JAN 11 1963

ORNL-3371
UC-10 - Chemical Separations Processes
for Plutonium and Uranium
TID-4500 (18th ed.)

MASTER

EVALUATION OF AUTOMATIC DATA PROCESSING
IN THE FLUORIDE VOLATILITY PILOT PLANT

E. C. Moncrief
M. C. Hill

OAK RIDGE NATIONAL LABORATORY

operated by

UNION CARBIDE CORPORATION

for the

U.S. ATOMIC ENERGY COMMISSION

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Printed in USA. Price: \$0.75 Available from the
Office of Technical Services
U. S. Department of Commerce
Washington 25, D. C.

— LEGAL NOTICE —

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

- A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or
- B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

ORNL-3371

Contract No. W-7405-eng-26

CHEMICAL TECHNOLOGY DIVISION

Pilot Plant Section

EVALUATION OF AUTOMATIC DATA PROCESSING IN THE
FLUORIDE VOLATILITY PILOT PLANT

E. C. Moncrief

M. C. Hill

DATE ISSUED
JAN 2 - 1963

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee
Operated by
UNION CARBIDE CORPORATION
for the
U. S. Atomic Energy Commission

**THIS PAGE
WAS INTENTIONALLY
LEFT BLANK**

ABSTRACT

Automatic data logging and digital-computer techniques were evaluated in the ORNL Fluoride Volatility Pilot Plant. The data reduction sequence consisted of encoding plant signals from conventional instrumentation, digitizing the encoded signals with an on-line automatic data logger, and processing the logged data off-line with a digital computer.

Data reduction and computational codes were useful in disseminating process data, with photographic curve plots being the most efficient means.

Considerable difficulty was experienced with logger output errors, which complicated the data processing and frequently resulted in erroneous results.

Based on continuous operation of the data-processing sequence for 12 months the following conclusions were made: (1) Output from a data logger is of limited use without recourse to a computer. (2) Loading of raw logger data to the computer and subsequent conversion to a useful form (engineering units) can account for up to 70% of total computer charges. (3) Some backup to automatic data logging, either as continuous or manual recording, may be desirable because logger downtime may be as much as 5%.

The use of the data reduction sequence will be continued in the pilot plant. Expanding the sequence to include on-line computation and process control features is not justified because of process limitations.

CONTENTS

	<u>Page</u>
1.0 Introduction	1
2.0 Data-Reduction Sequence	4
3.0 Data-Reduction Programs	6
3.1 Raw-Data Loading and Conversion	7
3.2 Printed-Sheet Copy	9
3.3 Photographic Curve Plotting	9
3.4 Plant-Corrosion Summary	12
3.5 Material-Balance Computations	14
3.6 Auxiliary Programs	14
4.0 Discussion and Evaluation	14
4.1 Reliability of Data-Logging System	15
4.2 Use of Processed Data	16
4.3 Programing Requirements	17
4.4 Use of Computer Time	18
5.0 Conclusions	19
6.0 References	20

1.0 INTRODUCTION

One of the many facets associated with the problem of process control by computers is that of data acquisition. The advent of automatic data-logging equipment has added a degree of sophistication to data acquisition. With modern high-speed data loggers the arduous task of assembling data for process evaluation has been simplified, at least in theory. Once the data is accumulated, either on punched cards or paper tape (as is normally the case), the means of data reduction and dissemination must be selected. Since most loggers present the recorded data in the form of "raw" percentage-of-scale readings, recourse to a digital computer is normally essential for data reduction. With many processes, on-line computation may be feasible, and in some instances computer control is being applied. This report deals with the use of automatic data logging and digital-computer techniques in the Fluoride Volatility Pilot Plant, in which UF_6 is separated and recovered from spent reactor fuel elements.

The Fluoride Volatility Pilot Plant is essentially a batch-type operation, and this fact, coupled with a reliance on analytical control in the fluorinator, makes on-line computation or process control by a computer unworkable at present. Accordingly, the data-reduction sequence selected for the Volatility Pilot Plant consisted of on-line automatic data logging and off-line data reduction. Equipment selected for the data processing was limited to facilities already available at ORNL, namely, the Giannini data-logging system, which was extensively modified, and the Oracle computer (Oak Ridge Automatic Computer and Logical Engine). Before discussing the data processing, the volatility process will be described.

The Fused Salt-Fluoride Volatility Process is a nonaqueous process for the recovery of uranium from spent zirconium alloy reactor fuel elements. The process is currently in the development stage and is being tested on irradiated long-decayed fuel in a remotely operated pilot plant, shown schematically in Fig. 1.

In the pilot plant, the zirconium-alloy fuel elements are dissolved at 500 to 650°C with anhydrous HF in a molten fluoride salt in a Hastelloy N dissolver. The zirconium-uranium alloy is converted to ZrF_4 and UF_4 , both soluble in the salt. After dissolution, the uranium bearing salt is transferred to an L-nickel fluorinator, where the uranium is largely separated from nonvolatile fission products by conversion to UF_6 (a volatile compound) with fluorine at 500°C. The UF_6 is further decontaminated from the volatile fission products by a sorption-desorption cycle on a bed of NaF in a temperature-zoned, movable-bed absorber, and collected in cold traps. The waste salt, containing more than 99% of the fission products, is buried as a solid. Decontamination factors of about 10^8 to 10^{10} have been obtained in the process. In other words, under optimum operating conditions approximately one fission product atom out of every billion follows the uranium through the process.

The authors acknowledge the assistance of R. K. Adams, ORNL Instrument and Controls Division, for programing and engineering modifications to the data-logging system. Appreciation is also expressed to W. F. Johnson and R. H. Whitt for their work on the system. Finally, thanks are extended to the personnel of the ORNL Mathematics Panel, and particularly the Oracle operators, for programing and computer assistance.

Fig. 1. Schematic Diagram of Volatility Pilot Plant.

2.0 DATA-REDUCTION SEQUENCE

Data from the Pilot Plant runs were routinely processed and disseminated¹ (Fig. 2). In step 1, 96 electrical signals were received from conventional plant instrumentation, were encoded, and the encoded signals transmitted to the data logger. Pneumatic signals were received by two pneumatic converters, which ultimately submit an encoded signal to the data-logger console.

Signals received by the data logger in step 2 were digitized and punched on paper tape in one of five logging cycles, ranging from continuous to 60 min. The console had provisions for eliminating one or more temperature recorders or pneumatic signals from a logging cycle. The paper-tape output was automatically printed by an on-line teletype for monitoring purposes. A total time of 6 to 7 min was required to log all 120 data points.

The logger output tapes were processed by the computer in step 3. By coded programs, the computer automatically loaded the logs and either processed them immediately or stored them indefinitely on magnetic tape. The data logger and the computer were at different locations at the Laboratory, but a telephone transmission line between the two sites was rejected as impractical.

The final step in the sequence (step 4) was the selection of the means of data dissemination. Computer output was as photographic curve plots, printed sheet copy, or merely as magnetic tape for permanent storage.

Fig. 2. Volatility Pilot Plant Data Reduction Sequence.

3.0 DISCUSSION OF THE DATA-REDUCTION PROGRAMS

When the data-logging system was installed in the Volatility Pilot Plant, careful consideration was given to the allocation of the 120-point capacity of the logger (Table 1). The calculation and curve-plotting function was allocated 60% of the logger capacity, and the chronology of the temperature of the equipment and the manual-logging relief functions were allotted 20% each. In many instances a process signal served more than one function.

Table 1. Allocation of Data-Logger Capacity

Function of Process Signals	Approximate Percentage of Logger Capacity Allocated
1 Process calculations and photographic curve plotting with the Oracle	60
2 Record of equipment temperature history for metallurgical review	20
3 Assistance to plant operations (to minimize manual data logging)	20

Computer codes written for data processing were incorporated into a consolidated program. The codes provided for both data reduction and engineering computations. "Open-end" programming was selected with executive features for program control.

The selection of the Oracle was not entirely for accessibility. Other advantageous features of the machine are its excellent curve-plotter and input-output means for liaison during code debugging. Any comparable high-speed computer would have sufficed, and one with more fast-memory capacity would have been more efficient.

In most cases the codes were too large for the 2048-cell Oracle fast memory. This necessitated breaking the codes into segments, each segment small enough for the memory. Such a program (stored on magnetic tape in the auxiliary memory of the computer) is called a "multisegment" program (Fig. 3). About 90% of all pilot-plant-data processing after raw-data conversion was performed by codes of the multisegment program.

3.1 Raw-Data Loading and Conversion

The data-logger output consisted of four-digit words representing either time or a percentage of scale reading. Since such output format was not directly acceptable for computation by the Oracle, a tape-loading code was written to convert the logger output to a ten-digit hexadecimal word² format that was acceptable.

The code also served as a tape monitor for logger-output errors such as missing carriage returns and missing spaces. Tape-parity errors were routinely monitored by the Oracle. Where this feature is not provided by a computer, some means of logical check would have to be included in the code. The code can, on request, correct the above errors and direct the computer to punch a corrected duplicate tape. All plant logger tapes to be processed by the computer passed through this code. For convenience, the tape-loading code was not a part of the multisegment program but was read directly to the computer fast memory from another location on the magnetic tape.

Prior to use in computations, the raw data were converted to engineering units by third-order linear-regression equations. Appropriate coefficients were used for each temperature recorder and pneumatic signal. The maximum standard error of estimate for all ranges was $\pm 0.1\%$, except

UNCLASSIFIED
ORNL-LR-Dwg. 64634

Fig. 3. Pilot Plant Data Logger Multisegment Sequence.

for pneumatic-flow instruments where it was $\pm 2.4\%$. If coefficients were changed because of instrument recalibration, provision was made in the code for automatic loading of the new values.

3.2 Printed-Sheet Copy

A code was desired which was capable of large-volume output in order to assemble the converted data into a format that identified the data with the appropriate pilot plant instrumentation. Such a code was included in the multisegment program and contained the necessary format instructions and alphameric headings to produce a printed-sheet copy of the engineering values (Fig. 4). The corresponding format of the data-logger on-line printer output sheet is shown for comparison.

3.3 Photographic Curve Plotting

Photographic curve plots were used in the Pilot Plant for surveying run conditions and plotting experimental results. The curve plots were of report quality and were routinely used for that purpose. Figure 5 is a demonstration plot. Titles, counters, and plotting symbols are selected from paper tape input, but data scaling and plotting are automatic, including labeling of the x- and y- axis units. A maximum of five independent variables can be plotted at one time. Once selected, the data (previously converted to engineering units) are processed and arranged serially for plotting. Processing includes conversion of the log time for plotting and evaluation of the range of the data. In addition, the ends of the data ranges are expanded 2% in order to avoid the crowding of data near the scale limits during plotting.

UNCLASSIFIED
ORNL-LR-DWG. 64635 R-1

Fig. 4. Printed Sheet Copy of Raw and Converted Data.

Fig. 5. Demonstration Plot of Pilot Plant Data.

A multiple-variable curve plot is shown in Fig. 6a. Three process temperatures, each with a distinct plotting symbol, are plotted versus time.

Eighty logs are plotted in Fig. 6b during autoresistance heating of a process pipe line. The value of automatic data logging of Volatility Pilot Plant conditions is graphically illustrated, because this process temperature was not recorded continuously at the panelboard and because the temperature excursion at 10 hr was completely missed during manual logging.

3.4 Plant-Corrosion Summary

Evaluation of the corrosion of process vessels was an inherent part of the Volatility Pilot Plant data analysis. Severe limitations are imposed on construction materials used in a corrosive environment consisting of molten fluorides, anhydrous hydrogen fluoride, and elemental fluorine. Two codes were written for surveying process conditions in the pilot plant and for tabulating the system temperatures and other process variables in order to help in evaluating the effects of corrosion. The use of these codes eliminated the time-consuming job of studying process-instrument charts and operating-data sheets to compile the desired information.

The codes routinely scanned 60 process pneumatic and electrical signals for an unlimited number of logs. The process-equipment residence time in five predetermined temperature ranges was evaluated and serialized. In addition, the codes evaluated the maximum data-point temperature, hydrofluorinator and fluorinator salt levels and residence times, and average flows and total quantities of hydrofluoric acid and fluorine used during the period. The codes also contained the necessary instructions and alphanumeric items required for producing a printed sheet copy of results.

UNCLASSIFIED
ORNL-LR-DWG. 64637 R-2

(a)

(b)

Fig. 6. Oracle Curve Plots of Volatility Pilot Plant Operations. (a) Plot of off gas system temperatures during a typical run. (b) Plot of molten salt autoresistance heated line showing temperature excursion at 10 hours.

3.5 Material-Balance Computations

Fuel-element dissolution rates and HF utilization efficiencies were routinely evaluated in the pilot plant in order to determine process performance. These computations were obtained by two codes of the multi-segment program through a material balance around the dissolver system.

The codes routinely inventoried the consumption of hydrogen fluoride from consecutive logs and calculated and serialized the fuel-element dissolution rate, HF utilization efficiency, and the percentage completion of the dissolution. Provision was made for obtaining either printed-sheet copy or curve plots of the above quantities for use in reports. The hydrogen fluoride inventory was computed from third-order linear-regression calibration equations for the four liquid-HF vessels.

3.6 Auxiliary Programs

Auxiliary codes were written to perform a variety of fused-salt-composition and fluorine-utilization calculations. Input to the codes was from analytical and operational data on paper tape. For example, one of the salt-calculation codes was extremely useful for calculating a series of hypothetical dissolver conditions for process design studies. The limited use and short length of these codes did not warrant their inclusion as part of the multisegment program.

4.0 DISCUSSION AND EVALUATION

The data-reduction sequence described previously (Sec 2.0) was used continuously (maximum logging cycle was 1 hr) in the Volatility Pilot Plant for 12 months. During this period, approximately 8500 data logs were processed and permanently stored on magnetic tape.

4.1 Reliability of Data-Logging System

During the 12-month period of the evaluation, the data logging system monitored the plant about 95% of the time. In general, shutdowns for logger repair were infrequent, and at least half of the 5% down time could have been avoided by establishing a high priority on repairs. However, the fact that the logger down time was only 5% does not mean that the system always performed satisfactorily while on stream.

Seldom during the period of the evaluation were strings of greater than 50 consecutive error-free logs obtained. Normally the errors were missing spaces, missing carriage returns, or parity errors. These output errors, often insignificant at the time, ultimately contributed to considerable difficulty in loading tapes into the computer. Periodic revision of the tape-loading code was necessary for efficient loading. In general, the frequency of the logger errors was unpredictable. Frequently, local overheating in the transistorized circuit of the logger caused lapses in the rate of logging. The performance of auxiliary equipment such as the tape-punch unit and on-line teletype, was excellent, with only one mechanical failure during the evaluation period.

The 120-point capacity of the logger was more than adequate to accommodate the plant data output. Changes were frequently made in the plant data points (both electrical and pneumatic) assigned to the logger. Where pneumatic data-point changes were made, alterations were necessary to change the headings of the printed-sheet-copy output code of the computer. New linear-regression coefficients were determined and inserted in the multi-segment code whenever a new data point was added to the logger or the calibration was changed on an existing point.

Proper servicing and calibration of conventional plant instruments was essential for reliable data reduction. Open plant thermocouples frequently doubled the normal logging cycle (6 to 7 min) by delaying the cycle while recorder pens drifted up or down scale.

4.2 Use of Processed Data

1. The data accumulated and processed in the Volatility Pilot Plant had both an immediate and a long-term usefulness. Immediate uses included: (1) continuous monitoring of the plant while uranium and fission products were in the system, and (2) rapid dissemination of results of a run. The availability of permanently stored data for future equipment-corrosion evaluations provided the greatest long-term advantage.

2. Data logs from each process run were routinely processed by the computer to provide results in engineering units. It was advantageous to assign each log a cumulative number and to record all logs in a master ledger. The equipment-corrosion summary (Sec 3.4) was prepared over each complete run, while the dissolver material-balance computations (Sec 3.5) were evaluated only over the dissolution step. About 15 photographic curve plots were routinely obtained from the data of each process run. The plots in general surveyed specific run conditions and were frequently included in formal reports to show normal process operation or some specific anomaly. On request (primarily from the plant-operations group) curve plots of other plant data points were provided for process analysis.

3. The plant-operations group made only limited use of the logger output data for two reasons: (1) delay in providing logger printup in engineering units, and (2) reluctance on the part of operating personnel to lose the close liaison with the plant provided by manual data logging.

The inherent disadvantage of off-line computation is illustrated in (1) on the preceding page. However, it is questionable whether Volatility Pilot Plant operations are of a nature to justify an on-line computer.

Photographic curve plots were the most efficient and practical means of data dissemination. The plots presented large volumes of data in graphical form for use in formal reports.

4.3 Programing Requirements

Obviously, the nature and complexity of a data processing facility must be dictated by the specific process it is to serve. If on-line computation or even process control can be economically justified they should be included in the system. The evaluation of the financial savings to a process by installation of data-processing equipment may be easy if the hardware included is simple, or difficult where it is complex. However, a component of the overall cost of such systems that is often underestimated is the cost of programing.

Total computer programing time for the Volatility Pilot Plant data-processing sequence was conservatively estimated at one man-year. While the programs in themselves were not mathematically complex, the meticulous bookkeeping necessary for successful programing of the large volume of logger output was often extremely tedious. To complicate matters, the careful monitoring of all logger output tapes for errors (Sec 4.1) was necessary to ensure valid results. Frequently, codes were completely rewritten to accomodate certain idiosyncrasies of the logger or computer that were not evident during initial programing. Also, even when valid data were processed, the results were frequently invalid because of improper servicing of process instrumentation. This was particularly the case for the dissolver material-balance computations (Sec 3.5).

Obviously, many programing inefficiencies resulted because both the Giannini data logger and the computer (the Oracle) are antiquated by current standards; coding could have been simplified with more-advanced devices. Also, the use of experienced programers could certainly have decreased the overall programing time required.

4.4 Use of Computer Time

No attempt is made in this section to present conclusions applicable to all data-reduction systems, but rather it is the intent to present results specific to the Volatility Pilot Plant sequence. However, these results should serve as a guide where similar systems are considered for installation.

About 50% of the total computer time during the evaluation was required to load logger tapes to the computer (Table 2). Although inefficiencies in the tape-loading codes certainly existed, the time required at the computer to monitor and correct tape errors was the principal factor reflected in the high percentage of the computer time required for this operation. In general, errors of a format nature (skipped spaces, missing carriage returns, too many data output points per recorder) were more difficult to correct than tape-parity errors.

Table 2. Allocation of Computer Time During Volatility
Pilot Plant Data Processing

Function	Percentage of Computer Time ^a
Tape loading	50
Raw data conversion to engineering unit	20
Photographic curve plotting	10
Corrosion summary and computational codes	20

^aAverage monthly computer costs were about \$600 to 800.

The computer time required for all other functions listed in Table 2 was not considered excessive for the results obtained. The salient point, however, is that about 70% of the computer time was required to load and convert the data to a useful form. The 30% used for curve plotting and miscellaneous computations during the evaluation period would probably not justify the logging system in the Volatility Pilot Plant on economic grounds. However, since the data are permanently stored in useful form, a continuous record of plant conditions would be readily available for curve plotting or computation at a future date. This feature would be particularly applicable to the plant-corrosion evaluation, especially where specific vessel conditions have not been covered by existing codes.

5.0 CONCLUSIONS

Based on continuous operation of a data processing sequence for 12 months in the ORNL Fluoride Volatility Pilot Plant the following conclusions are presented:

1. Output from a data logger is of limited use without recourse to a computer,
2. Loading raw logger data to the computer and conversion of the data to a useful form (engineering units) can account for up to 70% of total computer charges,
3. Some backup to automatic data logging, either as continuous or manual recording, may be desirable because logger downtime may be as much as 5%.

6.0 REFERENCES

¹E. C. Moncrief and M. C. Hill, Digital Computer Processing of Pilot Plant Data, ORNL-TM-95 (Dec. 21, 1961).

²S. E. Atta, Oracle Manual for Programmers, ORNL CF-57-6-68 (2nd rev., Jan. 22, 1958).

ORNL-3371

UC-10 - Chemical Separations Processes
for Plutonium and Uranium
TID-4500 (18th ed.)

INTERNAL DISTRIBUTION

1. Biology Library	43. A. T. Gresky
2-3. Central Research Library	44. C. E. Guthrie
4. Laboratory Shift Supervisor	45. M. C. Hill
5. Reactor Division Library	46. G. W. Keilholtz
6-7. ORNL - Y-12 Technical Library	47. L. J. King
Document Reference Section	48. C. E. Larson
8-27. Laboratory Records Department	49. F. R. McQuilken
28. Laboratory Records, ORNL R.C.	50. R. P. Milford
29. R. K. Adams	51-53. E. C. Moncrief
30. R. G. Affel	54. R. L. Moore
31. J. E. Bigelow	55. R. G. Nicol
32. R. E. Brooksbank	56. W. W. Pitt
33. R. E. Blanco	57. M. J. Skinner
34. K. B. Brown	58. W. G. Stockdale
35. W. E. Browning	59. J. A. Swartout
36. J. C. Bresee	60. A. M. Weinberg
37. W. D. Burch	61. M. E. Whatley
38. W. L. Carter	62. W. R. Whitson
39. W. H. Carr	63. J. J. Katz (consultant)
40. F. L. Culler	64. T. H. Pigford (consultant)
41. D. E. Ferguson	65. H. Worthington (consultant)
42. H. E. Goeller	66. C. E. Winters (consultant)

EXTERNAL DISTRIBUTION

- 67. H. P. Flatt, IBM Corporation, Los Angeles, California
- 68. B. H. Mount, Bettis Atomic Power Laboratory, Pittsburgh, Pa.
- 69. Research and Development Division, AEC, ORO
- 70-577. Given distribution as shown in TID-4500 (18th ed.) under Chemical Separations Processes for Plutonium and Uranium category (75 copies - OTS)