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Spent Fuel Test—Climax Data Acquisition System Integration Report

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June 1982

Lawrence Livermore National Laboratory

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SPENT FUEL TEST--CLIMAX
DATA ACQUISITION SYSTEM INTEGRATION REPORT

ABSTRACT

The Spent Fuel Test--Climax (SFT-C) is a test of the retrievable, deep geologic storage of commercially generated, spent nuclear reactor fuel in granitic rock. Eleven spent fuel assemblies, together with 6 electrical simulators and 20 guard heaters, are emplaced 420 m below the surface in the Climax granite at the U.S. Department of Energy Nevada Test Site. On June 2, 1978, Lawrence Livermore National Laboratory (LLNL) secured funding for the SFT-C, and completed spent fuel emplacement May 28, 1980.

This multi-year duration test is located in a remote area and is unattended much of the time. An extensive array of radiological safety and geotechnical instrumentation is deployed to monitor the test performance. A dual minicomputer-based data acquisition system collects and processes data from more than 900 analog instruments.

This report documents the design and functions of the hardware and software elements of the Data Acquisition System and describes the supporting facilites which include environmental enclosures, heating/air-conditioning/humidity systems, power distribution systems, fire suppression systems, remote terminal stations, telephone/modem communications, and workshop areas.

1. INTRODUCTION

The National Waste Terminal Storage (NWTS) Program of the U.S. Department of Energy (DOE) is a large, multidisciplinary program aimed toward construction of an operational nuclear waste repository in the 1990s. In support of that program, LLNL is conducting a field test of geological storage of spent fuel assemblies from a commercial nuclear reactor in Climax stock granite. This test--generally referred to as the Spent Fuel Test--Climax (SFT-C) and managed by the Nevada Operations Office of the DOE--is operated at the DOE Nevada Test Site (NTS), about 60 mi northwest of Las Vegas (see Fig. 1.)

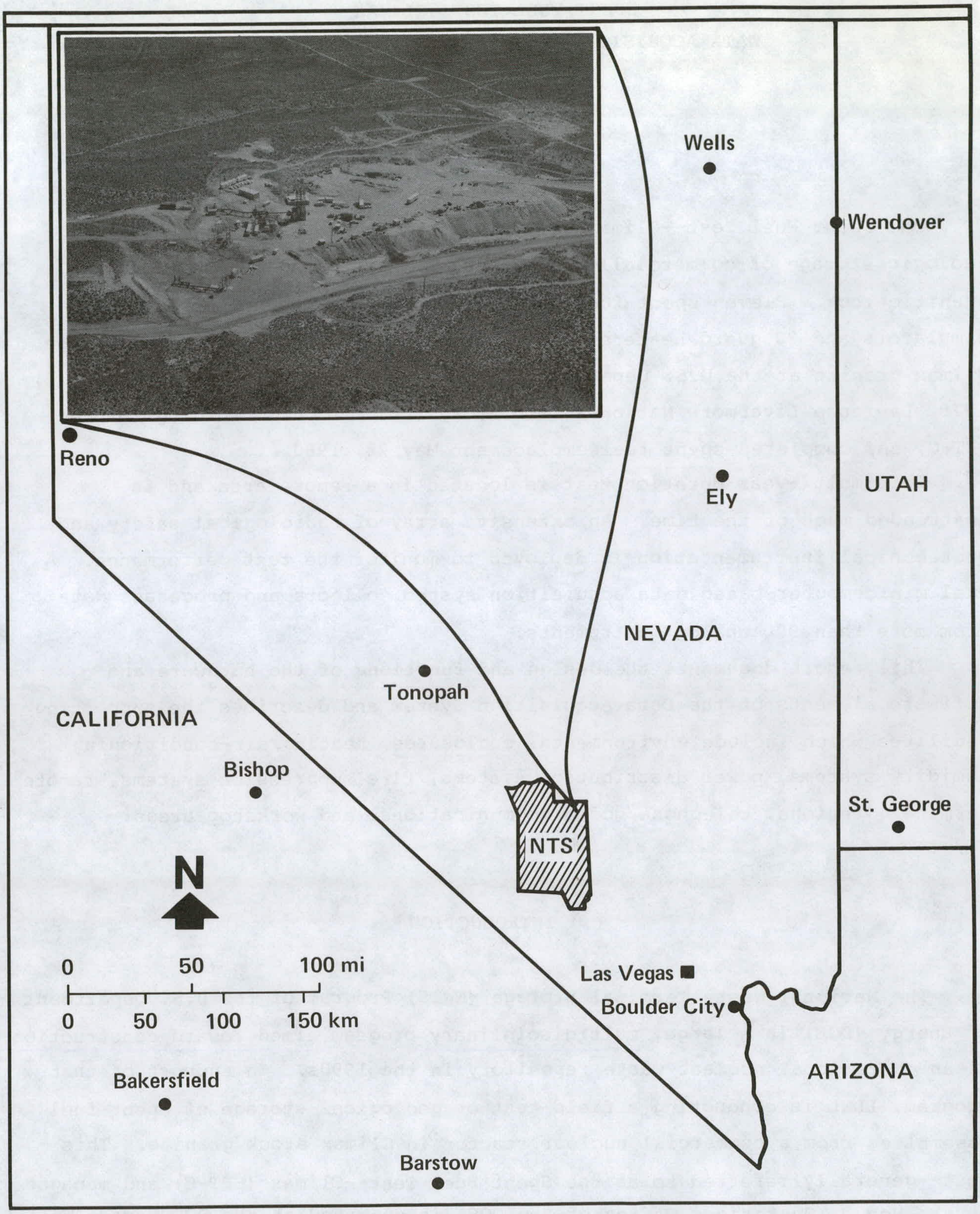

Figure 1. SFT-C experiment location.

Because the DOE operates the Nevada Test Site primarily to test nuclear weapons, the work force is already trained in the handling of nuclear materials. There are also adequate security procedures, and the facilities are well suited to field-testing nuclear waste handling and storage. The E-MAD (Engine Maintenance, Assembly, and Disassembly) facility located in the southwestern portion of the NTS (originally constructed during the nuclear rocket program) has been modified to encapsulate and provide temporary storage for spent fuel assemblies in canisters. Underground facilities originally developed to support weapons effects testing provide access to the Climax granite at a depth of 420 m (1400 ft)--comparable to the depth of a geologic repository.

There are a number of reasons for field-testing spent reactor fuel emplacement. The general public does not understand that spent fuel handling is a straightforward engineering problem involving "off-the-shelf" technology. Such a test, therefore, has great educational value and also provides technical benefits. Unless generic tests such as this are done, the first test emplacement of high-level waste will not occur until an actual repository is ready to be built. This, however, is a decade or more away. Furthermore, even though much information can be gained from laboratory measurements and computer modeling, the question of unpredicted, negative synergistic effects during storage can only be addressed by an actual field test. Therefore, the basic objective of the Spent Fuel Test is to determine the feasibility of safe and reliable short-term storage and subsequent retrieval of spent reactor fuel assemblies deep within a typical granitic rock.[1]

A secondary objective of the test is to gather technical data concerning:

1. Evaluation of granite as a repository medium.
2. Design of a repository in granite. This is done using the test geometry and instrumentation arrays to:
    a) Simulate the effect of thousands of nuclear waste canisters, using a small number of spent fuel assemblies and electrical heaters.
    b) Evaluate any differences between the effects of an actual radioactive waste source and an electrical simulator on the test environment.
    c) Validate and/or refine mathematical models so that host rock responses can be realistically predicted.

On June 2, 1978 the SFT-C was authorized and emplacement of 11 spent fuel assemblies was completed on May 28, 1980. Eleven Westinghouse PWR fuel assemblies from Turkey Point Unit No. 3 (Florida) have been statistically interspersed with six electrical heaters to compare the effects caused solely by heat with those of heat plus radiation. Two parallel side drifts, containing 10 electrical guard heaters each, allow simulation within the central drift of the thermal field of a large single-level nuclear waste repository. Instrumentation in the SFT-C includes radiation monitors, thermocouples, dewpoint meters, multipoint rod extensometers, convergence wire extensometers, three-axis fracture monitoring systems and vibrating-wire stress gauges. Data from these instruments are collected on a continuous basis by a computerized data acquisition system.

This report documents the design of the central Data Acquisition System (DAS), which collects and processes approximately 500 data points/h from more than 900 channels of analog instrumentation. We also discuss the DAS support facilities, including environmental enclosures, heating/air-conditioning/humidity systems, power distribution systems, fire suppression systems, remote terminal stations, communications, and workshop areas.

2. SUMMARY OF DATA ACQUISITION SYSTEM OPERATION

The SFT-C Data Acquisition System (DAS) is a computerized information processing system that supports the operational test safety and technical measurements program. In its normal mode, the DAS routinely acquires and processes approximately 500 data points/h from 927 channels of information. Each channel typically represents one analog instrument. For reliability, several critical devices are recorded as two redundant channels. These redundant channels include the continuous air monitors, remote area radiation monitors, and a few system status monitors.

Each transducer is assigned a unique 6-character alphanumeric designator (or "license plate") for the life of the experiment. An instrument may in time be assigned any number of designators, thereby affording a means of documenting modification/replacement of front-end transducers on the instrument. This minimizes the possibility of coming to false conclusions concerning instrument behavior due to maintenance or repair.

Tables maintained within the computers define and interrelate data channels. At predetermined intervals, ACQUISITION modules ingest a scan table containing the following information for each of the computers' devices:

- Channel logical state (ON or OFF).
- Scan-time interval at which each instrument is to be read.
- Time of last scan.
- Scanner channel to which instrument is wired.
- Type of reading to be taken (dc or ac voltage; or 2- or 4-wire resistance).
- Processing algorithm code (processor code).
- List of reference channels required by the processing algorithm.

A module then checks each channel to determine whether it should be scanned as ascertained by its logical state and by comparisons made among the current clock time, time of last scan, and scan time-interval. If the conclusion is true, the module:

- Builds a sequence of channels to scan based on the reference channels required by the processing algorithm.
- Requests that scans be made.
- Receives raw data values in response.
- Dispatches those values to the appropriate processor as defined by the processing algorithm code.

The PROCESS routines accept data packets of channel designator, system acquisition time, and raw data from the ACQUISITION routine. They then retrieve conversion parameters from the conversion coefficient tables to process the data to engineering units. Those channels requiring references, such as rod extensometers and thermocouples, are given access to the acquired data base as well.

The data packet is expanded to include the engineering value and is then passed to a central acquired data processor. At that point, the converted data are stored in the acquired data base and are also buffered for transmission to digital magnetic tape. Assuming acquisition of 500 data points/h on each of two computers, the data can be buffered for approximately 80 h in the event of tape drive failure.

The ALARM modules first see the data in the central acquired data processor. There each converted data point is compared to high- and low-alarm limits retrieved from the alarm coefficient tables. If the value falls outside its expected limits, the channel is further examined for recurring, contingent, redundant, and/or change-of-status alarms. When the alarm status is finally determined, it is logged for permanent record, and alarm messages are constructed and buffered. Finally the messages are routed to any combination of four devices by direct connection or line modems. After receipt of the alarm, the monitor (typically CP-40, NTS Radio Network Control Center and/or LLNL) contacts the appropriate project personnel, who respond to the alarm.

3. SYSTEM DESIGN REQUIREMENTS

3.1. GENERAL

The technical measurements program of the SFT-C required a data acquisition system that could be used over an extended period of time (about 5 to 7 years) to acquire and process data from a large number of thermocouples, stressmeters, and other more sophisticated devices. The system hardware was specified to be a standard commercial product with only minor modifications to meet specialized requirements. All electronic assemblies (with the possible exception of display devices) were to be solid state. The system was to be used by scientific personnel with specialized training not to exceed one man-month. The system was also to use ANSI FORTRAN IV and BASIC programs, and to be complete in both hardware and software (having previously been shipped, accepted and successfully used by others). Due to the nature of the experiments, excellent system reliability, high mean time between failures of equipment, and prompt service and repair were thought essential in providing the continuity of data and test conditions required. Hardware operation and maintenance manuals were to include all information needed for an experienced technician to maintain and repair the system, and to understand its operation.

3.2. HARDWARE

A specification (LES 22179, Rev. B) was written for procurement of a data acquisition system that could produce high-quality data and enhance real-time evaluation and control of selected test parameters. This specification stated that the DAS hardware was to provide at least the following basic functions:

1. Scan and measure at least 500 analog instrumentation signals. An additional 20 channels of output signals shall be provided. Expansion to at least 1500 channels shall be possible without hardware modification to the existing units.
2. Measure instrumentation signals, and linearize, compensate, and convert these into appropriate engineering units.
3. Measure, store, retrieve, reduce, analyze, display, and transmit to remote terminals via line modems, experimental data and status reports at preprogrammed intervals or on request by a user.
4. System scanning and measuring units shall be remotely operated and controlled at distances up to 1000 m. The remote units shall be operated by either of the two data acquisition system controllers via either of the two instrumentation communication buses. The DAS controllers shall be general-purpose minicomputers.
5. Low- and high-level, static, analog signals in the form of ac and dc voltages, ac and dc currents, and resistances will be generated by rock mechanics instrumentation and radiation monitoring equipment (LLNL-supplied) and shall be accurately measured by the DAS.
6. The scanning and measuring units shall interface directly to and be completely electrically and mechanically compatible with the IEEE 488-1975 instrumentation bus. All hardware necessary to increase the effective length of the bus to 1000 m shall be provided. The bus shall be rack-mountable and have slide-rail kits.
7. The DAS shall monitor selected channels as programmed, actuate remote controls, automatically establish telephone links to remote stations (at distances >50 km), and transmit alarms when established set-points are exceeded.
8. DAS controllers shall be operable and programmable from both local and remote terminals via telephone line modems.
9. The DAS shall permit program development and execution of various numerical codes independent of and simultaneously with data acquisition functions.
10. Once programmed, the system shall operate automatically without user response unless desired. The system shall be located in a remote area and shall not always be manned.
11. In the event of a power failure, the system shall automatically return to normal operation after restoration of power.

12. The DAS shall consist partly of two subsystems running parallel, which interact with each other, yet which can perform alone in the event the other subsystem malfunctions. For this reason, dual controllers and independent peripherals, communication buses, and measuring equipment shall be provided. Subsystem "stand-alone" capability shall be used whenever feasible to minimize the possibility of total system failure.

3.3 SOFTWARE

DAS software was specified to minimize total system and applications development costs, and to support a strong and expandable instrumentation system, as previously defined. Also important was integrated documentation for a standard commercial system that had been proven by others. The software was to provide at least the following:

1. The operating system (OS) shall constitute a collection of programs that act as an interface between the machine hardware and the user, simplifying the design, debugging, and maintenance of programs. The operating system shall also control the allocation of resources to ensure efficient operation.
2. The OS shall fully support use of FORTRAN, as well as Assembly language programs. All hardware interfaces shall be fully supported with FORTRAN-callable routines. It shall be possible to execute concurrently, on a priority basis, multiple mass-memory-resident FORTRAN programs that have been broken into several sections or overlays sharing common data areas and several smaller, memory-resident programs activated by interrupts.
3. All programs shall be capable of being modified, reassembled and linked on the system as configured. The software shall handle all I/O devices supplied by the seller with the system. Specific applications software will be developed by LLNL.
4. The OS shall allow programs to be either disc-resident or CPU-memory-resident. The OS shall allow the user to partition the CPU memory. The OS shall provide memory-protect fences between those partitions. The fences shall prevent user programs from gaining illegal access to these partitions. The OS shall allow the user to

define two classes of partitions (each class may have many subpartitions)--background and foreground (real-time programs).

5. The OS shall be capable of automatically exchanging programs between disc and CPU memory. This feature shall simulate simultaneously resident physical memory in all disc-resident programs. All programs shall be hardware-protected so that it is impossible for a user to overwrite the OS while in a protected status.
6. The system shall include a file management package to control manipulation of files on all mass storage devices. The commands shall be executable either by operation from the system console or by program control, and be accompanied by a series of error messages informing the user of illegal action, and preventing accidents.
7. FORTRAN IV and Assembly language[s] must be made available as standard packages. Provisions must exist for program overlay and chaining, task scheduling, string handling and processing, and comprehensive I/O capability to any system device.
8. Subroutine libraries shall be supplied to support standard mathematical calculations and scientific instructions.
9. The system software shall contain real-time I/O drivers to support all peripherals and peripheral interfaces.
10. An interactive editor shall be provided for the creation and modification of source programs.
11. A data base management system (DBMS) shall be provided to allow logical access to data independent of physical data base structure.
12. A comprehensive graphics plotting package is to be provided, displaying graphs, tables, and program listings, and producing hard copies of those displays.
13. A distributive network communications system shall be provided for exchanging information between the interconnected DAS controllers. The system is to be capable of supporting at least four computers of the type supplied without software modification. The link shall allow remote program task scheduling/communications, file manipulation, and data base access.
14. Diagnostic and maintenance routines are to be made available to exercise and troubleshoot all hardware.

15. A complete set of reference manuals shall be provided for use by a system programmer. These manuals shall clearly and completely describe all CPU instructions and timing, I/O and interrupt techniques, peripheral instructions, and other programming techniques for efficient operation of the system.

4. SYSTEM CONFIGURATION

4.1. GENERAL

During July of 1978 a specification (LES 22179, Rev. A) was completed for a data acquisition system to monitor and record the test data from the instrumentation. Quotes were requested from potential vendors and, of the 14 vendors solicited, only Hewlett-Packard responded with a bid. Subsequently, a purchase order was placed in November with Hewlett-Packard for an HP Model 1000E minicomputer-based data acquisition system.

The specification detailed a complete, stand-alone system that measures, digitizes, converts, and archives test data. Both hardware and software features were called out. The principal reason for requesting an entire system in one specification was to ensure that each component would be easy to integrate into the system.

During April of 1979 the system was delivered to LLNL, where it was installed and brought on line, ready for application code development. The following paragraphs describe the current (as-built) system, which has been modified slightly from its original configuration. Several additional pieces of equipment have been purchased during the past few years to supplement the original package, increasing the total system capacity and capability.

4.2. HARDWARE

4.2.1. On-Site Data Acquisition System

In its current configuration, the DAS meets or exceeds the original design criterion set forth in the specification. Figure 2 shows that the system is built around two Hewlett-Packard 21MX (HP 1000) disc-based computers. Each on-site unit has the following hardware:

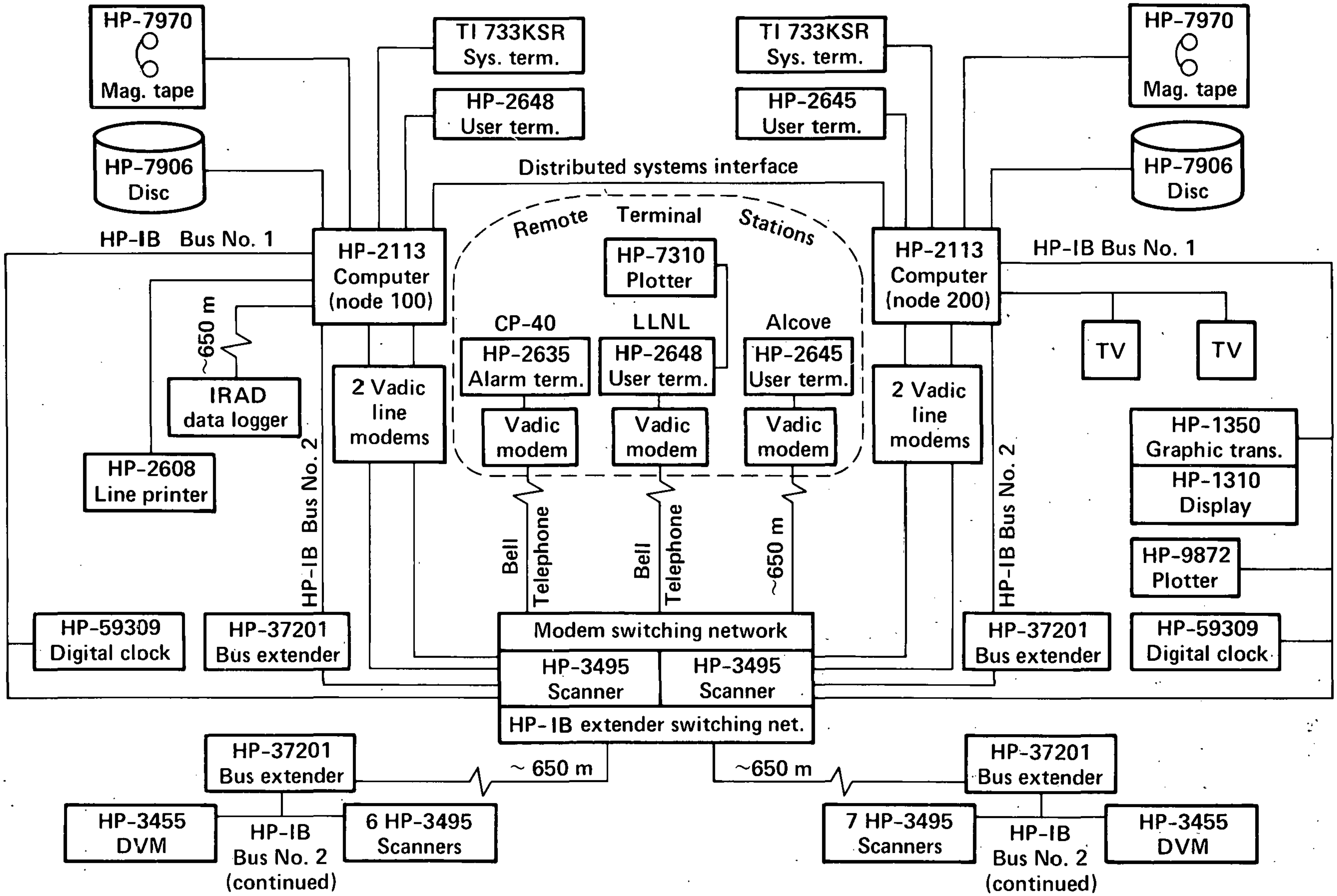

Figure 2. SFT-DAS hardware configuration.

1. HP 1000 Model 2113 16-bit E-Series mainframe for high-performance, real-time systems applications with 320 K words (expandable to 1.024 M words) of standard performance fault control memory, fast FORTRAN processor (FFP) firmware, and distributed system interface (DS/1000) firmware. Two HP-IB instrumentation buses are provided by the HP-59310 printed-circuit arrangements (PCA). One bus is dedicated to surface instruments and peripherals; the remaining bus is dedicated to data ingestion by the downhole acquisition hardware.

   The CPU is capable of executing 1 million instructions from its base instruction set or up to 80,000 floating-point instructions/s. The memory cycle has a standard speed memory of 595 ns, and is capable of direct memory access transfers at up to 1.8 million bytes/s. The HP 1000 computer is also microprogrammable, affording the user flexibility in defining a specialized instruction set. The CPU interface plane allows interfacing of up to 14 independently bused I/O channels (expandable to 46 I/O channels).
2. HP-7906 cartridge disc unit providing 19.6 megabytes of storage, half of which is on a removable disc cartridge. It has an average access time of 33 ms and a maximum data transfer rate (through direct memory access) of 937.5 K bytes/s. The disc is protected by a dual air filtering system. The device is hardware-interfaced via the HP-13175 PCA and HP-13037 disc controller.
3. Texas Instruments-733KSR printing system terminal. The "dumb" terminal is capable of communicating at either 110 or 300 baud and is interfaced by the HP-12966 PCA.
4. HP-2645/8 user-display terminal with dual mini-cartridge tape-drive units. Communication rates are selectable from 110 to 9600 baud. Built-in terminal features include reverse video, blinking characters, block mode, scrolling, cartridge control, and programmable function keys. The HP-2648 also provides graphics capability. Both terminal models are interfaced via the HP-12966 PCA.
5. HP-7970 9-track, NRZI, 800-BPI, 45-IPS digital magnetic tape unit. Read/write data transfer rates of up to 36 K bytes/s are attainable using direct memory access. The device may be interfaced directly to the CPU (master configuration) via the two-card PCA HP-13181 interface, or may be configured as a "slave" off a master unit. A maximum of three slaves may be configured.

6. HP distributed systems interface via the HP-12665 PCA. The computer networking capabilities provided are described in section 4.3.1.2 of this report.
7. HP-IB (IEEE-488) instrument interface (bus 1) to HP-59309 digital master clock with one-year battery backup, and HP-3495 scanner. The clock displays month, day, hour, minute, and second and will, on command, output time via the interface bus. Time can be set into the clock manually, or by remote commands received from the HP-IB. The auxiliary power supply is an HP-K10-59992 that can sustain the clock for up to one year. The scanner utilizes two 10-channel relay actuator assemblies for use in the modem switching and extender switching networks.
8. HP-IB (IEEE-488) instrumentation interface (bus 2) with HP-37201 bus extenders to an HP-3455 6-1/2 digit, high-resolution digital voltmeter (DVM) and HP-3495 80-channel scanners to provide the downhole data acquisition multiplexing hardware. At present, computer node 100 utilizes 6 scanners and node 200 utilizes 7 scanners. Both are expandable to 13 scanners totaling 1040 channels each.

   The bus extenders lengthen the downhole bus from 20 to 1000 m over twisted wire pairs, or infinite distances over modem. They transmit up to 38 HP-IB characters/s, and are transparent to the programmer in most cases. In its actual configuration, the extenders transmit data over twisted line pairs between the computer and the instrumentation alcove.

   The DVM is microprocessor-controlled and capable of measuring dc and ac voltage and 2- and 4-wire resistance. Although the instrument is capable of making these measurements over a broad range of scales, the scientific data most heavily depends on dc voltage readings in the millivolt range and on 4-wire resistance readings in the 125-Ω range. For this use the DVM guarantees measurements to 1 μV and 0.0042 Ω with 90-day drifts not to exceed 4 μV and 0.005 Ω, respectively. Resolutions are specified at 1 μV and 0.001 Ω.

   The scanners are versatile HP-IB instruments that can switch any analog input signal to an appropriate measuring device (i.e., the DVM). They can also control external devices with relay actuator closures. Any combination of five relay assembly types may be installed (four low-thermal assemblies and one actuator assembly).

9. Vadic telecommunications system with two modems, two data access arrangements (DAA), and two power supplies. The system operates at 1200 baud and is Bell 103-compatible. The system originally featured the Vadic Multiple Automatic Calling System (MACS), but it presented numerous problems when connected to the typically poor dial-up telephone service available at the experiment site. For that reason, the system was redesigned to incorporate leased-line telecommunication service (type 3002, 4-wire, data conditioned) and a custom modem switching network (MSN) shown in Fig. 2. The network utilizes two HP-3495 scanners and is operated by either computer to eliminate the need for the MACS. Each of the two modem communications ports is interfaced to the CPU by an HP-12966 PCA.

The two computers jointly share (and are capable of independently controlling) the Modem Switching Network (MSN) and HP-IB (bus 2) Extender Switching Network (ESN). Those networks utilize the HP-3495 scanner on HP-IB bus 2 and two LLNL custom-designed junction boxes, LEA-82-1638 and LEA-82-1600, respectively.

In addition, the node-100 computer unit is augmented by the following hardware:

- HP-2608 132-column, 400-LPM line printer for medium-speed printout. Together with the HP-1000 graphics package, it also provides dot-matrix plotting. Two character sizes, six or eight lines/in., are available via front panel function controls, and are programmable from the computer. The device is hardware interfaced via the HP-26099 PCA.
- IRAD Stressmeter Datalogger with two 10-channel switch modules. The system operates at 300 baud and is interfaced by the HP-12966 PCA.

The node-200 computer unit is augmented by the following hardware:

- Two remote 17-in. Conrac TV-system status monitors. The devices are parallel-connected and interfaced by the HP-91200 PCA.
- HP-9872 4-pen graphics plotter interfaced by HP-IB bus 1. The device offers five built-in character sets plus user-definable characters and an on-board microprocessor that responds to 38 different commands. Pen speed is programmable, as is pen color.

- HP-1310 large-screen, high resolution graphics display interfaced via a HP-1350 graphics translator on HP-IB bus 1. The display provides high picture quality and dynamic performance required for complex high-density computer-generated graphics. Any on-screen movement can be made in less than 500 ns.

4.2.2. Remote Communications Stations

Three remote terminal stations are shown in Fig. 2. The CP-40, NTS Radio Network Control Center operates with a Vadic modem and DAA, and an HP-2635 printing terminal. The station, which is manned 24 h/day, functions as an alarm communications center. The terminal is a printing type capable of running at speeds up to 9600 baud. However, the modem interface communicating with the experiment site limits its use to 1200 baud. The features of the terminal include bidirectional printing for efficient throughput and a choice of 5, 10, or 16 characters/in. All functional features are programmable from the computer.

The LLNL station is located in a room adjacent to the project personnel at Lawrence Livermore National Laboratory in Livermore, CA. The station operates with a Vadic modem and DAA, an HP-2648 graphics display terminal with dual mini-cartridge tape-drive units, and an HP-7310 graphics plotter. Built-in terminal features include reverse video, blinking characters, block mode, scrolling, cartridge control, programmable function keys, and graphics capability. Again, communications are modem-limited to 1200 baud. The graphics plotter provides hardcopy output via the terminal.

The third station, located downhole in the instrumentation alcove, functions as a work station. It operates with a Vadic modem and DAA, and an HP-2645 display terminal with dual mini-cartridge tape drive units. This work station operates in the same way as the LLNL station, but without graphics and hardcopy capability.

4.3. SOFTWARE

The DAS software consists of both Hewlett-Packard standard and special system software, and LLNL-developed special applications software. Because this report documents the design of the central Spent Fuel Test data acquisition system and its support facilities, we will not discuss the operation of the special applications software in detail. Rather, the interested reader should refer to the Spent Fuel Test--Climax Data Acquisition System Operations Manual. This section considers: 1) the system software that lends integrity to the DAS; and 2) the requirements, constraints, and design of the special applications software.

4.3.1. System Software

4.3.1.1. Operating System. The disc-based operating system supplied by Hewlett-Packard for the management of the general operations of the HP 1000 computer is the Real-Time Executive-version IVB (RTE-IVB). Major system features include

1. Event-driven, time-slice, and batch programs in same system.
2. Protected file domains.
3. Interactive help facility.
4. Management of up to 64 disc-resident multi-user program partitions in up to 2.048 megabytes of memory.
5. Nonexchangeable memory-resident programs.
6. Up to 54 K bytes/partition for the user program code, independent of physical memory used by the operating system and drivers.
7. User-addressing extended memory area for data limited only by available memory.
8. Support for 32-bit integer and 64-bit floating point.
9. Support for 4.9, 14.7, 19.6, 50, or 120 M byte system discs.
10. Batch-spool monitor for single-stream, multi-job batch processing.
11. Concurrent execution and development of FORTRAN IV, Assembly and PASCAL programs.
12. FORTRAN IV support of program access to large data arrays.
13. Interactive debug package and interactive editor to aid program development.
14. Memory partition and I/O reconfigurability at bootup.
15. Input/output spooling for slow peripherals.
16. RTE drivers and device subroutines for supported peripherals included with the system.
17. Support of IMAGE 1000 Database Management System for more efficient use of data files and easier access to them.

18. Support of multiple instrument clusters connected via the Hewlett-Packard interface bus (HP-IB).

19. Support of DS/1000 software-firmware for communication with other HP 1000 computer systems.

In RTE-IVB, maximum user partition space is 54 K bytes--a capacity undiminished by the physical memory allocated to the operating system, I/O drivers, or resident memory. It may, however, be diminished by table space requirements in very large systems by 2 K bytes.

Through the use of an extended memory area (EMA) capability, data arrays over 33 times larger than the maximum user partition space can be processed by the user's programs in systems with 2.048 megabytes of memory. The area available for data is equal to total physical memory less the memory allocated to the system, I/O drivers, resident programs, and COMMON areas, and the user's disc-resident program. Because all data is in main memory, processing is faster than a disc-virtual memory addressing scheme.

One or more disc-resident programs using exclusive extended memory areas (EMAs) for data processing can be executed concurrently. A disc-resident program using a large EMA may occupy all the space of a large "mother" partition. When that use is completed, other multiple EMA or non-EMA programs with smaller memory space requirements can run in subpartitions of the mother. Thus, large-scale computational needs and extensive multi-user operations can be handled easily in the same system.

The RTE-IVB Operating System provides a session monitor software package that can be installed to supervise the requirements of multiple users, transforming the disc-based system into several apparent systems, each serving one or more users. The system can receive and respond to data inputs, retrieve data, run computations, print reports, or perform other jobs for various distinct users at the same time. In addition to providing several systems in one, multiprogramming makes it easy to match the diverse needs of real-time measurement and control, or automatic test applications.

Programs under control of the RTE system are executed on a scheduled basis. The system tabulates all execution-ready programs in order of assigned priority. Programs are placed into this table by the operator when they are to run on a regularly scheduled basis, when an external event interrupt calls for program execution, or when requested by another program. The scheme offers fine control over which tasks are executed first, and uses 32,767 priority levels. Execution is initiated immediately for the highest priority-scheduled program. Programs may be scheduled on time resolutions as small as tens of milliseconds. If a higher priority program becomes scheduled, that program begins and the current program is temporarily suspended.

The RTE-IVB system provides fast multiprogram access to as much as 2.048 megabytes of physical memory. This is accomplished by a logical-to-physical address translation that uses memory maps and the Dynamic Mapping System (DMS) in the system computer. When it is time for a program to run, RTE-IVB sets up the appropriate map for that program in the DMS. Thereafter, memory addressing through the map is automatic and completely independent of RTE-IVB, although RTE-IVB may modify the map during program execution as discussed in the paragraph on memory management.

In addition to memory-resident program space, RTE-IVB manages up to 64 disc-resident partitions in memory. When a disc-resident program moves to the top of the scheduled list, the system dispatches it in an appropriate partition (after exchanging any program that may be in that partition). Exchanging greatly extends system program capacity while providing fast response for higher priority programs. Such programs do not have to wait for completion of lower priority programs before being granted execution space and time.

Below a specified priority level in the RTE-IVB system, multiple programs assigned to the same priority level can run on a time-sliced basis. Thus, by appropriate assignment of program priorities, the various demands can be assured a fair allocation of execution time, and monopolization of the system by any individual compute-bound program can be avoided. This provides a powerful method for load-balancing the system without affecting the fast response required for real-time process interrupts.

RTE-IVB allows batch operations at a priority normally lower than that used for most time-slicing user programs. These use the RTE-IVB batch-spool monitor (BSM), which usually operates alone at its own priority level, calling on other system resources for job-controlled program development and additional data processing tasks.

RTE-IVB uses the multipriority level, vectored hardware interrupt system of the HP 1000 computer for power fail detection, memory protect violation, parity error, time base interrupts, and for peripheral I/O and user-interfaced equipment. When one or more interrupts occur simultaneously, the interrupt with the highest hardware priority is recognized first. However, the system also remembers the other interrupts, so none are overlooked.

The system also offers a privileged interrupt capability that can be used to bypass normal RTE-IVB interrupt processing for fastest response to interrupts having the greatest urgency or highest frequency.

The integrity of the RTE-IVB system is protected by the following provisions:

1. Auto restart after power failure.
2. "Fence" register protection of the system table areas, driver partitions, COMMON, and base page from program alteration.
3. Dynamic Mapping System protection between the system, memory-resident programs, and disc-resident programs.
4. Write protection of the drivers, system, table areas, and base page.
5. Continued execution on parity error encountered in a user program (hard parity error aborts only the program encountering it; the system notifies operator and automatically downs affected partition until next boot-up).
6. Automatic "downing" (with a message to the operator) of I/O device that fails to respond within a predetermined time (I/O device timeout).
7. Protection of disc cartridges and other resources allocated to session monitor users.
8. Control of command capabilities available to session monitor users.
9. Optional exclusive assignment protection of disc tracks.
10. Optional user and group file domains.
11. Optional security code protection of disc files from unauthorized access.
12. Hardware protection of system memory image tracks on the disc.

An I/O control module manages I/O operations, which proceed concurrently with program execution, using only one I/O driver for each group of similar devices. It performs memory mapping for I/O drivers and also provides:

1. A waiting list of backlogged I/O work for optimal use of each I/O device.
2. I/O timeout capability for detecting I/O conditions that could stall the system.

3. I/O suspension with automatic rescheduling of programs awaiting I/O service so that processing time becomes available to other programs that can perform useful work.
4. I/O buffering that allows a program to initiate an I/O operation, then to continue execution while the I/O is in progress (rather than suspending for I/O completion).
5. Mailbox data exchange (class I/O) allowing designation of specific "mailbox" buffers for device-to-program or program-to-program communication rather than using COMMON.
6. Re-entrant I/O providing for exchange of a disc-resident program with an active I/O request in progress in favor of a higher-priority program and speeding system response.
7. Exclusive assignment of I/O devices that can be used, for example, to ensure that a low-priority program completes its use of a printer without having that use pre-empted by another program.
8. Automatic downing of I/O devices on a controller when they encounter an equipment error that could stall the system, without affecting other devices on the same controller.

The disc-based real-time multiprogramming design of RTE-IVB enables on-line program processing to occur simultaneously with real-time operations. All program development and loading is done from disc files, so there is no restriction on multiple use of any program development facility. Special commands provide for easy compile (or assemble) and load operations. Program development in RTE-IVB is supported by the following standard and optional disc-based software:

1. RTE FORTRAN IV compiler, which provides automatic generation of map request for EMA programs.
2. RTE assembler, which includes the ability to facilitate preparation of programmer-initiated mapping subroutine calls for EMA programs.
3. Cross-reference generator.
4. Relocating loader.
5. Batch-spool monitor.
6. Interactive debug package.
7. Interactive text editor.
8. Real-time I/O drivers for peripheral subsystems.

A number of utilities such as system generation, disc-save-and-restore, and development are also provided by the RTE-IVB utilities package.

4.3.1.2. Network Communications. The CPU to CPU communications package supplied for the 2-computer SFT-C network is the Hewlett-Packard Distributed Systems (DS 1000-IV) software-firmware package. DS 1000-IV software and firmware provide an integrated set of high-level network facilities and procedures for HP 1000 computer systems. These facilities and procedures support network resource-sharing, distributed data file management, communication between application programs, and the coordinated distribution of processor workloads to other HP 1000 systems.

DS 1000-IV software and firmware supports hardwired or modem network connections between HP 1000 systems operating under the HP disc-based RTE-IVB operating system. Some of the general features of DS 1000-IV are

- Generalized network architecture.
- Network-wide nodal addressing with store-and-forward for maximum configuration flexibility.
- Firmware driver optimized for concurrent servicing of multiple hardwired or modem lines with error correction.
- Remote system generation and remote program development and testing.
- Remote command processing between network nodes.
- HP 1000 virtual terminal capability.

Within a network of interconnected HP 1000 computers or systems, each system is assigned a unique node identification number by the user. Remote operator commands and user program requests reference the number(s) of the node(s) to which they are directed.

Node numbers for network connections are specified after an RTE operating system has been generated and loaded. A network routing vector (NRV)--specifying the logical unit (LU) number through which any transaction travels to get from the local node to the target node--can be generated interactively or read from a network description table (NDT) file at each node. An NDT specifies every connection in the network and consists of a list of the NRVs residing on each node.

The NRV describes a single communications path between any two HP 1000 nodes regardless of whether there is a direct, neighbor connection between them. Store-and-forward communications are not limited to a specified number of levels.

Nodal addressing with store-and-forward offers important advantages. Hardwired or modem-based lines can be shared in a string or ring configuration, reducing initial costs for hardwired connections or operating costs for data communications. A program can be written, debugged, and tested in one node and then transported to any other HP 1000 node in the network while accessing the same local or remote peripheral logical units, or slave application programs. Finally, no user application programs are required to perform store-and-forward functions on any node.

DS 1000-IV remote command and processing make it possible for a user at a local terminal to interactively access any HP 1000 system in the network. Using high-level distributed system calls, a FORTRAN, PASCAL, or Assembly language program in an HP 1000 node can initiate a data exchange with a named FORTRAN, PASCAL, or Assembly language program in a remote system.

Multiple program-to-program (PTOP) data exchanges can be concurrently active on the same network connection, and one program can also communicate with more than one remote node simultaneously. High-level DS 1000 calls can be used to define, access, control, and query the status of named files in remote systems. This capability facilitates the establishment, maintenance, and use of distributed data files.

Programs in an HP 1000 system can make calls to the system executive of remote systems to write to, read from, control, or get status of I/O devices. Other calls can be used to request partition and/or program status, schedule programs with or without wait, request system clock time, and to set execution intervals or start times of a program. A single node can concurrently service multiple system-executive request calls.

The FORTRAN IV formatter for RTE systems works with DS 1000 subroutine RMTIO, supporting locally programmed FORTRAN read/write statements so that any logical unit (LU) specified peripheral device can be read from or written to at any specified remote node.

DS 1000-IV also supports remote program development and remote system generation. A number of other system communication utilities are also provided.

4.3.1.3. Data Base Management. The Data Base Management System (DBMS) supported on the HP 1000 computers is IMAGE 1000, a subset of IMAGE for Hewlett-Packard's business machine HP 3000. IMAGE provides a centralized facility for the storage and retrieval of administrative-type data about tests. The primary advantage of IMAGE is that it provides a standard way to structure and access a data base shared by multiple-application programs. To some extent IMAGE reduces data redundancy and the possibility of developing inconsistent data. It also simplifies the maintenance of data management programs. Using a DBMS should result in reduced software costs.*

4.3.1.4. Graphics Software. The Hewlett-Packard GRAPHICS 1000 software consists of a set of semi-easy-to-use graphics subroutines for HP 1000 Computer Systems. The subroutines are capable of interfacing a variety of graphics devices to a user-written graphics application program.

The graphics plotting software features:

1. 56 graphics subroutines.
2. Device-independent syntax.
3. Graphics subroutines callable from FORTRAN IV, real-time BASIC, or HP RTE ASSEMBLER.
4. Ability to support both vector and raster graphics devices.
5. Declaration of graphics device may be deferred until program execution.
6. Simultaneous multiple graphics device capability.
7. Modular design for efficient use of memory.
8. Output subroutines for drawing points, lines, and characters.
9. Input subroutines for cursor information.
10. High-level functions for data plotting that include axis and grid drawing and labeling of graphs.
11. Descriptions of pictures in a user-defined coordinate system.
12. Absolute plot size control.
13. Support of special attributes of selected graphics devices.
14. Software-generated text.

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* To speed up the processing phase of data acquisition, the IMAGE 1000 Data Base Management software package supplied by Hewlett-Packard has been eliminated in favor of a much simpler custom system formulated by LLNL programmers. The new system reduces program size by as much as 30%, reducing the time needed for processing by better than half.

A graphics application program may be viewed by the programmer as consisting of three main levels. The first level is the user-written application program and application-dependent subroutines. The second level is the set of application- and device-independent "primitive" graphics subroutines. The third level consists of the "device" subroutines, which interface the second level with the selected graphics devices and associated RTE drivers.

The GRAPHICS 1000 software consists of a complete set of primitive graphics subroutines (second level) for most graphics tasks and device subroutines (third level) for the supported graphics devices. Also included is the device-select and communication linkage for interfacing Levels 2 and 3.

The device-select and communication linkage modules interface the device-independent and dependent modules. Functions performed by the device-select and communications-linkage modules are parameter checking, error detection, parameter conversion, and other general-purpose utility functions.

Device subroutines are used to perform all the device-dependent processing. The most important function is to translate from the device-independent functions to the specific-device protocol and back. In some cases, features not available in hardware are created in software by the device subroutine. A separate device subroutine is needed for each type of graphics device being used.

4.3.1.5. Input/Output Interfaces. The Spent Fuel Test--Climax Data Acquisition System utilizes a number of standard Hewlett-Packard input/output (I/O) interface drivers and three that are custom. This section documents the use of those drivers.

Hewlett-Packard has supplied the following standard drivers as part of the SFT-C DAS system software:

1. DVA05 is the general-purpose intelligent terminal I/O communications software interface. The driver provides full-duplex asynchronous modem support for the BELL 103 or equivalent type modems. A hardware interface is provided via the HP-12966 buffered asynchronous data set PCA.
2. DVB12 supports the HP-2608 line printer.

3. DVA13 and a library of graphic display subroutines supplied with the RTE-IVB OS for the HP-91200 TV interface PCA are used together to program display information on one or more black-and-white or color television monitors. DMA is required.
4. DVR23 controls the read/write/control functions of the HP-7970 9-track magnetic tape unit. DMA is required.
5. DVR32 communicates with the HP-7906 19.6-M-byte disc cartridge unit via the HP-13037 disc controller. DMA is required.
6. DVR37 is the general-purpose driver for the HP-59310 interface bus (HP-IB).
7. DVP43 is utilized by the power-fail recovery option of the RTE-IVB Operating System.
8. DVA65 provides the communications path by which the DS 1000-IV Distributed Systems network operates.
9. DVV00 is provided as part of the DS 1000-IV system. The driver supports the system's remote I/O mapping feature.

The nonstandard I/O drivers provided by Hewlett-Packard include:

- DVS51, the Vadic Multiple Automatic Calling System (MACS) software interface. Since the MACS has been replaced as noted in section 4.2.1., DVS51 is no longer configured into the system.
- DVS71 is a high-speed software interface to the front-end data acquisition hardware located down-hole in the instrumentation alcove. The hardware interface is via the HP-59310 PCA.

Applications programmers at LLNL have provided a dumb terminal I/O driver. That driver (DVB00) is used to interface the Texas Instruments 733KSR Silent 700 System printing terminals and the IRAD datalogger. Hardware interfacing is done via the HP-12966 Buffered Asynchronous Data Set PCA.

4.3.1.6. Diagnostics. Hewlett-Packard has supplied a set of diagnostic software capable of exercising the entire data acquisition system, including (but not limited to) I/O drivers, hardware functions, and assembler op-code functions.

4.3.2. Applications Software

As was noted previously, the technical measurements program of the Spent Fuel Test--Climax required a data acquisition system that could be used over an extended period of time (~5 to 7 years) to acquire and process data from a large number of thermocouples, stressmeters, and other more sophisticated devices. The system was to be usable by personnel with a scientific background, but without in-depth knowledge of computers and their operation. Furthermore, the system was to be located at the remote, normally unmanned experiment site, and was to be completely accessible via telephone line-modem communications. Limited acquired data was to be available at all times for up-to-date analysis and display. Detailed data analysis was to be performed at LLNL in Livermore. Due to the nature of the experiment, excellent data acquisition system reliability was established as being essential in providing a required continuity of data and status of test conditions.

Conceptual design of the special applications software categorized the data acquisition system according to the seven functions it was to perform. These functions included

1. DATA ACQUISITION to control the accumulation of raw data measurements.
2. DATA PROCESSING to collate data measurements (raw data) and convert to engineering units (converted data), update data bases and store to digital magnetic tape for analysis by scientific personnel and archiving.
3. DATA VERIFICATION to identify and facilitate correction of conditions in the DAS or instrumentation, which may adversely affect the quality and quantity of acquired data.
4. ALARM to determine out-of-limits measurements and to alert personnel to potential hazards.
5. DISPLAY to output converted real-time data to system-status monitors and hardcopy devices.
6. CONTROL to provide access to system control and conversion parameters.
7. CALIBRATION to provide a means of obtaining instrumentation calibration parameters.
8. MISCELLANEOUS to provide data base access and reporting capability, software documentation reports, system backup and maintenance capability, as well as a host of less significant tools for trouble-shooting.

These functions were to provide the highest possible degree of independence, fostering extreme system reliability, and ease of maintenance and trouble-shooting. Menu-driven user interfaces were to be implemented wherever possible to simplify the man-machine communications. Each data channel was to represent one analog instrument transducer, identified by a unique six-character alphanumeric designator, or license plate, for the life of the experiment. Replacement transducers on a single instrument were to be assigned a new designator, thereby affording a means of documenting modification/replacement of front-end transducers. Hence, the likelihood of drawing false conclusions based on instrument behavior due to maintenance or repair is minimized. Since the parameters being monitored are relatively stable in time, high scan rates were not deemed necessary. All references to time were to be recorded as decimal days on the Absolute Julian Calendar, where, for example, 1800 h, Jan. 1, 1980 GMT (Greenwich Mean Time) is day 2,444,240.25 (day transitions are made at noon, GMT). The following paragraphs describe the resulting LLNL-developed special applications software.

4.3.2.1. Acquisition. The acquisition software was designed to measure raw data under all conditions other than catastrophic computer failure since raw data was established as the system's critical product. Even when the system is not 100% operational, it has been designed to still be capable of measuring and writing to digital magnetic tape for later conversion to engineering units and analysis.

In the normal mode, acquisition is equally shared between two computers. If either unit fails due to either hardware or software malfunction, the acquisition modules automatically shift the full load to the healthy computer. That system then issues a series of requests to reboot the failing computer to bring it back to full operation. A log is maintained to show that such an event has occurred.

The interface to the front-end scanners, DVMs, and IRAD data logger is made via one computer program. The module is accessible from both computers via the program-to-program communications feature of the distributed system networking software. The sole interface was established to facilitate trouble-shooting and future expansion; it has proven to do both effectively.

Two other programs share responsibility for data acquisition. The first is a master data acquisition scheduler. It provides a means of turning acquisition on and off, and paces the second program (normally referred to as the scan driver). Tables maintained within the computers define and relate data channels. At intervals determined by the master acquisition scheduler, the scan driver will ingest a scan table containing the following information for each computer's devices:

- Channel logical state (ON or OFF).
- Scan time-interval at which each instrument is to be read.
- Time of last scan.
- Scanner channel to which the instrument is wired.
- Type of reading that must be taken (dc or ac voltage, or 2- or 4-wire resistance).
- Processing algorithm code (processor code).
- List of reference channels required by the processing algorithm.

The main module then checks each channel to determine whether it should be scanned as ascertained by its logical state, and comparisons made among the current clock time, time of last scan, and scan time-interval. If the conclusion is true, the module:

- Builds a sequence of channels to scan based on the list of reference channels required by the processing algorithm.
- Requests that the scans be made.
- Receives the raw data values in response.
- Dispatches those values to the appropriate processor as defined by the processing algorithm code.

For example, consider rod extensometer GCE242. Rod extensometers typically require an excitation supply and from two to seven thermocouples for processing to engineering units. Thermocouples, in turn, require reference block temperature devices (RTDs). RTDs and excitation supplies are independent devices. For this example, GCE040 is the required excitation supply and CET020, CET021, CET022 are the required thermocouples. All thermocouples require RTD008. The sequence of channels to be scanned is RTD008, CET022, RTD008, CET021, RTD008, CET020, GCE040 and, finally, GCE242. A check is made internally to eliminate multiple scans of any one channel within a list. Hence, RTD008 is only scanned once. The time of last scan is updated for each channel scanned and the raw data values are dispatched to the appropriate conversion module to complete the process.

4.3.2.2. Processing. Fourteen processing programs (one for each of 12 conversion algorithm forms), a miscellaneous program, and a system routine accept data packets consisting of channel designator, system acquisition time, and raw data from the acquisition scan driver. On receipt of a packet, these processors retrieve and load the channel conversion parameters from the conversion coefficient tables into the program memory data space. There the coefficients are maintained until modified by a user, thereby eliminating the need for a reload and significantly speeding up the processing function. Those channels with reference channels necessary for processing raw data, such as the rod extensometers and thermocouples, are given access to the acquired data base (described in subsection 4.3.2.8.). The data packet is expanded to include the calculated engineering value and is then passed to a central acquired data processor.

This central processor acts as a focal point for all recorded data. It is here that the acquired data base is updated to maintain a limited availability of up-to-date measurements for immediate user-commanded analysis and display. The data base is organized by data channel with direct access via an indexing scheme based on "logical channel number"--a unique link to the channel designator or license plate. In fact, the entire data acquisition system relies on this logical channel number and incorporates the channel designator only for user convenience (since it is easier on the human memory). The data base is currently configured to maintain each channel's 500 most current data values (the time span of which is obviously dependent on the rate at which each channel is scanned).

The central processor also buffers the acquired data packets for transmission to digital magnetic tape. The buffers are automatically expandable to consume all of a designated portion of the hard disc in the event of tape drive failure. Assuming acquisition of 500 points/h on each of two computers, the data can be maintained for approximately 80 h. Control is provided over the use of tape drives via a man-machine interface. Either of two drives may be used simultaneously or independently. Tape writing may also be suspended by the operator if the units are needed for other purposes.

The tape drive is interfaced by a single program, consistent with the philosophy of independence between the various facets of the system. That program writes data in blocks of 176 data packets, each containing eleven 16-bit words. The scheme provides high tape-use efficiency during recording, and high reading efficiency at LLNL. An actual "write" consists of a 2000-word write to verify tape availability, a record backspace, a data write followed by an end-of-tape (EOT) sentinel, and a backspace over the EOT. This procedure ensures 100% tape write success. Files are terminated every 24 h. The last data packet written to tape is always maintained so that 1) recovery may be made in the event of a power failure; and so that 2) a definite end of tape is known at all times (necessary for tape exchanges).

In the the first instance, the tape drives are fitted with a special kit that enables complete control over the unit by software, bringing it back on line, rewound to the loading point in case of a power outage. From there the program realigns the tape to the appropriate write position.

As part of a standard operational procedure, the recorded tapes are changed monthly, copied, and stored on site. The copies are then shipped to LLNL for analysis.

4.3.2.3. Verification and Alarming. Three criteria are used to routinely evaluate the quality of data being acquired on a real-time basis. First, the system is checked to ensure that data acquisition is progressing as expected. Second, an alarm log is examined to determine if out-of-range data values are being recorded. System-standard references have been installed with very narrow alarm limits which are exceeded in the event of DVM or other system problems. Third, data from a significant percentage of instruments are displayed or plotted to ascertain whether the data fall within reasonable limits. The first and third criteria are met as a result of system hardware configuration and user-imposed operating procedures, respectively. The second criterion is met using ALARM software developed at LLNL.

Validation of the acquired data is initiated in the central processor. The processor compares each properly recorded and converted data value to high- and low-alarm limits, which are retrieved from the alarm coefficients tables. If, for some reason, the scan driver is unable to measure a requested channel, or if a processor fails to convert raw data to engineering units, the data packet is flagged with a negative acquisition time value. These values are recorded on tape, but do not go through the validation process.

As with the data conversion processors above, these set points are maintained in the program memory data space for efficiency. If the value is found to fall outside its expected limits, the channel is further examined for recurring, contingent, redundant, and/or change-of-status alarms. On final determination of an alarm status, the alarm is logged for processing. Again this relates to our independence philosophy.

An alarm processor periodically examines the alarm log and checks for pending alarms. If there is an alarm, a permanent record of its occurrence is made in an alarm history file. Alarms constructed from a data base of skeleton messages are then independently buffered in automatically expandable files for output to any combination of four devices. After all outstanding alarms have been processed in this manner, the messages are unbuffered and singularly routed to the appropriate device via direct connection or line modem. Alarm output occurs similarly to writing data to tape (as described above) with the omission of record backspacing; each output device is verified before it is used. This is particularly important for remote stations for which line modems are employed. For this case the modem control subsystem is also accessed to obtain a connection.

Upon acknowledgeable receipt of an alarm, the monitor (typically, CP-40, NTS Radio Network Control Center and/or LLNL) follows a procedure that directs him to contact the project personnel, who will respond to the alarm and take action. When a device buffer is emptied, the program then checks the remote computer for any alarms that may be awaiting output, thus assuring 100% message reporting.

Control is provided over the alarm system so that it can be turned on and off, or run in the standard or "auto-acknowledge" mode. Also, alarm destinations can be reassigned via a master controller. Where line modems are concerned, they too can be independently switched on and off. Utility programs exist to examine and list the alarm log and history files as well as the alarm message buffers. Alarm skeleton messages can also be added and/or modified as part of the expansion capability built into the system.

4.3.2.4. Display. An independent set of programs was developed for information display. These include real-time status monitors, historical data-channel graphic routines, and numerous table and data base listing routines. The real-time status monitors are driven by one of two programs that are identical except for the output device to which they write (either a TV monitor or an HP-2645/8 display terminal).

The status monitors feature up to 67 screens of rotating real-time data. Each screen displays the state of 15 channels of instrumentation together with a descriptive header and current date/time line. The channel designator is provided with its most current converted data value and its alarm state (normal, over maximum, under minimum, instrument disabled/under repair.) The age of the measurement is also displayed in minutes referenced to current system time. Over-maximum and under-minimum conditions are shown in inverse video to attract attention. A man-machine interface is provided to control the screens displayed, channels presented on each screen, and rotation pause interval.

4.3.2.5. Control. A wide variety of control utility programs has been developed to provide a man-machine interface to all the subsystems. (Several of these have already been mentioned.) These include the 1) magnetic tape controller; 2) alarm controller; 3) modem controller; and 4) real-time status monitor controller. More important than any of these is the data acquisition controller and the central primary menu-driven user-machine interface.

The acquisition controller is responsible for all data processing. Through this controller the operator commands the system to perform. The controller is menu-driven, the first level providing access to a particular instrument device-"type" (i.e., thermocouple, rod extensometer, excitation supply, or "system"). System devices include subsystems modeled as data channels.

A second tier of the menu provides a means of checking channel status, turning a channel on or off, listing and/or modifying conversion coefficients, adding/substituting/deleting instruments, initializing an acquired data base, and modifying alarm or scan parameters. System devices are normally controlled by the ON/OFF control, or by modifying conversion coefficients.

The primary menu-driven user-machine interface provides simple communications dialog with the data acquisition system. This system greets the user and offers a choice of first-tier menus according to the user's assigned access level. The choices are general in nature. A second tier then allows the user to be more specific about his request before the machine takes over and transfers to the first tier of a program's menu. A "help" package is also provided at each decision point.

4.3.2.6. Calibration. A utility program has been developed to aid in the calibration of instrument transducers. The purpose of the routine is to rapidly obtain a series of measurements under known conditions. The data collected is written on magnetic tape and transferred to LLNL where it is processed. At LLNL a set of coefficients are derived to fulfill the requirements of the processing algorithms discussed above. Those resultant data are transferred back to the data acquisition system and inserted into the coefficient tables, more commonly referred to as the parametric or descriptive data base.

The calibration program features nine options:

- Define or redefine a scan table.
- Interpret or reinterpret scan table.
- Execute current scan table.
- Tabulate collected data.
- Process to engineering units.
- Tabulate processed data.
- Store to calibration data file.
- Tabulate memory.
- Save calibration data file on magnetic tape.

Normally, the options are executed in the order presented above, neglecting the last two. First, a set of channels are specified in a table. The table includes entries for channel identification via logical channel number, logical channel name (i.e., license plate), physical channel number, or scanner channel assignment (i.e., scanner and scanner channel number, which relate to physical channel number.) Entries are also provided for the measurement type to be made (i.e., ac or dc voltage, or 2- or 4-wire resistance), and the processing algorithm code by which the raw data is to be converted to engineering units, if so desired. Reference channel relationships are also defined at this point, as is the number of repetitive measurements to be made per channel. The table is then interpreted.

Table interpretation includes the determination of the physical channel and computer node on which to measure each of the table entries. It also establishes the measurement type and processing codes by consulting the appropriate data base files if the default of a blank entry is encountered. The table need only be interpreted after it has been modified. In fact, termination of the program does not clear the table; it is saved in the event of user error or calibration procedural difficulty.

The calibration measurements are made according to the scan table. The common interface to the front-end scanners and DVM is shared with the acquisition software. Minimal statistics including the minimum, average, and maximum are calculated for each channel scanned. The resultant data is temporarily stored and may be tabulated to the display terminal or hardcopy device if desired.

The raw data may be converted to engineering units according to the parameters currently in the Descriptive Data Base coefficients tables. Although this does not seem to make sense since the object of the calibration routine is to establish those parameters, it is often helpful to do so when calibrating a mechanical device for which thermal compensations are also to be included. For this case, converted temperatures would be utilized while the remaining converted data would be discarded. The minimum, average, and maximum converted values are calculated and may be tabulated at the display terminal or hardcopy device.

The data (when established as quality information) is stored in a calibration data file where it is buffered until transferred to magnetic tape. The storage format and buffering technique, with one exception, is identical to that of the acquired data defined in subsection 4.3.2.2. The exception is that the physical channel number is conveyed for calibration data, whereas the logical channel number is conveyed for acquired data. The utility programs available for examining the acquired data magnetic tape buffers are also applicable to the calibration data magnetic tape buffers.

The "tabulate memory" option is for trouble-shooting. It reports all internal memory tables to the display terminal or hardcopy device.

4.3.2.7. Miscellaneous. A wide variety of program modules have been provided to allow data base access and reporting, software documentation, system backup and maintenance, and trouble-shooting. In all, more than 400 modules have been written to support the data acquisition system; approximately 40% of those support miscellaneous functions.

The most noteworthy accomplishments include a descriptive data base reporting scheme that consolidates all parameterization for one data channel on one page in a report sorted by logical channel name. An automated software documentation procedure has been provided that reports all modules in one report in alphabetical order. Cross indexes are included that relate module and file dependencies. Both of these capabilities utilize the HP 1000 computer system and the larger computing facilities located in Livermore to attain their end result.

System backup and maintenance routines have been designed to incorporate basic utilities supplied by Hewlett-Packard. Trouble-shooting programs have been written to address a host of devices. Particularly important are the routines verifying the operation of the front-end scanners and DVMs.

4.3.2.8. Data Bases. Two major data bases exist within the computers. The first has been commonly referred to as the coefficients, parametric, or Descriptive Data Base. The second is the Acquired Data Base.

The Descriptive Data Base contains all information that defines a data channel, and governs its measurement and conversion of raw data to engineering units. This data base is built in four distinct parts or files. The first is known as the "core" and relates the known physical parameters of the data channels. The information fields are

1. Logical channel number, the linking and indexing parameter used throughout the data acquisition system.
2. Logical channel name (license plate), a six-character convenience designator.
3. Physical device type, specifies conversion processing algorithm.
4. Descriptor string, identifies transducer placement.
5. Wiring, relates transducer connection to scanners.
6. Redundant channel, identifies channels connected to the same instrument transducer.
7. High alarm, high converted value-set point.
8. Low alarm, low converted value-set point.
9. Last status (current alarm status determined by last recorded and converted data value).
10. Alarm destination 1 (alarm destination indicator).
11. Alarm destination 2 (alarm destination indicator).
12. Alarm destination 3 (alarm destination indicator).
13. Alarm destination 4 (alarm destination indicator).
14. Alarm destination 5 (alarm destination indicator).
15. High alarm message (skeleton message identifier).
16. Low alarm message (skeleton message identifier).

17. Contingent channel 1 (identifies contingent alarming channel).

18. Contingent channel 2 (identifies contingent alarming channel).

The second data file is the history file, which manages the control of logical channel names. Channel names must be unique to the acquisition system. As a name is deactivated and/or replaced, its history record is entered into this table. Data field entries exist for:

- Logical channel name.
- Logical channel number.
- Physical device type.
- Date installed, date the transducer was installed on the system.
- Date modified, date the transducer raw data conversion coefficients were last modified.
- Date removed, date the transducer was removed from the system.

The third "coefficients" file maintains the conversion coefficients necessary to the algorithm, which processes raw data to converted data in engineering units. The first data field is always the logical channel number. Subsequent fields vary depending on device type. Linear devices, device type "LD" for example, have data fields as follows:

- Logical channel name.
- Slope, linear coefficient "m" in $y = mx + b + c$.
- Intercept, linear coefficient "b" in $y = mx + b + c$.
- Offset, offset constant "c" in $y = mx + b + c$.

All device types maintain an offset field as the last entry. The current file configuration limits the total field width to 100 16-bit words; rod extensometers use all 100 available words.

The fourth and last file contributing to the descriptive data base is the scan table, which has previously been discussed in subsection 4.3.2.1.

The Descriptive Data Base is configured for 512 data channels per computer, the first 500 of which are available for instrumentation use. The remaining 12 channels are reserved for control of subsystems, as noted above. This data base is modified via the acquisition controller discussed in subsection 4.3.2.5. Copies of both data bases are maintained on each computer to allow the "remote" machine to carry on full data acquisition in the event of a functional failure (see subsection 4.3.2.1.).

The Acquired Data Base has been mentioned several times above; it is currently configured to maintain the 500 most recent records for each data channel assigned to the computer. In the event acquisition fails on a computer, and the full load of the system is transferred to the remote computer, only the data base for those channels local to the operational computer is updated. However, all acquired data is transferred to digital magnetic tape.

5. DAS SUPPORT FACILITIES

During the design phase of the DAS, a decision was made to locate the computers and peripherals in a surface facility, and to locate the front-end scanning and analog-to-digital conversion equipment underground. As much equipment as possible was located on the surface (above ground) to provide ready access for maintenance and repair. However, to achieve greater measurement accuracy and to minimize the cost of long, multiple cable runs to the surface, the front-end DAS equipment was located in an underground electronics instrumentation alcove. (Both the surface and underground DAS support facilities are discussed in the following paragraphs.)

5.1. SURFACE FACILITIES

5.1.1. DAS Trailer

A 6 × 16-m double-width trailer was designed and procured to house the surface-located portions of the DAS system. The facility was delivered and put into position in March of 1980. Figure 3 shows the trailer located about 30 m from the hoist headframe.

There were several objectives in mind when a floor plan was chosen. One objective was to provide a work area for system programmers and users that would be separate from the computer equipment. This would minimize the noise level in the work area and provide a good method for limited access control of unprotected portions of the system. A second objective was to minimize the area where high-reliability techniques would be required to ensure a proper environment for critical components of the DAS system. A third objective was to provide an area for maintenance and office stations separate from the two already mentioned. These objectives, therefore, required a minimum of four separate, partitioned areas. Figure 4 shows the floor plan chosen to meet these requirements.

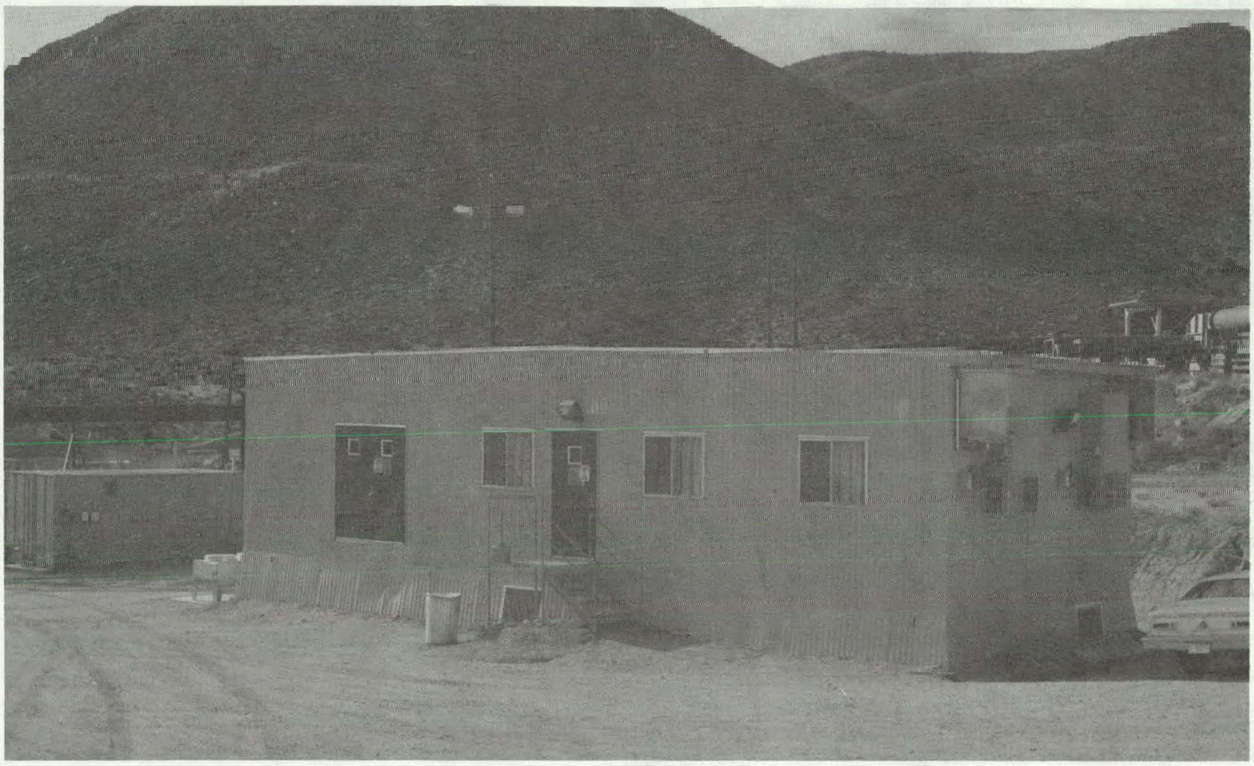

Figure 3. SFT-DAS computer trailer facility.

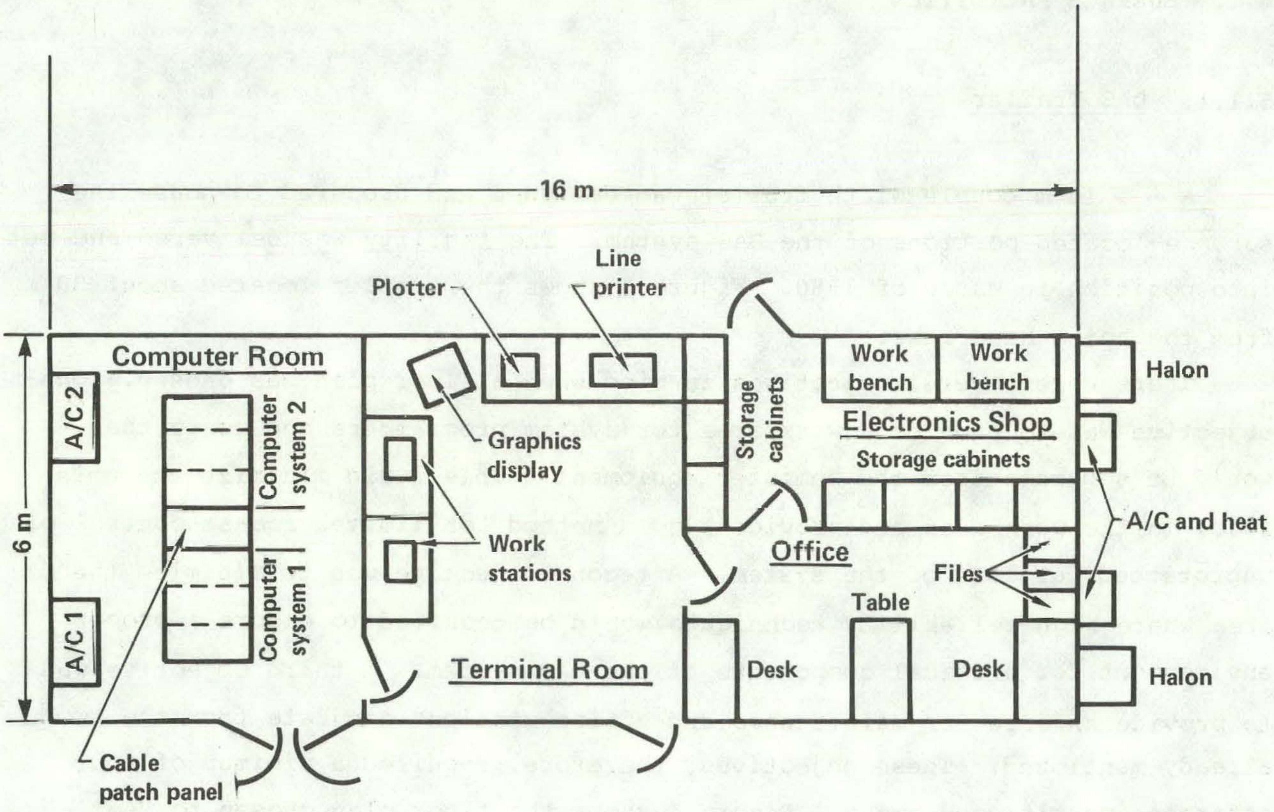

Figure 4. SFT-DAS computer trailer floor plan.

The CPUs, discs, magnetic tape units, clocks and downhole interface units are mounted in racks in the computer room, as shown in Fig. 5. The line printer, terminals, graphics display and x-y plotter are located in the adjacent terminal room as shown in Fig. 6. A subfloor in the computer room contains cable trays for the computer interface cables.

5.1.2. Power Distribution

The power source for the DAS system in the trailer comes from an uninterruptible power supply (UPS) system located in an air-conditioned transportainer adjacent to the DAS trailer, as shown in Fig. 7. Subsection 5.3 describes the UPS system in detail. The UPS feeds a single-phase, 120 VAC line into a distribution (circuit breaker) box in the DAS trailer. From the UPS distribution box, power is distributed to the instrumentation racks in the computer room and to an adjacent wall in the terminal room.

As a result of ground potential problems, isolation transformers were installed between the UPS distribution box and the DAS racks in the computer room. The UPS system provides ultra-isolation from utility power transients. In the event of utility power loss, the UPS will continue to supply power for a minimum of one hour before shutting itself down. There is also a temperature-sensitive, trip circuit that will automatically remove power from the DAS racks if the computer room exceeds a preset value ($\sim 35^{o}C$).

Normal utility power is supplied to the remainder of the trailer to operate lights and air conditioners/heaters.

5.1.3. Environmental Control System

Heating and air conditioning are governed by personnel and DAS equipment requirements. Because of the likelihood of air conditioner breakdown (considering the hot summers at the experiment site), two 60,000 Btu/h air conditioners were specified for the computer room, either one of which could handle the heat load from the room. The two units operate in a lead/lag mode, so that if the lead unit were to fail, the other unit would pick up the load. Integral to those units is a humidity control system. A filtered, pressurized water supply is located adjacent to the DAS trailer in a small metal shed. No heating is provided, because the computer equipment generates enough heat to keep the room at a good working temperature, even during the winter.

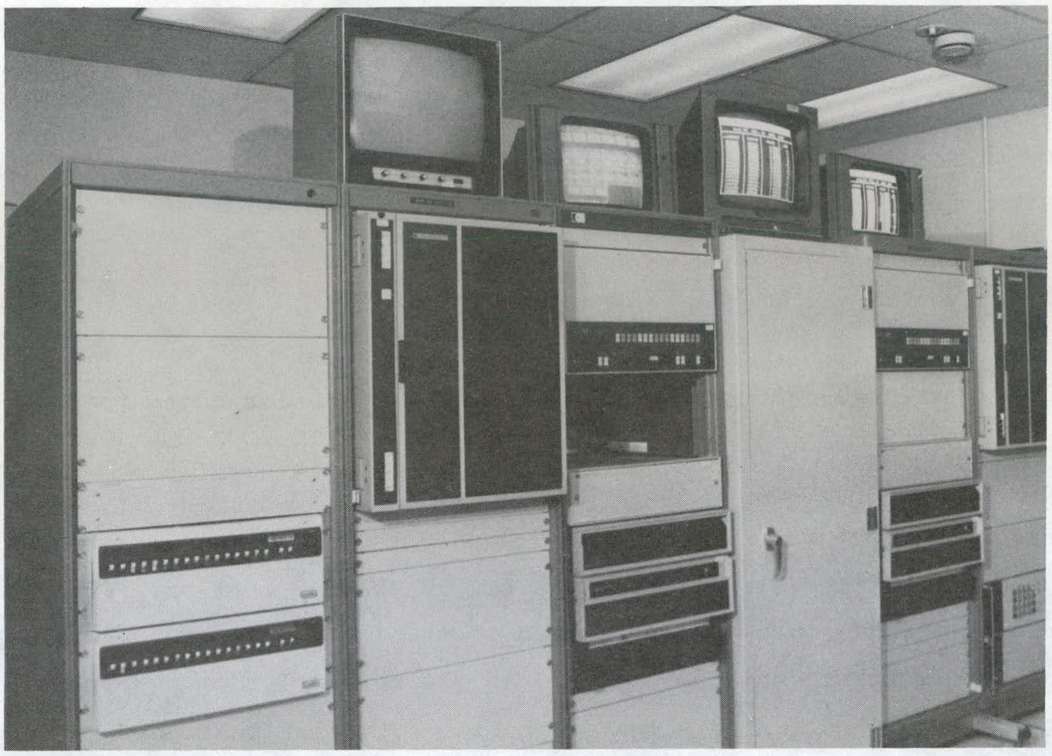

Figure 5. SFT-DAS computer room.

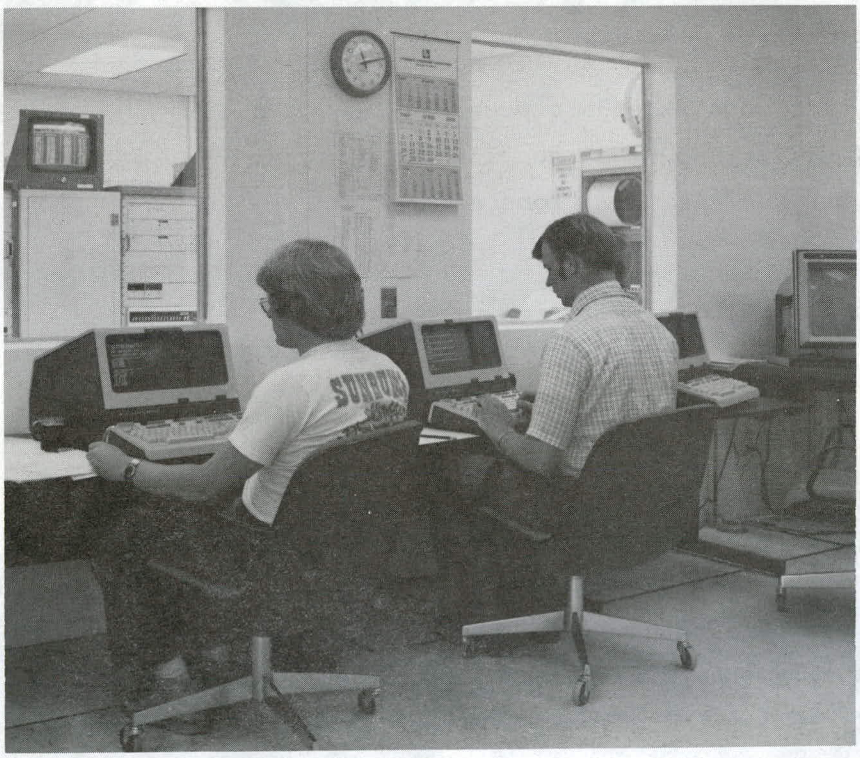

Figure 6. SFT-DAS terminal room.

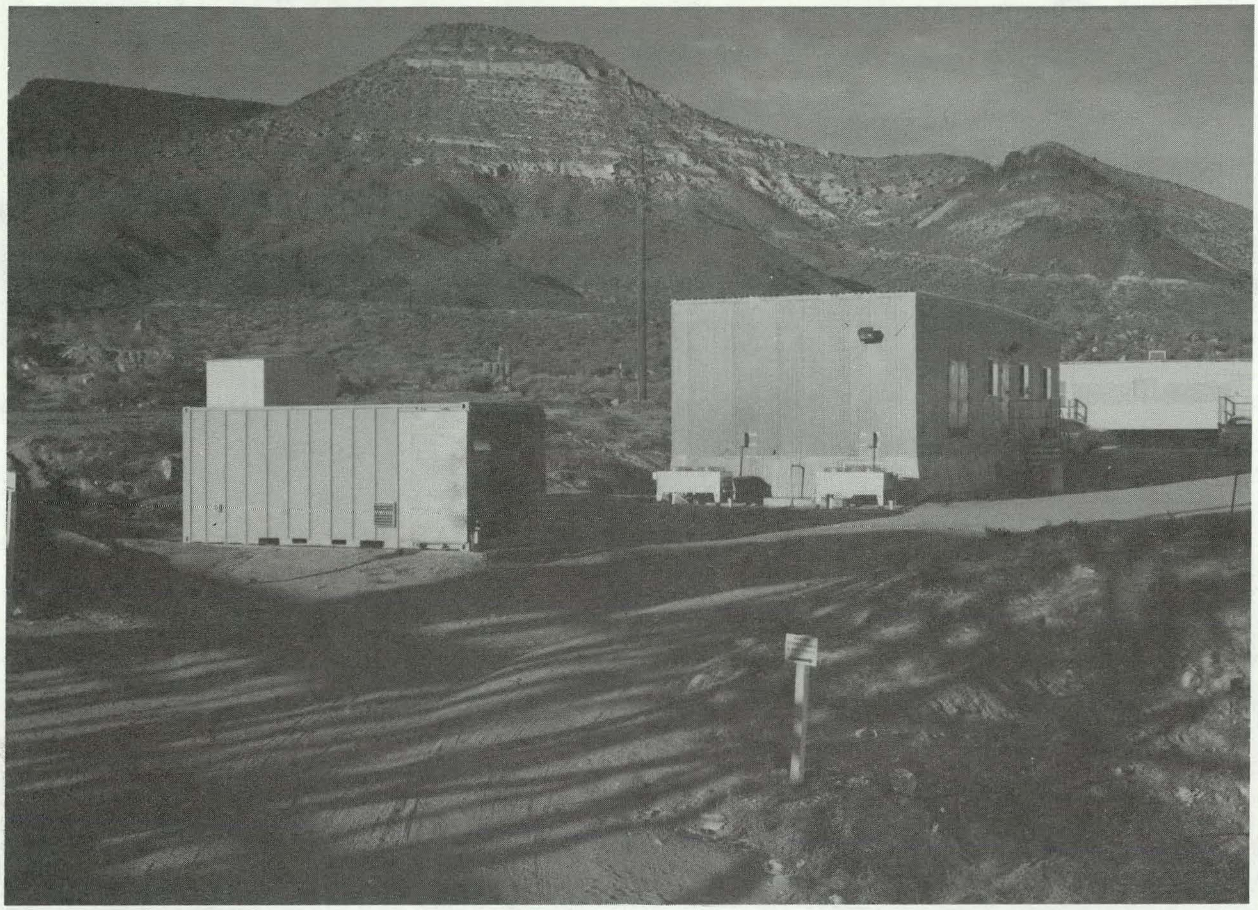

Figure 7. SFT-DAS surface UPS transportainer.

The remaining areas of the DAS trailer are served by two other air conditioning units, which have heater strips for winter operation. The entire installation has proven satisfactory, with the exception of the humidifier water supply, which has suffered numerous malfunctions.

5.1.4. Fire Suppression System

To meet DOE requirements for fire safety in computer facilities at the Nevada Test Site, a Fenwal-Halon 1301 fire suppression system is installed in the DAS trailer. Smoke detectors and heat detectors are used to generate local and remote alarms and to dump halon-filled bottles in the event of a fire. Nozzles are located in each room. Fire walls and fire-rated doors are also used to minimize the spread of any fire in the trailer. The fire suppression system status is monitored 24 h/day at a fire station in Area 12 (about a 15-min drive).

5.1.5. Communications Systems

Ten communications lines connect the DAS computer trailer with remote facilities. These include:

- Two telephone lines providing normal communication capabilities for trailer personnel.
- Four telephone lines providing dial-up modem communications with the DAS. The phone lines operate at 1200 baud and have special data terminators.
- Three dedicated telephone lines that provide leased-line modem communications with the DAS. Line terminations are located at the CP-40 (NTS Radio Network Control Center) in a room adjacent to the project personnel at LLNL in Livermore, CA, and in the downhole instrumentation alcove. The CP-40 and LLNL lines are type 3002, 4-wire, data conditioned, 4800-baud circuits; the alcove line is a twisted wire pair about 650 m long. These services operate at 1200 baud.
- One dedicated lease-line that connects the DAS trailer fire suppression system to the Area 12, NTS firehouse.

An intercom system in the DAS trailer provides communication services with the other surface and subsurface control and work stations.

5.2. SUBSURFACE FACILITIES

5.2.1. Instrumentation Alcove

An instrumentation alcove was constructed downhole to maintain a clean, temperature- and humidity-controlled environment. The facility (shown in Figs. 8 and 9) was mined between two drifts. A 4.5 × 9-m building was constructed there in accordance with fire safety guidelines. Twelve shock-mounted electronics racks were installed. In addition, 10 terminal cabinets were provided on the rear wall. Instrumentation cabling entering the alcove from both the surface and the experiment area is terminated in these cabinets. This arrangement provides flexibility in construction, instrumentation installation, maintenance, and modifications.

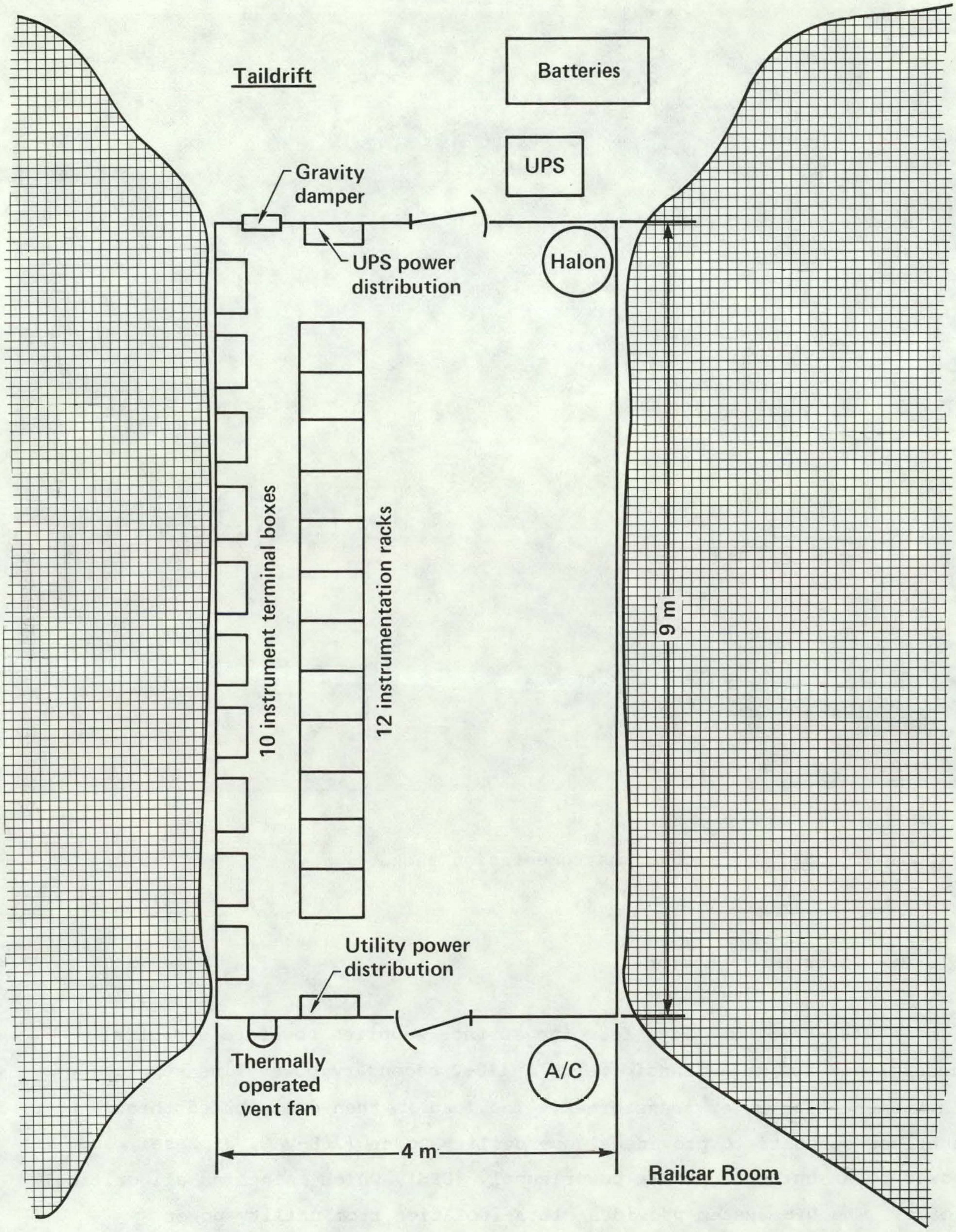

Figure 8. SFT-DAS instrumentation alcove floor plan.

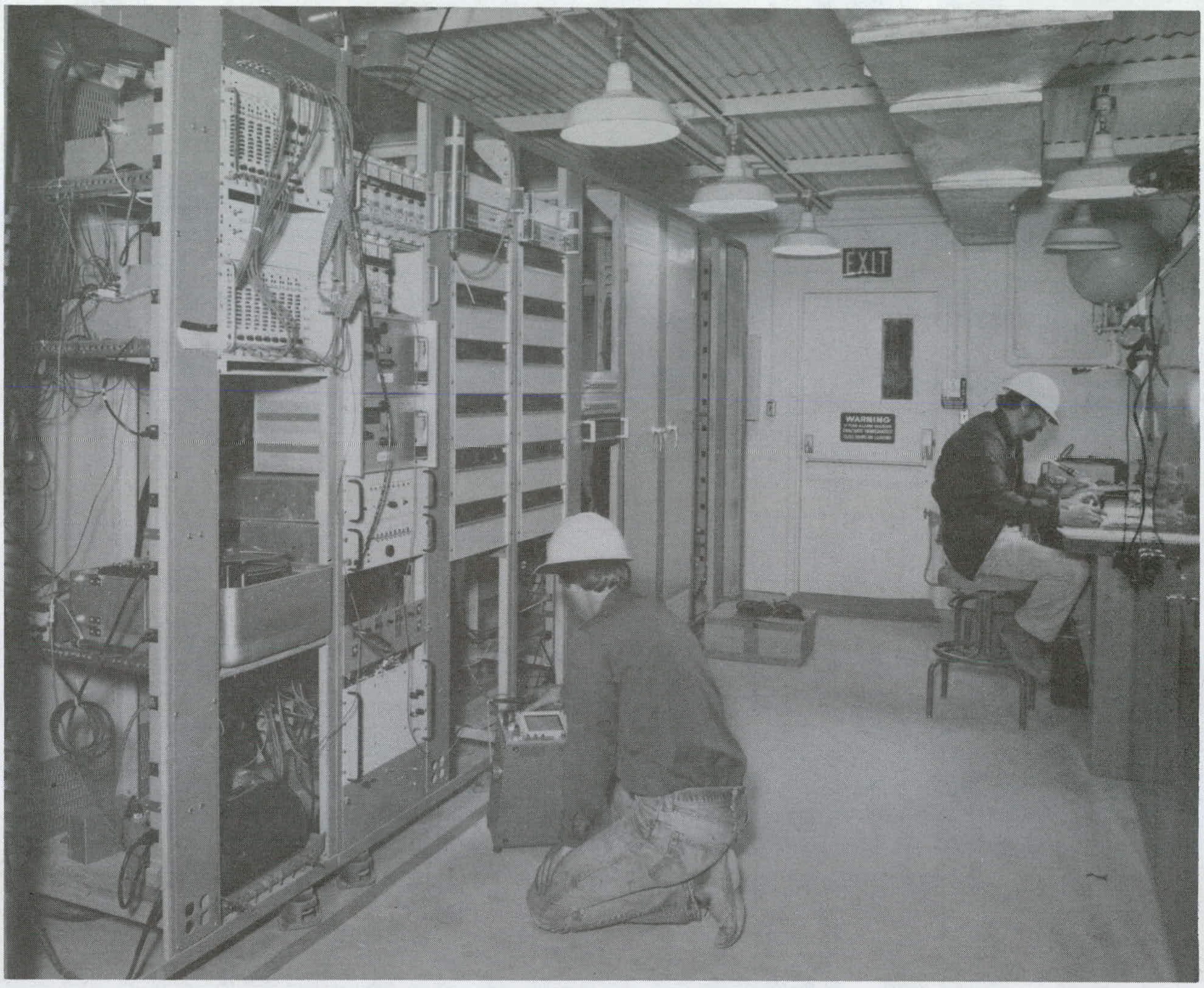

Figure 9. SFT-DAS alcove instrumentation racks.

5.2.2. Power Distribution

A 2400-V 3-phase line from the surface supplies power to a central underground 150 kV A transformer. A 480-V secondary power line supplies an instrumentation power transformer. The load is then distributed through subfloor conduits to provide alcove utility power (208-VAC, 3-phase), and power to an uninterruptible power supply (UPS), which maintains all critical loads. The UPS system provides ultra-isolation from utility power transients. In the event of loss of utility power, the UPS will continue to supply power for a minimum of 2 h before shutting itself down. Section 5.3 describes the UPS system.

5.2.3. Environmental Control System

The alcove temperature is maintained at 23° ± 1°C, as dictated by the instrumentation calibration specifications by a 40,000-Btu/h filtered air conditioning unit. A heating system is not necessary 420 m below the surface, where the temperature remains relatively constant.

5.2.4. Fire Suppression System

A Fenwal-Halon 1301 fire suppression system, similar to that described for the DAS trailer facility in subsection 5.1.4 is installed in the instrumentation alcove. In addition to its alarm function to the Area 12 Firehouse, it incorporates fused links on the alcove ventilation damper system. In the event of a fire, the halon is discharged and all louvre vents close automatically. In addition to a special power circuit, internal batteries ensure the system's continuous operation.

5.3. UNINTERRUPTIBLE POWER SUPPLY SYSTEMS

The Area 15 experiment is located on the end of a radially fed power grid. The history of the power system shows that outages have occurred frequently, but that no unscheduled outages longer than 4 h have occurred in 12 years. The need for uninterrupted power was thus established as a requirement during the design of the DAS.

The Uninterruptible Power Supplies (UPS) are line-powered battery chargers that maintain a bank of back-up batteries at full charge. An inverter system converts the battery dc voltage to 120 V @ 60 Hz. In the event of a power failure, the battery charger can no longer operate and the inverter relies on the batteries for its power source. An advantage to this system is that there is no changeover to another system to cause coupling of electrical noise into the power line delivered to the DAS. Another advantage is the extreme isolation from utility powerline electrical noise.

In selecting an uninterruptible power supply, we focused on several criteria. The UPS systems are unmanned, in a remote location, and subject to mine safety regulations. The units selected (7.5-kW Deltec) have been used on the Nevada Test Site for a number of years, making spare and replacement parts readily available. The units are housed in a seismic cabinet. The units have several status indicators that permit remote monitoring of the UPS operating condition.

Lead-calcium batteries were selected for the backup power source. Lead-acid batteries were rejected due to limited shelf life, and the cost of nickel-cadmium batteries was prohibitive. Hydrogen gas evolution during heavy charging is a mine safety concern that was resolved by installation of vent caps using catalytic action to eliminate hydrogen venting from the batteries. The 180-amp-hour subsurface and the 100 amp-hour subsurface battery capacities provide sufficient resource to endure most utility power outages.

6. REMARKS

As a general rule, all hardware purchased has performed as expected. However, there have been a number of nonconformances related to software. The major problems revealed themselves during system integration and have been resolved. A few insignificant difficulties remain to be worked out. The interested reader should consult the annual Spent Fuel Test-Climax Technical Measurements Interim Reports listed as Refs. 3, 4, as well as future reports, for an update on the status and performance of the DAS.

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