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DIGITAL COMPUTER PROCESSING OF PILOT PLANT DATA

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ABSTRACT

Automatic data logging and digital computer techniques are being used in the ORNL Fluoride Volatility Pilot Plant. Data reduction and computational codes have been useful in the dissemination of process data.

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INTRODUCTION

The use of high-speed data logging and data processing equipment in processing plants is not new. In many processes computer control is being applied. Since the Fluoride Volatility process is a batch process, this fact, coupled with the reliance on analytical control in the fluorinator, limits the use of on-line computer process control. Therefore the use of automatic data logging equipment and digital computer techniques in the ORNL Fluoride Volatility Pilot Plant is limited to data acquisition and dissemination of the large quantities of data emanating from the plant. 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).

In the pilot plant, zirconium-uranium fuel elements are dissolved (Fig. 1) with anhydrous HF in a fused salt, equimolar NaF-LiF containing 25-45 mole % ZrF_4 at 500 to 650°C. The zirconium-uranium alloy is converted to ZrF_4 and UF_4, both being soluble in the fluoride melt. After dissolution, the UF_4 is converted to volatile UF_6 in the fluorinator by elemental fluorine at 500°C. The UF_6 is decontaminated from fission products by an absorption-desorption cycle on NaF at 100°C and 100-400°C, respectively, and collected in cold traps.

PILOT PLANT DATA REDUCTION SEQUENCE

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

Signals received at the data logger (step 2) are digitized and punched on paper tape in one of five logging cycles ranging from continuous to 60 minutes. The paper tape output is automatically printed by an on-line teletype for monitoring purposes.

The logger output tapes are processed on the Oracle (step 3). By coded programs, the Oracle automatically loads the logs and either processes them immediately or stores them indefinitely on magnetic tape. The logger and Oracle are at different physical locations at the Laboratory, but a telephone transmission facility between the two was rejected as impractical.

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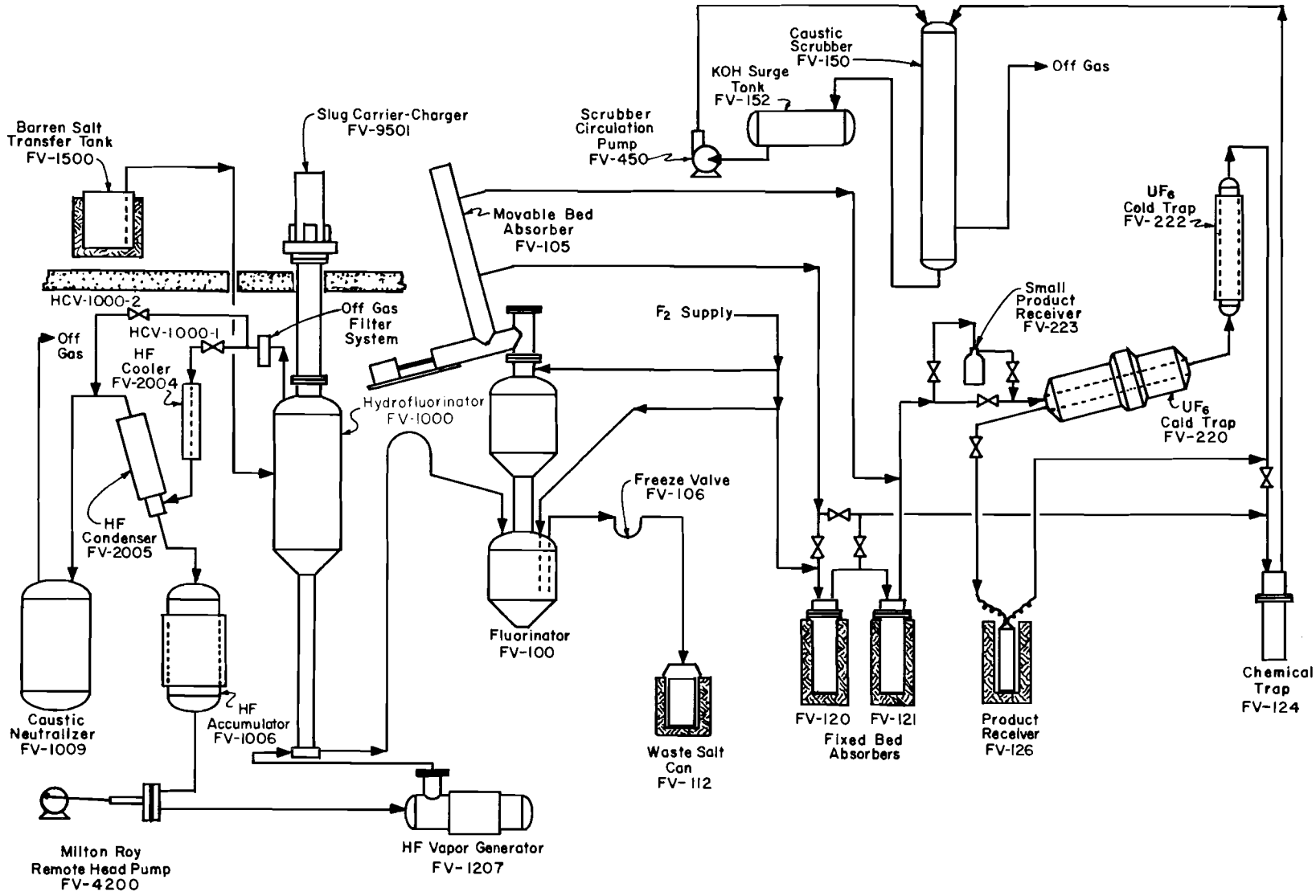

Fig. 1. Schematic diagram of Volatility Pilot Plant

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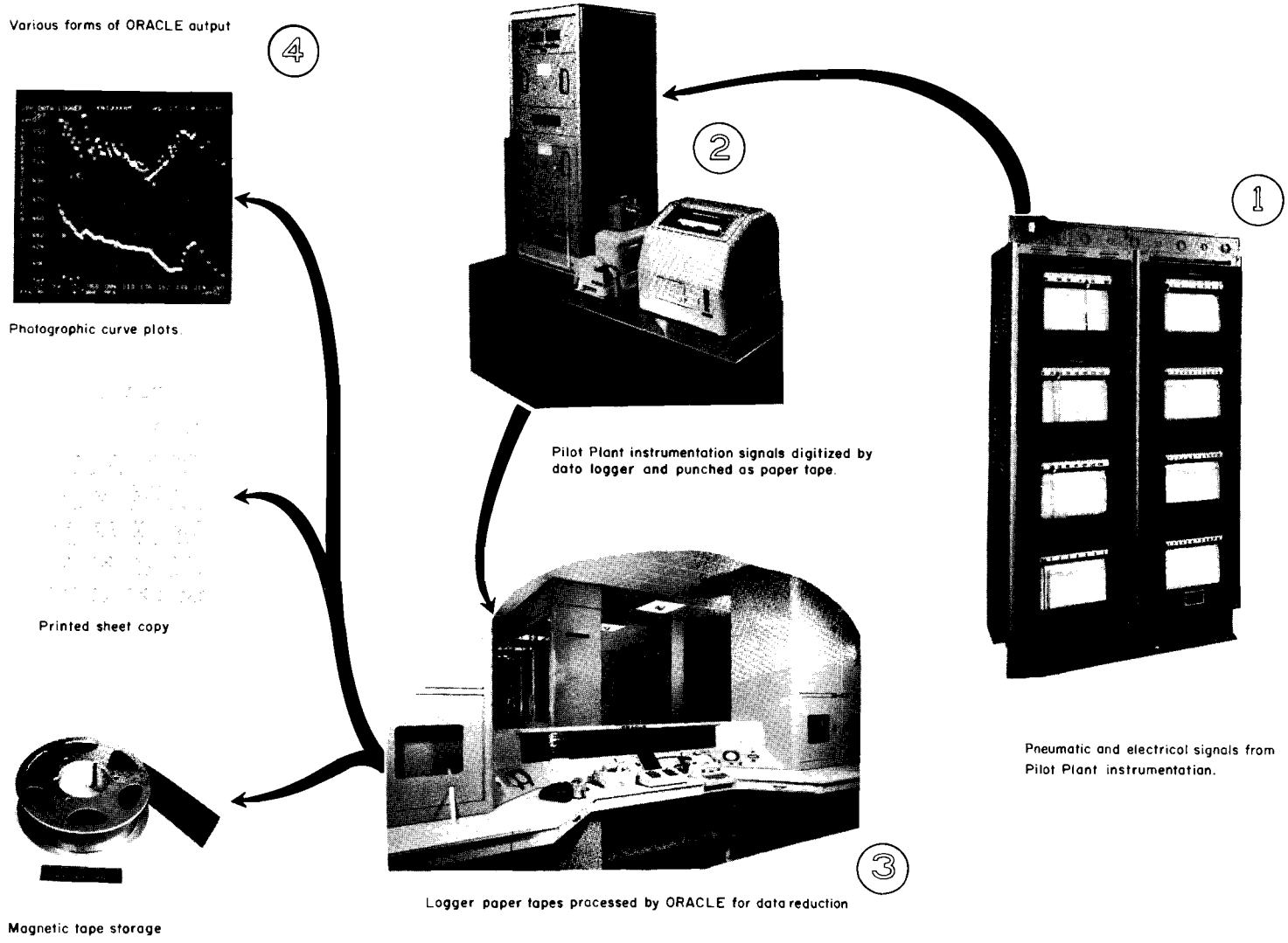

Fig. 2. Volatility pilot plant data reduction sequence.

The final step (step 4) is selection of the means of data dissemination. Oracle output may be as photographic curve plots, printed sheet copy of the logs or associated computational programs, or merely as magnetic tape for storage.

DATA LOGGING SYSTEM

The Giannini data logging system was selected for use in the Volatility Pilot Plant because of its availability. As installed, the components are: (1) console unit, (2) pneumatic unit, (3) temperature unit, and (4) teletypewriter and paper tape punch unit (Fig. 3). A total time of 6 to 7 minutes is required to log all 120 points. Shorter logging cycle times may be obtained by removing one or more recorders from the cycle. The system as originally engineered provided for 12 pneumatic and 108 electrical signals. Modifications increased the number of pneumatic signals to 24 at the expense of 12 electrical signals.

Console Unit

The console unit is the heart of the data logging system. Encoded signals from the plant instrumentation are automatically scanned, digitized, and serialized according to a preset logging cycle. The console has provisions for eliminating one or more temperature or pneumatic recorders from a log. The elimination of one or more data points on a recorder is not possible.

Pneumatic Unit

The pneumatic unit consists of two pneumatic servos, each giving a signal to the console proportional to the pneumatic signal it is receiving. The two units provide for the encoding of process measurements of flow, pressure, liquid level, and density.

Temperature Unit

Eight multipoint recorders, for temperatures ranging from -200 to +1200°C, constitute the temperature unit. The recorders are connected in parallel with pilot plant signals.

Teletypewriter and Paper Punch Unit

Shown in Fig. 3 with the console unit is the logger on-line output equipment. The teletypewriter and tape reader are visible; the tape punch unit is located in the cabinet. Logger output is in the form of a 7-hole paper tape and teletypewriter printed sheet copy.

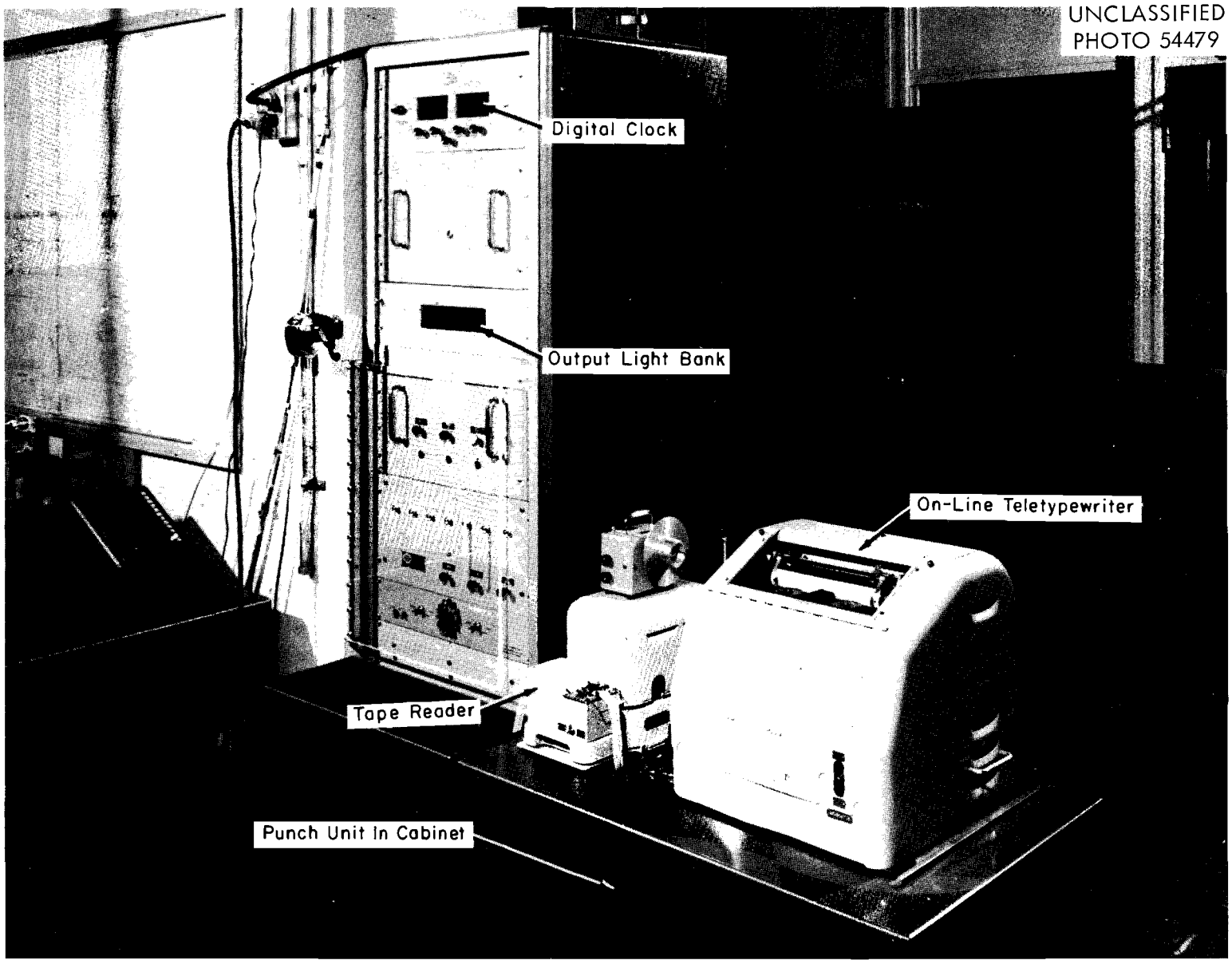

Fig. 3. Giannini data logger system.

DESCRIPTION OF THE ORACLE

The Oracle (Fig. 4) performs computations in binary arithmetic. Machine fast memory is limited to 2048 forty-binary-digit words. Auxiliary memory is provided by four magnetic tape units capable of reading or writing 2500 words per second. Console facilities include displays of all primary registers and counters as well as cathode-ray-tube monitors of the fast-memory and curve-plotter output. Tape, both paper and magnetic, is the normal means of data input and output with the Oracle. An additional means of output in the form of photographic plots is widely used.

Codes for the Oracle are normally written with the aid of a compiler which automatically assigns the necessary memory space. An additional compiler is available, the Orbit, whose language is similar to that of Fortran in that coding format can use basic algebraic expressions.

VOLATILITY PILOT PLANT DATA REDUCTION PROGRAMS

The principal function of the Volatility Pilot Plant is to provide process data. Computer techniques are used in the plant to expedite the acquisition and dissemination of the data.

When the logging system was installed, careful consideration was given to allocation of the logger's 120-point capacity (Table 1). In many instances

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

a process signal served more than one function. Actual plant experience de-emphasized function 3 for two reasons: (1) delay in providing logger printup in engineering units, and (2) reluctance of operating personnel to loose the close liaison with the plant provided by manual data logging. Only limited use of the logger output is possible without recourse to a computer.

Computer codes written for data processing were incorporated into a consolidated program. The codes provided for both data reduction and engineering

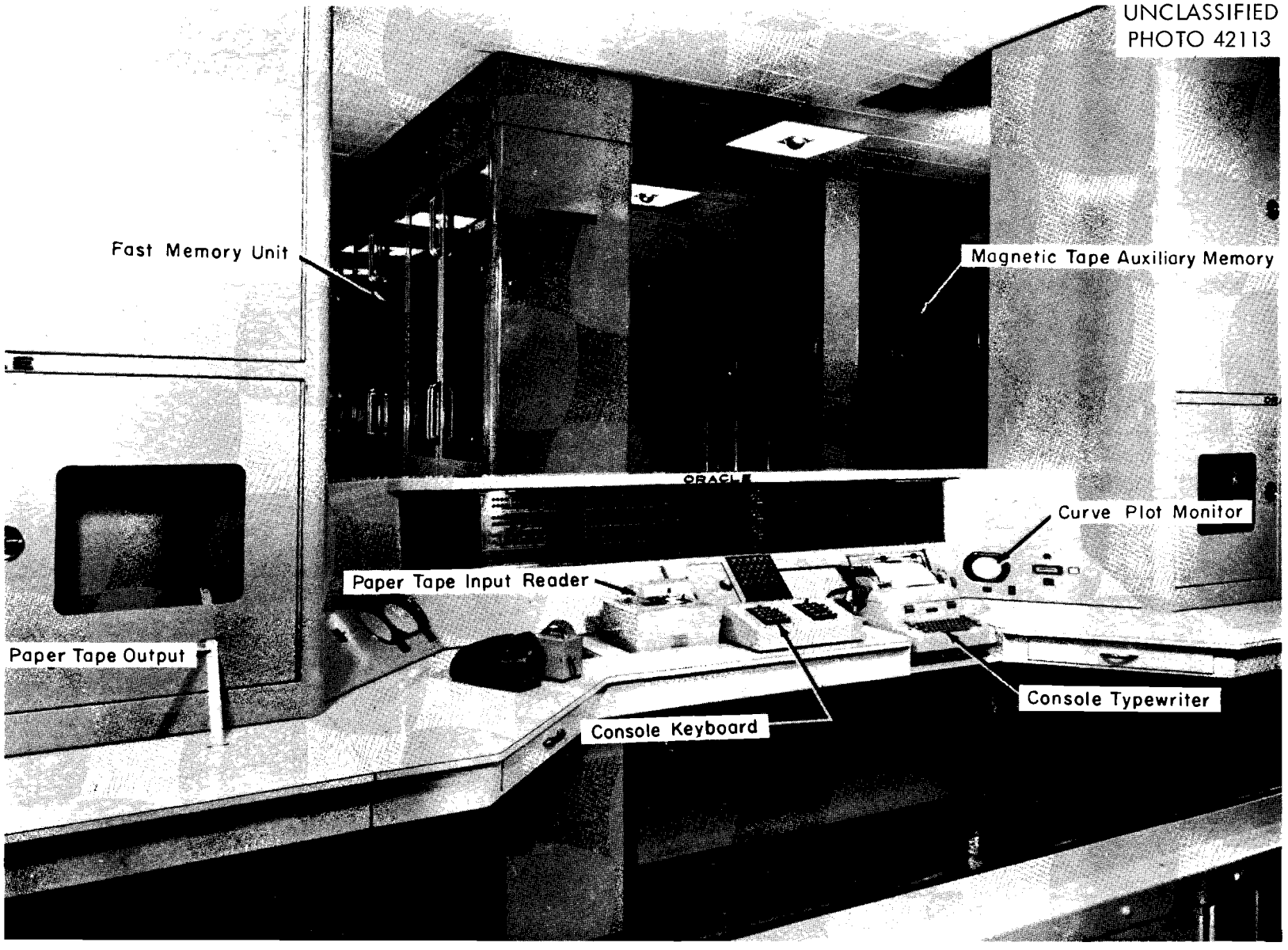

Fig. 4. The ORACLE.

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 computer auxiliary memory) is called a "multisegment" program (Fig. 5). Approximately 90 per cent of all pilot plant data processing is performed by codes of the multisegment program. For simplicity, reference to codes will be as segments of the multisegment program.

Tape Loading

Data logger output consists of four-digit words representing either time or a percentage of scale reading. Since such output format is not directly acceptable for computation by the Oracle, a tape loading code was written to convert the logger output to a ten-digit hexadecimal word format which is acceptable.

The code also serves as a tape monitor for logger output errors such as missing carriage returns and missing spaces. Tape parity errors are 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 must pass through this code. For convenience, the tape loading code is not a part of the multisegment program but is read directly to the computer fast memory.

Raw Data Conversion

Two segments of the multisegment program provide for conversion and printup of the data logger output.

Conversion of logger percentage of scale readings to engineering units is by third-order linear regression equations. Appropriate coefficients are used for each logger temperature recorder and each pneumatic signal. The

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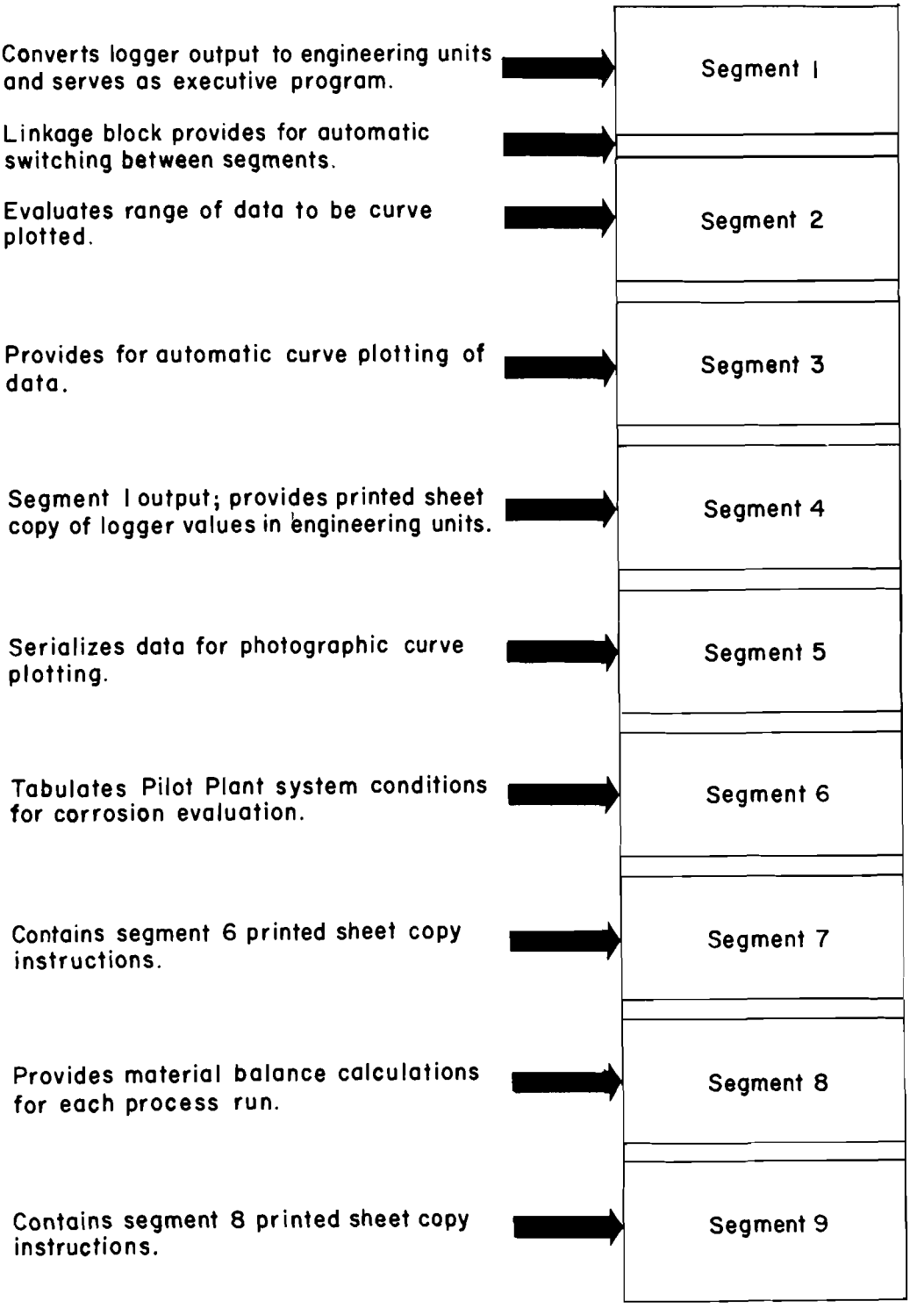

Fig. 5. Pilot Plant data logger multisegment sequence.

maximum "standard error of estimate" for all ranges was ±0.1 per cent, except for pneumatic flow instruments where it was ±2.4 per cent. If coefficients must be changed because of instrument recalibration, provision is made in the code for automatic loading of the new values.

A code capable of large volume output to assemble the converted data into a format that identifies the data with the appropriate pilot plant instrumentation was desirable. Such a code is included in the multisegment program and contains the necessary format instructions and alphameric headings to produce a printed sheet copy of the engineering values (Fig. 6). The corresponding format of the data logger on-line printer is shown for comparison.

Photographic Curve Plotting

Three codes of the multisegment program are devoted to producing photographic curve plots. The plots are used in the Pilot Plant for run analyses and are subsequently used in formal reports of the data. The photographic curve plots are the most practical and efficient means of data dissemination available from the data reduction programs.

The curve plotter codes select the data points to be plotted from each log. A maximum of five independent variables can be plotted on a single curve plot, each with a distinct plotting symbol. 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 per cent to avoid crowding of data near the scale limits during plotting. Information on paper tape is entered during execution of the codes for selecting the desired plotting symbol(s) and for labeling the axes. The codes automatically select the corresponding y- and x- axis variables and plot each variable in turn. The Oracle has provisions for monitoring the curve plots.

Figure 7 is an example of two typical pilot plant curve plots. Eighty logs were plotted in Fig. 7a during autoresistance heating of a process pipe line. The value of data logging and curve plotting of plant conditions is graphically illustrated, since the temperature excursion at 10 hours was completely missed in the manual data logging of this temperature.

Figure 7b is an example of a multiple-variable curve plot, showing three process temperatures plotted during a fuel element dissolution. Plots

VOLATILITY PILOT PLANT DATA LOGGER VALUES

PNEUMATIC INSTRUMENTS

Time	Log
400	639

Hy Off Gas (FR 1009-1) SLM	Hy Off Gas (PR 1009-1) Ins./Water	Process OG (FR X124-1) SCFM	Process OG (PR X124-1) Ins./Water
.7637102e+01	.6276608	.1499610	.8064235
Fluor Flow (FR X100) SLM	Fluor Press (PR X100) Psig	Fluor Press (PR 161) Psig	Fluor Press (PR 162) Psig
.5262881e+01	.6703512e+01	.3240986e+02	.2984129e+01
Hydrofluor Pressure (PR 1000) Psig	Hydrofluor Level (LR 1000) Ins./Water	Fluorinator Level (LR 100) Ins./Water	Fluorinator Density (DR 100) Sp. Gr.
.3041940e+01	.2831453e+03	.1894333e+01	.2207170e+01
Vapor Gen Pressure (PR 1207) Psia	Vapor Gen Level (LR 1207) Ins./Water	HF Recycle Level (LR 1006) Ins./Water	Neutralizer Level (LR 1009) Ins./Water
.7263805e+02	-.1112036	.7351813e+01	.6848745e+02
HF Flow (FR 2207) Gm. Min.	N. He Man (PR He N) Psig	S. He Man (PR He S) Psig	He Flow (FR He) SLM
.2151838e+03	.3427827e+01	-.5115364e+02	.3427827e+01
HF Surge Tk (LR 1003) Ins./Water	HF Pump Tk (LR 1202) Ins./Water	Water Return FR CWR 2004-1 SLM	Water Return FR CWR 2004-3 SLM
.2882937e+02	.1932487e+02	.3903700e+01	.2506749e+01

ORACLE output of proces values as engineering units.

```
CC29 CC29 CC29 CC29 CC29 CC29 CC29 CC29 CC29 CC29 CC29 CC29
CC20 CCCC CC18 CC18 CC18 CC20 CC20 CC21 CC21 CCCC CC20 CC20

CCCC CC63 C117 C169 CC61 CC-4 CC34 C176 CC53 CC36 CC31 CC35 CCCC
C197 CCC7 CC29 CC31 CCC7 CCC7 CCC7 CC39 CC22 CC28 CC21 CC41
C681 C669 C682 C683 C685 C686 C669 C678 C637 C639 C669 C671
C967 C210 C211 C208 C186 C183 C321 C201 C206 C225 C202 C231
C173 C186 C187 C161 C161 C163 C153 C186 CCCC C151 C166 C149
CC45 CC45 CC45 CC45 CC45 CC45 CC45 CC45 CC45 CC45 CC45 CC45
CC41 CC41 CC41 CC41 CC41 CC41 CC41 CC57 CC49 CC41 CC41 CC41
CC25 CC25 CC25 CC25 CC26 CC27 CC27 CC25 CC25 CC25 CC27 CC27
CC29 CC29 CC29 CC29 CC29 CC29 CC29 CC29 CC29 CC29 CC29 CC29
CC20 CCCC CC18 CC18 CC18 CC20 CC20 CC21 CC21 CCCC CC20 CC20

CCCC CC63 C116 C133 CC6C CC45 CC34 C175 CC53 CC12 CC3C CC34 CCCC
C196 CCC7 CC29 CC29 CCC7 CCC7 CCC7 CC39 CC22 CC23 CC20 CC43
```

Logger on-line teletype output as per cent of scale readings.

TEMPERATURE RECORDERS
(Temps in Degrees C.)

Time	Log
400	639

Rec. No. 3			
-.4652821e+02	-.3590363e+02	-.1260365e+02	-.5403728e+01
-.3105233e+02	-.5800215e+02	.5026294e+01	.3048832e+02
.2090358e+02	.7136556e+02	.2709177e+02	-.4987523e+02
Rec. No. 4			
.1440182e+03	.3062567e+02	.3093987e+02	.2957123e+02
.3200477e+02	.3185762e+02	.4892424e+02	.2926717e+02
.3002737e+02	.4175435e+02	.3002737e+02	.2395150e+02
Rec. No. 5			
.4486000	.2925226e+01	.4486000	.2814497e+02
.2845069e+02	.2986829e+02	.2735991e+02	.2008466e+02
.4486000	.6055550e+02	.9379107e+02	.2262618e+02
Rec. No. 6			
.4465450e+02	.4465450e+02	.4465450e+02	.4465450e+02
.4465450e+02	.4465450e+02	.4465450e+02	.4465450e+02
.4465450e+02	.4465450e+02	.4465450e+02	.4465450e+02
Rec. No. 7			
.3979622e+02	.3979622e+02	.3979622e+02	.4049714e+02
.4049714e+02	.3979622e+02	.3769432e+02	.4821656e+02
.4540755e+02	.3979622e+02	.3979622e+02	.3979622e+02
Rec. No. 8			
.2531778e+02	.3980507e+02	.7235576e+02	.5124655e+03
.4221838e+02	.4463133e+02	.4583767e+02	.4583767e+02
.3618446e+02	.3980507e+02	.4583767e+02	.4463133e+02
Rec. No. 9			
.2926372e+03	.4198460e+03	.4056675e+03	.6784398e+02
.3377684e+03	.6524996e+02	.5875497e+02	.5615299e+02
.3124966e+03	.4949009e+03	.5745427e+02	.5354871e+02
Rec. No. 10			
.4717192e+03	.2112612e+03	.5193475e+03	.5193475e+03
.5205389e+03	.4300815e+03	.5217304e+03	.5169647e+03
.4717192e+03	.4181895e+03	.4288726e+02	.2148335e+03

Fig. 6. Printed sheet copy of raw and converted data.

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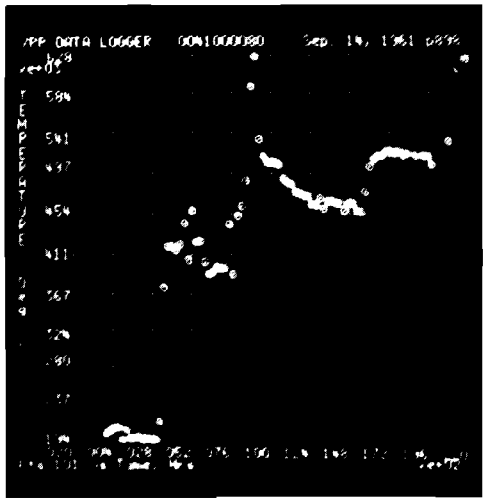
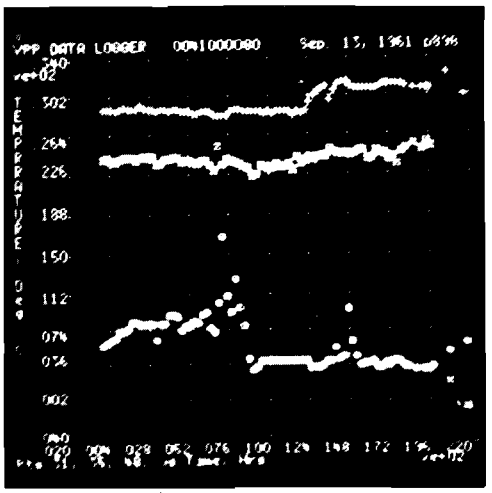


Plot of molten salt autoresistance heated line showing temperature excursion at 10 hours.



Plot of off gas system temperatures during a typical run.

Fig. 7. ORACLE curve plots of volatility pilot plant operations.

of this type are extremely useful in scrutinizing process operations as well as in assisting in dissemination of the data.

Plant System Condition Summary

Evaluation of process vessels for corrosion is an inherent part of the Volatility Pilot Plant data analysis. Severe limitations are imposed on the types of construction materials used in the corrosive environment of molten salt, anhydrous HF, and elemental fluorine. Two codes were written for surveying process conditions in the pilot plant and tabulating the system temperatures and other process variables for corrosion evaluation. The use of these codes eliminates the time-consuming job of studying process instrument charts and operating data sheets to compile the desired information.

The codes routinely scan 60 process pneumatic and electrical signals for an unlimited number of logs. The process equipment residence time in five predetermined temperature ranges is evaluated and serialized. In addition, the codes evaluate 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 contain the necessary instructions and alphameric items required for producing a printed sheet copy of the results.

Material Balance Computations

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

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

Auxiliary Programs

Three auxiliary codes have been written to perform a variety of fused salt composition and fluorine utilization calculations. Input to the codes is from analytical and operational data on paper tape. One of the salt calculation codes is extremely useful for calculating a series of hypothetical

dissolver conditions for process design studies. The limited use and short length of the codes does not warrant their inclusion as part of the multi-segment program.

ACKNOWLEDGMENTS

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