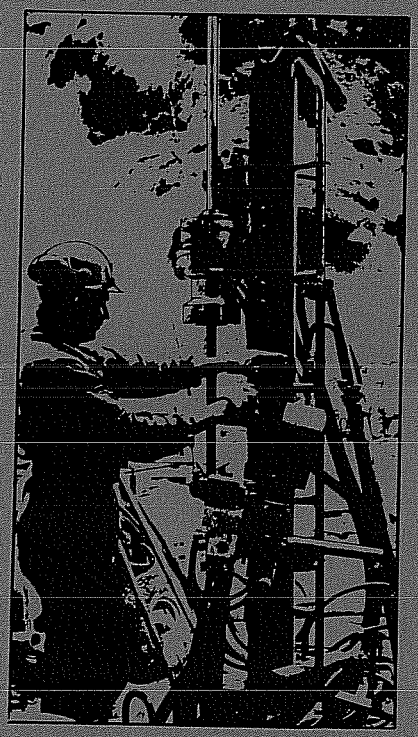
LBL-7062
SAC-14
UC-70

SWEDISH-AMERICAN COOPERATIVE PROGRAM ON RADIOACTIVE WASTE STORAGE IN MINED CAVERNS IN CRYSTALLINE ROCK



Technical Information Report No. 14

DATA ACQUISITION, HANDLING, AND DISPLAY FOR THE HEATER EXPERIMENTS AT STRIPA

Maurice B. McEvoy

Real-Time Systems Group
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

February 1979

A Joint Project of

Swedish Nuclear Fuel Supply Co.
Fack 10240 Stockholm, Sweden

Operated for the Swedish
Nuclear Power Utility Industry

Lawrence Berkeley Laboratory
Earth Sciences Division
University of California
Berkeley, California 94720, USA

Operated for the U.S. Department of
Energy under Contract W-7405-ENG-48

This report was prepared as an account of work sponsored by the United States Government and/or the Swedish Nuclear Fuel Supply Company. Neither the United States nor the U.S. Department of Energy, nor the Swedish Nuclear Fuel Supply Company, nor any of their employees, nor any of their contractors, subcontractors, or 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.

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 Code: A05

DATA ACQUISITION, HANDLING, AND DISPLAY FOR THE HEATER EXPERIMENTS AT STRIPA

Maurice B. McEvoy

Real-Time Systems Group
Lawrence Berkeley Laboratory
University of California
Berkeley, California

February 1979

This report was prepared by the Lawrence Berkeley Laboratory under the University of California contract W-7405-ENG-48 with the Department of Energy. The contract is administered by the Office of Nuclear Waste Isolation at Battelle Memorial Institute.

PREFACE

This report is one of a series documenting the results of the Swedish-American cooperative research program in which the cooperating scientists explore the geological, geophysical, hydrological, geochemical, and structural effects anticipated from the use of a large crystalline rock mass as a geologic repository for nuclear waste. This program has been sponsored by the Swedish Nuclear Power Utilities through the Swedish Nuclear Fuel Supply Company (SKBF), and the U.S. Department of Energy (DOE) through the Lawrence Berkeley Laboratory (LBL).

The principal investigators are L. B. Nilsson and O. Degerman for SKBF, and N. G. W. Cook, P. A. Witherspoon, and J. E. Gale for LBL. Other participants will appear as authors of the individual reports.

Previously published technical reports are listed below.

1. Swedish-American Cooperative Program on Radioactive Waste Storage in Mined Caverns by P. A. Witherspoon and O. Degerman. (LBL-7049, SAC-01).

2. Large Scale Permeability Test of the Granite in the Stripa Mine and Thermal Conductivity Test by Lars Lundstrom and Haken Stille. (LBL-7052, SAC-02).

3. The Mechanical Properties of the Stripa Granite by Graham Swan. (LBL-7074, SAC-03).

4. Stress Measurements in the Stripa Granite by Hans Carlsson. (LBL-7078, SAC-04).

5. Borehole Drilling and Related Activities at the Stripa Mine by P. J. Kurfurst, T. Hugo-Persson, and G. Rudolph. (LBL-7080, SAC-05).

6. A Pilot Heater Test in the Stripa Granite by Hans Carlsson. (LBL-7078, SAC-06).

7. An Analysis of Measured Values for the State of Stress in the Earth's Crust by Dennis B. Jamison and Neville G. W. Cook. (LBL-7071, SAC-07).

8. Mining Methods Used in the Underground Tunnels and Test Rooms at Stripa by B. Andersson and P. A. Halen. (LBL-7081, SAC-08).

9. Theoretical Temperature Fields for the Stripa Heater Project by T. Chan, Neville G. W. Cook, and C. F. Tsang. (LBL-7082, SAC-09).

10. Mechanical and Thermal Design Considerations for Radioactive Waste Repositories in Hard Rock. Part I: An Appraisal of Hard Rock for Potential Underground Repositories of Radioactive Wastes by Neville G. W. Cook; Part II: In Situ Heating Experiments in Hard Rock: Their Objectives and Design by Neville G. W. Cook and P. A. Witherspoon. (LBL-7073, SAC-10).

11. Full-Scale and Time-Scale Heating Experiments at Stripa: Preliminary Results by Neville G.W. Cook and Michael Hood. (LBL-7072, SAC-11).

12. Geochemistry and Isotope Hydrology of Groundwaters in the Stripa Granite: Results and Preliminary Interpretation by P. Fritz, J.F. Barker, and J.E. Gale. (LBL-8285, SAC-12).

13. Electrical Heaters for Thermo-mechanical Tests at the Stripa Mine by R. H. Burleigh et al. (LBL-7063, SAC-13).

TABLE OF CONTENTS

Page

LIST OF FIGURES vii

LIST OF ABBREVIATIONS ix

ABSTRACT 1

1. INTRODUCTION 3

2. DATA ACQUISITION SYSTEM 7

2.1 Computer System 7

Central Processor 11

Peripheral Devices 14

Remote Instrument Interface 16

System Integration 20

2.2 Suplementary System 20

2.3 On-Line Data 21

Predicted Temperature, Stress, and Displacement Values 22

Fracture System Representations 23

Sensor Parameters 24

Acquired Data 24

2.4 On-Site Applications Software 25

Instrument Calibration 26

Data Acquisition Software 29

Graphic Displays 32

Software Utilities 38

Software Documentation 39

2.5 Alarm System 40

Page

2.6 System Verification, Safeguards, and Operation . . 42

Data Backup Procedures 43

Computer Restart Procedures 44

Staffing 45

3. DATA HANDLING 45

3.1 Data Sources 46

3.2 Data Transfer and Storage at LBL 47

3.3 Index of Project Data at LBL 49

4. SUMMARY AND CONCLUSIONS 50

5. ACKNOWLEDGMENTS 54

6. REFERENCES 57

7. APPENDIX: ENVIRONMENT 59

7.1 Instrument Characteristics 59

Thermocouples 59

Extensometers 61

USBM Gauges 62

IRAD Gauges 63

Borehole Decrepitation Sensors 64

Heater Monitors 64

7.2 Power Supply System 64

7.3 Computer Room and Instrumentation Sheds 67

7.4 Fire Protection System 70

7.5 References 71

LIST OF FIGURES

Page

Figure

1. Graphic illustration of U.S. heater experiments in the Stripa mine 4
2. Block diagram of the data acquisition system 8
3. Computer system 9
4. Graphic display console 9
5. Computer block diagram 12
6. Front view of computer 13
7. Asynchronous communications multiplexer 15
8. Moving head disc drive 15
9. Magnetic tape drive 16
10. Electrostatic printer/plotter 17
11. Block diagram of the Wide-Range-Relay Analog-Input subsystem 18
12. Averaging interval versus time for each heater experiment 25
13. Instrument calibration diagram 27
14. Sample thermocouple calibration curve 27
15. Data acquisition diagram 30
16. Graphic display generation diagram 32
17. Displacement versus time plots 34
18. Sample four-curve display 34
19. Sample temperature contours on a vertical section . . . 35
20. Plot linkage diagram 36
21. Software utilities diagram 38

Page

22. Equivalent logic diagram for the alarm and interlock system 41
23. Sample interconnection wiring list 43
24. Tektronix 4051 desktop computer system 49
25. Plot of the H10 heater temperatures versus time 53
A-1. Instrument interface diagram 60
A-2. Power distribution diagram 65
A-3. Diesel generator 66
A-4. Motor generators 67
A-5. Computer room drawing 69

LIST OF ABBREVIATIONS

A/D	Analog to Digital conversion
ANSI	American National Standards Institute
ASCII	American Standard Code for Information Interchange
BCD	Binary Coded Decimal
CDC	Control Data Corporation
CPU	Central Processing Unit of a computer
CRC	Cyclic Redundancy Character
CSM	Colorado School of Mines
DAS	Data Acquisition System
DCB	Display Control Block
DCDT	A special Linear Variable Differential Transformer (LVDT) transducer containing hybrid circuits that provide signal conditioning
DECwriter	A printing terminal manufactured by Digital Equipment Corporation
DMA	Direct Memory Access
GDS	The University of California at Berkeley's Graphical Display System
IDDS	LBL's Integrated Data Display System
I/O	Input/Output
IOIS	Modcomp's Input/Output Interface Subsystem
IRAD	IRAD Engineering Consultants, Lyme, New Hampshire
KBS	Swedish Nuclear Fuel Safety Company
LBL	Lawrence Berkeley Laboratory

LBLDMP	Name of the software routine that is used to copy the long-term data file from disc to magnetic tape
MAX-IV	Modcomp's multitasking interactive real-time operating system
MG	Motor Generator
MODCOMP	Modular Computer Systems, Inc.
MUX	Multiplexer
NETED	A text editor used by LBL and other members of the Advanced Research Projects Agency (ARPA) computer network.
PCB	Plot Control Block
PSD	Program Status Doubleword
PSS	LBL's Program Storage System
RC filter	An electronic frequency filter constructed using resisters and capacitors
REMAC	Modcomp's Remote Data Acquisition Unit
RTD	A temperature-sensing transducer that relates change in electrical resistance as a function of temperature
RTSG	LBL's Real-Time Systems Group
USBM	United Sates Bureau of Mines

ABSTRACT

In June 1978, a joint Swedish/American research team began acquiring data from the Stripa mine in Sweden, 340 m below the surface. Electrical heaters were installed and are now used to assess the suitability of granite rock as a repository for radioactive waste material. Extensive instrumentation also measures temperature, stress, and displacement effects caused by these heaters, which are intended to simulate nuclear waste canisters in size and power output. A data acquisition system is used to acquire and digitize data, convert measured values to engineering units, store data for random access, provide on-site graphical data displays, and transfer data to Lawrence Berkeley Laboratory for further analysis. Duplicate computer peripherals and backup data loggers were used to reduce data losses caused by failure during the planning 1.5 years of operation.

This report describes the data acquisition system, its design considerations, capabilities, and operational use. The techniques employed to detect and analyze any anomalous experimental results are also described. Many design considerations were the result of instrument capabilities and characteristics, and the desired accuracies imposed by our research requirements. The system also required additional support such as adequate power supply, protective enclosures, and fire protection. Relevant environmental considerations are therefore described in the Appendix (Section 7).

1. INTRODUCTION

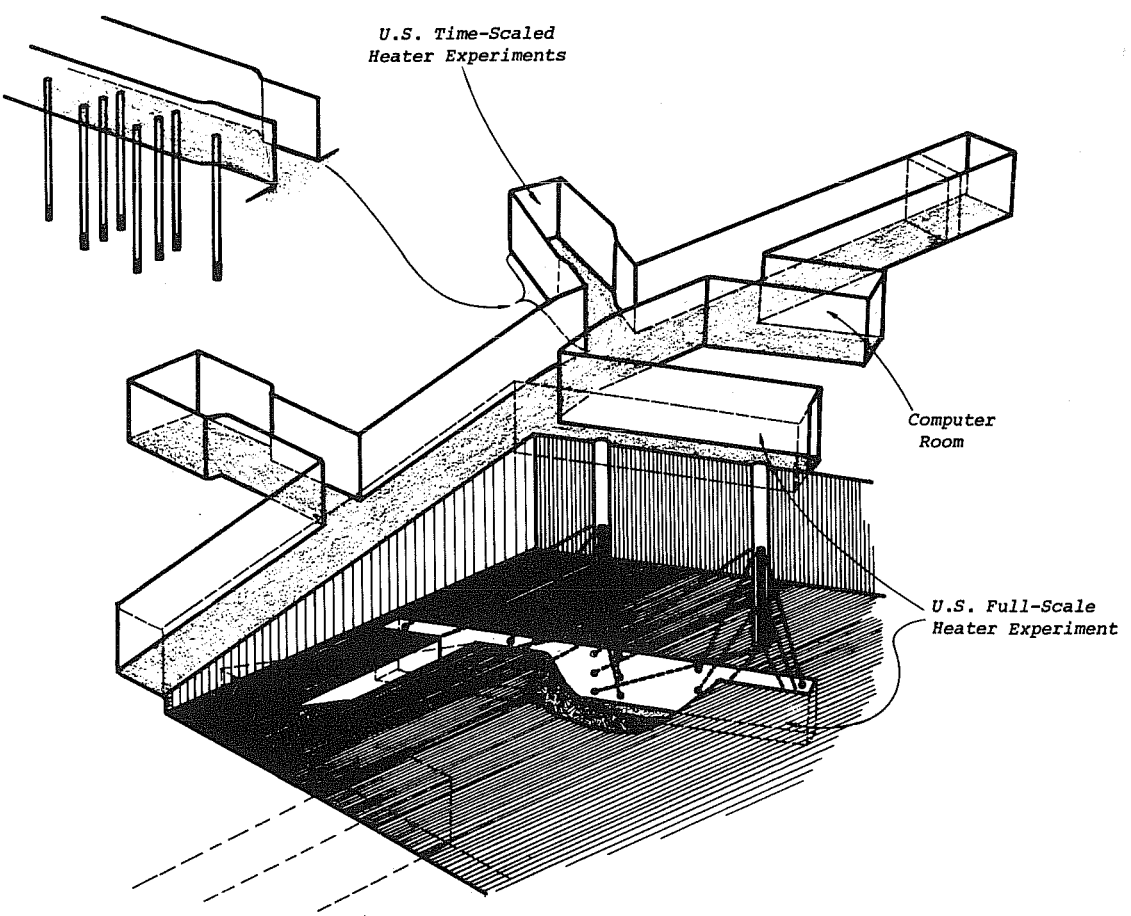
Field experiments, currently underway in Sweden, should determine the design parameters for repositories of high-level radioactive waste, and provide data that can be used to assess the safety of these facilities. In the Stripa mine, heaters have been installed that simulate the heat produced by actual radioactive-waste canisters. Experiments have been designed using these heaters to test both short- and long-term thermal loading effects on granite.

Two full-scale "main heater" canisters were constructed to simulate the physical dimensions and energy output of potential radioactive-waste canisters. The power output of one heater is 5 kW, and that of the other main heater is 3.6 kW. Figure 1 shows a cutaway of the two full-scale heaters and some of the horizontal instrument holes that were driven from an adjacent lower-level extensometer drift. A second phase of the full-scale heater experiment is designed to evaluate sequential canister emplacement--and thus sequential heat loadings--by using a ring of eight small 1-kW peripheral heaters placed in a 0.9-m radius surrounding the 5-kW heater. Both heaters have been in full operation since August 1978.

A separate array of eight "time-scaled" heaters, also shown in Fig. 1, was used to simulate long-term effects of the thermal-mechanical loading on a repository. The dimensions, power levels, and spacing of these smaller heaters were scaled, consistent with the laws of heat conduction, to permit tests planned through May 1979 to yield data equivalent to more than 10 years of information obtainable from full-scale heater tests. The power level started at 1.125 kW and it is being decreased to simulate the decrease

in power output of radioactive waste over the simulated period. The design of these heaters is described by Burleigh et al. (1979).

Extensive instrumentation (Schrauf et al., in preparation) was placed around the heaters to measure rock displacement, temperature, and thermally induced stress in the surrounding rock mass. Each of the 763 sensors will be sampled at 15-minute intervals during the planned 12 months of heater operation and 6-month cool-down period. The sheer magnitude of acquired data makes manual data collection impractical and error prone. For economy and reliability, a computer-based Data Acquisition System (DAS) was created that can automatically acquire, monitor, safeguard, summarize, display,



XBL 7711-10802A

Fig. 1. Graphic illustration of U.S. heater experiments in the Stripa mine.

and compare predictions with measurements for all 763 channels of data. Additional DAS features facilitate the detection, analysis, and troubleshooting of anomalous results. On-site system status displays and data alarm conditions help operators detect faulty hardware or software problems and help isolate a problem's source. Unexpected results are accentuated by displaying "actual" data together with "predicted" data obtained from numerical models (Chan, Cook, and Tsang 1978). The ability to rapidly compare data speeds their proper interpretation and provides insight into changes in the rock mass. Although novel in rock mechanics experiments, similar computer-based data acquisition systems are often used in other fields in which large amounts of data must be accurately and reliably obtained. Witherspoon and Degerman (1978) describe the overall LBL program in the first report of this series.

The current report describes the DAS, its display capabilities, design considerations, operation, use in validating predictive models, and its relationship to the study's overall objectives. The appendix describes relevant instrument characteristics and associated support equipment such as the power supplies, protective enclosures, and fire protection.

2. DATA ACQUISITION SYSTEM

The DAS was designed and constructed to provide a failure-tolerant system. Duplicate computer peripherals, raw-data log tapes, a file save/reload feature, and backup data loggers that print data on paper tape minimize data loss caused by any single failure. Figure 2 shows a block diagram of the DAS.

Some sensor output voltage levels are low and require pre-amplification before analog-to-digital conversion. These signal-conditioning circuits may drift during the years of operation. Precision voltage-source inputs to the data loggers provide a reference that facilitates detection, and helps isolate the cause of such drifts should they occur. It is important that the conclusions reached by the experimenters not be compromised by missing, faulty, or incorrectly labeled data.

2.1 Computer System

A Modcomp IV, shown in Fig. 3, provides the basis of the computer system. Modcomp was selected primarily because of their off-the-shelf process input/output hardware, which greatly simplified instrument interfacing, and their excellent hardware reliability experienced in other LBL real-time applications. Computer system components were purchased, assembled, and tested by the Real-Time Systems Group (RTSG) in Berkeley. This system was used during software development, shipped to Sweden, installed in the underground computer room, and in full operation by February 1978. Interactive control and monitoring of the experiment is achieved by displaying option lists on the graphic display devices shown in Fig. 4 with subsequent actions, displays, etc. determined by those options selected by the users.

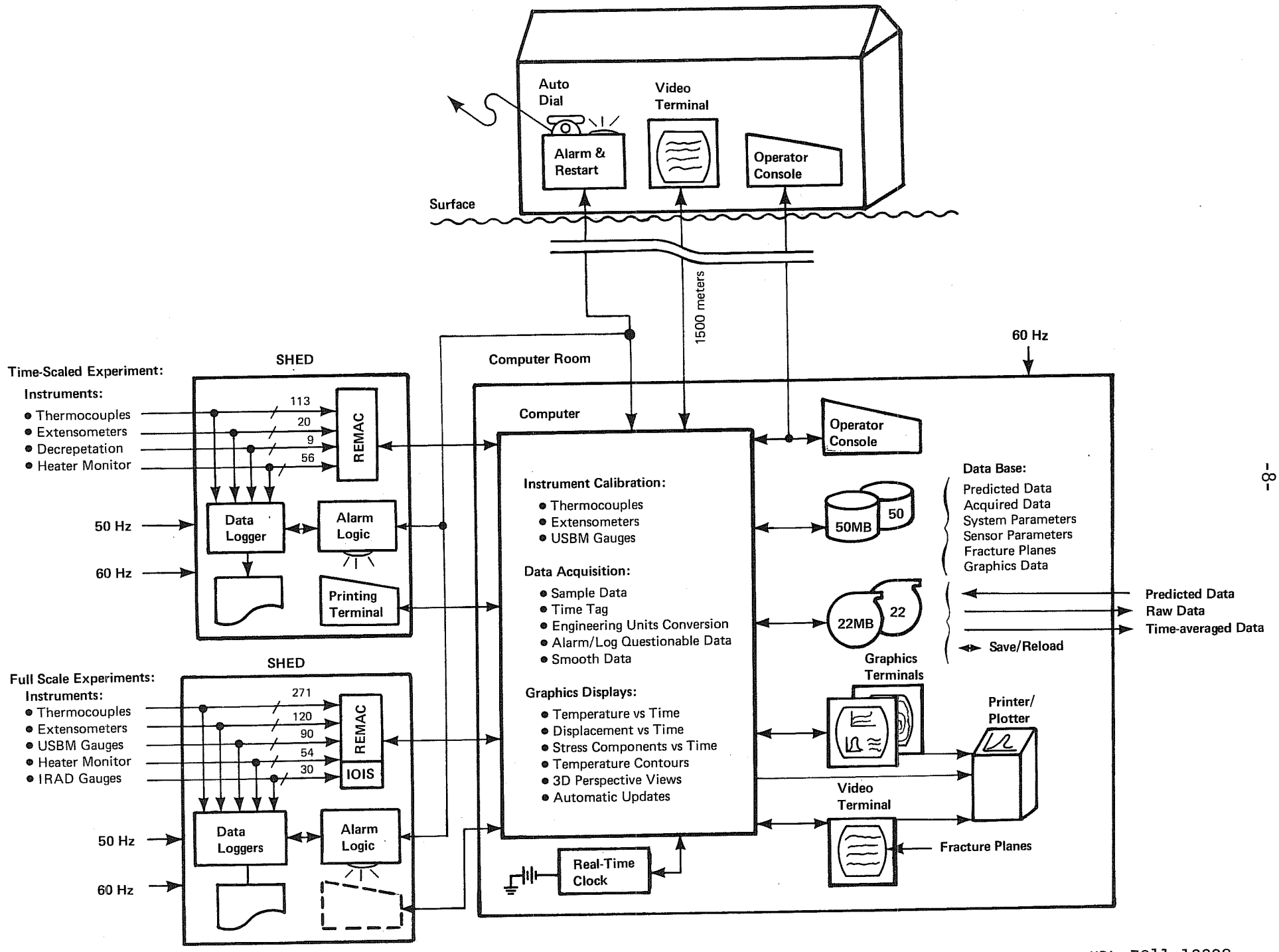
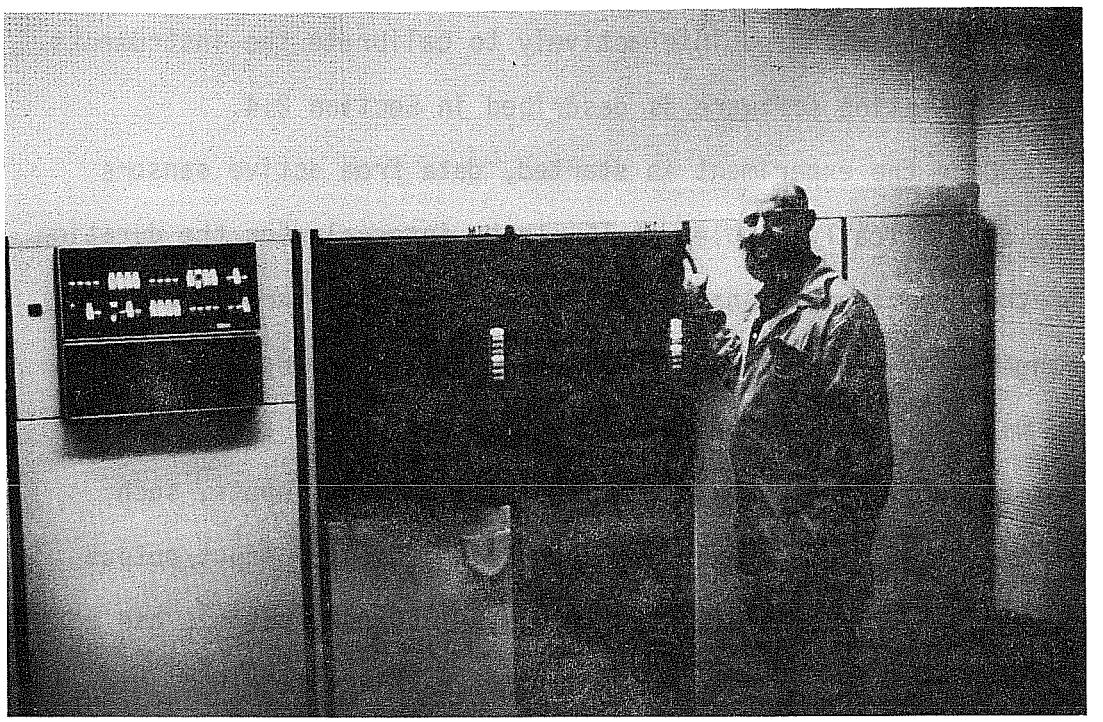


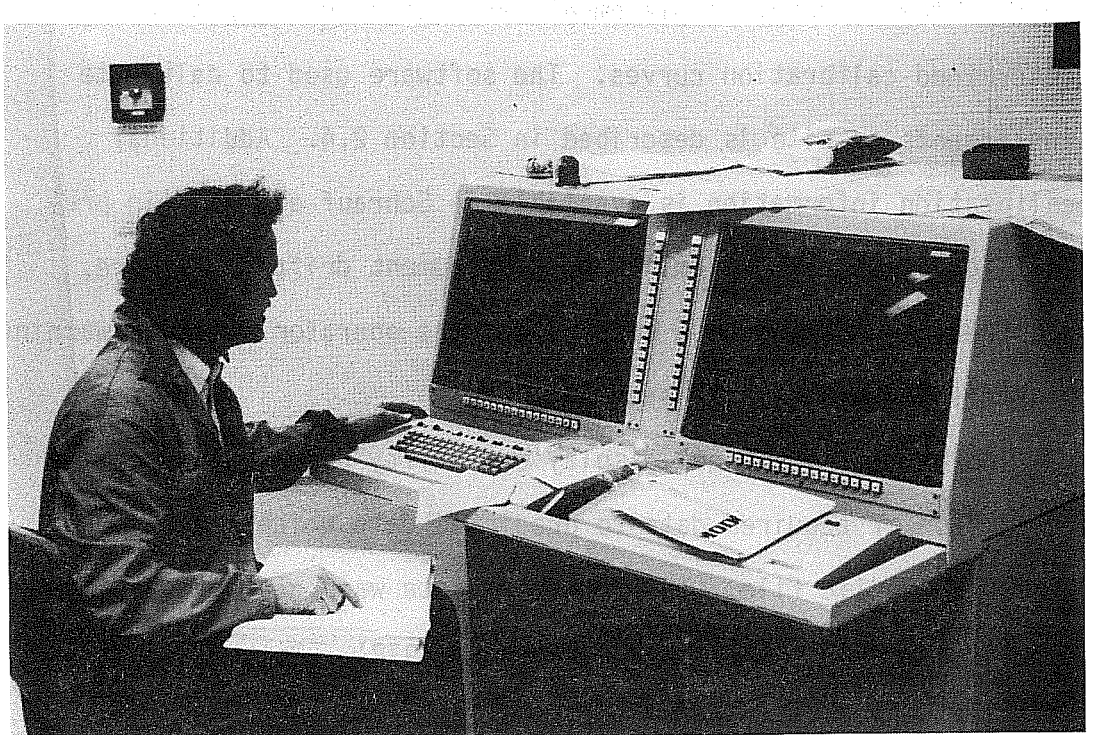
Fig. 2. Block diagram of the data acquisition system.

XBL 7811-13308



(CBB 783-3166)

Fig. 3. Computer system.



(CBB 783-3164)

Fig. 4. Graphic display console.

Before the time-scaled and full-scale experiments were begun, the computer was used interactively to calibrate the instruments. The calibration software is described in Section 2.4.

Once the experiment is started, data from active sensors are automatically sampled at 15-minute intervals for the duration of the experiment. Analog data are multiplexed through wide-range relay hardware with analog-to-digital conversion occurring in Wide-Range-Relay Analog-Input subsystems which are housed in Remote Data Acquisition (REMAC) units. Digital inputs, such as the IRAD gauge, are accessed through a digital input/output system. The data acquisition is under software control, and active sensors are distinguished from an active-sensor file that can be updated by the user.

Acquired data are logged on a raw-data tape and buffered on a disc file. Raw data are converted to engineering units such as temperature, displacement, and stress using previously determined calibration curves. The software used to calibrate instruments on-site is described in Section 2.4. Additional calibration information is available in Schrauf et al. (in preparation). Data are examined for instrument drift or failure, smoothed, and stored on a disc file. The operator receives warning messages in the event of such failure.

An on-site graphical display capability facilitates the comparison of acquired data to predicted data which are also stored on a disc file. The predicted data were generated using numerical models (Chan, Cook, and Tsang 1978). Both raw and time-averaged data stored on disc are recorded on magnetic tapes which are then airmailed biweekly to LBL for analysis. Section 3 describes data handling in more detail.

LBL's Real-Time Systems Group (RTSG) purchased the hardware and provided system software, system integration, and maintenance expertise. Teknekron provided software for instrument calibration, data acquisition, and graphical displays.

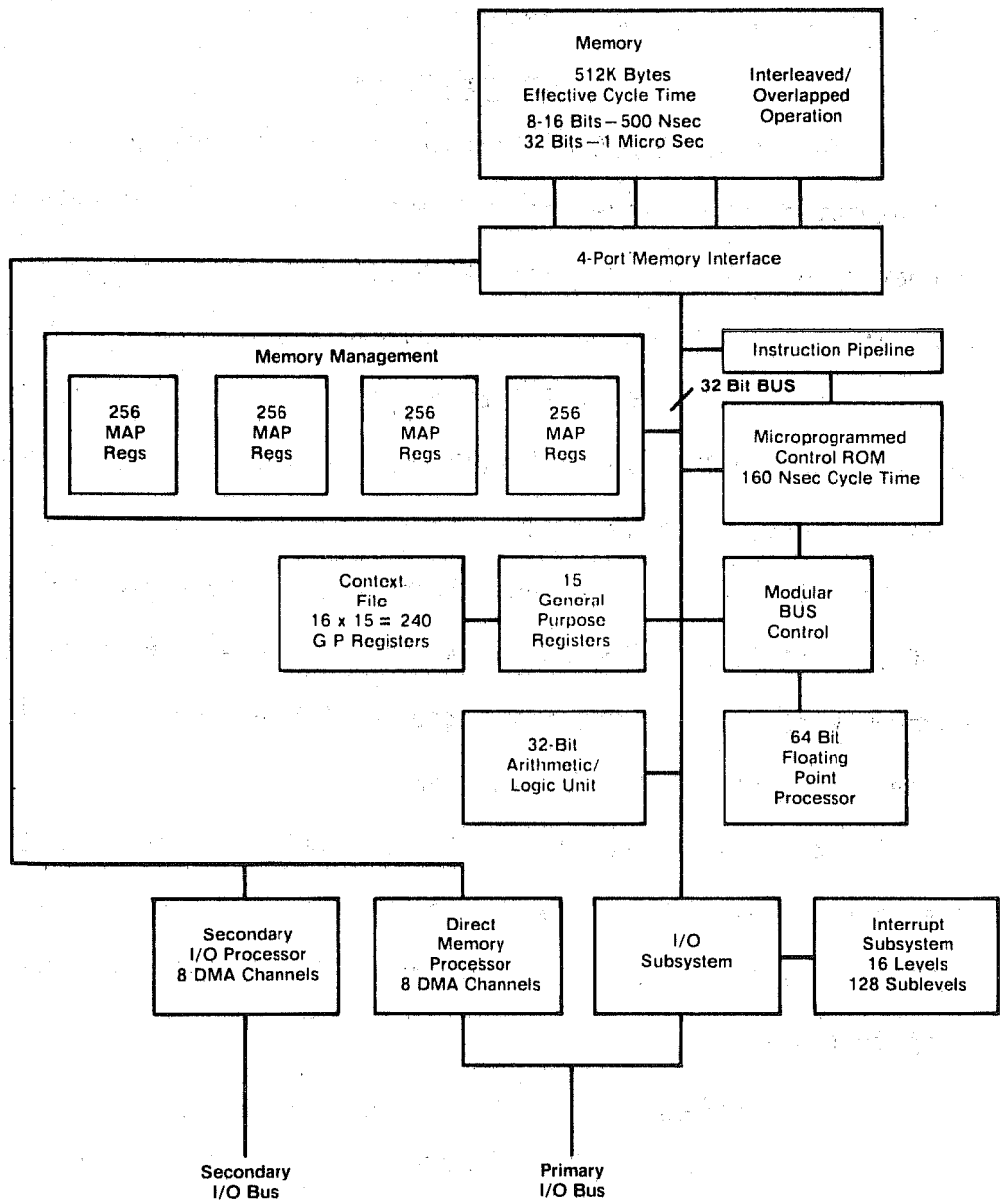
Central Processor

The Modcomp IV-25 central processor (CPU) shown in Fig. 5 executes 32-bit fixed-point operations, 64-bit floating-point operations, and has multiple high-speed 32/64-bit registers. A total of 512 K bytes of core memory were provided with automatic task address relocation. Sixteen priority interrupt levels are used with two Input/Output (I/O) interrupts connected to sublevels used by device controllers and external user signals.

Activation of interrupts or sublevels causes automatic transfer of control to associated software routines, and the Program Status Doubleword (PSD) is stored. Program switching consists of storing the old PSD and obtaining the new PSD.

Interrupt control instructions permit each level to be selectively enabled, disabled, requested, activated, or cleared. Assignments of the sixteen priority levels are listed in decreasing order of priority:

Priority	Interrupt Description
0	Power Fail Safe/Auto Start
1	Memory Parity
2	System Protect
3	Multiprocessor Communications
4	Unimplemented Instruction Trap
5	Floating-Point Overflow
6	Real-Time Clock - 200 Hz
7-B	External



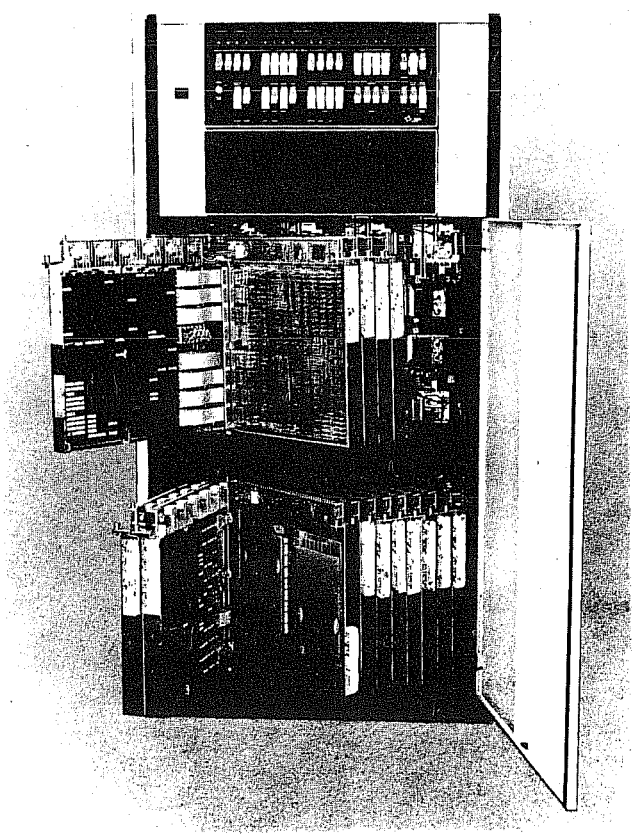
XBL 787-9841

Fig. 5. Computer block diagram.

C	I/O Data Party Line
D	I/O Service Party Line
E	Console Interrupt
F	Task Scheduler

The computer is packaged on vertically hinged planes, shown in Fig. 6. This simplifies service because all integrated circuits are socketed and the sockets are accessible for testing on both sides of each plane. No extenders or other special test tools are required.

The cabinet contains the CPU planes in the upper half and the memory interface planes plus 256 K bytes of core memory in the lower half. Each core plane contains 16 K 16-bit words.



XBB 788-9323

Fig. 6. Front view of computer.

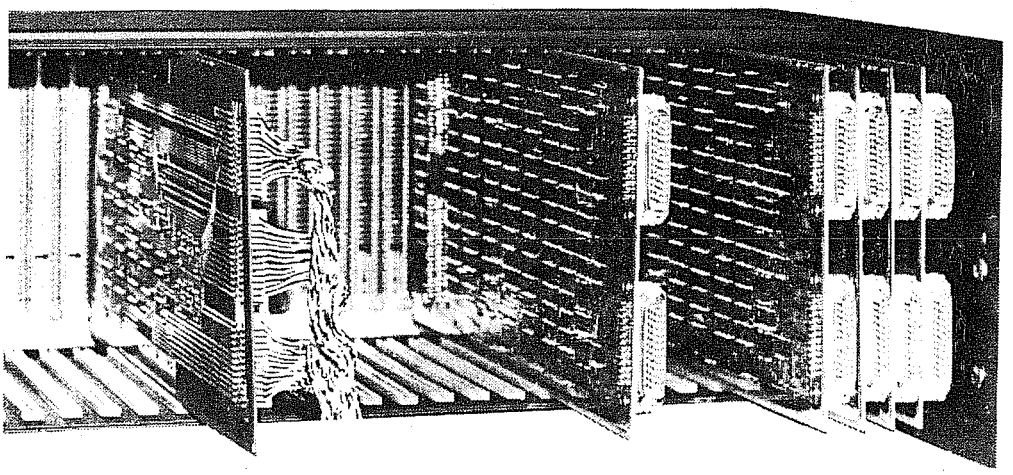
An adjacent memory expansion cabinet, which is the same size as the basic cabinet, contains an additional 256 K bytes of memory. An air cooling system consisting of dual blowers, ducting, and a plenum is located below each group of planes. Filtered air intake and exhaust ports are located in the upper rear part of the cabinet. The external panels can be removed from the cabinet to permit easy access to all areas inside the computer.

Peripheral Devices

A common alarm channel produces a computer interrupt signal when any one of sixteen inputs changes state. The computer then inputs the 16 status bits to determine which bit was responsible for the signal. A counter accumulates input pulses which are read into the computer under program control.

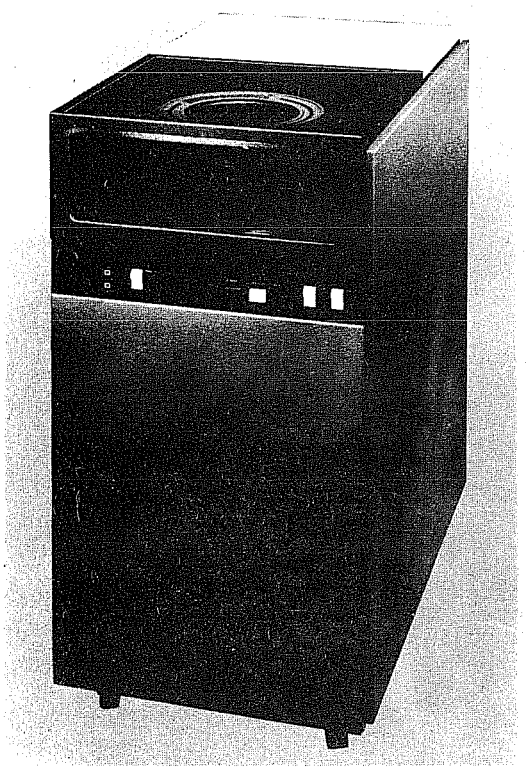
I/O couplers provide the necessary interface capability required to allow external devices to use the two standard I/O party line interrupts. One coupler allows up to eight external interrupts to use the standard service interrupt party line.

Asynchronous communications. An asynchronous communications multiplexer, shown in Fig.7, provides six full duplex channels for interfacing asynchronous communication lines to the computer. As many as 128 channels can be accommodated in multiples of 2. Two Digital Equipment Corporation DECwriters and one Texas Instruments TI-743 printing terminal operate at 30 characters per second. Two Ann Arbor 4080 video terminals and two Tektronix 4014 graphics terminals operate at 960 characters per second. Both RS-232C and 20-mA current-loop interfaces are available. Character transfers are double buffered, interrupt driven, with automatic parity checking and generation available.



XBB 780-14710

Fig. 7. Asynchronous communications multiplexer.



XBB 788-9320

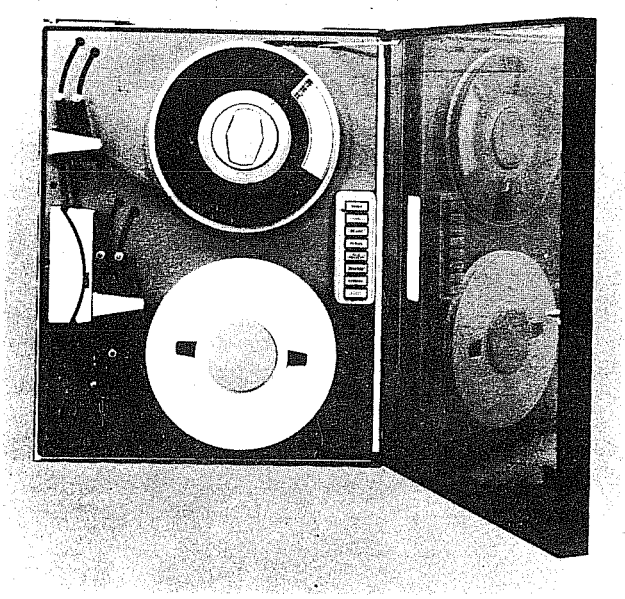
Fig. 8. Moving head disc drive.

Disc drives. Two extended capacity (2314 type) moving head disc drives, shown in Fig. 8, share a common disc controller. Each drive holds 50 million 8-bit bytes and has direct access to the computer's core memory via a direct memory access channel. The disc packs are removable; and have 35 msec average seek time, 12.5 msec average latency, and a 312 K byte/sec transfer rate.

Tape drives. Two single capstan nine-track magnetic tape drives, shown in Fig. 9, share a common controller. The controller provides Cyclic Redundancy Character (CRC) error detection provisions. Tapes as long as 2400 feet are recorded and played back at 45 ips and 800 bpi. These tapes are the primary means of receiving and sending data between Stripa and LBL.

Remote Instrument Interface

Modcomp's REMAC subsystem provided the interface between the large numbers of analog and digital inputs from the borehole instrumentation to the Modcomp computer. REMACs, in effect, reconstruct the computer's I/O bus at remote instrument locations which are more than 50 m from the computer. One REMAC terminal was located in the full-scale instrumentation shed and another REMAC was located in the time-scaled instrumentation shed.

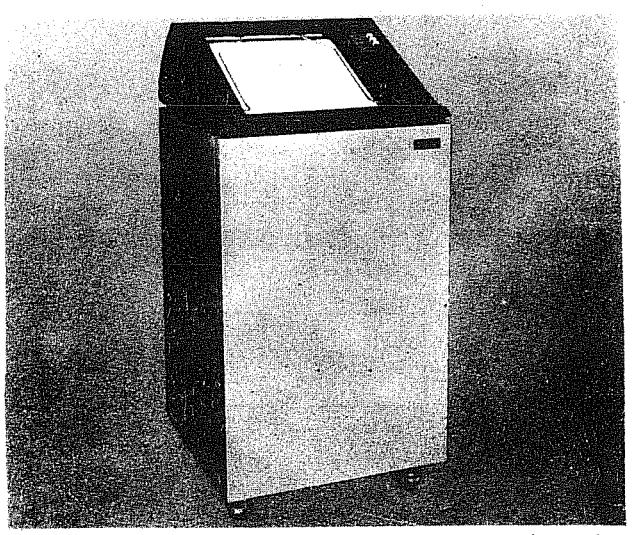


XBB 788-9321

Fig. 9. Magnetic tape drive.

Printer/plotter. A Versatec electrostatic printer/plotter, shown in Fig. 10, provides a high-speed output capability. The device prints 132 (7 x 9 dot) characters per line at a speed of 500 lines per minute on 11-inch-wide heat-sensitive paper. The 64 ASCII standard characters are spaced 12.5 characters per inch horizontally and 6.6 lines per inch vertically. A Versatec controller copies the information displayed on the Ann Arbor video terminal screen and the Tektronix 4014 graphic terminal screen onto the Versatec printer/plotter at the push of a button.

Wide-Range-Relay Analog-Input subsystems, shown in Fig. 11, were used in conjunction with the REMACs to sample, multiplex, and digitize the analog instrumentation signals. An automatic gain ranging from 1 to 2048, in twelve binary increments, provides a full-scale measurement capability from ±5 mV to ±10.24 V. A voltage comparator on the output of the amplifier determines

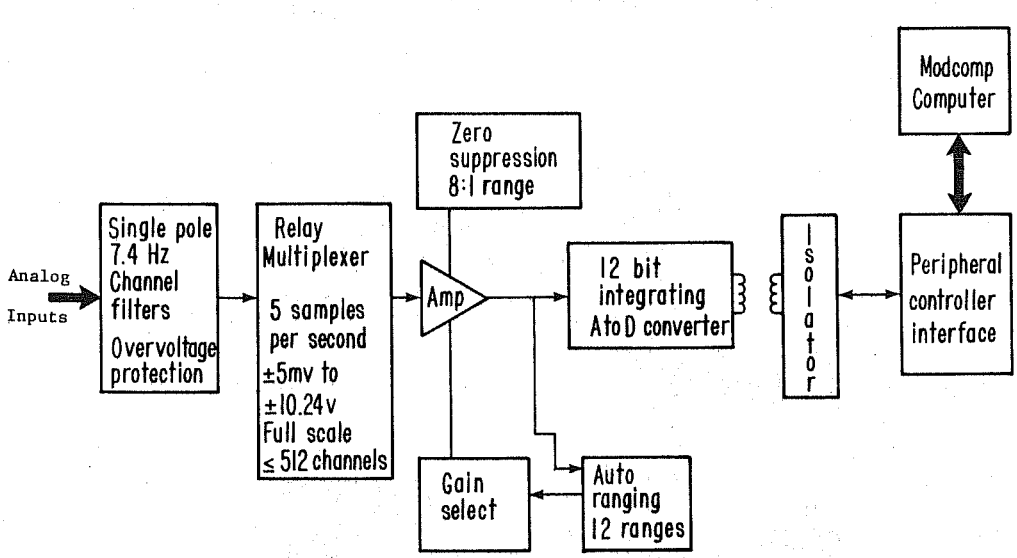


XBB 788-9322

Fig. 10. Electrostatic printer/plotter.

if the output signal level is less than ±3/8 full scale. If less than this level, a gain counter is stepped to the next highest gain. This process is repeated until the output is greater than ±3/8 full scale, or until maximum gain is reached. Mercury-wetted contact relays provided excellent switching characteristics; however, they occasionally had to be replaced due to erratic behavior. Low-pass single-pole resistance-capacitance (RC) filters were used on each analog channel to attenuate signals above a 7.4 Hz cut-off frequency. Guarded (three wire) differential inputs are clamped at ±12 V to provide sustained overvoltage protection up to ±30 V. Common mode voltages as high as + 200 V peak are suppressed.

The integrating analog-to-digital converter provides additional common mode rejection by integrating over one or more full cycles



XBL 788-2619

Fig. 11. Block diagram of the Wide-Range-Relay Analog-Input subsystem.

of the 60-Hz power-supply frequency. This integration process also causes a considerable reduction in amplifier noise resulting in noise levels "referred to input" of less than 5 μV peak on the ±5 mV range.

The amplified signal is converted into an 11-bit plus sign binary value by means of a dual-slope integration technique which makes the digitized value independent of integrating capacitor variations. The 12 bits of data, together with the 4 bits of gain information, are transmitted back to the CPU. All data and control signals are transformer coupled to provide common mode isolation. A five-sample-per-second scan rate was used. Wide-range amplifier overranging is detected and transmitted back to the computer indicating that the digitized number is invalid.

Signal connection to the multiplexer is made through printed circuit cards and edge connectors. The multiplexer uses three levels of signal switching. A gate card performs analog switching using mercury-wetted relay switches. Three levels of analog signal switching are used to minimize channel-to-channel cross talk and also to minimize differential distributed capacitance tied to the analog bus. The first level selects one channel out of eight on the multiplexer module. A second level switch selects the addressed multiplexer module (one of eight). A third level switching selects one of eight groups, each group consisting of 64 channels.

An IRAD data logger supplies six binary coded decimal (BCD) digits per measurement to a digital input/output subsystem that is mounted in the REMAC used for the full-scale experiment.

Full duplex (8.7 K 16-bit words per second) data transfer between the CPU and the REMAC terminals takes place over two coaxial-cable serial-links under direct memory access control. A 7-bit character redundancy check is used to detect data transmission error. The system software automatically requests retransmission whenever transmission errors are detected.

System Integration

LBL's RTSG was responsible for purchasing the computer system, staging the system at LBL, and maintaining the hardware and system software during software development. Modcomp's MAX-IV multitasking interactive real-time operating system was used. A task queue is ordered according to task priority with round robin scheduling of tasks with equal priority. Task switch-over occurs whenever significant events such as interrupts from peripheral devices occur. Modcomp supplied process input/output software, which permitted all of the applications software to be written in American National Standard Institute (ANSI) standard Fortran IV with Modcomp-supplied real-time extensions.

RTSG also packaged, shipped, installed, and maintained the computer system and provided operations personnel during instrument calibration, installation, and routine operations once the heaters were running and the system was functioning correctly.

2.2 Supplementary System

Results from the heater experiments would be seriously compromised if data were lost for extended periods of time; especially if losses occurred immediately after a heater was turned on or turned off. Once a heater has been turned on, it cannot be turned off temporarily without greatly confusing the interpretation of the

results. Data loggers were added to the DAS to insure that data could be acquired even if the computer were not functioning for an extended period.

The data loggers have several deficiencies when compared with the computer system. Data are printed on paper tape, and are thus readable by humans but not by machines. The cost of paper tape punches or digital magnetic tape recorders did not justify adding them. Data loggers used only one, National Bureau of Standards (NBS), calibration curve for all thermocouples. The individually calibrated non-linear thermocouple curves used in the computer are much more accurate, and differ by as much as 2.5°C from the "average"NBS curve. The data loggers were also unable to use individual non-linear calibration curves for the other gauges, IRAD gauge calibration curves parametric in temperature, or provide temperature compensation for the thermal expansion of the extensometer rods. The data loggers also had no means of storing, retrieving, or displaying either acquired or predicted data.

Acurex Autodata 9, "B and F," and IRAD data loggers acquire data parallel with the computer, thereby providing a backup. The data loggers proved valuable to test and debug instrument prototypes, and they were also used to monitor the heater tests that were run in Berkeley before the equipment was shipped to Sweden.

2.3 On-Line Data

Two 50-M-byte disc drives provide a substantial amount of on-line storage capacity which is accessed using Fortran random input/output, with a worst-case access time of 95 msec. This

section describes the major data files that are maintained on these discs. Detailed descriptions of file designs and use are available in a user's guide (Teknekron 1978) and a program description manual (Teknekron 1979).

Predicted Temperature, Stress, and Displacement Values

The Stripa heater experiments provide field data that are being compared with predictions of theoretical models (Chan, Cook, and Tsang 1978). These field measurements should establish the extent to which current modeling predicts the measured behavior of the rock. In time, the measurements should suggest improvements that will make the theoretical models fit observed events more accurately. Validated models are necessary to provide design data such as the maximum tolerable temperature, thermal gradient, and canister power for specific rock types and conditions.

Predicted temperature, displacement, and stress fields were calculated and stored on disc files accessible by the on-site computer. A graphic display system is used to plot these data for real-time comparison with time-averaged field data, thus facilitating on-the-spot detection and correction of problems.

Initial predictions of temperature, displacement, and stress values were obtained using an analytical three-dimensional heat-conduction model that assumed a homogeneous medium, and a finite-length heat source. Image techniques were used to model isothermal or adiabatic boundary conditions on the floor of the heater drifts. The properties of Stripa granite used in these models were determined from laboratory tests reported by Pratt et al. (1977).

The analytical models described above predict results assuming the Stripa granite is homogeneous. If local inhomogeneities become

important, then detailed numerical models can be used to more accurately represent the actual environment, thus increasing the accuracy of the predictions. These models can use more accurate rock properties such as rock moduli determined from Colorado School of Mines (CSM) cell measurements, and virgin stress states obtained using hydraulic fracturing methods. Chan, Cook, and Tsang (1978) described these mathematical models, the equations used, and the predicted results.

Predicted temperature, displacement, and stress data are written on nine-track magnetic tapes with compressed ASCII characters before they are shipped to Sweden.

Fracture System Representations

Real rock masses are jointed and these joints usually contain water. This fracture network is responsible for virtually all fluid flow in a granite rock mass. The more extensive fractures are expected to alter the thermomechanical behavior of the rock from that predicted in a homogeneous numerical model.

Development of the three-dimensional fracture network for each experiment involved synthesis of geophysical and geohydrological data and the fracture data contained in the borehole TV surveying and drill cores (Thorpe, in preparation). Estimates of the local fracture network provide a three-dimensional picture of significant fractures in the vicinity of the heaters.

Fracture-plane data are input and maintained on discs as labeled planes with associated triangular sub-plane sections. Users may interactively add, modify, or delete data in the fracture-plane file. Three-dimensional perspective views of these fracture planes can aid in the interpretation of the stress, deformation, and temperature data collected during the experiments.

Sensor Parameters

Parameters such as sensor type, sensor number, associated experiment, sensor location, calibration constants, data channel numbers, time of last change, and time of last access are maintained on disc for each signal source.

Users can access either the sensor-parameter file or the fracture-plane file to display the contents of any record, search for records with specified contents, produce permanent printed records of portions of the files, or alter the contents of user-accessible fields.

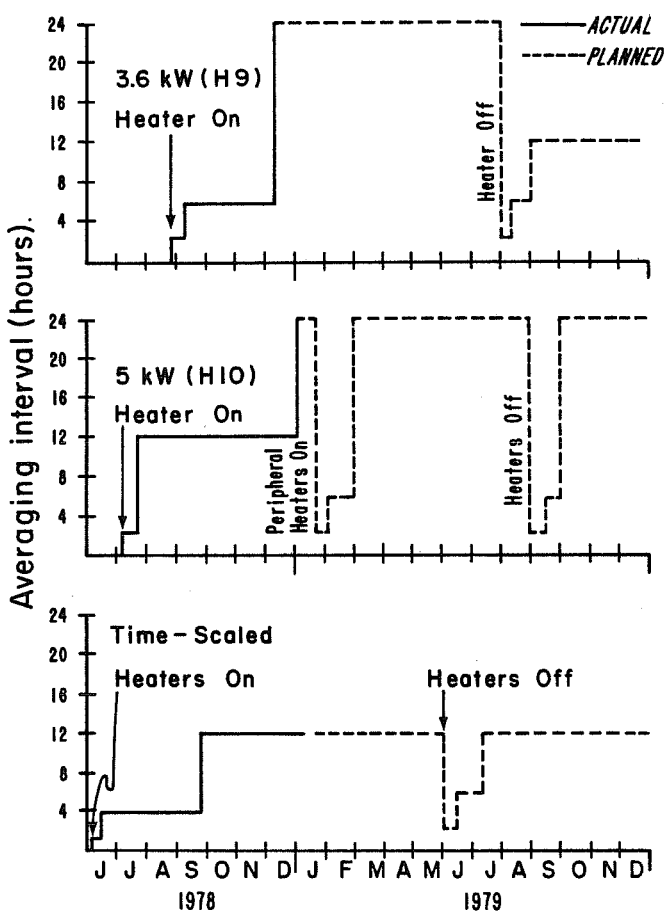
Acquired Data

All active sensors are sampled at 15-minute intervals. These "raw" data points are time tagged, converted to engineering units using calibration curves obtained on-site (see Section 2.4), temporarily stored in a 24-hour disc buffer, and logged on magnetic tape.

Once these raw data points have accumulated for one time-averaging interval (see Fig. 12), their arithmetic mean is computed to obtain a representative mean data value and associated mean time. These less frequent time-averaged points are stored in a long-term disc file which is maintained on-line for the duration of the experiment. The number of raw points per averaging interval varies with time, as shown in Fig. 12. These intervals are chosen to retain more long-term points whenever interesting changes are expected. The total number of stored long-term points is limited by a disc space allocation of 1200 tracks. The long-term file permits rapid access for graphic displays and analysis.

2.4 On-Site Applications Software

The basic functions of the software and associated interfaces are shown in Fig. 2. Provisions were made for changing many parameters in the data acquisition software up to and after the experiments were begun. Table storage space was allocated for sensor descriptions and calibration results. Parameters such as starting times and sampling intervals, which are unique to individual experiments, are recorded and maintained in a system parameter file.



XBL 791-7343

Fig. 12. Averaging interval versus time for each heater experiment.

Software was designed to acquire and display the experimental data. On-site experimenters can compare actual results with predictions using graphical displays that are easily specified and redefined on-site. A user's guide (Teknekron 1978) describes how to operate the system. A program description manual (Teknekron 1979) provides the details needed to maintain or modify the software.

Critical computer peripherals were duplicated to permit continued system operation in the event of a hardware failure. The software was designed to function correctly when any one of these peripherals has failed or has been taken off line. The system operates automatically and unattended during evenings, weekends, and holidays. Normal operating conditions are handled automatically with provisions for manual override and control to handle unexpected conditions.

Instrument Calibration

This section describes instrument calibration techniques, procedures, software, and graphic displays as they affect the data acquisition system. Additional instrument calibration details are discribed by Schrauf et al. (in preparation). Software was provided to permit users to interactively control on-site calibration of each instrument using a terminal located near the instrument, as shown in Fig. 13. Desired instrument conditions were determined and entered into the computer via a portable terminal located in the instrument drift. Stable instrument conditions were established for each calibration point. The computer was then commanded to use its REMAC unit to sample data from the sensors being calibrated. The results were displayed in both tabular and graphic form, as shown in Fig. 14.

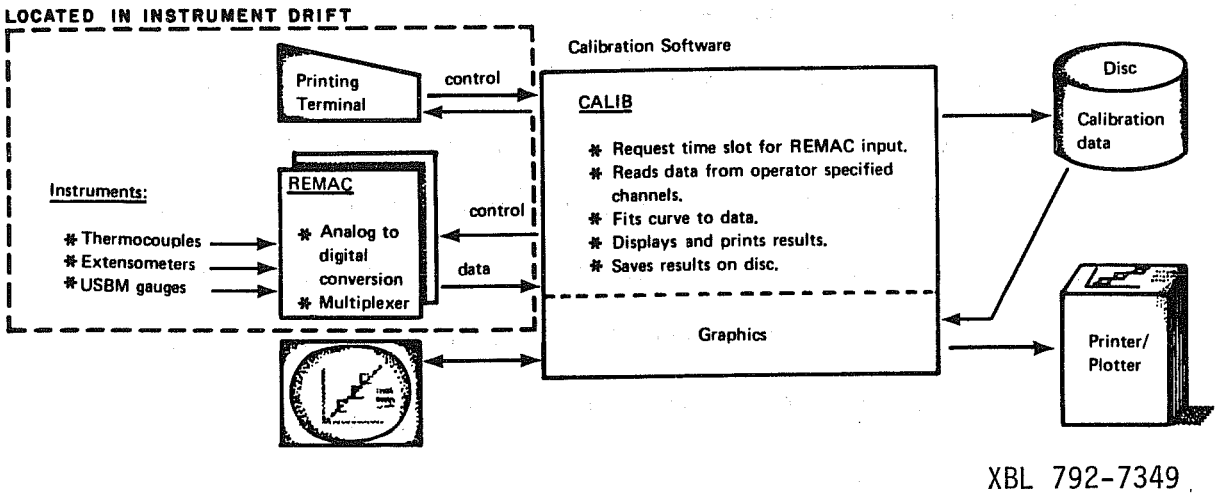


Fig. 13. Instrument calibration diagram.

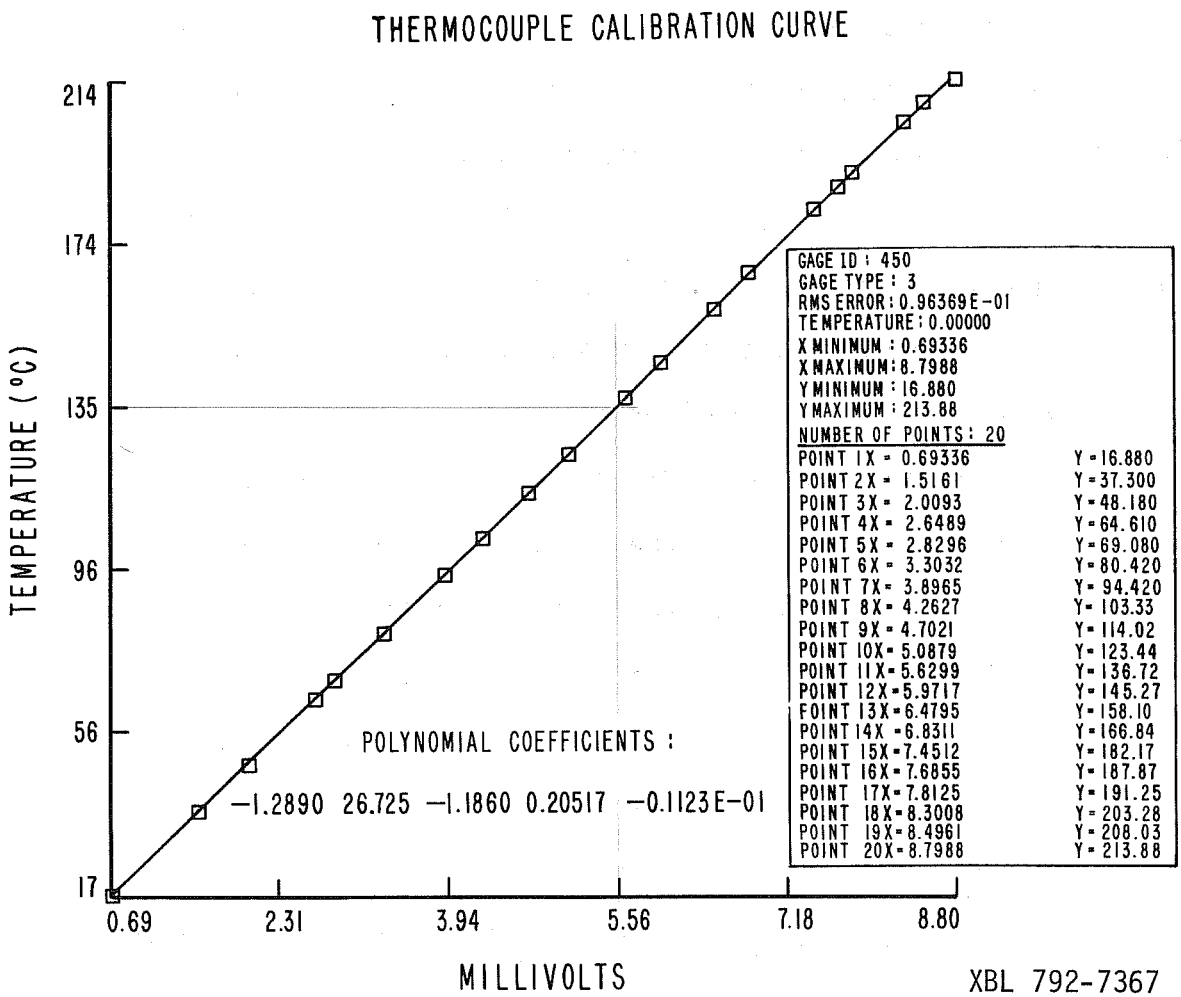


Fig. 14. Sample thermocouple calibration curve.

The calibration software makes it easy to test each data channel. It also automates the fitting of analytical curves to the calibration data, using weighted least-squares curve fits. The root-mean-square error is minimized during the least-square fits; thus it provides a measure of the accuracy of each curve fit. Data handling is flexible, requires minimal input, is user-oriented, and the displays are given in engineering terms and units.

Thermocouple calibration. The thermocouples were calibrated using comparison techniques (ASTM 1972 and ASME 1974). Temperature-versus-voltage calibration curves were individually established for each low-temperature thermocouple. The thermocouples were calibrated with ice-point references maintained at $0^{o}C$ and the temperature of the thermocouples was varied from $10^{o}C$ to $250^{o}C$ in increments of approximately 10°. The computer read the thermocouple's output voltage; the calibrated temperature of the thermocouple, as measured by a resistance temperature device (RTD), was entered manually. This RTD was calibrated by the Swedish Bureau of Standards, and its calibration curve was accurate to $\pm$ $0.1^{o}C$. When data were obtained over the specified range of temperatures, a fourth-order polynomial was fit to the data, as shown in Fig. 14. National Bureau of Standards calibration data (ANSI 1976) were used for thermocouples that were expected to monitor temperatures above $250^{o}C$ because of limitations in maximum available oven temperatures.

Extensometer calibration. Displacement-versus-voltage calibration curves were established individually for each extensometer rod. Calibration consisted of displacing the extensometer heads using

a series of 5-mm calibration blocks. Enough blocks were used to include the maximum predicted displacement. The computer read the voltage and someone manually entered the actual displacement obtained using the blocks. The calibration curves were obtained as a linear least-squares curve fit of those data points.

USBM gauge calibration. Displacement-versus-voltage calibration curves were established individually for each pair of United States Bureau of Mines (USBM) gauge buttons. Calibration consisted of setting a known displacement and causing the computer to read the corresponding voltage. The set displacement was entered manually. The calibration curve was obtained as a linear least-squares curve fit of those data points. The equivalent calibration value of a shunt resistor was determined from the fitted curve.

The gauges were pre-loaded after installation. The resulting offset was measured and compensated for during the experiment.

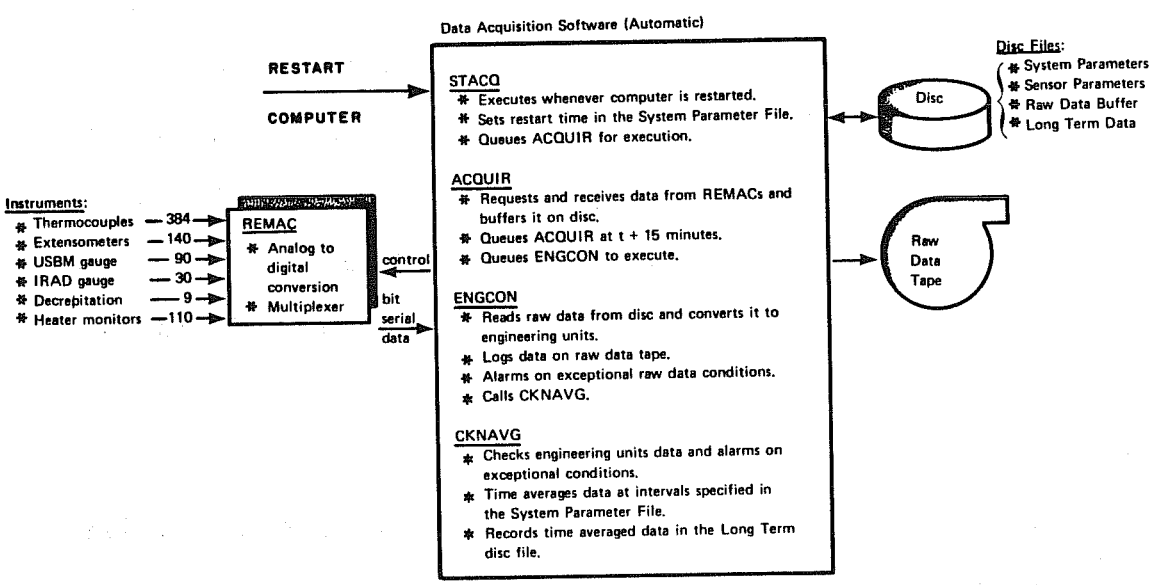
IRAD gauge calibration. IRAD gauges were calibrated by placing the instrument in a borehole in a test rock at a laboratory at Terra Tek, and subjecting the rock to a known biaxial stress, with temperature as a parameter. Spline curve fits using this calibration data were used to provide a set of calibration curves, parametric in temperature.

Data Acquisition Software

Data are acquired, at 15-minute intervals, from each active sensor (see Fig. 15). New data samples are requested via calls to standard Modcomp-supplied system software routines. Analog data from the thermocouples, USBM gauges, extensometers, decrepitation sensors, and heater monitors are digitized in a Wide-

Range-Relay Analog-Input subsystem which is located in the Remote Acquisition (REMAC) units. An RTSG-supplied software handler reads the digital data output from the IRAD data logger. All data are time division multiplexed and transmitted, bit serial, over coaxial cables from the REMACs in both the full-scale and the time-scaled instrument sheds to the Modcomp central processor (CPU), which is located in the computer room.

Full-scale heater data are recorded for 271 thermocouples, 120 extensometer channels, 90 USBM channels, 30 IRAD channels, and 54 heater monitor channels. Time-scaled heater data are recorded for 113 thermocouples, 20 extensometer channels, 9 decrepitation channels, and 56 heater monitor channels. Schrauf et al. (in preparation) provides a detailed discussion of these instruments.



XBL 792-7346

Fig. 15. Data acquisition diagram.

Acquired data are time-tagged from a system clock and converted to engineering units, using previously obtained calibration data and associated curve fits. These raw data are recorded on magnetic tape and stored in a 24-hour disc buffer to prevent data loss whenever the tape unit is off line.

The arithmetic means of data, in engineering units, are computed over user-specified time intervals and stored in a long-term disc file. This permits up to 1280 data points to be maintained on disc for each of 1200 allocated channels. These time-averaged data are retained on disc for the duration of the experiment and are used as the source of all graphic data displays.

Measured data, converted to engineering units, are maintained on disc and are available to be displayed in graphical form. USBM borehole deformation measurements, however, are difficult to interpret, so they are transformed to corresponding principle stress values and the angle between the principle stress axes and the local radial, tangential, and vertical coordinate systems is computed when graphical displays are requested.

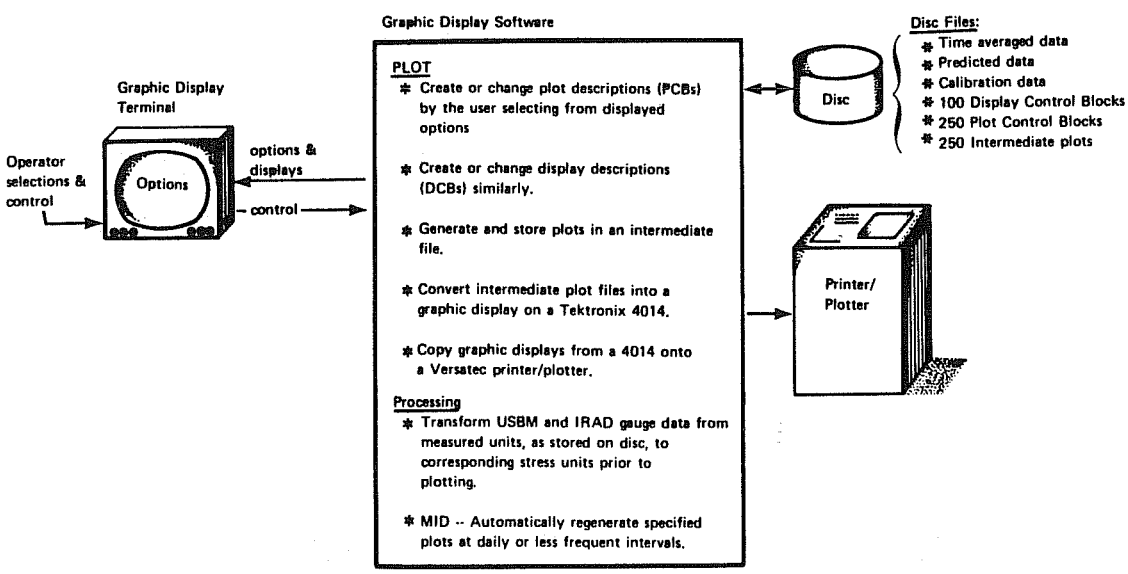
Exceptional conditions are monitored and software alarm flags are set or reset for zero data, maximum value (all binary ones) data, and data that are outside alarm ranges or that exceed maximum rates of change specifiable by users.

Data maintained on disc can be lost due to head crashes or other malfunctions. Potential data loss is reduced by recording all critical files on magnetic tape once per day. Operators use these files to recover after failure. Data-missing flags are provided for data missed during system outages.

Graphic Displays

A data display capability was needed to facilitate monitoring of the heater experiment's 763 data channels. The graphics software was designed to prompt users by presenting them with lists of options. Users control subsequent processing by selecting desired options and entering requested parameters. This system was developed because most of the experimenters were not programmers and therefore not familiar with computer operations. Our goal was to be able to easily specify complex plots, store and update them automatically as new data are acquired, and then recall and display them (see Fig. 16).

Two Tektronix 4014 graphic display terminals gave good display resolution, with their grid of 4096-by-4096 addressable locations. A cursor controller allowed manipulation of selected portions of a display. An array of of 32 lighted push-buttons was mounted adjacent to the display screens on both 4014s (see Fig. 4).



XBL 792-7348

Fig. 16. Graphic display generation diagram.

Buttons lit up to remind the user which button was pushed last. The buttons can be used to design a display. They can also facilitate storage and retrieval of displays from a library that resides on discs, allowing rapid review of the status of the experiment. Permanent copies of graphic displays are obtained from a Versatec printer/plotter, and important results thus obtained are regularly transmitted to LBL in graphic form via a telecopier.

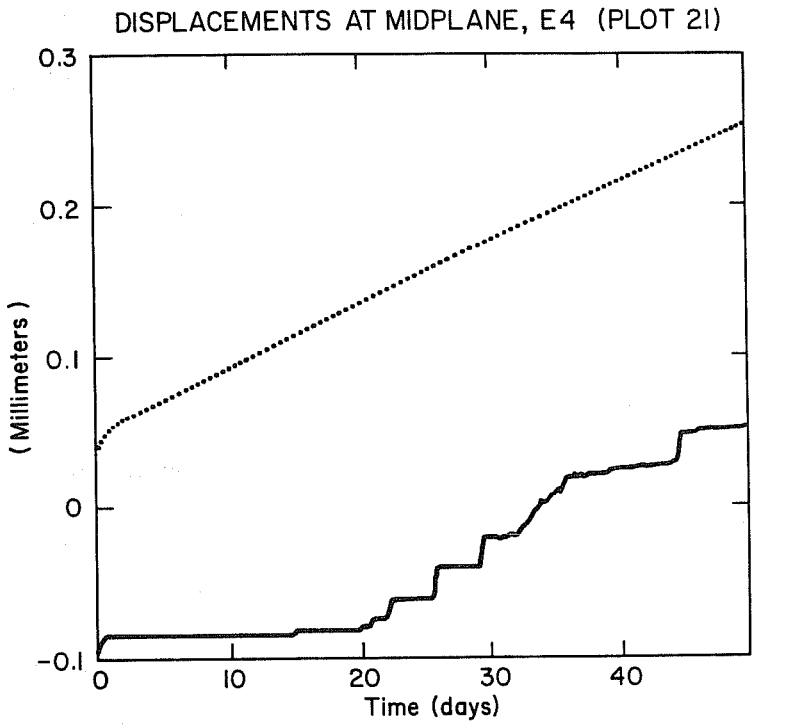
The University of California at Berkeley's Graphical Display System (GDS) software was converted to run on the Modcomp at Stripa. GDS provided the basis of the on-site Stripa graphics system. The implementation of the graphics software is independent of display devices; however, a device-specific output driver was provided for the Tektronix 4014 display terminals. The software prompts users by displaying a menu of available options. Users define desired plot types and the layout of portions of a display by selecting a series of options and specifying requested parameters.

Displays consist of multiple elementary plot types, which are overlayed on either the full screen or any quadrant. The following elementary plot types are available:

1. Plot of variable versus time. Predicted, measured, or computed quantities such as temperature, principle stress, or displacement can be plotted versus time. Up to eight curves can be displayed on the same plot. Figure 17 shows a displacement-versus-time plot. Figure 18 shows four temperature-versus-time plots on one display.

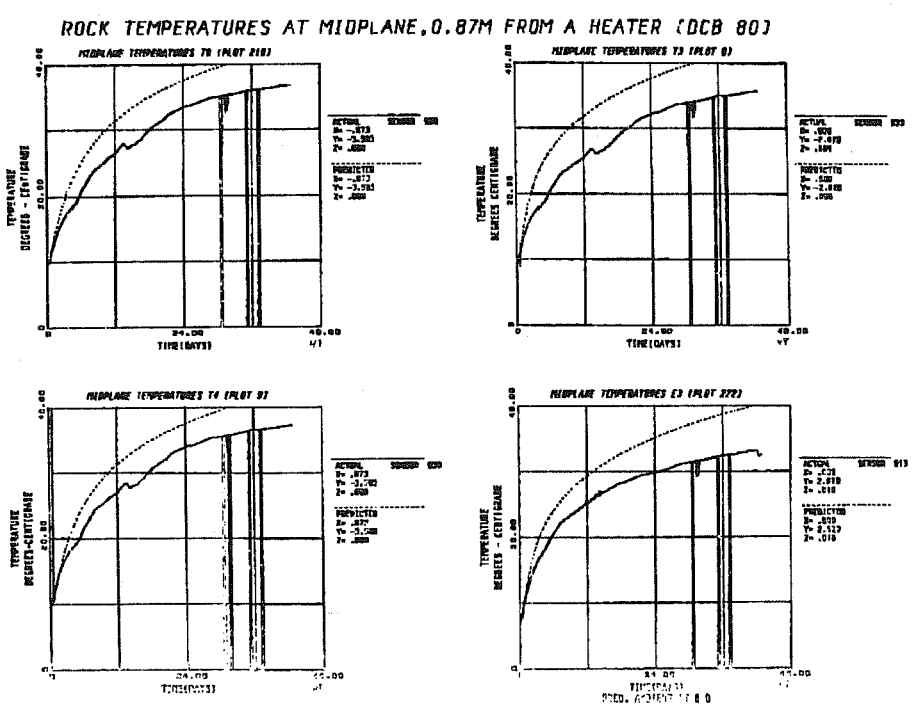
2. Plot of variable versus distance. Data can be plotted versus distance along a user-specified line in space.

3. Contour and scatter plots. Contour plots of predicted temperature data can be displayed for a user-specified plane



XBL 788-10015

Fig. 17. Displacement versus time plots.



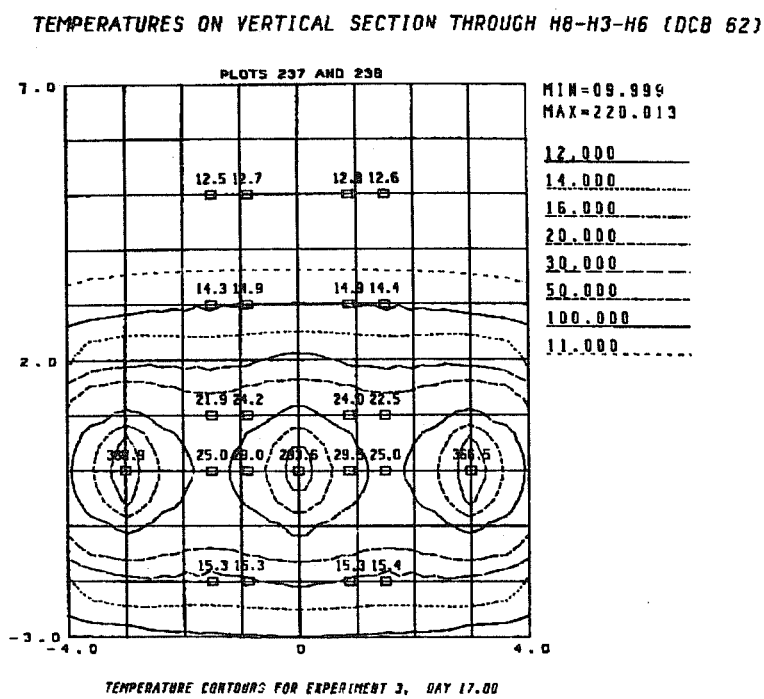
XBL 788-9865

Fig. 18. Sample four-curve display.

in space. Local highs and lows can be labeled. A maximum of twenty-five levels can be contoured using as many as eight line types. Figure 19 shows predicted temperature contours overlaid with a scatter plot of actual temperatures measured at thermocouple locations, all plotted on a vertical section.

4. Perspective views. Perspective views showing the relative position of three-dimensional objects can be displayed according to user-specified viewpoints. Transparent perspective plots can be modified from the terminal by locating unwanted lines with a cursor. Lines which would normally be hidden by opaque objects can thus be removed, yielding a more realistic view.

5. Space plane intersections. Planes, such as fracture planes, can be intersected with a user-specified base plane,



XBL 788-9867

Fig. 19. Sample temperature contours on a vertical section.

and then displayed. Users can combine these basic types of plots to generate the desired graphic displays. The final display is defined by the user interactively selecting appropriate options from a menu, using an on-site graphics terminal.

Displays are defined by Display Control Blocks (DCBs), Plot Control Blocks (PCBs), and can be associated with one of thirty one push buttons, as shown in Fig. 20. DCBs and PCBs are created, maintained, and updated, bsaed on user selections from displayed options. PCBs contain all the information necessary to construct a particular display. Plot parameters can be changed readily at any time.

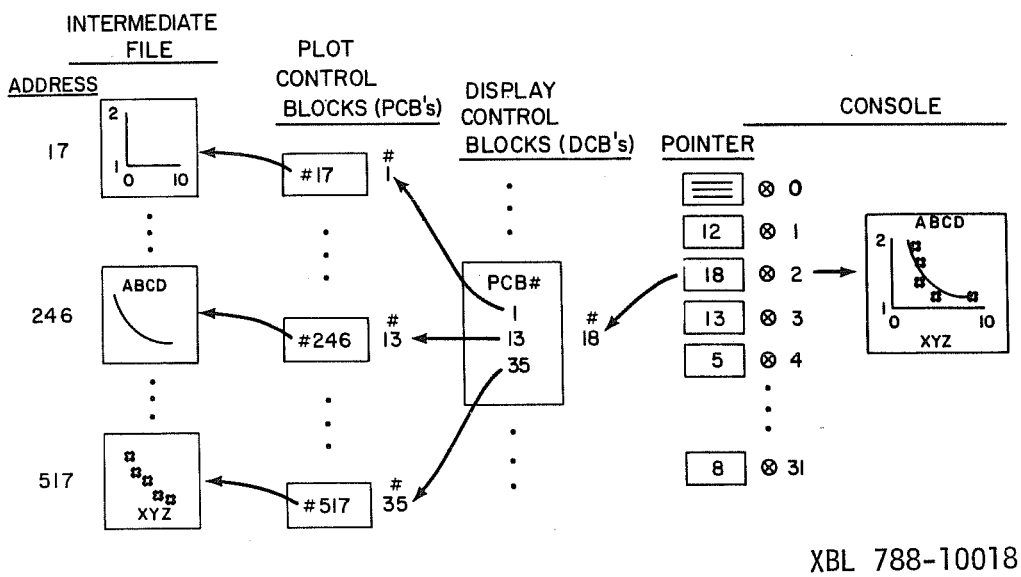


Fig. 20. Plot linkage diagram.

Plots are constructed from data stored in their PCBs, using a separate algorithm for each plot type. A device-independent intermediate plot file is produced. The file describes solid and dashed lines, symbols, various sized text, and specifies their placement on the display.

A device-dependent display driver interprets the intermediate plot file and generates the graphic output commands required to form the display on either of the Tektronix 4014 terminals.

Displays can be labeled with an identifying number and stored in a library. The display library contains both PCBs and associated intermediate plot files. Hardware buttons, which are mounted adjacent to the display screen, can be associated with stored plots and can then be used at any time to recall the associated display. Recalled plots can be viewed, modified, restored, or deleted using menu-controlled operations.

Displays that use current data can be scheduled for automatic updating daily or at less frequent intervals. These plots are reconstructed using the most recent data. Updated intermediate plot files are stored on disc.

USBM gauge displacement data and IRAD gauge period data are maintained on disc in their measured units. Prior to plotting, however, these data are transformed to corresponding stress units. IRAD gauges are installed in pairs. The first sensor of the pair measures a period related to tangential stress (σ_θ) and the second sensor of the pair measures either radial stress (σ_r) if the hole is vertical, or vertical stress (σ_z) if the hole is horizontal. Each USBM gauge measures three displacements. Stress quantities (σ_r, σ_θ, or σ_z), derived from USBM gauge displacements, use the same convention used for the IRAD gauges. A third derived quantity gives the angular misalignment (θ_p) from the principle stress directions, which is expected to be a small angle.

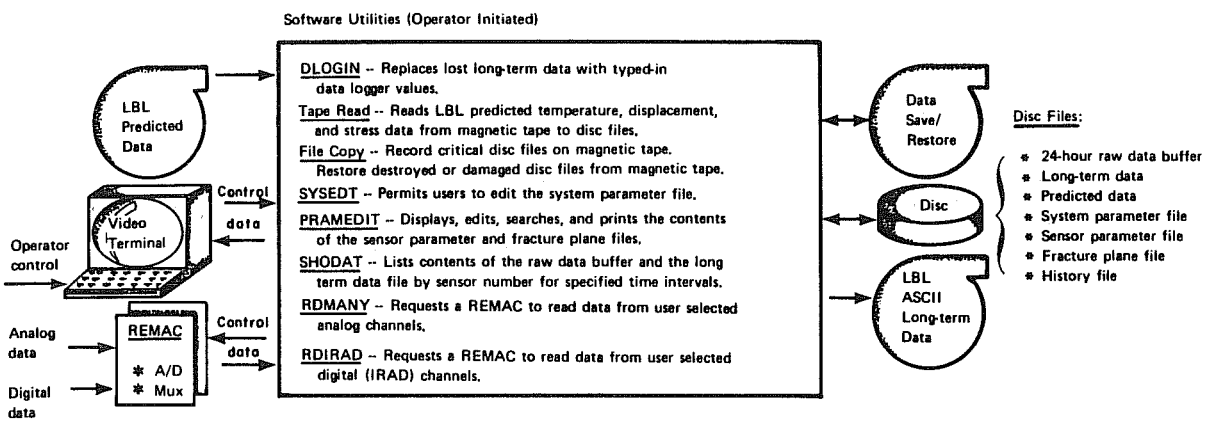
Operators use displayed parameters to assess the operational condition of the experiment. The displays provide a flexible

tool to diagnose, troubleshoot, isolate, and correct problems that arise. Displays include the measurements that most recently caused an alarm, and the most recent portion of the error log.

Experimenters and analysts can examine summaries of the acquired data, spot areas of interest, and focus on those areas in detail. They can display temperature, displacement, and stress measurements to detect unexpected behavior and visually correlate the results. This aids in understanding the phenomenon causing the measured data to deviate from the predicted model.

Software Utilities

Necessary support functions that are incidental to the major functions of the DAS are shown in Fig. 21 and described in this section. Data files are acquired and maintained on disc as time-averaged values in engineering units. Data from the data loggers can be inserted on disc to replace data missed due to computer outages. Missing or operator-inserted data are so labeled.



XBL 791-7345

Fig. 21. Software utilities diagram.

Files that describe the predicted behavior of all measured variables are maintained on disc. These include temperature,

displacement, and stress data that arrive from LBL on magnetic tape. The graphics-programs access and plot these files.

The data and parameter files on disc are backed up daily onto a revolving set of magnetic tapes. Each tape is read and verified to be readable. An automatic rescheduling capability handles periods of unattended operation. Disc data files can be individually restored from previously stored tape files.

Data and parameters are accessible and changeable, with some constraint checking made before parameter alterations. All system parameter file changes are logged and the logs are maintained. Parameters that can be modified include: sampling rates for both time-scaled and full-scale experiments, smoothing time intervals (see Fig. 12), experiment start time, heater turn on times, calibration values, and data channel assignments.

Software Documentation

A user's manual (Teknekron 1978) serves two purposes. First, it provides on-site operations personnel with a comprehensive set of instructions on the operation of programs they will be responsible for running. The manual includes the following points:

- cold starting the system
- warm starting the system
- monitoring routine system operation
- periodic saving of disc files
- recovering lost data by reading log-tape data
- recovering lost data by restoring from a previously written save tape
- duplicating log tapes for mailing to LBL
- recording time-averaged data tapes for mailing to LBL
- troubleshooting instrumentation problems

- interpreting the significance of all exceptional-condition messages

The user's manual also provides instructions on how to operate the system from an experimenter's point of view. Familiarity with computers was not assumed when the manual was written.

A program description manual (Teknekron 1979) provides information required by maintenance programmers to maintain or enhance the system in the future. The documentation includes functional charts describing the relationship between routines and tasks, and a description of the data flow, file layouts, and functional system constraints.

2.5 Alarm System

A power interlock system, local audible alarms, and an automatic telephone dialer are provided to warn about the occurrence of problems such as: computer power outages, no central processor response, instrumentation-shed power outage, smoke detector activation, or a heater power outage. The alarm panels located on the surface and in the power room are implemented with relay logic. The alarm panels for the full-scale and time-scaled experiments are implemented with solid-state logic. Figure 22 shows a simplified logic diagram that is logically equivalent to the actual alarm system. Minor alarm conditions are displayed at the alarm panels, using light-emitting diodes (LEDs). The solid state alarm panels include a switch that permits operators to latch alarm conditions. Latched alarms indicate which, if any, alarm conditions occurred since the last manual reset.

The Autodata 9 data loggers are programmed to sense and alarm out-of-tolerance ($\pm 2\%$) heater voltage, power, and other major and minor alarm conditions. A software test routine in

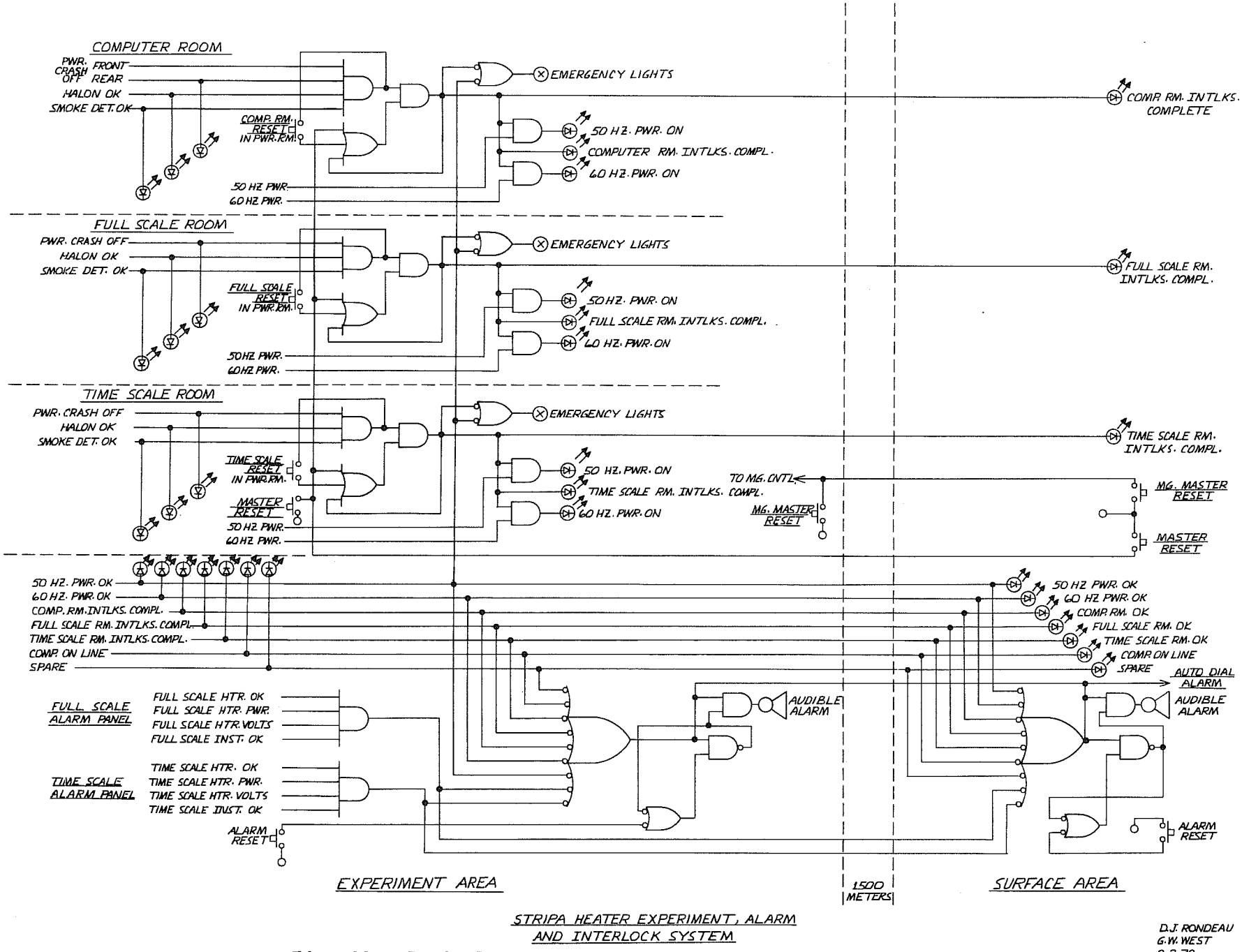


Fig. 22. Equivalent logic diagram for the alarm and interlock system.

XBL 791-8176

the computer executes at 15-minute intervals, to ensure that the most recent data acquisition cycles have indeed acquired data, correctly time-tagged data, stored data on disc, and recorded raw data on tape. Major alarm conditions cause audible alarms to sound both in the mine and on the surface. In addition, an automatic telephone system notifies an answering service which then contacts on-call maintenance personnel. Major alarm conditions can be corrected and reset either in the mine or from the surface. The computer has been modified so that it, too, can be remotely started from the surface.

Real-time displays of both experimental data and current system status also facilitate the detection and diagnosis of problems. Dynamic software alarms that signal out-of-tolerance or failing sensors provide an additional warning system. The computer arithmetically sums the power from individual heaters to cross check the electrically summed heater power. The computer also calculates individual heater power from the measured voltages and currents, as an additional cross check.

2.6 System Verification, Safeguards, and Operation

Before the heaters were turned on, a system check was made to verify that: the actual installation agreed with the instrument installation wire list (see Fig. 23); both observed readings and actual data transformations were valid; and the calibration parameters being used corresponded accurately with both the instrumentation installation wire list and the calibration logs. Logs are also maintained for changes to sensors, data loggers, and REMACs, and for system reconfigurations.

Duplicate tape and disc drives were provided to both safeguard acquired data and minimize data loss should a vital system component

DATA LOGGER						ICE POINT REFERENCE & SIGNAL SPLITTER OR OTHER RACK CHASSIS						COMPUTER MULTIPLEXER INPUT								DISK FILE RECORD NO.	TRANSDUCER			HOLE AND LOCATION OF TRANSDUCER (OR ANCHOR)					
TYPE	CHANNEL	CONNECTOR PINS +	CONNECTOR PINS −	CONNECTOR PINS SHLD	ALARM PRIORITY	UNIT	CHANNEL	CHASSIS LOCATION	CONNECTOR	CONNECTOR PINS CHR (BLK) +	CONNECTOR PINS AL (RED) −	CONNECTOR PINS SHLD	TERMINAL	EXPANDER	CHANNEL	SUB CHANNEL	CONNECTOR PINS +	CONNECTOR PINS −	CONNECTOR PINS SHLD	COMPUTER INPUT NUMBER		TYPE	NUMBER	PAIR/LENGTH CODE	EXPERIMENT	HOLE NUMBER	DEPTH (m)	R (m)	θ (DEGREES)	Z (m)
AD-9	133				0	63				17L	18R	18L	0-0-11-3	11	M	L				91	929	TC	193		3	T2		1.75	180.0	1.0
AD-9	134				0	64				19R	19L	20R	0-0-11-4	14	R	13				92	930	TC	194		3	T2		1.75	180.0	3.0
AD-9	135				0	65				20L	21R	21L	0-0-11-5	18	V	T				93	931	TC	195		3	T2		1.75	180.0	5.0
AD-9	136				0	66				22R	22L	23R	0-0-11-6	21	Y	20				94	932	TC	196		3	T3		2.62	180.0	1.0
AD-9	137				0	67				23L	24R	24L	0-0-11-7	24	LB	LA				95	933	TC	197		3	T3		2.62	180.0	3.0
					0	68				A	C	+	- - -									IPR	609	1	3					
AD-9	138												- - -																	
AD-9	139												- - -									OREF								
AD-9	140				0	69				1RH	1LH	2RH	0-0-12-0	2	B	1				96	934	TC	198		3	T3		2.62	180.0	1.0
AD-9	141				0	70				2LH	3RH	3LH	0-0-12-1	5	E	D				97	935	TC	199		3	T3		2.62	180.0	3.0
AD-9	142				0	71				4RH	4LH	5RH	0-0-12-2	8	J	7				98	936	TC	200		3	T3		2.62	180.0	5.0
AD-9	143				0	72				5LH	6RH	6LH	0-0-12-3	11	M	L				99	937	TC	201		3	T4		3.61	166.0	1.0
AD-9	144				0	73				7RH	7LH	8RH	0-0-12-4	14	R	13				100	938	TC	202		3	T4		3.61	166.0	0.0
AD-9	145				0	74				8LH	9RH	9LH	0-0-12-5	18	V	T				101	939	TC	203		3	T4		3.61	166.0	1.0
AD-9	146				0	75				10R	10L	11R	0-0-12-6	21	Y	20				102	940	TC	204		3	T4		3.61	166.0	3.0
AD-9	147				0	76				11L	12R	12L	0-0-12-7	24	LB	LA				103	941	TC	205		3	T4		3.61	166.0	5.0
AD-9	148												- - -																	
AD-9	149												- - -									OREF								
AD-9	150				0	77				13R	13L	14R	0-0-13-0	2	B	1				104	942	TC	206		3	T5		2.30	40.6	3.0
AD-9	151				0	78				14L	15R	15L	0-0-13-1	5	E	D				105	943	TC	207		3	T5		2.30	40.6	0.0
AD-9	152				0	79				16R	16L	17R	0-0-13-2	8	J	7				106	944	TC	208		3	T5		2.30	40.6	4.0
AD-9	153				0	80				17L	18R	18L	0-0-13-3	11	M	L				107	945	TC	209		3	T5		2.30	40.6	6.0
AD-9	154				0	81				19R	19L	20R	0-0-13-4	14	R	13				108	946	TC	210		3	T5		2.30	40.6	8.0
AD-9	155				0	82				20L	21R	21L	0-0-13-5	18	V	T				109	947	TC	211		3	T6		3.81	23.2	1.0

XBL 787-9836

Fig. 23. Sample interconnection wiring list.

fail. Raw data are buffered for 24 hours on disc, thus ensuring that they are not overwritten under the heaviest expected computer loadings or the longest expected tape-drive outage. Raw data are also logged on magnetic tape to protect against disc failure.

A check is made before periods of unattended operation, such as weekends, to verify the availability of adequate unused tape on the raw-data tape drive. Care is taken to ensure that "write rings" are inserted in the hubs of all raw- and long-term data tapes when they are mounted.

Data Backup Procedures

A program that copies disc files to magnetic tape is automatically scheduled on a daily basis to provide a backup data

source if the disc files are destroyed or damaged. The operator has a tape mounted and positioned for recording prior to the scheduled time of execution. Once the data have been recorded on tape; operators manually initiate tape rewind, unload the tape, and reload the "oldest" tape from a rotating sequence of three magnetic tapes.

Computer Restart Procedures

Once stopped, the computer's data acquisition program can be manually restarted from either the computer room or remotely from the surface of the mine. Once restarted, a "restart" program reads the date and time from a battery-powered real-time clock and marks all data in time slots during which data were missed. If desired, the operator can replace any data that are missing in the computer's long-term disc file with data from the data logger printout. Any data manually entered from the data logger are so marked. If necessary, the 24-hour raw-data buffer can be restored from the raw-data log tape.

It may be necessary to restore disc files from backup magnetic tapes before restarting. The latest saved files would be reloaded from tape, as required, and then the recover operation would continue.

Hardware changes were made to the computer to permit manually initiated restart from the surface of the mine. Provisions are being made to automatically reposition the tape drives after a power outage. In the meantime, the last 24 hours of raw data are buffered onto discs, and then appended to the raw-data tape when the operators return to the computer room in the mine.

Staffing

The mine is staffed 5 days a week, 8 hours a day, and the computer system is designed so that an operator need not be present during off hours. Maintenance personnel are on call, however. Before the computer is left, all terminals are inactivated, all operator-initiated programs are cancelled, and daily backup tapes are written. Sufficient space is left on the raw-data tape, and sufficient paper in the DECwriter system console, to cover the time that the computer will be unattended. Data logger paper was changed daily at first, and less frequently as the sampling rate decreased.

3. DATA HANDLING

Initially, many of the researchers gathered data in their own personal files in Sweden. Other researchers needed to be aware of what data existed and how they could be accessed, so the files were centralized in Berkeley and an index was provided. Project data can be stored on paper, microfiche, film, or strip charts. A project data-librarian, who provides centralized control over the data at LBL, carries out the following tasks:

- maintains an index and sees that project data are accessible to all project investigators
- assures completeness of the data file
- in collaboration with the task investigators, provides adequate description of and comments on the data
- prepares a newsletter to inform task investigators of additions to and deletions from the project's data file
- provides for the security of the data files and maintains a permanent copy (sometimes microfiche) of all raw data.

3.1 Data Sources

Most of the data described in this report were digitized and processed by the DAS in the mine, but many were obtained in other ways. Most of these other data were acquired at Stripa, although laboratory testing is also being performed at the Richmond Field Station, the University of Waterloo, and the Lawrence Livermore Laboratory. Other reports in this series describe and analyze the data acquired in experiments not directly coupled to the DAS. These data include:

- chemical analysis of water samples
- TV logs of boreholes
- oriented core (obtained using a triple-tube barrel), logs of core, and photographs of core
- multiple packer injection test results
- multiple point piezometer measurements of fluid pressure
- results of testing a "large rock core" using the large triaxial testing facility at the Richmond Field Station
- air flow, temperature, humidity, barometric pressure, and pressure gradients in the rock walls surrounding the ventilation experiment's test tunnel
- detailed geologic maps of the time-scaled and full-scale drifts
- characterization of major fracture planes
- stereophotography of the walls and floors of the drifts
- measurement of water flowing into boreholes
- measurement of water removed from heater boreholes using the dewatering and desteaming systems
- results of the SCM cell surveys
- surveyed coordinates of all boreholes

- analysis of groundwater samples including Eh, pH, conductance, temperature, dissolved oxygen, and carbon-14 age dating
- water table measurements
- results of borehole injection tests
- results of pump tests in boreholes
- strip-chart recordings of geophysical borehole logs measuring: natural gamma, neutron-thermal neutron, gamma-gamma density, acoustic velocity, borehole diameter, and electrical resistance
- polaroid photographs of the amplitude and velocity behavior of ultrasonic compressional and shear waves

3.2 Data Transfer and Storage at LBL

Computer-acquired raw data are ASCII encoded and logged on "raw-data" tapes at 15-minute intervals as the experiment progresses. Raw-data tapes are stored in an on-site tape library and copies of the tapes are airmailed to LBL biweekly. These tapes contain unprocessed experimental data and associated calibration parameters which permit later reprocessing if changes to calibration data or engineering conversion algorithms are needed.

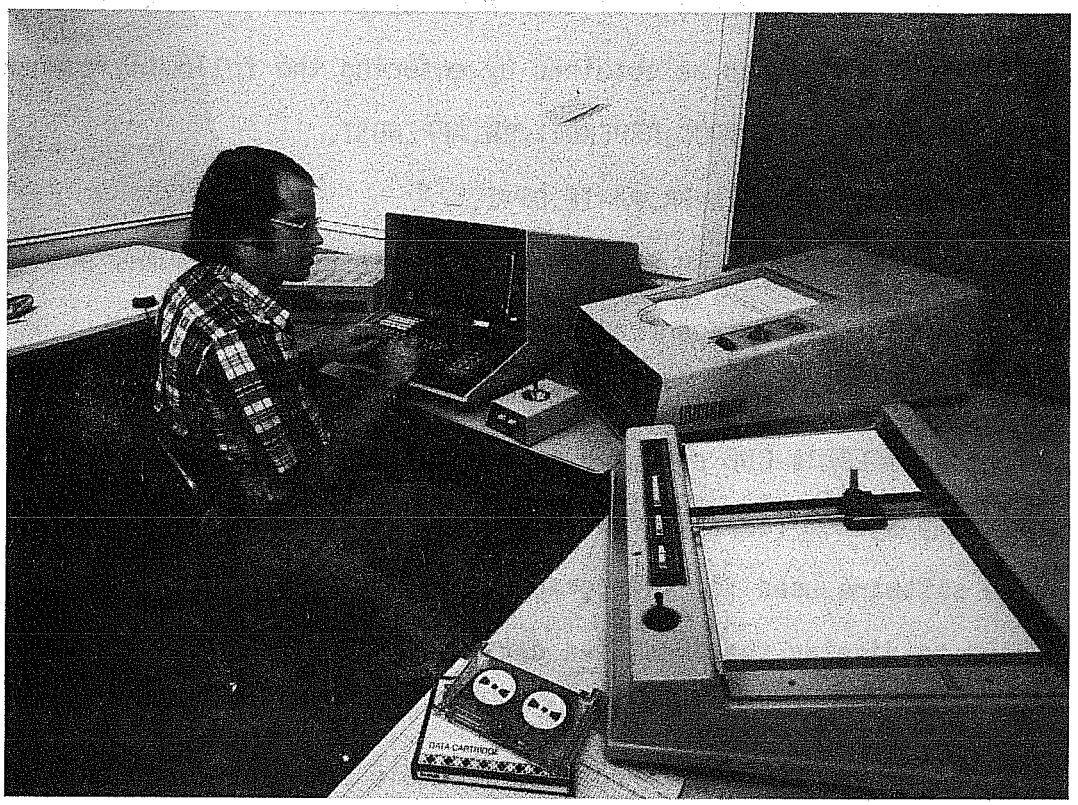
Data used for on-site display and analysis are obtained from the raw data by applying calibration curves to convert the raw data to engineering units and time-averaging the data over variable time intervals (see Fig. 12). The time-averaging reduces the quantity of data that is stored on on-line discs. These "long-term" time-averaged data are recorded on tape encoded in ASCII form, and the tapes are airmailed to LBL biweekly. To avoid duplication, the program only records long-term data points

collected since the previous tape was made, plus an overlap of ten data points. If a previous tape was lost or damaged, the starting data-point numbers are adjusted accordingly for retrieval. ASCII encoding facilitates reading the tapes on the Control Data Corporation (CDC) 6000 computers at LBL.

When magnetic data tapes are received at LBL they are read and loaded into the mass storage system of LBL's CDC computer system. Large amounts of data are stored on 6250 bpi magnetic tapes. Smaller amounts of data that are used more frequently are stored on data cells which comprise a Program Storage System (PSS). These data can then be accessed interactively via CDC 6400 and 6600 computers. The data can also be staged to disc, and accessed by a CDC 7600 in batch mode.

Additional hardware is being added to RTSG's Modcomp IV that is used for software development in Berkeley. This will permit users to access and display data interactively at LBL, using the same capabilities that are available in the mine in Sweden.

Some nondigital data, such as the geophysical strip chart recordings, were digitized at LBL using a Tektronix 4051 desktop computer system. This system consists of a Tektronix 4051 graphic computing console, a data communication interface, 32K bytes of read/write random-access memory, a joystick, a 4956 graphic tablet digitizer (manufactured by Summagraphics) with a four-button cursor, and a 4631 hard-copy unit. Data digitized using this system can be stored locally on DC300A data cartridges; however, most of the data are transferred to LBL's central computer site's mass storage system via a 240-character-per-second, full-duplex, RS-232C asynchronous data link, using short haul modems and four-



CBB 788-9454

Fig. 24. Tektronix 4051 desktop computer system.

wire dedicated telephone lines. Figure 24 shows the components of the computing system.

3.3 Index of Project Data at LBL

An index to all data from the Stripa experiments is maintained on LBL's CDC computer system, using the computerized documentation system called BARB. The index lists data items, their location, and means of access, all organized by project task. A copy of the data index can be obtained from a terminal that has been logged onto the CDC 6400 or CDC 6600 computer system, using the following commands:

```
LIBCOPY,STRIPADOC,INDEX/RR,INDEXST.
DISPOSE,INDEX=PR,PA=1F,DT=I.
```

LBL text editors, such as NETED, can be used to quickly examine the current status of the index file. Additional data are also

available in an appendix to the index described above. A listing of the appendix can be obtained by entering the following commands:

```
LIBCOPY,STRIPADOC,APPENDIX/RR,APPENDST.
DISPOSE,APENDIX=PR,PA=1F,DT=I.
```

Additional information regarding available data and means of access can be obtained from Ramsey Haught at LBL.

Data from the Stripa experiments are displayed in graphical form from LBL's CDC computer system, using the Integrated Data Display System (IDDS) software and the Calcomp plot routines. The software used for this graphic display is similar to that used to display the predicted data.

4. SUMMARY AND CONCLUSION

Hardware for a powerful and flexible computer-based DAS was specified, purchased, integrated, and installed in the Stripa mine to support the heater experiments. An easy-to-use graphics software system was designed, implemented, and installed to enable experimenters not oriented to computers to rapidly request graphical displays of predicted and actual experimental results in real time. Graphic data displays also facilitated communication between Americans and Swedes.

The original plan was to complete the software, calibrate the instruments on-site, and then begin the experiment. All these activities actually took place concurrently, after the time-scaled heaters were turned on. Whenever this increased demand for memory exceeded the amount of memory physically available, the computer would cease to function properly. Normally, the problem would be alleviated by placing low-priority tasks onto disc, to make room in the computer memory for higher-priority tasks. Unfortunately, the Modcomp-supplied disc-swapping software

did not work. The problem was initially circumvented by procedurally limiting the number and size of tasks running at any time. An additional 128 K bytes of memory were then added, which essentially eliminated the procedural constraints.

An electrical storm, which occurred several hours after the time-scaled experiment was begun, tested and proved the usefulness of the electrical isolation provided by the computer's motor-generator power supply. The storm caused temporary data losses in both the computer and the data loggers. Electrical transients so severe that light bulbs were burned out in the buildings at the surface of the mine had no adverse effect on the DAS. Electric grounding difficulties were encountered initially in the full-scale experiment. Changes that seemed to reduce the noise in the computer channels increased the noise in the data loggers, and vice versa. Grounding, filtering, and shielding modifications eventually resulted in an acceptable system.

The hardware and software systems described in this report have provided experimentalists with a flexible tool with which to view the progress of the experiments and to compare that progress with theoretical predictions. Permanent copies of graphic data displays can be obtained with the push of a button. When necessary, graphic results are sent from Stripa to Berkeley via a telecopier. Most data, however, are routinely airmailed to Berkeley on magnetic tapes, where they are examined and reviewed in a non-real-time environment.

Because of careful attention to detail during the preparation, on-site calibration, and installation of the instruments, the primary limitation on the precision of initial measurements was only the inherent limitation of the transducers. Unfortunately,

this precision could not be maintained for some measurements. Shortly after the 5-kW heater experiment began, there was noise on some thermocouples, as shown in Fig. 25. A systematic analysis of the associated voltages and currents resulted in changes to the grounding system which seemed to help. Shortly afterward, some of the noisy thermocouples failed. Removal and inspection revealed that corrosion caused the failures, which occurred only on stainless-steel-clad thermocouples (Irvine, in preparation). Heat treatment of the thermocouples, which was intended to increase their precision, had sensitized their stainless-steel cladding to corrosion. Graphic displays were helpful in detecting and diagnosing this problem. Figure 25 indicates that thermocouple 511 failed about day 11. Other subtle failures were noticed where the thermocouple was neither open nor shorted, as illustrated by thermocouple 512 about day 70. All five thermocouples in the T19 borehole were replaced with inconel-sheathed thermocouples at about day 87 (Carlsson 1978). These replacement thermocouples were not calibrated individually.

Occasional erratic operation of the relays used to select analog channels was detected from the graphic displays. The distinctive pattern of these failures became easy to spot visually. These relay problems were fixed by replacing the faulty printed circuit board. A test fixture was used to repair boards with faulty relays.

At one time during the experiment, the analog-to-digital converter boards were interchanged between the two Wide-Range-Relay Analog-Input subsystems (see Fig. 11) in an attempt to isolate an electrical problem. Differences between these two boards caused an offset in the data values from USBM gauge U18

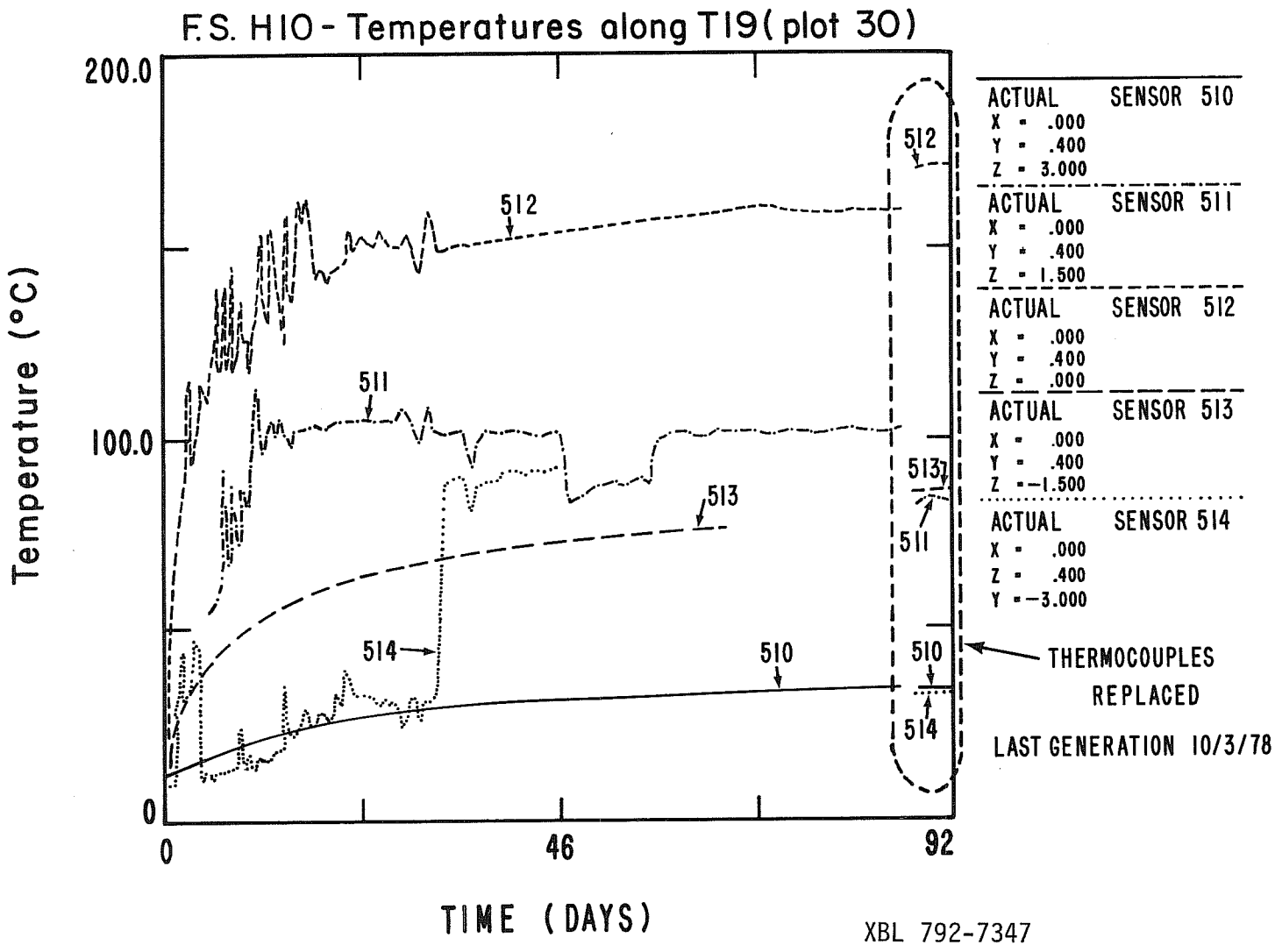


Fig. 25. Plot of the H10 heater temperatures versus time.

of about 4 MPa, which was a 30% change. The initial configuration of these boards was re-established later. The times of these changes were logged and the resulting offsets will be removed by processing at LBL.

Occasionally, water became trapped in the heater's thermocouple tubes. The water condensed in the bottom of the tube, boiled off, and recondensed, causing the thermocouple readings to jump between 100°C and the actual, higher temperature. These occurrences were readily detected from the graphs, and the water was then blown out of the tubes, using compressed air.

The ability to graphically overlay data from selected extensometers aided in the interpretation of an apparent "stick-slip" phenomenon, which can be seen in Fig. 17.

5. ACKNOWLEDGMENTS

Many people contributed to the design, testing, and implementation of the Data Acquisition System (DAS) described in this report. Don Rondeau of LBL's Real-Time Systems Group (RTSG) designed and specified the power supply system, computer room, alarm system, and, together with Ken Wiley, specified the computer hardware and its layout. The design and specifications of the heater drivers and monitors, instrumentation sheds, data loggers, and much of the instrument interface electronics were directed by Gene Binnall, together with Chuck Arthur, Jerry West, and Tony Ortiz (all of LBL's Field Systems), and additional support was given by Edgerton, Germeshausen, and Grier (EG&G). Van Jacobson determined many of the software requirements, John Lynch provided system software support, and Jim Greer integrated and tested the computer hardware at LBL before it was installed at Stripa. Martha Halliwell provided drawings and coordination support.

The detailed design and implementation of the software were performed by John Wells, Bill Ingram, Philip Tucker, and John Medcalf, all of Teknekron. Computer calibration algorithms and the equations used to convert the measurements to engineering units were established by Roger Simonson of Terra Tek.

Computer hardware installation and verification in Sweden were performed by Jack O'Riva and Jim Greer, both of RTSG. Philip Tucker installed the software at Stripa. Jack O'Riva and Martha Saarloos (RTSG) operate and maintain the DAS in Sweden. Ramsey Haught of LBL's Earth Sciences Division is responsible for organizing, maintaining, and disseminating the acquired data at LBL. Kam Ang of RTSG installed the software on a Modcomp IV in Berkeley and implemented some software modifications.

6. REFERENCES

ANSI. 1976. American National Standard for Temperature Measurement Thermocouples. ANSI-MC96.1-1975. Pittsburgh, Pennsylvania: Instrument Society of America.

ASME. 1974. Temperature Measurement: Performance Test Codes Supplement on Instruments and Apparatus, Part 3. ASME/ANSI PTC 19.3-1974. American Society of Mechanical Engineers.

ASTM. 1972. Standard Methods for Calibration of Thermocouples by Comparison Techniques. ASTM E220-72. American Society for Testing and Materials.

Burleigh,R.H., E.P. Binnall, A.O. DuBois, D.U. Norgren, and A.R. Ortiz. 1979. Electrical Heaters for Thermo-mechanical Tests at the Stripa Mine. LBL-7063, SAC-13. Berkeley, California: Lawrence Berkeley Laboratory.

Carlsson, H.S. 1978. Replacement of Stainless Steel Thermocouples in the T-Holes. LBL Earth Sciences Division Technical Memorandum. Berkeley, California: Lawrence Berkeley Laboratory.

Chan, T., N.G.W. Cook, and C.F. Tsang. 1978. Theoretical Temperature Fields for the Stripa Heater Project, Vol 1. LBL-7082, SAC-09. 2 vols. Berkeley, California: Lawrence Berkeley Laboratory.

Irvine, J.A. in preparation. Corrosion of Stainless Clad Thermocouples. LBL Earth Sciences Division Technical Memorandum. Berkeley, California: Lawrence Berkeley Laboratory.

Pratt, H.R., T.A. Schrauf, L.A. Bills, and W.A. Hustrulid. 1977. Thermal and Mechanical Properties of Granite, Stripa, Sweden. Summary Report TR 77-92. Salt Lake City, Utah: Terra Tek.

Schrauf, T.W., H.R. Pratt, W.A. Hustrulid, and E.R. Simonson. in preparation. Evaluation, Calibration, and Installation of the Borehole Instrumentation for the ONWI/Swedish Heater Experiment. LBL-8313. Berkeley, California: Lawrence Berkeley Laboratory.

Teknekron. 1978. Geotechnical, Graphical, and Data Acquisition System User's Manual. Berkeley, California: Teknekron.

_____. 1979. Technical Software Guide for the Geotechnical, Graphical, and Data Acquisition System. Berkeley, California: Teknekron.

Thorpe, R.K. in preparation. Characterization of the Fracture System for the Time-Scaled Heater Experiment. LBL-7083. Berkeley, California: Lawrence Berkeley Laboratory.

Witherspoon, P.A., and O. Degerman. 1978. Swedish-American Cooperative Program on Radioactive Waste Storage in Mined Caverns. LBL-7062, SAC-01. Berkeley, California: Lawrence Berkeley Laboratory.

7. APPENDIX: ENVIRONMENT

Equipment necessary to support the DAS and characteristics of the instruments used in the experiments strongly affected the design of the DAS. This appendix describes this equipment and its interfaces with the DAS.

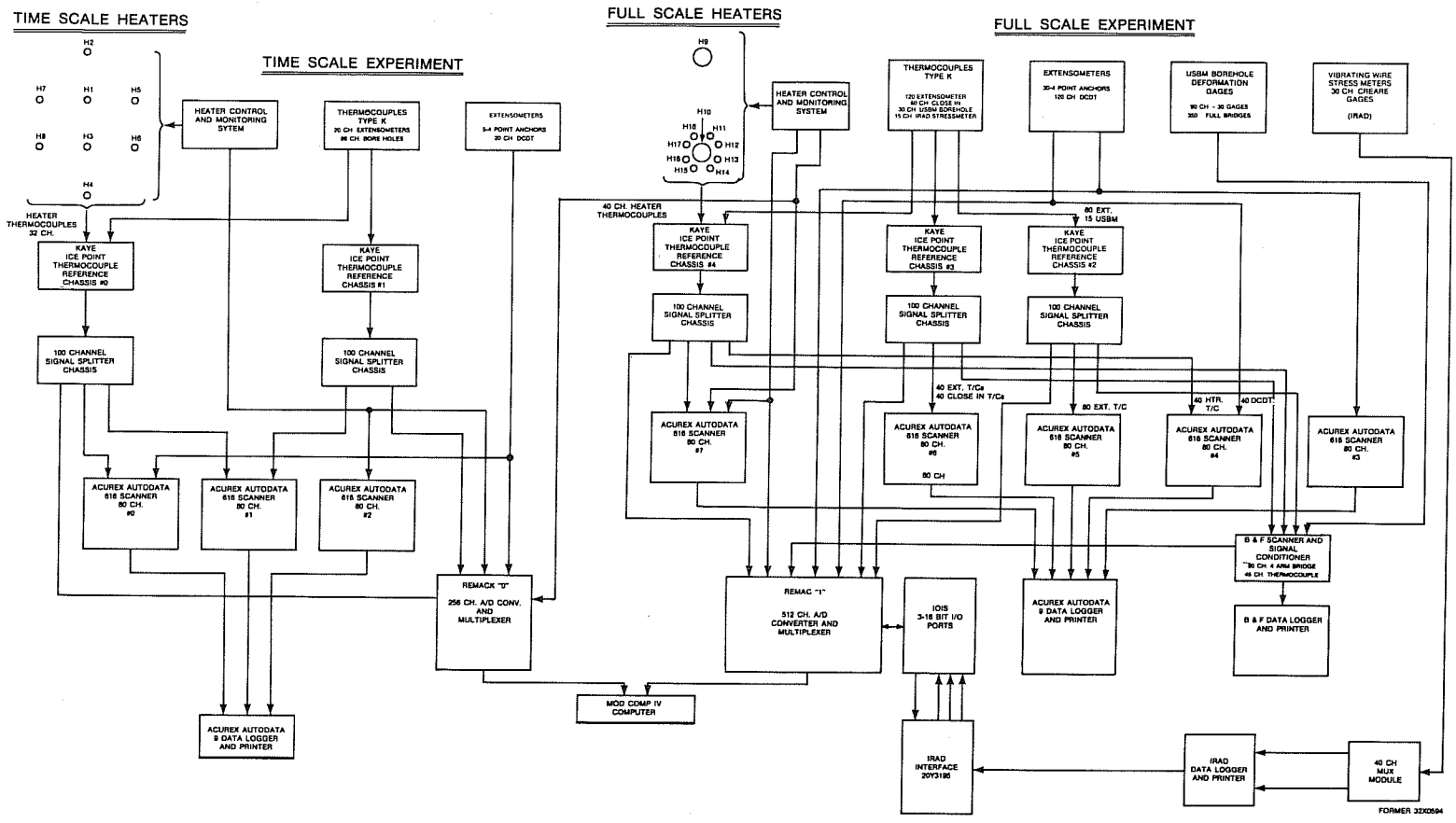
7.1 Instrument Characteristics

This section describes instrumentation characteristics that require support from the computerized DAS. Borehole instrumentation at Stripa measures temperatures, displacements, and stresses that are induced in the rock mass adjacent to the heater experiments. Schrauf et al. (in preparation) have given a detailed description of the development, testing, calibration, and installation of this instrumentation.

A total of 763 channels of instrumentation monitor the two full-scale and the one time-scaled heater experiments. Figure A-1 illustrates the instrumentation and associated interfaces. High accuracy requirements necessitated: individual instrument calibrations; temperature compensation for USBM gauges, IRAD gauges, and extensometers; annealing the thermocouples; heat treating the super invar extensometer rods; and a low-noise instrument environment. The initial borehole and instrument layouts were specified by Hustrulid (1977). The surveyed locations of these instruments are described by Kurfurst, Hugo-Persson, and Rudolph (1978). The calibration, testing, and emplacement procedures are described by Schrauf et al. (in preparation).

Thermocouples

Temperature is measured by 271 chromel/alumel (ANSI type K) thermocouples in the full-scale experiment, and 113 type K thermocouples in the time-scaled experiment. These thermocouples



XBL 784-649A

Fig. A-1. Instrument interface diagram.

are attached to each instrument and are also positioned throughout the granite to enable the temperature field around each heater to be measured in three dimensions. The low-temperature thermocouples have a fused teflon cover capable of functioning to 280°C. The close-in thermocouples are covered in either 304 stainless steel or inconel sheaths capable of functioning at temperatures in excess of 1000°C. Kaye ice-point temperature references were used with the thermocouples rather than isothermal blocks; this eliminated the necessity of measuring and compensating for the temperature of an isothermal block.

Where possible, thermocouples were obtained from the same melt to minimize variability due to differences in metallurgy. A desired precision of ±0.5° over a temperature range of 10° to 220°C necessitated individual calibrations in an environment as close as possible to actual operating conditions. All teflon thermocouples were, therefore, calibrated in their operating environment with all scanners, data loggers, ice-point references, and the computer fully wired and operational. This eliminated as many electrical and electronic uncertainties as possible. The oven used to calibrate the thermocouples was limited to a maximum temperature of 220°C, so it could not be used for the high-temperature thermocouples. National Bureau of Standards calibration data (ANSI 1976) were therefore used for the high-temperature thermocouples, which decreased their precision to approximately ±2°C. Thermocouple nonlinearities necessitated use of nonlinear calibration curves.

Extensometers

Rock displacements in the full-scale experiment are measured by twelve vertical and eighteen horizontal extensometers. Displace-

ments in the time-scaled experiment are measured by five vertical extensometers. Each extensometer consists of four direct-coupled linear-variable differential-transformer (DCDT) displacement transducers, four super invar rods, and an anchor system. The DCDTs are rigidly attached to the collar of the borehole and measure the axial displacement of super invar rods between each of four downhole anchor points and the collar of the borehole. The transducers are calibrated to give displacements as a function of output voltage. Positive voltages correspond to increased longitudinal displacement.

The DCDTs resolve motion on the order 1 to 3 μm. Instrument accuracy, however, is impaired by the thermal expansion (about 0.4 mm at 200°C) of the super invar rods used in the extensometers. Temperatures are monitored along the extensometer borehole (usually at anchor points). They provide rock temperature data and are used to correct for thermal expansion of the super invar rods.

USBM Gauges

Thirty USBM borehole deformation gauges are emplaced in boreholes in the full-scale experiment to measure the borehole diameter along three coplanar axes that are 120° apart. Each displacement is measured with a pair of buttons which contacts the borehole wall and is attached to cantilevers. Strain gauges, attached to the cantilevers, measure the strain which is a linear function of the displacement of the beam. The strain gauges are wired into a four-arm bridge which requires signal conditioning amplifiers. Positive voltages correspond to a decrease in hole diameter.

IRAD Gauges

The IRAD vibrating wire stressmeter is a hollow steel cylinder containing a highly tensioned steel wire stretching across the diameter of the cylinder wall. The stressmeter is placed in a borehole and held securely in place with a sliding wedge and platen assembly. Changes in rock stress cause a change in the borehole diameter, which causes a change in the stress of the wire and hence in its natural frequency of vibration. This change in natural frequency of the wire is measured electronically and is related by calibration data to the temperature-induced stress. The device requires nonlinear calibration curve fits, which are temperature dependent, to represent its frequency-versus-stress relationship.

Two adjacent IRAD gauges were placed in each of the fifteen IRAD boreholes. Their sensing directions were placed perpendicular to each other and were oriented in radial, vertical, or tangential directions from their associated heater's centerline.

One IRAD MA-2 data logger converts the frequency of each of the thirty IRAD gauges in the full-scale experiment to its corresponding period and displays the results on a printer. A digital output interface provides the data to the Modcomp's digital input/output subsystem as 6 BCD digits per measurement. A zero output implies either a weak signal or high electrical noise. A faulty connection or no gauge connected results in a maximum data value, which consists of a word containing 16 binary one bits.

Borehole Decrepitation Sensors

We anticipate that the high temperatures and high thermal gradients may cause spalling of the heater's borehole walls. Two types of sensors have been used to monitor decrepitation in two of the time-scaled heater boreholes. For both types of sensors, conditioning circuits are used to boost the microvolt strain gauge output to a 0 to 10 V range. High temperature near the heaters is expected to degrade strain-gauge accuracy; however, the primary goal is to detect when decrepitation occurs. Cost constraints limited the continuous decrepitation monitoring to the two central (i.e., hottest) time-scaled heaters.

A caliper system decrepitation sensor design consists of three caliper arms that press against the borehole wall of the time-scaled heater. High-temperature strain gauges are welded to the calipers to sense motion of the borehole wall. Two of these caliper systems are used on the H1 time-scaled heater.

A weighing pan annular ring fits between the H3 time-scaled heater and its borehole, and is positioned below the heater's hot section. The pan is suspended by three wires that are attached to high-temperature weldable strain gauges. The device weighs debris that falls down the borehole.

A borescope is used several times per week to examine the borehole walls adjacent to the time-scaled and main heaters, to measure visible damage of the borehole.

Heater Monitors

Heater power is set and controlled manually. Heater voltages, currents, powers, and temperatures are monitored by the DAS.

7.2 Power Supply System

The Swedish 10-KV 3-phase 50-Hz grid power is inserted into

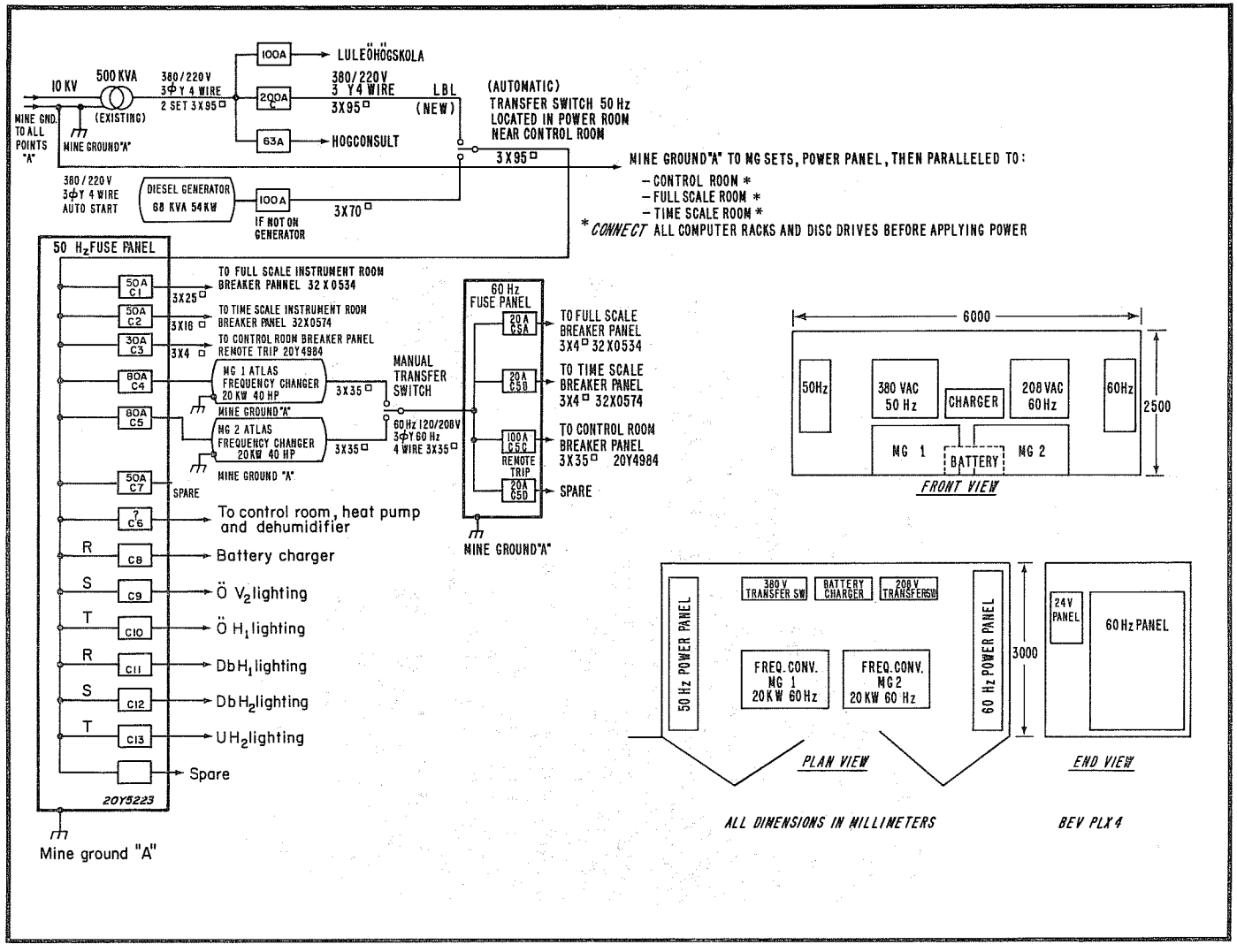
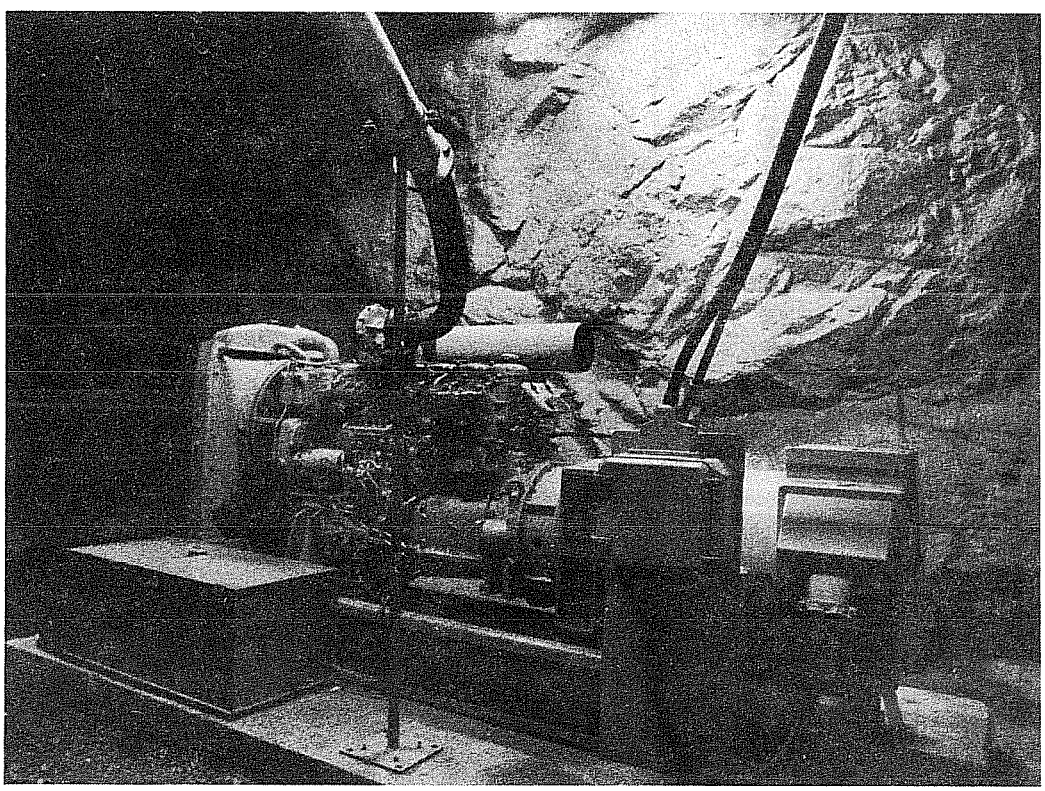


Fig. A-2. Power distribution diagram.

XBL 791-7344

the mine where it is transformed to 380/220-V 3-phase power, as shown in Fig. A-2. A 68-KVA 54-KW diesel generator, which is located in the mine (see Fig. A-3), provides a backup to the 50-Hz grid power. The full-scale and time-scaled heaters are powered from the 380/220-V 3-phase power, as shown in Fig. A-2. The maximum acceptable down time is 1 hour for heaters and 67 hours for the computer system. These limits are critical during the first 30 days of the experiment.

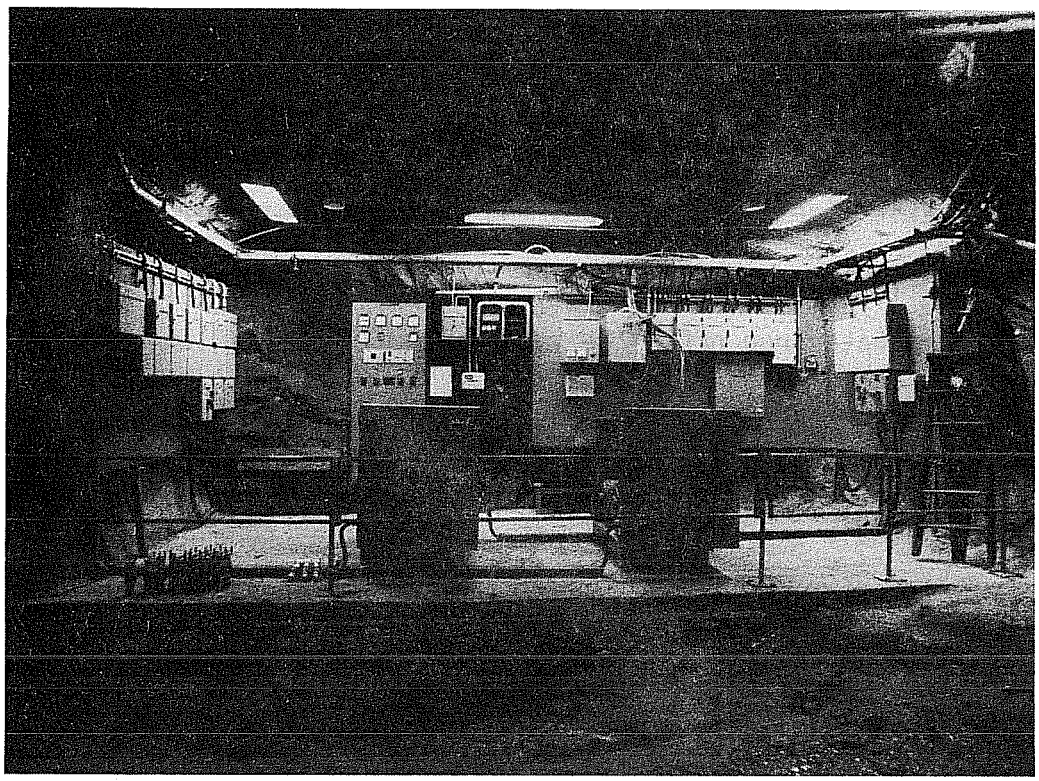


XBC 786-7284

Fig. A-3. Diesel generator.

A motor-generator unit (see Fig. A-4), operated from the 50-Hz power, generates the needed 208/120-V 60-Hz 3-phase power, eliminates noise on the line from mining usage, and isolates the computer from large transients that occur during electrical storms. A second motor-generator serves as a backup unit. Most

of the data acquisition system, including the computer, is powered from the 60-Hz motor-generator source.



XBC 786-7283

Fig. A-4. Motor generators.

All power cables were placed in separate cable trays and kept as far away as practical from instrumentation cables, in order to minimize coupling from the power lines into the low-voltage instrument leads. The mine's electrical ground is at the primary transformer. The mine ground is run to the power room and distributed radially to the full-scale, time-scaled, and computer enclosure. All equipment is referenced to this ground.

7.3 Computer Room and Instrumentation Sheds

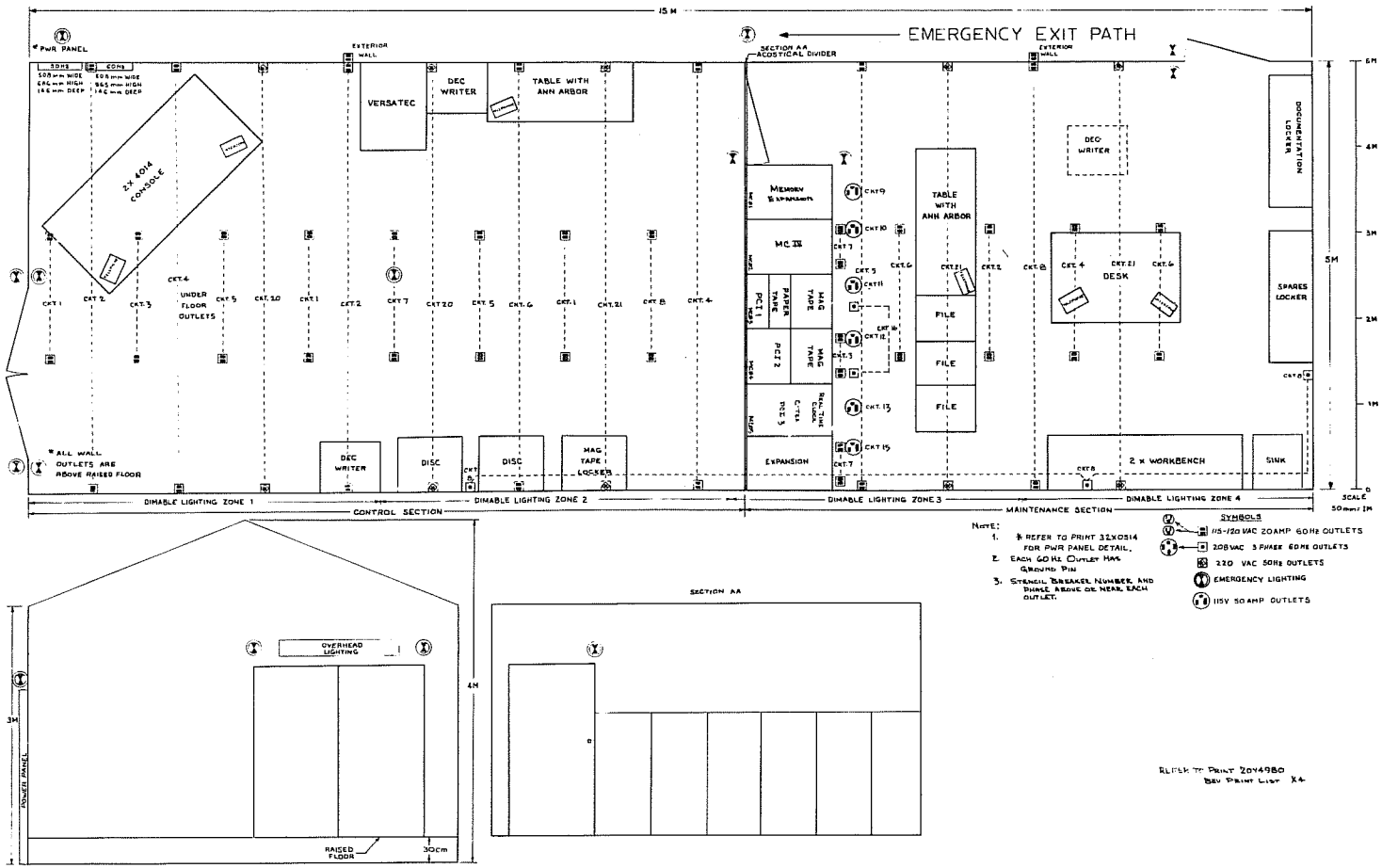
The computer system is housed in a computer room that was constructed underground near the heater experiments. The Swedish Nuclear Fuel Safety Company (KBS) constructed the computer room

in the computer drift, as well as two instrumentation sheds--one in the full-scale drift, and the other in the time-scaled drift. The computer room is 15 x 15 x 3 m, with a simple wall placed in front of the computer racks to suppress noise (see Fig. A-5). A concrete foundation was constructed by filling uneven portions of the rock floor with sand, covering the sand with a plastic sheet, and then pouring 10 cm of concrete. The exterior walls and framework are made of steel and allow for the dripping of some water run off. The interior walls and ceiling are covered with acoustic tile for additional noise suppression. The floor is raised 30.5 cm and has removable panels 61-cm square. The floor panels are capable of withstanding 1464 kg/m^2 and their supporting structure can support 976 kg/m^2. Drinking water and restroom facilities are available.

Pre-experiment temperature in the mine was $10^{\circ} \pm 2^{\circ}$C. Electrical equipment in the computer room generates 3415 Btu/hr/kW. People in the room generate 650 Btu/hr. The computer and its peripheral equipment operate over a range of 5° to 24°C within a noncondensing humidity range of 25% to 75%. An air conditioning system controls the temperature and humidity in the computer room and maintains a positive pressure for dust control.

Air is forced through the crawl space beneath the floor to keep moisture from condensing on the wires. Because the absolute filters on the disc drives cannot filter nicotine, smoking could cause severe damage to disc heads and the magnetic surfaces of the discs, and is therefore not recommended in the computer room.

Four circuits of overhead fluorescent lighting over the console that contains the graphic displays can be dimmed. These



XBL 788-9871

Fig. A-5. Computer room drawing.

lights are backed up with strategically placed 24-V battery-operated emergency lights.

One telephone line in the computer room provides access to the surface area above the mine. This phone is also used occasionally for voice communications with LBL, but a separate telephone line at the surface of the mine is generally used for voice and telecopy transmissions between Berkeley and Stripa. An intercom system was built between the computer room and each instrumentation shed to facilitate instrument calibration and trouble shooting.

The design and construction of the two instrument sheds is simpler than that of the computer room. The floor is approximately 3 x 4 m in the time-scaled shed, and about 2.5 x 8 m in the full-scale shed. Access walkways and safety gates control traffic to and from the drift. No active air conditioning was provided in the sheds, because equipment operation increases the temperature, thereby reducing the relative humidity to acceptable levels. REMACs, instrumentation racks, heater power controls, and data loggers are housed in the instrumentation sheds that are adjacent to both the full-scale and the time-scaled heater experiments. Two coaxial cables connect the REMAC in each instrument shed to the computer. These coaxial cables provide a bit-serial data path for all data communications between the computer and the instrument sheds.

7.4 Fire Protection System

A halon fire-suppression system is located both overhead and under the floor. Smoke detectors, when activated, give signals to a power interlock system, which then disconnects the input power. Figure 22 (Section 2.5) shows the 24-V power and interlock

logic. The interlock system can be manually reset either in the mine or from the surface.

7.5 References

ANSI. 1976. American National Standard for Temperature Measurement Thermocouples. ANSI-MC96.1-1975. Pittsburg, Pennsylvania: Instrument Society of America.

Hustrulid, W.A. 1977. Underground Borehole Instrumentation Program, Stripa Mine, Joint Swedish/ERDA/OWI/LBL Program. Salt Lake City, Utah: Terra Tek.

Kurfurst, P.J., T. Hugo-Persson, and G. Rudolph. 1978. Borehole Drilling and Related Activities at the Stripa Mine. LBL-7080, SAC-05. Berkeley, California: Lawrence Berkeley Laboratory.

Schrauf, T.W., H.R. Pratt, W.A. Hustrulid, and E.R. Simonson. in preparation. Evaluation, Calibration, and Installation of the Borehole Instrumentation for the ONWI/Swedish Heater Experiment. LBL-8313. Berkeley, California: Lawrence Berkeley Laboratory.

This report is part of a cooperative Swedish-American project supported by the U.S. Department of Energy and/or the Swedish Nuclear Fuel Supply Company. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory, the Department of Energy, or the Swedish Nuclear Fuel Supply Company.

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. Department of Energy to the exclusion of others that may be suitable.

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720