proposed hardware system for the Annapolis Field Office.

for BASIC users in potential future revisions. For the system to be time-shared, various users' programs must be brought into active core and executed, each user getting a certain amount of time before another user takes over. Most of the BASIC user programs are so large that only one user can fit in active core at one time. Therefore, users are presently swapped in and out of core from a fixed-head disk. It takes approximately 0.2 sec to transfer from disk to memory and vice versa. A transfer to and from the extra core could be done in about 100 μ sec -- a considerable and worthwhile time saving.

For the present, this additional memory is not included. When all the initial instruments are running simultaneously a mild degradation of response is noticed by the operators of the existing systems. As additional instruments are interfaced this degradation may become unacceptable. If so, additional core can be added then.

The Eclipse C/300 computer is recommended because it provides improved file management capabilities through Data General's INFOS system. Sample management programs can make use of INFOS to speed the operations log-in, workload listings, and report generation. A less expensive alternative to the C/300 (\$32,700) might be Data General's S-200 (\$26,700). Although the S-200 has the same operating system (MRDOS) as the C/300, it is not provided with INFOS. If the S-200 were chosen and at some future time INFOS were desired, the S-200 would have to be replaced with a C/300.

2. Disk storage. A rapid-access storage of programs and data is provided by disk systems. A fixed-head and a moving-head disk are proposed.

The fixed-head disk is used primarily for overlays and swapping. Its specialty is the ability to find data rapidly, but it is not particularly fast at transferring data, so it is used primarily with small files. The proposed fixed-head disk is identical with those in the present systems and has not been very reliable.

The proposed moving-head disk is a considerably faster unit than the one used in the present systems. Although it takes a little longer to find data than the fixed-head disk, it transfers data much faster. As an example, it can transfer an average BASIC program almost three times as fast as the fixed head and twice as fast as the present moving head. In addition, it provides more storage than the present disk. While this additional storage is not needed to implement the present functional description, no smaller disk drive is available with the desired speed. Its reliability is expected to be

excellent, since it is built by Control Data Corporation and marketed by them as the CDC 644 and by IBM as the 3330.

Several open-ended options are possible. We recommend purchasing the fast moving-head disk (\$31,760) initially. The fixed-head swapping disk (\$10,045) can be deferred. Response time will be acceptable with the initial instruments installed. When additional instruments are added to the system, the fixed-head swapping disk may be required. As an alternative to the above for the initial installation, a slower moving-head disk can be procured (\$10,250), but the swapping disk will also be required. This latter alternative gives the minimum cost for acceptable performance.

3. Magnetic tape. Magnetic tape is used as the primary backup medium for the system. It is also important for long-term bulk storage and for the transfer of data from one physical location to another.

The proposed system includes a magnetic tape drive running at 75 inches per second (ips). The present systems have a variety of tape drives: MERL has 12.5 ips, which is painfully slow; CRL V has 45 ips; and EMSL has two, 12.5 ips and 75 ips.

If, in the future, legal requirements make a continuous log of all system transactions necessary, additional drives, up to a total of eight, can easily be added.

4. Line printer. One of the major ways in which the computer communicates with the user is through the line printer. It will be used to produce workload listings, sample wheel patterns, notebook results, and final results and progress reports, as well as listings of programs.

The proposed line printer is twice as fast as the present one, printing 300 lines per minute versus 150. It is also considerably quieter.

5. Paper tape reader. The paper tape reader is used almost entirely for start-up of the system and for diagnosis of hardware problems. As an interim measure, it has been used to transfer data from instruments with their own computer into the Data General system. The proposed reader is identical with those in the present systems.

6. Analog-to-digital converter system. The analog-to-digital converter is used to read the signals coming from all the different automated instruments. The proposed converter is the same as that found in the present systems.

The proposed converter can measure 32 different signals. It has a resolution of one part in 16,384 (2^{14}) of a full-scale signal.

7. Terminals. The terminals are the major means of entering information into the computer system other than the analog-to-digital converter. They are also used to report interim data and warnings during automated runs.

Two different terminal types are proposed. One is a silent, hard-copy device. Two of these are used with the computer console to control systems operation. At least one other would be available for use wherever hard copy is needed.

The terminal used with all instruments and management is a cathode ray tube (CRT) type. These have the advantage of more rapid display and of not creating large amounts of unneeded paper. Some have the ability to roll back, that is, redisplay information that has already scrolled off the screen. It is proposed that ten terminals be included in the initial system. Additional terminals can be added as needed with future instruments.

8. Instrument interfaces. These are the units that convert the output of each instrument to a signal that is usable by the computer. Also, a digital interface is used to drive the computer-controlled sample wheel. Where possible, units designed for previous systems will be used. The interfaces for the Technicon CSM-6 AutoAnalyzer, the Perkin-Elmer 305B atomic absorption instrument, and the Varian Techtron AA6 atomic absorption spectrophotometer will have to be designed, since these instruments have not been interfaced previously.

9. Sample wheel. A sample wheel that is fully controlled by the computer is proposed for use with an atomic absorption instrument. Similar wheels have been delivered to other installations. The wheel can hold up to 40 samples and has a solenoid valve for automatic blank injection.

SOFTWARE

1. Existing software. The following programs are presently available:
 - a. Single channel Technicon II AutoAnalyzer.
 - b. Up to three channels Technicon II AutoAnalyzer.
 - c. Up to three channels Technicon I AutoAnalyzer.
 - d. Beckman total organic carbon analyzer (inorganic carbon removed with acid).
 - e. Flame mode, manual atomic absorption.
 - f. Flame mode, automatic (sample wheel) atomic absorption.
 - g. Graphite furnace mode, manual atomic absorption.

h. Multi-element emission spectrometer.

i. Mettler electronic balance.

Describing each of these programs in any detail is beyond the scope of this study. Detailed specifications are available for each as separate documents. There are certain general and similar functions that most of these programs include:

- A method of creating standard curves using first-, second-, or third-degree polynomials.
- Calculating unknowns by interpolating between the two nearest standards.
- Immediate display of concentration as soon as unknowns are run.
- Correction for instrument and reagent blank.
- Calculation of spike recovery.
- Calculation of error in check standards.
- Calculation of difference between duplicates.
- Calculation of statistical error bands, using the Shewhart or Cusum method.
- An operator's notebook report, including all raw and final data.
- A final report for distribution.

2. Modified software. Since no two laboratories function exactly alike, there are bound to be differences in software needs. Unfortunately, software is the largest part of the cost of any system, and the fewer changes made in it, the less costly the system. Also, it becomes impossible for a central facility such as ERC Cincinnati to maintain the programs as the different versions proliferate. Modifications should be limited to features that have a wide demand.

It is beyond the scope of this report to spell out all modifications that the Annapolis Field Office would like to see. These differences are spelled out in the functional descriptions. Some examples of desired modifications follow:

- a. The inclusion of sample file control to reduce the analyst's burden and the number of transcription errors between sample log-in and final consolidated reports.
- b. The program for the Beckman total organic carbon analyzer modified to look at total carbon and inorganic carbon, and calculate organic carbon by difference.

- c. The Technicon AutoAnalyzer program modified so that inorganic phosphorus and total phosphorus are compared and total Kjeldahl nitrogen and ammonia are compared to catch impossible numbers.
- d. The multichannel Technicon AutoAnalyzer programs modified to handle four to six channels from the CSM-6.
- e. All programs modified to include the industrial statistical error band method for standards.
- f. All programs modified to store statistical parameters about standards from run to run, so as to allow automatic updating of control limits after about 25 runs of a particular standard type.
- g. The atomic absorption programs modified to accept compliance monitoring license limits and to assure immediate rechecks for marginal or high concentrations of pollutants.

5. Comparison of the Proposed System with Alternative Approaches

The intention of the Pilot Laboratory Automation Project is that software and hardware development for any particular EPA laboratory will be transferable to other EPA laboratories. Many operations are similar from one laboratory to another, and thus automated procedures developed for one laboratory can often be used in another laboratory with little or no change. The benefits of automation for a given operation may differ from one laboratory to another because of differences in the emphasis given the operation. In this section we compare the costs and benefits of two different approaches to automating the AFO laboratory versus the alternative of leaving the laboratory as it is. The two automation approaches are: (1) install an automation system with both hardware and software selected from the system developed for the EPA laboratories in Cincinnati and Chicago, and (2) install the existing and tested system with modified software to better suit the AFO operations (i.e., the system proposed in Section 4 of this report).

We have ruled out consideration of systems from other suppliers because of the existing investment in engineering and software design applicable to Data General systems. Over \$400,000 has been invested in coding and debugging the present programs. More than 40% of this would have to be repeated for a

new system; and further, the programs would not be exchangeable with present installations and would have to be maintained by local staff.

COST COMPARISONS

Table 1 compares the costs of two alternative systems for the AFO laboratory. The alternative of leaving the AFO laboratory as it is, with no further automation, is not shown in Table 1; if it were, all its costs would be zero since it represents no change in the existing situation. Explanations of the various cost categories follow.

One-Time Costs

These are costs that are incurred only once in the automation of a given laboratory.

- Computer and peripherals. This is the estimated price, with discounts, of the computer system as of January 1976. A cost comparison of three alternative systems for the AFO laboratory is given in Appendix 2 (Table 2-1). As can be seen, the costs of disk and magnetic-tape storage units and printers are a major fraction of the total cost. Estimates of software size and storage requirements are also shown in Appendix 2 (Table 2-2).

- Terminals. To be useful to and accepted by the operator, the computer system must be designed so that the operator can interact with it easily. We recommend placing a terminal at each instrument or logical group of instruments. We estimate a need for ten terminals: one as master console, one for sample file control, one as a utility terminal, and seven at instruments. Hard copy terminals and some CRT terminals cost about \$1500 each.

- Site preparation. This is the cost of preparing a room to house the computer, a room having adequate electrical service and air conditioning. It also includes pulling cables from instrument sites to the computer room. A nominal figure of \$20,000 is used.

- Installation. This is the cost for LLL to ship, install, debug, and test the complete system in Annapolis, and to train the users.

- Interfaces. These costs are estimated from previous installations. In the case of already-designed modules, only fabrication costs are included, no design costs. Where a new instrument is specified (i.e., one for which an interface design is not already available), an estimate of the interface design costs is included. Sometimes a model change in an instrument

Table 1. Comparative costs and benefits of two systems proposed for the AFO laboratory.

	Existing EPA software ^a	Modified EPA software ^b
One-time costs:		
Computer and peripherals	\$ 98,000	\$ 98,000
Terminals	15,000	15,000
Site preparation	20,000	20,000
Installation	33,500	33,500
Interfaces	45,000	59,200
Software	0	84,000
Total	\$211,500	\$309,700
Operating expense (annual):		
Vendor's hardware maintenance	\$ 11,760	\$ 11,760
in-house hardware maintenance	7,200	8,900
in-house software maintenance	—	34,900
Total	\$ 18,960	\$ 55,560
Operating benefit (annual):		
Saving in personnel (FTE) ^c	1.95	4.97
Equivalent cost saving	\$ 68,055	\$173, 450
Net annual operating benefit (annual operating benefit less annual operating expense)	\$ 49,095	\$117,890
Payout time for system (years)	5.91	3.20
Net present value of savings over 5 years	\$ 25,400	\$137,220

^aThis column includes only features now implemented in either Cincinnati or Chicago.

^bThis column includes enhancements to software and additional instruments as indicated in Tables 2-3, 2-4.

^cFTE = number of full-time-equivalent employees.

is enough to require such additional interface design costs. A breakdown of interface costs is given in Appendix 2 (Table 2-4).

- Software. Only those costs which are for requested improvements in the existing software system are included. In particular, new instrumentation will necessarily call for software changes or new modules to accommodate the change.

A breakdown of software costs is given in Appendix 2 (Table 2-3). The costs to modify existing computer programs written for the Data General computer in one EPA laboratory so as to adapt the programs to another Data General computer in the Annapolis laboratory are about 30% of the original costs to write the programs. Since the software that allows interaction of such programs with a sample file control will be shared among the EPA laboratories, only one-fifth of the total software development cost for standard SFC is included in column 2 of Table 1.

Operation Costs

The estimates of annual costs of maintaining the computer automation system are listed here, including both hardware and software maintenance.

Data General offers a hardware maintenance contract at a monthly cost of about 1% of the initial cost of the hardware. We recommend this maintenance contract rather than the alternative of providing in-house hardware maintenance. The corresponding annual cost, or 12% of the computer and peripherals cost, is shown in Table 1.

The software maintenance costs will be fairly high during initial usage, but will soon taper off to low levels, to be replaced by modifications in output, calculations, etc., which will be requested by the users as they become experienced with the system. The software will be maintained initially by the supplier, by EPA Cincinnati, and by the users after acceptance of the system. In the system using only the existing software, monthly cost of maintenance is estimated at 1% of the initial cost of terminals plus interfaces. In order to use the system effectively, the laboratory scientist will have to develop certain skills. He must interact with the system by entering data and control information on a typewriter keyboard adjacent to the instrument. He must modify his previous manual procedures and methods in order to accommodate this new "man-machine dialogue." He should be aware of what actions are necessary when an abnormal condition arises: if he types the wrong sample, or the computer detects or causes some sort of error. As he

becomes familiar with the system over a period of a few months of production operation, the laboratory scientist will be able to spot and correct human, instrument, or computer malfunctions quickly himself or describe the symptoms of a more involved problem to the maintenance person. These skills are acquired by the laboratory scientist in several ways:

- Working visits to ERC Cincinnati for tutorial instruction before delivery of the system. This includes observation and use of a similar automated instrument or procedure by the prospective new client, under guidance of a scientist who has acquired and is already using these skills.
- Remote access (via dial-up terminal) to an existing system for learning BASIC and instrument program dialogues prior to system delivery.
- Tutorial sessions given by the automation installation team during actual installation (1-4 days per analyst).
- Self-study of the operational documentation provided with the system for the use of each instrument.

As the laboratory scientist becomes more familiar with the use of his automated instrument, he will probably want to modify and extend the capabilities of the software as follows:

- He may want to streamline the instrument setup and operation dialogue once he has gained familiarity with what the system needs to carry out his analysis.
- He may want to convert options provided with the delivered system into program constants to save time, in the event that the items are not changed during a normal run.
- He may want to change the instrument data reduction algorithm to accommodate a special analysis requirement or to implement a new analysis method.
- He may want to change the structure or appearance of an output report.

While the laboratory scientist will be able to make changes in input and output formats and procedures easily using BASIC, there are certain tasks which will require skills that may not be easily developed in the laboratory staff. If one of the existing staff members cannot be trained, a new employee will be required. This employee's duties will include system responsibilities such as maintenance and upgrading of:

1. Hardware, including handling the computer vendor's service contract and maintaining the custom hardware.

2. Instrument control and applications software, including assisting and advising the laboratory scientists responsible for the individual instruments.

3. Sample file control functions, including tailoring reports and definition of file structure.

To the laboratory's unique needs this employee will have the primary responsibility for the computer system operation, including maintaining backup copies of all programs and important files. His educational background might be in electronics, chemistry, or computer science, but he must develop familiarity with all these fields. Appendix 6 amplifies on the manpower and skills problems.

There will be a higher level of software assistance provided by ERC Cincinnati. They will maintain and develop assembly language patches for new instruments, as well as serve as an exchange point and documentation center for software enhancements developed in or out of the Agency.

BENEFIT COMPARISONS

Each of the three alternatives considered in the preceding cost comparisons must be looked at critically to see which is best suited to the AFO laboratory: (1) no further automation, (2) adopting the Cincinnati automation system without change, (3) using the modified Cincinnati system as proposed in Section 4 of this report. For each alternative we list advantages and disadvantages below.

Summary of Advantages and Disadvantages

(1) No Further Automation -

This means the AFO laboratory as it stands, and includes any existing computer automation that may have been applied previously.

Advantages -

- The large amount of capital funds that would have been spent for computer hardware with automation could instead be used for other purposes such as additional laboratory equipment.
- No time would need to be spent for training personnel in automation procedures.

Disadvantages --

- No reduction in man-hours spent in routine, uninteresting tasks.
- No reduction in calculational, transfer, and typographical errors.
- No immediate indication of faulty conditions.
- No easy way to produce consolidated reports, workload listings, and status reports.
- No automatic updating of statistical quality-control criteria.

(2) Existing Automation System

This is the system presently running in two laboratories at the Environmental Research Center in Cincinnati and in the Region V Central Regional Laboratory in Chicago. There would be differences in hardware to take advantage of the latest models, but all the software would be the same as that presently running on one of these three existing systems.

Advantages --

- Reduction in man-hours spent in routine, uninteresting tasks.
- Reduction in calculational, transfer, and typographic errors.
- Immediate indication of faulty conditions.
- Software tested and debugged by others.

Disadvantages --

- Cost of the computer system and extra hardware.
- Time required to train personnel.
- Space required by computer system.
- Software not idealized for all functions of the AFO laboratory.

(3) Modified Automation System (the Proposed System)

This is the system described in Section 4. It uses the same hardware, but the software has been modified to specifically fit the operation of the AFO laboratory, and to include sample file control.

Advantages --

- All advantages of the second alternative except the last.
- Programs would be adapted to the particular needs of the AFO laboratory.
- Easy creation of consolidated reports, status reports, and workload listing.
- Simplified operation of the instruments because of automated work plans operating from sample file control.

- Automated updating of statistical quality-control criteria.

Disadvantages -

- All disadvantages of the second alternative except the last.
- Additional software cost.
- Debugging would be slower as others might not be using the same software.
- Implementation of report capability would be delayed, since tailoring of reports would be done by the local staff.

Estimating the Value of Benefits

(1) Instrument Time Savings

Each instrument to be automated has its own internal procedure and requirements for tending. Appendix 3 shows the identifiable actions that occupy a chemist's time and the best estimates of how his time is distributed among them. The estimates are based on Region III experience, and we can confirm that they fall within the range of reasonable times for such procedures. These are summarized in Table 2.

(2) Managerial Time Savings

The savings due to management functions performed by the computer system, as defined in the AFO functional specifications for the sample file control, are derived from a model. This model is discussed in Appendix 4, and the benefits are summarized in Table 2.

Although the AFO laboratory effort is expected to grow at 20% per year, this growth is not explicitly included in the benefit from automating the instruments. The impact of growth will be felt on both automated and non-automated analyses. For simplicity, and to estimate conservatively, we assume the effort level of 50,000 determinations per year represents a mean over the 5-year payoff period. This number is applied to the management model. More detailed growth estimates do not significantly change the payout period shown in Table 1.

Quality Control Benefits

EPA guidelines for quality control (QC)* call for a minimum of 10% of all analyses to be repeat standards, duplicate unknowns, spiked unknowns, and

* *Minimal Requirements for a Water Quality Assurance Program*, U.S. Environmental Protection Agency, Washington, D.C., EPA-440/9-75-010 (1975).

other similar analysis checks. The goal is to raise this to 20-40%. Under the pressure of sample volume it is all too easy to overlook these QC samples. With automation they are handled at very little extra cost, only the small additional analyst time for pipetting the QC test samples, which is more than offset by the savings the computer provides in handling the complex statistical calculations that have to be carried out for good quality control. Thus, since the present staff time on the instruments to be automated is 4.72 FTE (full-time-equivalent employees), 30% of this, or 1.42 FTE, will be saved by automation. An additional 0.5 FTE is presently devoted solely to collecting and reporting QC, making a total saving of 1.92 FTE or \$67,000 per year directly attributable to quality control.

Operating Benefits and Payout

The manpower savings in Table 2 apply to the full automation system for the AFO laboratory as proposed in Section 4. The proposed AFO system owes its increased manpower savings and increased one-time costs mainly to the following three factors:

1. The inclusion of sample file control.
2. Automation of the CSM-6. The manpower saving of 0.75 attributed to automating this instrument is gained at a cost of \$14,000 in software and \$14,200 in hardware.
3. Use of the industrial chart method. A fractional benefit of 0.2 out of the 0.5 manpower saving estimated for automating the managerial aspects of quality control is attributed to use of the industrial chart method at AFO. This preferred method may well be of general interest for other laboratories in the EPA.

While no benefit is assigned to other, less significant changes to the Cincinnati system, their importance to user acceptance should not be minimized, and most of them may also be useful to other EPA laboratories as well.

The annual operating benefit for the proposed system is the 4.97 total shown in Table 2, whereas the benefit assigned to the present system without upgraded software is the 1.95 subtotal for instrument automation alone. The benefits of 1.95 and 4.97 are carried to Table 1.

The operating benefits are converted to a dollar value on the basis of the mean manpower costs for the payout period (Appendix 3) so that a direct comparison to costs can be made. The net annual benefit is the operating benefit less the annually incurred cost.

The payout time is calculated on the basis of 10% per annum discounting, compounded annually. Given the ratio of initial cost to annual benefit, C/B, the payout time, T, is estimated as

$$T = -\ln(1 - I \cdot C/B) / \ln(1 + I) = -\ln(1 - 0.1 C/B) / 0.09531,$$

where I is the discount rate, 0.1/yr.

The net benefit realized in five years is estimated as

$$B_5 = B \cdot [1 - (1 + I)^{-5}] / I - C = 3.791B - C.$$

Table 2. Summary of estimated savings in manpower requirements at the AFO laboratory with the proposed automation system.

Manpower saved by replicate instrument automation:

Atomic absorption	0.80
AutoAnalyzers	0.94
Total organic carbon	<u>0.21</u>
Subtotal	1.95

For full automation add:

CSM-6	0.75
Industrial chart QC method	<u>0.20</u>
Subtotal	0.95

Manpower saved by automated management functions:

Managers' reports and projections	0.73
Workload lists	0.21
Sample summary reports	0.32
WARS's and form letters	0.19
Update records	0.32
Quality control	<u>0.30</u>
Subtotal	2.07

Total manpower saved by full automation	4.97
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Note: The benefit of 1.92 men attributable to improved quality assurance is included in the above. It is not clearly shown because of the different methodology used to prepare this summary.

6. Impact of the Proposed System on AFO Laboratory Operations

Our general impression is that the AFO people are ready and willing to convert to a more automated system. The number of samples that must be handled and the number of reports to be written are a great incentive. The automation will be done in a stepwise and logical fashion, making all reasonable efforts not to disrupt operations more than absolutely necessary. Initially, data will be taken in the conventional way in addition to the computer output. As confidence grows in the automated system, the conventional readouts can be phased out.

The recommended system is designed so that modifications to operating procedures can be made by the chemists themselves. Maintenance of the operating system's software and hardware will be provided by the manufacturer of the computer.

Further expansion of the Annapolis Field Office would require additional automation. Many new instruments now come with their own minicomputer or microcomputer that should logically be connected to the sample file control system. The recommended system has the flexibility to accommodate such developments.

Appendix 1.

Guidelines Followed in Evaluating Automation Systems

1. A high-level programming language. We have chosen Dartmouth BASIC, as extended, as the most desirable programming language to use in the EPA laboratory environment. Invariably, modifications are needed in the computer programs to meet future laboratory requirements. If such changes are difficult to make, the operator will either live with less than optimum conditions or revert to manual operation, thus undoing many of the benefits that automation was to provide. Of the various high-level languages, BASIC has proven to be the most widely available, being supported by most of the major minicomputer vendors. FOCAL, which was introduced by Digital Equipment Corporation, is no longer supported by them. FORTRAN is a slightly more powerful language than BASIC, and usually faster in execution, but the BASIC interpreter makes program development and modification easier and much faster for the chemist, who can do it while other instruments operate as usual.

Modification of FORTRAN programs requires stopping the computer, and restarting it with the new program. This can happen many times as a new program is debugged (perfected), which would destroy normal laboratory procedures.

BASIC is now being taught in many high schools and colleges as the language of preference for the occasional computer programmer. Although there are some differences among vendors in the way BASIC is used, these are in the extensions to the language and are easily understood. Standards are presently being developed by a committee of the American National Standards Association. Another strong point of BASIC is that it can be modified on-line and tested immediately. This means that a simple change in calculations or instrument operation can be made directly by an analyst in a very short period of time -- on the order of 15 minutes. Although interpreted codes like BASIC run more slowly than compiled codes like FORTRAN in most systems, this will not be a disadvantage in the system we propose, because the gain from BASIC's flexibility will more than offset the slower running time.

2. Field-proven operating system. We feel that no new or prototype operating system should be considered. Our observation is that new systems have many "bugs" in them. Often, too, prototype systems are announced with the promise of early delivery, and then the manufacturer finds he cannot deliver them until months after promised. To avoid such problems, only operating

systems that have been in the hands of independent users should be considered. The system proposed in this report (Section 4) is a composite of the systems now installed at the Environmental Monitoring and Support Laboratory and the Municipal Environmental Research Laboratory in Cincinnati and at the central Regional Laboratory of EPA Region V in Chicago. Thus problems with electronics, operations, and analysis should be at a minimum. The disadvantage of insisting on a time-proven system is that newer, possibly more powerful systems will necessarily be rejected. We are deliberately taking a conservative position.

3. Supplier support of operating systems. It is common practice for manufacturers to guarantee support of their operating systems (if unmodified) for periods up to five years. Any large software system can be expected to have a few residual bugs in it even after years of testing. By installing a widely used system we increase the probability that someone else will discover the bugs, and that the manufacturer will fix them before they cause problems for EPA.

We also feel that a single system should be designed which will be versatile enough to satisfy the differing needs of users in different laboratories. If EPA were to set up a minicomputer systems group to develop and maintain a unique, special-purpose operating system for its water quality analyses, for example, a faster, more efficient operating system could no doubt be written. It would be very difficult to change, however, and would require the assistance of the systems group for most modifications. Such special operating systems now on the market are exemplified by the Finnigan GC/MS, Hewlett-Packard, Perkin-Elmer, and Varian GC systems. These are single-purpose systems and work very well; but they are proprietary, making any changes impossible without the aid of the original supplier. We feel that EPA should not put itself in the hands of a unique supplier, but rather should adopt systems that can be modified by the users.

In the particular case of the GC and GC/MS systems, however, we feel that EPA should continue with these existing tested systems, which are cost-effective as they stand, and couple the output from these special-purpose computers into the sample file control system.

4. Multi-user, multi-application, real-time, time-share. There are a number of potentially attractive systems which lack one or more of these characteristics. The operating system must be designed to handle several users and several instruments simultaneously while giving each at least the

appearance of a dedicated computer. A time-shared system can do this while providing for the sharing of expensive peripherals such as line printers and magnetic tape. A time-shared system also gives the option of adding additional instruments to the system inexpensively. With individual computers, an additional computer has to be purchased with each new instrument. A disadvantage of the time-shared computer is that failure of the single shared computer forces all users back to manual methods.

5. Data management language. The computer system selected should provide the ability to easily reprogram the names and relationships of all the data. At the outset this ability aids in the programming of the sample file controller. But most important, it will prevent obsolescence in the not unlikely event of new management requirements. For example, making a change in analytical reporting procedures or adding biological assay categories to the existing systems should be easily possible for the user by means of only simple reprogramming procedures.

6. Rapid response time. Because of human impatience, worst-case computer response time from the issuing of a keyboard command must be no more than a few seconds. After about 10 seconds, most users become irritated. For automated data collection, worst-case times from the receipt of a "data is ready" indication to data collection action must be less than 200 μ s.

7. Instrument input/output handlers. It would be advantageous if the computer vendor provided software to handle data acquisition from instruments, calculation, and reporting functions. No vendor known to us now supplies software for all the particular instruments we have been asked to consider. Custom algorithms and data acquisition and control programs must be provided. The computer system vendor must allow these algorithms to be simply implemented with a clear description of how to pass to and from BASIC and how to use the operating system for input and output of instrument data.

8. String manipulation capability. For the simplest and most natural interaction between operator and computer for efficient information flow between data and reports, the system must have the ability to handle alphanumeric strings. If this feature is not provided by the manufacturer it will have to be added by the system implementer.

9. Swapping. In order to make the most efficient use of core storage, effective program swapping must be available. This implies that run, swap-in, and swap-out areas must be concurrently active. Virtual systems using paging have been proposed as an alternative. For laboratory automation, however, we

do not feel that the art of virtual memory has advanced to the same level of effectiveness as program swapping systems. At present, virtual memory systems require careful tailoring of the programs to avoid excessive page swapping. If programs are to be modified by the chemists, the burden of tailoring the programs cannot be placed on the chemists.

10. Chaining and overlays. The ability to chain programs and to overlay segments is imperative. The alternative is to have all programs core-contained, which would require excessive core storage.

11. Files. Data files will be stored on the disk for later manipulation and development of new analysis methods by the chemists. These files must be accessible from both the machine language and BASIC level code, since some files will be built by the machine level code and used by the BASIC code.

12. Foreground-background operation. This feature is desirable for sample file control and report preparation. The instrument control programs must run in real time, along with their operator prompts. Calculation routines, summary reports, etc., do not require real-time capability, and so can be run in a background mode, using otherwise idle time and increasing the overall efficiency of system use.

13. Analog-to-digital converter. Most data acquisition will be done by a multiplexed A/D converter. To provide for future growth this converter should be easily expandable to at least 32 channels. Instrument interfaces will convert the data to high-level analog form (± 10 volts) for input to the A/D converter. This will permit the inclusion of additional instruments in the future with a minimum of difficulty. At this time individual digitizers on each instrument are not an economical alternative.

14. Random-access mass storage. The computer must have storage for large amounts of sample data and extensive libraries of special-purpose calculational routines. These should be available on-line for maximum effectiveness, rather than being on special magnetic tapes that have to be physically removed from a file and hung on a tape deck each time they are used. We propose enough storage to keep at least one month's worth of data available at all times, together with the search routines necessary for analysis of the data by the analysts, engineers, and managers. This will allow for such functions as checking for dilutions on previous samples from the same site, addition of data from long term tests, and addition of results from analyses put off during peak workloads.

A large disk pack is the peripheral device that best meets these needs, although a moderate-size disk supplemented by several on-line magnetic tapes might be an economical alternative.

15. Bootstrap loader. If the system is to be used effectively without a professional data-processing staff, there must be a hardwired bootstrap loader enabling the occasional user to reload the system after power failures and similar catastrophes. This feature is also very valuable during the initial implementation and debugging, and when new instruments are being incorporated into the system.

16. Real-time clock. A real-time clock whose rate is an integral multiple of 60 Hz is needed. This will be used primarily for timing the sampling of data from instruments.

17. Multiple terminals. An analyst's acceptance of the computerized system is strongly influenced by his ability to control it and to know what is happening *all the time*. There should be a terminal (either a hard-copy typewriter or CRT screen) at each active analytical instrument or group of instruments. This allows initiation of runs, display of data as calculated, and display of diagnostic messages such as out-of-range concentrations. The operator need not be at the terminal at all times, but he must have immediate access to it so he can verify proper operation.

18. Printer. A medium-speed printer is needed for rapid printout of reports. Users will not want to wait for slow typewriter-style printers, especially for such long lists as work loads. One printer would be shared by all users.

19. Magnetic tape. IBM-compatible magnetic tape is needed for three functions: (1) to store the entire data files on a routine (approximately weekly) basis to cover catastrophic system failures, (2) to transmit properly formatted data to the STORET system, and (3) to exchange programs between laboratories.

20. High-speed paper tape reader. This is necessary to load diagnostics programs. It is primarily a backup system to the disks and magnetic tape.

21. Software transportability. Software transportability among the EPA laboratories is a primary goal of the Pilot Laboratory Automation Project. The low cost estimated for the AutoAnalyzer and atomic absorption software is dependent upon the use of existing software for these instruments. Likewise, the cost for interfaces include only incremental production costs, since the engineering costs were paid in designing the previously installed systems.

Appendix 2.

Costs of Hardware and Software

In this appendix we give costs of hardware and software as well as data storage requirements for the AFO system. Table 2-1 compares the cost of the central computer hardware and peripherals for the proposed AFO system and the Chicago system. Table 2-2 summarizes the estimated data-storage requirements for the proposed AFO system. Table 2-3 gives estimated software costs for application programs for the instruments to be automated in the AFO system, and Table 2-4 gives hardware costs for automating these instruments.

Table 2-1. Hardware costs for central computer and peripherals for the proposed AFO system. The Eclipse C/300 computer is a Data General product. Costs figures are discounted.

	Minimum system	Recommended system	Maximum system
Computer main frame with 65K-word core, real-time clock, memory allocation and protection	\$ 38,376	\$ 38,376	\$ 38,376
Additional 65K core	-	-	19,352
Fixed-head disk	10,045	-	10,045
Moving-head disk	8,938	31,760	31,760
Magnetic tape	7,380	7,380	13,712
Line printer and interface	5,648	9,812	9,812
Paper tape reader and interface	-	1,640	1,640
Analog-to-digital converter system	5,354	5,354	5,354
Rack	1,900	2,850	2,850
Software from Data General	1,000	1,000	1,000
Totals	\$ 78,641	\$ 98,172	\$133,901

Table 2-2. Estimated data-storage requirements (in 8-bit bytes) for the proposed AFO system, based on 100 samples and standards.

Instrument	BASIC language program ^a	Data files	Number of files	Total	Assembly language patch
Atomic absorption	25,000	25,600	2	101,200	1000 ^b
Technicon AutoAnalyzer I	40,000	115,200	4	500,800	5000
Technicon AutoAnalyzer II	40,000	115,200	5	616,000	5000 ^b
Technicon AutoAnalyzer CSM-6	60,000	230,400	1	290,400	-
Beckman total organic carbon	25,000	271,360	1	296,360	-
Sample file control	200,000	100,000 ^c	1	<u>2,400,000</u>	-
			Total	4,204,760	

^aAll BASIC programs are broken into parts each no longer than 18K bytes, so as to fit in 64K words of core along with the operating systems.

^bCore-resident data. The first two entries service all other instruments.

^cOne day's worth of data. Provision will be made to store at least one month's worth of data.

Table 2-3. Estimated software costs for applications programs for the instruments and functions to be automated in the AFO system.

Instrument or function	Upgrading costs to meet proposed AFO system requirements
Atomic absorption (PE305B, V-AA6)	\$ 7,000
AutoAnalyzers (I, II, CSM-6)	14,000
Carbon analyzer	7,000
Sample file control	<u>56,000^a</u>
	\$84,000

^aIt is assured that an agency-wide SFC system will be developed based on agency-wide specifications now being developed under the auspices of MIDSD. About 20% of the estimated development costs have been included in this feasibility study, with the assumption that this SFC will be used in at least four other laboratories.

Table 2-4. Estimated hardware costs for automating the AFO instruments.

	Number of units	Design cost	Cost to build, debug, assemble	Cost of parts	Total cost
General interface	1	0	\$ 4,120	\$3,200	\$ 7,320
AutoAnalyzer I, II	9	0	15,900	2,700	18,600
AutoAnalyzer CSM-6	1	\$11,800	1,900	500	14,200
Sample wheel	1	0	2,800	800	3,600
AA 305B	1	0	910	400	1,310
AA Varian AA6	1	11,800	910	200	12,910
Total carbon	1	<u>0</u>	<u>1,060</u>	<u>200</u>	<u>1,260</u>
Totals		\$23,600	\$27,600	\$8,000	\$59,200

Appendix 3.

Instrument Time Savings as a Result of Automation

We have adopted a model in which the total time needed for any one instrumental sample analysis, t_s , is broken into a number of increments which are then summed and modified by the following equations:

$$t_s = p + (1. + f)(l + i + c) + fd,$$

where

t_s = total chemist time needed for each sample,
 p = time for preparation of sample and log book,
 l = time control to log and introduce sample,
 i = chemist time needed tending instrument,
 c = time needed to calculate and transcribe results,
 d = time taken for dilution,
 f = fraction of samples diluted;

and

$$e = t_s q r \frac{H}{H - T_b},$$

where

e = the effective chemist time taken per sample,
 t_s = total time calculated by the previous formula,
 q = quality assurance factor (total determinations/unknown),
 r = fraction of samples retested,
 H = time of a work session (usually 8 hours except where the average weekly load can be completed in less than 8 hours; it is assumed the instrument must be operated at least once a week to prevent delay in reporting results),

T_b = time to set up instrument at the beginning of each work session, shut it down at the end, and run standards.

Table 3-1 summarizes the manpower savings expected from automation of the various instruments, as calculated with the above model. Tables 3-2 through 3-5 give the results for the various instruments to be automated. Times given in the columns headed "present techniques" are consistent with values received from Jim Marks and Ort Villa of AFO. Times given in the columns headed "automated techniques" are our estimates of the times needed after automation.

Table 3-1. Summary of manpower savings calculated to result from automation.

Instrument	Man-years per year		
	Present	With automation	Savings
AutoAnalyzer CSM-6	1.39	0.64	0.75
Atomic absorption spectrophotometers	1.36	0.56	0.80
AutoAnalyzer I	1.43	0.49	0.94
Total organic carbon analyzer	0.54	0.33	0.21

Table 3-2. Estimated savings with automation for the Technicon AutoAnalyzer CSM-6, assuming four channels working.

Item	Symbol ^a	Present techniques	Automated techniques	Difference
Preparation of sample	p	0.60 min	0.60 min	0
Log and introduce sample	l	0.77 min	0.50 min	0.27 min
Instrument time for chemist	i	1.5 min	0.4 min	1.1 min
Calculate and transcribe results	c	1.0 min	0.0	1.0 min
Dilution of off-scale samples	d	5 min	4.8 min	0.2 min
Fraction of samples diluted	f	0.15	0.15	0
Total chemist time per analysis	t _s	5.11 min	2.36 min	2.75 min
Retest factor	r _s	1.2	1.2	0
Quality control factor	q	1.2	1.2	0
Setup and shutdown time per session	T _b	2.5 hr	2.5 hr	0
Hours per work session	H ^b	8 hr	8 hr	0
Effective chemist time per analysis	e	10.71 min	4.94 min	5.77 min
Number of samples per chemist-day		44.8	97.1	52.3 samples
Sample load assumed per year		14,000	14,000	0
Chemist-days needed per year		313	144	169 days
Chemist-years needed per year		1.39	0.64	0.75 year

$$t_s = p + (l + f)(l + i + c) + fd, e = t_s r q \frac{H}{H - T_b}.$$

^aSymbols apply to equations at bottom of table.

Table 3-3. Estimated savings with automation for atomic absorption analysis.

Item	Symbol ^a	Present techniques	Automated techniques	Difference
Preparation of sample	p	2.23 min	2.23 min	0
Log and introduce sample	l	1.45 min	0.25 min	1.20 min
Instrument time for chemist	i	2.15 min	0.45 min	1.70 min
Calculate and transcribe results	c	2.0 min	0.0	2.0 min
Dilution of off-scale samples	d	5.0 min	4.8 min	0.2 min
Fraction of samples diluted	f	0.27	0.27	0
Total chemist time per sample	t _s	10.69 min	4.42 min	6.27 min
Retest factor	r ^s	1.05	1.05	0
Quality control factor	q	1.1	1.1	0
Setup and shutdown time per session	T _b	30 min	30 min	0
Hours per work session	H ^b	8 hr	8 hr	0
Effective chemist time per sample	e	13.17 min	5.44 min	7.73 min
Number of samples per chemist-day		36.5	88.2	51.7 samples
Sample load assumed per year		11,175	11,175	0
Chemist-days needed per year		306	127	179 days
Chemist-years needed per year		1.36	0.56	0.80 year

$$t_s = p + (1. + f)(l + i + c) + fd, e = t_s r q \frac{H}{H - T_b} .$$

^aSymbols apply to equations at bottom of table.

Table 3-4. Estimated savings with automation for Technicon AutoAnalyzer I (total phosphate, total Kjeldahl nitrogen).

Item	Symbol ^a	Present techniques	Automated techniques	Difference
Preparation of sample	p	2.04	2.04	0
Log and introduce sample	l	1.86 min	0.5 min	1.36 min
Instrument time for chemist	i	2 min	0.2 min	1.8 min
Calculate and transcribe results	c	2.6 min	0.0	2.6 min
Dilution of off-scale samples	d	5 min	5 min	0
Fraction of samples diluted	f	0.1	0.1	0
Total chemist time per sample	t _s	9.65 min	3.31 min	6.34 min
Retest factor	r _s	1.1	1.1	0
Quality control factor	q	1.1	1.1	0
Setup and shutdown time per session	T _b	45 min	45 min	0
Hours per work session	H _b	8 hr	8 hr	0
Effective chemist time per sample	e	12.88 min	4.42 min	8.46 min
Number of samples per chemist-day		37.3	108.6	71.3 samples
Sample load assumed per year		12,000	12,000	0
Chemist-days needed per year		322	110	212 days
Chemist-years needed per year		1.43	0.49	0.94 year
$t_s = p + (l + f)(l + i + c) + fd, \quad e = t_s r q \frac{H}{H - T_b}.$				

^aSymbols apply to equations at bottom of table.

Table 3-5. Estimated savings with automation for Beckman total organic carbon analyzer, assuming five runs per sample.

Item	Symbol ^a	Present techniques	Automated techniques	Difference
Preparation of sample	p	4.0 min	4.0 min	0
Log and introduce sample	l	2.5 min	2.5 min	0
Instrument time for chemist	i	7.5 min	7.5 min	0
Calculate and transcribe results	c	9 min	0	9 min
Dilution of off-scale samples	d	5 min	4.8 min	0.2 min
Fraction of samples diluted	f	0.14	0.14	0
Total chemist time per sample	t _s	26.36 min	16.07 min	10.29 min
Retest factor	r _s	1.00	1.00	0
Quality control factor	q	1.2	1.2	0
Setup and shutdown time per session	T _b	1.5 hr	1.5 hr	0
Hours per work session	F ^b	8 hr	8 hr	0
Effective chemist time per sample	e	38.9 min	23.7 min	15.2 min
Number of samples per chemist-day		12.3	20.2	7.9 samples
Sample load assumed per year		1500	1500	0
Chemist-days needed per year		122	74	48 days
Chemist-years needed per year		0.54	0.33	0.21 year
$t_s = p + (1. + f)(l + i + c) + fd, \quad e = t_s r q \frac{H}{H - T_b}$				

^aSymbols apply to equations at bottom of table.

Appendix 4.

Manpower Savings as a Result of Automation

SAMPLE MANAGEMENT SAVINGS

We have chosen to develop a linear model for sample management operations. The results for the model are validated against the sample management estimates for the Annapolis Field Office.

We first identify the sample management functions as follows:

- Work plans and sample log-in
- Sample load projections
- Workload selection
- Interim reports
- Sample summary reports
- Query reports
- Form letters
- Work accountability reports
- Updating files for status and results
- Quality control reports and updating files for quality control.

These items correspond to the functional description of the sample file control (SFC) system.

Each of the functions is considered in terms of how much effort is expended with and without sample file control. Each function is modeled as some number of transcriptions, filing and retrieving of files, and data checking or tallying. Times for the various processes are estimated; for example:

Transcriptions —	$t = 6 \text{ sec}$
File and retrieve —	$f = 4 \text{ min}$
Checking —	$c = 3 \text{ sec}$

These numbers include the time for correcting transcription errors.

In ultimately converting the time in minutes to man-years, a 7-hr day is assumed to allow for human overhead (efficiency), and a 250-day work-year is used. The factor is

$$k = \frac{1}{60 \times 7 \times 250} = 9.52 \times 10^{-6} \text{ man-year/minute.}$$

For the purpose of counting the number of transcriptions or checking, only a portion of the information in the SFC is used for a given report. The following average maximum numbers of each data type are obtained from the functional description of the sample file:

data that describe the study -	8
data that describe the sample -	15
data that describe the analysis -	9

For the purpose of counting the number of reports per year, we obtained the following estimates from the Annapolis Field Office:

<u>Report type</u>	<u>Frequency</u>	<u>Annual frequency used in the model, N</u>
Workload list	Daily	250
Interim, short	Daily	250
Interim, Long	Weekly	50
Study status	Weekly	50
Query	Twice daily	500
Sample load	Tri-weekly	15
Form letters	One/study	100*
Summary sample	One/study	100
WARS	Monthly	12

*The number of studies is complicated by quarterly repeats of the same study, fiscal year accounting, etc., and was estimated at Annapolis to be as many as 150-200 annually.

We take rounded figures for the key parameters describing the level of effort at the AFO:

Number of determinations per year, D	50,000
Number of samples logged per year, S	2,500
Number of studies (projects) per year, P	100
Number of samples per study, S_p	25
Number of determinations per sample, D_s	20
Mean time to complete study, T_p	10 days

On the following pages the assumptions made in developing the benefit models for each managerial function are discussed. In general, the most efficient manual record-keeping and filing formats are assumed, and the analyses are assumed to be managed in such a way as to minimize paperwork, even though in fact this is not possible if the samples have a limited life. The effort required for the automated reports is assumed negligible, although some manual effort is required to get lineprinter output. All benefits are therefore net benefits. Following the detail of the models, the derived benefits are summarized in Table 4-1, and carried to Table 2 (in Section 5 of the report).

The annual growth of the sample effort has been estimated by O. Villa of AFO to be 20%. For simplicity, and to estimate conservatively, we assume the effort level of 50,000 determinations a year represents the mean over the 5-year period of amortization.

Work Plans and Sample Log-In

The information about the samples and project must be provided to the sample file by keying-in data, whether the sample file is automated or not. The automated procedure should be at least as easy as the manual method, in which preformatted sheets and ditto marks ease the entry of data. No net benefit is claimed for the functions of work plans and log-in.

Sample Load Projections

Assume: For every parameter, for one month of planned samples, check four items: date, subelement number, status, and analysis.

Table 4-1. Summary of net benefits derived from a model for the managerial functions.

	Net benefit (man-years)
Work plans	0.00
Sample log-in	0.00
Sample load projection	0.13
Workload lists	0.21
Interim reports	0.56
Sample summary	0.32
Query reports	0.04
Form letters	0.09
Work accountability	0.10
Update status and results	0.32
Quality assurance	<u>0.50</u>
Total	2.27 man-years

Number of reports, N_r	15
Files looked up, D_s	20
Studies planned, P	100/12
Items checked, N_c	4

$$\text{Benefit} = [D_s f + P S_p D_s N_c c(\frac{1}{60})] N_r k$$

$$= [20 \times 4 + \frac{100}{12} \times 25 \times 20 \times 4 \times 3 (\frac{1}{60})] 15 \times k = 0.13 \text{ man-year.}$$

Workload Selection

Assume: For every active study and every sample, the parameter and status are checked ($N_c = 2$). If the status is "not done," transcribe the limits, sample number, and due date ($N_t = 3$). Assume two different parameters are run each day for the 10 days (T_p) required to complete the study.

Projects active on any given day, P	4
Number of parameters run per day, D_s/T_p	2
(implies 200 determinations/day)	
Number of reports, N_r	250
Files looked up, D_s/T_p	2
Checks, N_c	2
Transcriptions, N_t	3

$$\text{Benefits} = [D_s f + P S_p D_s (N_c + N_t) (\frac{1}{60})] N_r k / T_p$$

$$= [20 \times 4 + 4 \times 25 \times 20(2 \times 3 + 3 \times 6) (\frac{1}{60})] 250 k / 10 = 0.21 \text{ man-years.}$$

Interim Reports

Short Reports

Assume: For every active study, for every sample, list the sample number and parameter status. Also transcribe the study and subelement number.

Number studies active, on a given day, P	4
Number of reports, N_r	250
Files looked up, N_f	1 (assumes a special file).

$$\text{Benefit (short report)} = [f + P (2t + S_p (t + D_s t)) / 60] N_r k$$

$$= [4 + 4(12 + 25(6 + 20(6))) / 60] 250 k = 0.51 \text{ man-year.}$$

Long reports

The long interim report calls for a sample description to be transcribed in addition to the above, but fewer reports, $N_r = 50$.

$$\text{Benefit (long report)} = [f + P(2t + S_p (2t + D_s t)) / 60] N_r k$$

$$= 0.11 \text{ man-year.}$$

Because the daily reports are available and collated, the claimed benefit for the long report will be less. We estimate 50% less, or 0.05 man-year.

Weekly Reports

Assume: The weekly status report lists the subelement, title, and status of each active study. The checking of each sample status is included. Number of reports, $N_r = 50$.

$$\text{Benefit (weekly)} = [f + P(3t + D_s c)/60] N_r k = 0.005 \text{ man-year.}$$

Sample Summary Reports

Assume: For one study and all samples and parameters, list the results. List study description, sample descriptions (14 items) and parameter units, analyte code and STORET number plus the result or status. Include column header transcriptions.

Studies, P	1
Number of reports, N_r	100
Files looked up, D_s	20

$$\begin{aligned}\text{Benefit} &= [D_s f + P[t + D_s + S_p(14t + D_s(c + 4t))]/60] N_r k \\ &= [20 \times 4 + 1(6 + 20 + 25(84 + 20(27)/60)] 100 k \\ &= 0.32 \text{ man-year.}\end{aligned}$$

Query Reports

For one study, for each sample, check the parameter for a match; if found, list the result or status.

Studies, P	1
Number of reports, N_r	500
Files looked up	1 (the parameter file)

$$\text{Benefit} = [f + (P S_p(c + t) + D_s c)/60] N_r k = 0.04 \text{ man-year.}$$

Form Letters

For one study, we assume 10 values are transcribed, and the time to type a 200-word letter at 60 wpm is saved.

Studies, P	1
Number of reports, N_r	100
Files looked up	10 (one value for each of 10 parameter files)

$$\text{Benefit} = [10 f + 200/60 + S_p D_s t/60] N_r k = 0.09 \text{ man-year.}$$

Work Accountability Reports

During any one-month period we estimate 11 studies will have accountability data; of these, eight studies were begun during the month and three studies carry over. The status of each analysis and the dates started and completed are tallied. The title and subelement of the studies are listed.

Number of reports, N_r	12
Studies, P	11
Files looked up, D_s	20

$$\begin{aligned} \text{Benefit} &= [D_s f + P(2t + 3S_p D_s c)/60] N_r k \\ &= 0.10 \text{ man-year.} \end{aligned}$$

Updating Files for Status and Results

A status is kept for the study, each sample, and each parameter. We assume two updates of each during the course of a study. Six items are transcribed for each parameter: result, units, operator, date done, status, and QC approval. We assume updates are done in batch fashion twice a day.

Studies active, P	4
Files looked up, D_s	20 (parameter files)
Parameters in progress/day	2
Number of days/yr, N_r	250

$$\begin{aligned} \text{Benefit} &= [D_s f + [(P + S_p + 6PS_p D_s)t/60] N_r k/T_p \\ &= 0.32 \text{ man-year.} \end{aligned}$$

Quality Control Report and Updating Files for Quality Control

This report is not so well defined that modeling is justified at present. From the discussion in Sec. 5 we have estimated that 0.5 FTE would be required to achieve the desired quality control.

The rough estimate given by AFO for time spent in performing the functions in Table 4-1 was 1.6 man-years/year. The staff at AFO has increased by two since then. If one considers that a number of the functions are neglected or done less frequently than desired because of a lack of time and personnel, it appears that the 2.3 man-years benefit estimated here is realistic and reasonable.

Appendix 5.

Estimates Used in Developing Manpower Costs

In Table 1 (Section 5 of the text) estimates are given for the cost savings expected as a result of automating the AFO laboratory. Manpower costs used to estimate these savings are based on the following assumptions and calculations.

1. Basic average salary as of October 1974 is a GS-9 at \$12,000-13,000 per year.
2. The goal for the average salary is a GS-11 at \$14,000-15,000 per year (not including allowance for inflation).
3. Assume a salary of \$13,000 per year as the average over the first five years of the computer's life.
4. Add a payroll burden of 33.5% to take care of pensions, health plans, insurance, etc.
5. Add a support burden of 16.3% to take care of secretaries and administrators.
6. Add a general overhead of 66.5% to take care of building rent, custodial care, utilities, travel, etc.

$$\$13,500 \times 1.335 \times 1.163 \times 1.665 = \$34,900 \text{ per man-year.}$$

This figure checks closely with a best guess of \$35,000 per man-year made by O. Villa of the AFO laboratory. An estimate of \$43,000 per man-year was given by B Fairless of the CRL Region V laboratory in Chicago.

Appendix 6.

New Personnel Skills and Capabilities Recommended for the Automated Laboratory

(Prepared by Bruce P. Almich, ERC Cincinnati, 7/1/76)

The purpose of this appendix is to provide the management of a prospective automatable client laboratory with a concise description of the new skills and capabilities required so that planning and implementation in the areas of training, manpower allocation, and (if necessary) hiring may be carried out before the system is installed. This appendix is also designed to serve as an operational policy cornerstone for client-ERC-LLL-vendor maintenance relationships.

The new operational functions and responsibilities required in an automated laboratory are divided into two broad areas: laboratory utilization, and computer system maintenance. The two areas require different personnel skills and capabilities. Within the area of laboratory utilization two functional subdivisions exist:

1. Using the system as a means of processing analytical samples. For example, conducting a dialogue with the computer as it executes the instrument control and data acquisition/manipulation programs.
2. Modifying programs, as required, to tailor them to the specific needs of the laboratory. Modifications by the laboratory scientist are limited to changes in the basic programs in such areas as output report format, data reduction procedures, etc.

Within the computer maintenance activity, three subdivisions exist:

1. Hardware maintenance and upgrades. This includes handling the computer vendor's service contract, as well as responsibility for maintaining the custom electronics hardware involved. These skills are detailed below.
2. Maintenance and upgrades (if any) to instrument control and applications software. This includes assisting the laboratory scientist in modifying programs (item 2 above).
3. Maintenance and upgrades to data management software.

The first broad skills area is associated with the day-to-day use of the system by the laboratory scientist. In order to use an automated laboratory system, the laboratory scientist must interact with the computer, by entering data and control information in response to computer queries and prompts. This

is done at the typewriter terminal located near the instrument. The analyst must modify his previous manual analytical procedures and methods somewhat in order to accommodate this new "man-machine dialogue." He should be aware of what actions are necessary when an abnormal condition arises: for example, when he types in the wrong thing, or injects the wrong sample, or the computer detects or causes some sort of error. As his familiarity with the system increases over a period of the first two months of production operation, the laboratory scientist should become able to spot and correct human, instrument, or computer malfunctions quickly himself and to clearly present the symptoms of more involved problems to the systems maintenance person for action. These direct system utilization skills are acquired by the laboratory scientist in several ways:

- Working visits to ERC Cincinnati for tutorial instruction before delivery of the system. This includes observation and use of a similar automated instrument or procedure by the prospective new client, under the guidance of a scientist who is already using these skills.
- Remote access to an existing lab system computer (via dial-up terminal) for the purpose of learning the basic language and instrument program dialogues prior to system delivery at the client's site.
- Tutorial sessions given by the automation installation team at the client's site during the system installation phase.
- Self-study of the operational documentation provided with the system for the use of each instrument and facility.

As the laboratory scientist becomes more familiar with the use of his automated instrument, he will probably want to modify and extend the capabilities of the BASIC applications software as follows:

1. He may want to streamline the instrument setup and operation dialogue once he has gained familiarity with the inputs the system needs to carry out his analyses. (Example: Shorten "ENTER NUMBER OF SPIKED SAMPLES" to "SPIKES?")
2. He will want to convert runtime selectable options (provided with the delivered system) to program constants in order to save time, in the event that the inputs would not need to be changed during a normal run in the future. (Example: Remove variable input prompt "SPIKES?" above, altogether, and convert it to a program constant.)

3. He may want to change the instrument data-reduction algorithm to accommodate a special data-analysis requirement or to implement a new analysis method.

4. He may want to change the structure, content, or appearance of an output report.

To do these things, the analyst must spend some time in learning additional details of the BASIC language interpreter and the specifics of the structure and operation of the currently implemented BASIC program for his instrument. The depth of knowledge required is, of course, dependent on the degree of program modification desired. Again, informal course work and self-study are required. For the good of everyone involved, the analyst should also learn how to produce good documentation for the programming changes he makes in the delivered BASIC code. He should make every effort to keep the documentation for the automated operation of his instrument current and accurate. He assumes local software support responsibility for any programs in which he substantially modifies the disk file or the operational logic structure from those of the delivered system. Local responsibility is also assumed for local post-delivery modifications to the sample file control interface, to the extent that a single agency-wide SFC may exist in the future.

The first broad skills area thus represents a reallocation of existing laboratory efforts and skills to effectively use the automated system. For each analyst, new skills are required in order to interact with the computer in performing laboratory analyses. For the elementary skills, no programming training or knowledge is required. For the optional and highly desirable purposes of modifying the delivered package of BASIC language applications software to meet unique post-delivery requirements, it is necessary to acquire programming skills in the BASIC language. This language is the simplest, most flexible general programming facility available and is typically taught to high school students in mathematics classes as well as being a required study area for most technical undergraduate and graduate university degree programs. Cumulative experience within EPA indicates that the operational instrument dialogues are easily learned. In-house modification and enhancement of the delivered BASIC programs by EPA Laboratory personnel is also being accomplished, albeit at a fairly low level at the present. Table 6-1 summarizes the above discussion, in terms of milestones and estimated resource requirements for training in the first broad skills area.

Table 6-1. Summary of training required in the broad skills area of laboratory utilization. Asterisk (*) means optional item.

Milestone	Resources required
1. Learning how to use the system as delivered (tutorial course given at installation time).	1 man-wk/analyst, 1 man-wk/instructor.
2. Learning how to spot and correct malfunctions.	First two months of use.
3. Predelivery orientation (dial-up or travel to ERC Cincinnati).	3 man-days/analyst.
4. Introductory course/study in BASIC (*).	1 man-wk/analyst, 1 man-wk/instructor.
5. Advanced topics in BASIC (*) (required for extensive program modifications).	1 man-wk/analyst, 1 man-wk/instructor.
6. Training or self-study in program structure (*) (making full use of the system).	Learned during first 9 months of operation, by motivated users.

The second broad skills area is associated with the maintenance of the overall laboratory automation system, as a collection of hardware and software elements, including instruments, interfaces, computers, and programs. For convenience, the term "inhouse maintenance person" is defined as a composite for the skills and capabilities required in this area, although these skills may be either concentrated in one or two people or shared among several in an actual laboratory situation. The following summary of hardware and software classes is provided for reference in the subsequent discussion:

- Two types of software:
 1. *System*: NOVA/ECLIPSE assembly language, vendor-supplied (Data General Corp.), and LLL/EPA-developed.
 2. *Applications*: Standard high level languages. BASIC interpreter code for instrument automation and data reduction, and sample file control (SFC) applications language (unchosen).
- Three types of hardware:
 1. *Computer* (maintained under service contract, cost \$1000/mo).
 2. *Custom hardware* (designed and developed by LLL/EPA) includes terminals, cables, connectors, instrument interfaces, computer interfaces, etc.

3. *Lab instruments* (e.g., Technicon AutoAnalyzer, Perkin-Elmer AA, etc.).

With these classes and the three functional maintenance activity subdivisions mentioned earlier in this appendix in mind, we can now define the maintenance activity.

MAINTENANCE OF THE EXISTING LABORATORY
AUTOMATION SYSTEMS

The primary responsibility of the maintenance person is to keep the various hardware and software system elements in full working order by applying the techniques of preventive and remedial maintenance as well as installing hardware and software upgrades, as required. In the preventive mode, the following represents the major activity and responsibility elements:

- Monitor the computer hardware maintenance contract and see to it that the computer receives its monthly preventive maintenance service from Data General, as provided in the contract. Keep Data General apprised of problem areas with the equipment.
- Periodic inspection (for example, offline testing, and observing the production operation) of the custom and lab instrument hardware to ascertain proper operation.
- Periodic backups and library maintenance of all software disk files. Backups should be made in triplicate on magnetic tape, with an indexing system for locating disk file images on the tape. A backup should be made of the affected program and data files whenever a net investment (or replacement cost) of people time in these files exceeds an average of 4 hr of work per laboratory analyst or computer programmer.

Remedial maintenance is required when something breaks, whereas preventive maintenance is something one does to minimize the frequency, losses, and restoration costs of unforeseen breakage. The in-house remedial maintenance skills required are those needed to successfully complete the following sequence of events whenever something breaks:

1. Identify the symptoms of the problem and find out which instruments, users, and system operating functions are affected.
2. Isolate the problem to the subsystem level: for example, to one of the three types of hardware in the system.
3. If the problem is in a lab instrument, initiate in-house, contract, or out-of-contract extramural service repairs. (It is extremely important to

have minimum administrative delays in placing service procurements with established, reputable service organizations.)

4. If the problem is in the custom EPA/LLL hardware, initiate in-house repairs. Begin by swapping in working spares at the plug-in module level. (Note: the client lab should have a full complement of replaceable spare parts for all custom hardware on site; this is recommended to all clients who do not have ready access to a large electronics and mechanical hardware stockpile.) If difficulty is encountered in this process, assistance may be had from another client, ERC Cincinnati, or ultimately, LLL through ERC. ERC will provide a list of recommended tools and troubleshooting/repair equipment, if requested.

5. If the problem is in the computer, two determinations must be made next:

- A. The problem must be identified as a hardware or software problem.
- B. The problem must be identified as a "Data General" problem or a "non-Data General" problem. Lack of caution here can result in a premature commitment to expensive out-of-contract vendor service.

Generally, if the problem is in the computer hardware and is present when either Data General diagnostic or unmodified Data General system software is running (with the LLL custom hardware interface board removed), Data General may be called in for free in-contract repairs. If the problem is in the agency-wide supported version of the operational software, a second client lab or ERC Cincinnati may be called for immediate consultation and, if necessary, assistance. In the absence of local resources, all other cases are handled on an individual basis, with the primary resolution responsibility placed on the client lab and its local resources. In-house hardware repairs and modifications should not be made on Data General hardware. Other electronic repairs should be carried out at the module/board replacement level. Purchase of electronic troubleshooting and replacement equipment is up to the client, but ERC Cincinnati will consult in the process if requested. Parts list and availability information for custom electronic and mechanical hardware should be kept in good order.

The bottom line (i.e., governing principle) on maintenance policy for EPA lab automation is:

- Agency-wide support (that is, all support external to the client lab) is available for all hardware and software as delivered and made operational by the installation team, as well as for all agency-wide supported upgrades.

- Depending on the nature and extent of local post-installation modification to the delivered system and the adherence to agency-wide upgrades, post-delivery support levels from all sources external to the client laboratory will vary. Generally speaking, "If you change it, you support it, even if the person who changes it goes away." Undocumented changes cannot be supported by anyone. The Data General service contract with GSA is a handy reference in this area.

Another aspect of the maintenance person's responsibility lies in assisting the laboratory staff in making workable changes and additions to the delivered package of applications software. At present, this is limited to the BASIC instrument programs and does not include sample file control applications activity. In an operational situation, the maintenance person has historically become closely involved with the laboratory-scientist training milestones 1-4 (Table 6-1), as instructor and consultant.

The remaining area of responsibility for the maintenance person on the existing system is in the installation and testing of hardware and software upgrades. An upgrade occurs in one of the following circumstances:

- If the client lab determines that it has a need for additional hardware or software which is not on the "agency-wide support" list, the lab can take responsibility for designing, obtaining approval for, and implementing the new facility. This can be a very involved and complex process, especially the modifying of system software and the obtaining of headquarters approvals.

- If a proposed upgrade is determined to have applicability on an agency-wide basis, external support can be had for its implementation. In these cases, a system design is performed, approvals are secured, and the implementation is accomplished with the assistance of ERC Cincinnati. This is the preferred procedure for adding a new instrument to the system. An ongoing example of this is the agency-wide maintenance of the Data General systems software subscription service, distributed by ERC Cincinnati and installed as appropriate in all laboratory automation sites.

Some of the systems level upgrades are required to be made on all machines in order to extend performance, fix system bugs, and assure applications software transportability. These are easily performed at the client site since the only skills required are the ability to use the Data General

operating system command language and the text editor. More complicated upgrades in software may be handled by directly loading a client computer with operating software via telecommunications with the ERC Cincinnati facilities.

MAINTENANCE WITH ADDITION OF A SAMPLE FILE CONTROL

Up to this point, the skills and capabilities required for maintaining existing automated laboratory functions have been discussed. When a sample file control or laboratory data management function is installed, however, additional skills will be required to maintain the delivered system and install upgrades in this software area. Although this function is grouped under the computer maintenance activity area above, the exact means by which it will be carried out are undetermined at this time. The following notes represent guidelines of current thinking as to how post-delivery support of the data management facility should be carried out:

1. A choice between two courses of action will have to be made fairly soon. The most desirable and cost-effective route will be to develop a single, agency-wide SFC package which can be modified to suit the needs of the individual laboratory. The alternative is to develop unique systems for each laboratory or, better, each lab type, i.e., regional-production, research-production, instrument-automation/manual-data-entry mixes, and research-research.

2. With the decision in item 1 above made, it is quite likely that a laboratory which chooses to implement an SFC capability will need to modify the delivered programs for one of two reasons: (a) the delivered system did not meet the original needs due to remoteness of the implementer, etc., or (b) needs of the lab change over time and the applications programs must be modified to meet them.

3. Give 1 and 2 above, the type of support required to modify the delivered packages is not presently available or even potentially available to most EPA Laboratories, either in-house or on a service basis from places such as the Regional ADP Office. This type of support is unique in that it represents skill requirements from the "Business ADP" areas of computer technology, and thus is sharply differentiated from the skills described above, which are more directly obtainable by most EPA Laboratories.

4. It is presently felt that some sort of SFC capability can be developed and installed for the laboratory environment (although the computer hardware performing these functions may not be best located in the laboratory itself) and used with very little post-delivery modification until the proper skills are made available to the laboratory. In most cases, it appears that the source and management of these skills should be the Regional ADP Branch, although it also appears highly desirable to have the technical person performing these activities physically located or assigned to the actual laboratory location.

With the above in mind, one can limit further definition of the skills required to maintain the SFC capability to the following:

- The skills required are those that would be found in the traditional ADP operation, rather than in the laboratory scene. Therefore the person who performs these activities should be under the supervision of a traditional ADP manager.
- The manpower required for this support varies between zero man-years per year (e.g., existing lab system maintenance people can handle it) for a "no-modification" situation to a maximum of two man-years per year of full-time effort for a "maximum justifiable modification level" condition. Therefore, once designed and delivered, the maintenance of the SFC applications software will be a planning and resources management issue between the laboratory and the ADP fund administrators of the geographical area involved. Hence, further manpower estimates will not be made for this function in this feasibility study.

How will the maintenance person be trained to provide the services to the laboratory in the second broad skills area just discussed? The following are notes on this training requirement, gained from agency-wide experience to date:

1. With the purchase of a Data General computer system, the customer is entitled to a limited number of free training credits (2 man-weeks) at one of two Data General training centers in the U.S. It is essential that 2 to 4 man-weeks of training be gained by preferably two laboratory people before the system is delivered. Each person should obtain one week of training in Data General operating system concepts and facilities and one week in either assembly programming, FORTRAN programming, or hardware maintenance overview. It is desirable for two people to pursue this study for each laboratory in

order for the laboratory to realize service continuity in the case of absenteeism or a job change by the trained in-house maintenance person.

2. Each maintenance person should spend a minimum of one week of pre-delivery orientation training at a working laboratory facility elsewhere in the agency. Five to eight working days at ERC Cincinnati would be optimum.

3. Each maintenance person should participate actively in the installation and delivery testing phase after receiving 1 and 2 above and obtain an additional week of training from the installation team members at delivery time.

4. Approximately six months of post-delivery operation time will be required for the maintenance person to get up to full speed in his duties.

In conclusion, we have provided the prospective client laboratory with the above description of new personnel skills required for the full and appropriate utilization of a laboratory automation system, by describing functions and responsibilities in two broad areas. The first area represents a reallocation of existing personnel within the laboratory. The second area can be staffed in one of the following ways:

1. One or two existing laboratory people can be trained and reassigned to perform the functions, as did Region V, with no additional personnel required. This would be especially appropriate in a small-to-medium-sized laboratory with modest post-delivery modification wishes and external SFC support. The people could be selected from those chemists with some computer background, or from existing in-house persons with electronics and some high-level language programming background.

2. A new chemist or electronics technician with some previous computer background could be hired. Background in electronic equipment service and repair and BASIC/FORTRAN programming is extremely valuable. This is the most appropriate course of action for the large production laboratories with sincere interest in proper system utilization and upgrades.

3. Items 1 and 2 above can be combined to form a working team of "principal automation chemist" and system maintenance person, which seems like a very desirable concept for a lab engaged in large sample volume production and significant enhancements.

4. Item 1 above can be combined with hiring a computer person whose primary emphasis would be software maintenance and enhancement. Hardware maintenance could be performed with additional extramural assistance. The

software person would inherit the SFC specification and maintenance function and could carry out elementary add-ons himself.

With any of the above alternatives, it is estimated that the first broad skills area should require no new hiring. The minimum requirement for the second skills area is no new hiring, in a lab environment of well-motivated in-house chemists with previous computer backgrounds, little wishes for enhancements, and external SFC support. The most probable situation would be hiring one new chemist or engineer/technician for the minimum support level by the maintenance person of 0.5 man-year/year. The maximum new personnel requirement would be 2.0 man-years/year, which would provide full in-house hardware and instrument/SFC software support, maintenance, and upgrades. In this cost/benefit analysis 1.0 man-year has been allocated to the system function for the recommended system.

ERC Cincinnati is available to consult on these matters.