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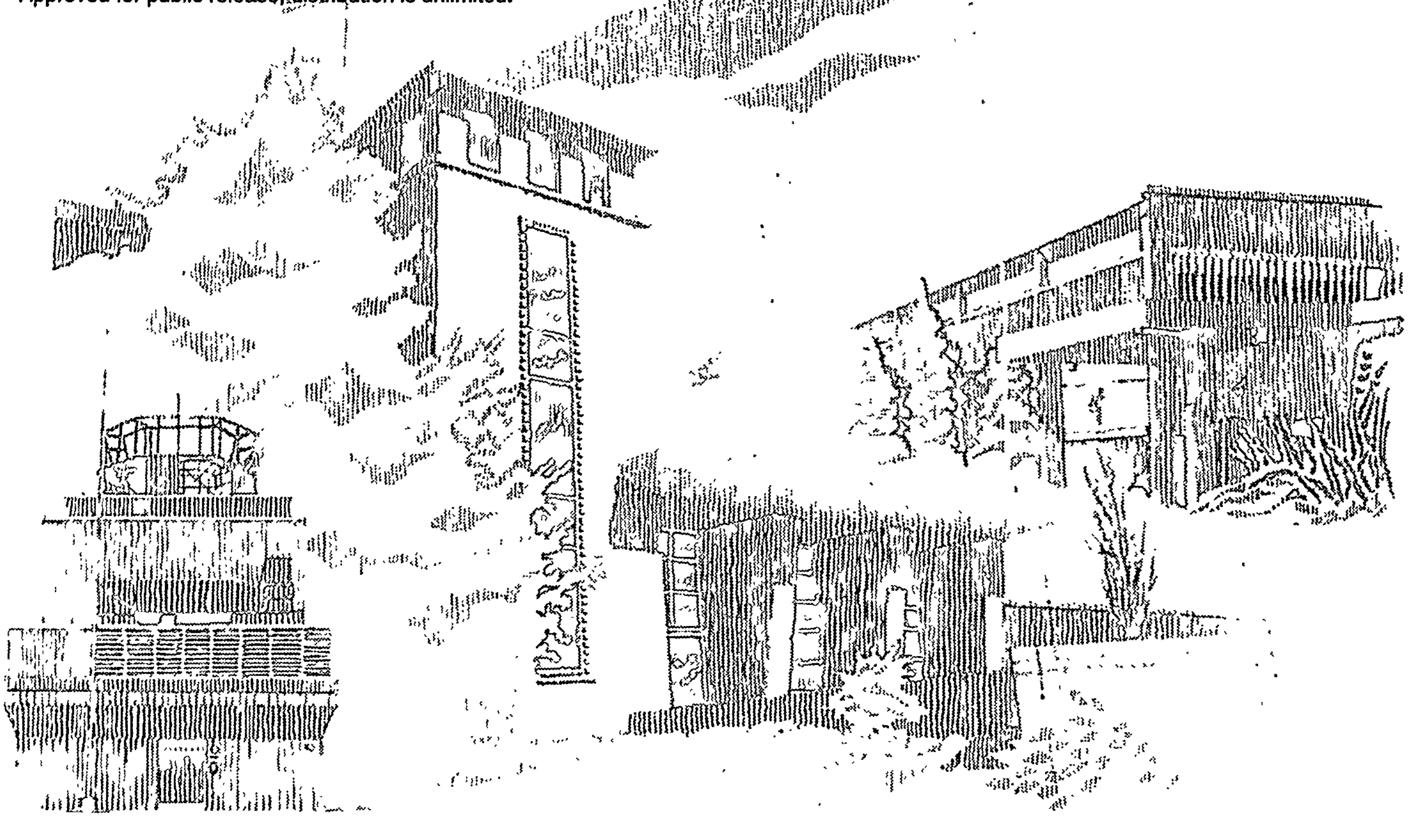
Construction of the Thermal/Structural Interactions In Situ Tests at the Waste Isolation Pilot Plant (WIPP)

Darrell E. Munson, David L. Hoag, Douglas A. Blankenship, Robert L. Jones,
Sally J. Woerner, Glenn T. Baird, Rudy V. Matalucci

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550
for the United States Department of Energy
under Contract DE-AC04-94AL85000



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CONSTRUCTION OF THE THERMAL/STRUCTURAL INTERACTIONS IN SITU TESTS AT THE WASTE ISOLATION PILOT PLANT (WIPP)

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ABSTRACT

The Department of Energy has constructed the Waste Isolation Pilot Plant (WIPP) to develop the technology for the disposal of radioactive waste from defense programs. Sandia National Laboratories has the responsibility for experimental activities at the WIPP and has emplaced several large-scale Thermal/Structural Interactions (TSI) in situ tests to validate techniques used to predict repository performance. The construction of the tests relied heavily on earlier excavations at the WIPP site to provide a basis for selecting excavation, surveying, and instrumentation methods, and achievable construction tolerances. The tests were constructed within close tolerances to provide consistent room dimensions and accurate placement of gages. This accuracy has contributed to the high quality of data generated which in turn has facilitated the comparison of test results to numerical predictions. The purpose of this report is to detail the construction activities of the TSI tests.

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1 INTRODUCTION

In 1981, the U.S. Department of Energy (DOE) began construction of the Waste Isolation Pilot Plant (WIPP) in southeastern New Mexico to develop the technology for disposing of radioactive waste from defense programs. This facility may eventually become a repository for defense transuranic (TRU) wastes, provided the facility is demonstrated to be in compliance with Environmental Protection Agency requirements. Although the complete facility includes both surface and underground construction, Sandia National Laboratories (Sandia) is primarily concerned with the development of the underground portion of the facility.

As shown in Figure 1.0.1, the underground facilities were constructed primarily in three phases: (1) the Site and Preliminary Design Validation (SPDV) construction, consisting of the excavation of two shafts and shaft stations, a limited entry system, the SPDV Test Panel, and an exploratory drift (the South Drift) to the southern extremity of the facility; (2) the expansion of the shaft system and the construction of the Experimental Area, which consisted of the construction and instrumentation of several research and development (R&D) test rooms; and (3) the TRU Waste Storage Area, which consists of panels for the disposal of contact-handled (CH) and remote-handled (RH) waste, if the repository is found to be acceptable. Table 1.0.1 gives a listing of all the acronyms and abbreviations used in this report.

Different underground test programs (Figure 1.0.2), including the Thermal/Structural Interactions (TSI) in situ tests, have been instituted to develop the technology needed for a repository. The in situ experiments and demonstrations consist of several large-scale and many small-scale tests (Figure 1.0.3) which directly address the compliance and

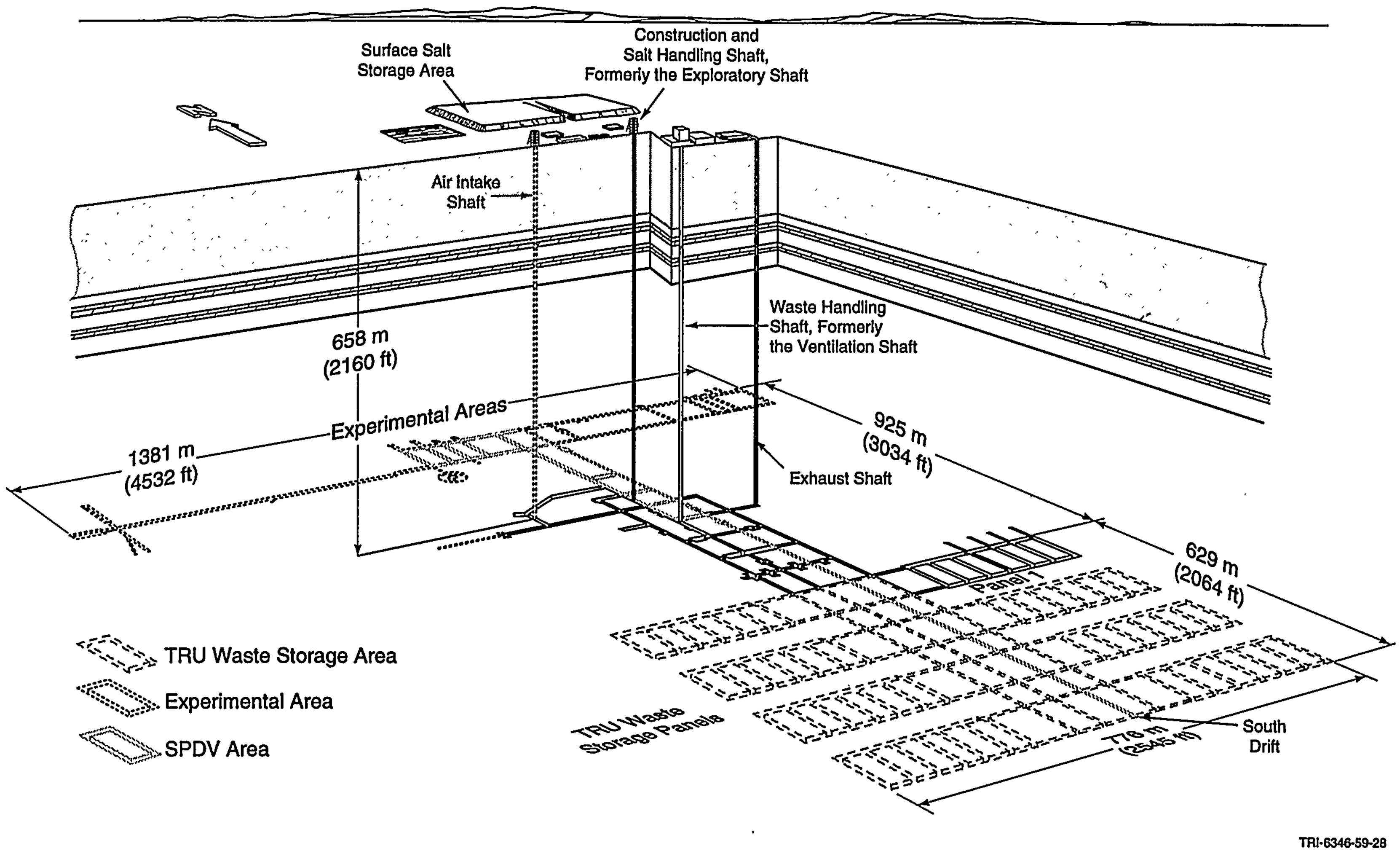

Figure 1.0.1. WIPP Surface and Underground Facilities, Planned and Existing

Table 1.0.1. Acronyms and Abbreviations

AIS	Air Intake Shaft
CCP	Construction Contract Package
CH	Contact-Handled [Waste]
CWI	Cementation West, Inc.
C&SH	Construction and Salt Handling [Shaft]
DAS	Data Acquisition System
DHLW	Defense High-Level Waste
DOE	U.S. Department of Energy
DRS	Disposal Room Systems [Program]
ERDA	Energy Research and Development Administration
FFT	Fluid Flow Transport [Program]
ISBT	Intermediate-Scale Borehole Test
IT	International Technology [Corporation]
LHD	Load-Haul-Dump [Machine]
LVDT	Linear Variable Differential Transformer
ModComp	Modular Computer Systems Inc.
PI	Principal Investigator
QA	Quality Assurance
PSP	Plugging and Sealing Program
RH	Remote-Handled [Waste]
RIS	Repository Isolation Systems [Program]
R&D	Research and Development
SPDV	Site and Preliminary Design Validation
Sandia	Sandia National Laboratories
TBM	Tunnel Boring Machine
TRU	Transuranic
TSI	Thermal/Structural Interactions
TSP	Twisted-Shielded-Pair [Cable]
WISDAAM	WIPP In Situ Data Acquisition, Analysis, and Management [System]
WIPP	Waste Isolation Pilot Plant
WPP	Waste Package Performance

	SPDV	Technology Experiments	Demonstrations
Site Characterization and Evaluation	• Site Validation Investigation	• Hydrological and Geological Studies	
Repository Development			
Thermal/Structural Interactions	• Preliminary Design Validation	• 18 W/m^2 Mockup • DHLW Overtest • Geomechanical Evaluations • Heated Axisymmetric Pillar • In Situ Stress Field • Direct Shear of Clay Seam (not performed) • Air Intake Shaft Performance Tests • Intermediate Scale Borehole Test	
Plugging and Sealing		• Permeability Tests • Plug Test Matrix • Field (Borehole) Tests • Gas Testing • Small-Scale Seal Tests	
Operations			• Mock TRU Waste Handling
Waste Package Interactions			
Waste Package Performance		• Simulated-Waste Package Performance • Simulated TRU Waste Technology Experiments	
Near-Field Effects		• Brine Migration • Large Scale Brine Inflow Test	

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Figure 1.0.2. WIPP In Situ Test Matrix

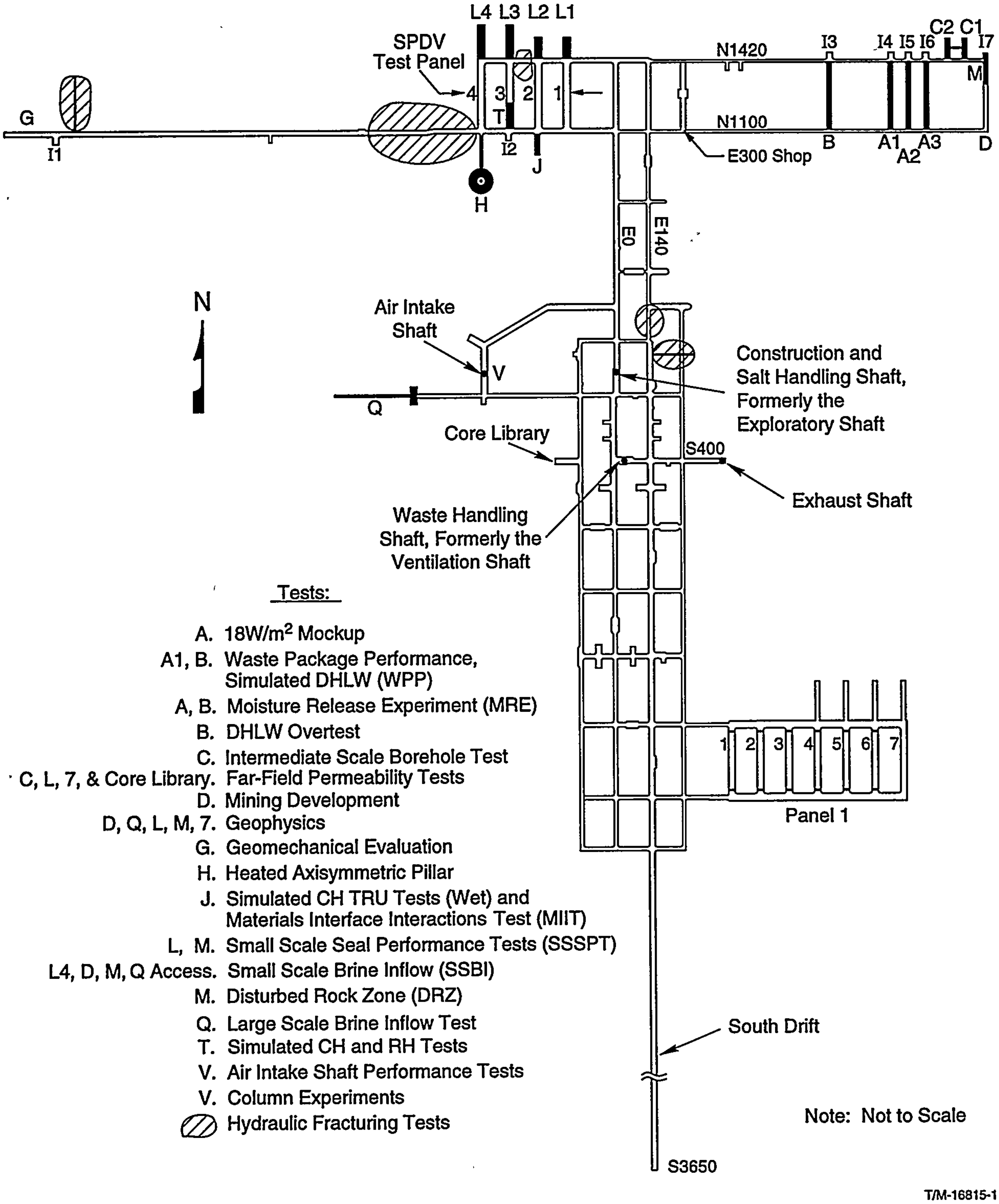

Figure 1.0.3. Plan View of the WIPP Underground Experimental Area

technology development issues in the Repository Isolation Systems (RIS), Disposal Room Systems (DRS), and Fluid Flow and Transport (FFT) programs. The in situ testing specifically addresses the disposal and isolation of CH and RH TRU waste generated from current and past defense programs. Although some tests initially addressed the disposal of defense high-level waste (DHLW), this waste is currently slated for disposal in another repository; however, the results of these tests will still contribute to the validation of TRU waste disposal technology.

There were originally five major experiments within the TSI tests: (1) the 18-W/m^2 Mockup for DHLW in Rooms A1, A2, and A3; (2) the Overtest for Simulated DHLW in Room B; (3) the Geomechanical Evaluation in Room G; (4) the Heated Axisymmetric Pillar in Room H; and (5) the In Situ Stress Field - Hydraulic Fracturing Tests in Room G. In situ data have also been obtained from Room D, an early excavation initially created for facility ventilation. Each of these experimental areas is shown in Figure 1.0.3. Several documents provide details on the planning and implementation of the TSI in situ tests [1-12]. Data reports for the various experiments [13 through 24] provide test configurations, engineering data (thermal and mechanical), and associated information from the experiments. Details of the Hydraulic Fracturing Tests are discussed in another report [25]. A Clay Seam Shear Test was originally planned, but never executed.

Later in the experimental program, other tests were added that contributed to TSI test objectives. These included (1) the Air Intake Shaft (AIS) performance tests in the Air Intake Shaft (Shaft V), (2) the Intermediate Scale Borehole Test (ISBT) between Rooms C1 and C2, and (3) the Large-Scale Brine Inflow Test in Room Q.

The intent of this report is to accurately describe the construction of the R&D TSI in situ tests. Chapter 2 describes early underground construction and developments that preceded the TSI test construction. Details of the site stratigraphy, which influenced construction, are given in Chapter 3. Chapter 4 highlights the development of excavation tolerances, survey procedures, drilling expertise, and instrument installation methods. Chapter 5 traces the underground activities associated with the construction of the original five in situ tests in essentially chronological sequence. The efforts covered therein include preliminary activities such as the assembly of the Data Acquisition System (DAS) and the mining of access drifts and instrumentation alcoves. Also covered are general construction items such as mining and drilling methods, instrument and heater installation, as well as detailed information on the construction of each of the original five major experiments. Chapter 6 covers the construction of in situ tests that were instituted later in the TSI test program. Chapter 7 provides a brief summary of this report and is followed by the Reference section. Finally, Appendices A1 through V contain as-built drawings of the TSI test rooms.

This report was initially started in 1987, but the completion was delayed until 1996 to permit inclusion of all of the TSI construction. However, the original report number has been retained because it has been a reference in many reports written during this period.

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2 SPDV CONSTRUCTION HISTORY

Two major construction contracts for the development of the underground facility preceded the contract for the excavation of the TSI in situ test rooms. These Site and Preliminary Design Validation (SPDV) contracts specified the construction of the first two shafts, the excavation of underground drifts to collect additional site characterization information, and the construction of the SPDV Test Panel to simulate a representative portion of the TRU Waste Storage Area. The objective was to mine a sufficient number of underground entries to allow a determination to be made as to whether the designed facility would perform as expected. Following the two SPDV contracts, a third contract included additional shaft construction. Although these activities were not a part of the R&D in situ test construction, they did play a direct part in subsequent test development by providing information on mining practices, achievable construction tolerances, survey and measurement techniques, and a more detailed stratigraphy of the repository horizon. Furthermore, the SPDV excavations provided a field setting for the evaluation and development of techniques to be used in the construction of the tests. The following sections provide a brief description of the construction activities associated with these first contracts, while more details are available in other reports [26, 27].

2.1 Shaft Drilling, Contract CCP-1A

Construction of the underground facilities at the WIPP began in April, 1981 with the award of Construction Contract Package CCP-1A to Fenix and Scisson, Inc. This contract included the drilling and lining of the Exploratory Shaft and the drilling of the Ventilation Shaft, and was completed in February, 1982.

The Exploratory Shaft, later to be renamed the Construction and Salt Handling (C&SH) Shaft (Figures 1.0.1 and 1.0.3), and presently shortened to the Salt Handling Shaft, was drilled to a diameter of about 3.7 m (12 ft) and to a depth of 700 m (2,298 ft). The first 30 m (100 ft) of the shaft was drilled by auger through soft regolith and cased with steel. The drilling rig was then erected and drilling continued with a full-face roller bit and fresh water drilling fluid. Before contacting the salt of the Salado Formation, the drilling fluid was changed to a brine-based fluid to prevent dissolution of the shaft wall. Upon completion of drilling, a 3 m (10 ft) diameter welded-steel liner was floated in place to a depth of 258 m (845 ft), just below the interface of the overlying Rustler Formation and the evaporite sequences of the deeper Salado Formation. The liner was grouted in place and the drilling fluid removed from the shaft.

The Ventilation Shaft, later to be enlarged and renamed the Waste Handling Shaft (Figures 1.0.1 and 1.0.3), was drilled using the same techniques following the completion of the Exploratory Shaft. This shaft was unlined and was drilled to a diameter of 1.8 m (6 ft) and to a depth of 671 m (2,202 ft). Its initial use was to provide flow-through ventilation for the early underground construction.

2.2 Shaft Outfitting and Underground Development, Contract CCP-1Fa

The CCP-1Fa Construction Contract Package constituted the second major construction effort for the development of the SPDV Area. Cementation West, Inc. (CWI) mobilized on site in January, 1982 during the drilling of the Exploratory Shaft to prepare for hoist and headframe construction, and completed the contract in July, 1983. As part of the CCP-1Fa package, CWI outfitted both of the drilled shafts, and excavated the remainder of the

SPDV area.

Prior to any work below the shaft collar, CWI supplied and erected the present hoist and headframe system to service the Exploratory Shaft. Shaft outfitting activities began with the excavation and placement of a concrete key at the interface of the salt and the overlying strata to form a barrier to restrict seepage below the steel liner. After the shaft had been lined, wooden conveyance guides, buntons (shaft dividers and supports for the guides), and underground utilities were installed. The outfitting was performed on a three deck Galloway (platform) suspended from synchronized capstan winches by wire ropes. A permanent hoist system was then brought on line and used for conveyance of equipment, personnel, and mined salt for the SPDV phase of facility construction. An additional temporary hoist system was also installed to service the Ventilation Shaft.

The Exploratory Shaft station was excavated using drill and blast methods. The resulting space was used as a work area to develop the shaft loading pocket and surge bin, a staging area for shaft outfitting, and an assembly area for mining equipment. A pilot drift to connect the Exploratory Shaft with the Ventilation Shaft was also excavated using drill and blast methods.

Following the excavation of the Exploratory Shaft station and the single pilot drift, excavation of the SPDV area continued with a Dosco LH-1300 continuous mining machine (roadheader type) supported by trucks and load-haul-dump machines (LHDs) working three shifts per day and seven days per week. The first use of the continuous miner was to complete the Exploratory Shaft station and to enlarge the drift connecting the shafts to final dimensions. An exploratory drift (the E140 or South Drift) was then excavated 1,114 m (3,656 ft) to the south, as part of a negotiated change order, to verify the continuity of the stratigraphy to the southern boundary of the facility. The last part of this contract was the excavation of the SPDV Test Panel, a series of four rooms located between the N1100 and N1420 drifts (Figure 1.0.1) that simulated the dimensions of the planned TRU Waste Storage Area.

As the architect/engineer for the WIPP, Bechtel National, Inc. was responsible for the design validation studies for the TRU Waste Storage Area, as well as total facility design. During the SPDV construction, geomechanical instruments were placed throughout the shafts and drifts, and cores were taken systematically from drill holes above and below the horizon. Data from the these efforts formed the basis for the design validation of the TRU waste storage area, and supported the conclusion that the designed excavations would perform adequately to warrant completion of the facility [27]. Data from the SPDV areas have been collected, and were presented and analyzed in various reports [28, 29].

2.3 Waste and Exhaust Shaft Excavation, Contract CCP-1Fb/1D

Construction Contract Packages CCP-1Fb and 1D were let as one contract and included completion of the Waste Handling Shaft, excavation of the Exhaust Shaft (the third shaft at the WIPP facility), and excavation of the TSI experimental rooms. Although this shaft work was not part of the SPDV construction, it is convenient to include it here while the excavation of the experimental rooms is discussed in Chapter 5. This contract was awarded to the Ohbayashi Corporation and was completed in April of 1985.

Under CCP-1Fb/1D, the Ventilation Shaft was enlarged by drilling and smooth-wall blasting to a diameter of 6.1 m (20 ft) to become the Waste

Handling Shaft. This shaft was cased with concrete to a depth of 274 m (900 ft), and lined with wire mesh from there to the bottom. After installation of the lining and mesh, the shaft was outfitted for handling radioactive waste.

Also under this contract, the Exhaust Shaft was excavated in a series of four steps. The first step was started by drilling a hole through the surface material with an auger to a depth of 24 m (80 ft). This hole was cased with steel, and a 200 mm (7 7/8 in) diameter pilot hole was drilled from there down to the WIPP horizon. During the second step, the hole was reamed to a diameter of 311 mm (12 1/4 in) from the bottom to the top. The third step involved reaming the hole to a diameter of 1.8 m (6 ft) with an up-reaming bit and a raise boring machine. After this step, the concrete shaft collar was poured and the shaft sinking plant was erected. The fourth and final excavation step then proceeded with drilling and smooth-wall blasting of the shaft from the surface to the bottom with a diameter of 4.6 m (15 ft). The shaft was lined with concrete to a depth of 276 m (907 ft) and covered with steel mesh from there to the bottom station.

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3 STRATIGRAPHY

The SPDV construction presented a detailed exposure to the site stratigraphy through the shafts and from stratigraphic drill core. Vertical, 15 m (50 ft) deep core holes were drilled by the mining contractor above and below the facility horizon every 90 m (300 ft) throughout the excavations. Information from these exposures formed the basis for refining the reference stratigraphy [30] which was originally based on information from the ERDA-9 (Energy Research and Development Administration) borehole drilled from the surface. Furthermore, the refined reference stratigraphy showed that a single stratigraphic characterization is applicable throughout the facility, i.e., local variations in the stratigraphy are not significant. A new reference stratigraphy [31] was developed later which contained more exact features, particularly for the sequences immediately above and below the facility horizon.

The stratigraphy of the WIPP repository horizon is predominantly thick halite layers with thinner layers of clay and anhydrite [32]. The halite layers are up to 3 m (10 ft) thick and contain small amounts of clay and polyhalite (generally less than 5%). The clay seams generally range from 2 to 20 mm (1/16 to 3/4 in) in thickness, but can be 50 mm (2 in) thick locally. The anhydrite layers are typically from 50 mm to 1 m (2 in to 4 ft) thick and are consistently underlain by a clay seam. The stratigraphy is continuous throughout the area immediately surrounding the WIPP site, and no significant geologic structures such as folds or faults exist in the vicinity.

The test rooms were located on two different levels within the stratigraphy as shown in Figure 3.0.1. All SPDV excavations were at the

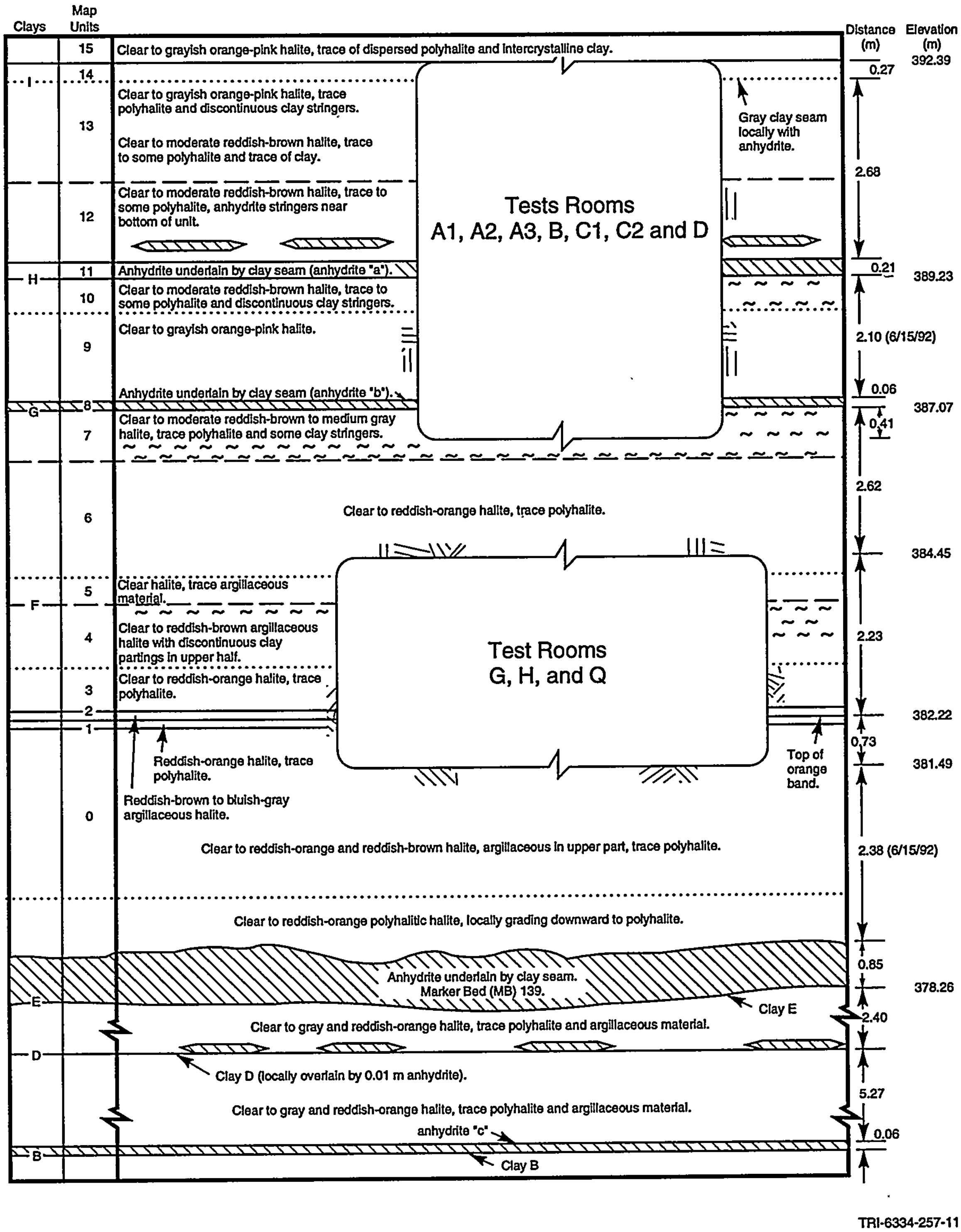

Figure 3.0.1. Location of the TSI Test Rooms in the WIPP Stratigraphy

lower level, as were the in situ experiments to the west and south (Rooms G, H, and Q). In contrast, all in situ experiments to the east (the A, B, C, and D test rooms) were at the higher level.

The lower-level test rooms were located in the same horizon as that selected for the TRU waste facility. This placed their backs (roofs) at a nominal elevation of 384 m (1,261 ft) above sea level, although the actual elevation was maintained just above the friable interface of Map Units 5 and 6 to ensure a stable back (as shown in Figure 3.0.1). The elevation was controlled during excavation by keeping Map Unit 1, a well defined orange halite band, about 2 m (7 ft) below the back.

The upper-level test rooms were placed above the horizon chosen for the waste storage facility so that their heaters (emplaced in the room floors) would be located within that horizon. Within this general framework, the actual location of the upper test rooms was again governed by the nature of the local stratigraphy. To provide a stable back for the rooms, it was necessary to locate the back at a well defined clay seam at the interface of Map Units 14 and 15, as shown in Figure 3.0.1. This placed the backs of the test rooms at a nominal elevation of 392 m (1,287 ft) above sea level with anhydrite layer "a" (Map Unit 11) near room mid-height and anhydrite layer "b" (Map Unit 8) near the floor.

The Air Intake Shaft (AIS), of course, was an exception to the test room locations. The AIS spanned the strata from the surface of the WIPP site to the underground facility depth of 655 m (2150 ft).

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4 DEVELOPMENT OF TEST METHODS, SPECIFICATIONS, AND RECORDS

Prior to the construction of the TSI in situ tests, it was necessary for Sandia to develop and evaluate drilling technology, gage installation procedures, construction tolerances, and surveying methods. In accomplishing these objectives, advantage was taken of opportunities provided by the SPDV excavations for evaluating conventional mining technology and developing procedures for test construction [2 through 4].

4.1 Drilling Technology

Sandia initiated a drilling development and evaluation program during the SPDV construction phase in response to the need for the drilling of specialized holes demanding strict specifications and tolerances. These holes included instrument holes that were added to the tests after the construction contract was awarded, large-diameter heater holes, and holes to provide core for stratigraphic mapping and laboratory testing. Rather than delay the contractor's schedule by adding to their responsibility, Sandia developed the in-house capability for this drilling. In addition, the drilling program provided the opportunity to evaluate the practical precision of the drilling process and develop a set of borehole tolerance specifications that would not only meet the experimental requirements, but would be achievable by the drilling contractor. In all, more than 55 holes were drilled in the development program. Advantage was taken of these holes to develop and demonstrate borehole measuring and surveying methods, and to demonstrate installation procedures for many of the gage types to be utilized in the experiments.

Core holes and heater holes were generally drilled with Longyear EHS-38 drills, while instrument holes were drilled with Longyear D-65 drills. The EHS-38 drills were electrohydraulic rigs rated at 50 horsepower. These drills were mounted on 1.2 m (4 ft) high, wheeled trailers, and required three-man crews. The D-65 drills were pneumatic, column-mounted, screw-feed rigs with four selectable feed rates. The D-65s were smaller rigs that were rated at 20 horsepower, weighed approximately 90 kg (200 lb), and required two-man crews. Although the D-65 rigs were capable of coring holes up to 400 mm (16 in) in diameter, compressed air restraints made this difficult. Because of this, the larger EHS-38 eventually became the drill of choice for the larger diameter holes. Small holes, such as those for manual closure points, were drilled with Longyear 300 concrete coring drills, or hand-held hammer drills. The Longyear 300 was a two horsepower electric drill mounted on a hand-crank, screw-feed advance platform which was in turn mounted on a lightweight, wheeled stand.

The program for the development of large-diameter drilling capabilities progressed from drilling various diameter holes vertically downward to drilling large diameter horizontal holes. The procedure that was developed called for starting with a 47.6 mm (1 7/8 in) diameter pilot hole drilled along the hole axis, and then overcoring with specially made thin-wall masonry bits of various diameters and lengths with surface-set diamond teeth. After coring to the depth of the barrel, the drill string was withdrawn and the core section broken off with a hammer-driven wedge or a thin flat jack placed in the annulus. An anchor bolt was then set in the central pilot hole and attached to the drill hoist to lift the core segment out of the hole. This operation was repeated until the final depth was reached. The holes were drilled with diameters of 406, 762, and 914 mm (16, 30, and 36 in). Some of the core obtained was recored at a later time for laboratory test specimens.

The larger diameter holes were drilled without difficulty, but problems were encountered drilling the 406 mm (16 in) diameter holes. During heater hole drilling, the surface-set diamond segments tended to come off the 406 mm (16 in) diameter bits. Failed bits were repaired using a material known as "Cut-Rite". This material is manufactured in the form of brazing rod imbedded with particles of tungsten carbide. When applied with a torch, the tungsten carbide is laid down with the brass matrix and provides a suitable replacement for the original segments.

A series of eight 102 mm (4 in) diameter, 15 m (50 ft) deep core holes were drilled with the objective of obtaining good, unbroken core for stratigraphic mapping and laboratory testing. Several types of bits were evaluated including diamond masonry bits and bits with core barrels. Core barrels, including double-tube core-retaining barrels, proved no more satisfactory than the masonry bits. After a minimal amount of practice, techniques were established for obtaining exceptional quality core.

An important series of practice boreholes was drilled for the development of borehole tolerances and measuring techniques, and for the demonstration of gage installation procedures. One set of these holes was drilled through the 30 m (100 ft) pillar between Rooms 3 and 4 of the SPDV Test Panel so that the total deflections could be determined using conventional surveying methods. Another set of holes in the E140 drift and Room 4 demonstrated the ability to drill stress meter holes with a tight diameter tolerance (Table 4.3.1). All holes were drilled using the aforementioned hole location and drill orientation methods. Optical surveys and borehole inspections confirmed that the boreholes were within specified tolerances.

4.2 Instrumentation Procedures

There were three concerns related to instrumentation that needed to be resolved before construction:

(1) accuracy of gage installation procedures,

(2) development of collar installation procedures, and

(3) interference with gage installation by salt deposits.

Various types of gages were installed on a trial basis in the holes provided by the drilling development program. Although the instrumentation trials could not uncover all possible problems, they served as a first pass at eliminating any obvious errors in the instrumentation process. Techniques for the installation of gages evolved continuously throughout the construction and maintenance processes and are discussed in more detail in the Instrumentation Report [33].

Most holes intended to house permanent instruments, with the exception of inclinometers, were outfitted with steel collars. Most instruments utilized a collar made of a 530mm (21 in) length of Schedule 40 steel pipe with a 125 or 150 pound (nominal rating) steel pipe flange welded to one end (Figure 4.2.1). Either 127 mm (5 in) or 76 mm (3 in) diameter pipes were installed, depending on the type of instrument. Centralizers made of round steel stock were welded to the collar pipes to approximate the diameter of the collar hole.

In order to develop a collar installation method, several collars were installed in the holes provided by the drilling development program. A workable installation procedure was established, as illustrated in Figure 4.2.1, after a trial method was modified by incorporating suggestions from the contractor. During the drilling process, the instrument hole was drilled first, then a 457 mm (18 in) long collar hole

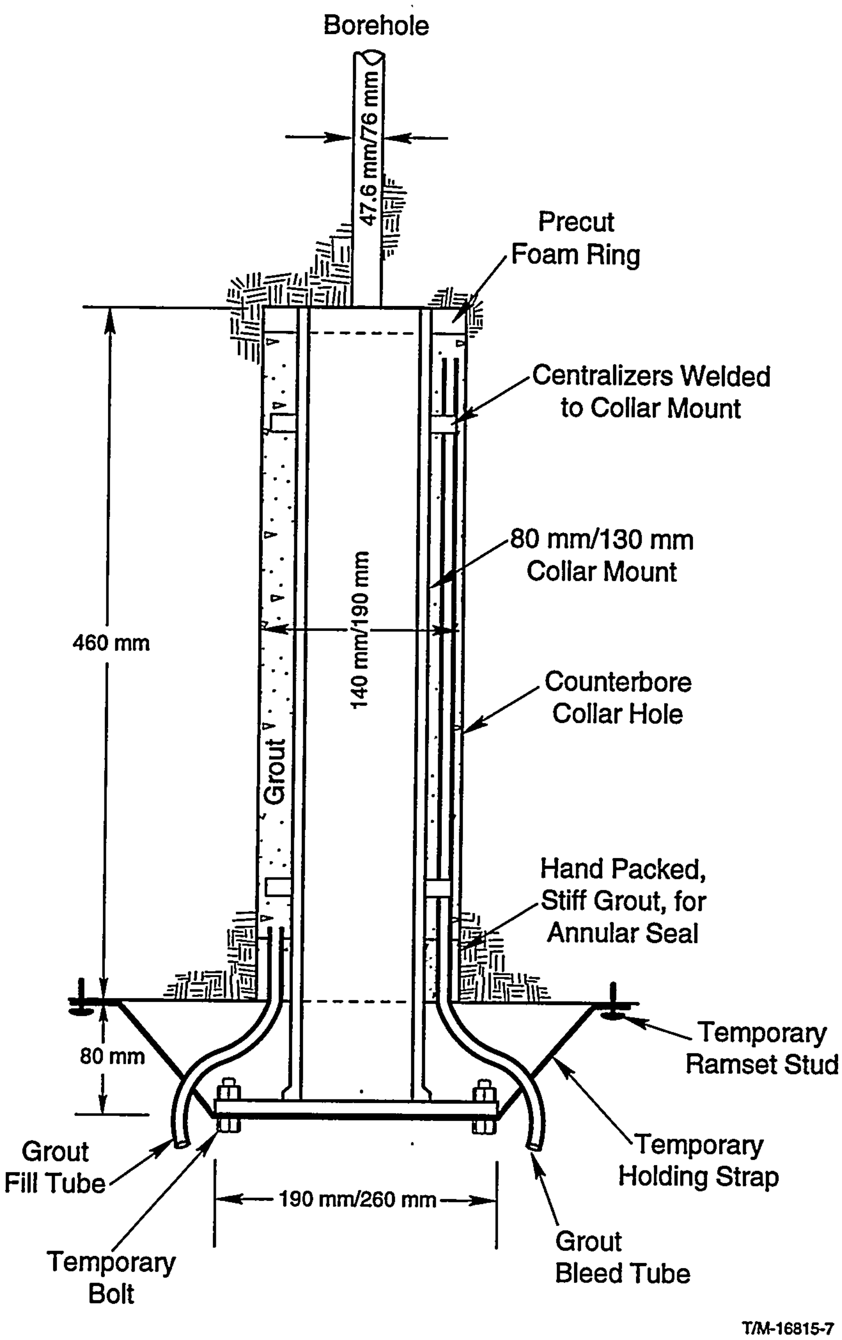

Figure 4.2.1. Instrument Collar Installation

was drilled immediately afterward without moving the drilling rig. A circular foam rubber disk was then placed at the bottom of the collar hole to serve as a grout seal. The collar was inserted in the hole and pushed tight against the foam disk, and two grout tubes (one for filling and one for bleeding) were placed in the annulus. The collar was secured in place with a steel strap fastened to the formation with "Ramset" studs, and the collar of the annulus sealed with hand-packed grout. After the seal had set, the annulus was pumped full of grout. A quick-setting grout made of cement and brine was developed to provide a strong bond between the collars and the formation.

Manual closure points and anchor bolt extensometers used collars that differed from those described above. Manual closure points located in the floor required an unflanged pipe to be grouted in place in the recess hole to provide firm support for a protective cap (Figure 4.2.2). Anchor bolt extensometer heads were protected by a steel collar held against the formation by the collar bolt (Figure 4.2.3).

Because of the unavoidable delay between drilling and gage installation, deterioration of boreholes was observed. The holes drilled in the SPDV excavations for gage demonstration purposes remained uninstrumented for several months as they were first used for developing drilling tolerances and then as practice holes for borehole survey teams. When the holes were eventually free for demonstrating gage installation procedures, many were encrusted with salt deposits. As a solution, a procedure was developed to clean the holes and restore the diameters to the original specifications. After trying different setups using wire brushes, a hand-held drill with an appropriately sized masonry bit was chosen as the best tool for restoring holes. After a hole was reamed,

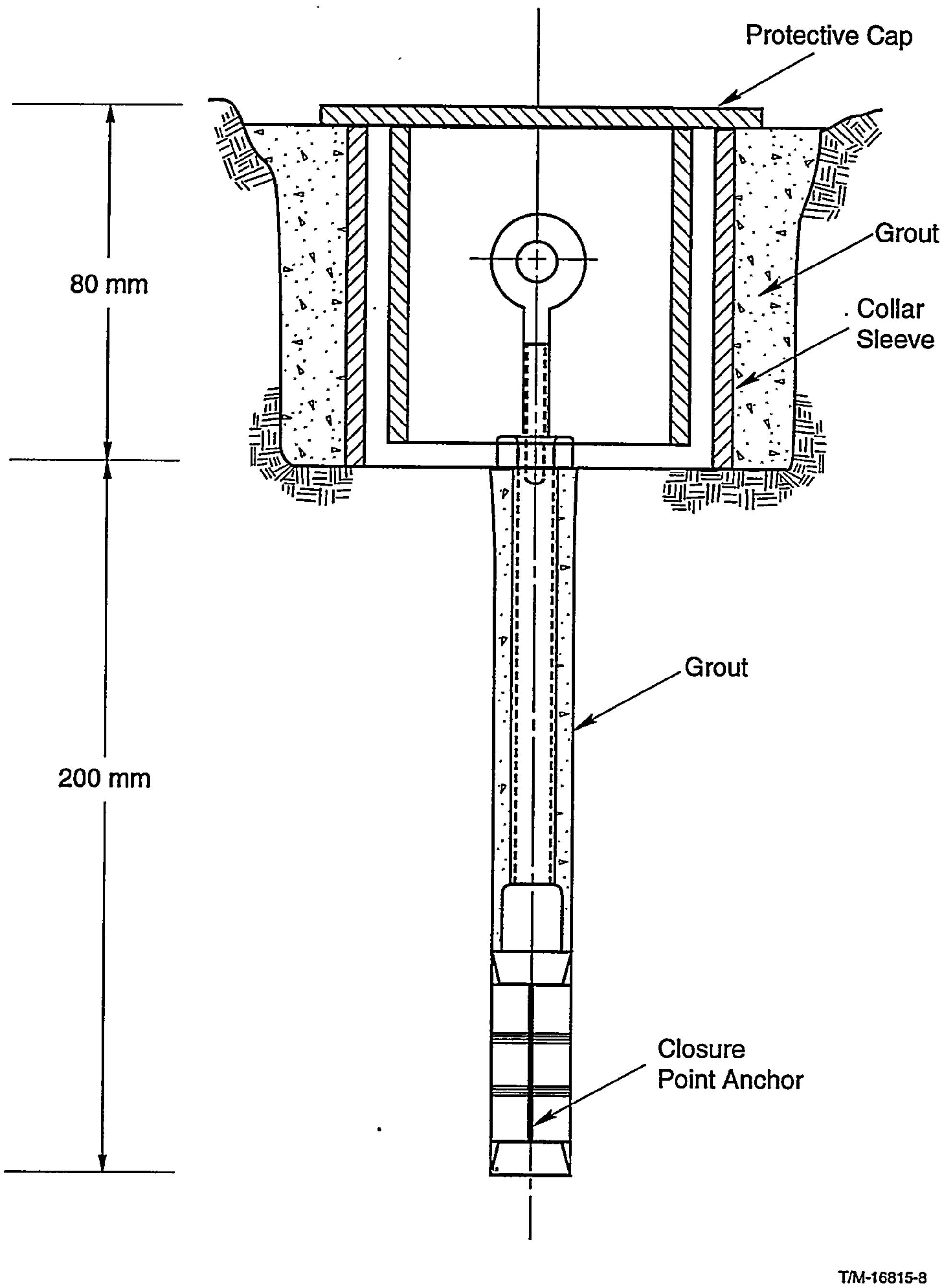

Figure 4.2.2. Manual Closure Point Installation

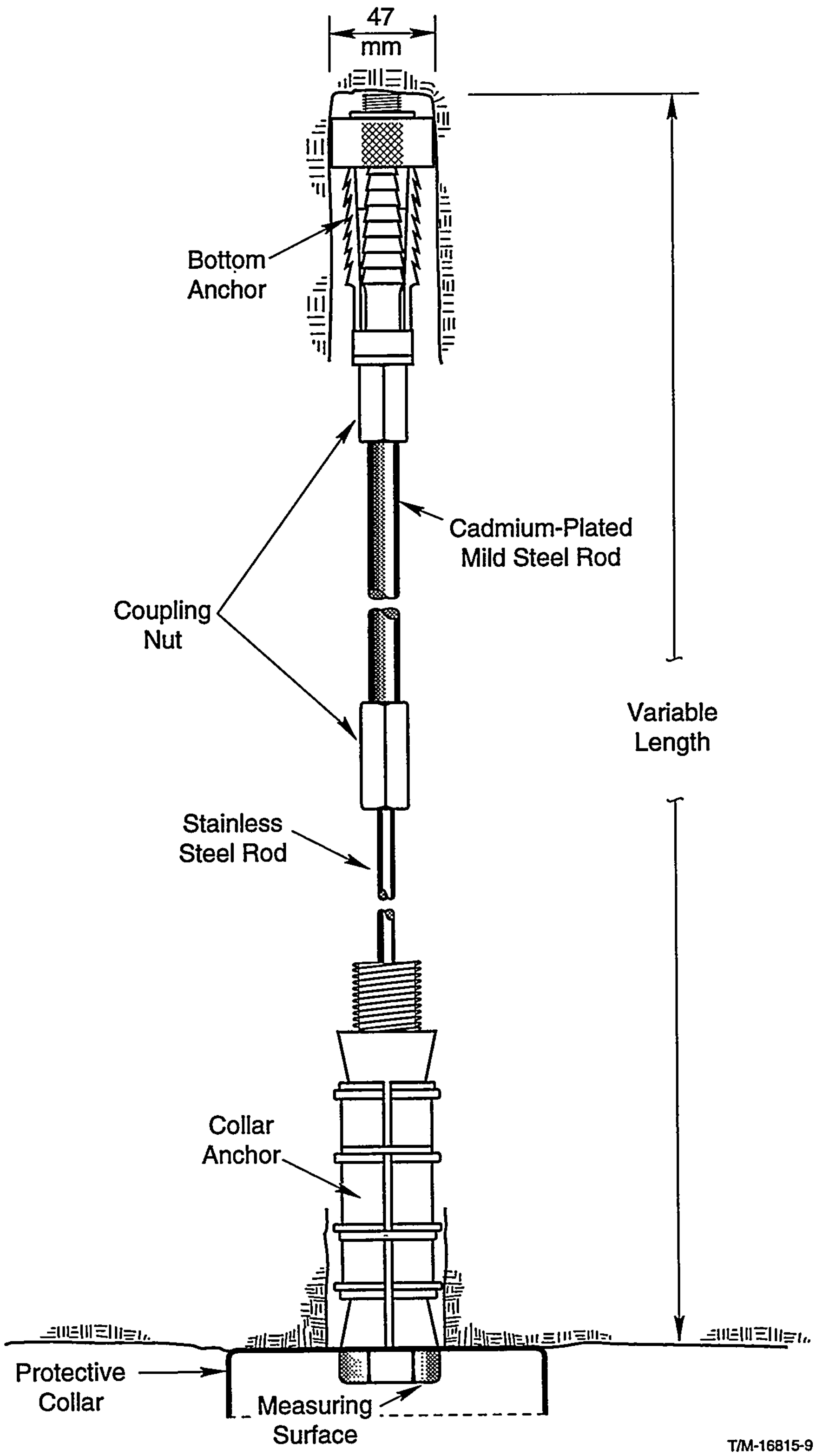

Figure 4.2.3. Anchor Bolt Extensometer Installation

debris was blown out with a flexible airline fitted with a nozzle to reverse the direction of air flow.

4.3 Tolerances

In the TSI experiments, construction tolerances were based not only on the capabilities of the mining and drilling methods to be used, but also on the need to excavate the test rooms with consistent and accurate geometries. The numerical methods employed to predict rock mass response utilized laboratory-based constitutive models and as-built test room dimensions. The models were sensitive to changes in test room dimensions; a small variance in dimension could have a great effect on the predicted response. The actual test response was then compared to the predicted response with the goal of validating the constitutive model. In order to achieve an accurate comparison, errors in the measured response must be minimized. It was therefore necessary to excavate the test rooms and emplace the gages with the greatest accuracy that could reasonably be achieved. The selection of the various test room and borehole tolerances is detailed in the following sections. The tolerances are listed in Table 4.3.1.

4.3.1 Room Dimensions and Roughness: Observations of the SPDV Test Panel, where only loose tolerances were in place, showed that the cross sectional perimeter of a room could potentially be held within a 75 mm (3 in) envelope. The floor of a room, however, could only be held within a 150 mm (6 in) envelope because the floors were cut under a layer of muck (mined salt) which obscured the cutting process. (It was later found to be necessary to muck out the room and blow the floor clean before cutting the final pass.) Based on these observations, room roughness tolerances were set at +76, -0 mm (+3, -0 in) for the back and ribs, and +150, -0 mm

Table 4.3.1. Test Construction Tolerances

Construction	Feature	Tolerance	Remarks
Test Rooms	Centerline (Horizontal)	±0.2°	±0.3 m/ 90 m (±1 ft/300 ft)
	Room H Centerline (Horizontal)	±150 mm (± 6 in)	Room Radius From Pillar Axis
	Centerline (Vertical)	None	Follow Strata
	Width	+150, -0 mm (+ 6, -0 in)	
	Height	+230, -0 mm (+ 9, -0 in)	
	Roughness (Floor)	+150, -0 mm (+ 6, -0 in)	
	Roughness Back, Ribs	+ 75, -0 mm (+ 3, -0 in)	
Instrument Holes	Surface Location	± 25 mm (± 1 in)	
	Orientation	± 1.0°	
	Straightness	Line of Sight :o Hole Bottom	Within One Hole Diameter
	Diameter	+ 2.5, -0.0 mm (+ 0.1, -0.0 in)	Manual Closure
	Diameter	+ 0.381, -0.000 mm (+ 0.015, -0.000 in)	Stressmeters
	Diameter	± 2.5 mm (± 0.1 in)	All Others
	Depth	± 13 mm (± 0.5 in)	Manual Closure
	Depth	+230, -0 mm (+ 9, -0 in)	All Others

(+6, -0 in) for the floor. This amounts to a room width tolerance of +150, -0 mm (+6, -0 in) and a room height tolerance of +230, -0 mm (+9, -0 in).

Considering a nominal test room width and height of 5.5 m (18 ft), the maximum deviations allowed would produce width and height variations of 2.8% and 4.2%. Since stress increases with the room height-to-width ratio [34], variations in dimension cause variations in stress concentrations around the room. While these values may seem small, experimental evidence has shown that the creep rate increases with the effective stress (a function of the stress difference) to the power of 5.5 [31]. Variances of 2.8% and 4.2% can thereby cause peak variances of 16% and 25% in creep rate. In practice, the roughness had a root-mean-square effect on the room dimension and the peak variances were never realized.

The test room cross sections presented in Appendices A1 through H indicate that the room width, height, and roughness tolerance specifications were adhered to closely. In addition, room dimension and geometry data [35] provide as-built documentation that the rooms were excavated, with minor exceptions, within specifications.

<u>4.3.2 Room Bearing</u>: The tolerance set for the bearing of the test rooms was a maximum deviation of 0.2° from one end of a room the other, or 0.3 m (1.0 ft) in a 90 m (300 ft) long test room. It should be noted that this tolerance proved to be loose and that the test rooms were all excavated with a deviation of less than 0.1°. The orientation tolerance for Room H was set by limiting the inner and outer radii of the room to +150, -0 mm (+6, -0 in). Once again, this tolerance was quite loose and was easily met by the contractor, as can be seen from the "as-built" survey data [35]. No tolerances were set on the vertical location, or

grade, of the test rooms because mining was specified to follow the stratigraphy to satisfy safety concerns and provide a stable back. Also, by maintaining the room within the same stratigraphic layers, the excavation conformed better to the two-dimensional configuration typically used in the analytical procedures.

4.3.3 Borehole Tolerances: Setting tolerances for the drill holes was conceptually based on the permitted error in gage response due to the uncertainty in hole location. Using results from preliminary calculations of room performance, ellipses of acceptable uncertainty were mapped that defined gage response within an acceptable tolerance (Figure 4.3.1). Depending on the type of gage and the location within the experiment, these ellipses had various orientations and dimensions. The ellipses were then used to specify the acceptable variability in the gage locations. Placement of the gages within these zones assured that the measured responses would compare favorably with calculated responses within the acceptable tolerance. In almost all cases, the tolerances based on equipment capabilities, as discussed below, were within the tolerances considered to be acceptable for the experiments.

The surface location of the instrument boreholes was set to be within 25 mm (1.0 in) of the surveyed target, and the initial orientation was set to be within 1° of the designed orientation. The drillers were able to achieve an initial surface location and orientation that were very accurate and well within tolerances by aligning the drill string with the surveyed target and backsight (see Section 4.4.1).

The straightness of the instrument holes was another parameter that was important to the accurate placement of instruments. As it turned out, the drilling contractor was able to drill very straight holes; measuring

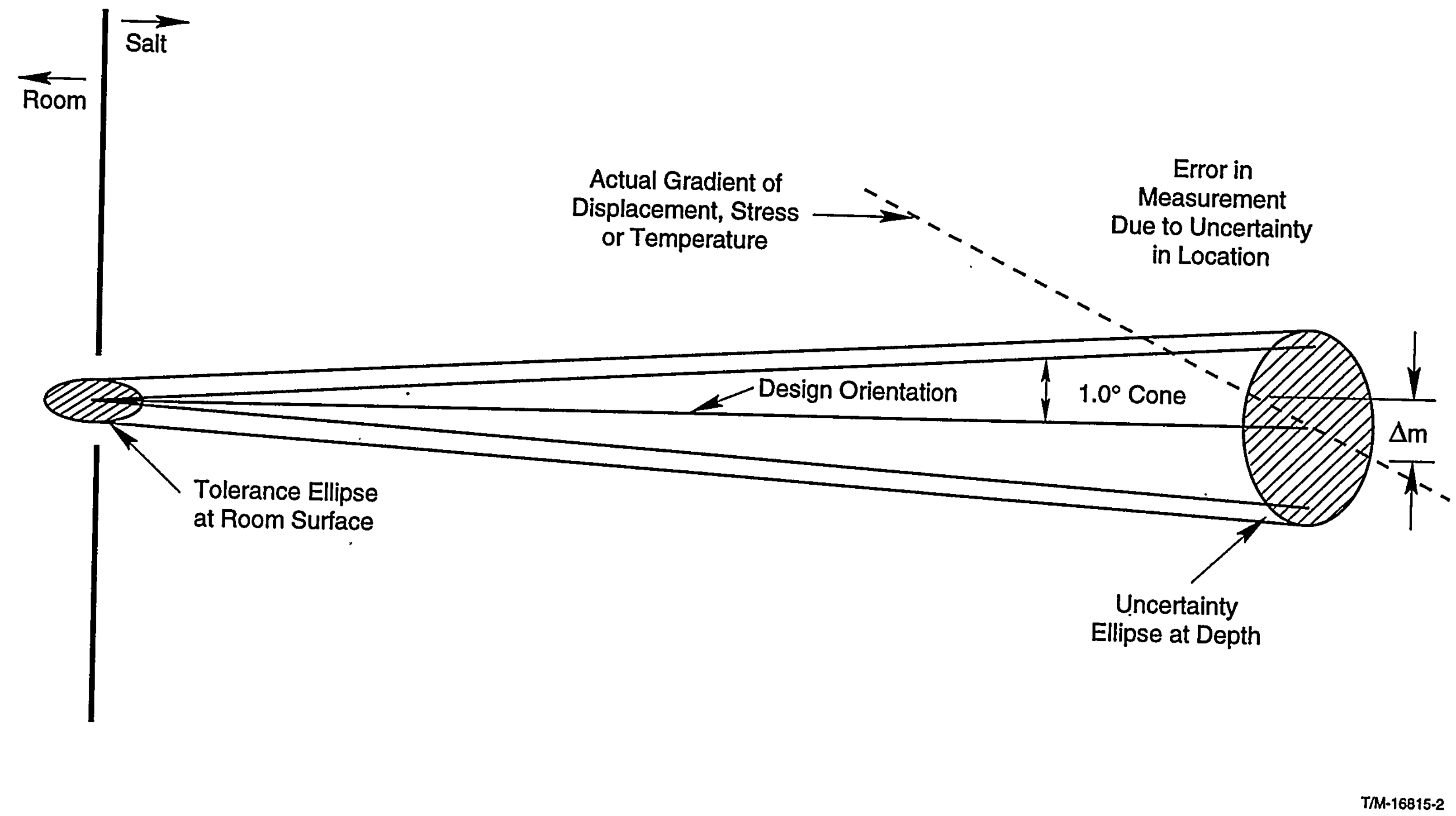

Figure 4.3.1. Instrument Hole Location and Measurement Accuracy

the straightness was more difficult. After other methods were investigated, a light source placed at the bottom of the borehole proved to be a quick, simple, and effective means of evaluating the straightness of the hole (Section 4.4.2); if any portion of the light source was visible, then the borehole was within one diameter of being straight. Thus, the straightness tolerance for all instrument holes was set to be one borehole diameter. This tolerance was within the calculational requirements and was able to be met by the contractor, with only a few exceptions, as indicated by the hole rejection rate discussed in Section 5.3.3.2.

The accuracy required for the diameter of an instrument hole depended not on calculational requirements, but on gage installation requirements. For all gages (except manual closure and stress gages) it was found that a tolerance of ±2.5 mm (±0.1 in) was sufficient for gage installation and was easily attainable by the drilling contractor [35].

Manual closure gages are based on a bolt that is anchored in the formation with an expansion shell anchor. It was found that a diameter tolerance of +2.5, -0.0 mm (+0.1, -0.0 in) was needed for installation of the anchor, and could easily be achieved with a hand-held hammer drill.

Emplacement of the stress gages, on the other hand, required holes with very accurate diameters. It was initially specified that stress gage holes be drilled with a tolerance of +0.25, -0.00 mm (+0.010, -0.000 in), but that was found to be unattainable. A more practical tolerance of +0.381, -0.000 mm (+0.015, -0.000) was finally specified. In fact, the hole diameter for the stress gages was so critical that by the time of gage installation, borehole closure and salt deposits made stress gage installation impossible. To alleviate this problem, it became a standard procedure to ream all stress gage holes with a properly sized bit immediately before gage installation.

Borehole depth was not a critical parameter for calculational requirements and gage installation. It was only necessary to drill the holes deep enough so that the gages could be installed at the designed depths. As such, a depth tolerance of +230, -0 mm (+9, -0 in) was set for all gages except manual closure gages. A depth tolerance of ±13 mm (±0.5 in) was set for the manual closure gage anchor holes.

The decision was made by Ohbayashi to subcontract all drilling to Christensen-Boyles Brothers Corporation. A demonstration of the subcontractor's ability to meet the borehole tolerance specifications was conducted before the instrumentation hole drilling in the TSI test rooms. Because of its similarity to most of the TSI test rooms, Room D was chosen as the site for the drilling demonstration. It was decided that a series of five, 15 m (50 ft) deep holes drilled in the south end of this room would be adequate to verify this capability. Table 4.3.2 lists the specifications for each of the holes drilled and compares them to the hole survey results. While there were minor discrepancies in hole locations and diameters, the results suggested that the contractor could, with minor refinements in technique, meet the specifications required for the instrumentation holes. In fact, as-built borehole characterization data [35] confirm that the great majority (99%) of instrumentation boreholes were drilled within specification during the construction process.

This early drilling gave the contractor survey crews a chance to familiarize themselves with the hole location and orientation control methods suggested by Sandia, and gave the geotechnical crews an opportunity to refine hole survey techniques in a realistic setting.

Table 4.3.2. Borehole Data from Drilling Demonstration

Hole	Specified Diameter	Recorded Diameter Range	Recorded Diameter Range Last 3 m (10 ft)	Specified Orientation	Deviation from Specified Orientation	Deviation from Specified Collar Location
DX01	47.6 mm (1.875 in)	47.70 to 48.26 mm (1.8780 to 1.9001 in)	47.70 to 48.12 mm (1.8780 to 1.8946 in)	Vertical Up	0.70° to the North	8 mm (0.3 in) to the NE
DX02	101.6 mm (4.000 in)	Not Calipered	Not Calipered	45° Up	0.40° to the North and Down	10 mm (0.4 in) to the South and Down
DX03	47.6 mm (1.875 in)	47.66 to 49.39 mm (1.8762 to 1.9445 in)	47.70 to 47.66 mm (1.8778 to 1.8762 in)	Horizontal	0.40° to the North and Up	15 mm (0.6 in) to the South and Down
DX04	47.6 mm (1.875 in)	47.98 to 48.37 mm (1.8891 to 1.9044 in)	47.98 to 48.02 mm (1.8891 to 1.8905 in)	Vertical Down	0.40° to the NE	15 mm (0.6 in) to the South
DX05	47.6 mm (1.875 in)	47.87 to 48.76 mm (1.8848 to 1.9197 in)	47.87 to 48.04 mm (1.8848 to 1.8914 in)	45° Down	0.30° Down	30 mm (1.2 in) Down

Notes:
1. Light source visible at bottom of all holes.
2. All holes 15 m (50 ft) nominal length.

4.4 Surveying Methodology

In order to ensure accurate emplacement of instruments, it was necessary to devise a well defined system of room surveying and borehole location that would consistently account for the natural variation in stratigraphy and the as-built variation in room dimensions. Considerations were also given to developing simple, yet accurate, methods of verifying borehole tolerances. The methods developed were used to characterize the geometry and bearing of the test rooms, instrument holes, and heater holes, and records of the surveys performed during the construction process are maintained on file in the WISDAAM records system [35].

4.4.1 Room Surveying: The specified plan locations of the test rooms were easily established from the contract drawings using standard surveying methods. However, to avoid any unnecessary ground control problems and to keep the test rooms in the same geologic horizon, it was necessary to maintain the excavation elevation relative to the stratigraphy. That is, all cross sections of a test room appear the same in relation to the stratigraphy. The sedimentary beds in the facility horizon dip gently towards the south and west. In addition, slight undulations of the beds are present throughout the facility. As a consequence, the elevations of the room centerlines are neither horizontal nor straight, but vary with the stratigraphy as shown in Figure 4.4.1.

To have used this continuously varying horizon as the reference for drill hole locations would have been difficult and unnecessary. Instead, the concept of the principal station was used to simplify both surveying and subsequent analysis. If one examines the Room B instrument placement shown in Figure 4.4.2, it is evident that during initial test planning,

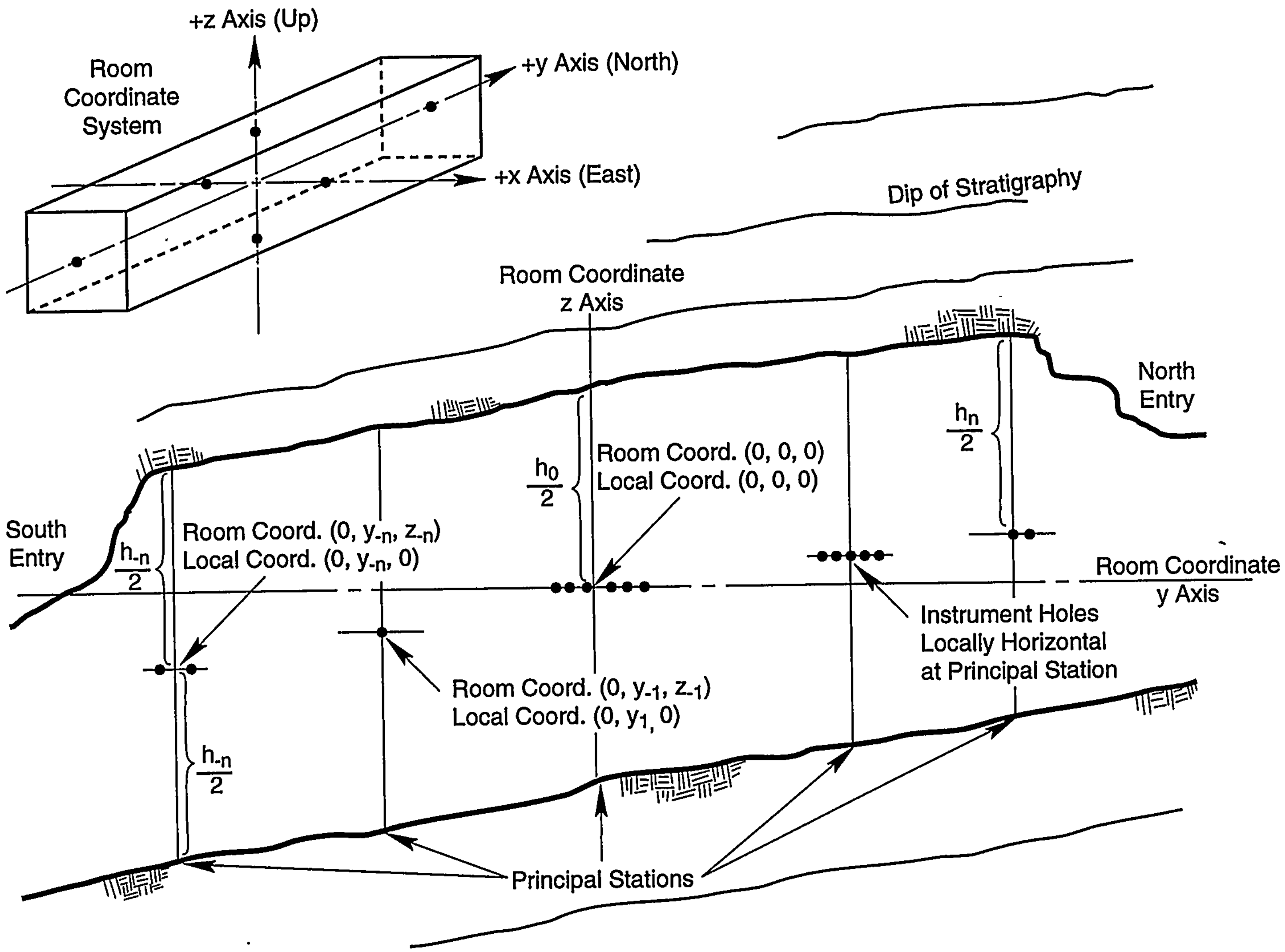

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Figure 4.4.1. Principal Station and Room Coordinate Systems

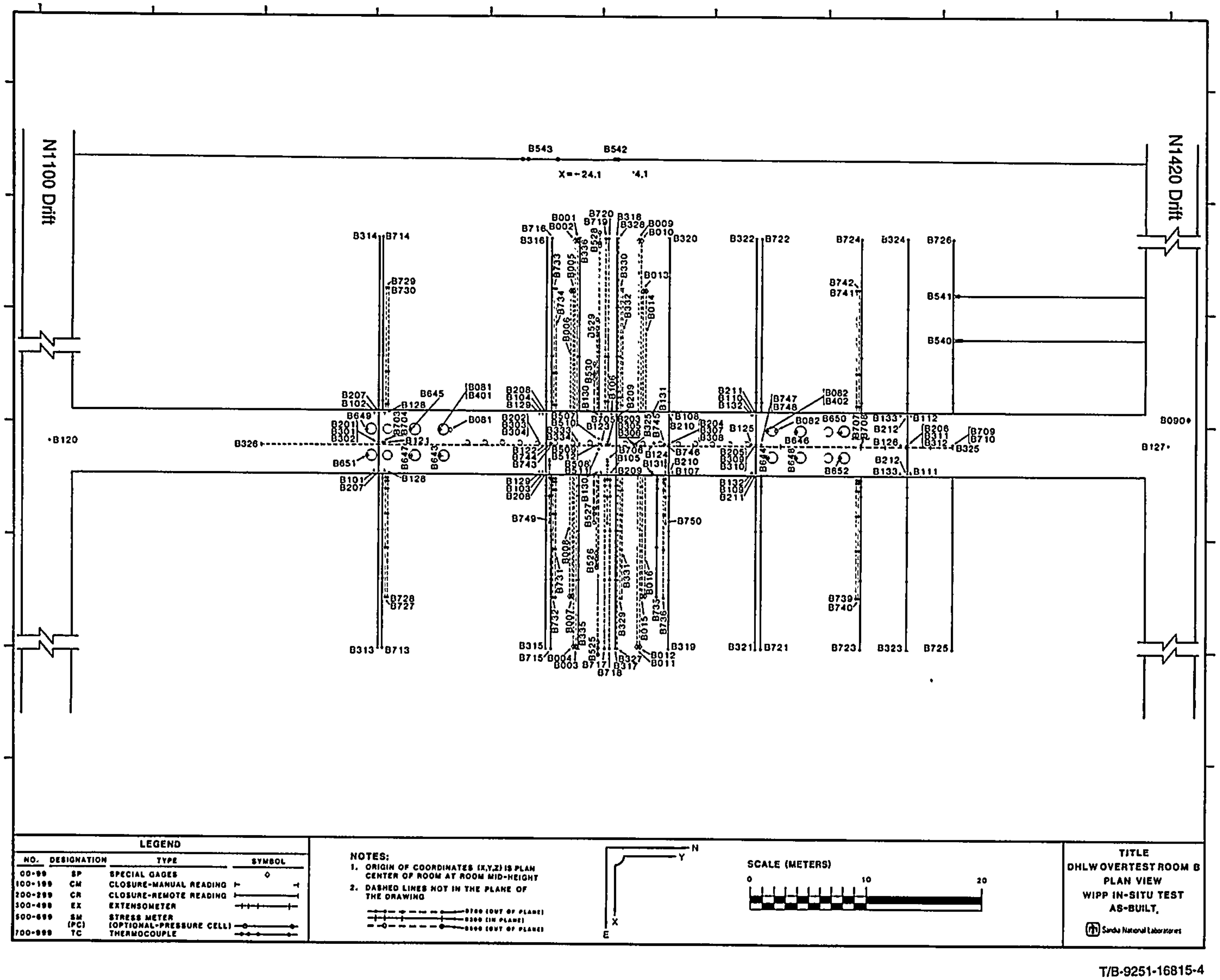


Figure 4.4.2. Plan View of Instrument Locations, Room B

the instruments were intentionally located in concentrated groups, rather than distributed uniformly throughout the length of the room. Each of these groups of instruments was assigned to a separate principal station, with the local vertical zero being defined as the room mid-height at that station, and the horizontal axis of the station intersecting the local zero. By this system, the instrumentation holes assigned to a principal station, even though several feet to either side of the station, were surveyed to the same local horizontal axis. The exaggerated schematic of Figure 4.4.1 illustrates several principal stations with locally defined horizontal axis segments.

The method of identifying principal stations was the same for all test rooms that used Cartesian coordinates. In these rooms, principal stations were defined as vertical sections located at discrete points along the length of the room. In Room H, which was developed using cylindrical coordinates, stations were defined as vertical sections located at selected angles around the room axis.

The planned locations of all instrument holes were based on the theoretical room cross sections. However, openings mined using conventional mining methods only approximate the designed shape. In order to accurately locate the instrumentation holes, an approach was developed for consistently dealing with irregularities in the test room surfaces. As depicted in Figure 4.4.3, the theoretical room cross section at a principal station was centered at the local zero. To locate an instrument hole, a line was first set up that was oriented in the planned direction and intersected the theoretical room surface at the planned location. This line was then projected onto the actual room surface to locate the drilling target and survey backsight. The hole locations and backsights

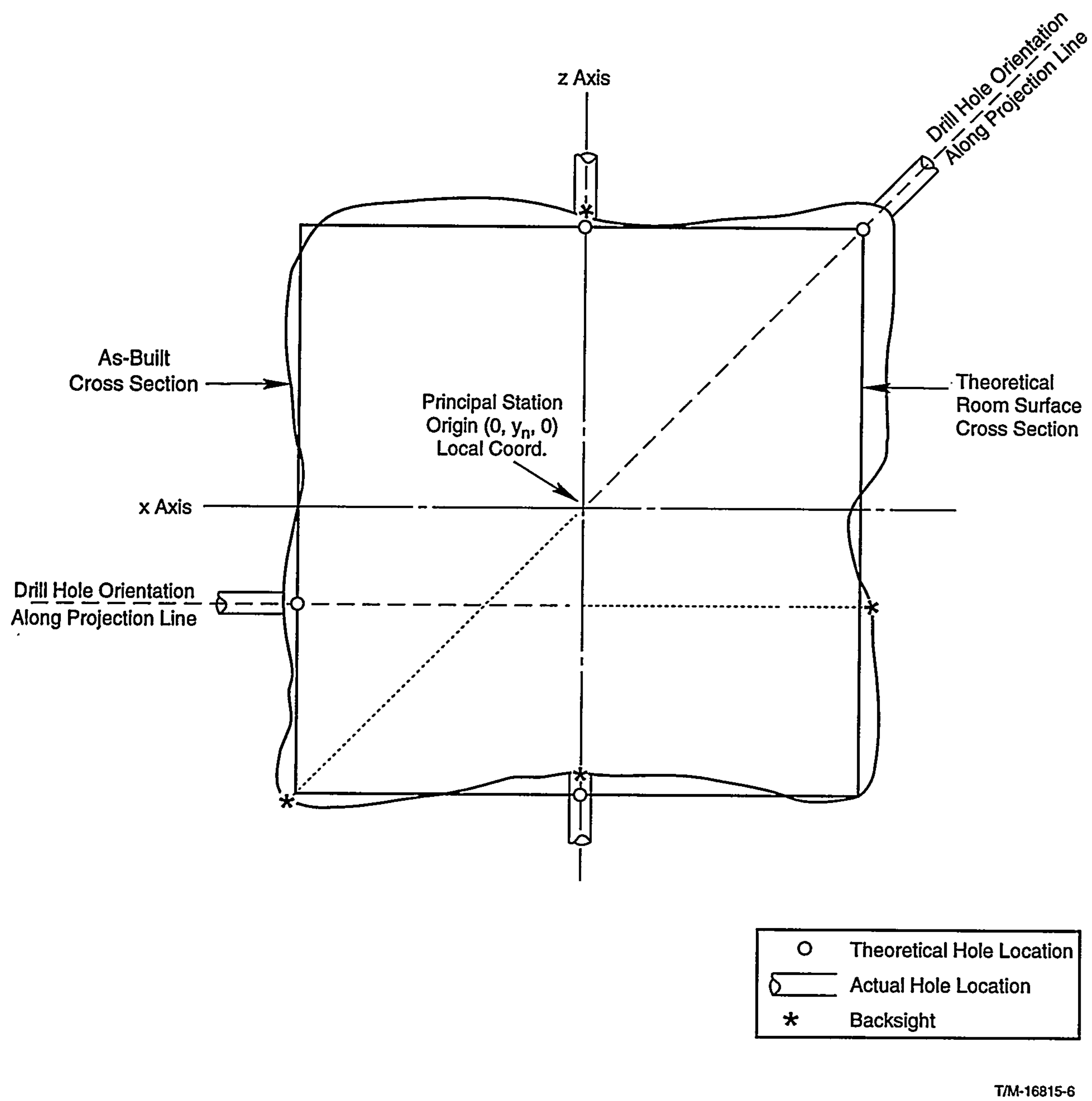


Figure 4.4.3. Instrument Hole Location Technique

were marked with "Ramset" brand studs, identified with tags, and painted with colors that were coded to gage type. ("Ramset" is a fastening system that uses .22-caliber charges to drive 6 mm (1/4 in) studs into the formation.) By using this method, uncertainties in hole location and direction due to irregularities in the room surfaces were eliminated.

Different strategies were needed for locating heater holes and emplacing the heaters. Two basic types of heat sources were used in the TSI in situ tests: canister heaters and heater tapes. Canister heaters were emplaced in the floors of the A and B test rooms, while heater tapes were placed on the surface of the Room H pillar. The location of the canister heaters was straightforward, as it was simply a matter of locating the center of the heater holes in the room floor. No backsight was required because all heater holes were vertical, and the drill could be aligned with a plumb bob. To establish control on heater hole depth and heater placement depth, a grade was established along the length of the room and was defined as a horizontal plane set 2.29 m (7.50 ft) below the average vertical zeros of all principal stations in that room. All drilling, placement of heaters, and installation of heater instrumentation were measured from this grade. In Room H, the control for heater tape placement was established by setting a circular string line parallel to the room back in the fillet radius that was cut at the intersection of the back and the central pillar. A similar string line was located at the intersection of the floor and the pillar. The heater tapes were then vertically positioned such that they were centered between the two string lines.

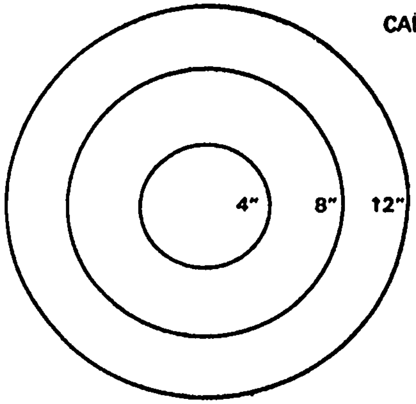
4.4.2 Borehole Surveying: Surveying methods were devised to determine instrument hole orientation, deflection, diameter, and length to assure that all holes were within the specified tolerances. Since the instrument holes were to be surveyed during the instrument hole drilling phase of construction, it was essential that methods be straightforward, efficient, and not severely impact ongoing construction.

The initial orientation of the instrument holes was determined by using a laser mounted in a 1 m (3 ft) long plug. To make a measurement, the device was inserted into a borehole and, with the help of adaptors, centered to align the axes of the plug and borehole. After centering, the laser beam was projected out of the hole and onto the opposite side of the room. By measuring the offset between the projected beam and the surveyed backsight, along with the distance between the hole collar and backsight, it was possible to calculate the initial direction of the hole relative to the specified direction.

Deflection of a borehole from its initial direction was determined by the progressive offset of a 38 mm (1.5 in) diameter light source as the source was pushed into the hole. The specified tolerances dictated that the light had to be at least partially visible over full hole length; therefore hole deflection could not be more than one hole diameter. As the light source was pushed into the hole, the portion of the light visible was sketched and recorded at regular intervals to show the orientation and magnitude of the hole deflection (Figure 4.4.4). To aid in viewing, a 10-power monocular was used to track the light in the deeper sections of the hole. For horizontal and vertical down holes, the source was either pushed or lowered to the end of the hole. In vertical up holes, the light source was attached to a rod and pushed up the hole during the survey. Although this method may seem crude, it provided reliable data on the straightness of the instrumentation holes.

22

LASER ALIGNMENT



CALCULATIONS:

E ← 7/8, ↑ 3/8

DATE 2 / 28 / 90
SHIFT DAY
TIME 11 / 07

ROOM 1420
STATION –

HOLE NO. C372
GAGE NO. —
GAGE TYPE —

TEAM DC TAB
APPROVAL BAS
Q. A.

14' 1 1/4"

$X = \sqrt{(.375)^2 + (.875)^2} = 0.95$

$X = \tan^{-1}\left(\frac{0.95}{169.25}\right) = 0.32$

Date: 2/22/90 Time: 1305 Team. T.M., S.C.

LIGHT SOURCE

DEPTH FROM COLLAR	55'10"	45'6"	35'6"	32'6"						
LIGHT-SOURCE PATTERN	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

DEPTH FROM COLLAR										
LIGHT-SOURCE PATTERN	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

SPECIFICATIONS

1. BOREHOLE COLLAR LOCATION: ±1 INCH — IN SPEC? –
2. BOREHOLE DIAMETER (NON STRESS GAGE): ±0.1 INCH — IN SPEC? –
3. BOREHOLE DIAMETER (STRESS GAGE): ±0.01 INCH — IN SPEC? –
4. BOREHOLE DEPTH: +0.75 FEET, -0.0 FEET — IN SPEC? –
5. BOREHOLE ORIENTATION: HOLE MUST BE CONTAINED WITHIN A 1° ENVELOPE STARTING AT COLLAR — IN SPEC? Y
6. LIGHT MUST BE VISIBLE AT BOTTOM OF HOLE — IN SPEC? /

Figure 4.4.4. Typical Borehole Orientation and Deflection Survey Form

Remote, servo-controlled, three-point borehole calipers were used to measure borehole diameters. Each caliper contained a motor to drive three measurement points against the borehole wall, and an LVDT (linear variable differential transformer) to translate the measurement to a voltage output. A manually operated control unit containing a power source and readout was connected to the caliper with an electrical cable. The calipers were fabricated in three sizes to measure 47.6 mm (1 7/8 in), 76.2 mm (3.0 in), and 101.6 mm (4.0 in) diameter instrument holes. Calibration was performed before and after each borehole survey by using a set of machined aluminum tubes with known internal diameters. Most of the instrument holes were measured at 1.5 m (5 ft) intervals along the length of the hole. Thermocouple holes were only spot checked, since thermocouples were grouted into place. Because inclinometer holes were cased, their diameter was not critical and was not measured.

Some boreholes contained a series of three hydraulic pressure cells. These holes were unique because they required three different diameters along the drill hole. The holes were drilled up to the instrument depth with a diameter of 57.2 mm (2.25 in). The size was then reduced to 55.1 mm (2.17 in) for the next 2.13 m (7.0 ft), then reduced again to 38.1 mm (1.50 in) for the last 0.46 m (1.5 ft). Two of the gages were placed in the 55.1 mm (2.17 in) diameter region and one was placed in the 38.1 mm (1.50 in) region. Borehole calipers were used to measure the larger diameter sections and go no-go gages of various diameters were used to measure the diameter of the 38.1 mm (1.50 in) region, where the diameter tolerance was +0.381, -0.000 mm (+0.015, -0.000 in).

Borehole depths were measured with coupled rods of known lengths.

4.5 Records

Extensive records of all aspects of the TSI in situ testing program are maintained on file in a notebook system at the Nuclear Waste Management Program Information Centers at the WIPP site near Carlsbad, NM and at Sandia Offices in Albuquerque, NM [35]. Many records are on file that relate to the construction of these tests. These records include construction change requests, excavation data, room dimension and geometry data, drilling and core logs, borehole characterization data, gage location and installation records, heater installation records, survey procedures and data, photographs, and drawings. Many logbooks are on file including those of the PI and his representative, shift engineers, surveyors, gage installation crews, geotechnical crews, data acquisition personnel, and quality assurance (QA) coordinators.

5 CONSTRUCTION OF THE TESTS

The construction of the original five major TSI in situ tests was a significant undertaking that involved extensive planning and development by several organizations before the actual construction of the tests could proceed. Construction of the tests was preceded by the excavation of access drifts and instrumentation alcoves, and by the development of storage and repair facilities and a comprehensive data acquisition system. Test room excavation was followed by surveying, drilling, instrumentation, and heater installation.

5.1 Organization of the Testing Program

The conceptual development of the in situ tests progressed as shown in Figure 5.1.1. Overall, the WIPP R&D Program defined the general requirements for developing the technology needed for designing a repository for radioactive waste from defense programs, and specified the laboratory, analytical, and in situ testing necessary to achieve the technological basis. From this program, a WIPP R&D In Situ Testing Plan [1] was prepared that established the motivation, relationship, and concept of the in situ tests, including the TSI tests relevant to this report. Based on this planning document, principal investigators (PIs) prepared test plans [5 through 12] for each of the TSI in situ tests. These plans detail the test geometry, construction sequence, instrumentation, data acquisition specifications, and QA requirements for each test. As the TSI tests progressed, data reports [13 through 24] were published to make a complete record of the experimental data available for analysis and evaluation. The evaluation and analyses of the experimental data will provide, in part, the technical basis for a waste repository.

The test plans were implemented through a cooperative effort of

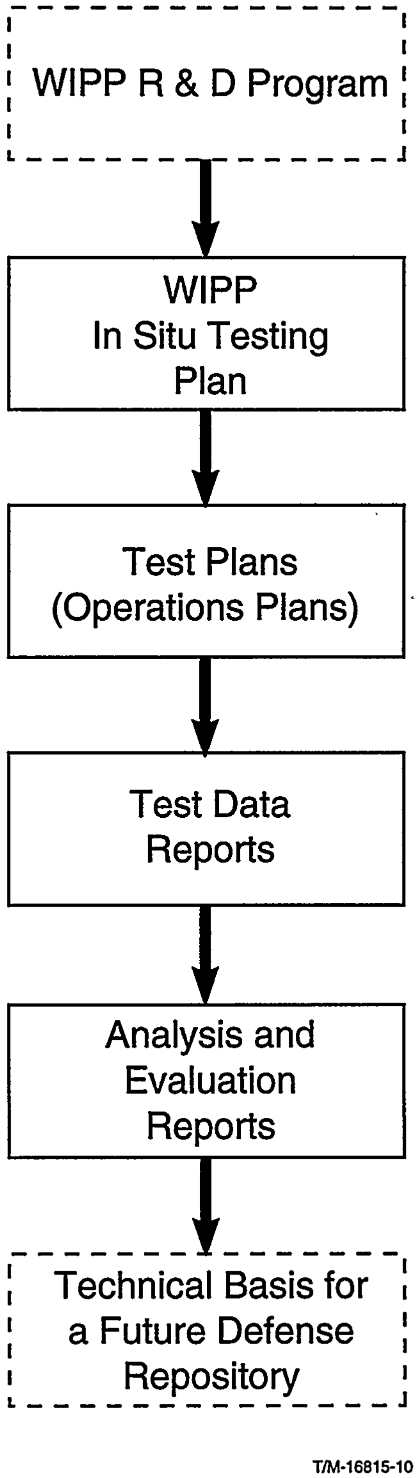


Figure 5.1.1. In Situ Test Concept Flow Diagram

several participants under the direction of the DOE, as shown in Figure 5.1.2. Sandia provided scientific support and was responsible for the WIPP R&D program and the generation of the in situ test plans. Bechtel National, Inc., as the architect/engineer, prepared all construction drawings, specifications, and special provisions of the formal bidding package for the CCP-1Fb construction contract package. The U.S. Army Corps of Engineers acted as the contract manager and provided all construction inspection through Dravo Engineers, Inc.

The Sandia field organization for the construction of the in situ tests is shown in Figure 5.1.3. The Experimental Program and Data System supervisors, WIPP Experiment Engineering, PIs, In Situ Test Coordination, and Experiment/DAS Coordination were all Sandia responsibilities. The other positions were filled by support contractors. RE/SPEC Inc. supported the PIs as field representatives, drilling program coordinators, and instrument installation team leaders. Tech Reps Inc. coordinated the QA program. The mining contractor provided drilling personnel and mine laborers. Subcontractors under Sandia supervision provided cable fabricators, gage installers, administrative personnel, and quality assurance support personnel. Geotechnical crews assisted in monitoring construction work and were initially supplied by International Technology (IT) Corporation, and later by Westinghouse Electric Corporation. Westinghouse, as the operating contractor, provided technical support for operating the experiments.

The successful bidder for the CCP-1Fb mining contract was the Ohbayashi Corporation, a firm specializing in tunnelling and underground construction. This firm was contracted to enlarge the Ventilation Shaft to become the Waste Handling Shaft, to sink an Exhaust Shaft, and to mine

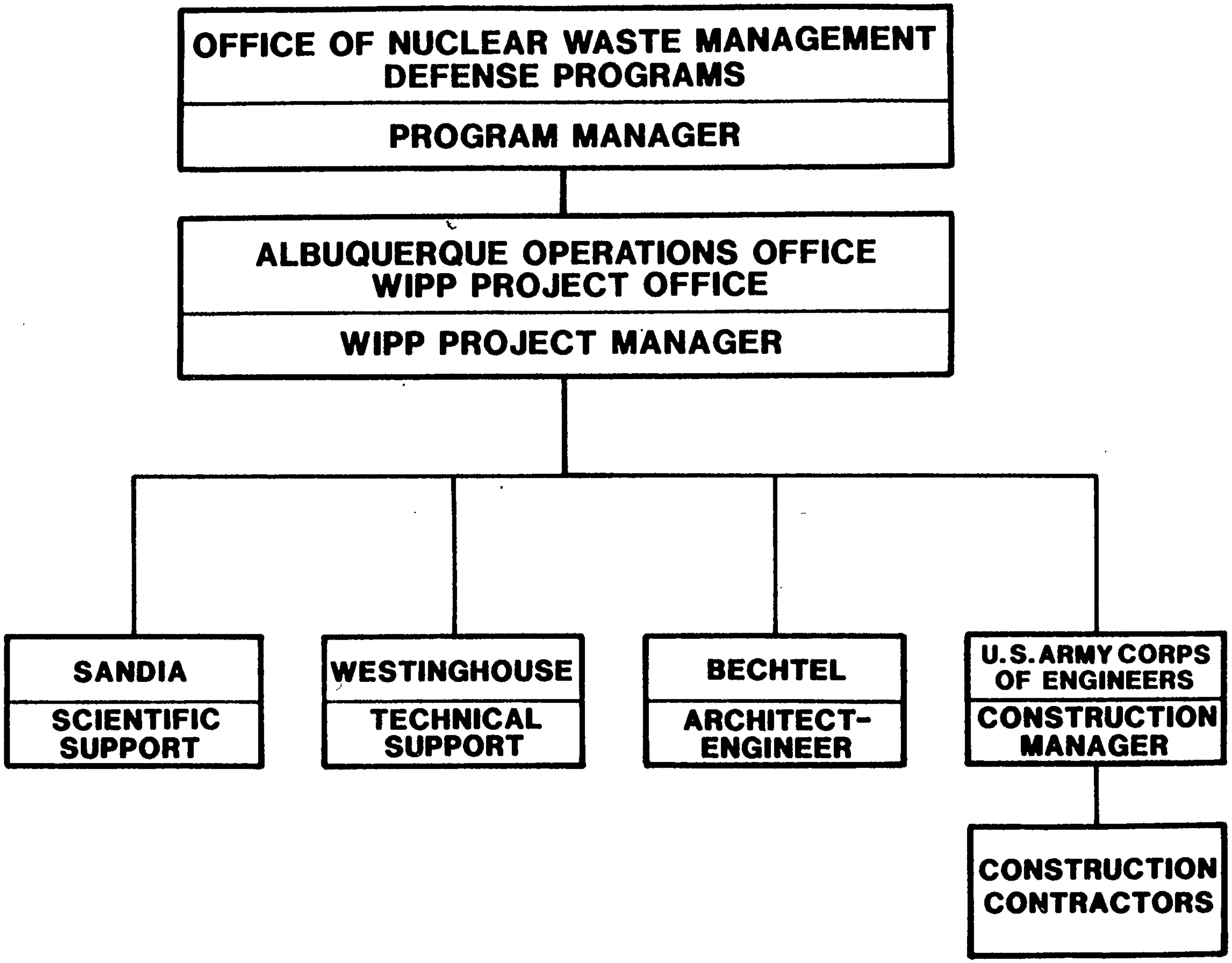


Figure 5.1.2. Major Participants in Early WIPP Test Planning

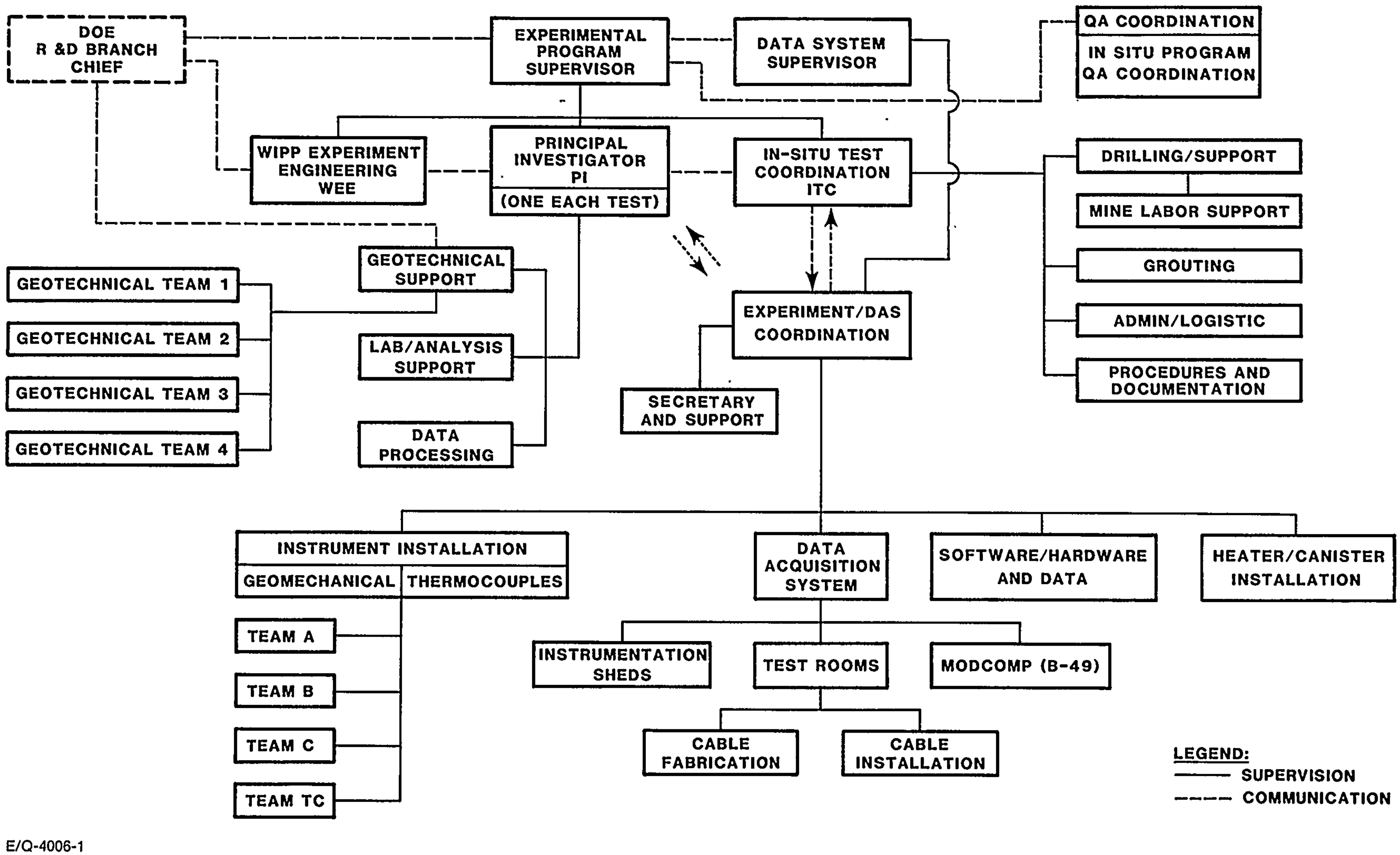


Figure 5.1.3. Sandia In Situ Test Field Organization

the Experimental Area for the R&D in situ tests (Figure 1.0.1). During this contract work, the Exploratory Shaft was renamed the Construction and Salt Handling (C&SH) Shaft (later it was shortened to the Salt Handling Shaft), although no modifications were made thereto. Christensen-Boyles Brothers Corporation was subcontracted by the mining contractor for the test room drilling portion of the contract. The mining contractor would also excavate, through the CCP-1E contract, additional portions of the main entry system to the south of the shafts. The period of performance for these contracts was August, 1983 through April, 1985.

5.2 Preliminary Construction Activities

Several activities directly linked to the TSI in situ tests preceded the excavation and instrumentation of these tests. The automated DAS was fabricated, installed, and tested [36] before test room construction proceeded in order to monitor instrumentation as soon as possible after test construction. Underground storage and support facilities were established to prepare for the instrumentation and drilling portions of the test construction. In essence, these activities mark the beginning of the TSI in situ test construction.

5.2.1 Data Acquisition System: A central DAS was used to monitor over 3,500 remotely read gages (Table 5.3.5) from all of the TSI in situ tests at the WIPP [36]. The system consisted of a surface-based computer system, underground instrument sheds, and an extensive cabling system. Each of the TSI tests had an instrument shed that contained the instrumentation and signal conditioners necessary to operate and monitor the test instrumentation. The instrument sheds were connected to the test instrumentation by jumper cables, and were connected to the surface computer system by transmission cables running from the underground to the surface. The system was previously developed and used for data acquisition in a large-scale oil shale retort testing program. A schematic of the DAS is shown in Figure 5.2.1.

<u>5.2.1.1 Computer System</u>: The surface portion of the DAS was a self-contained computer system housed in a semitrailer referred to as B-49. Two ModComp (Modular Computer Systems Inc.) computers, a primary and a secondary unit, were the center of the system. The secondary computer was used to operate the system when the primary computer was down for maintenance. Both computers used the same operating system and programs, and shared the same disk and peripheral equipment. Sandia developed a library of over 50 separate software programs for data acquisition and other activities such as data management, system diagnostics, and plotting. The major peripherals housed in B-49 included instrumentation busses, disk and tape drives, printers, terminals, and a clock traceable to the National Institute for Standards and Technology.

The computer system monitored all instrumentation and power systems associated with the in situ tests. The system was capable of handling 65,534 measurands, where a measurand is a single measured value such as resistance, voltage, current, or a calculated engineering value such as displacement, temperature, or pressure. Programs on the ModComp calculated the engineering values using the measured values and gage calibration equations. At one time, the system scanned as many as 16,000 measurands once every four hours. Any measurements that exceeded data acquisition alarm limits were identified in an alarmed measurand file which alerted instrumentation personnel of possible gage problems.

<u>5.2.1.2 Instrument Sheds</u>: It was decided early in the test planning that each of the TSI test rooms would have a dedicated underground

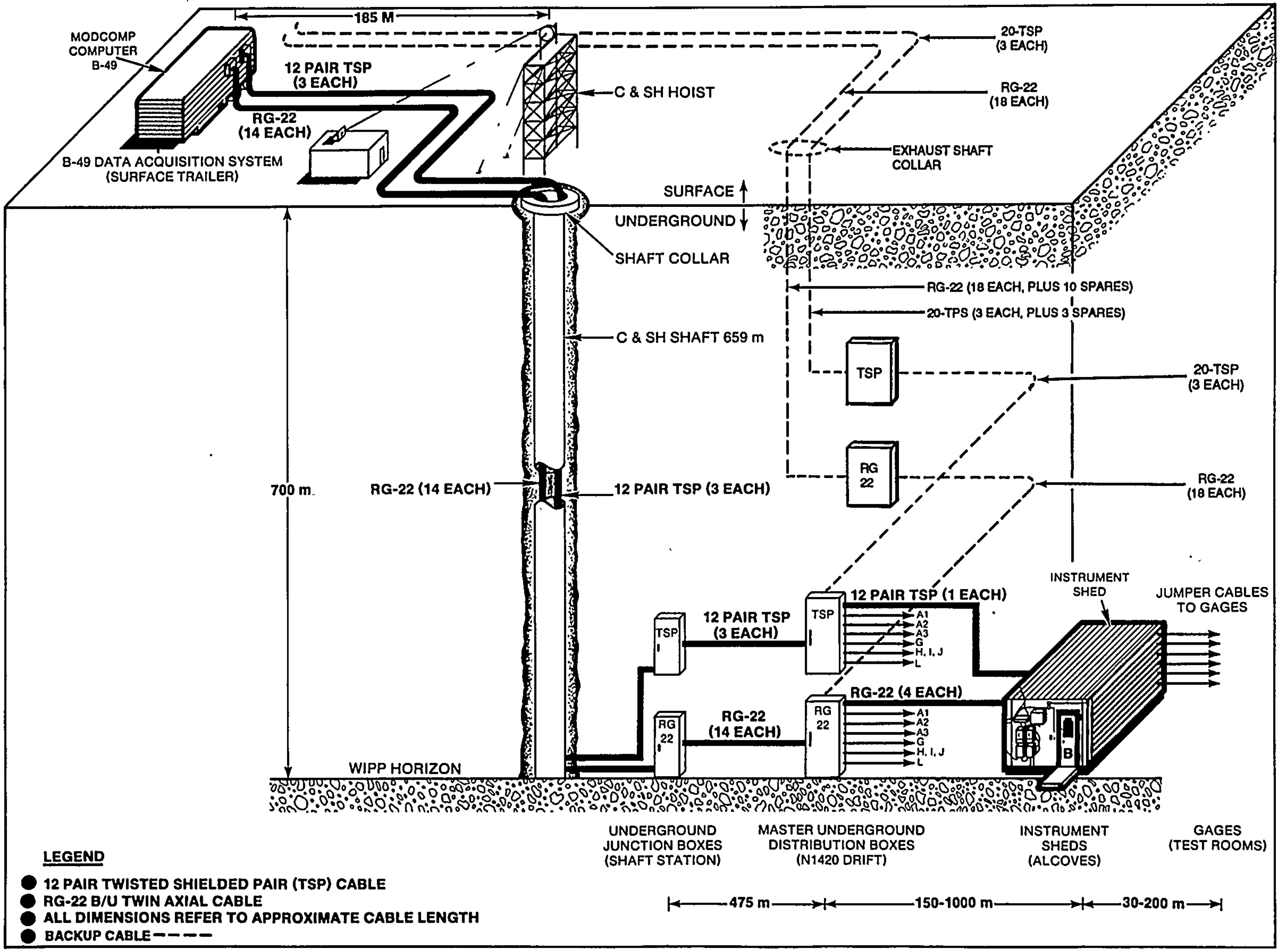


Figure 5.2.1. In Situ Test Data Acquisition System

instrument shed for gage monitoring and signal conditioning. Each of the TSI test rooms had an associated alcove excavated for the purpose of housing an instrumentation shed. The alcoves associated with Rooms G, H, B, A1, A2, and A3 were named I1, I2, I3, I4, I5, and I6, respectively (Figure 1.0.3), and were placed as close to the test rooms as possible to minimize signal degradation. A total of seven sheds were originally placed underground for the purpose of data acquisition. One shed was erected in Room 3 of the SPDV Test Panel for eventual placement in Alcove I2 for Room H. Four were erected in the N1420 drift just north of the SPDV Test Panel for eventual placement in Alcoves I3, I4, I5, and I6. Because of the low back height in the access to Room G, the sixth shed was left unassembled for eventual installation in Alcove I1. The seventh shed was assembled as a spare for use in future tests. Two sheds were added later for other tests.

The sheds were purchased as modular components and assembled by the contractor once underground. Each of the sheds measured 4.3 by 6.1 m (14 by 20 ft) and was of steel construction with plywood floors placed on welded I-beam skids. In order to prevent excessive failure of electronic equipment, the sheds were equipped with air conditioners to maintain moderate temperature and humidity levels, and to minimize the intrusion of salt dust and diesel fumes. After assembly, the sheds were completely outfitted for data acquisition before being pulled into the appropriate alcoves. Early assembly and instrumentation of the sheds expedited data acquisition by allowing the gages to be connected to the DAS immediately after installation.

5.2.1.3 Cabling: The design of the data acquisition cabling system was the responsibility of Sandia. The three main components of this system were the transmission cables between the computer system on the surface and the equipment in the underground sheds, the short interconnecting cables between the equipment and cable racks in the sheds, and the jumper cables between the cable racks and the test instrumentation.

The mining contractor was responsible for placing 14 RG-22B/U (a military specification coded to cable construction and impedance) twin axial cables, and three 12-pair twisted-shielded-pair (TSP) cables from the junction boxes at B-49, through the C&SH shaft, and to the junction boxes at the instrumentation sheds. The RG-22 cables provided a data and command link between the surface computer and the instrumentation sheds, while the TSP cables were used for telephones, intercoms, and computer terminals. Concern over the loss of cables from conductor separations or accidental damage in the shaft led to the installation of 18 RG-22 and three 20-pair TSP cables through the Exhaust Shaft for backup purposes.

Sandia had responsibility for making the connections between the junction boxes and B-49, and between the junction boxes and the instrumentation sheds. Sandia also had all responsibility for running the jumper cables from the instrumentation sheds to the gages in the test rooms. Prior to the instrumentation of the TSI and other in situ tests, all of the jumper cables were fabricated, labeled, and transported underground. A team of eight technicians worked one and a half years to fabricate 9,000 m (30,000 ft) of 20-TSP and 70,000 m (230,000 ft) of 1-TSP copper and thermocouple extension cables to meet the data acquisition needs of the TSI tests. The typical cable configuration consisted of running 20-TSP cables from the sheds into the rooms and then using the 1-TSP cables to connect the individual gages to the 20-TSP cables.

Exceptions to this configuration were in Room B where various TSP thermocouple extension cables were run into the rooms, and in Room D where 1-TSP cables were run from the shed to the room.

For the most part, the distribution of electrical power to the sheds and test rooms was the responsibility of the mining contractor, although the heater power cables were installed by Sandia.

5.2.2 Storage and Support Facilities: Constructing tests of this size and complexity required that Sandia have space underground for storage and support facilities. During the construction of the TSI tests, Rooms 3 and 4 of the SPDV Test Panel, and Rooms L1, L2, and D were allocated to Sandia for these purposes.

The northern half of Room 3 was used to house and stage the test room instrumentation. Underground storage of instruments was essential because of the large quantity and variety of gages, and the need for timely access to these gages. After the gages were brought underground, they were assembled to the extent possible before installation. Each gage was packaged along with the necessary components and separated according to the installation location. The northern half of Room 3 was also used to provide space for a machine, fabrication, and repair shop. These support facilities were required to fabricate and maintain trailers, drill stands, electrical power centers, and other custom-designed equipment. The remainder of Room 3 was used for instrument cable storage and Sandia vehicle parking. The instrument sheds for Rooms G and H were also stored in Room 3 before being pulled into the appropriate alcoves.

Room 4 was used for Sandia drilling equipment storage; core inspection, recoring, and storage; and instrument cable storage. These two rooms filled rapidly, and consequently Rooms L1, L2, and part of the

N1420 entry drift were used to store heaters, insulation, and prepared backfill materials. Large-diameter core (406 mm or 16 in and larger) was stored along the rib in Room D.

5.3 General Construction Activities

Responsibility for test construction was shared by the contractor (Ohbayashi Corporation) and by Sandia. The primary responsibilities of the contractor included all test room and access mining, most of the instrumentation hole drilling, bulkhead installation, and associated survey control. In addition the contractor was required to provide as-built survey information on the locations of room centerlines and drill holes. Any construction activities not defined in the contractor's work package were assumed by Sandia. Work performed by Sandia included the drilling of heater holes, additional instrumentation holes, and stratigraphic core holes; the installation of instrumentation and heaters; and the connection of the instrumentation to the DAS.

5.3.1 Mining: To ensure an orderly execution of the tests, it was imperative that the test rooms be mined in sequential order. Such a mining schedule ensured greater control over the contractor's activities and timely installation of test room gages. Prior to the excavation of the underground tests rooms, some developmental mining was necessary. This included excavation of the access drifts, instrumentation alcoves, and the C and D test rooms. Upon completion of this work, the excavation of the test rooms proceeded. The mining schedule followed during the CCP-1Fb contract is shown in Table 5.3.1 and includes the mining activities accomplished by both of the mining machines described below (Section 5.3.1.1). For purposes of clarity, the two mining machines used for the excavation work will be referred to herein as Machines 1 and 2.

Table 5.3.1. Construction Schedule, TSI In Situ Tests

YEAR	1984												1985												1986	
MONTH	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F
N1100 EAST MINING (MACHINE 1)	9		13																							
ROOM D MINING (MACHINE 1)			13	15																						
ALCOVE I7 MINING (MACHINE 1)			30	1																						
ROOM D DRILLING DEMONSTRATION				13 30																						
ROOM D INSTRUMENT DRILLING					7 23																					
ROOM D INSTRUMENT INSTALLATION						21 28																				
ROOMS L1, L2 MINING (MACHINE 1)				15 27																						
ROOM G ACCESS MINING (MACHINE 1)				27	4	4 24																				
HYDROFRAC MAPPING (G ACCESS)				30	4	4 11																				
ROOM B MINING (MACHINE 1)					4	4																				
ROOM B INSTRUMENT DRILLING						4 28																				
ROOM B HEATER HOLE DRILLING						29		7																		
ROOM B INSTRUMENT INSTALLATION							2 16																			
ROOM B HEATER INSTALLATION								8		INTERMITTENT				5												
ROOM B HEATER TURN ON																23										
ROOM A2 MINING (MACHINE 1)						28	25																			
ROOM A2 INSTRUMENT DRILLING							26	9																		
ROOM A2 REMEDIAL WORK								9 24																		
ROOM A2 INSTRUMENT INSTALLATION								27	12																	
ROOM A2 HEATER HOLE DRILLING								29	11																	
ROOM A2 HEATER INSTALLATION											8		INTERMITTENT				21									
ROOM H, B, A2, & G REFERENCE GAGE DRILLING			13		3							27	17													
DEVELOPMENT MINING (MACHINE 1)							25	31																		

Table 5.3.1 (continued). Construction Schedule, TSI In Situ Tests

YEAR	1984												1985												1986	
MONTH	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F
ROOM A1 MINING (MACHINE 1)									14	10																
ROOM A1 INSTRUMENT DRILLING										15_25																
ROOM A1 HEATER HOLE DRILLING											5 20															
ROOM A1 INSTRUMENT INSTALLATION											5 30															
ROOM A1 HEATER INSTALLATION											28 - -	- -	- -	- -	- -	- -	1	(INTERMITTENT)								
ROOM A3 MINING (MACHINE 1)										13	5															
ROOM A3 INSTRUMENT DRILLING											7_16															
ROOM A3 HEATER HOLE DRILLING												3_12														
ROOM A3 INSTRUMENT INSTALLATION												3_17														
ROOM A3 HEATER INSTALLATION													8 - -	- -	- -	23	(INTERMITTENT)									
ROOMS A1, A2, & A3 HEATER TURN ON																							20			
ROOM G MINING (MACHINE 1)											9		9													
ALCOVE I1												20	24													
ROOM G INSTRUMENT INSTALLATION													1 6													
ROOM G INSTRUMENT DRILLING													11_23													
ROOM H MINING (MACHINE 1)													24	12												
ROOM H INSTRUMENT DRILLING														14_21												
ROOM H INSTRUMENT INSTALLATION															4	4										
ROOM H HEATER INSTALLATION																			3							
ROOM H HEATER TURN ON																										13
N1420 EAST, ALCOVES I2-I6, ROOMS C1, C2, & J MINING (MACHINE 2)	11			15																						
ROOM H ACCESS MINING (MACHINE 2)				15_21																						
DEVELOPMENT MINING (MACHINE 2)				21					9																	

5.3.1.1 Major Equipment: Mining of the TSI in situ test rooms and their access drifts was performed using two Mitsui-Miike S-125 road header, continuous mining machines. These are small machines compared to others in the industry. Each machine mined an average of 200 tons per day during the excavation of the in situ test rooms. Although these machines had a low production capacity, they did not adversely impact the contractor's schedule. In fact, these machines helped the contractor meet the tight tolerances specified for test rooms because of the telescoping action of the cutting head. While trimming the test room boundaries, it was necessary to take small cuts on the order of 100 mm (4 in) or less to meet the dimensional specifications. With a boom extension of about 500 mm (20 in), several cuts could be made without moving and releveling the machine.

Muck was transferred from the mining machines by conveyors to either LHDs or dump trucks and transported to the hopper at the base of the C&SH shaft. Muck from the hopper was then transferred to a 7,300 kg (16,000 lb) loading pocket, which in turn dumped into the skip to be hoisted to the surface. At the surface, the mined salt was dumped into trucks and transported to an on-site spoils pile. The trucks and LHDs were also used to support mining and mucking operations associated with shaft construction, excavation of the area south of the shafts, and maintenance of underground facilities. Specifications for the mining machines and other major equipment used for facility excavation are given in Table 5.3.2.

5.3.1.2 Entries and Alcoves: Mining of the entries and alcoves commenced with Machine 1 excavating the S400 drift to provide access for the development of the Exhaust Shaft (see Figure 1.0.3 for locations of

Table 5.3.2. Major Mining Equipment Used in TSI Excavations

Item	Type	Quantity	Comments
Continuous Miner	Mitsui-Miike S-125	2	30,000 kg (66,000 lb) weight. 127 kW (170 hp) Cutting Motor. 37 kW (50 hp) Hydraulic Motor.
Load-Haul-Dump	Eimco 913	1	2.3 m^3 (3.0 yd^3) Capacity. Road Header Mucking.
Load-Haul-Dump	Eimco 912	1	1.5 m^3 (2.0 yd^3) Capacity. General Maintenance.
Truck	Jarvis-Clark JDT-413	3	12,000 kg (26,000 lb) Capacity. Road Header Mucking.

excavations). After completing the S400 cut, this machine was used to remove 1.2 m (4.0 ft) from the floor of the E0 access drift, leaving a final drift height of 3.7 m (12 ft). The floor removal extended from the C&SH Shaft to the N1420 drift. After the E0 drift was finished, Machine 2 was brought on line for the parallel excavation of the N1100 and N1420 drifts; Machine 1 worked in the N1100 drift while Machine 2 worked in the N1420 drift, both mining to the east. These two entries were started in early January, 1984 and finished mid-March, 1984. During and following the excavation of the N1420 drift, Machine 2 mined Alcoves I3, I4, I5, I6, two electrical substation alcoves, and Rooms C1 and C2 along the length of the drift. Machine 2 was then moved to the west where it mined Room J, Alcove I2, and the Room H access drift. After mining the Room H access drift, Machine 2 moved to the south and excavated the entries associated with the TRU Waste Storage Area (CCP-1E contract).

The remainder of the Experimental Area was excavated with Machine 1. After the N1100 drift was completed, the contractor excavated Room D and Alcove I7, followed by Rooms L1 and L2. The contractor then began to excavate the Room G access where the In Situ Stress Field - Hydraulic Fracturing Tests took place. Excavation continued in the Room G access until the first Hydraulic Fracturing Test Zone was reached. At this time, the contractor had finished the demonstration of drilling capabilities in Room D, and Machine 1 was removed and used to excavate Room B. Excavation in the Room G access continued after Room B was excavated and the first Hydraulic Fracturing Test zone had been mapped. Alcove I1 was mined during the excavation of Room G, and was the last of the support excavations to be mined.

5.3.1.3 Test Rooms: Following the successful demonstration of drilling capabilities by Christensen-Boyles Brothers Corporation, Ohbayashi began the excavation of Room B on May 4, 1984. Room A2 mining was not allowed to proceed until the previously mined Room B was turned over to Sandia, that is, until all contractor activities in the room were complete. This delay in mining activity was required to ensure that installation of critical instrumentation kept pace with room excavation. Sandia occupied Room B on June 28, 1984 and mining immediately commenced in Room A2.

The mining of Room A2 was completed on July 25, 1984; other scheduled contractor activities in this room were completed on August 9, 1984. A 21-day delay in test room excavation was originally included in the contractor's schedule to allow Sandia enough time to instrument Room A2 for monitoring the effects of the excavation of Rooms A1 and A3. However, excavation nonconformities and the resulting remedial actions

(Section 5.4.4.1) further delayed excavation of Room A1 until September 14, 1984. Room A1 mining commenced immediately following the completion of the required Room A2 instrumentation.

Rooms A3, and G were mined with only minimal interruption, with mining beginning on October 13, 1984 and November 9, 1984, respectively. As part of the mine-by test monitoring in Room A2, Sandia specified that Rooms A1 and A3 be mined with as little delay as possible, and no delay for instrumentation was imposed. There was no delay imposed on the mining of Room G because the anticipated two month excavation period would allow ample time to instrument Room A3 before the contractor finished in Room G. Alcove I1 for Room G was excavated during room mining.

Room H was the last of the test rooms to be mined. Mining in Room H, which began on January 24, 1985, was not allowed to proceed until contractor activities in Room G were complete.

The excavation of the test rooms varied slightly from room to room, but typically was performed with a sequence of four passes through the length of the room. Each excavation pass was executed continuously through the length of the room before a new pass was started. An example of the excavation sequence is shown in Figure D-1 (Appendix D.) Two passes each were required to cut the upper and lower bench. All four passes proceeded from the N1100 drift to the N1420 drift. In order to "turn in" from the N1100 drift, it was necessary to replace the standard rear conveyor on the mining machine with a shorter unit. With the shorter conveyor, it was necessary to use the lower-capacity LHDs for mucking operations. The longer conveyor was therefore reinstalled as soon as the machine had progressed a sufficient distance along the first pass. It was also necessary to cut a pit approximately 0.3 m (1 ft) deep in the floor of the room entry so the machine could ramp up to the top working bench at a greater angle. If the angle of entry had been too low, the machine would not have been able to cut the brows at the south end of the room from the upper bench. The first mining pass progressed to the upper brow at the north end of the room. Utilities for mining were carried into the room during the first pass and included a 0.6 m (2 ft) diameter flexible ventilation duct, a 100 mm (4 in) diameter water supply for machine cooling, and electrical power. Following completion of the first pass, the machine was backed up to the south end of the room for the mining of the second pass. This pass included the final cut of the upper bench, mining of the north brows, and connection with the N1420 drift. The machine was then turned around and the south brows were cut from the upper bench. The last two passes were excavated in essentially the same manner, except that the floor was intentionally left above the design elevation and trimmed to the final grade on retreat. This final trimming proved difficult because the contractor chose to cut the floor "blind" under as much as two feet of muck. Starting with the excavation of Room A1, the rooms were mucked out and blown clean before trimming the floor.

The mining contractor was initially under no contractual obligation to excavate the test rooms in any given sequence, or to inform the PI of the excavation plan. Results from Room D and eventually Room B would modify this approach. The Room D advances were essentially uninterrupted during the 31 days required to complete test room excavation as illustrated by the excavation advance rates shown in Figure D-2 (Appendix D). The Room B excavation, in contrast, was more complex (see Section 5.4.3.1) and added unnecessary complications to mining sequence measurements and closure modeling. As a result, it was decided that the excavation of the remaining test rooms would follow the excavation sequence of Room D (the "typical" sequence described above).

Both Rooms D and B were constructed with two brow cuts at the room entrances. Separation of clay seams in these brows was observed, creating stability and safety concerns in these entries. In an effort to minimize this potential, it was decided that the entries to Rooms A1, A2, and A3 would have a single brow (see Figures A1-4, A2-4, A3-4, B-4, and D-4 of the Appendices).

The mining sequences in Rooms G and H varied from the typical because of their different geometries. Room G, because of its greater length and lower back, was excavated with a simpler sequence (Section 5.4.5.1). Room H required a different mining sequence because of its annular shape (Section 5.4.6.1).

Following the excavation of each test room, the contractor was required to remove all muck from the room floor in such a way that all solid rock was exposed. The clean floors facilitated the layout of drill holes and aided in room inspection.

5.3.2 Surveying: Prior to the excavation of the TSI test rooms, the contractor was required to perform a closed traverse survey of the existing underground workings and surface monuments to establish the necessary reference points for test room construction. The contractor was also responsible for most of the survey control during the test construction. Specific tasks included excavation control, establishment of instrument hole locations and backsights, location of heater holes in the required rooms, and as-built surveys of each of the test rooms. All traverse surveys were performed to Second Order, Class II accuracies established for geodetic control surveys [37].

Excavation control for room bearing and width was achieved by using laser beams directed along the azimuth of the room and located a set distance (usually 460 mm or 18 in) from the final rib. The mining crew would periodically check the distance from the laser beam to the rib to ensure that excavation was proceeding within the tolerance envelope, and would check the alignment of the laser at least once per shift. In all cases, the back was level in the direction transverse to the room length, but followed the stratigraphy along the length of the room (Figure 4.2.1). Plumb lines were used to check the verticality of the ribs, and steel rods cut to the minimum room height were used to check room height. Control of the floor elevation was difficult, however, because of the large quantities of muck left on the floor during the final cut. Nevertheless, the contractor was generally able to remain within the room tolerance envelope as shown by the as-built cross sections and profiles in Appendices A1 through H. Roughness was checked with straight edges to ensure that no gouges or ridges were left on the surface that would interfere with instrumentation.

Room H is annular in shape and was laid out in cylindrical coordinates. Because of this, excavation controls differed from those discussed above. In Room H, room width was checked with plumb lines suspended from two sets of points: one set was located on a radius 305 mm (12 in) greater than the nominal inner room radius, the other on a radius 305 mm (12 in) less than the nominal outer room radius. Templates cut with the proper arc were used to check pillar roughness. Additional details of Room H excavation control and surveying are discussed in Section 5.4.6.1.

The first activity following excavation was the determination of the as-built room centerline. The room centerline was established by running string lines across the width of the room at intervals along the room length. The middle of each line was located using conventional surveying methods and the offset from the theoretical centerline was noted. In all cases the as-built centerline was well within the specified allowable deviation and consequently the theoretical centerlines were used as the references for instrument hole location. After establishing the room centerline, the point of room mid-length was established by Sandia in conjunction with the contractor. Locating the centerline in Room H required a different procedure because of the cylindrical coordinate system (Section 5.4.6.1).

Sandia supplied the contractor with the locations of the principal stations relative to the room center and stations were marked along the length of the room. The contractor determined the as-built room height at each principal station and, thereby, the local origin for each of the stations. With the local origins established, the instrument hole collars and associated backsights were located and marked according to the procedure outlined in Section 4.4.1. The contractor also located and labeled the center of each heater hole in the rooms where heaters were to be installed. Following the completion of instrument hole drilling and collar installations (Section 4.2), the contractor performed a complete as-built survey of all instrument hole collar locations and provided the results to Sandia for review.

5.3.3 Drilling: Drilling responsibilities for the TSI in situ tests were divided between the mining contractor and Sandia. The contractor was charged with drilling the reference gage holes and the instrument holes. The reference hole drilling was a time consuming affair, but was not subject to the scheduling and manpower requirements of the instrument hole drilling, nor was it as directly related to test room construction as the instrument hole drilling. The two tasks were further distinguished by the types of crews required, equipment used, and the types of holes drilled. In total, The contractor drilled four deep reference gage holes and over 600 instrumentation holes within the tolerances specified in the construction contract.

Sandia had the responsibility for drilling all holes outside the construction contract. These included instrument holes for gages added to the tests after the contract was written, all heater holes, near-field thermocouple and fluxmeter holes, and stratigraphic core holes.

5.3.3.1 Fixed Reference Gage Holes: Fixed reference gages were constructed in the access drifts near Rooms B, A2, G, and H, and were designed as underground elevation benchmarks for the TSI tests. It was necessary to establish such reference points to determine the absolute vertical displacement of the gages. Drilling of the reference gage holes began before TSI test room mining, and continued throughout test room development, as shown in the schedule in Table 5.3.1. Room H, B, and A2 reference gage holes were drilled between March 13 and June 3, 1984, while Room G reference gage holes were drilled between December 27, 1984, and January 17, 1985.

The typical reference gage is shown in Figure 5.3.1 and was installed in a pair of vertically opposed boreholes in the floor and back of an access drift. The first 15 m (50 ft) of each hole was 254 mm (10 in) in diameter, the next 12 m (40 ft) was 152 mm (6 in) in diameter, and the final 4 m (13 ft) was 47.6 mm (1 7/8 in) in diameter. The gage itself consisted of a pair of cables that were anchored in the end of each hole

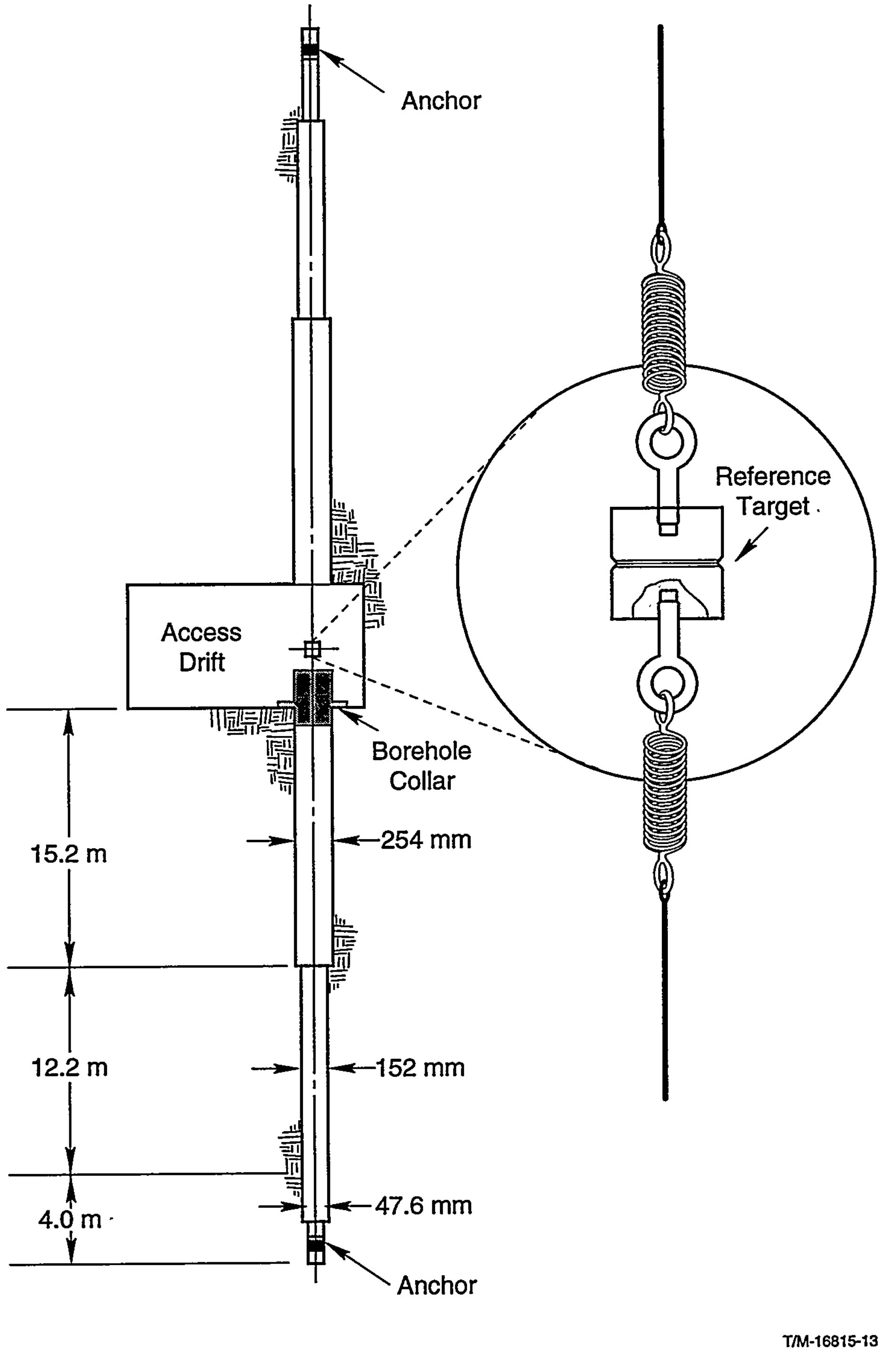


Figure 5.3.1. Reference Gage Installation

and joined by extension springs to a central survey target. To establish a reference gage, two vertically opposed holes were drilled to depths of 31 m (103 ft) in the floor and back of the access drift using diamond plug bits of the smallest hole diameter. After these holes were drilled, they were inspected by the PI for alignment and depth. After the inspection, the holes were reamed to the specified diameters using a bit with a "stinger" pilot, and centralizers along the drill string. The holes were drilled with a skid-mounted Longyear EHS-34 electrohydraulic drill using either saturated brine or air for the drilling fluid. The EHS-34 is similar to the EHS-38 (Section 4.1) but is somewhat larger.

Following the reference gage installation near Room H, it was found that the anchor cable wire was touching the side of the deeper portion of the upper hole. To remedy this, the anchor was removed from the hole and the remaining 152 mm (6 in) diameter portion of the hole was reamed to 254 mm (10 in). With the exception of the Room H hole, all reference gage drilling proceeded without incident.

5.3.3.2 Instrument Holes: Four Longyear D-65 drills (Section 4.1), mounted on self-powered scissors lifts, were used for nearly all instrument hole drilling. The drills were mounted on chain-driven, air-powered slide tracks which, together with the screw feed on the drill, permitted a bit advance of an entire 1.5 m (5 ft) rod segment without rechucking. This mounting made rod changes in front of the drill possible. The slide was clamped on a horizontal post that was securely attached to the scissors lift; this permitted the drill to be adjusted laterally as well as rotated about the post. Drill height was set by adjusting the lift height. The scissors lift platform was stabilized with "crutches" that fit under the platform frame and were adjusted to fit tightly against the floor. In addition, the entire lift was secured using guy wires and come-along tighteners that were stretched from the four corners of the platform to bolts in the test room floor. The final adjustment was made with a string line stretched from the surveyed hole target, through the drill stem, to the surveyed backsight. The rig was adjusted until the drill stem centerline was coaxial with the string line. An adjustable fixture to locate and guide the drill bit was then mounted with small anchor bolts over the borehole target to hold the bit in position and stabilize the drill string while starting the hole.

Following the drilling demonstration in Room D (Section 4.3.3), the contractor drilled boreholes to be instrumented by Sandia in the central portion of Room D and in the access to Room H. The Room D holes were drilled according to a contract change issued at the request of Bechtel National, Inc. for monitoring room deformation. Four 47.6 mm (1 7/8 in) diameter extensometer holes, and three 102 mm (4 in) diameter inclinometer holes were drilled to a depth of 15 m (50 ft). Two of the 102 mm (4 in) holes were cored to the full depth. In addition, the contractor drilled a series of closure point holes. The holes drilled in the Room H access drift were part of the original test plan and were drilled into the future pillar from the end of the access drift (which was excavated almost one year before the test room was mined). The instruments installed in these holes would later monitor stress and deformation in the central pillar during the excavation of Room H.

As shown in the schedule in Table 5.3.1, instrument hole drilling in the test rooms directly followed room excavation. The time periods reflected in the schedule include the drilling activities as well as the installation of the flanged collars and the installation of the permanent manual closure points. In most of the test rooms, instrument hole drilling progressed on a 24-hour, three-shift-per-day basis using four rigs. Room H, however, was drilled on a two-shift-per-day basis. Typically three drills would be operating at any time while a fourth rig was being readied for the next hole. In each room, drilling was performed on an array basis. That is, all holes located in one principal station were drilled before the rig was moved to the next station. Typically, one eight-hour shift was required to set up a rig in the proper location and orientation, drill a hole to a depth of 15 m (50 ft), and move to the next hole. Upon completion of a station, the full array of holes was typically turned over to the geotechnical crews for inspection by the methods described in Section 4.4.2. In the event that a hole was found to be unacceptable, an alternate hole location was determined by the Sandia PI, the new drilling target and associated backsight were located, and the hole was redrilled. The identification tag was removed from the rejected hole and placed adjacent to the new hole. If the instrumentation design necessitated that two holes be directly opposite, and only one of the holes was out of tolerance, both were redrilled. Table 5.3.3 gives a breakdown of the total number of holes drilled within specifications in each room and the number of holes that were redrilled because of tolerance violations.

The instrument holes drilled by Sandia were, in general, added to the tests after the CCP-1Fb construction contract package was awarded. The additional holes contained near-field thermocouples, thermal flux meters, borehole stress gages, and ultrasonic velocity measurement devices. Holes were drilled in the vicinity of selected heaters in the A and B series rooms to house near-field thermocouples and thermal flux gages; flux gage

Table 5.3.3. Summary of Accepted and Rejected Boreholes

Test Room	D	B	A2	A1	A3	G	H	TOTAL
Total Holes Accepted	82	317	381	292	309	169	162	1,712
Total Holes Rejected	0	9	2	0	10	1	2	24
Percent Holes Rejected	0.0	2.8	0.5	0.0	3.2	0.6	1.2	1.4
Total Holes Drilled	82	326	383	292	319	170	164	1,736

holes were also drilled in the Room H pillar. These holes were drilled during the construction of the respective tests and instrumented before the heaters were activated. The ultrasonic test holes were drilled along the lengths of Rooms A2 and A3, outside of the excavation envelopes, and before excavation of Room A3. Strain gage holes were drilled along the mining axes of Rooms A1 and A2, but before test room excavation.

A Longyear 300 rig (Section 4.1) was used to drill the short plug holes for the manually read room closure points. Before drilling, the drill was simply secured over the hole and aligned by sight. A 300 mm (12 in) deep by 19 mm (3/4 in) diameter hole for anchoring the closure point was drilled first and was followed by a 102 mm (4 in) diameter recess hole.

<u>5.3.3.3 Heater Holes</u>: Longyear EHS-38 (Section 4.1) drills mounted on mobile drilling platforms were used for all heater hole drilling. To complete the drilling in a timely manner, two of these drilling rigs were required. The drilling methods had been well established during the practice drilling (Section 4.1) and no notable problems occurred with this work. Drill logs for each hole were maintained and the core was appropriately labeled and stored in Room D. A 406 mm (16 in) diameter hole took about one eight-hour shift to complete, including setup time.

The 762 and 914 mm (30 and 36 in) diameter holes required two to three shifts. After the holes were completed, they were surveyed for alignment, diameter, and depth.

In each of the A and B test rooms, electrical resistance heaters were placed in boreholes drilled into the test room floors. Heater holes contained two basic types of heaters: TSI and Waste Package Performance (WPP) heaters. The TSI canister heaters were similar in form to the proposed design of DHLW waste canisters and, together with the TSI guard heaters, provided simulated waste heat. The WPP heaters placed in Rooms A1 and B were part of the WPP Technology Experiments and were designed to provide information on the performance of waste package materials in a repository environment. Although not part of the TSI in situ tests, the WPP heaters provided a portion of the experimental heat source in Rooms A1 and B. Four of the twelve WPP heaters placed in Room B were filled with a glass form, however, and provided no heat. The heater holes ranged from 406 to 914 mm (16 to 36 in) in diameter and were drilled to nominal depths of 4.6 to 5.5 m (15 to 18 ft) below the test room floors. In all, 101 heater holes were drilled during test construction. A summary of the heater holes for each room is given below in Table 5.3.4.

Immediately following the contractor's release of each test room, Sandia-sponsored personnel surveyed and marked a grade for heater hole drilling and heater installation. The heater grade was defined as a horizontal plane located 457 mm (18 in) above the average floor elevation which was established by averaging all hole collar elevations in the room floor located on the room centerline. At each heater hole location along the length of the room, "Ramset" brand brackets were shot into the ribs to mark the grade. Depths were measured relative to string lines stretched

Table 5.3.4. Heater Hole Summary

Room	Test	Heater	Number of Holes	Hole Diameter mm (in)	Hole Depth m (ft)
B	TSI	Guard	4	762 (30)	4.9 (16.0)
B	TSI	Canister	17	406 (16)	4.9 (16.0)
B	WPP	Canister	11	914 (36)	4.6 (15.0)
B	WPP	Canister	1	762 (30)	4.6 (15.0)
A1	TSI	Guard	13	406 (16)	5.5 (18.0)
A1	WPP	Canister	4	762 (30)	5.0 (16.5)
A1	WPP	Canister	2	914 (36)	5.0 (16.5)
A2	TSI	Guard	4	406 (16)	5.5 (18.0)
A2	TSI	Canister	28	762 (30)	5.5 (18.0)
A3	TSI	Guard	17	406 (16)	5.5 (18.0)

between the opposing brackets.

Heater hole drilling was the responsibility of Sandia and began immediately after the heater grades were set. It is important to note that heater hole drilling and instrumentation occurred during the same time period. Because of the potentially conflicting activities, it was necessary to carefully coordinate this phase of test room construction. It would have been most convenient if heater hole drilling had been completed before instrumentation began. However, it was also important that critical instrumentation be installed and data recording be initiated as early as possible in each of the test rooms. Since heater hole drilling would not have been possible after the instruments had been installed, the two activities were performed concurrently. This situation caused some difficulties, but was unavoidable. In Rooms B and A2, heater hole drilling began before the start of instrument installation. Instruments located in areas that would obstruct drilling or drill access were not installed until the heater holes in those areas had been completed. Heater hole drilling was conducted on a one-shift-per-day basis, usually during the evening shift, to avoid interference with the instrumentation activities.

5.3.3.4 Coring: Coring operations for stratigraphic mapping and the collection of laboratory test specimens were initiated prior to the construction of the TSI tests and took place primarily in Room 4 of the SPDV Test Panel. During test construction, two other large coring efforts were undertaken. Core 102 mm (4 in) in diameter was taken above and below the south end of Rooms A1 and A3, and the north end of Rooms A2 and B. Each of the holes was cored to a depth of approximately 15 m (50 ft). The second suite of core holes was drilled in the northern portion of Room D. This work consisted of coring 406 mm (16 in) diameter holes, about 6 m (20 ft) deep horizontally into the eastern rib. This core was subsequently recored perpendicular to the bedding to obtain laboratory test specimens from within the room horizon. The 406 mm (16 in) diameter coring operations were carried out with the Longyear EHS-38; the smaller diameter core holes were drilled with both Longyear D-65 and EHS-38 drills (Section 4.1).

5.3.4 Instrumentation: Over 4,200 manually and remotely read gages were installed in the TSI in situ tests (Table 5.3.5). The tests contained mechanical-response gages to monitor the response of the rock mass, and thermal-response gages to monitor the thermal field produced by the test heaters. Detailed descriptions of all gages installed in the TSI tests are given in the Instrumentation Report [33].

Table 5.3.5. Quantities* of Gages Installed, TSI In Situ Tests

Gage	Room - A1	A2	A3	B	C	D	G	H	Q	V	Total
Manual Gages											
Mining Sequence Closure	21	21	21	21	14	21	12	19	8	8	166
Temporary Closure	8	8	8	14	-	-	12	11	-	10	71
Permanent Closure	20	18	20	12	-	6	-	8	-	6	90
Remedial Closure	50	50	50	28	-	-	-	-	-	-	178
Brow Closure	8	6	8	6	-	8	-	-	-	-	36
Anchor Bolt Extensometers	-	-	-	-	-	-	96	-	-	-	96
Inclinometers	-	24	-	16	-	3	-	10	-	-	53
Fixed Reference	-	1	-	1	-	-	1	1	-	-	4
Manual Gage Total	107	128	107	98	14	38	121	49	8	24	694
Remote Gages											
Permanent Closure	9	10	9	12	18	2	14	8	12	-	94
Remedial Closure	12	12	12	-	-	-	-	-	-	-	36
Brow Closure	-	2	-	2	-	-	-	-	-	-	4
Extensometers											
Serata E-200L	92	132	87	170	60	20	-	56	-	-	617
Serata E-300	-	-	-	-	-	-	-	24	-	-	24
Irad Model 4000	19	18	19	20	-	-	100	38	-	60	274
Serata C-300	-	11	-	8	-	-	-	-	-	-	19
Stress Gages											
Strain-Gaged	-	72	-	6	60	-	21	9	-	-	168
Bureau of Mines	-	6	15	42	43	-	21	60	-	-	187
Thermocouples											
Far-Field	78	186	176	207	-	-	-	100	-	36	783
Near-Field	78	186	150	162	-	-	-	-	-	-	576
Heater**	70	104	54	134	-	-	-	-	-	-	362
Flux Meter	35	39	-	36	-	-	-	8	-	-	118
Air Stream	-	-	-	-	-	-	-	-	-	6	6
Flux Meters	35	39	-	36	-	-	-	8	-	-	118
Heater Power**	19	32	17	29	-	-	-	19	-	-	116
Environmental, Ventilation	4	4	4	9	-	-	-	7	-	-	28
Borehole Strain	2	2	2	-	8	-	-	-	-	-	14
Remote Gage Total	453	855	545	873	189	22	156	337	12	102	3544
Grand Total	560	983	652	971	203	60	277	386	20	126	4238

* Quantities of individual gages, as opposed to multiple-gage units.
** Includes WPP gages that also contributed to the TSI experiments.

The mechanical-response gages included room closure gages, borehole extensometers, borehole stress meters, and inclinometers. Room closure gages were used to monitor the closure of the test rooms while borehole extensometers monitored extension of the rock mass. Many closure gages were attached directly to the extensometers and together they provided complete deformation measurements at various cross sections in the test rooms. Different types of borehole stress meters were utilized to evaluate the stress field in the rock mass around the test rooms. Inclinometers were used in specially cased boreholes to measure relative displacements of the rock mass.

The thermal-response gages included thermocouples, thermal flux meters, and heater power gages. Three different applications of thermocouples were installed in the test rooms: far-field, near-field, and heater. The far-field thermocouples were installed in arrays of boreholes to measure the thermal field around the test rooms. Near-field thermocouples were installed in boreholes to measure the steep thermal gradient in the vicinity of the heaters. Heater thermocouples were built into the heaters to measure the temperature of the heater surface. Thermal flux meters were installed in the annulus of selected heaters, both on the heater surface and on the borehole wall. Heater power meters complemented the thermal measurements by evaluating the amount of experimental heat generated in the test rooms.

Instrumentation began, in some tests, before the excavation of the test room to aid in the evaluation of the rock mass response during excavation. In the A Test Rooms, borehole strain gages were installed in holes drilled along what would become the axes of the rooms to evaluate strain in the rock mass as the mining machine approached. In addition, ultrasonic velocity measurement devices were installed in boreholes drilled around the perimeters of Rooms A2 and A3, but before the excavation of Room A3, in order to monitor the development of a disturbed zone around the rooms. In Room H, borehole stressmeters and extensometers were installed in the end of the access drift (in what would become the central pillar of the room) to monitor deformation of the pillar during and after mining.

Aside from the aforementioned special gages, instrumentation activities normally began during the period of test room excavation with the installation of mining sequence closure gages and temporary closure gages. In a typical test room, the construction schedule called for nearly two and a half months for excavation, drilling, and instrumentation. The substantial delay that would occur between the onset of excavation and the eventual gage monitoring spawned the decision to obtain early measurements of test room closure. In each of the test rooms, three or more mining sequence stations were established at which closure measurements were taken during each pass of a four-pass mining sequence as shown in Figure 5.3.2. After test room excavation was completed at a station, the contractor was charged with the installation of temporary closure points to supplement the mining sequence points. These points were monitored by Westinghouse geotechnical crews until the room was available to Sandia for the installation of permanent gages.

Because of the large number of instruments allocated to each of the test rooms (Table 5.3.5), it was necessary to set priorities for the installation sequence. Upon completion of contractor activities, test room control was transferred to Sandia and instrumentation activities began immediately. At this time, the jumper cables were run into the

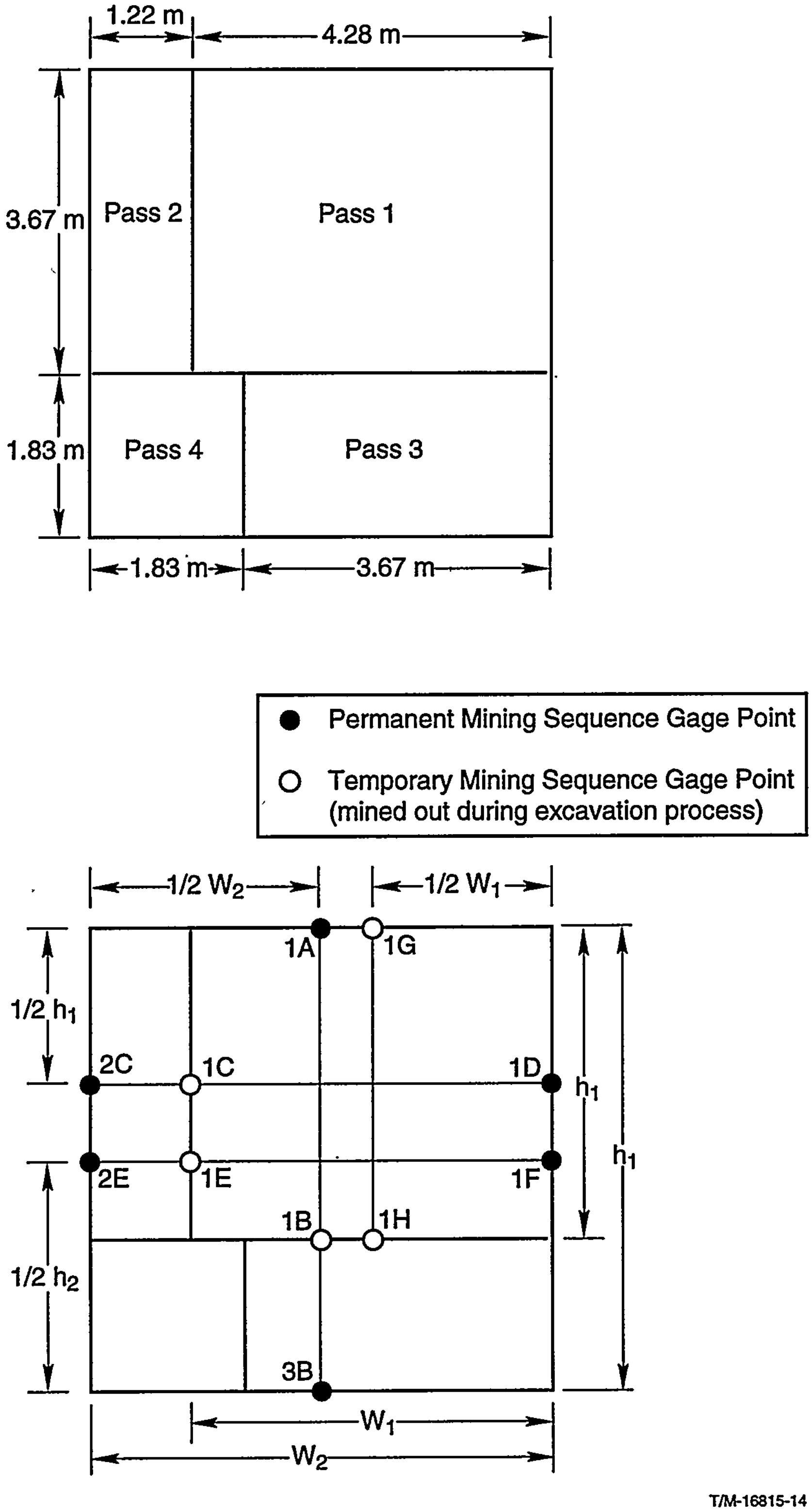


Figure 5.3.2. Typical Mining Sequence Closure Station

rooms and a majority of the mechanical-response instruments were installed and connected to the DAS. Extensometers and closure meters were installed first followed by stress meters and inclinometers. In addition, the preferred sequence of gage installation was to install gages closest to the center of the room first. In practice, the thermal-response gages were installed after the mechanical-response gages. The only constraint on the installation of the thermal-response gages was that they be installed before the activation of the test room heaters. The priorities were established to provide guidelines for instrument installations, but at times the installation sequence varied from these guidelines. For example, instruments were preferentially installed at locations that would not interfere with heater hole drilling and would allow both activities to proceed concurrently.

5.3.5 Heater Installation: Installation of heaters was the final major construction activity in the heated test rooms. Canister type heaters were installed in the floors of Rooms A1, A2, A3, and B, while the central pillar of Room H was heated with a set of heater tapes placed vertically around the circumference of the pillar (Table 5.3.6).

Prior to the installation of canister heaters, the heater holes were instrumented as required with thermocouples and thermal flux meters. A backfill of crushed salt was then poured into the holes and compacted to create a level surface at the proper elevation on which to place the heaters. After the elevation of the pads was checked, the heaters were installed. Most commonly a forklift was adequate to lower the heaters in place, but in some instances pick points (removable, wedged hooks) were placed in the back and used to lower the heaters into the holes. Following heater placement, the annuli were backfilled with various

Table 5.3.6. Heater Summary

Room	Test	Heater	Number of Heaters	Heat Load (W)	Canister Diameter mm (in)	Canister Length m (ft)	Heated Length m (ft)
B	TSI	Guard	4	4,000	610 (24.0)	3.0 (10.0)	2.6 (8.5)
B	TSI	Canister	17	1,800	325 (12.8)	3.0 (10.0)	2.6 (8.5)
B	WPP	Canister	2	1,500	800 (31.5)	3.4 (11.0)	2.6 (8.5)
B	WPP	Canister	6	1,500	610 (24.0)	3.0 (9.8)	2.6 (8.5)
B	WPP	Canister	2	0	800 (31.5)	3.4 (11.0)	0.0 (0.0)
B	WPP	Canister	2	0	610 (24.0)	3.0 (9.8)	0.0 (0.0)
A1	TSI	Guard	13	470	325 (12.8)	2.6 (8.5)	2.3 (7.6)
A1	WPP	Canister	6	470	610 (24.0)	2.9 (9.5)	2.6 (8.5)
A2	TSI	Guard	4	1,410	610 (24.0)	2.6 (8.5)	2.3 (7.6)
A2	TSI	Canister	28	470	610 (24.0)	2.6 (8.5)	2.3 (7.6)
A3	TSI	Guard	17	1,410	325 (12.8)	2.6 (8.5)	2.3 (7.6)
H	TSI	Tape	157	89	N/A	N/A	3.0 (10.0)

mixtures of salt, sand, and bentonite. In a few holes, however, no backfill was emplaced [15, 17]. An example of a canister heater installation is shown in Figure 5.3.3.

In Room H, the heating system for the central pillar consisted of hanging 157 heater tapes from top to bottom around the perimeter of the pillar (Figure 5.3.4). The pillar surface and heater tapes were then covered with blankets for thermal insulation.

<u>5.3.6 Additional Activities</u>: In addition to mining and drilling, the contractor was required to install lighting systems in the test rooms, and to run cabling and J-hooks from the instrumentation sheds to the test

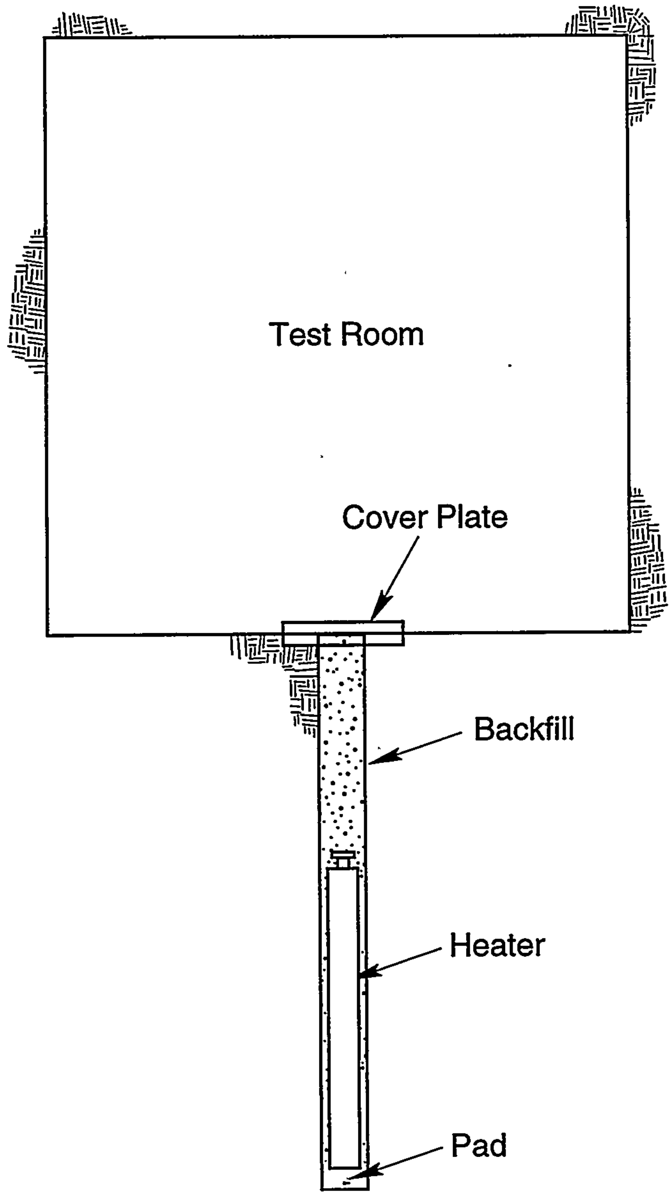


Figure 5.3.3. Typical Canister Heater Installation

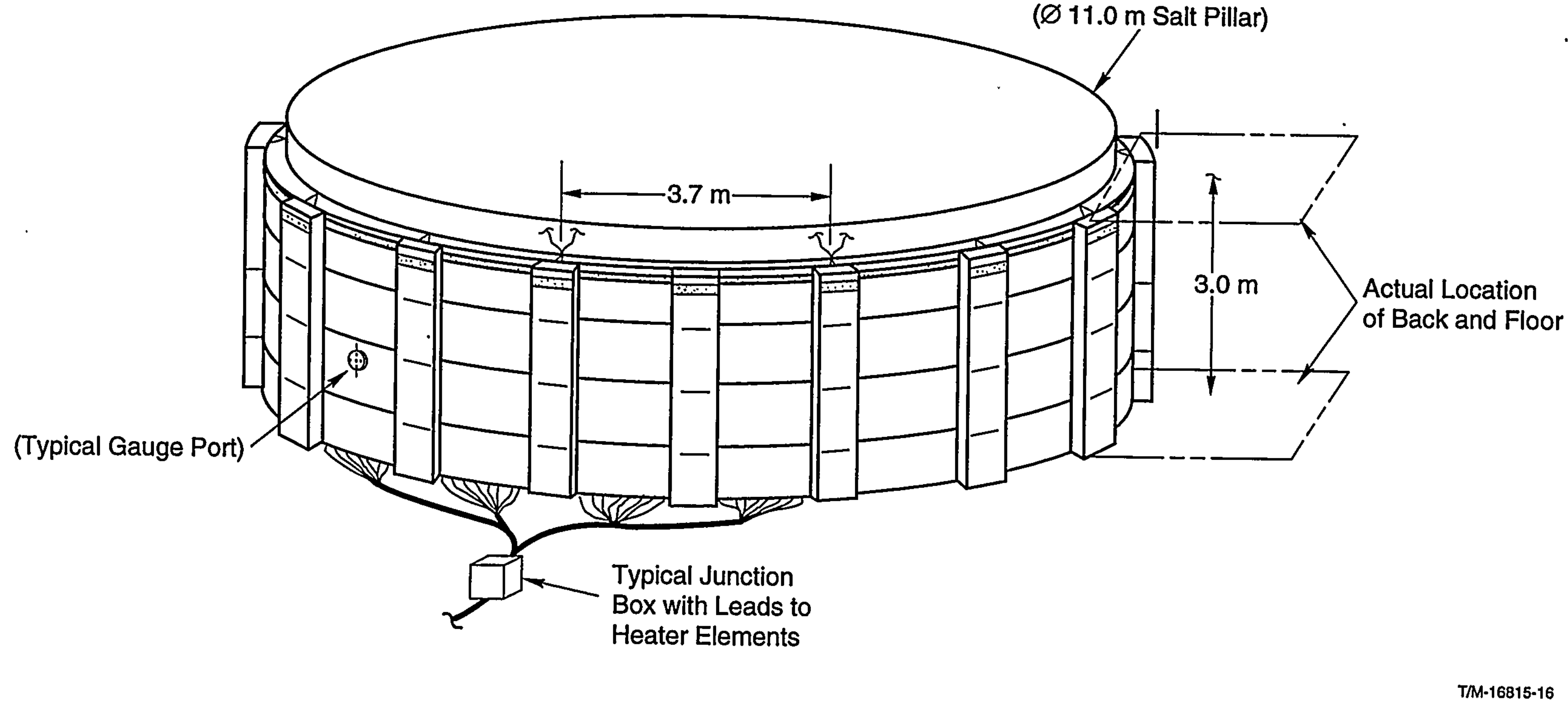


Figure 5.3.4. Room H Pillar Heating System

rooms. After Sandia had completed the final phases of test construction, the contractor installed bulkheads at the entrances to the heated test rooms. Sandia insulated the bulkheads with insulation in a fashion that did not impede test room access, but sealed the room from unnecessary heat loss.

5.4 Construction of Individual Experiments

The construction of the individual TSI experiments is discussed below in the order in which the tests were constructed.

5.4.1 Mining Development Test, Room D: The excavation of Room D was included in the CCP-1Fb construction contract package to establish ventilation for the eastern portion of the Experimental Area (Figure 1.0.3), and commenced upon the completion of the N1100 drift. Initially Room D was not part of the TSI tests, but during the test planning stage it was realized that this room (a duplicate of the A and B test rooms) offered an excellent opportunity to train site personnel in several activities, and to collect valuable data. The excavation provided the contractor an opportunity to practice mining to the tolerances specified for the TSI test rooms, and provided the geotechnical crews an arena to practice monitoring the advance of an active mining face and to perfect the surveying techniques used for measuring room dimensions. A relatively small number of gages were installed in Room D compared to the other TSI test rooms. As-built drawings of Room D are provided in Appendix D. Additional test details may be found in the Data Report [14].

5.4.2 In Situ Stress Field - Hydraulic Fracturing Tests: The purpose of the In Situ Stress Field - Hydraulic Fracturing Tests was to measure the in situ stress state of the formation in the repository horizon.

These tests were performed in two phases; (1) the performance of the hydraulic fracturing which included hole pressurization and fracturing of the formation, and (2) the subsequent mapping of the fractures during mining to determine the orientation of the minor principal stress (the stress perpendicular to the fractures). The general locations of the hydraulic fracturing tests are shown in Figure 1.0.3.

As a precursor to the main hydraulic fracturing tests, a suite of six trial tests were performed during the CCP-1Fa construction phase [25] in boreholes parallel and normal to the E140 drift axis. These tests allowed a field evaluation of the appropriateness of the test equipment, and established test parameters and fracture characteristics. The portion of the tests that took place along the drift axis allowed fracture mapping in the test zone during drift excavation.

The main hydraulic fracturing tests took place along the axis of the Room G access drift. Approximately one year before the mining of the drift, a series of eleven hydraulic fracturing tests were performed in a borehole drilled within the future drift perimeter. The individual test zones ranged in depth between 14 m (46 ft) and 126 m (412 ft) from the borehole collar. The second portion of the test was conducted during the mining of the drift when excavation was controlled to allow photographing and mapping of the fracture patterns within the test zones. This phase of the test was initiated after the mining machine reached the first test zone and the contractor removed the mining machine to begin the excavation of Room B. Excavation of the Room G access drift and fracture mapping continued after Room B mining was complete (Table 5.3.1). As-built drawings of Room G are provided in Appendix G. Details of the In Situ Stress Field - Hydraulic Fracturing Tests may be found in the Test Plan

[5] and test report [25]. Laboratory testing and finite element analyses were performed in conjunction with the hydraulic fracturing to aid in the evaluation of the test results [5, 25].

Further hydraulic fracturing tests were later performed in holes drilled into the rib north from Room G, and into the pillar between Rooms 2 and 3 of the SPDV Test Panel (Figure 1.0.3), although these tests have not been excavated to allow fracture mapping.

<u>5.4.3 Overtest for Simulated Defense High-Level Waste, Room B</u>: Room B, which supported the Overtest for DHLW, was the first of the TSI test rooms to be mined. Room B consisted of a 5.5 by 5.5 m (18 by 18 ft), 90 m (300 ft) long room with heaters in the floor, and an array of instruments in the room and rock mass to measure the response of the formation to the test. The purpose of the experiment was to simulate the design of the DHLW repository, but with a thermal loading of four times that of the repository load to accelerate room closure and failure. The acceleration was designed to aid in the validation of techniques used for the prediction of repository performance. The sequence of construction activities is outlined in Table 5.3.1. Additional details of the experiment may be found in the Test Plan [6] and Data Report [15].

<u>5.4.3.1 Contractor Activities</u>: Room B was mined with the same methods and equipment that were described in Section 5.3.1.3, but with a notable variation in the excavation sequence. In the other test rooms, four uninterrupted, continuous passes were used during excavation; however, Room B was excavated with three passes with the last pass a discontinuous end-to-end effort (Figure B-1, Appendix B). During the third pass the mining machine did not progress through the room in one complete pass, but moved forward and backward until an area of the room

was excavated to the full design cross section. Figure B-2 (Appendix B) shows that mining progressed on a fairly uniform schedule during the first two passes (except during site power outages), but was erratic during the full-width mining of the third pass. The three-pass excavation sequence made room closure measurements during mining difficult because a closure point installed in the floor would be repeatedly mined out until the machine moved to the next area of the room. Additionally, this "leapfrog" mining method added unnecessary complications to any effort to model the closure of the room during mining. As a result, it was agreed that further test room mining would be conducted with continuous, uninterrupted passes.

Following the completion of test room mining, surveys of room geometry were performed. The results of these surveys are shown in the selected cross sections of Figures B-3a through B-3e and in the room profile of Figure B-4 (Appendix B). It is seen from these cross sections that the mining was generally within the specified tolerances.

Instrument hole drilling in Room B was carried out without any major difficultly. As shown in Table 5.3.3, nine holes were redrilled due to tolerance violations out of a total of 326 holes drilled in Room B.

<u>5.4.3.2 Sandia Activities</u>: Sandia's drilling responsibilities in Room B included heater hole drilling, stratigraphic coring at the north end of the room, and the drilling of flux meter and near-field thermocouple holes. A combined total of 33 holes were drilled in Room B for 21 TSI canister and guard heaters and 12 WPP canister heaters (Table 5.3.6). The canister heaters were arranged in a single row along the length of the room floor to simulate the heat from waste canisters. At each end of the row, guard heaters with increased thermal power were

emplaced to minimize the end effects of the heater row by simulating the heat from an infinite row of heaters. WPP heaters located at the ends of the canister heater row also provided heat to the test. Heater installation was a discontinuous effort with heaters being installed, backfilled and connected to the data acquisition and power distribution systems on a time-available basis. An as-built profile of the heater installations is given in Figures B-4.

The instrumentation of Room B consisted of room closure gages, borehole extensometers, borehole stress meters, inclinometers, thermocouples, thermal flux meters, and heater power meters. Three two-man crews installed all of the mechanical instruments within the time period shown in the construction schedule (Table 5.3.1). One crew performed the installation of thermocouple packages in the test room at a later date, but before the heaters were energized. The thermocouple installation was a very discontinuous effort and is not explicitly included in Table 5.3.1. The gages used in Room B are described in detail in the Instrumentation Report [33].

5.4.4 18-W/m^2 Mockup for Defense High-Level Waste, Rooms A1, A2, and A3: The 18-W/m^2 Mockup for DHLW experiment was located in Rooms A1, A2, and A3, and was designed to closely simulate the design repository configuration and thermal loading for DHLW. Heaters were emplaced in each of the rooms to simulate a thermal load of 18 W/m^2 from waste canisters, and arrays of instruments were installed in the test rooms and in the rock mass to measure the response of the formation to the test. Additional details on the experiments may be found in the Test Plan [7] and Data Reports [16, 17].

In addition to the Mockup experiment, the close proximity of these three rooms provided the opportunity to perform a mine-by experiment wherein the central room, A2, was mined first and completely instrumented before mining the two adjacent rooms, A1 and A3. This provided the opportunity to measure the response of the central room to the mining of the two outside rooms.

5.4.4.1 Contractor Activities: Test room mining for the 18-W/m^2 Mockup for DHLW was performed by first mining Room A2, allowing Sandia time to install all mechanical-response instrumentation, then sequentially mining Rooms A1 and A3. The excavation schedule for Test Rooms A1, A2, and A3 is described in Section 5.3.1.3 and is shown in the construction schedule in Table 5.3.1.

The mining of Room A2 followed the four-pass sequence described in Section 5.3.1.3 and is shown schematically in Figure A2-1 (Appendix A2). The excavation advance rates (Figure A2-2, Appendix A2) show that the mining of Room A2 proceeded in a consistent and almost uninterrupted manner. However, after mining was complete and the floor cleared of salt, tolerance violations in floor roughness and room height were discovered. Trenches that had been inadvertently cut in the room floor were the cause of the violations, and were the obvious result of the floor having been cut under a layer of muck which limited visibility during the cutting process. Some of the trenches were cut along the length of the room while others were cut away from the ribs, perpendicular to the room axis. The trenches ranged from 0.2 to 0.3 m (1/2 to 1 ft) in depth, were about 0.5 m (2 ft) wide, and ranged from 1 to 6 m (3 to 20 ft) in length. Areas outside of the trenches were generally within the specified tolerances.

Preconstruction calculations of the deformations of the test rooms indicated a high sensitivity of strain rate to the as-built height-to-width ratio (Section 4.3.1). In order to correlate any anomalies in room response with deviations in room dimension, it was necessary to obtain more detailed closure information. As such, the contractor was required to install densely spaced "remedial" closure gages in Rooms A1, A2, A3, and B [38]. The intent was to ensure that any increase in closure in Room A1 would be observed when comparing closure histories of the rooms. A total of 50 manually read and 12 remotely read remedial closure gages were installed in each of the A test rooms, and 28 manually read gages were installed in Room B. These additional closure points were located at the same stations in each of the rooms. The contractor was also required to fill the trenches with compacted salt to provide a passable surface for carts, scissors lifts, drills, and other construction vehicles. It was stipulated that the remedial work be complete before the mining of Room A1 could begin.

The results of the room geometry surveys are shown in the cross sections of Figures A1-3a through A1-3f, A2-3a through A2-3g, and A3-3a through A3-3f, and in the room profiles of Figures A1-4, A2-4, and A3-4 (Appendices A1 through A3). Although the Room A2 cross sections do not display any gross violation of the tolerances, they do indicate the trend of over excavation at the lower corners of the room. Comparison of the Room A2 cross sections with those of Rooms A1 and A3 indicates a greater variance in the floor profile across the width of Room A2.

Figures A1-1 and A3-1 (Appendices A1 and A3) provide illustrations of the mining sequences used in Rooms A1 and A3. Note that mining passes 3 and 4 did not extend to the final floor elevations because they were followed by final floor-trimming passes which ensured that the floors would be cut within the specified tolerances. Before the trimming passes were started, the floor was cleaned of muck to allow the cutting head to be seen at all times. Excavation advance rate data for Rooms A1 and A3 are shown in Figures A1-2 and A3-2.

Instrument hole drilling proceeded without any major problems. As shown in Table 5.3.3, only 12 holes (1.2%) were rejected due to tolerance violations out of a total of 994 holes drilled in Rooms A1, A2, and A3.

5.4.4.2 Sandia Activities: Drilling of the heater holes began at the completion of the contractor's activities and the transfer of room responsibility to Sandia. During the mining of Room A1 the heater hole drilling activities in Room A2 were stopped to prevent any accidental damage to instruments in Room A2, since the excavation of Room A1 was a critical time to measure deformation in Room A2. Heater installation commenced as crews became available and was coordinated with instrumentation to minimize construction conflicts. The central room, A2, contained two rows of TSI canister heaters along the length of the room floor to simulate the heat from waste canisters. Guard heaters with increased thermal power were located at the ends of the canister rows minimized end effects by simulating the heat from infinite rows of heaters. The outer rooms, A1 and A3, contained single rows of guard and WPP heaters and were designed to simulate the thermal effect of adjacent rooms on the central room of a waste panel. Table 5.3.6 contains a description of the heaters installed in the test room floors, while figures A1-4, A2-4, and A3-4 (Appendices A1 through A3) provide profiles of the installed heaters. A total of 32 heater holes were drilled in Room A2, 19 in Room A1, and 17 in Room A3.

The instrumentation of Rooms A1 and A3 proceeded without any notable incidents. The gages installed included ultrasonic velocity measurement devices, room closure gages, borehole extensometers, borehole stress meters, inclinometers, thermocouples, thermal flux meters, and heater power meters. The instrumentation in Room A2 commenced after the contractor finished the remedial work in Room A2 and was carried out with the same team structure used in Room B. As shown in Table 5.3.1, all of the mechanical-response instruments were installed within the 21-day delay in test room mining in preparation for monitoring the excavation of Rooms A1 and A3. The thermal-response gages, however, were installed later on a time-available basis. The gages used in the A test rooms are described in detail in the Instrumentation Report [33].

Two special tests were conducted in association with the mining of the A Test Rooms. The first test was designed to monitor strain in the drift alignment as the mining machine approached. For this test, boreholes were drilled from the N1420 drift along the centerlines of each of the A Test Rooms. Borehole strain gages were emplaced in these holes and radial deformations were monitored as the mining machine progressed from south to north towards the gages. Monitoring continued until the gages were destroyed by the mining machine.

The second special test involved cross-hole ultrasonic velocity measurements [39] to determine the extent of the disturbed rock zone in the perimeters of Rooms A2 and A3. Following the mining of Room A2, but before A3, a series of holes was drilled from the N1420 drift just outside the rooms and parallel to the room axes. The spacing of these holes was 1, 3, and 6 m (4, 10, and 20 ft) from the room ribs. Similar holes were also drilled from the ribs of the rooms for placement of additional gages. Velocity measurements were made by placing transducers for both transmission and reception of ultrasonic compressional waves in each of the holes.

5.4.5 Geomechanical Evaluation, Room G: The purpose of the Geomechanical Evaluation was to determine the long term creep deformation of salt at room temperature using different room geometries, and to study salt yield and failure conditions. The test was designed to provide information for the validation of two- and three-dimensional predictive techniques, and was planned to be constructed in four phases: three isolated drifts of differing cross-sectional dimensions, and a wedge shaped pillar. Only the first phase has been constructed. Figure G-1 (Appendix G) provides a plan view of the completed Phase 1 and the planned future work. The sequence of construction activities for Phase 1 of the Geomechanical Evaluation is shown in the schedule in Table 5.3.1. The Geomechanical Evaluation is described in further detail in the Test Plan [8] and the Data Report [18].

5.4.5.1 Contractor Activities: Two simplifications were made to the mining methods in Room G as compared to the typical mining sequence discussed in Section 5.3.1.3. One major difference was that Room G was not mined with multilevel, continuous passes. Only two passes, combined with trimming, were needed to mine Room G. Unlike the previously mined test rooms, these passes were not continuous because of the room length of 363 m (1190 ft); it would have been unreasonable to move utilities into a room of this length for one pass, then remove and reinstall them for the second pass. In an effort to satisfy Sandia's requirements for the installation and monitoring of the mining sequence closure points, the contractor agreed to mine the room in sections of about 30 m (100 ft), where each section was mined with continuous passes. The excavation sequence used in Room G is best described in the schematics of

Figures G-2a through G-2c and the excavation advance rates shown in Figure G-3 (Appendix G). The other difference was that the access drift to Room G had the same back height as the test room, thus eliminating the entrance brows.

Alcove I1 excavation was completed on December 28, 1984, and Room G excavation was completed on January 9, 1985. Because the Geomechanical Evaluation experiment is a long term (ten year) experiment, instrumentation drilling and gage installation were not immediately performed upon completion of room excavation. This permitted the excavation and drilling contractors to assign equipment and personnel to the more critical construction of the A and B test rooms. Instrumentation drilling began on January 11, 1985.

Room geometry surveys were performed following the completion of mining. The results of the surveys are shown in the selected cross sections in Figures G-4a through G-4i and the room profile shown in Figure G-5 (Appendix G).

In Room G, only one instrument hole (0.6%) was rejected because of tolerance violations out of a total of 170 instrument holes drilled (Table 5.3.3).

5.4.5.2 Sandia Activities: Instrumentation began soon after the contractor released the room to Sandia. The test room was instrumented with an array of room closure gages, borehole extensometers, and borehole stress meters. In addition to the instruments connected to the DAS, a large number of manually recorded instruments were installed in Room G. The manual instruments were designed to last through the duration of the ten-year experiment and were of a more rugged design than comparable instruments used in the other experiments. The gages used in the

Geomechanical Evaluation are described in detail in the Instrumentation Report [33]. There were no heaters installed in the room because the experiment was designed for nonthermal numerical code and model validation.

Since the Geomechanical Evaluation was designed to evaluate the long-term deformation of salt, recording the initial deformation was not critical. Only one gage installation team was used to instrument the room and the schedule in Table 5.3.1 reflects the relatively long time required for gage installation. The instrumentation of Room G, Phase One was completed on February 6, 1985, but remote data collection did not begin until April 23, 1985. An exception to this was the manual gages, including the mining sequence closure gages, which were monitored immediately following installation.

5.4.6 Heated Axisymmetric Pillar, Room H: Room H was designed to produce test data for the validation of both structural and thermal codes with two-dimensional, axisymmetric models. The test consisted of heaters placed around the central pillar of an annular room, and an array of instrumentation to measure the response of the formation to the test. Room H was the last TSI test room constructed as shown in the schedule of construction activities in Table 5.3.1. Additional details of the test are given in the Test Plan [9] and the Data Report [13].

5.4.6.1 Contractor Activities: The access drift to Room H was excavated between April 15, 1984 and April 21, 1984, several months before the mining of the test room. As part of the access drift construction, the contractor was required to install a set of manually read closure points in the access drift. Additionally, since the drift extended to the surface of the central pillar, it was requested that the contractor drill boreholes into the pillar for the installation of stress meters and an extensometer. This early instrumentation allowed for a continuous record of formation stress and deformation before, during, and after test room mining.

The actual test room was excavated between January 24, 1985 and February 12, 1985. Although the general construction issues were the same in all of the test rooms, Room H proved to be the most unique in terms of excavation sequence and control. The axisymmetric geometry of the test room precluded using the excavation sequences that were used in all other mining activities at the WIPP (Section 5.3.1.3) as illustrated in Figure H-1 (Appendix H).

To mine Room H, the contractor first excavated an octagonally shaped room around the central pillar. Initial survey control was established in the access drift at the first vertex of the octagon. From this point the mining machine progressed in a counterclockwise direction toward the second vertex of the octagon. Once the machine proceeded an adequate distance, the second vertex (control point) was established in the room back and the machine was directed towards the third vertex. Mining continued in this fashion until the machine returned to the access drift. At the end of the first pass, each side of the octagon was about 3 m (10 ft) from the inside or outside final room dimensions.

The theoretical centerline of the test room was used as a guide for excavation. Once the mining machine progressed beyond the second vertex of the octagon, contractor surveyors began locating the room centerline as a 128-sided figure with equal chord lengths. Each of the vertices of this 128-sided figure was located on the theoretical centerline and the figure therefore provided a very good guide for excavation.

The second mining pass consisted of removing material adjacent to the outer rib and proceeded in a clockwise direction so that the operator would be positioned near the face being excavated. During this pass, the outer rib was mined about 0.3 m (1 ft) short of the final radius as measured from the centerline points. Room width control was maintained by making many measurements from the discretized centerline to the outer rib.

The final trim of the outer rib followed the second pass. In order to excavate the rib to the final dimensions and to maintain the specified tolerances, reference marks were established using the room centerline as a datum. These marks were located by using a 5.18 m (17.0 ft) rod with a small cup at one end and a can of spray paint at the other. To locate a reference mark, the cup was placed over one of the 128 points on the centerline and an arc was painted on the back near the outer rib. Painting 128 arcs established the reference circle for room width with the radius of the reference circle being 305 mm (12 in) short of the final radius. Hanging plumb lines from the reference circle gave an accurate measure of the room width and allowed the contractor to stay within specifications.

During the third pass, material was excavated adjacent to the central pillar in a counterclockwise direction to place the operator as close as possible to the face being excavated. Mining of this pass was carried out in the same manner as was the second pass. The final trim of the central pillar followed the third pass and was also performed in the same manner as before, using 128 arcs measured from the theoretical room center line.

Excavation advance rates shown in Figure H-2 (Appendix H) depict the change in direction of Room H mining and the continuity of the excavation process. Mining in Room H concluded with a series of three floor-trimming passes.

The drilling of instrument holes immediately followed excavation and proceeded on a two-shift-per-day basis. Operating on a two-shift schedule was a variation from the other test rooms, where contractor instrument hole drilling was carried out on a three-shift schedule. A total of 164 instrument holes were drilled in Room H with only two of the holes needing to be redrilled because of tolerance violations (Table 5.3.3).

As with the other test rooms, room geometry surveys were performed after the completion of mining. The results of these surveys are shown in the selected cross sections of Figures H-3a through H-3g and in the room profile of Figure H-4 (Appendix H).

5.4.6.2 Sandia Activities: Following the mining and drilling of Room H, Sandia entered the room and began the installation of instruments. The instrumentation consisted of room closure gages, borehole extensometers, borehole stress meters, inclinometers, thermocouples, thermal flux meters, and heater power gages. The installation proceeded in the typical manner, although the effort was not as intense as it was in the A and B test rooms because of commitments remaining in the other tests. Nonetheless, all mechanical-response gages were installed within one month from the time Sandia entered the room, and all thermal-response gages were installed before the heaters were energized. The gages used in Room H are described in detail in the Instrumentation Report [33].

The heaters installed on the central pillar consisted of 3 m (10 ft) long heater tapes attached to the pillar surface. A total of 157 heater tapes were evenly spaced on 218 mm (8.6 in) centers around the circumference of the central pillar. The pillar surface was then covered with 150 mm (6 in) thick insulation. After installation, the heaters were connected to the power source and to the DAS on a time available basis. During the operation of the test, the heaters were powered with an average of 89 Watts each.

The only Sandia drilling in the test room was that associated with the flux meters which were located on the surface of the central pillar.

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6 CONSTRUCTION OF ADDITIONAL TSI TESTS

After the original TSI in situ tests were constructed, other experiments were added to the WIPP R&D testing program that contributed to TSI objectives. These additional tests included the Air Intake Shaft Performance Tests in the AIS (Shaft V), the Intermediate-Scale Borehole Test between Rooms C1 and C2, and the Large-Scale Brine Inflow Test in Room Q. The construction of these three tests is discussed in the following sections.

6.1 Air Intake Performance Tests, Shaft V

The Air Intake Shaft (AIS) was excavated to complete the underground ventilation system at the WIPP site (see Figure 1.0.3 for location). The AIS Performance Tests were planned in conjunction with the AIS in order to validate techniques used for predicting shaft performance; the geomechanics and geohydrologic parameters of the shaft walls must be assessed in order to predict whether the repository shafts can be adequately sealed. The Air Intake Shaft Performance Tests were originally a joint effort between the TSI and PSP (Plugging and Sealing Program) testing programs, and were grouped into four categories consisting of (1) structural tests, (2) near-field permeability tests, (3) near-field hydrologic monitoring, and (4) moisture inflow tests. Only the structural tests, however, were pursued. Additional details of the tests are given in the Test Plan [10] and the Data Report [21].

6.1.1 Contractor Activities: The AIS construction was performed by Frontier-Kemper Constructors, Inc. under a contract managed by Westinghouse Electric Corporation, the operating contractor for the WIPP facility [40]. The shaft was excavated by the raise-boring method in a series of three steps. The first two steps consisted of drilling and reaming a pilot hole with a conventional oil-field rotary drilling rig. In the first step, a 229 mm (9.0 in) pilot hole was drilled from the surface to the repository horizon at a depth of 655 m (2150 ft). During this process, the borehole was surveyed every 9 m (30 ft) to determine if the hole was being drilled within allowable tolerances. In order to keep the pilot hole on line, the hole needed to be cemented and redrilled several times before reaching the bottom. The second step was to ream the pilot hole from the surface to the bottom to a diameter of 352 mm (13 7/8 in). Drilling and reaming was completed during the period between December 3, 1987, and February 7, 1988. During this period, Westinghouse was engaged underground with the excavation of access drifts and a station for the future shaft. This excavation was completed between November 14, 1987 and January 26, 1988.

The third step involved the final reaming of the 6.20 m (20.3 ft) diameter shaft. Before this work could begin, it was necessary to pour a concrete collar and erect a Robbins 81R raise-boring machine. While this work was pursued on the surface, a 6.20 m (20.3 ft) diameter raise-boring head fitted with 50 carbide button roller bits was assembled underground in the shaft station. When assembly was completed, the boring head was connected to the raise-boring machine on the surface by a 330 mm (13 in) diameter drill stem. Continuous up-reaming of the shaft began on May 1, 1988. On May 8, boring was interrupted temporarily to allow early closure measurements to be made (see Section 6.1.2). In mid-June the boring rate began to slow appreciably and by July 19, the rate had diminished drastically. At this time, reaming was halted for 29 days so worn cutters in the boring head could be replaced. Since convergence of the shaft walls in the Salado Formation made lowering of the head to the shaft station impossible, a 762 mm (30 in) diameter hole was bored and cased from the surface to the boring head below. This borehole was located within the shaft envelope and provided access for personnel to repair the head in place. Reaming resumed on August 17, 1989 and was completed on August 25 when the head broke through to the surface.

Shaft construction was completed with the erection of a headframe and work deck. The shaft was lined with concrete from the surface to a depth of about 274 m (900 ft). Appendix V provides a graph of the excavation advance rate and a profile of the completed shaft.

6.1.2 Sandia Activities: Between May, 1988 and October, 1991, Sandia supervised the instrumentation of the structural (geomechanical) tests in the AIS. Sandia-sponsored personnel installed the gages while Westinghouse Electric Corporation provided support for surveying and drilling operations.

Instrumentation of the shaft began on May 8, 1988 with the emplacement and measurement of early (mining sequence) closure points in the Salado Formation. On this date, two pairs of closure points were emplaced and measured at two different stations (depths): 630 m (2067 ft) and 612 m (2007 ft). Shaft boring operations were halted temporarily to allow the "Early Closure Point Emplacement Machine" to be hoisted up into the shaft. This machine was designed and fabricated by Sandia and was made of a length of pipe with two smaller-diameter sections of pipe enclosed in both ends. Each of the smaller pipes contained an electric hammer drill which was extended and withdrawn by means of a double-acting hydraulic cylinder. A remotely operated displacement transducer measured the distance between the two drills and was calibrated to the bottom of the measurement point holes. A more detailed description of the closure machine and its operation is given in other publications [21 and 40].

Eighteen months later on November 20, 1989, access to the AIS was again possible and a second reading of the early closure points was made. At this time, permanent sets of manual closure points were installed near the early points and at five additional stations (depths) in the Salado Formation. Between May, 1990 and October, 1991, three of these stations were instrumented with permanent gages including closure gages, borehole extensometers, thermocouples, and ultrasonic gages. In addition, arrays of boreholes at three different stations throughout the length of the shaft were instrumented with ultrasonic transducers. All gages were installed from a Galloway (movable platform) suspended in the shaft.

6.2 Intermediate-Scale Borehole Test, Rooms C1 and C2

The purpose of the Intermediate-Scale Borehole Test (ISBT) was to determine whether a scale factor exists in the structural behavior of underground openings in salt; the ISBT is midway in size between a full-scale test room and a small laboratory specimen. The ISBT was conducted in a 914 mm (36 in) diameter horizontal hole drilled between Test Rooms C1 and C2 (see Figure 1.0.3 for location). In order to obtain a complete deformation history of the pillar material, instrumentation was emplaced in the surrounding formation and in the pilot hole before coring, and within the borehole itself after the hole had been cored. Additional details of the test are given in the Test Plan [11] and the Data Report [20].

6.2.1 Contractor Activities: Rooms C1 and C2 were mined by the Ohbayashi Corporation in March and April of 1984 along with the excavation of the N1420 drift (see Table 5.3.1 and Figure 1.0.3). The 5.5 m (18 ft) high test rooms were both mined by first excavating an upper and then a lower bench. The mining machine first excavated short portions of the upper benches in Room C2 and C1, respectively. The machine was then fitted with a longer conveyor belt and the upper benches and brows were completed, first in Room C1 and then C2. The machine then completed the lower bench in both rooms, mining Room C2 first. Both rooms were mined to a width of 5.5 m (18 ft) and a length of about 30 m (100 ft); and were in the same stratigraphic horizon as the A, B, and D test rooms (Figure 3.0.1).

Over six years later, the 18.3 m (60 ft) long borehole for the ISBT was drilled in the pillar separating Rooms C1 and C2. Westinghouse Electric Corporation drilled the hole in two steps with a Longyear EHS-38 drilling rig (Section 4.1). The first step was a 47.6 mm (1 7/8 in) diameter pilot hole which was drilled on November 29 and 30, 1989. The second step involved the actual coring of the test borehole during an 11 day period between December 3 and December 13, 1990. A 914 mm (36 in) long, 914 mm (36 in) diameter thin wall masonry bit with surface-set diamond teeth and a centralizing pilot was used for coring. The drilling proceeded in segments of about 914 mm (36 in), the length of the core barrel, to allow lengths of core to be broken off and removed from the borehole. The first core taken from the hole indicated that the hole was dipping about 13 mm (1/2 in) from the pilot hole. By the time the third core was removed, the hole was found to be dipping about 44.5 mm (1 3/4 in). At this time, various means were undertaken to correct the alignment of the drilling. A template was installed over the pilot hole to maintain the pilot of the core barrel on course and the upper portion of the core hole was chipped away to allow the core barrel to be started on line. In addition, a shorter core barrel was used to restart the drilling and allow the coring to follow the new and correct centerline without binding. After a few attempts, the realignment was successful and the remainder of the hole was completed on line. The resulting borehole was not quite horizontal, but dipped gently to the east to follow the stratigraphy; the hole was situated in the middle of a clean halite bed between two thinner anhydrite beds. As-built drawings of the borehole and the excavation progress are included in Appendix C.

Instrument holes in the pillar between Rooms C1 and C2 were surveyed and drilled by Westinghouse. These activities took place from two to eleven months before the coring of the test hole began.

6.2.2 Sandia Activities: Instrumentation of the ISBT was performed by Sandia-sponsored personnel. Various gages were installed in the ISBT test including closure gages, extensometers, stressmeters, and borehole strain gages. Most of the instrumentation was installed prior to the excavation of the test hole to enable three-dimensional displacements and stress component changes to be measured as the hole was drilled. Instrumentation began on January 15, 1990 when surface closure gages were installed on the rib of Room C2 around the perimeter of the future borehole. During the next several months, extensometers and stressmeters were emplaced in instrument holes that were drilled into the pillar from Rooms C1 and C2, and from the N1420 drift. During drilling, borehole strain gages were placed in the pilot hole to monitor strain ahead of drilling, and drilling sequence closure measurements were made closely behind the drilling to monitor early closure in the borehole. After the drilling was completed, permanent remote closure gages were installed within the borehole for long-term monitoring of borehole closure. Most of the gages were installed in groups that were located at discrete distances, called principal stations, along the length of the test hole. More detailed discussions of the ISBT instrumentation are contained in the Test Plan [11] and the Data Report [20].

6.3 Large-Scale Brine Inflow Tests, Room Q

The Large-Scale Brine Inflow Tests were conducted in Room Q, a 2.9 m (9.5 ft) diameter horizontal borehole that was drilled at the west end of the S90 drift (see Figure 1.0.3. for location). The purpose of these tests was to validate WIPP site brine inflow models for large-scale excavations. Room Q also provided the opportunity to obtain closure data from an excavation of this scale. Additional details of the tests are given in the Test Plan [12] and test reports [22 through 24].

6.3.1 Contractor Activities:

The first step in the construction of the Large-Scale Brine Inflow Test was to excavate an access drift westward from the AIS. This drift was excavated by a continuous mining machine and measured 6.1 m (20 ft) in width, 3.7 m (12 ft) in height, and 91.4 m (300 ft) in length. The west end of this drift was then enlarged with the mining machine to become the instrument alcove for the test. The finished alcove was 9.1 m (30 ft) in width, 4.9 m (16 ft) in height, and 24.4 m (80 ft) in length. The access drift and alcove were excavated during November and December, 1988.

Room Q was excavated with a Robbins Hard Rock Tunnel Boring Machine (TBM), Model 91. This machine was shipped to the WIPP site in pieces which were brought underground and assembled in the Room Q instrument alcove. Before the TBM could be assembled, however, it was necessary to fabricate a launching frame for starting the TBM with the proper height and alignment (the bottom of Room Q was 1 m above the floor of the alcove). The TBM and launch frame were both supplied by Boretec, Inc.

The head of the TBM was equipped with twenty 305 mm (12 in) roller disk cutters and was driven by four 75 horsepower electric motors. Forward thrust was provided by a system of hydraulic rams and grippers. Cuttings were removed from the excavation face by a system of buckets that dumped on to a conveyer within the TBM. The conveyor dumped the cuttings from the rear of the TBM onto wagons for conveyance to the Salt Handling Shaft. Boring began on July 12 and was completed on August 8, 1989. Room Q was originally designed to be 91.4 m (300 ft) in length, but the designed length was changed to 106.7 m (350 ft) to accommodate the change in the resistivity experiments. The as-built length of Room Q was between 108.4 and 109.0 m (355.6 and 357.6 ft); because of the shape of the cutting head, the end wall was not cut flat. As-built drawings of the Room Q profile and excavation progress are included in Appendix Q.

6.3.2 Sandia Activities: A number of instrumentation and test holes were drilled around Room Q. Before the room was excavated, 15 holes were drilled from the instrumentation alcove for the purposes of establishing a measurement system to evaluate the hydrologic parameters of the Salado Formation in the WIPP horizon. These holes were drilled above, below, and to the north of the future test room, and were drilled between February 7 and March 23, 1989. By May 9, 1989, the holes were fully instrumented with pore pressure tools and collected pore pressure data before, during, and after the excavation of Room Q. Between April 17 and May 1, 1989, five holes were drilled in the floor of the Room Q access drift to monitor the unlikely migration of sump water from the base of the AIS to Room Q. In October of 1989, two instrumentation holes were drilled from within Room Q for the installation of resistivity source electrodes. Most of the instrumentation, however, required only short holes (less than 0.3 m or

1 ft deep) for mounting the gages to the room walls.

Instrumentation in Room Q was installed by Sandia-sponsored personnel and included mining sequence closure gages, remote closure gages, thermocouples, humidity sensors, resistivity electrodes, and barometric pressure gages. This instrumentation was installed between December, 1989 and April, 1990. Mining sequence closure points were installed during excavation (July through August, 1989) at the mining face to capture the earliest closure data. These points were installed and measured at the one-quarter, half, and three-quarter points along the length of the test room. Several months later, in April of 1990, the permanent remote closure gages were installed.

Room Q was designed to be equipped with seals to minimize evaporation and moisture loss from within the room. These seals were constructed and installed by Westinghouse personnel under the supervision of Sandia. In October, 1989, two months after excavation was completed, the first of two seals was installed. This seal consisted of a steel frame with brattice cloth and an aluminum door. The frame was fit closely to the borehole periphery and was caulked to reduce leakage. Five months later, the second temporary seal was installed. This system consisted of two seals installed 2.4 m (8 ft) apart to form an air lock In March of 1991, the permanent seal system was installed. This system also consisted of two seals set 2.4 m (8 ft) apart to form an air lock, with each seal consisting of an aluminum bulkhead surrounded by an inflatable element. The permanent seals were designed to accommodate radial closure in the test room.

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7 SUMMARY

The underground facilities at the Department of Energy's Waste Isolation Pilot Plant in southeastern New Mexico were constructed primarily in three stages: (1) the Site and Preliminary Design Validation (SPDV) excavations (1981 through 1983), (2) the Experimental Area and the expansion of the shaft system (1983 through 1990), and (3) the initial panel of the transuranic (TRU) Waste Storage Area (1986 through 1988).

The SPDV stage included the construction of three shafts, the excavation of an underground entry system, and the mining of the SPDV Test Panel with a geometry similar to that of a Waste Storage Area panel. The objective of the SPDV excavations was to provide data to support the validation of the repository design. The SPDV phase of construction was an important predecessor to the experimental activities in that it provided Sandia an opportunity to evaluate drilling, surveying, and instrumentation techniques. Tighter tolerances were required for the TSI test rooms than would be required in conventional mining operations since test room performance is compared to numerical analyses which are based, in part, on as-built dimensions. To minimize errors between the predicted response and the field response, room dimensions were required to be as consistent as possible. All development activities indicated that the test rooms could be excavated and instrumented within the tolerances necessary to achieve test objectives.

The testing that took place in the underground Experimental Area was largely the responsibility of Sandia National Laboratories (Sandia) and included the Thermal/Structural Interactions (TSI) in situ tests. The TSI tests were conducted to provide a validation of the techniques used to predict repository performance and originally included five major tests:

(1) the In Situ Stress Field - Hydraulic Fracturing Tests (Room G), (2) the Overtest for Simulated Defense High-Level Waste (Room B), (3) the 18-W/m^2 Mockup for Defense High-Level Waste (Rooms A1, A2, and A3), (4) the Geomechanical Evaluation (Room G), and (5) the Heated Axisymmetric Pillar (Room H).

Later in the experimental program, other tests were added that contributed to TSI objectives: (1) the Air Intake Shaft Performance Tests conducted in the AIS (Shaft V), (2) the Intermediate-Scale Borehole Tests (between Rooms C1 and C2), and (3) the Large-Scale Brine Inflow Test (Room Q).

The stratigraphy in the vicinity of the repository horizon was known from earlier investigations to consist mainly of thicker halite layers interbedded with thinner anhydrite layers. However, core obtained during the SPDV phase of construction provided a more detailed stratigraphy of the WIPP site. The SPDV excavations and Rooms G, H and Q of the TSI in situ tests were all excavated in the same stratigraphic horizon as the eventual waste storage facility with their backs at a nominal elevation of 385 m (1,263 ft). Rooms A, B, C, and D of the TSI experiments were excavated in slightly higher strata with test heaters emplaced in the floors so that they were in the repository horizon. Other experiments were conducted in the Air Intake Shaft (AIS) which was sunk from the WIPP site surface down to the repository horizon.

The planning of the TSI in situ tests proceeded with the participation of many organizations and followed the requirements of the WIPP R&D Program [1]. Before excavation of the actual test rooms could begin, several preliminary developments were necessary including: (1) fabrication of the Data Acquisition System, (2) warehousing and staging of gages and heaters, and (3) excavation of access drifts and instrumentation alcoves.

The actual construction of the TSI in situ tests was the responsibility of both the mining contractor and Sandia. The contractor was responsible for all excavation, most of the instrumentation drilling, as-built surveying, and the installation of lights, cables, and bulkheads. Sandia was responsible for all construction tasks not assigned to the mining contractor including the drilling of heater and instrumentation holes, installation of the gages and heaters, and the connection of the gages to the DAS.

Installation of gages and heaters took place in different stages. During the mining of a test room, closure measurements were taken at mining sequence closure stations to record early room response. Immediately after excavation, temporary closure gages were installed to continue the recording of room response. The installation of permanent mechanical response gages and heaters commenced after the contractor's release of a test room to Sandia. Thermal response gages were installed later, but before test heaters were energized.

The construction of the TSI in situ tests was completed without any significant deviations from plan. The tests have generated a large volume of exceptional quality data which has contributed greatly to the development and validation of techniques used to predict the performance of a waste repository in the geologic formations at the WIPP site.

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Attachment 1, Weart Memo

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: August 17, 1984

to: W. R. Cooper - DOE/WPO, Carlsbad

from: W. D. Weart - 6330

subject: Sandia Recommendation for Addressing the Effects of the Out-of-Specification Trenching in Room A2

Sandia has reexamined all of the potential approaches available to mitigate the consequences of the over-excavation in Room A2. There are no solutions which would eliminate all technical concerns short of remining the Room A complex several hundred feet east of Room D. This would result in unacceptable delay with major programmatic impact. Therefore, we have concluded, aided by bounding calculations, that we can continue to conduct experiments in Room A2 if several conditions are met. These calculations bound the expected deformation behavior of the room (with the trench deviation from the desired two-dimensional symmetry) by modeling (2-D) a room complex in which the center room (A2) has continuous trenches along both walls (Enclosure 1). This results in closures which are 14 to 17 percent greater than for a room without trenches. Recognizing the bounding nature of this simulation, required by the code capabilities, it is reasonable to expect an actual deviation of less than 10% due to the three-dimensional asymmetry. This is a small enough perturbation that the room can be used providing data is acquired to allow us to evaluate the actual magnitude of the effect. Tamped backfilling of the trenches will also lessen, but not eliminate, the concern over the thermal conductivity contrast.

To best mitigate the consequences of the Room A2 asymmetry, the following steps should be taken:

1. Clean out and determine the cross-sectional dimensions of the trench on five (5) footcenters.

2. Fill the trenches with salt compacted to maximum attainable density. Salt may be wetted to do this. As-built density values should be determined.

3. Install manual and remote closure stations in Room A2 and Room B as soon as practical and in Rooms A1 and A3 per the general guidance in Enclosure 2. Additional detail will be provided by R. Matalucci and/or D. Munson to allow a CCR to be prepared.

4. Sandia will perform the necessary work in Room B because of concern over possible damage to the installed experiments.

   Other construction work should be performed by the mining contractor.

5. Sandia will provide and emplace jumper cables and gages for the additional remote measurements.

6. Sandia will provide to DOE the actual costs of the incremental work, time, and materials, and will estimate the costs of future work, such as data acquisition, analysis, calculation, dictated by this deviation.

It is worth repeating that such deviation as that in Room A2 can be potentially disastrous to the WIPP in situ test program. Once they occur, there is no easy remedy and therefore constant and timely Quality Assurance control is mandatory. All parties must recognize this and act accordingly.

WDW:6331:cds

Copy to:
DOE/WPO J. Anderson (Carlsbad)
DOE/WPO A. Hunt (Carlsbad)
6332 L. D. Tyler
6332 D. E. Munson
6332 R. V. Matalucci

APPENDIX A1: TEST ROOM A1 AS-BUILT DRAWINGS

LIST OF FIGURES FOR APPENDIX A1

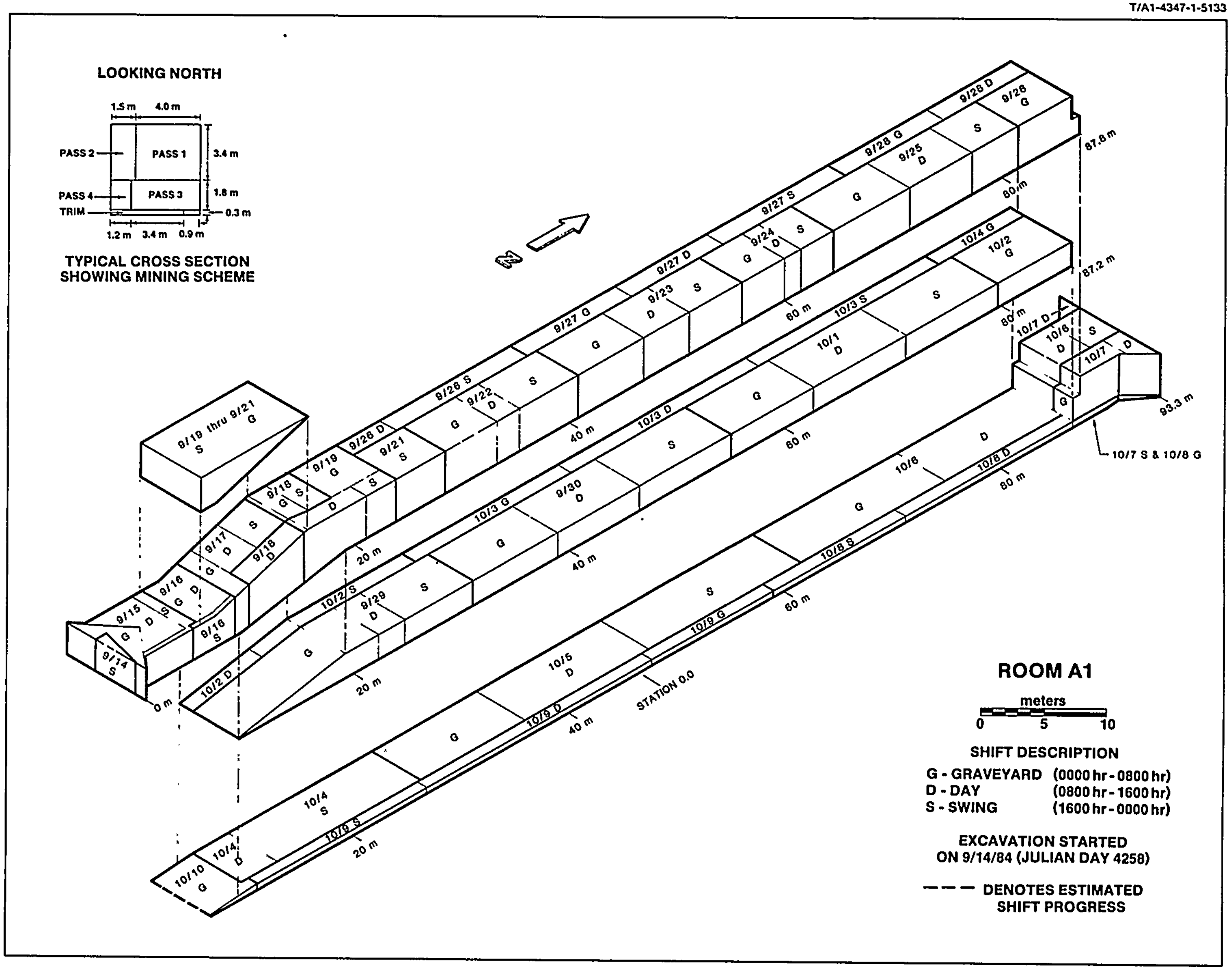


Figure A1-1. Isometric View of Excavation Progress, Room A1

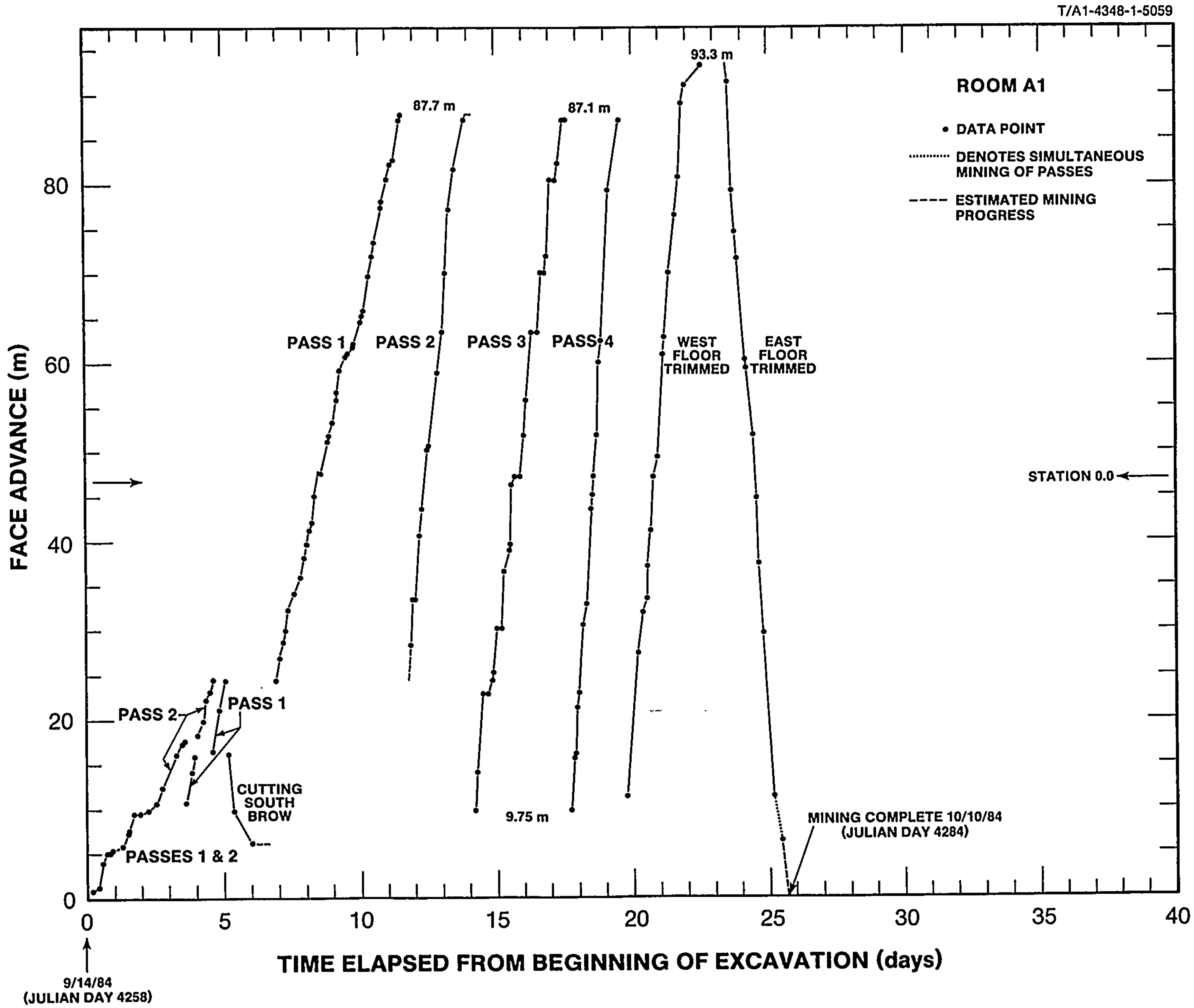


Figure A1-2. Face Advance During Excavation, Room A1

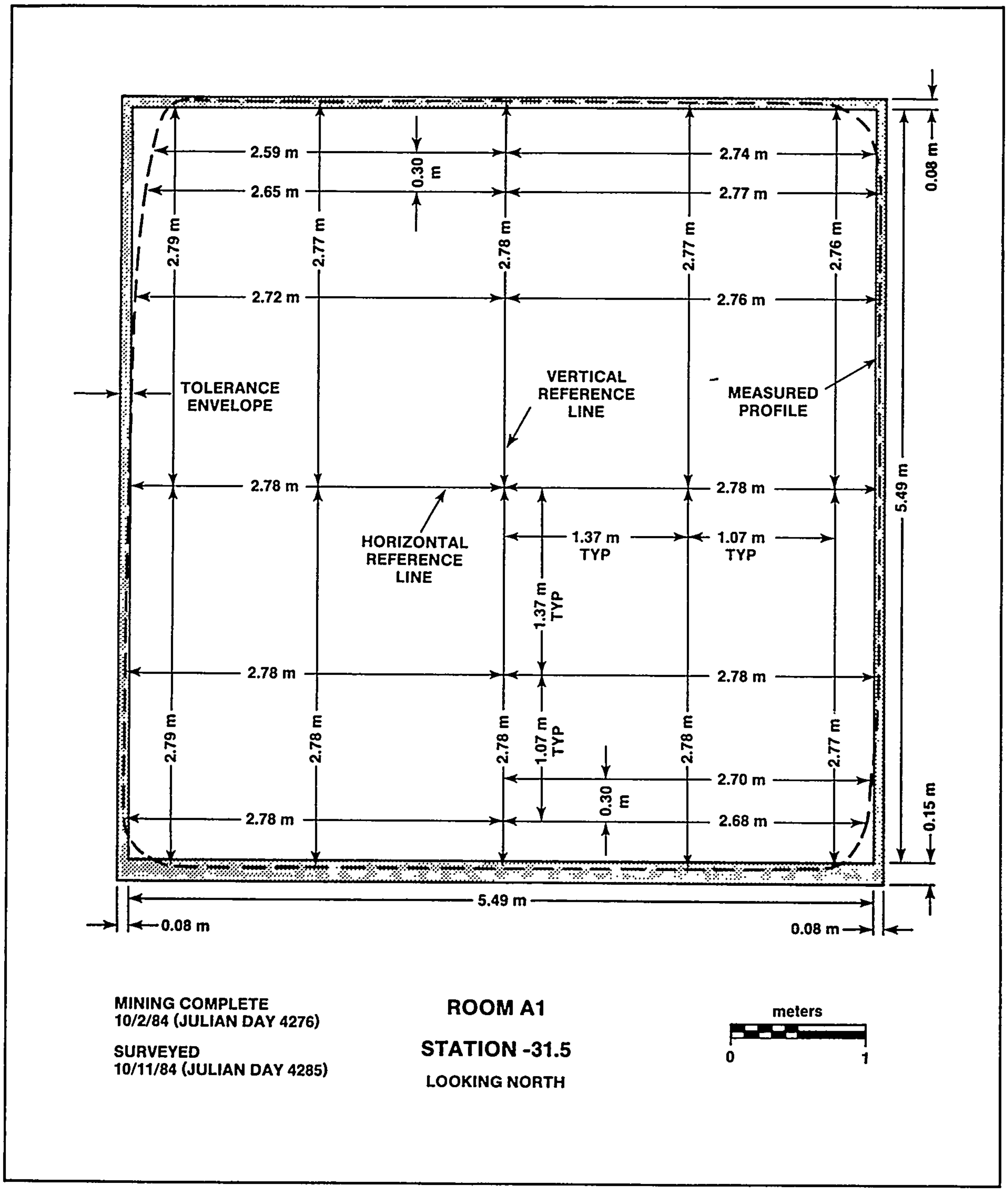


Figure A1-3a. As-Built Cross Section of Station -31.5 m, Room A1

T/A1-5065-1

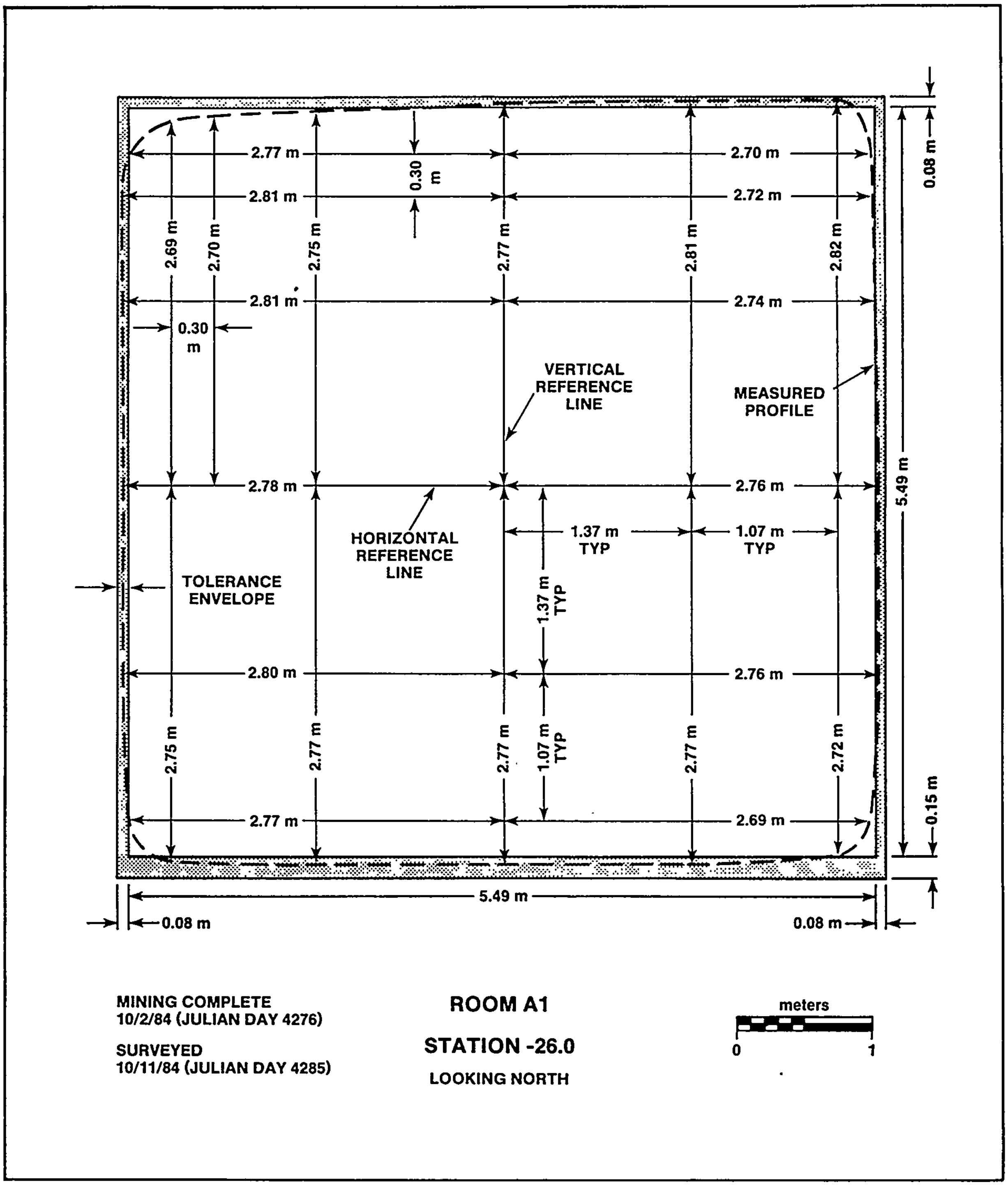
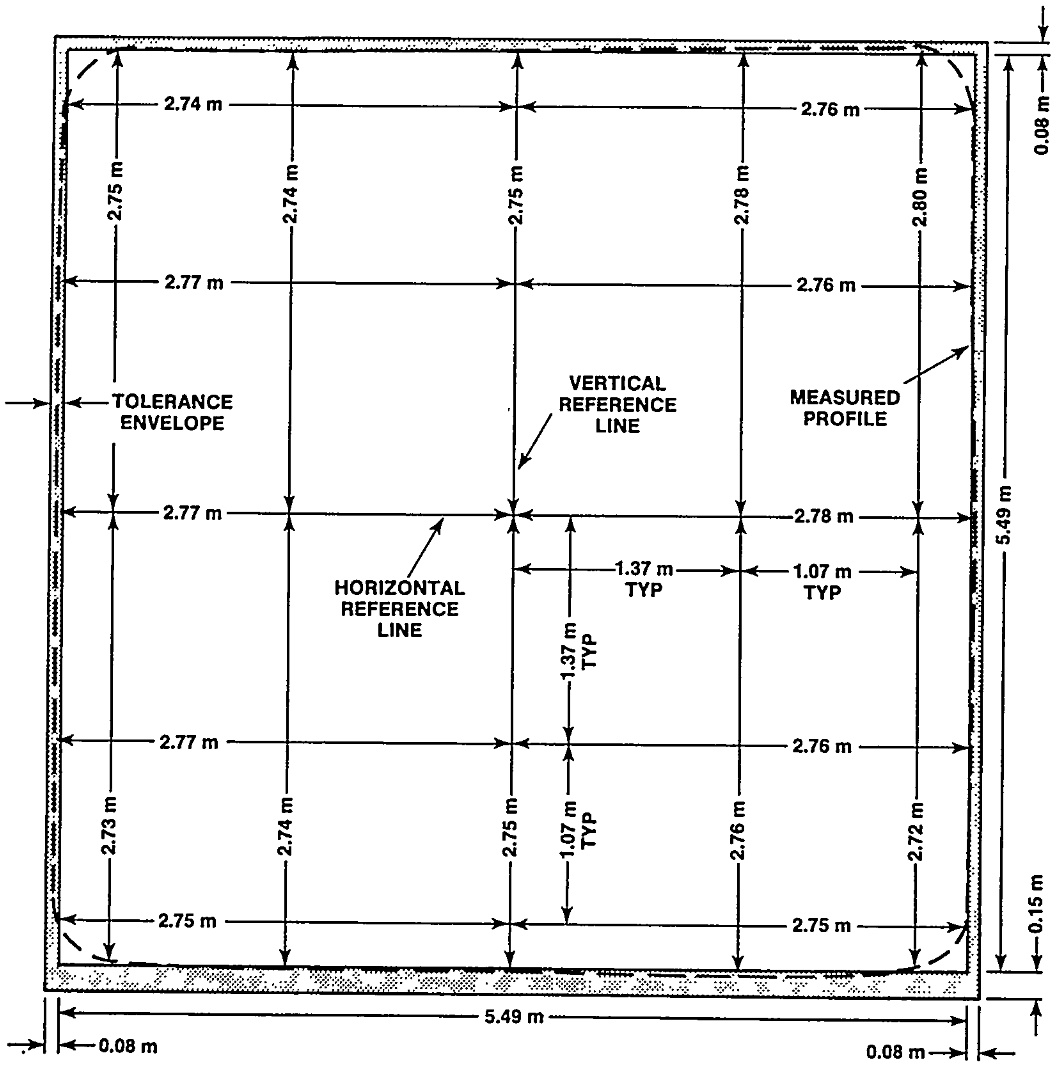


Figure A1-3b. As-Built Cross Section of Station -26.0 m, Room A1

T/A1-5064-2



MINING COMPLETE
10/2/84 (JULIAN DAY 4276)

SURVEYED
10/11/84 (JULIAN DAY 4285)

ROOM A1

STATION -20.5

LOOKING NORTH

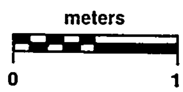


Figure A1-3c. As-Built Cross Section of Station -20.5 m, Room A1

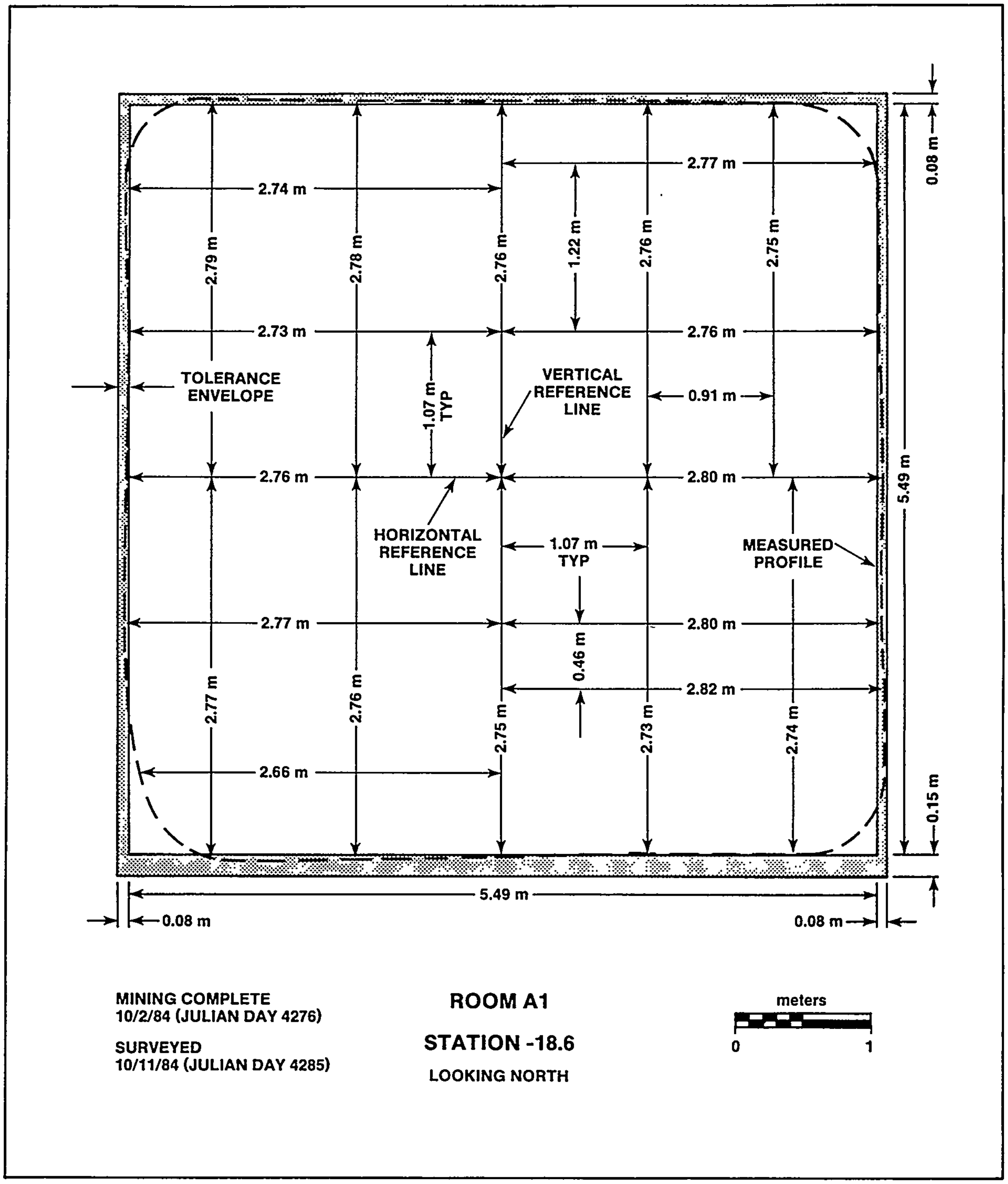


Figure A1-3d. As-Built Cross Section of Station -18.6 m, Room A1

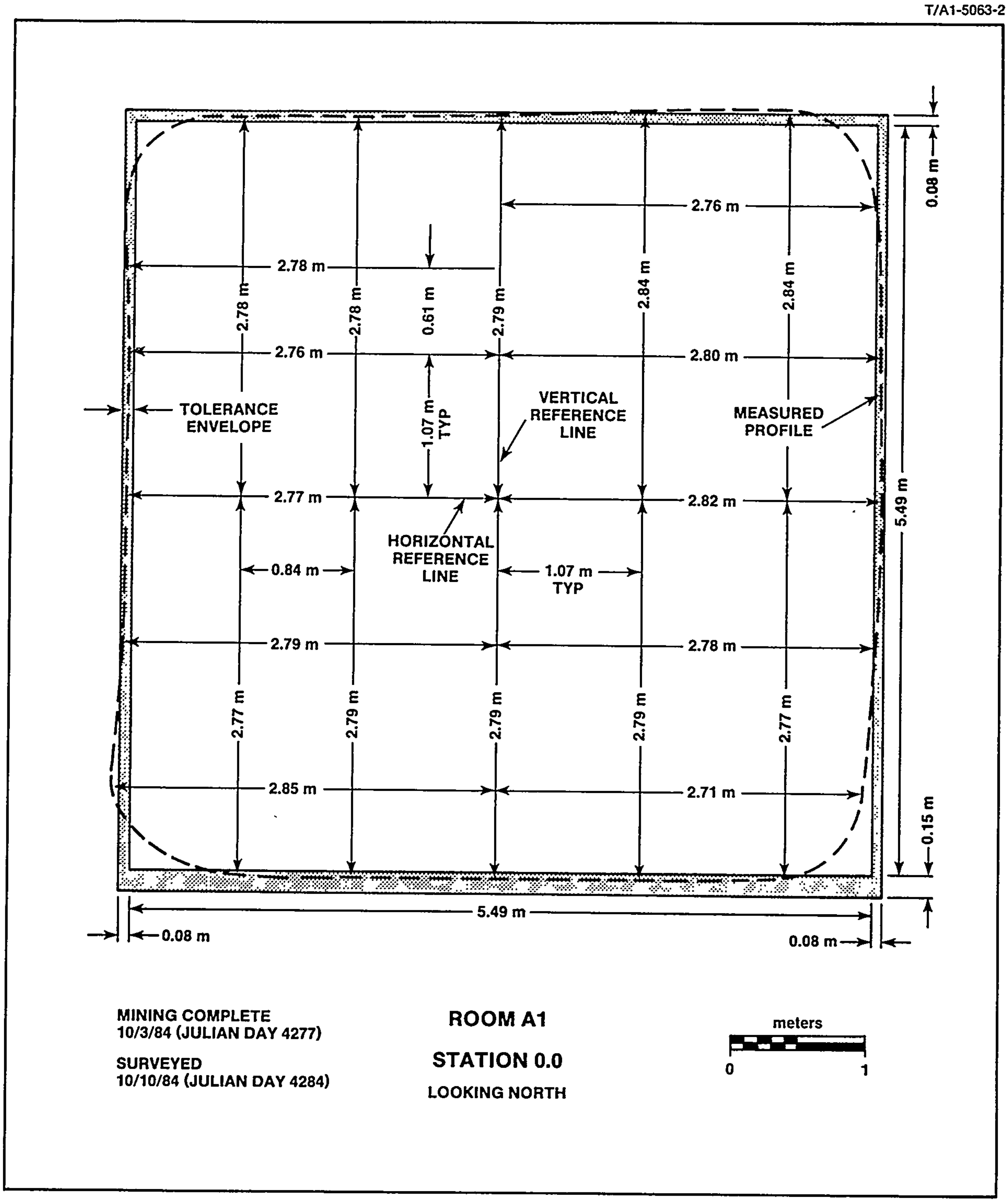


Figure A1-3e. As-Built Cross Section of Station 0.0 m, Room A1

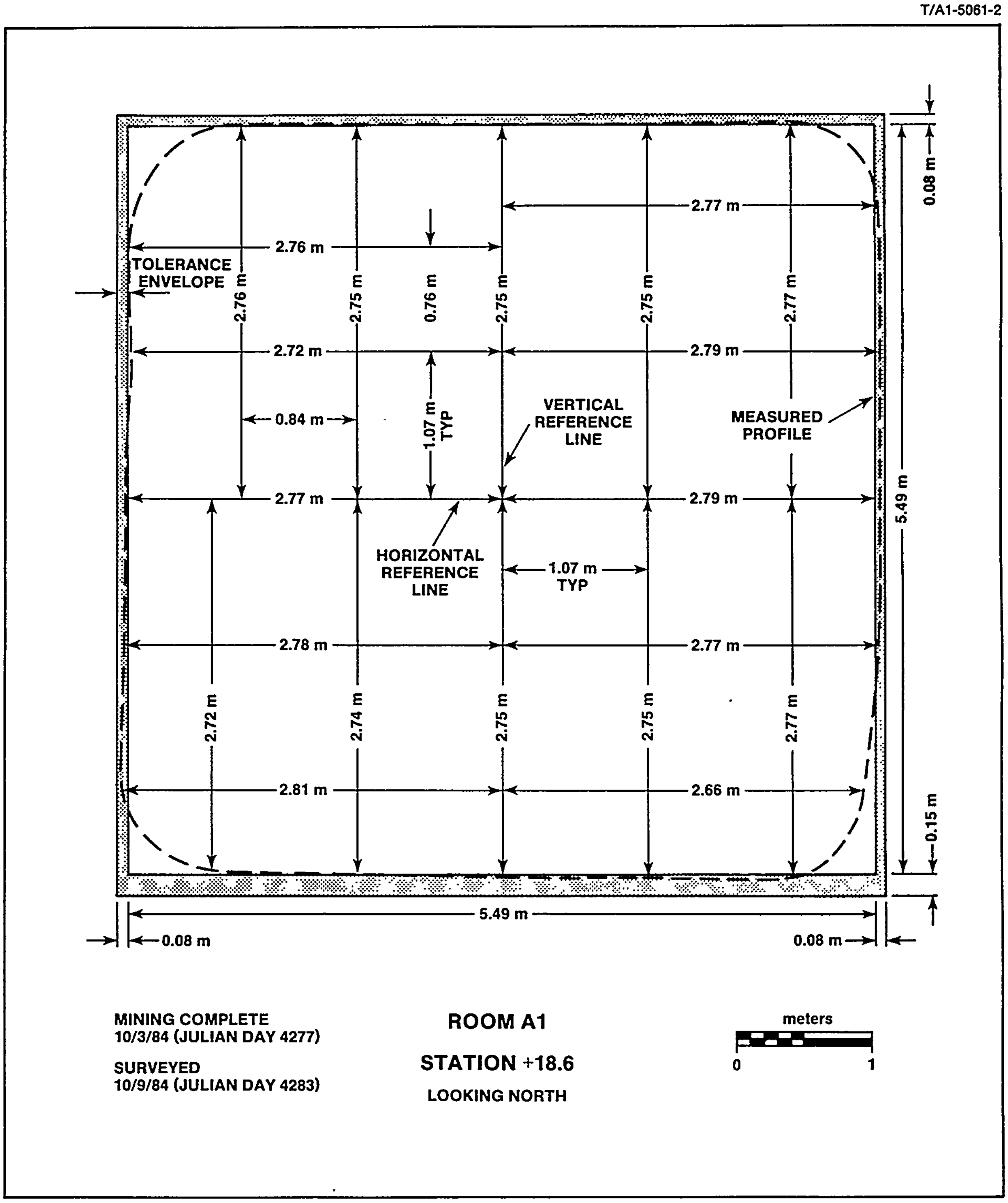


Figure A1-3f. As-Built Cross Section of Station +18.6 m, Room A1

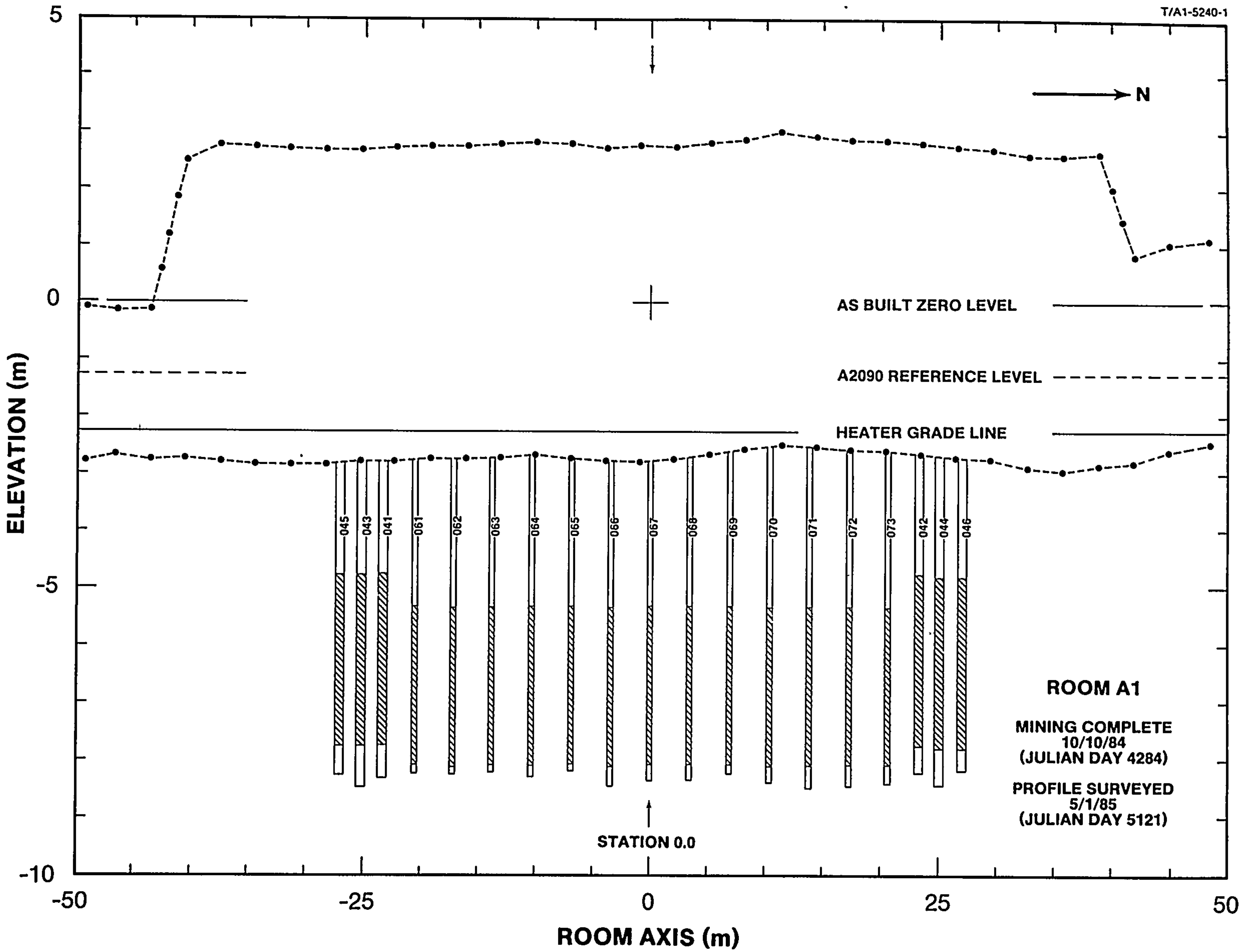


Figure A1-4. As-Built Profile of Room A1

APPENDIX A2: TEST ROOM A2 AS-BUILT DRAWINGS

LIST OF FIGURES FOR APPENDIX A2

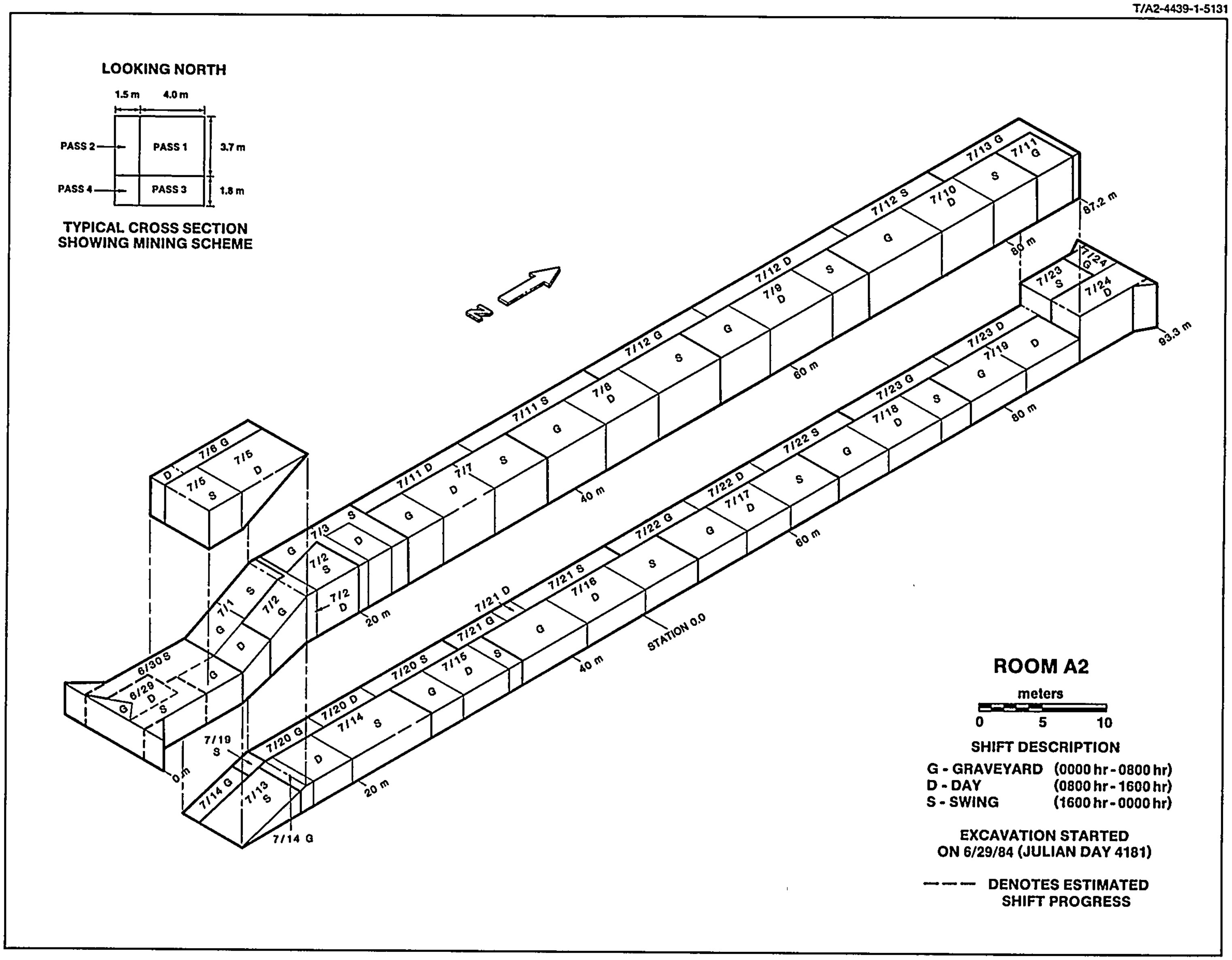


Figure A2-1. Isometric View of Excavation Progress, Room A2

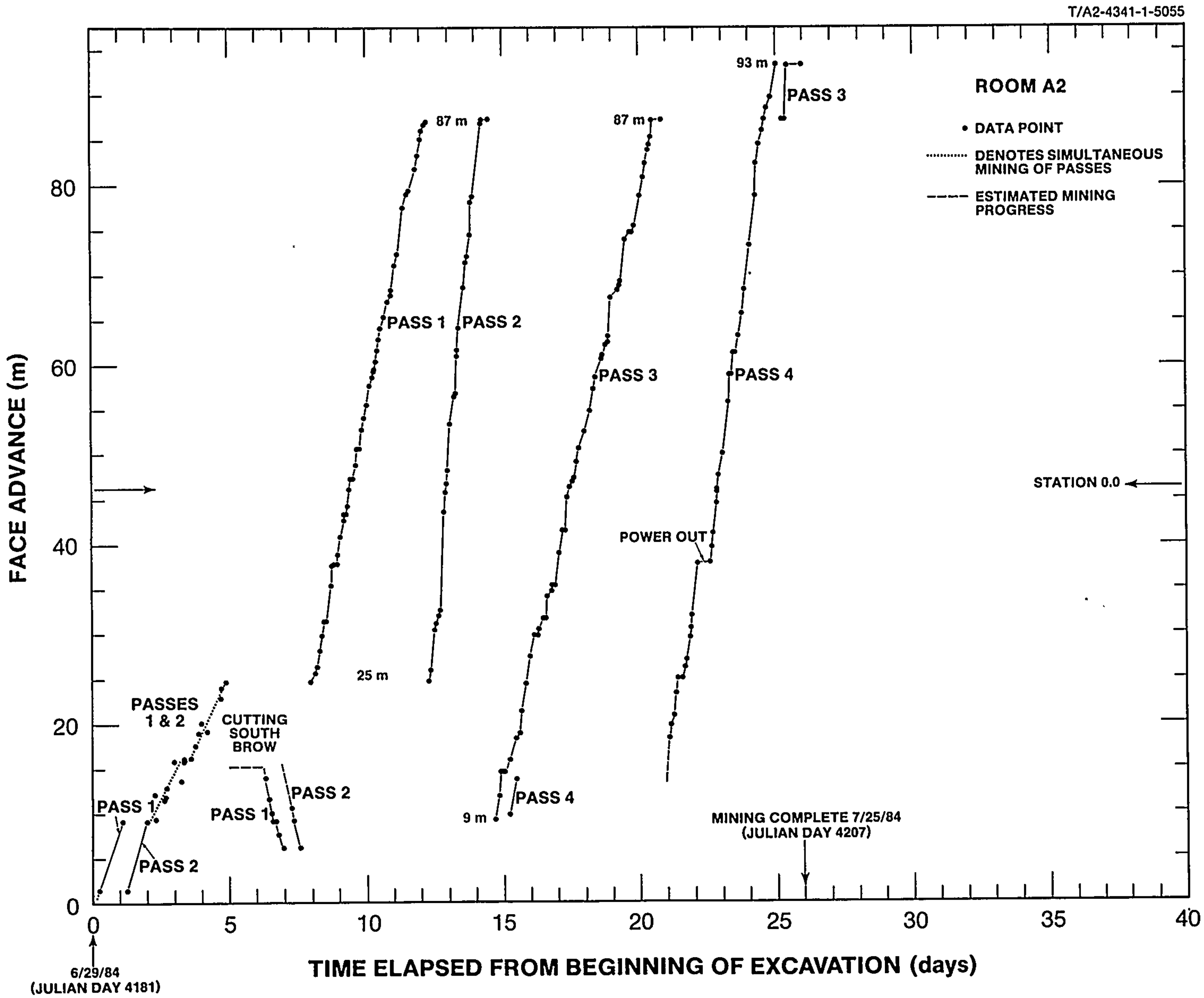


Figure A2-2. Face Advance During Excavation, Room A2

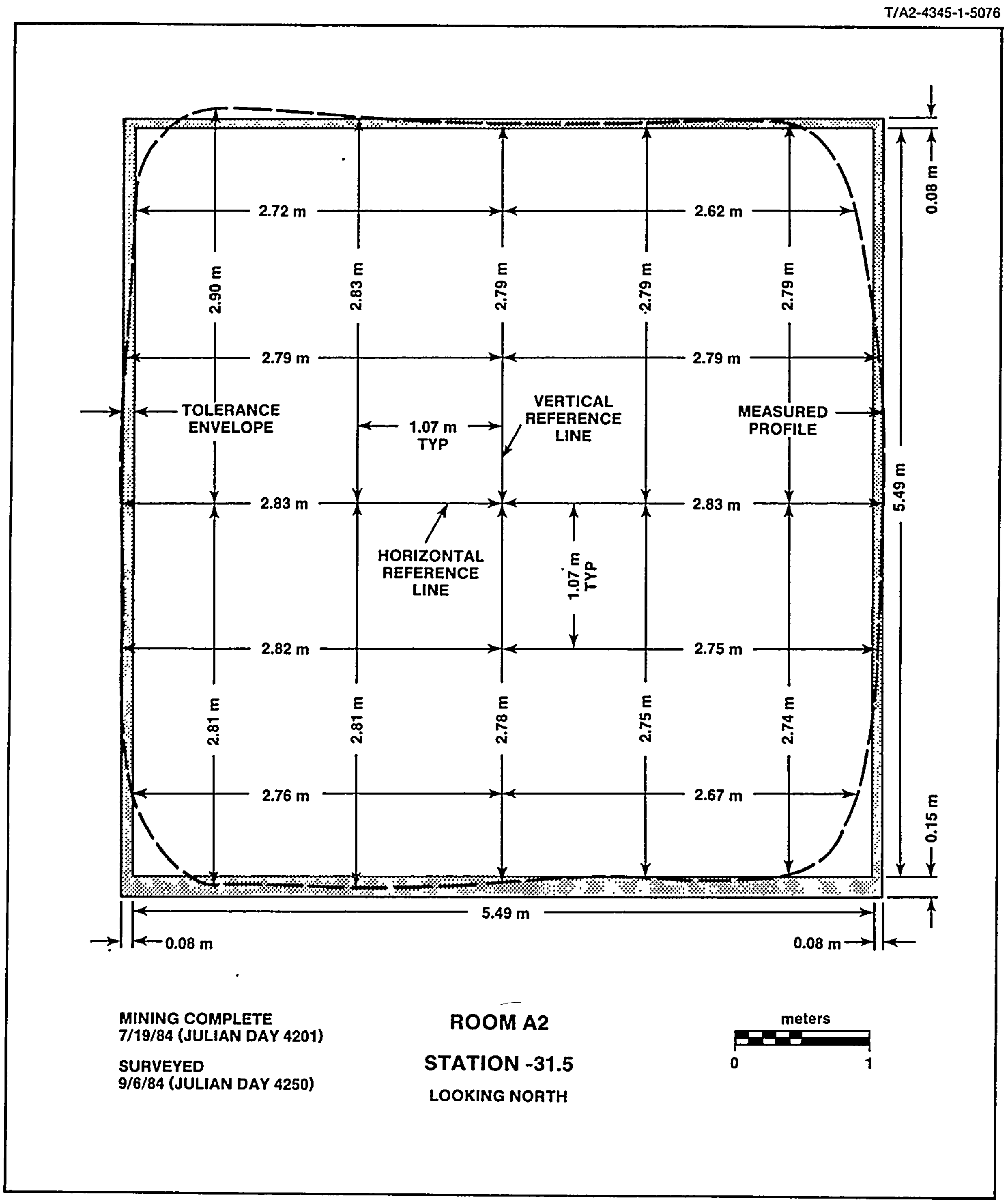


Figure A2-3a. As-Built Cross Section of Station -31.5 m, Room A2

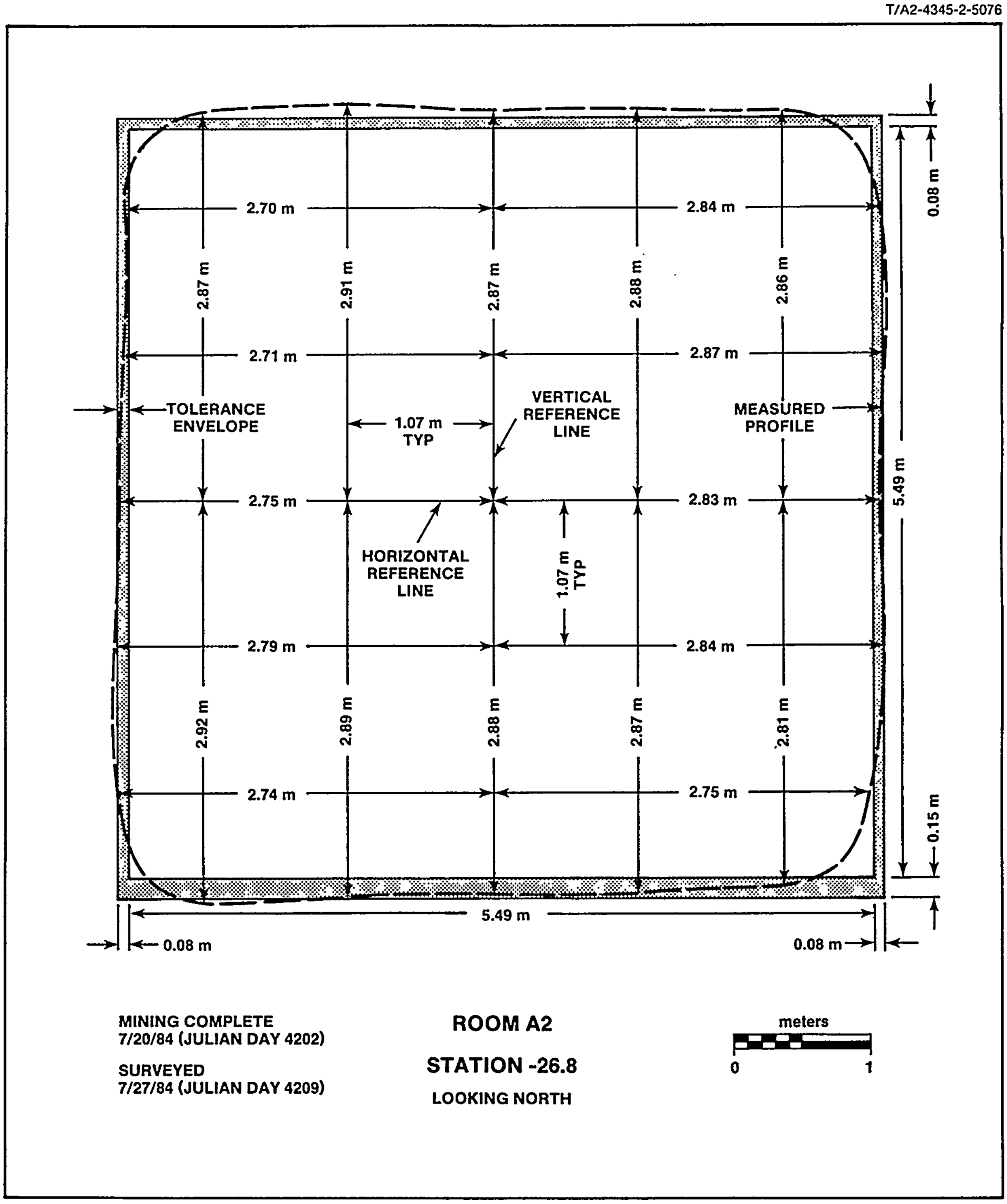


Figure A2-3b. As-Built Cross Section of Station -26.8 m, Room A2

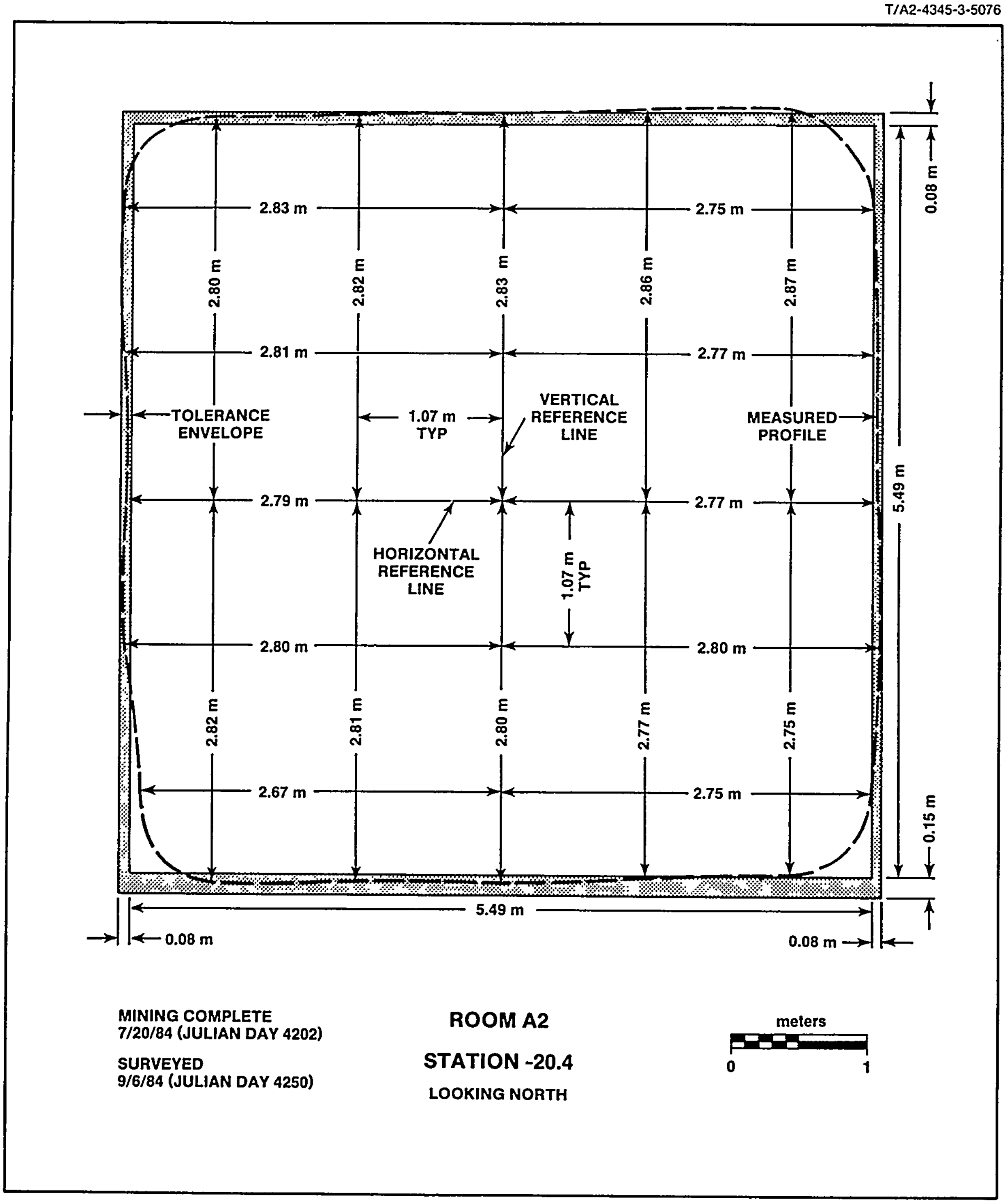


Figure A2-3c. As-Built Cross Section of Station -20.4 m, Room A2

T/A2-4345-4-5076

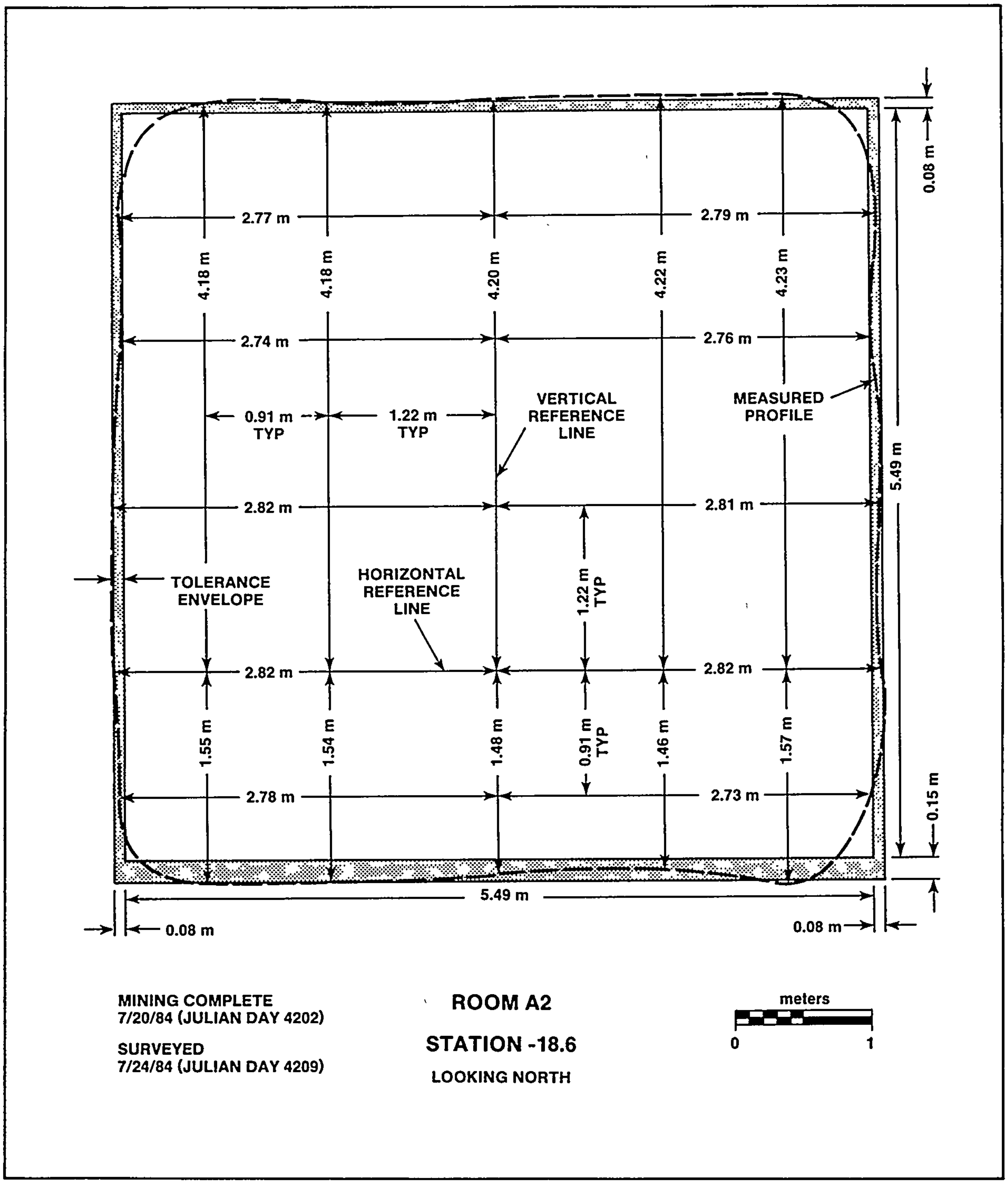


Figure A2-3d. As-Built Cross Section of Station -18.6 m, Room A2

T/A2-4346-1-5075

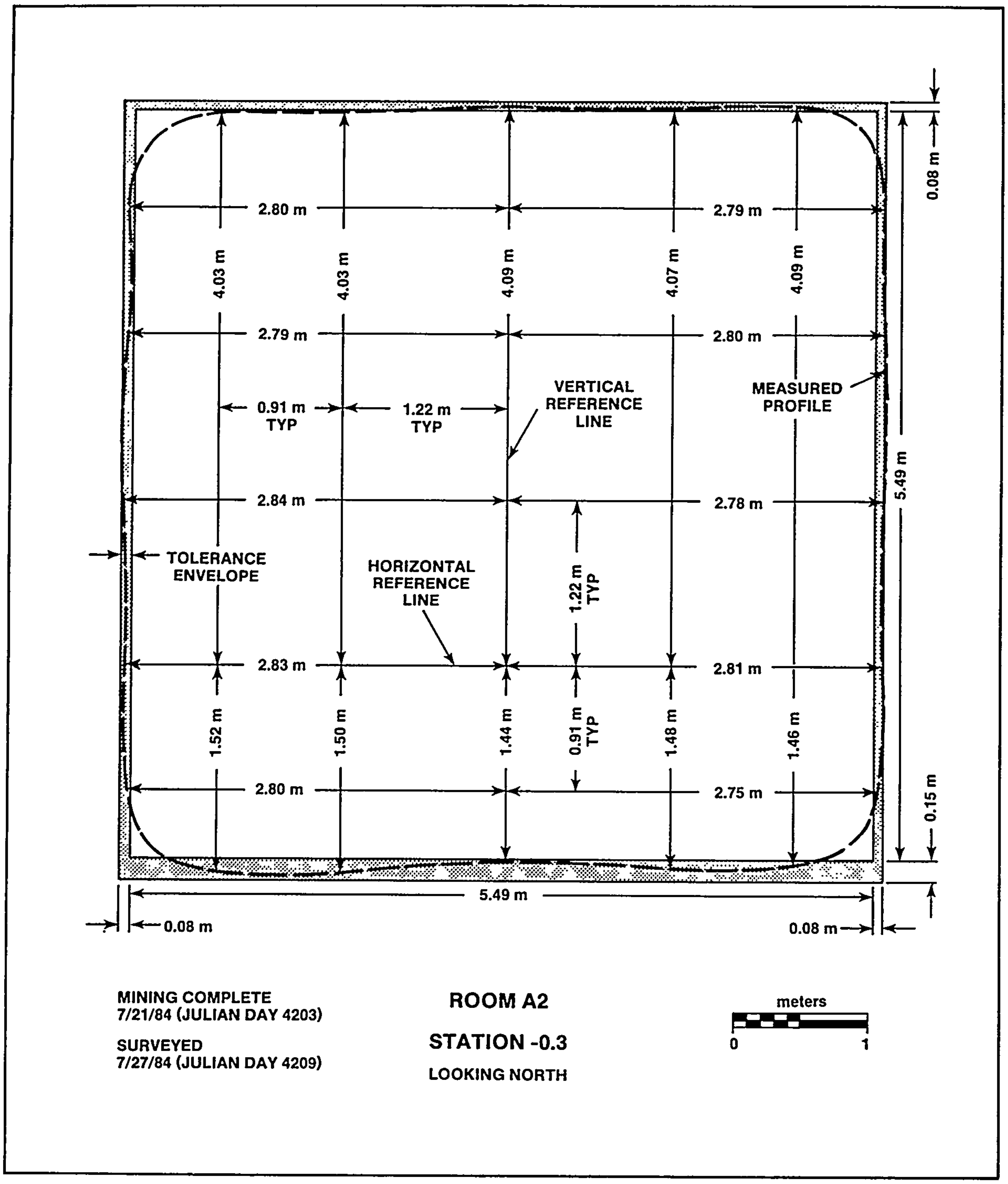


Figure A2-3e. As-Built Cross Section of Station -0.3 m, Room A2

T/A2-4346-3-5075

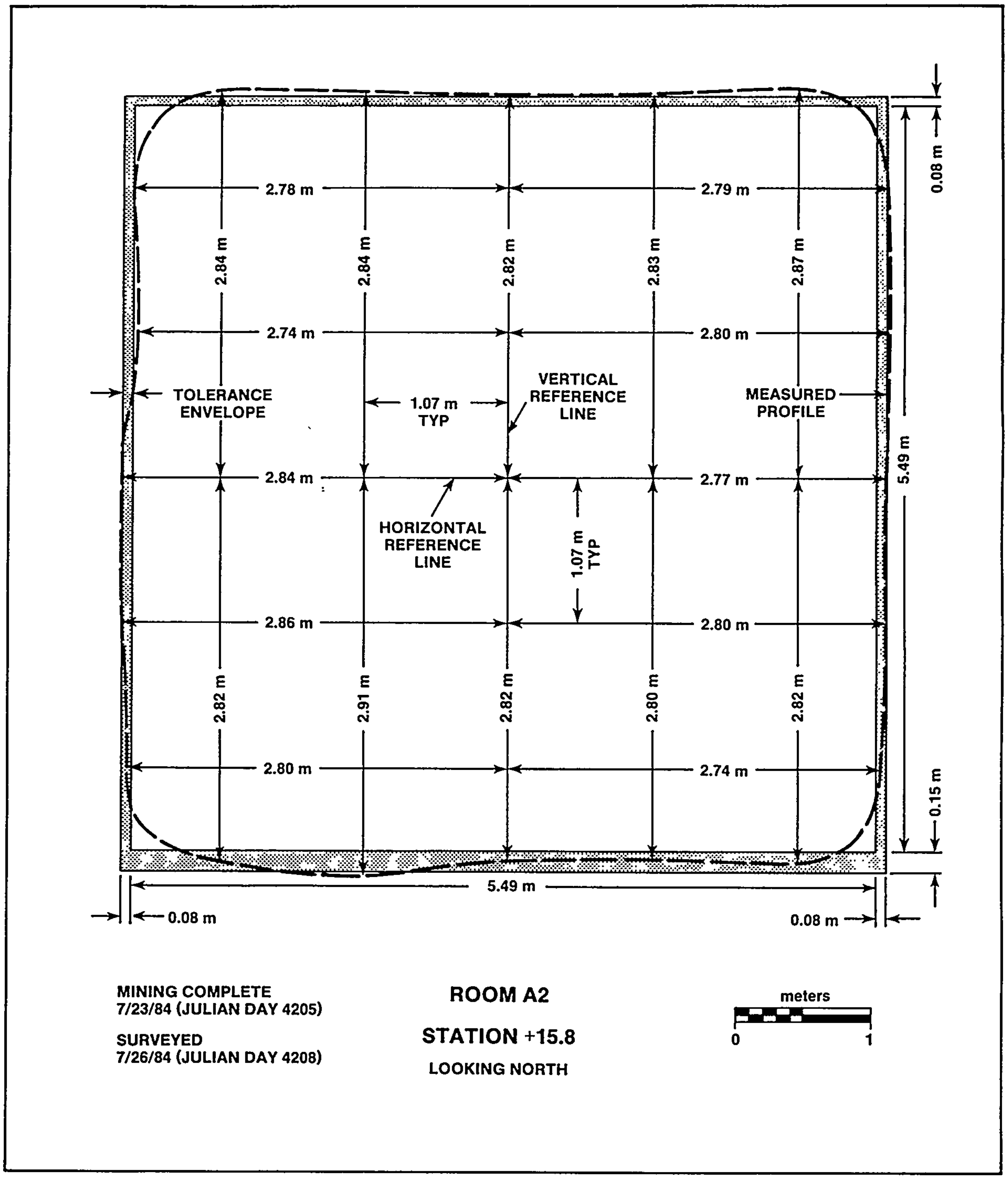


Figure A2-3f. As-Built Cross Section of Station +15.8 m, Room A2

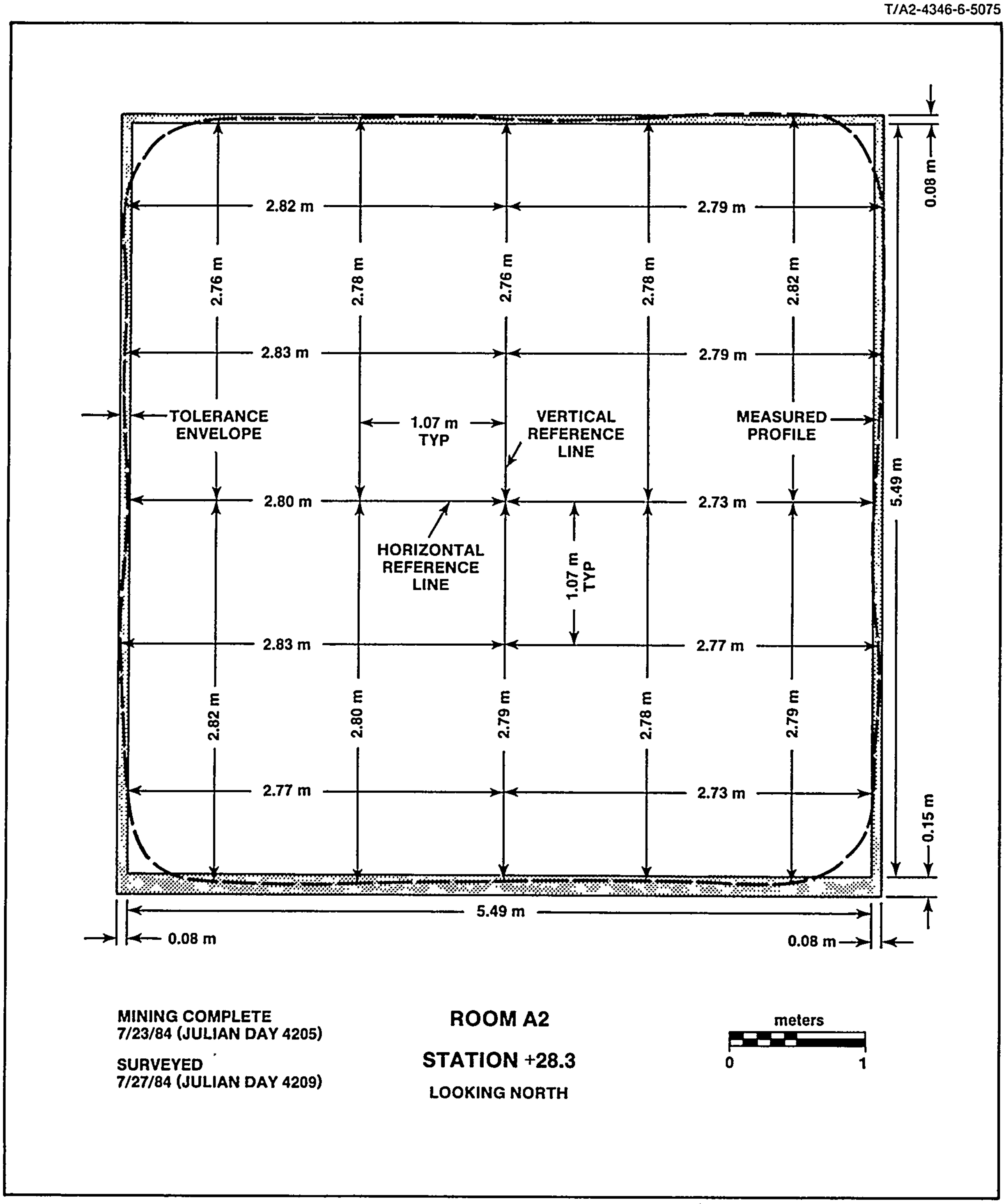


Figure A2-3g. As-Built Cross Section of Station +28.3 m, Room A2

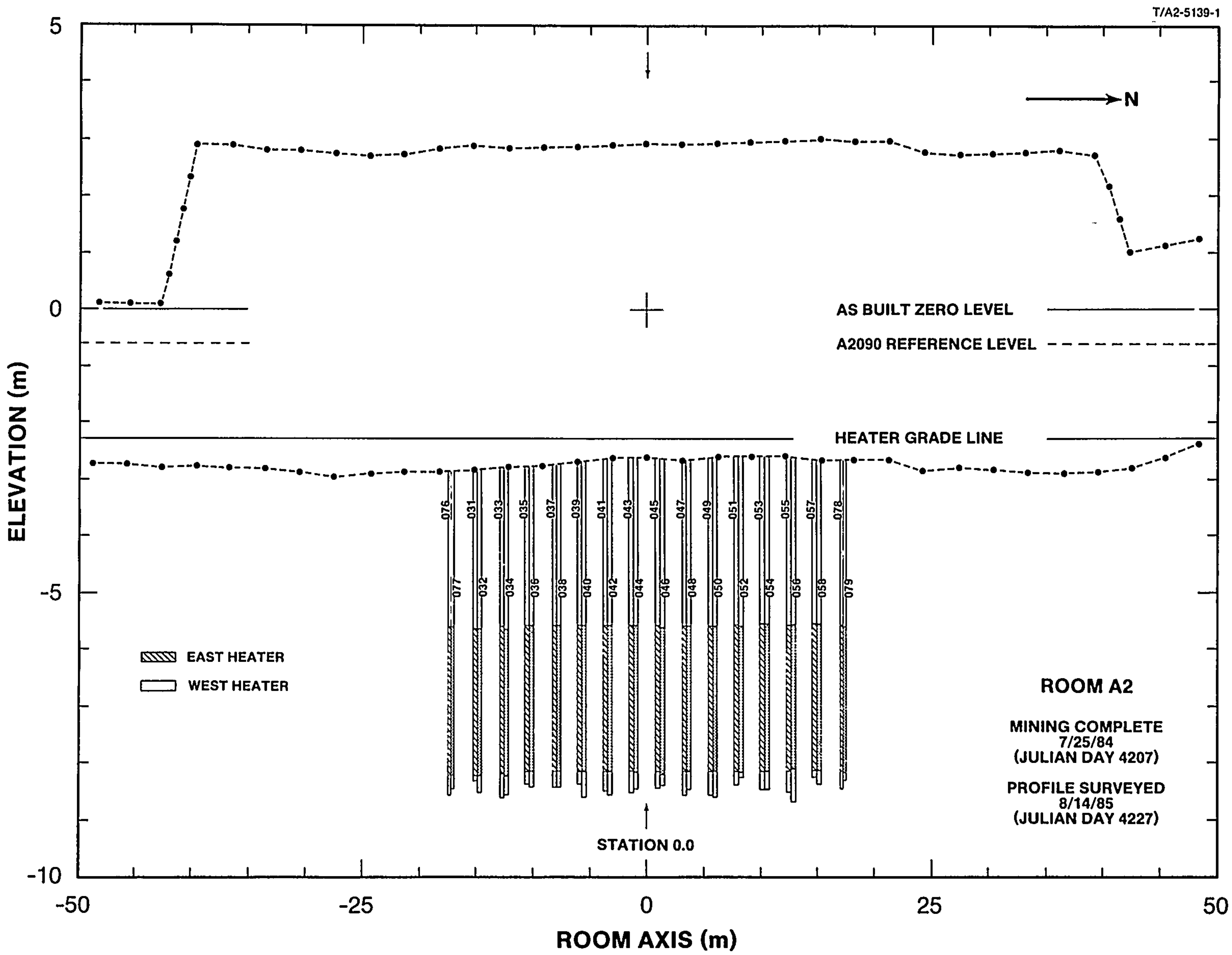


Figure A2-4. As-Built Profile of Room A2

APPENDIX A3: TEST ROOM A3 AS-BUILT DRAWINGS

LIST OF FIGURES FOR APPENDIX A3

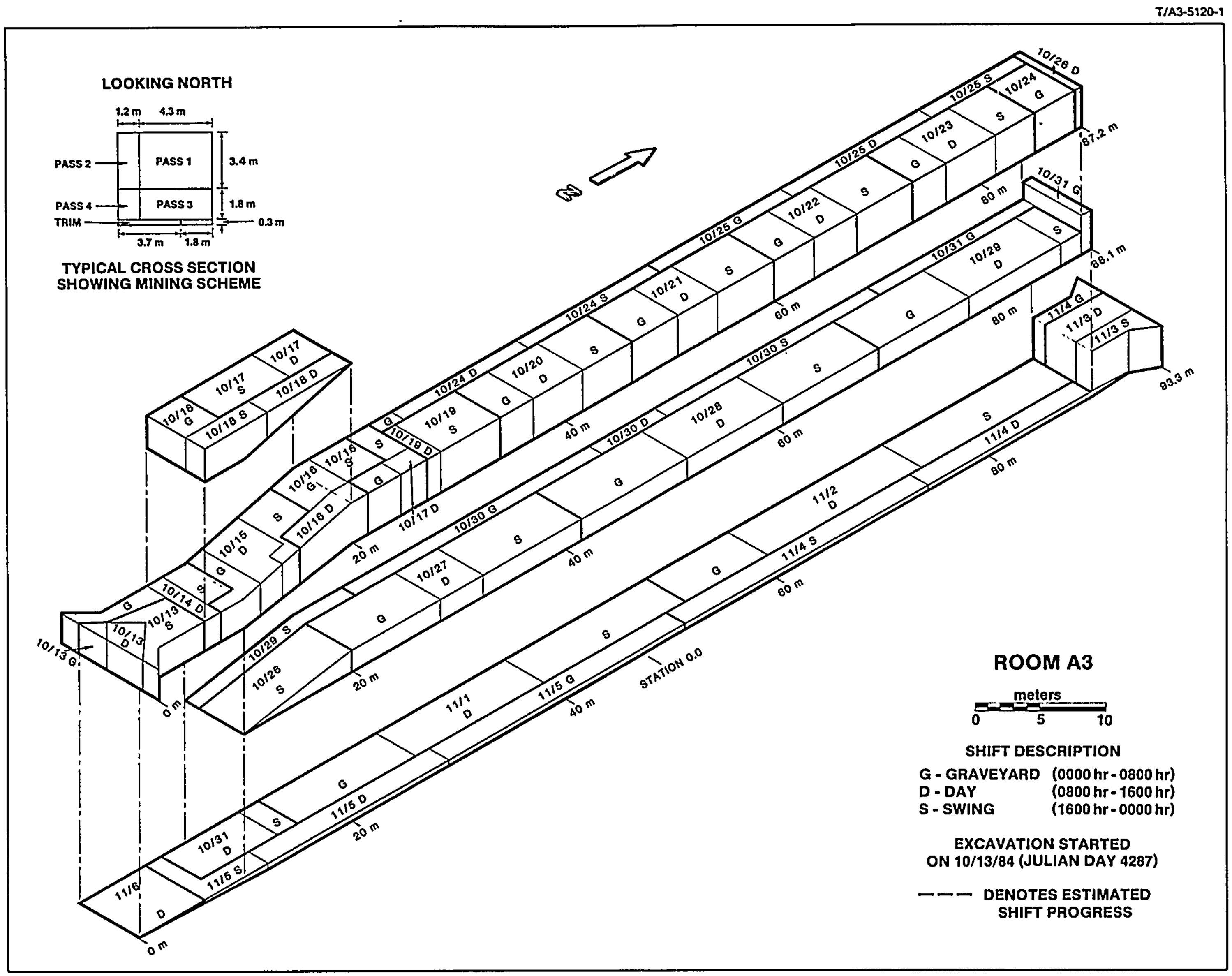


Figure A3-1. Isometric View of Excavation Progress, Room A3

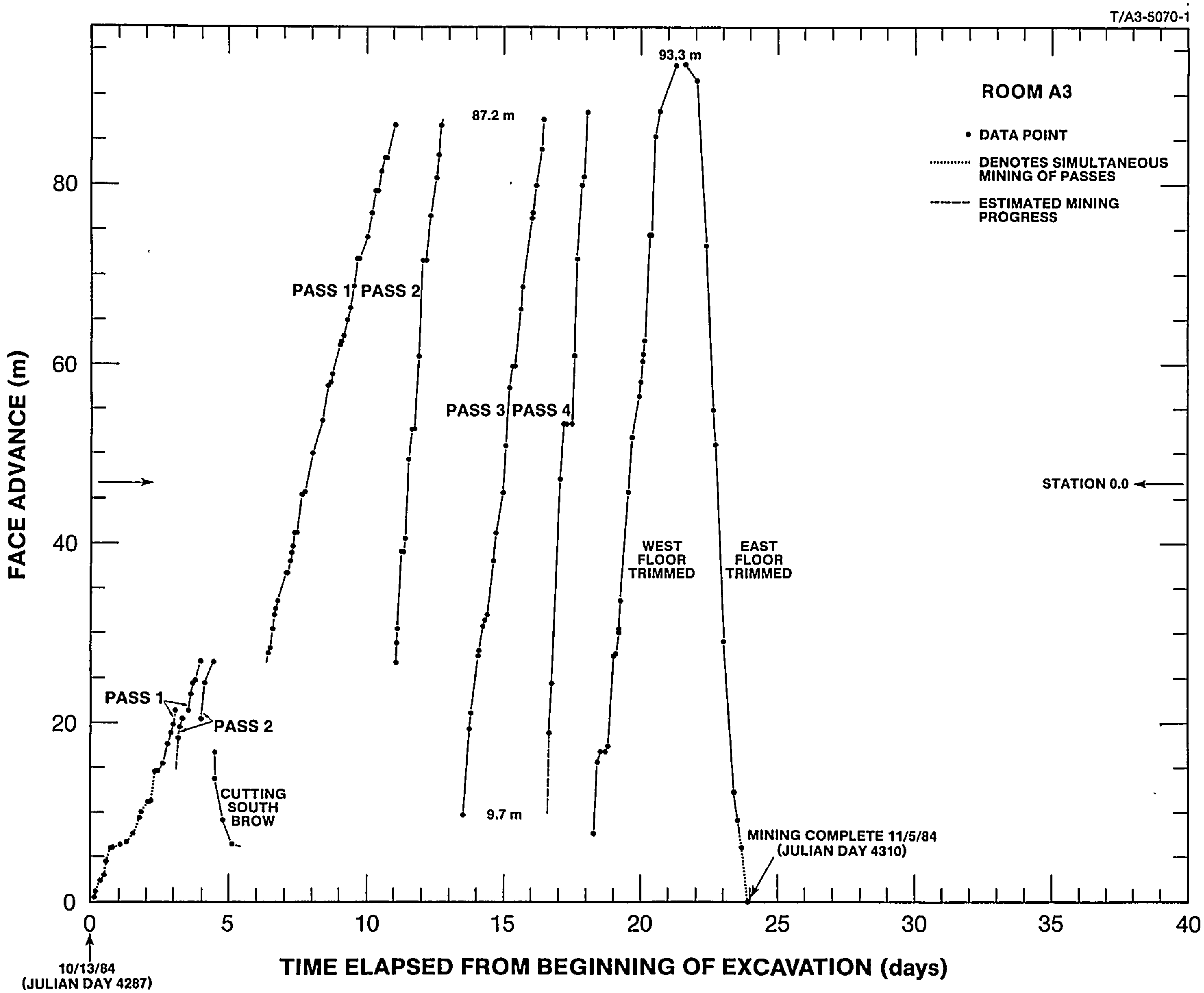


Figure A3-2. Face Advance During Excavation, Room A3

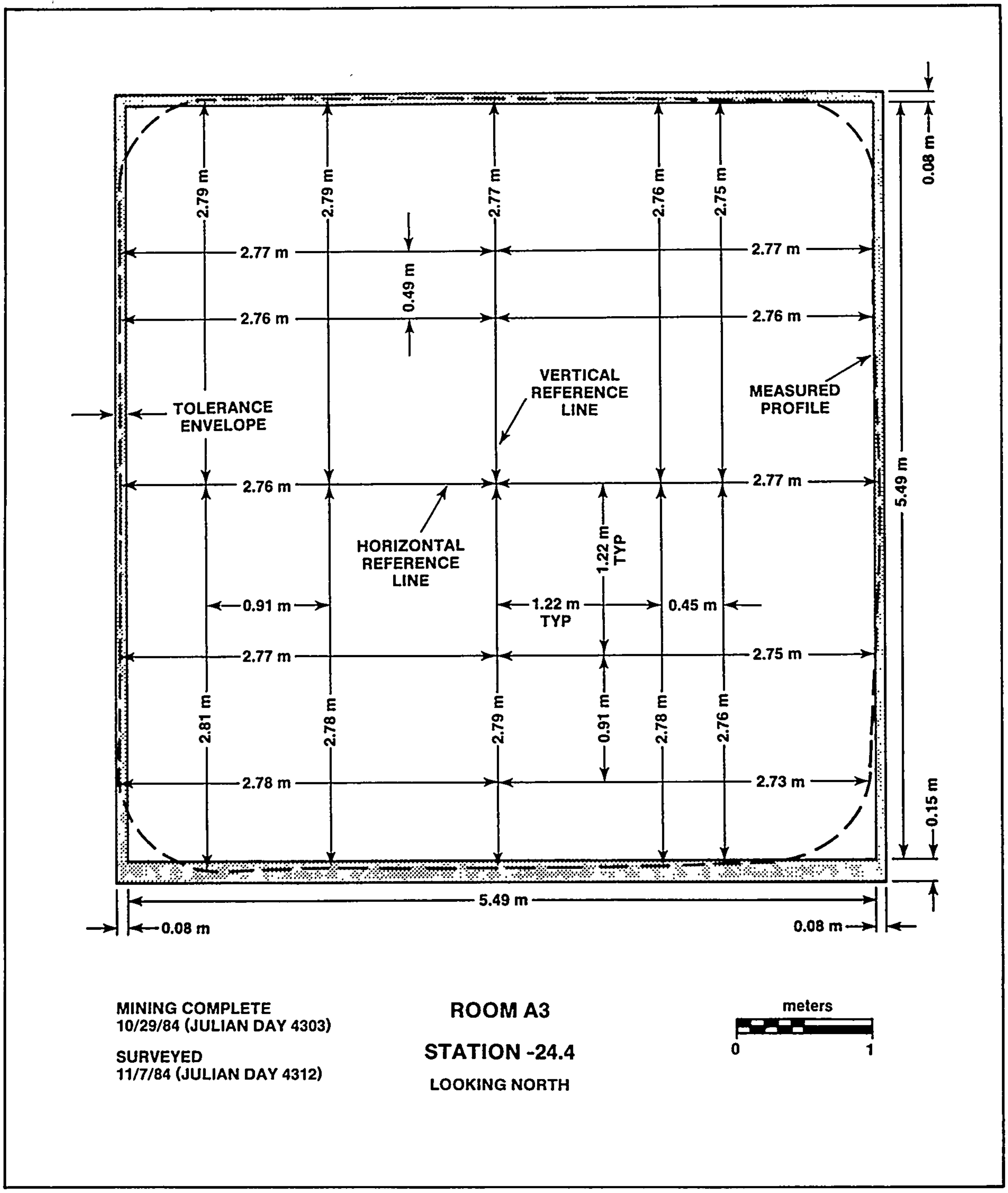


Figure A3-3a. As-Built Cross Section of Station -24.4 m, Room A3

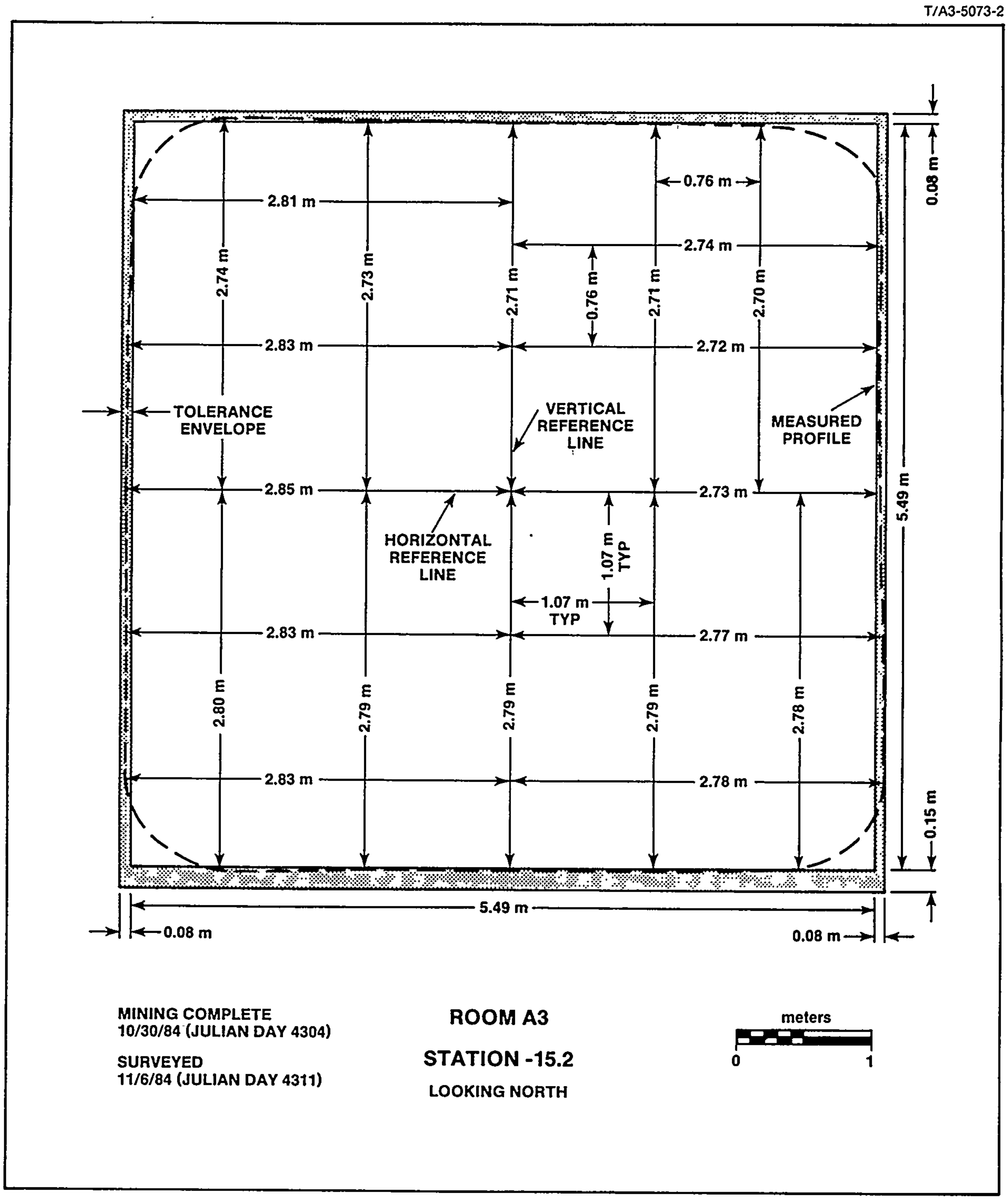


Figure A3-3b. As-Built Cross Section of Station -15.2 m, Room A3

T/A3-5072-2

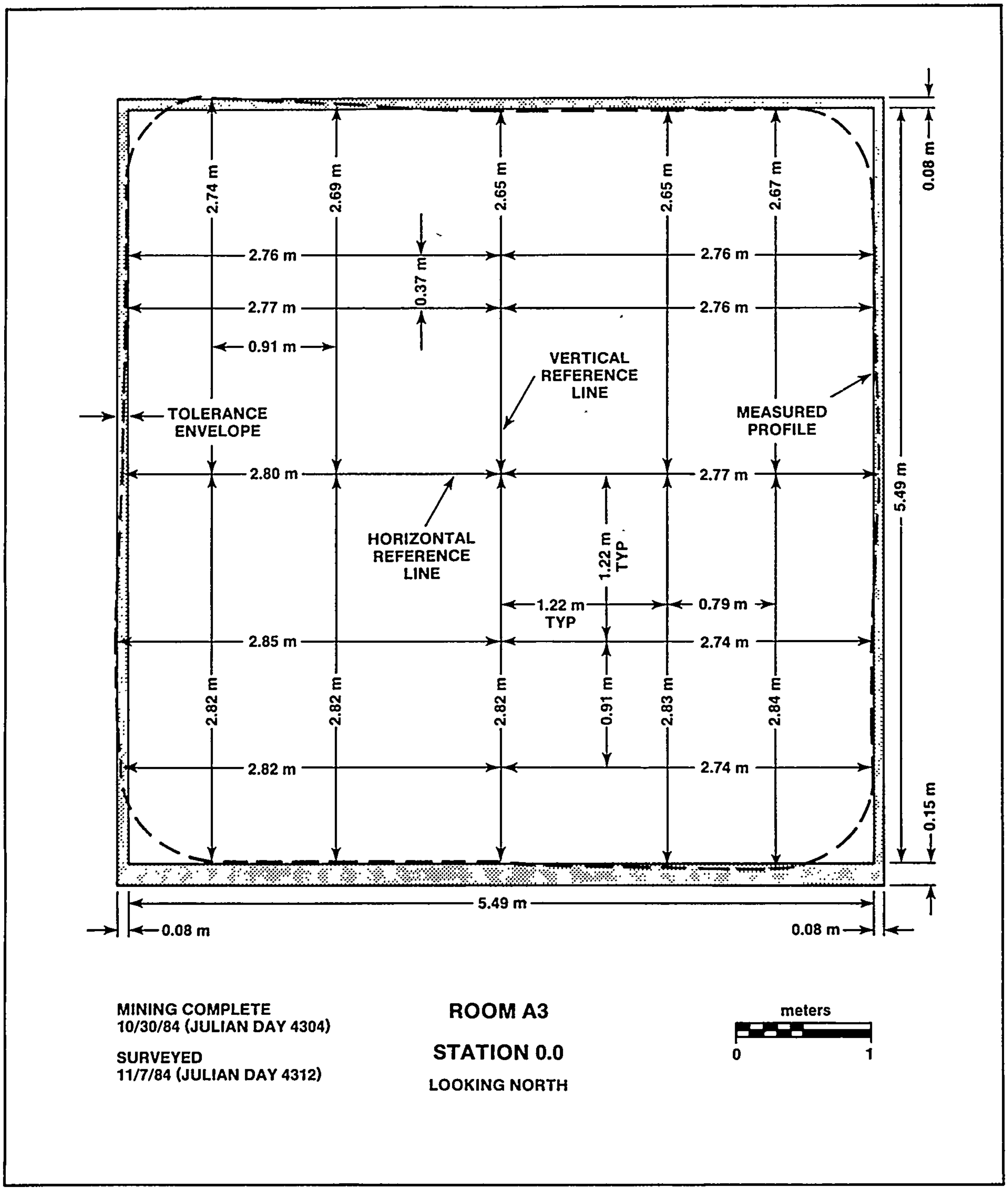


Figure A3-3c. As-Built Cross Section of Station 0.0 m, Room A3

T/A3-5072-1

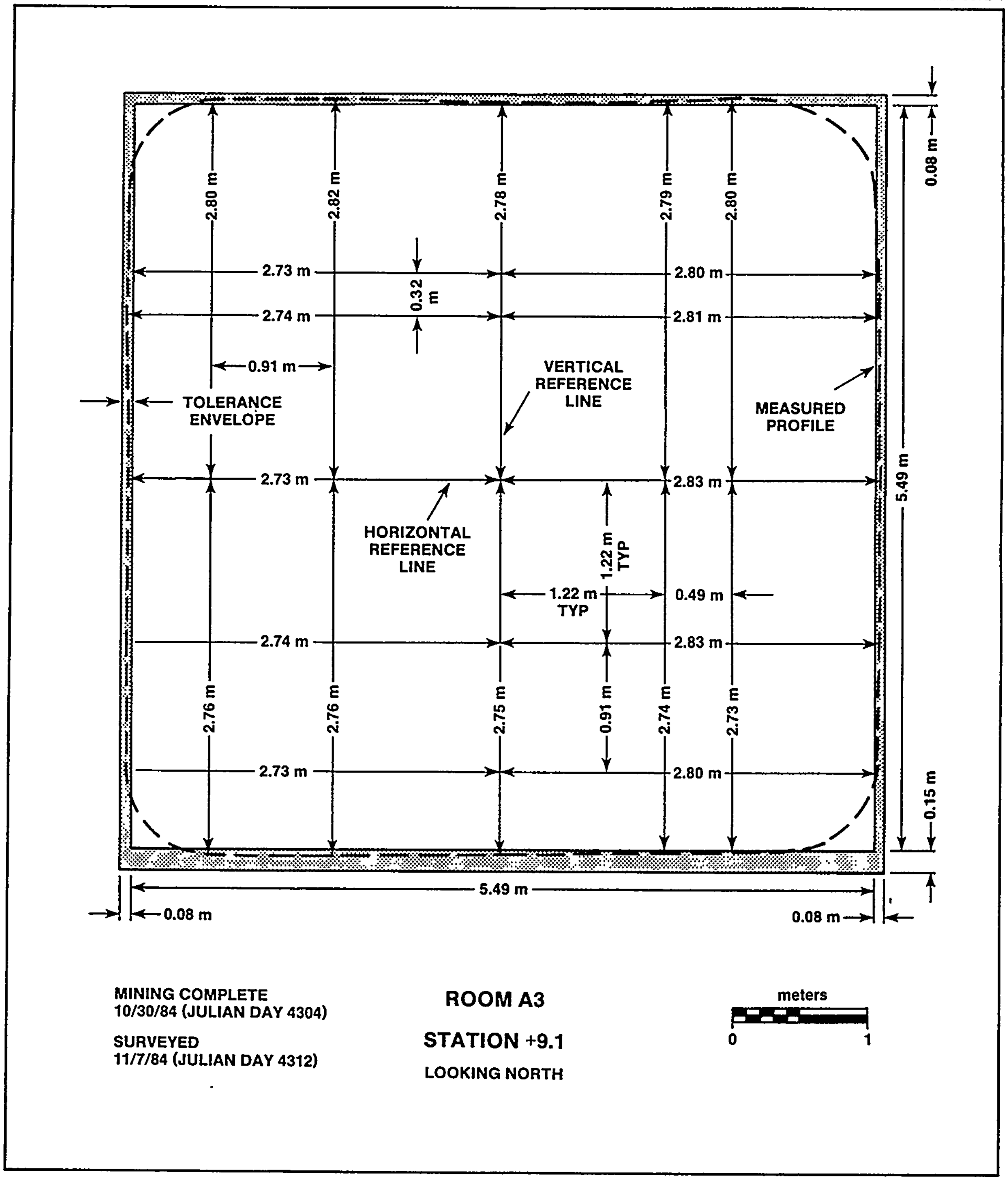


Figure A3-3d. As-Built Cross Section of Station +9.1 m, Room A3

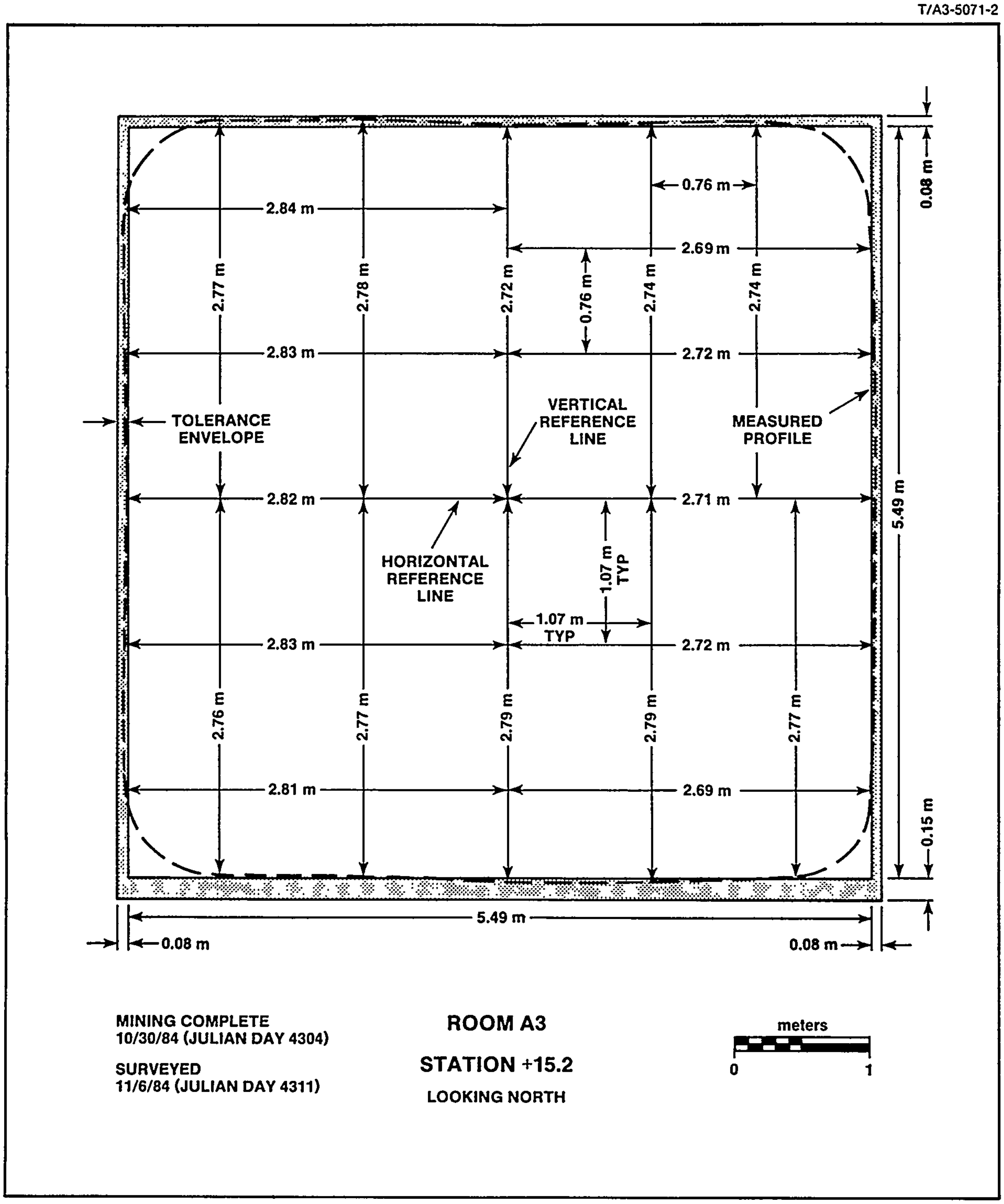


Figure A3-3e. As-Built Cross Section of Station +15.2 m, Room A3

T/A3-5071-1

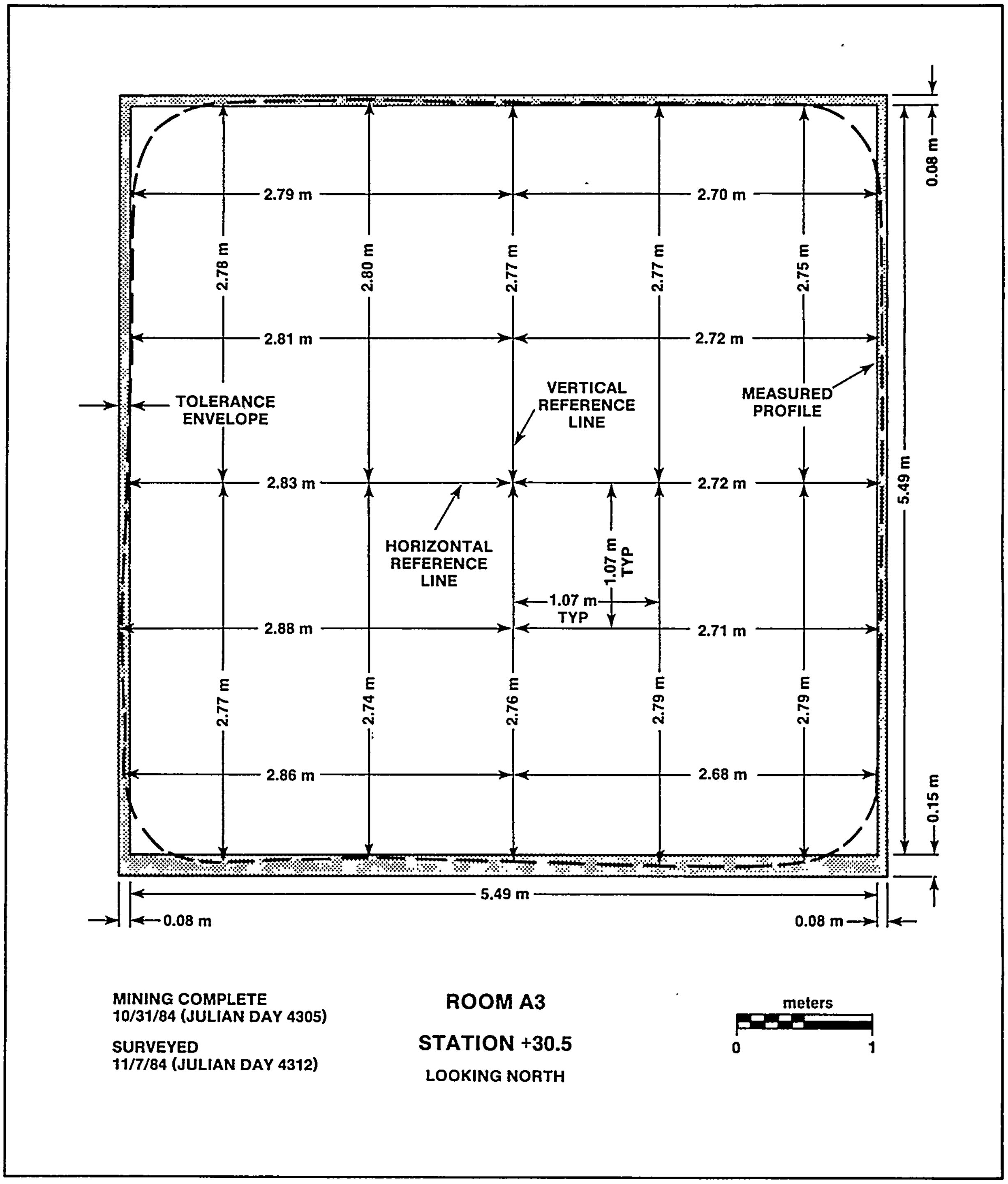


Figure A3-3f. As-Built Cross Section of Station +30.5 m, Room A3

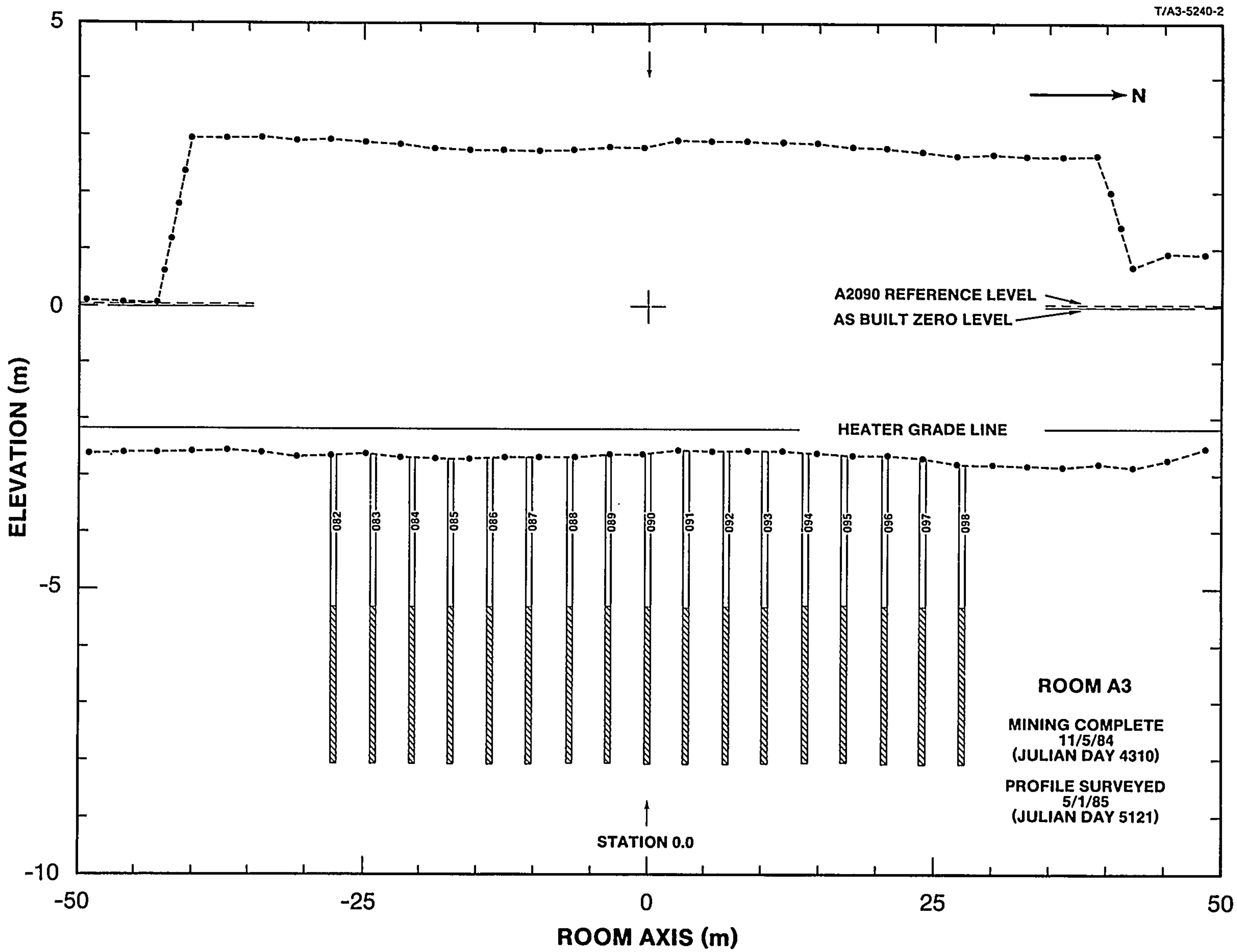


Figure A3-4. As-Built Profile of Room A3

APPENDIX B: TEST ROOM B AS-BUILT DRAWINGS

LIST OF FIGURES FOR APPENDIX B

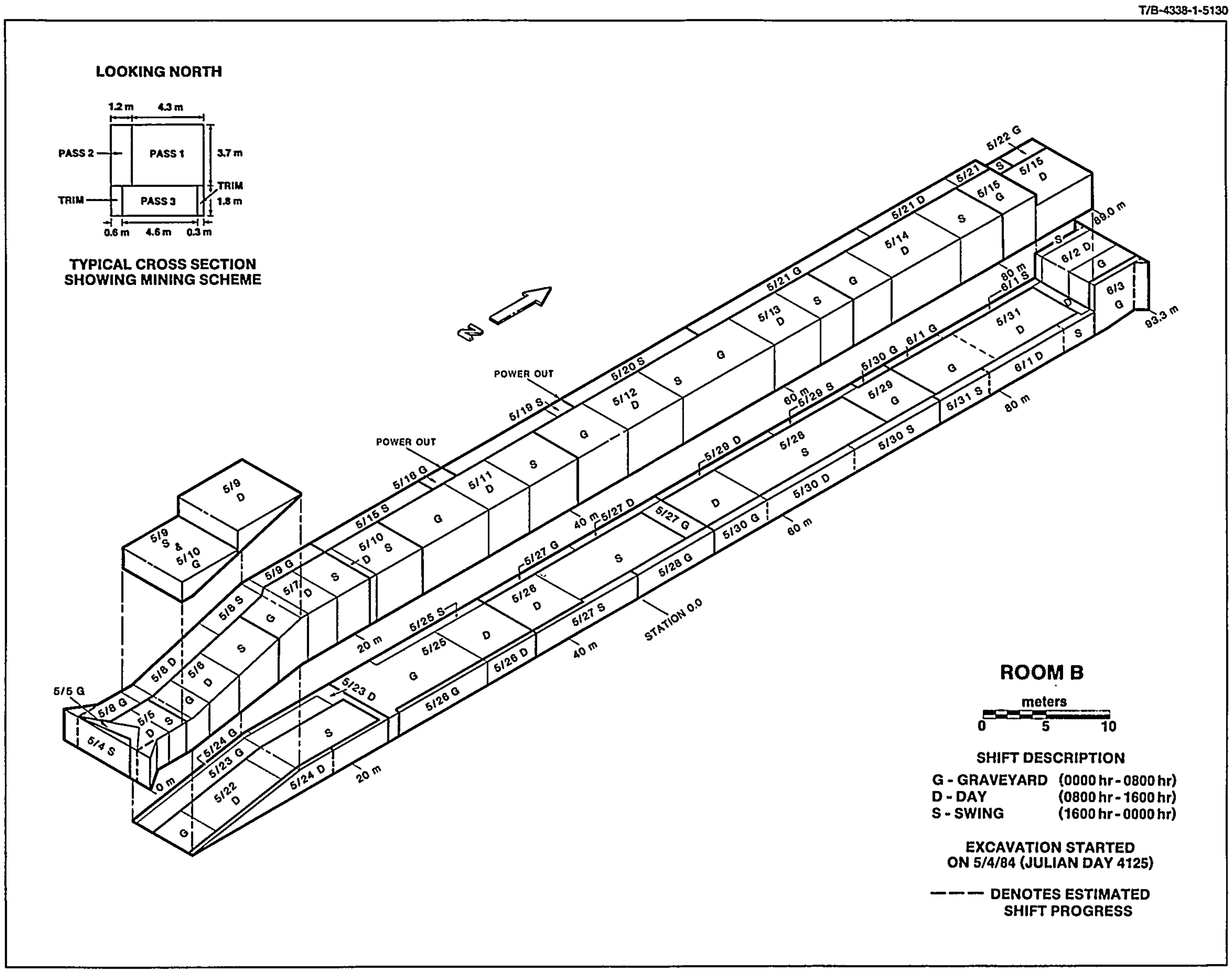


Figure B-1. Isometric View of Excavation Progress, Room B

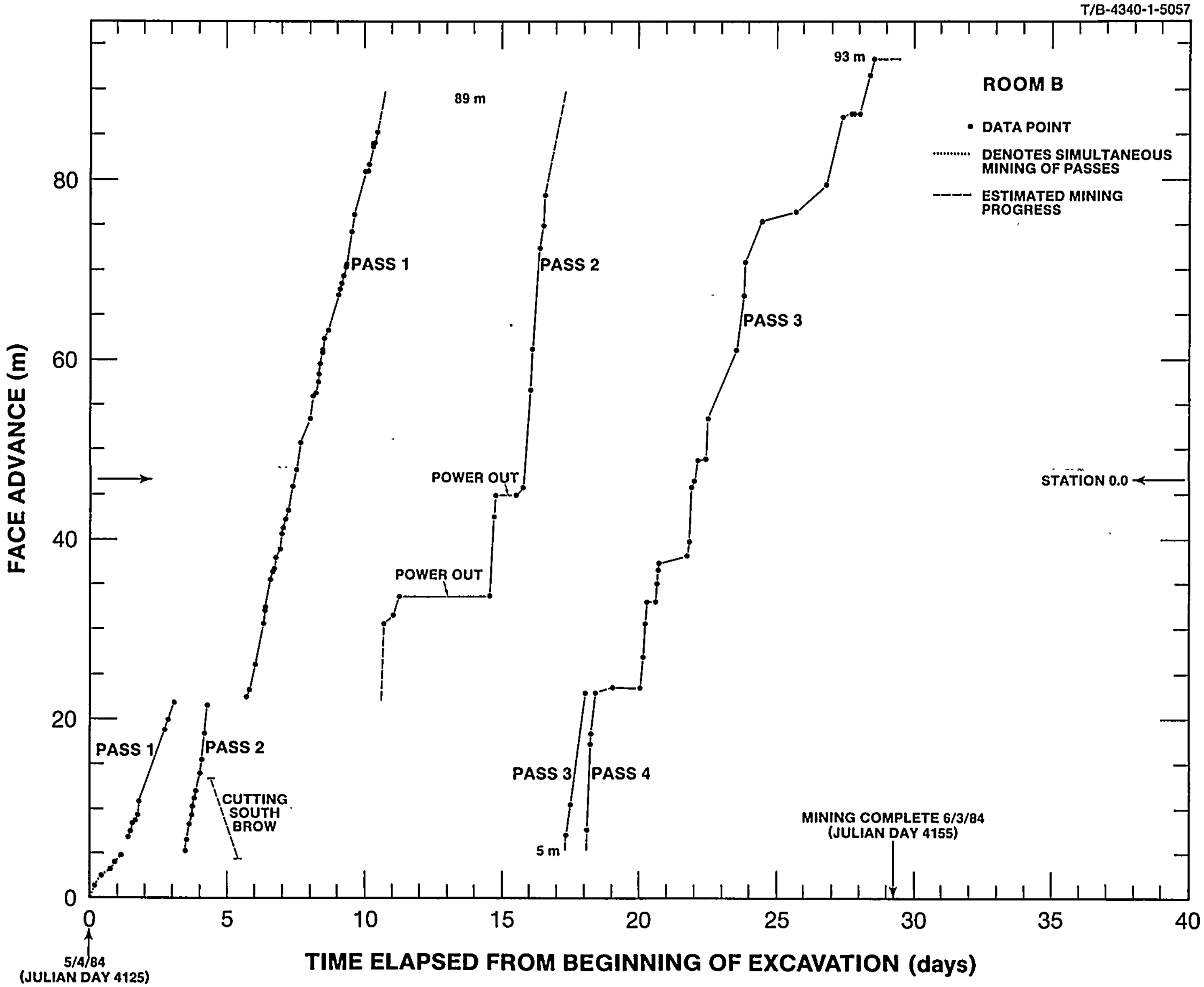


Figure B-2. Face Advance During Excavation, Room B

T/B-4326-1-5074

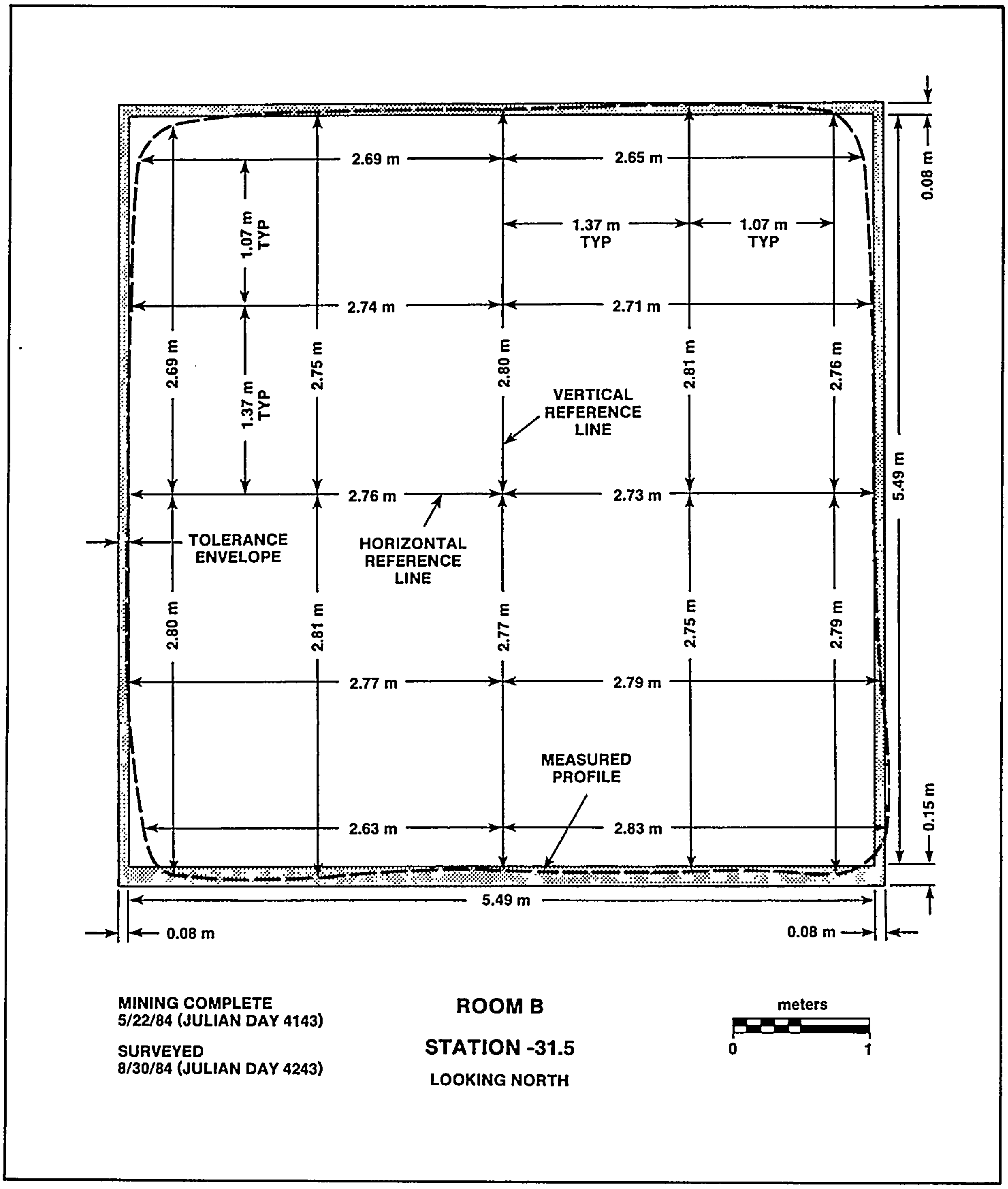


Figure B-3a. As-Built Cross Section of Station -31.5 m, Room B

T/B-4326-2-5074

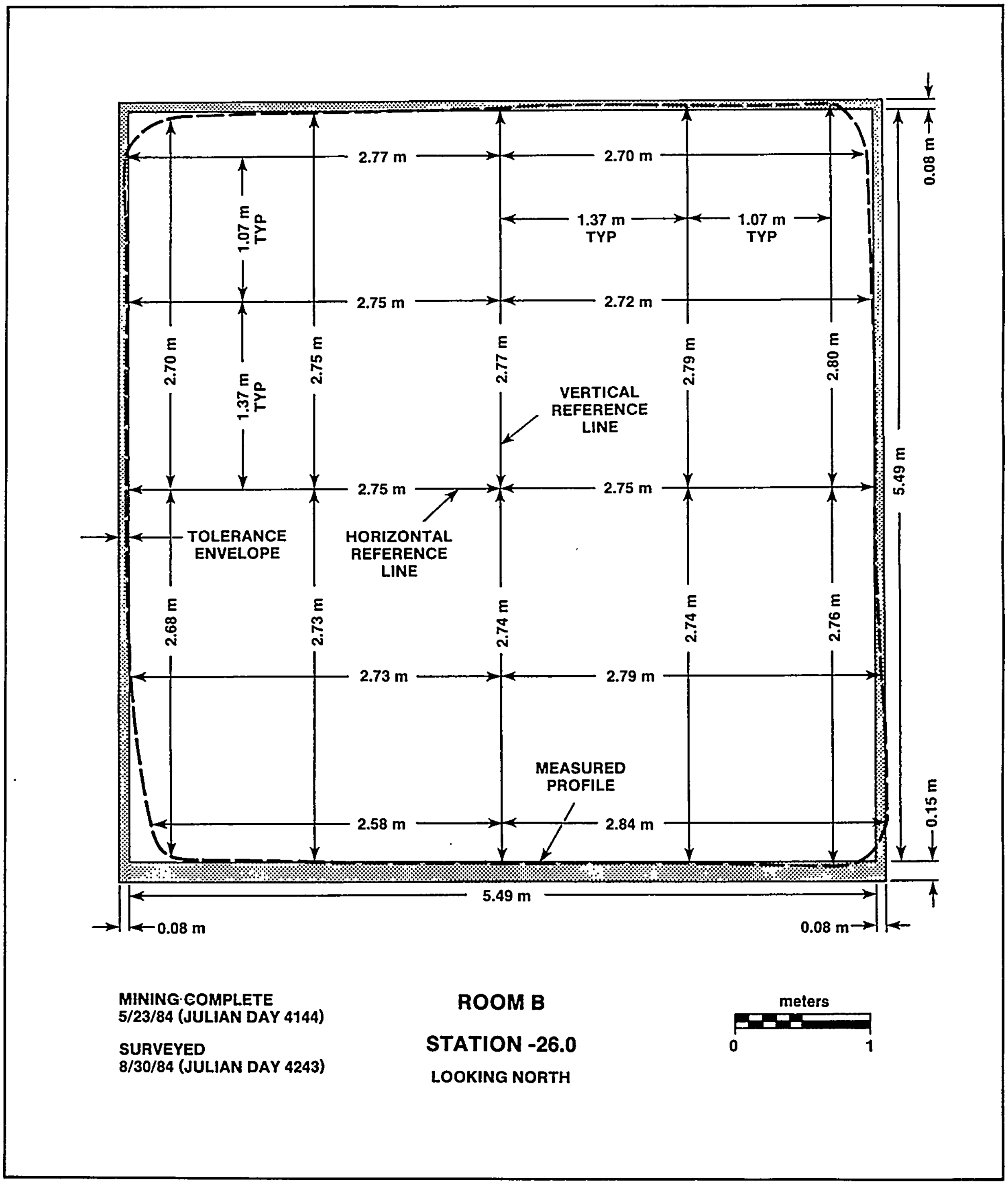


Figure B-3b. As-Built Cross Section of Station -26.0 m, Room B

T/B-4326-3-5074

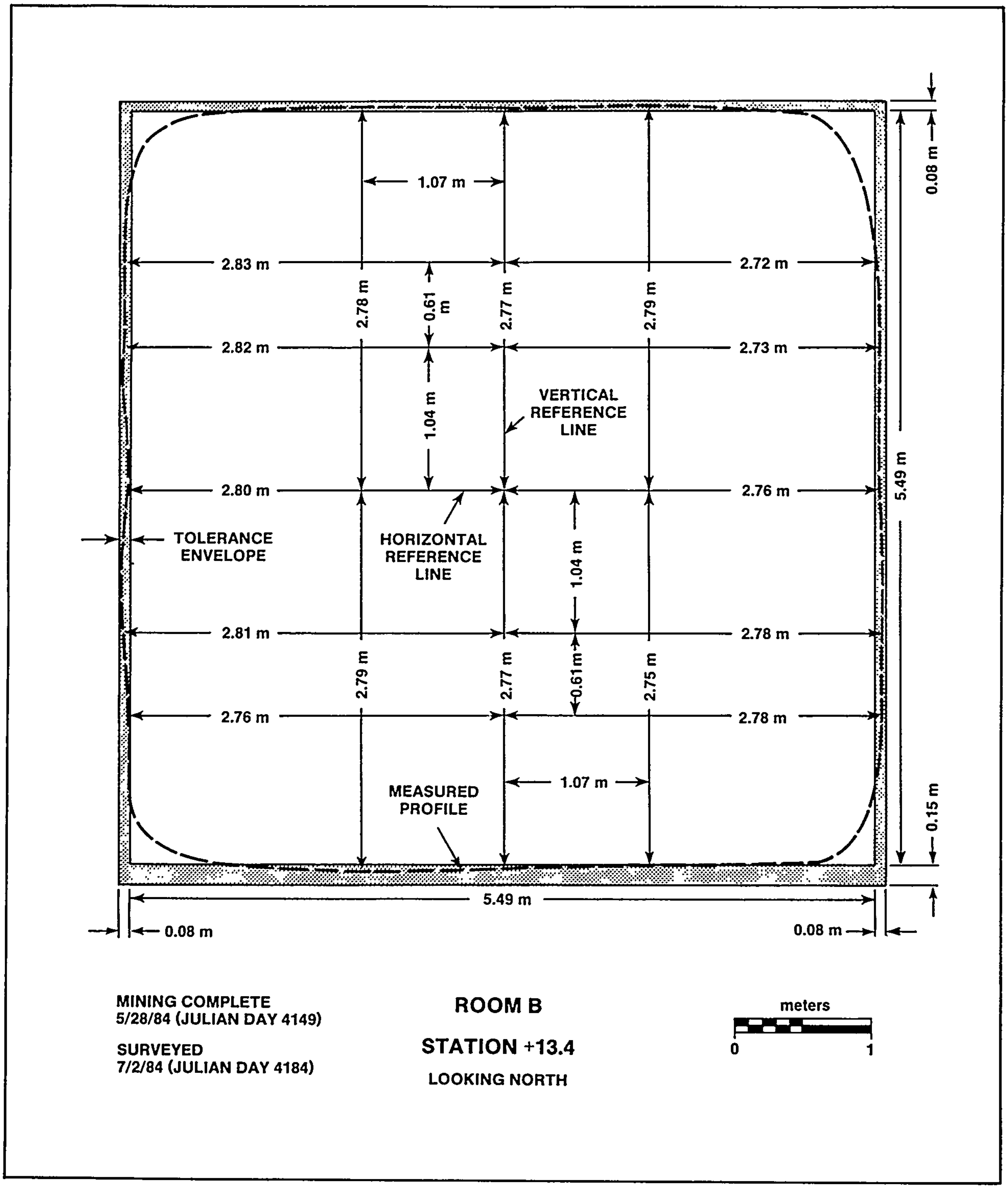


Figure B-3c. As-Built Cross Section of Station +13.4 m, Room B

T/B-4339-2-5074

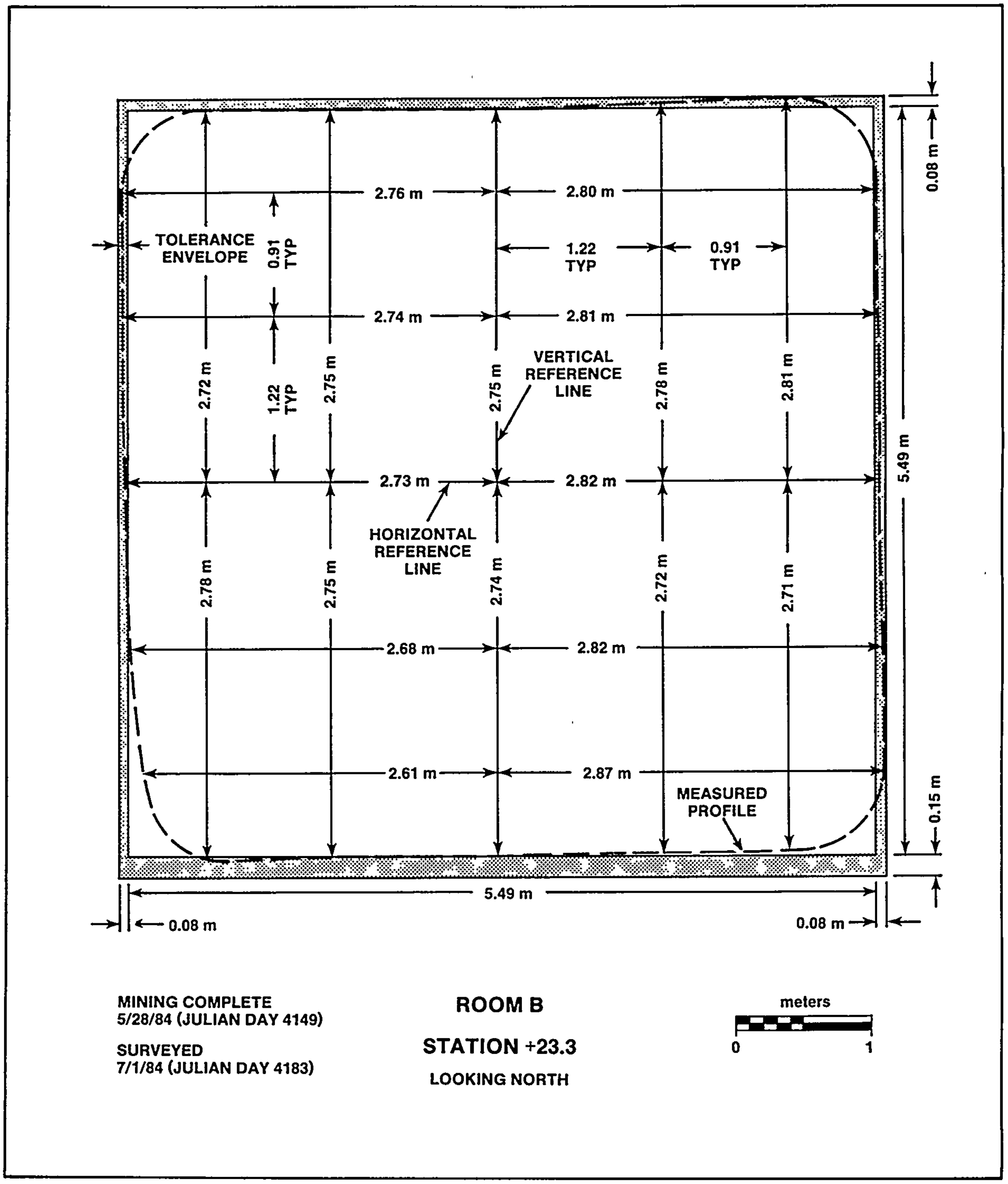


Figure B-3d. As-Built Cross Section of Station +23.3 m, Room B

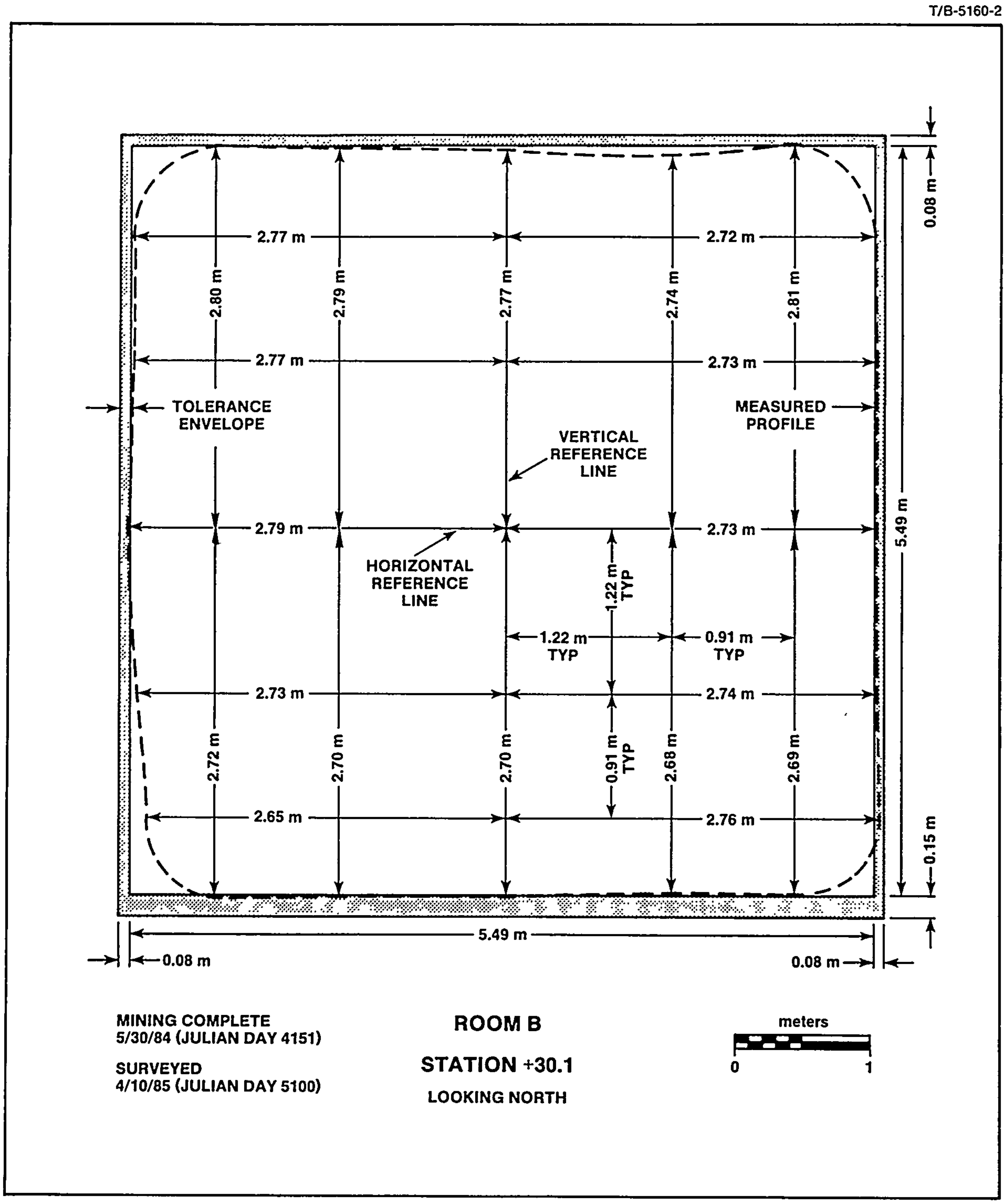


Figure B-3e. As-Built Cross Section of Station +30.1 m, Room B

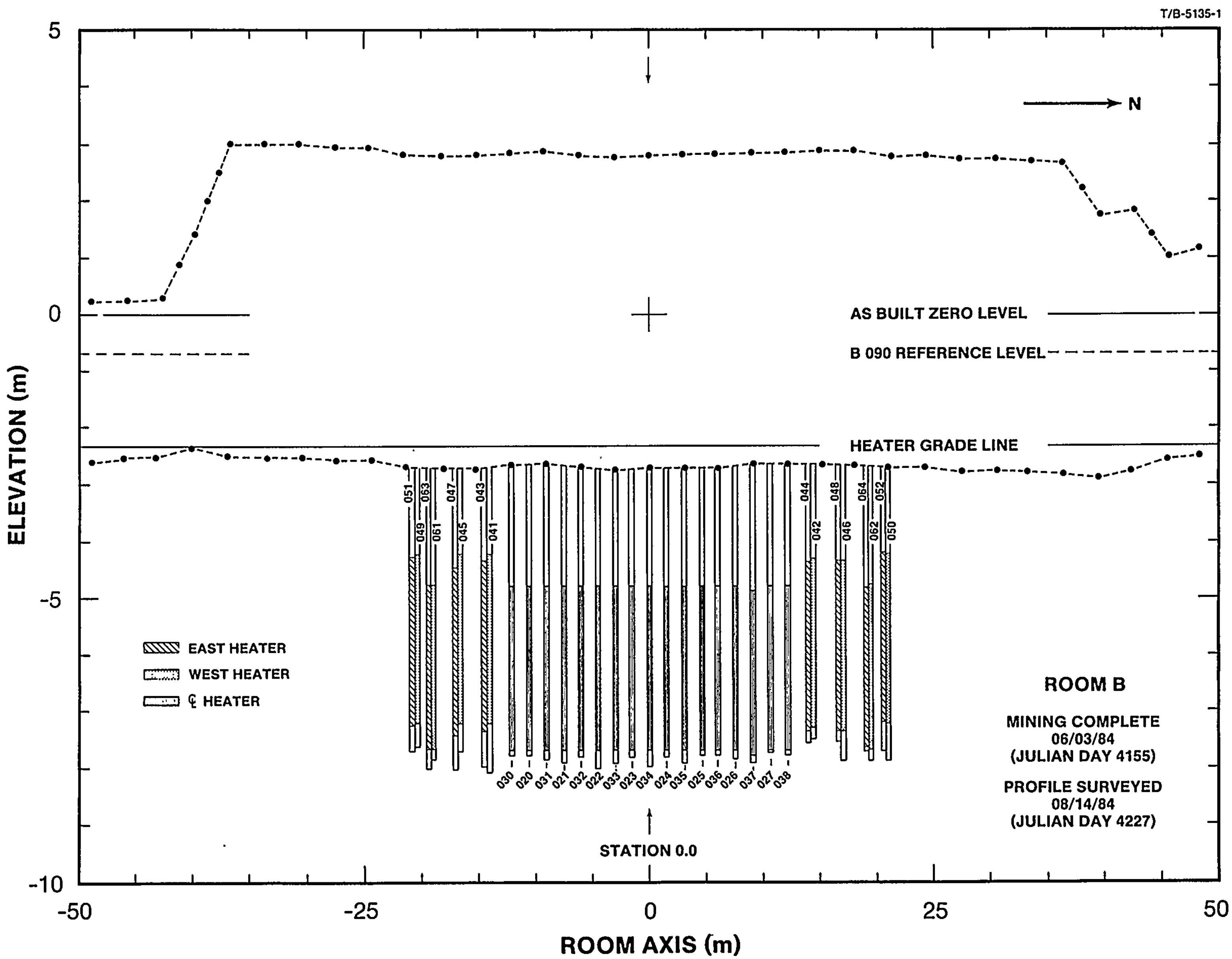


Figure B-4. As-Built Profile of Room B

APPENDIX C: TEST ROOMS C1/C2 AS-BUILT DRAWINGS

LIST OF FIGURES FOR APPENDIX C

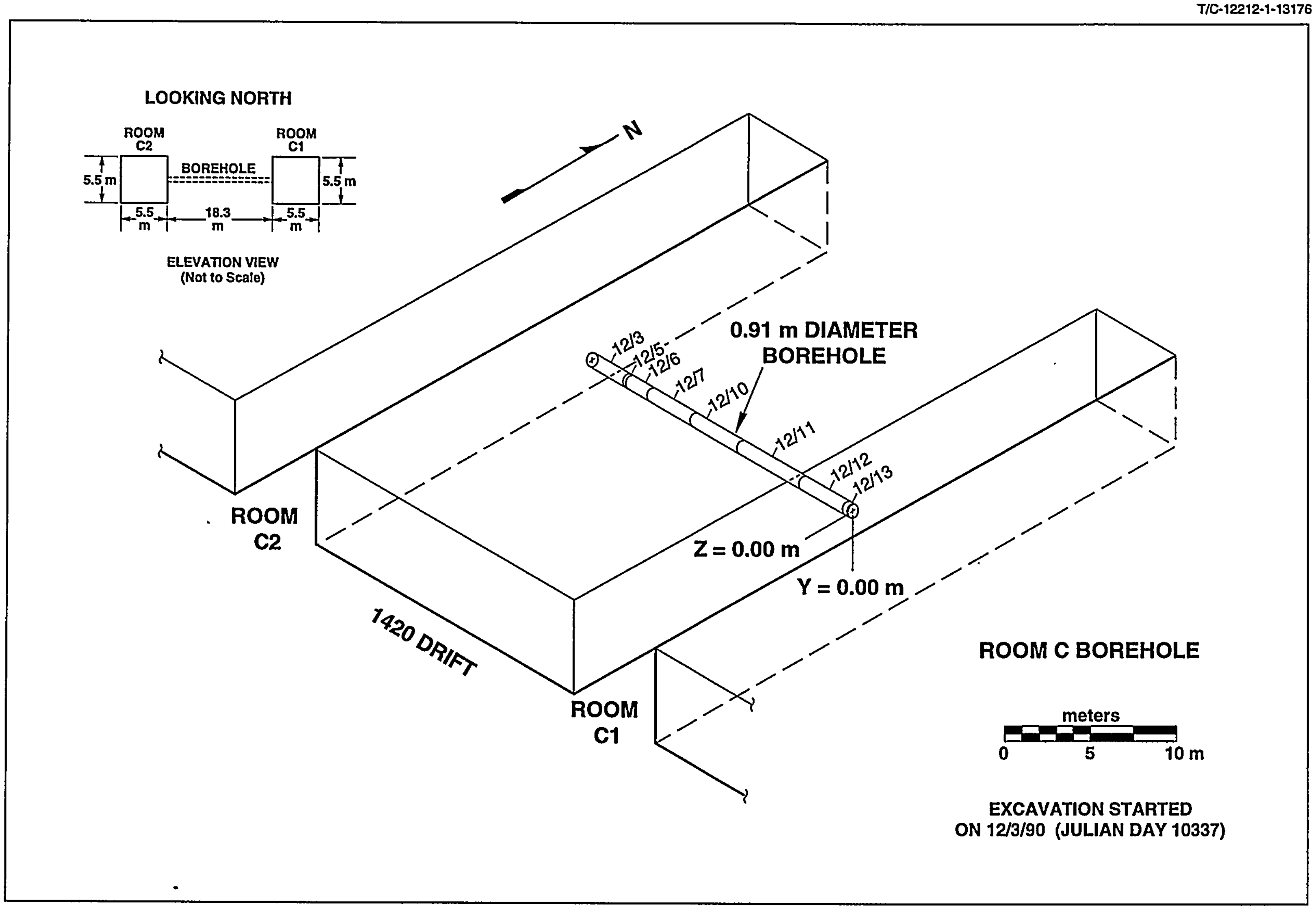


Figure C-1. Isometric View of Excavation Progress, Room C

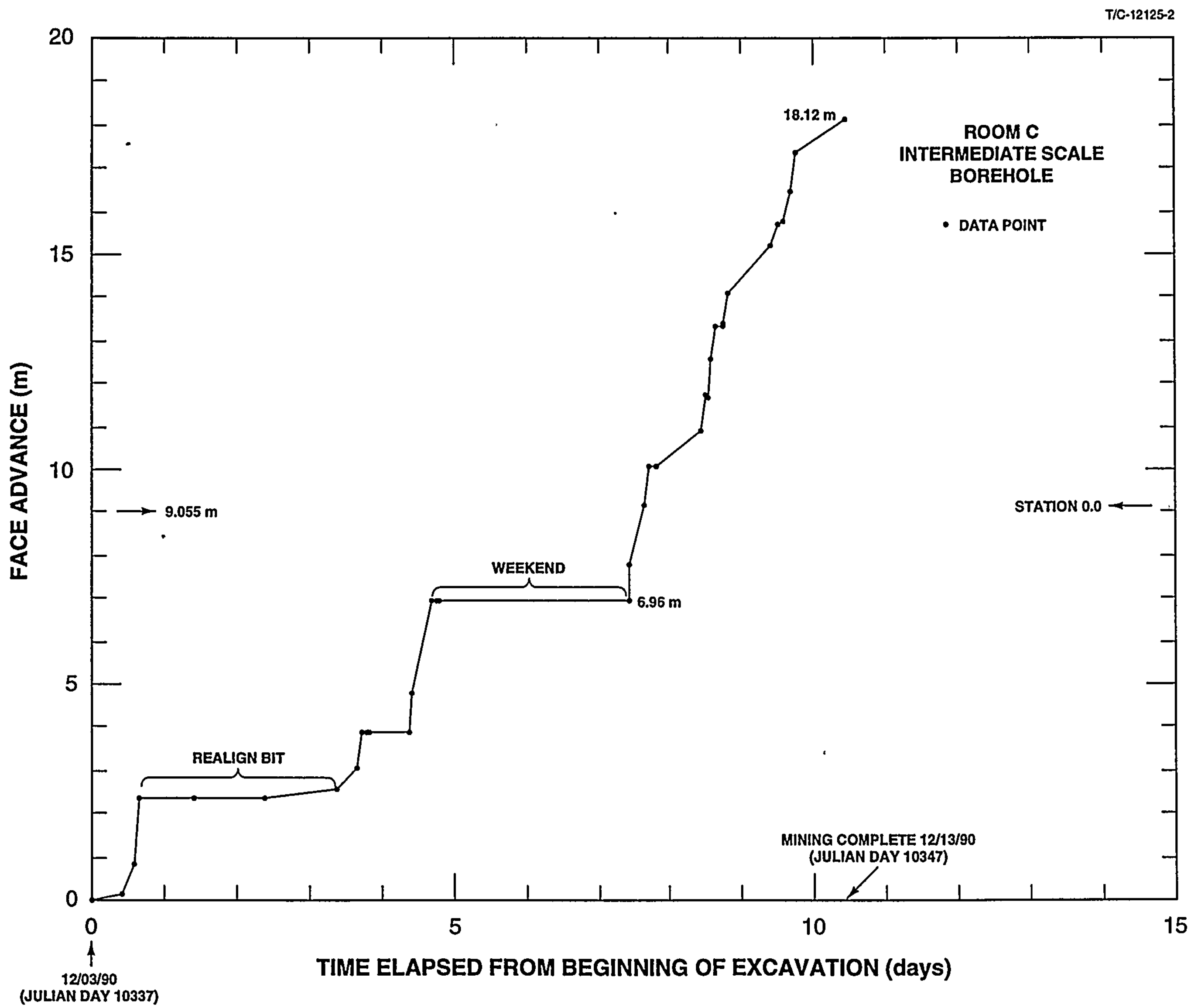
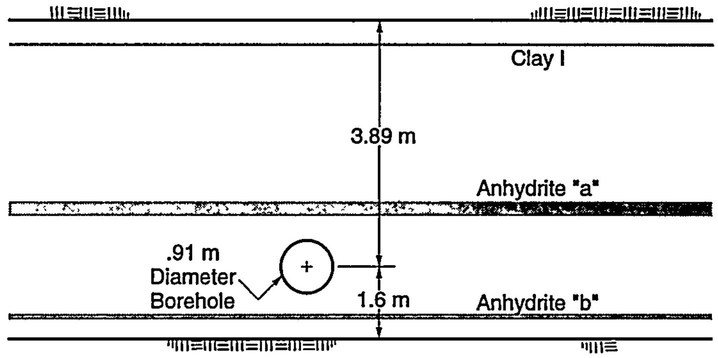
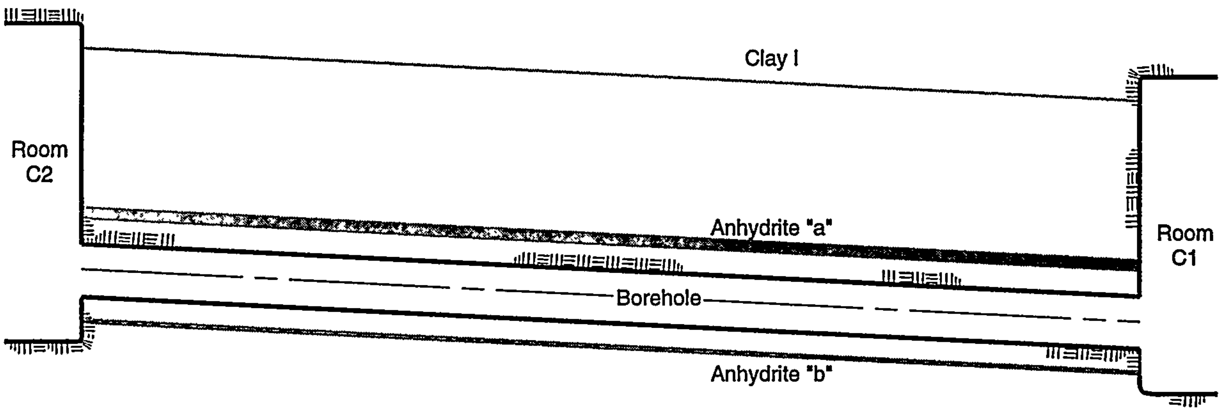


Figure C-2. Face Advance During Excavation, Room C



Borehole Endview
(Looking East)



Borehole Profile
(Looking North)

T/C-13160-1

Figure C-3. As-Built Cross Section and Profile of Room C

APPENDIX D: TEST ROOM D AS-BUILT DRAWINGS

LIST OF FIGURES FOR APPENDIX D

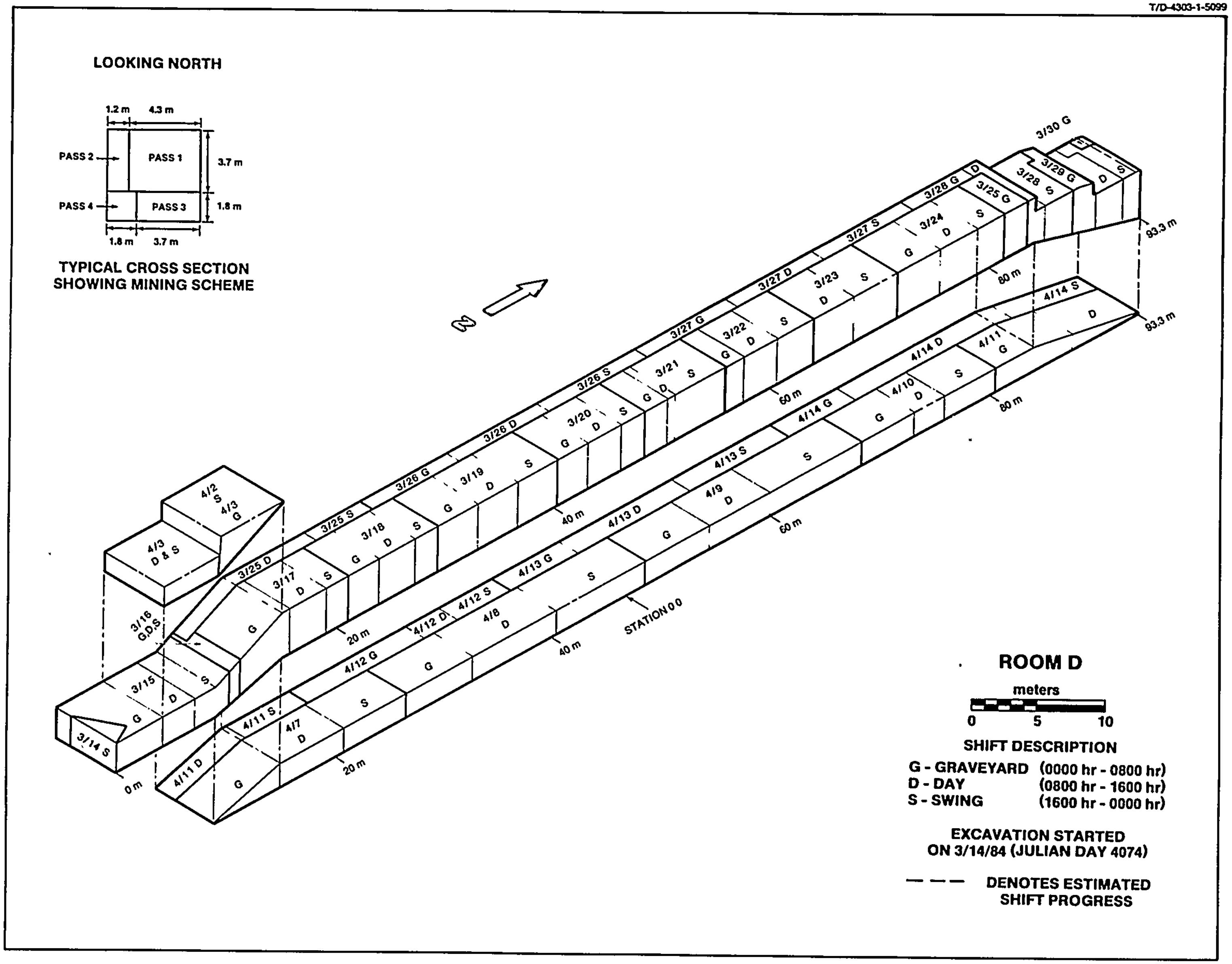


Figure D-1. Isometric View of Excavation Progress, Room D

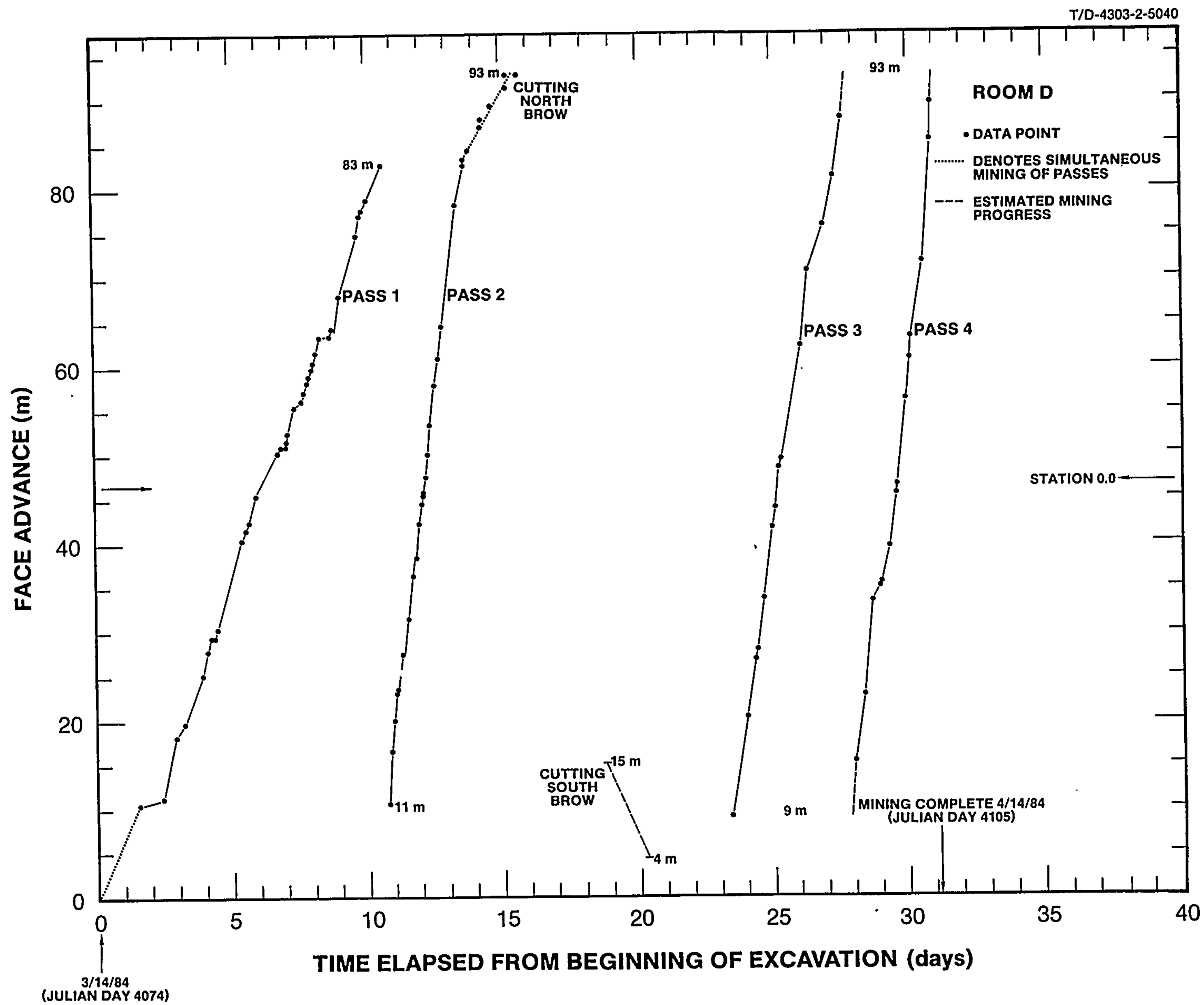


Figure D-2. Face Advance During Excavation, Room D

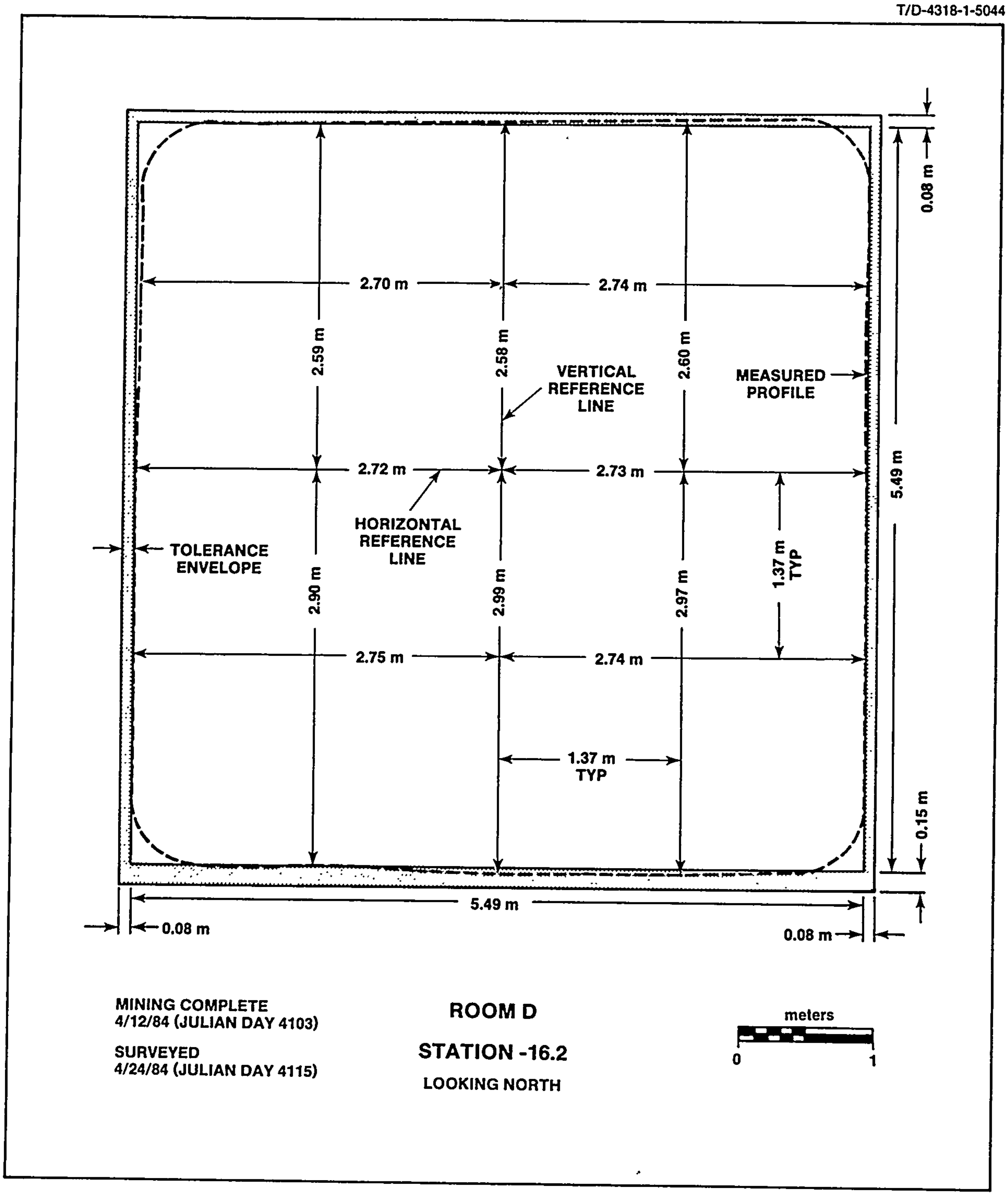


Figure D-3a. As-Built Cross Section of Station -16.2 m, Room D

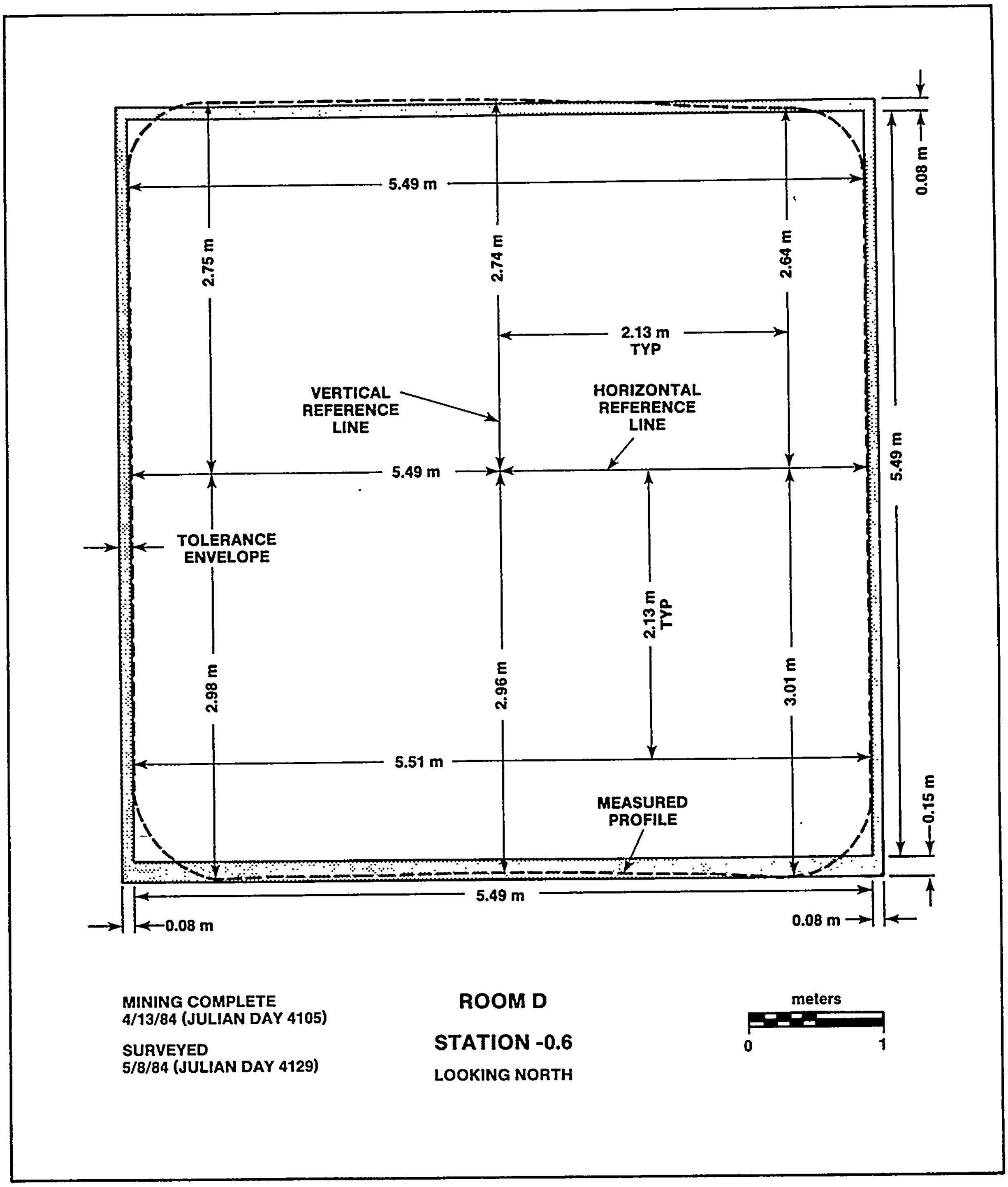


Figure D-3b. As-Built Cross Section of Station -0.6 m, Room D

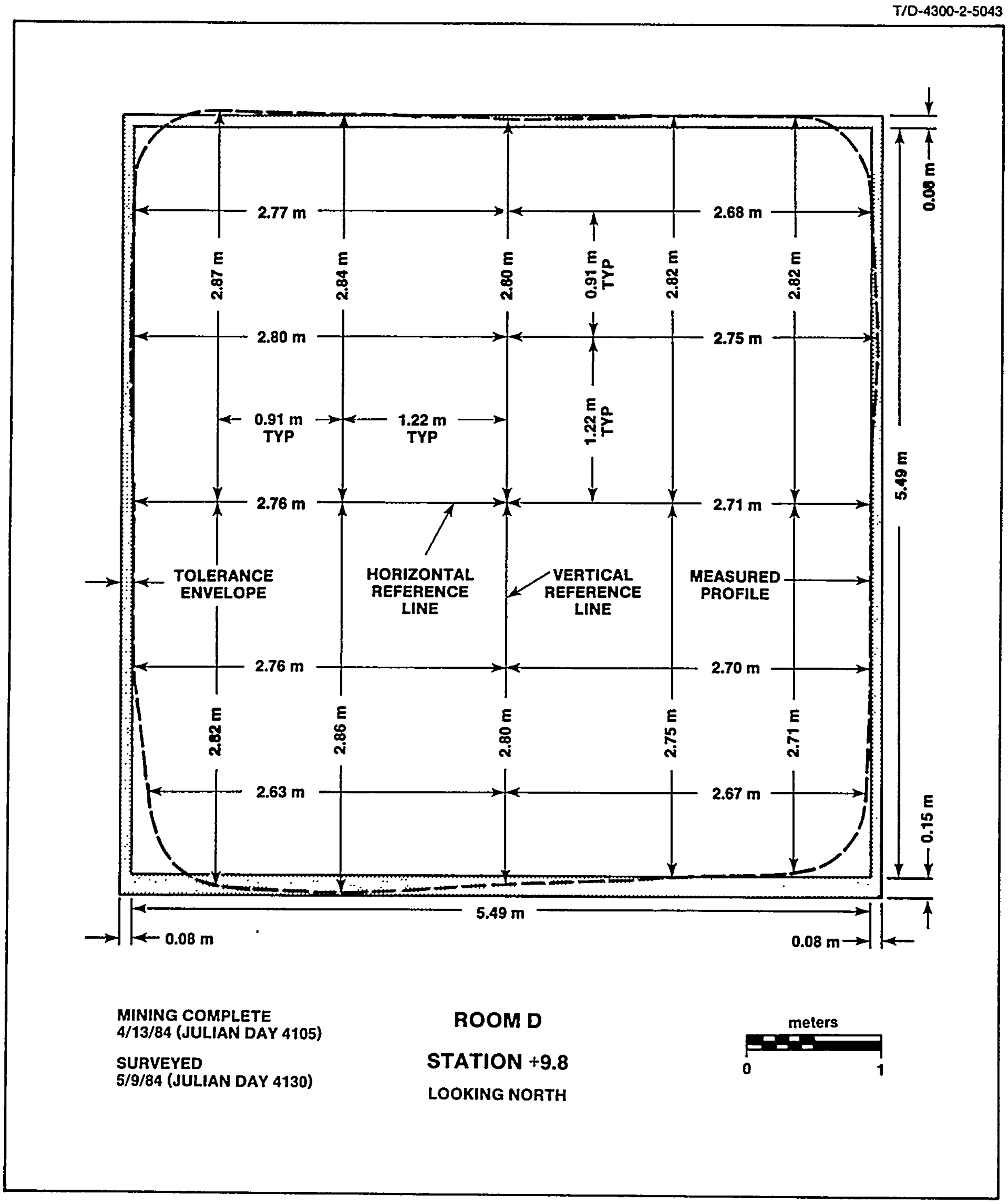


Figure D-3c. As-Built Cross Section of Station +9.8 m, Room D

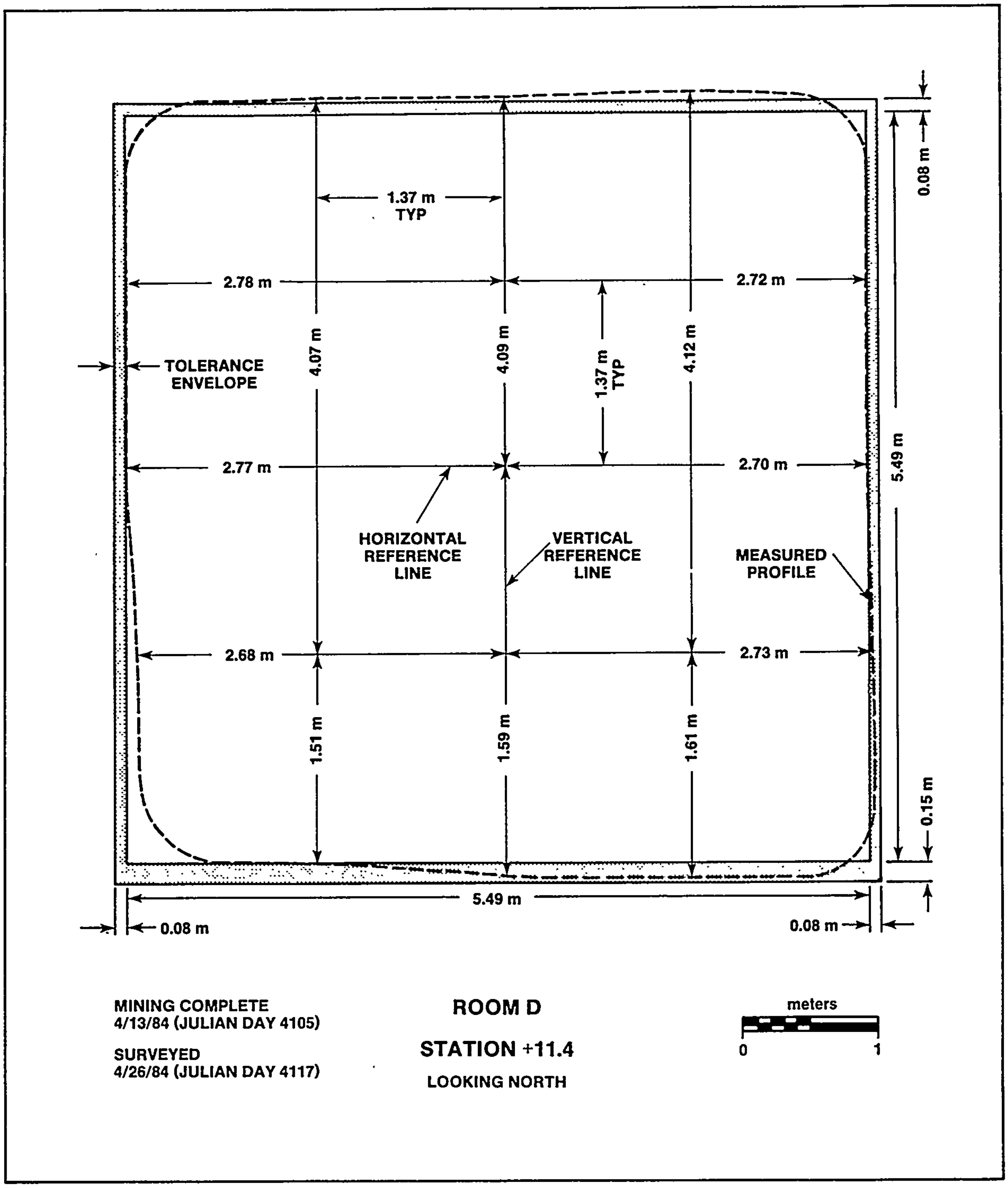


Figure D-3d. As-Built Cross Section of Station +11.4 m, Room D

T/D-4300-4-5046

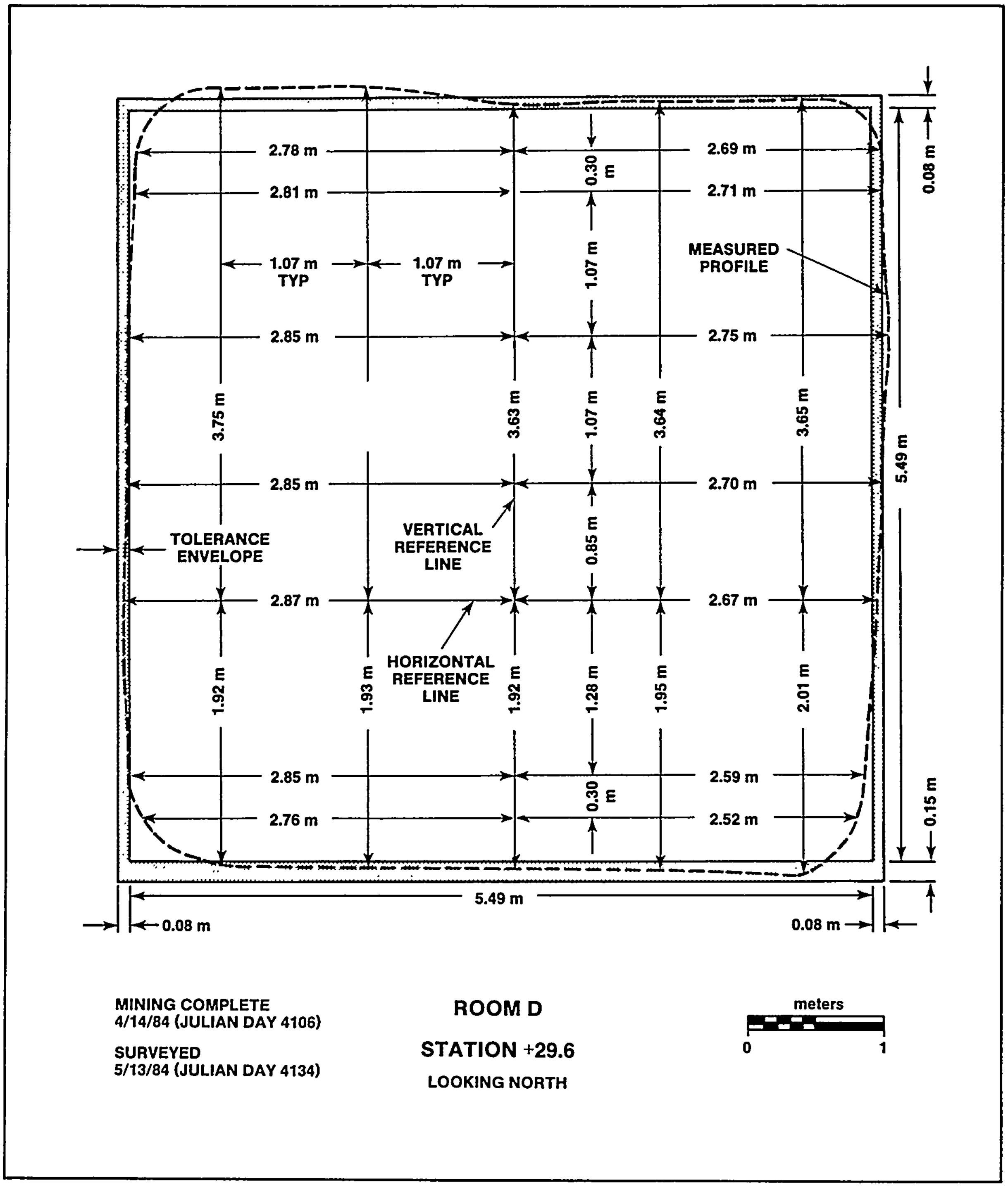


Figure D-3e. As-Built Cross Section of Station +29.6 m, Room D

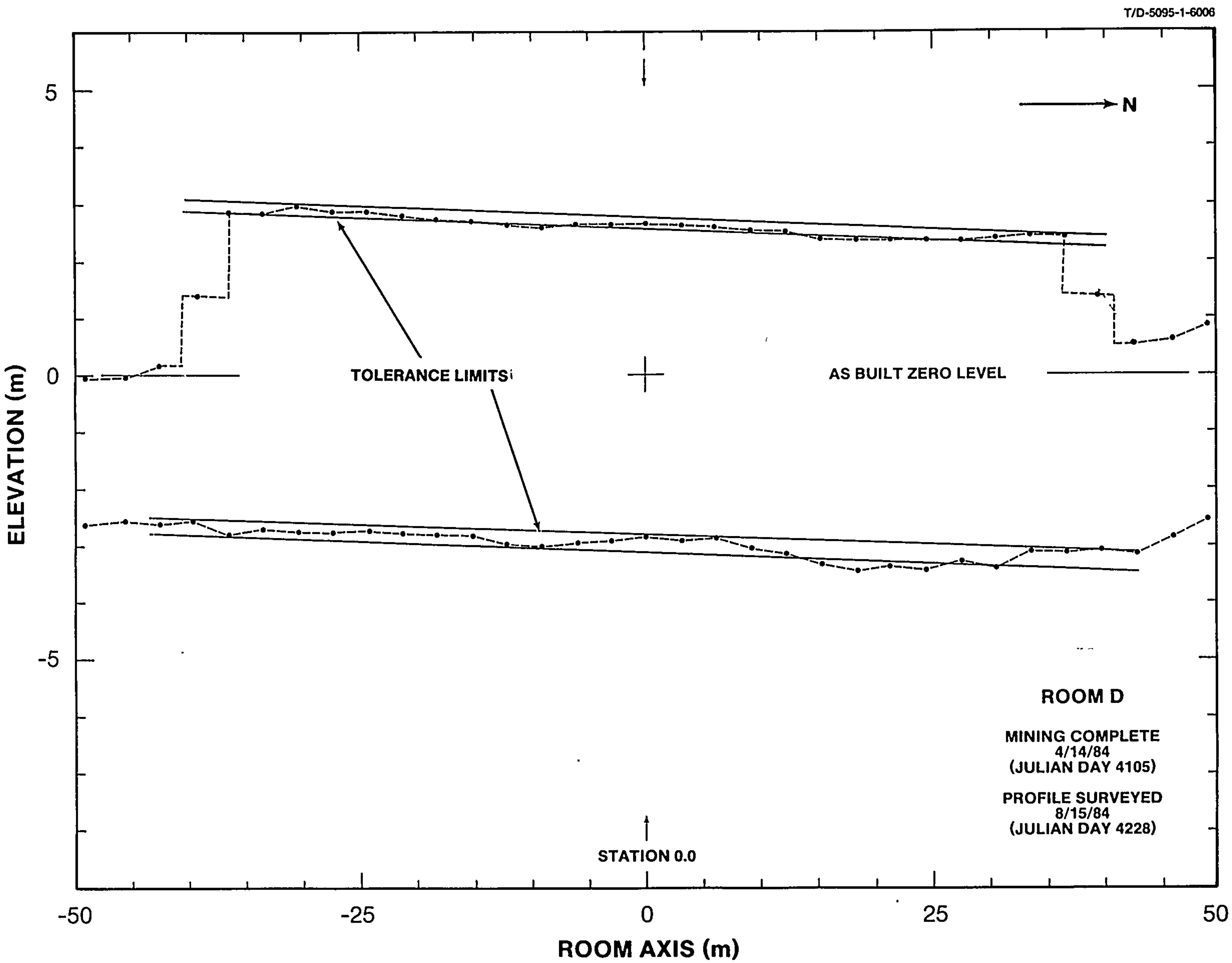


Figure D-4. As-Built Profile of Room D

APPENDIX G: TEST ROOM G AS-BUILT DRAWINGS

LIST OF FIGURES FOR APPENDIX G

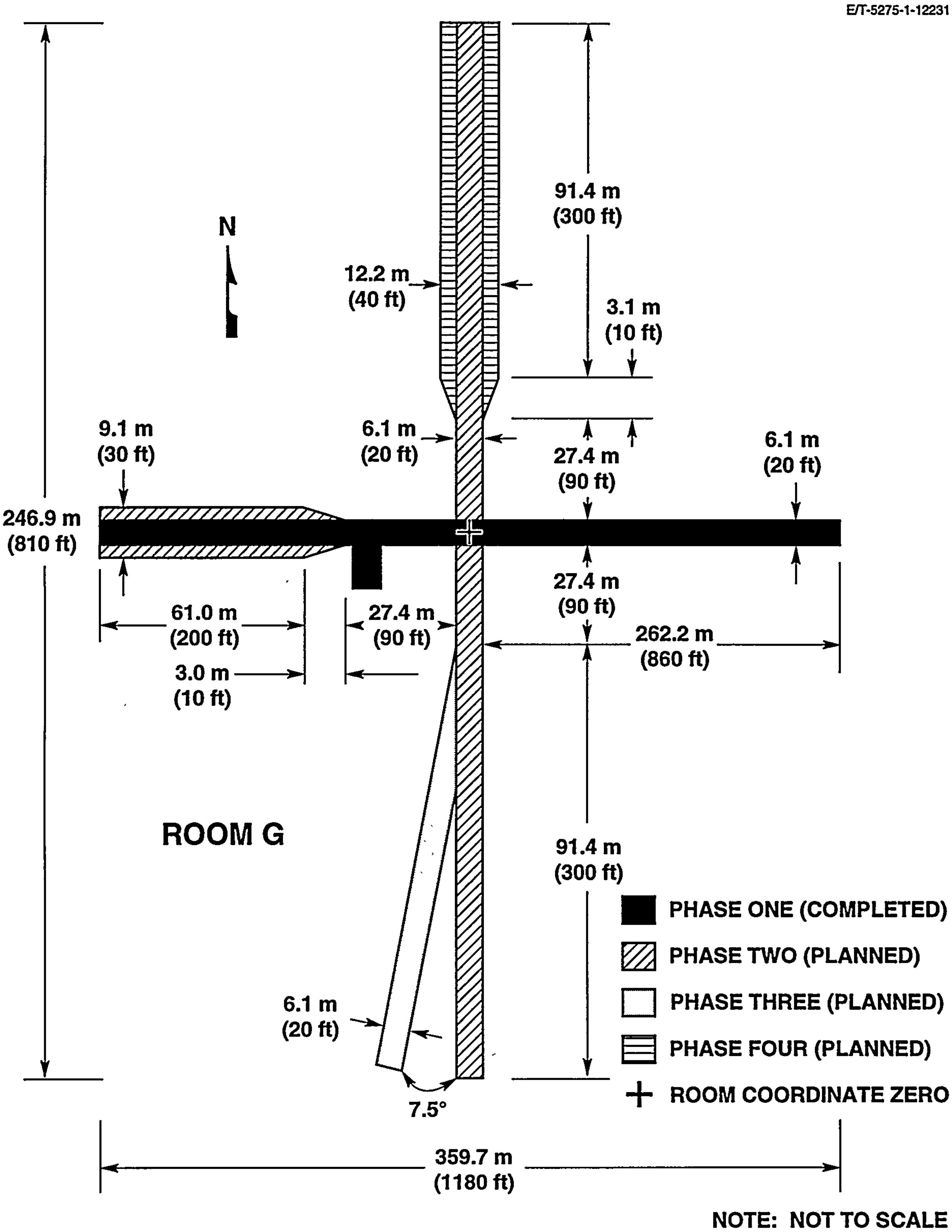


Figure G-1. Plan of Geomechanical Evaluation, Room G

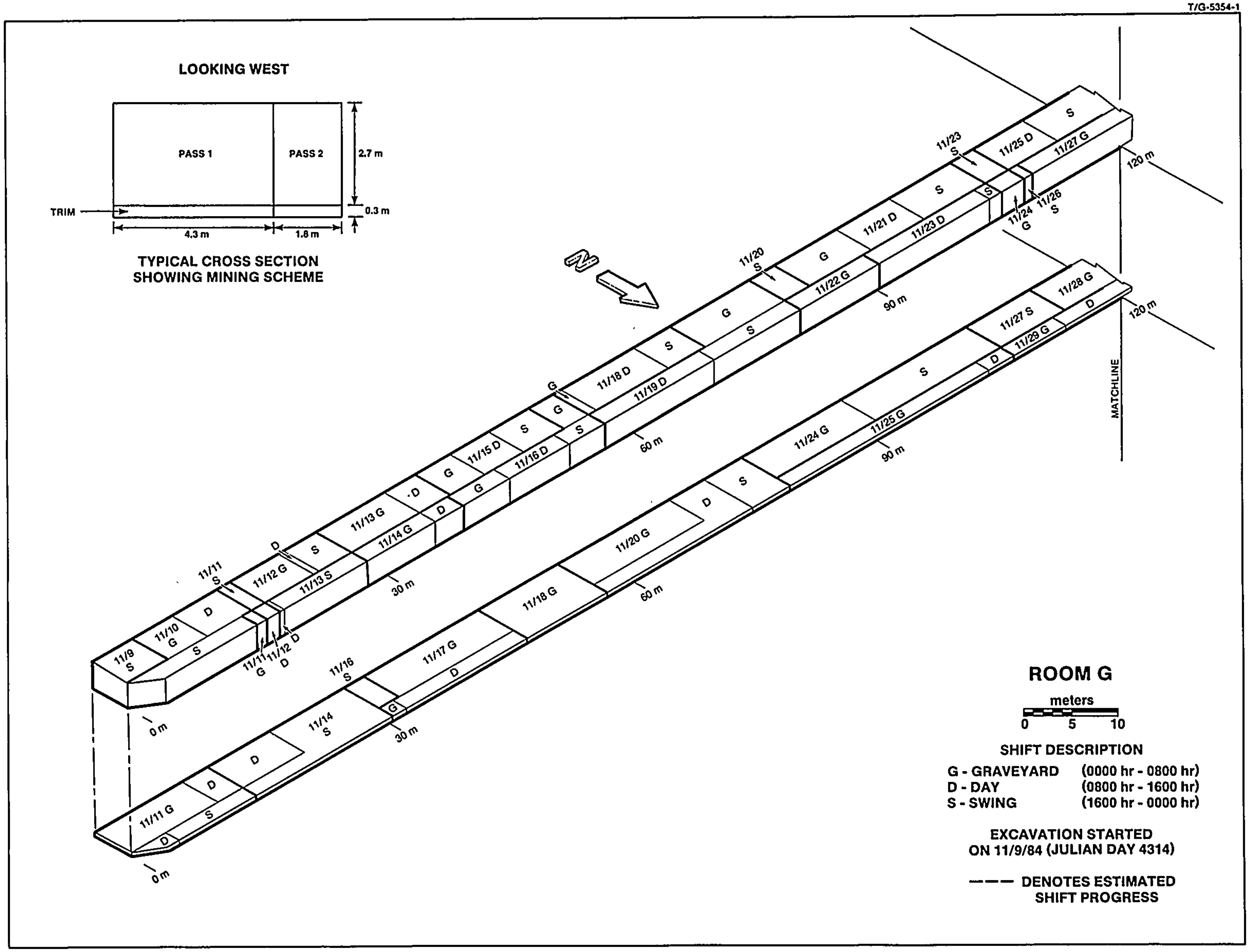


Figure G-2a. Isometric View of Excavation Progress, Room G, 1 of 3

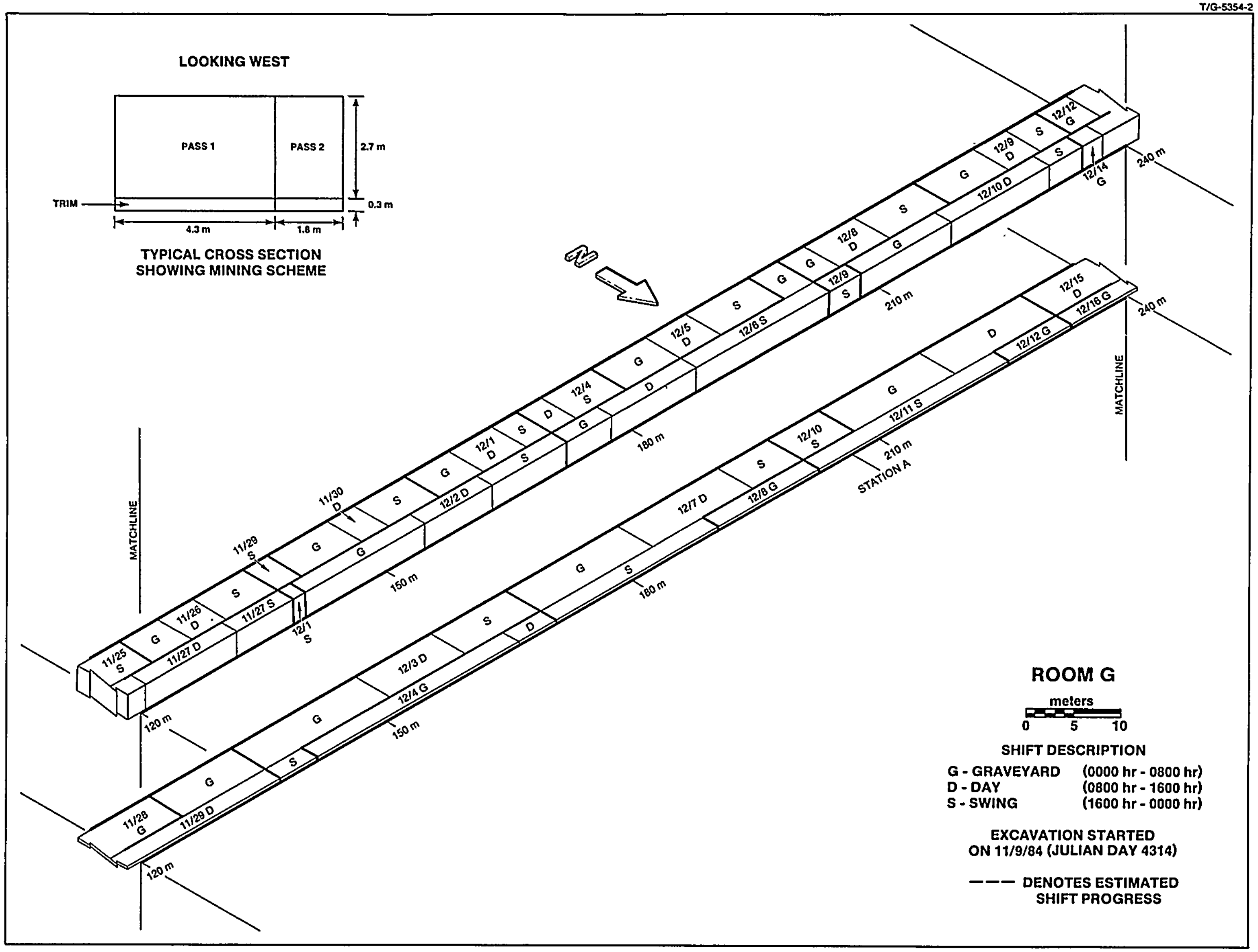


Figure G-2b. Isometric View of Excavation Progress, Room G, 2 of 3

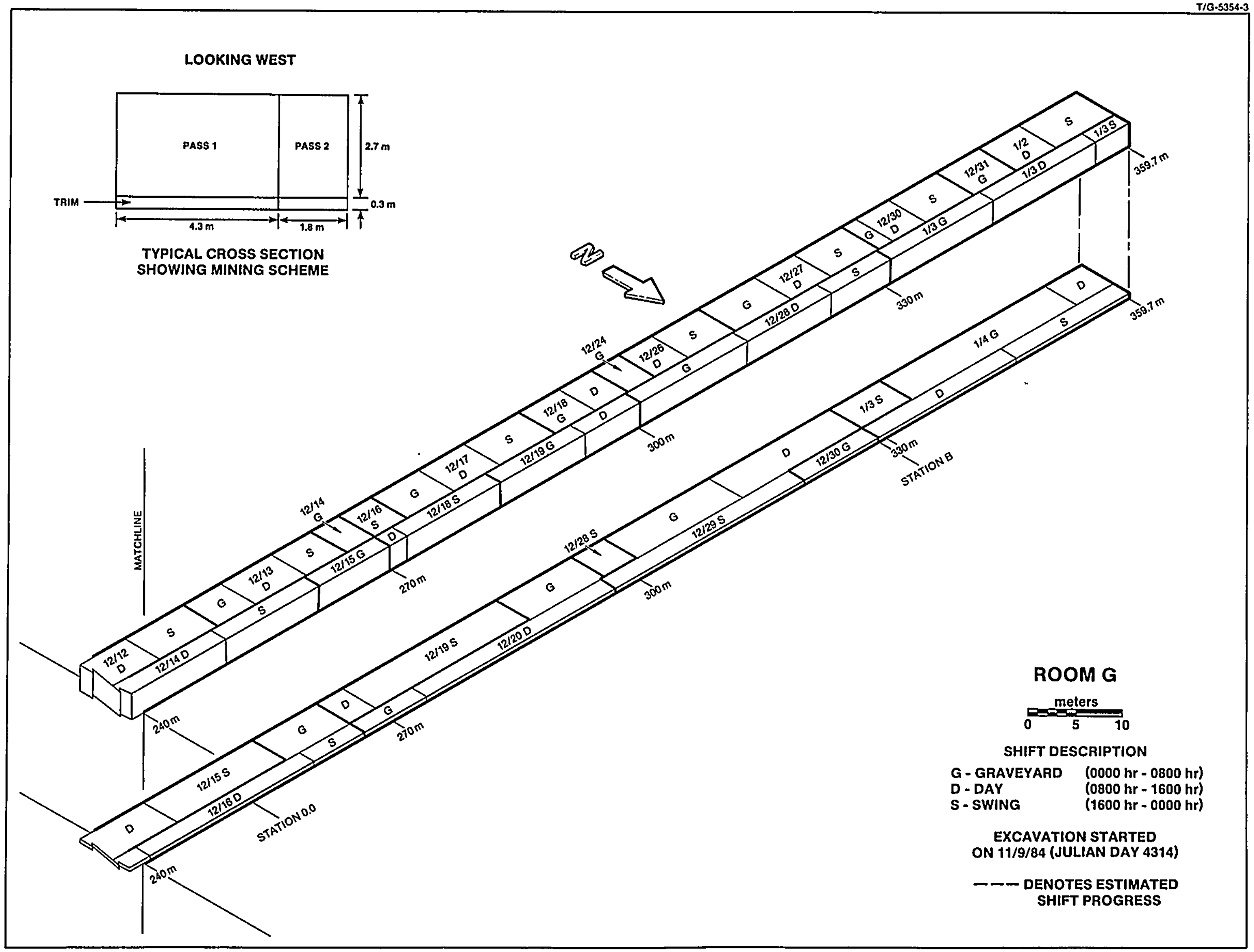


Figure G-2c. Isometric View of Excavation Progress, Room G, 3 of 3

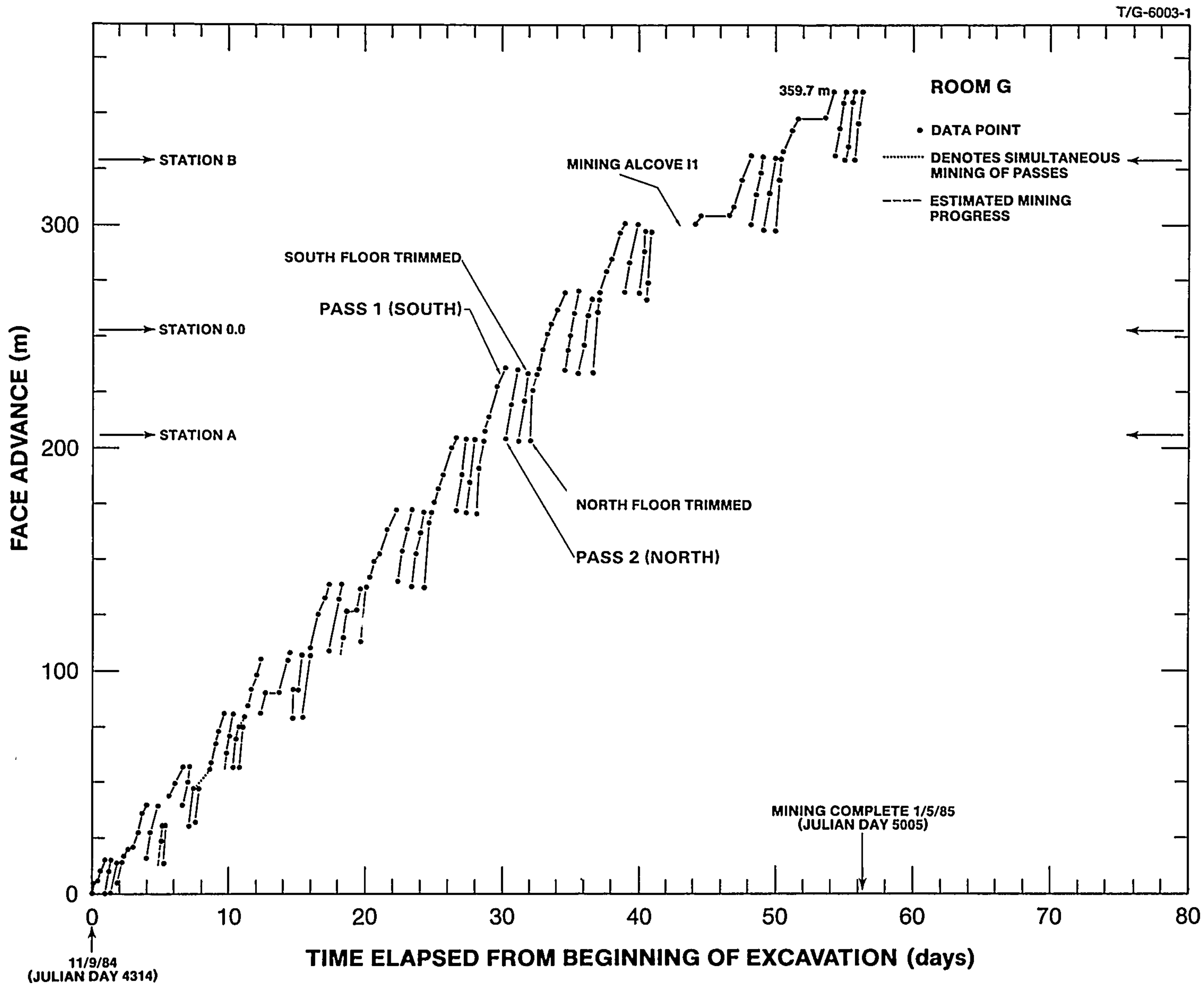


Figure G-3. Face Advance During Excavation, Room G

T/G-5364-1

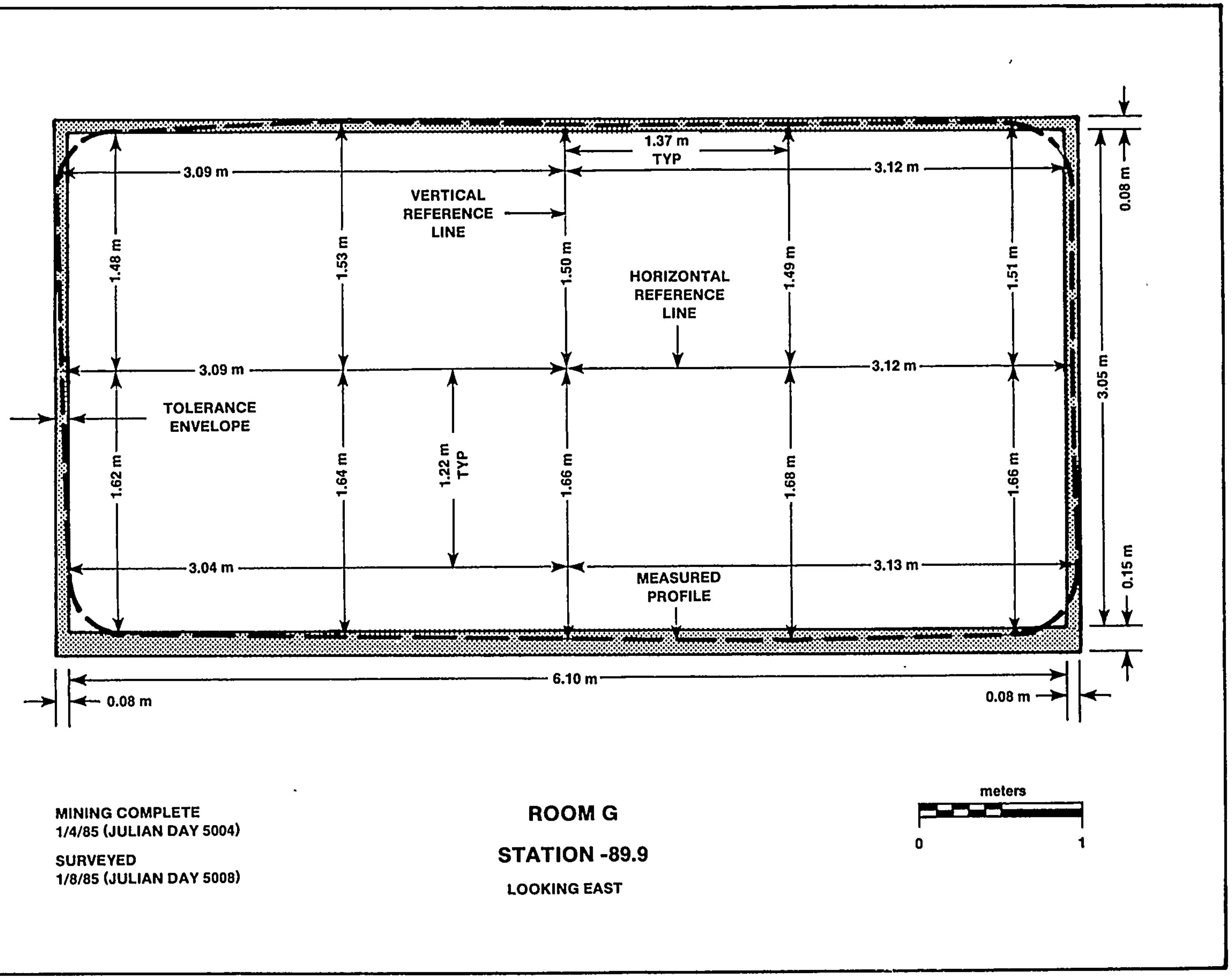


Figure G-4a. As-Built Cross Section of Station -89.9 m, Room G

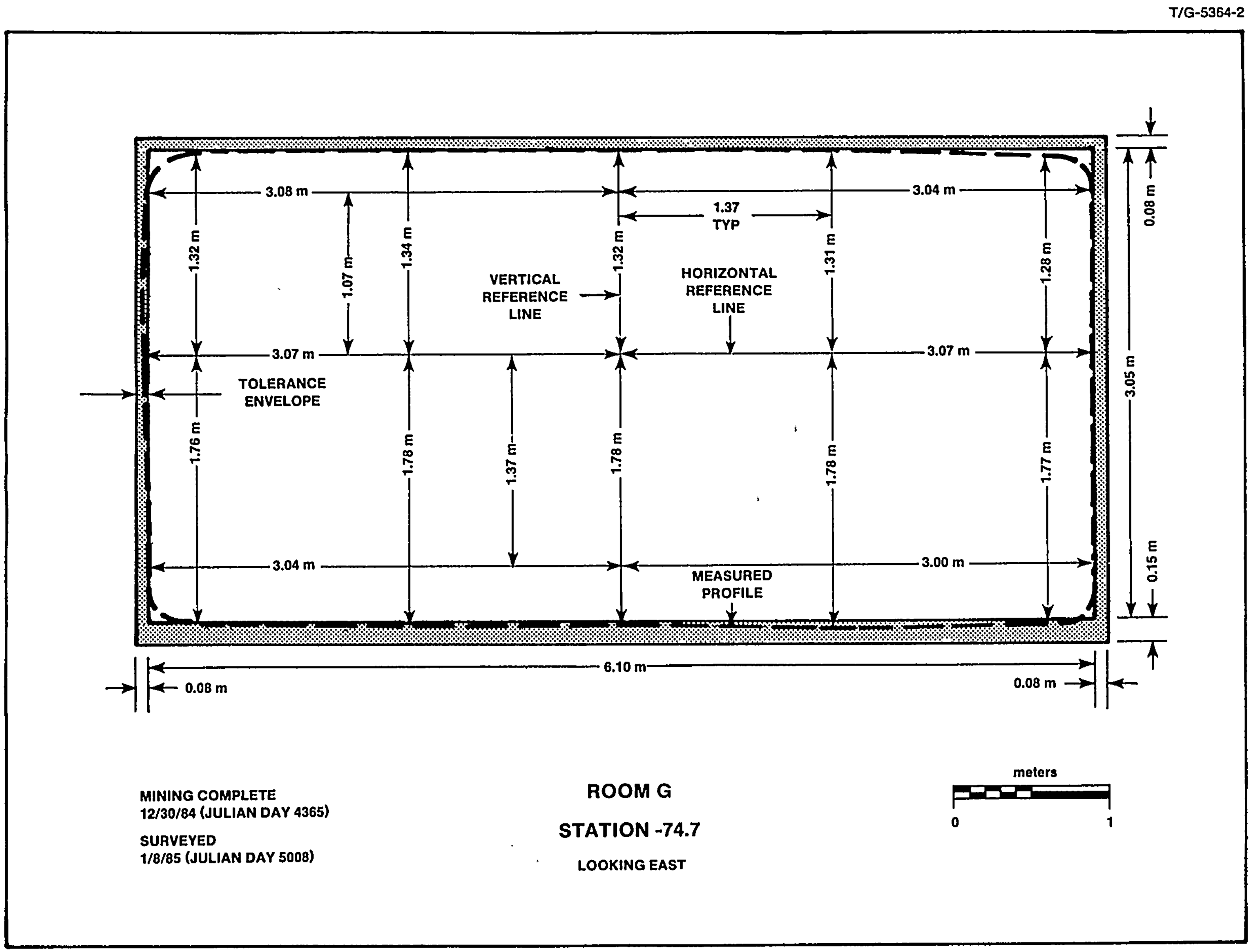


Figure G-4b. As-Built Cross Section of Station -74.7 m, Room G

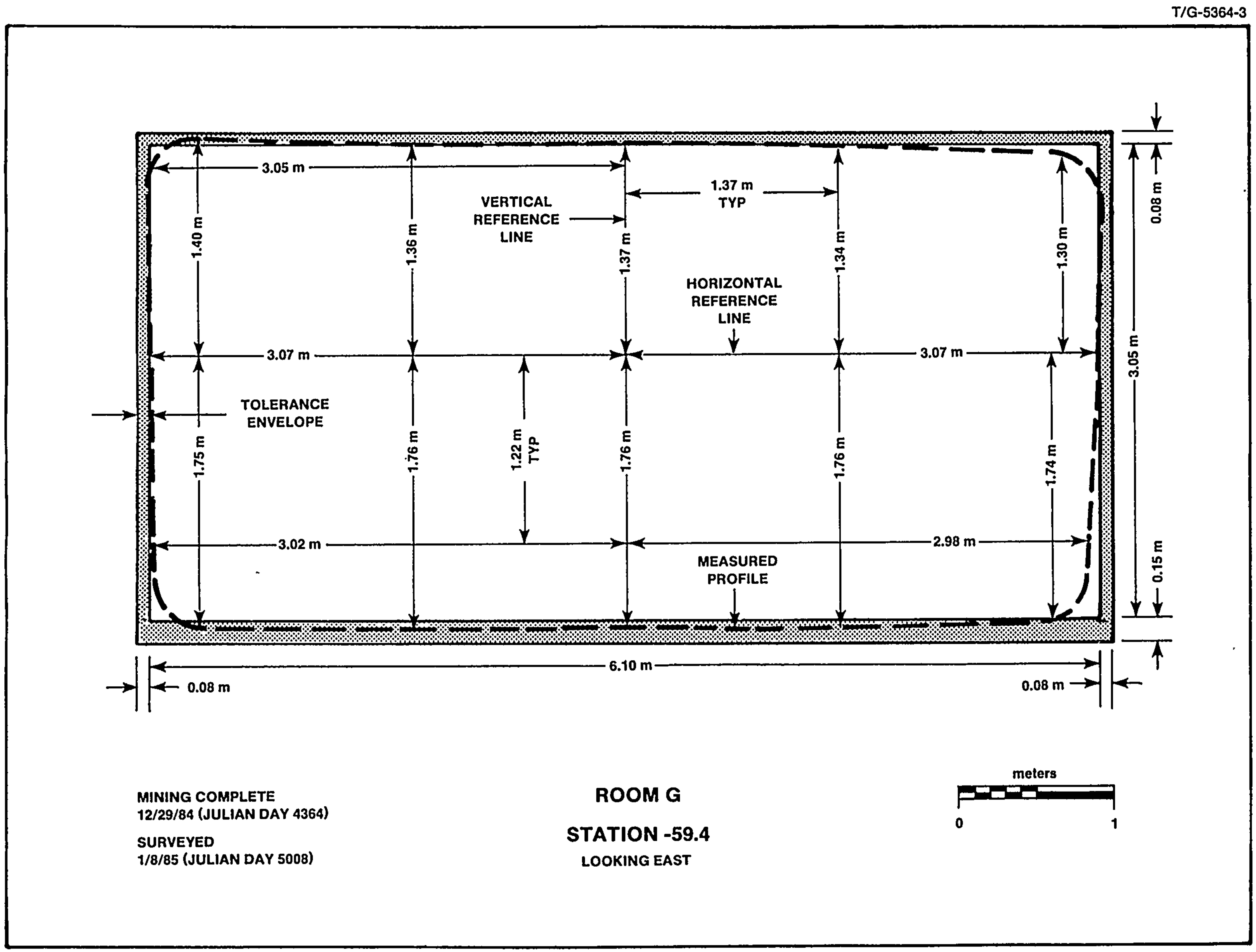


Figure G-4c. As-Built Cross Section of Station -59.4 m, Room G

T/G-5364-4

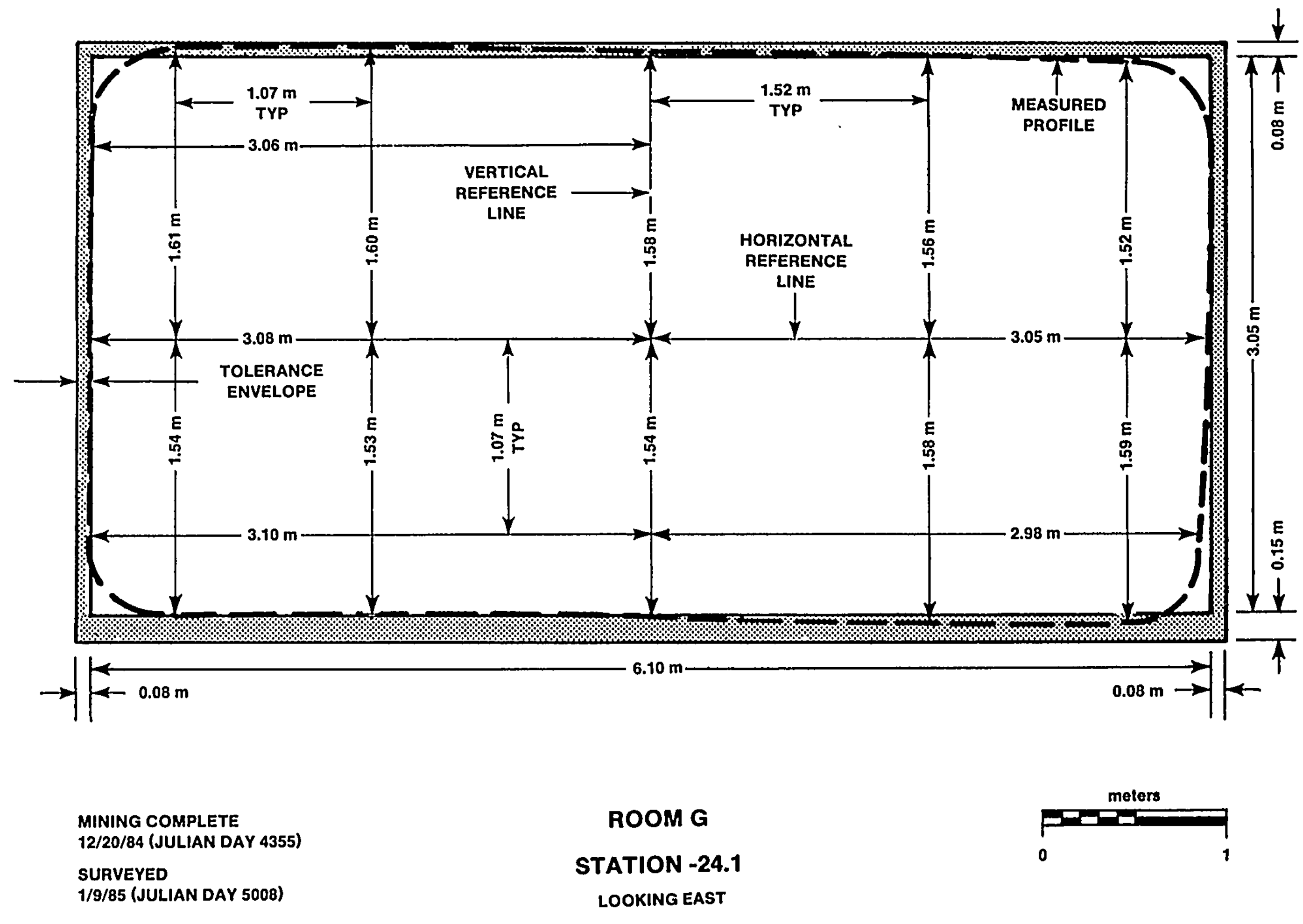


Figure G-4d. As-Built Cross Section of Station -24.1 m, Room G

T/G-5364-5

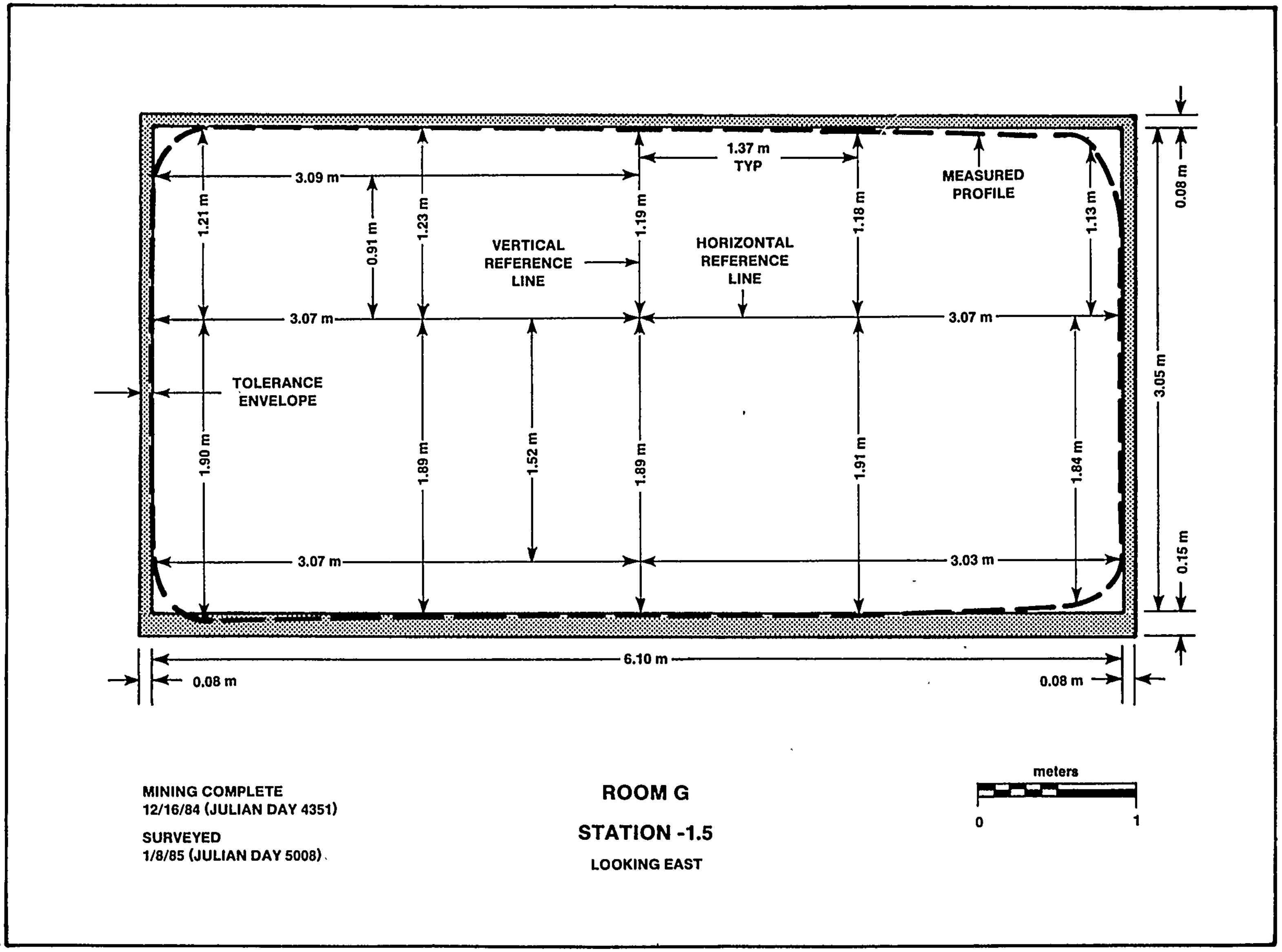


Figure G-4e. As-Built Cross Section of Station -1.5 m, Room G

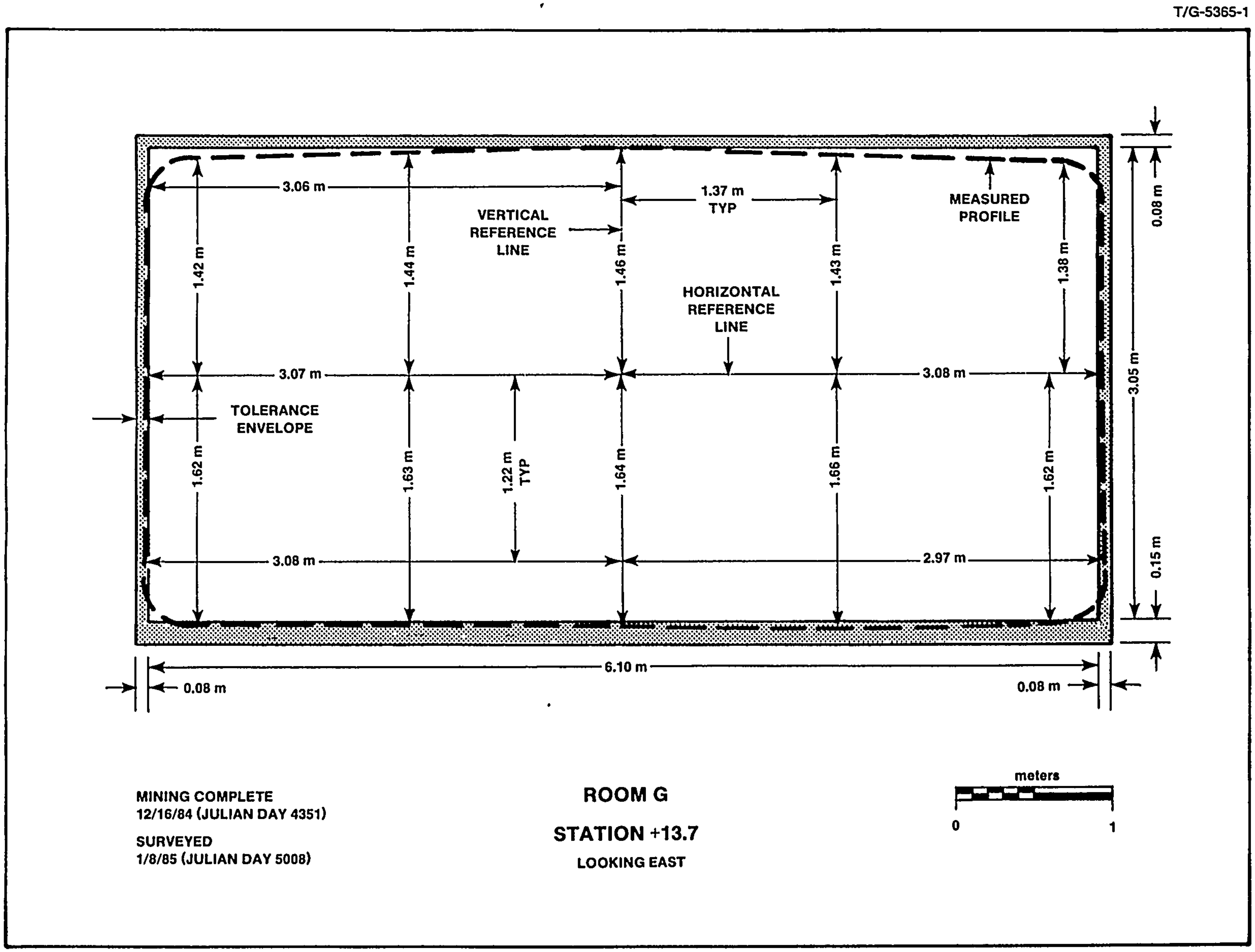


Figure G-4f. As-Built Cross Section of Station +13.7 m, Room G

T/G-5345-2

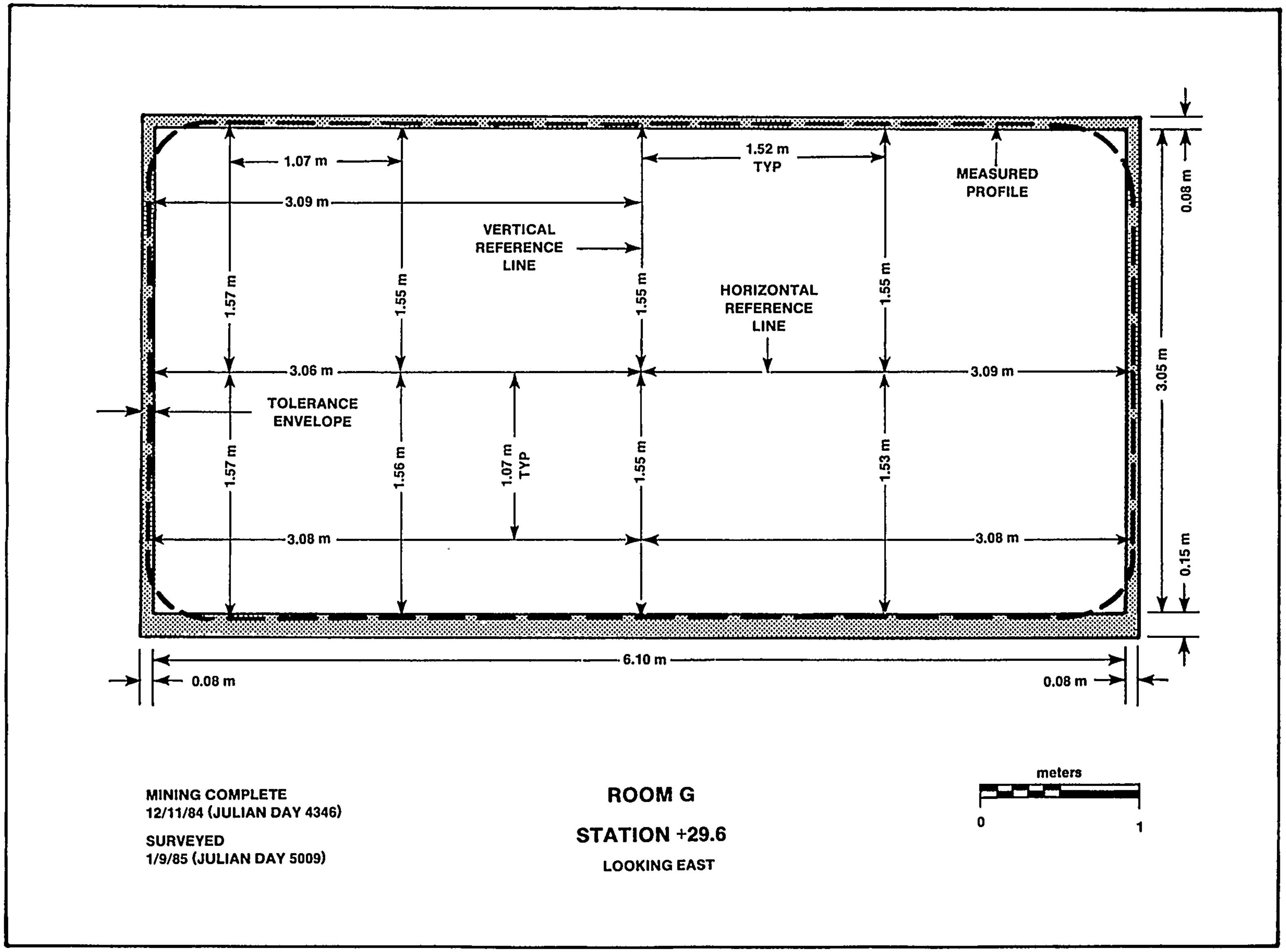


Figure G-4g. As-Built Cross Section of Station +29.6 m, Room G

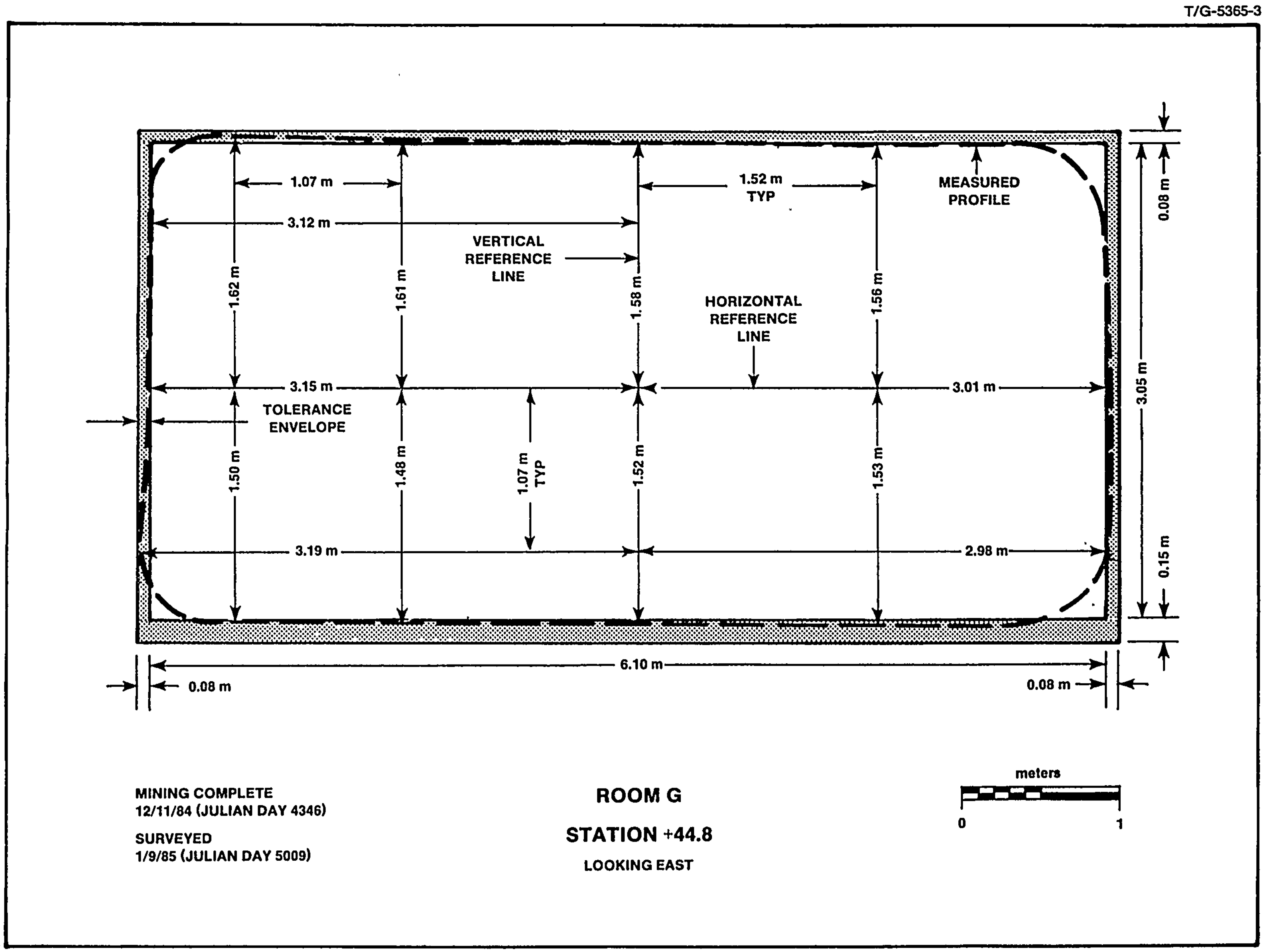


Figure G-4h. As-Built Cross Section of Station +44.8 m, Room G

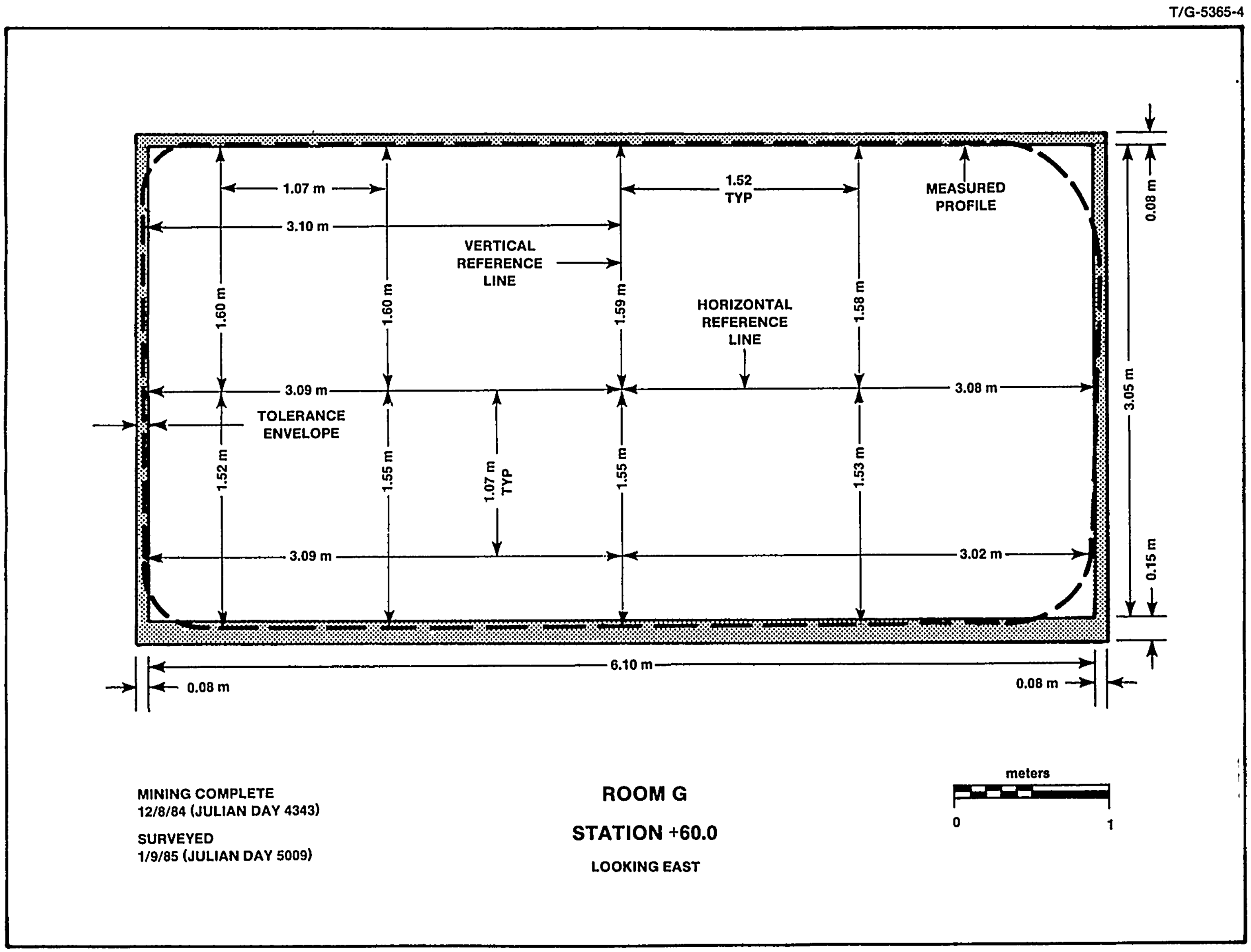


Figure G-4i. As-Built Cross Section of Station +60.0 m, Room G

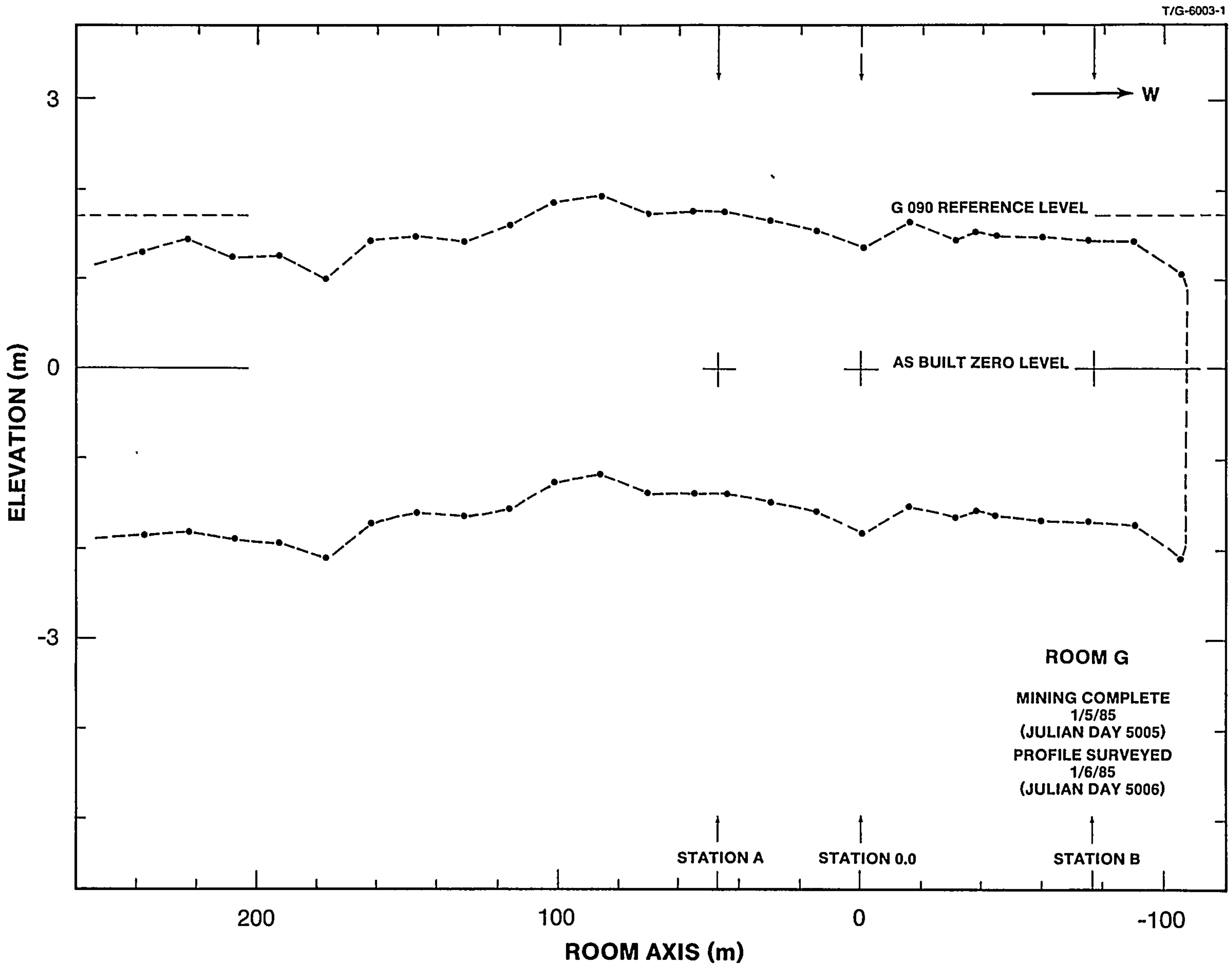


Figure G-5. As-Built Profile of Room G

APPENDIX H: TEST ROOM H AS-BUILT DRAWINGS

LIST OF FIGURES FOR APPENDIX H

T/H-6002-1

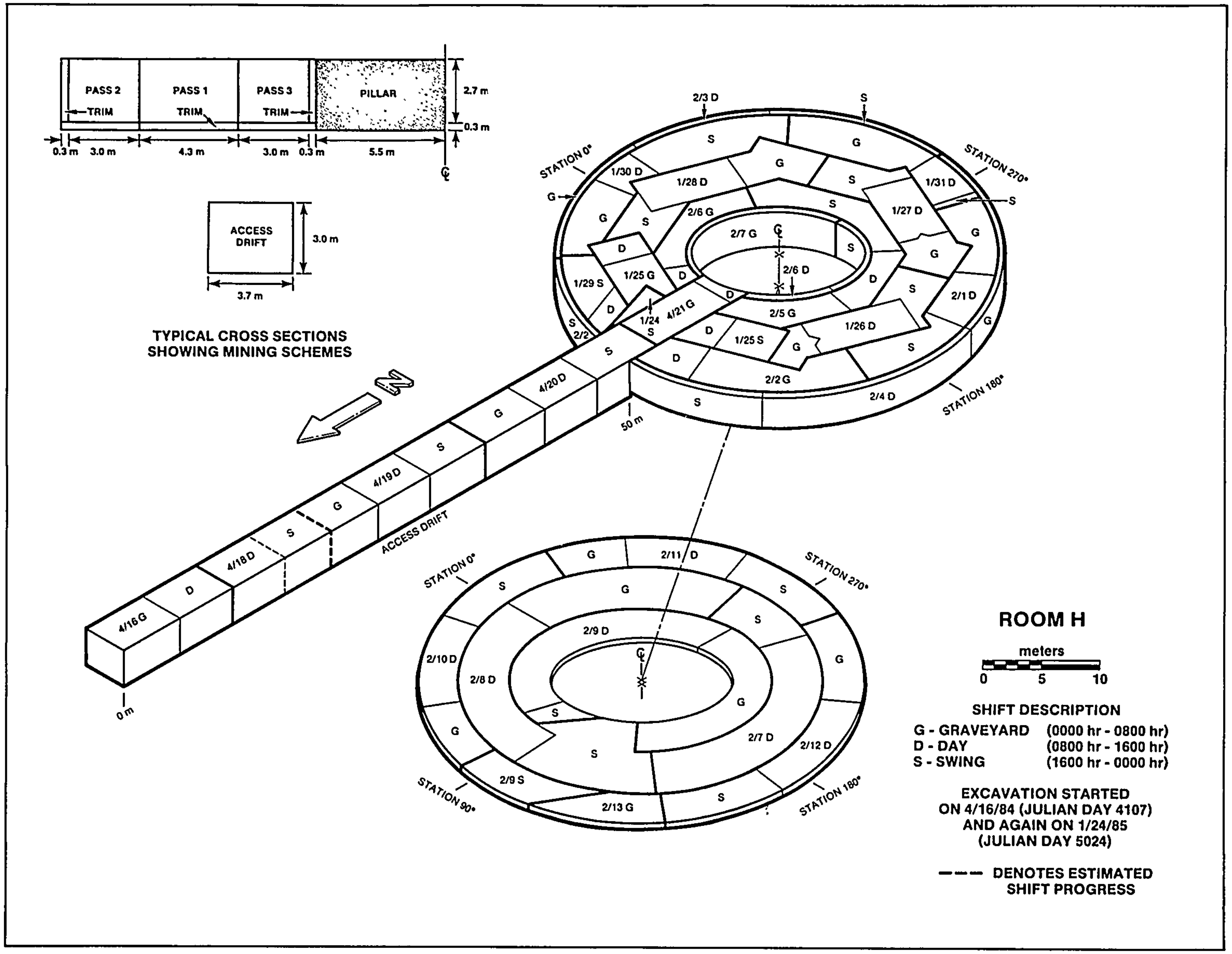


Figure H-1. Isometric View of Excavation Progress, Room H

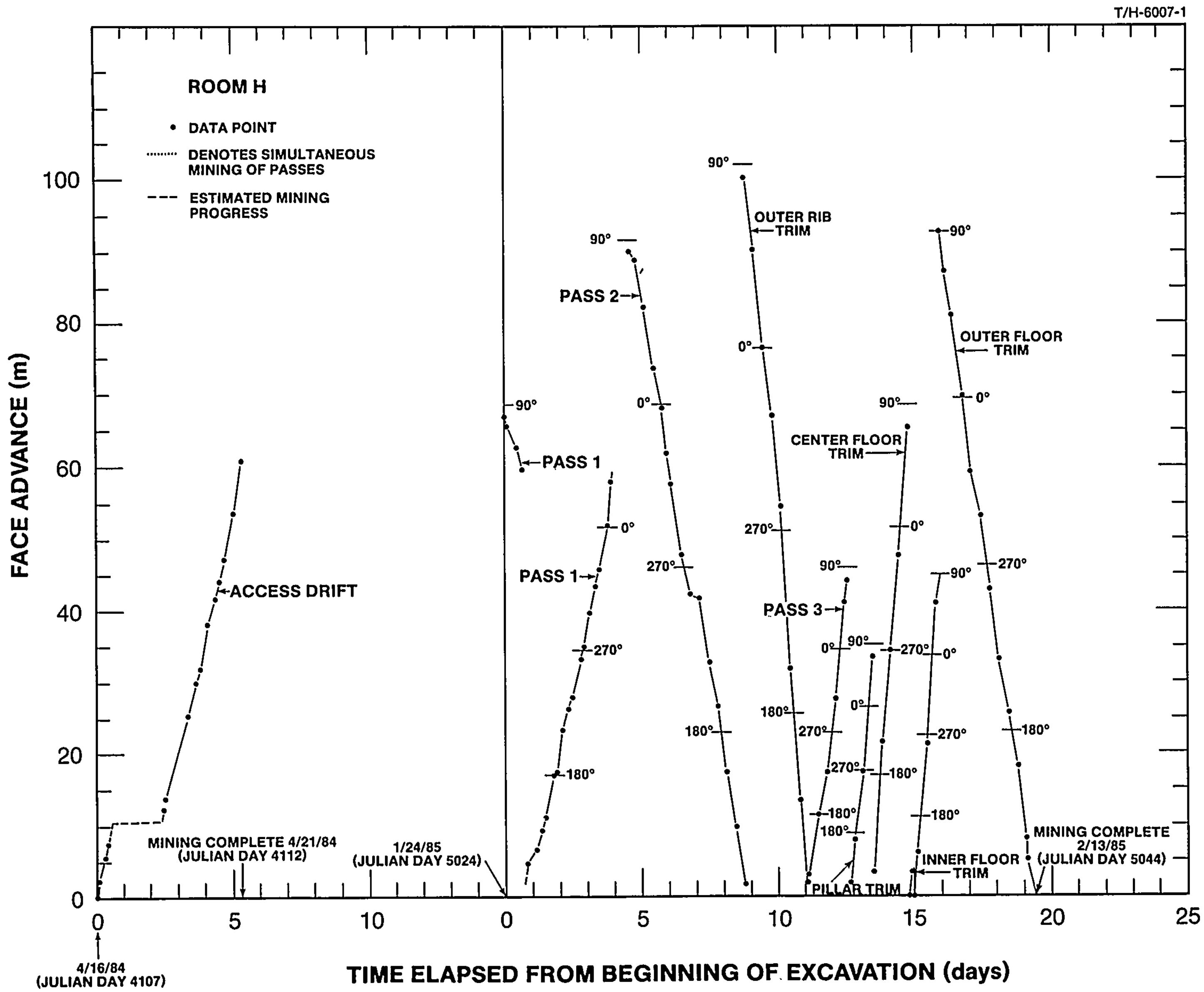


Figure H-2. Face Advance During Excavation, Room H

T/H-5352-1

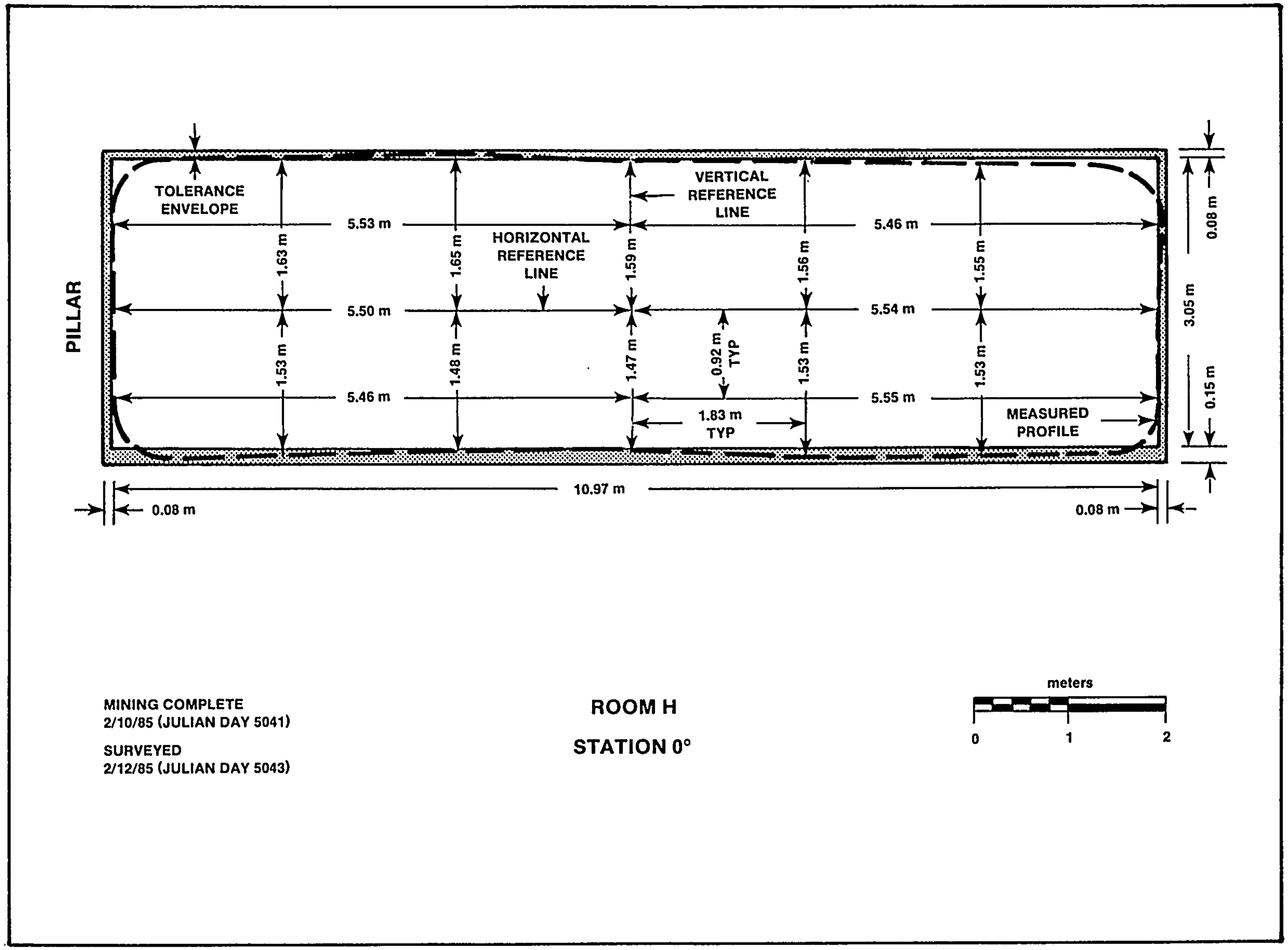
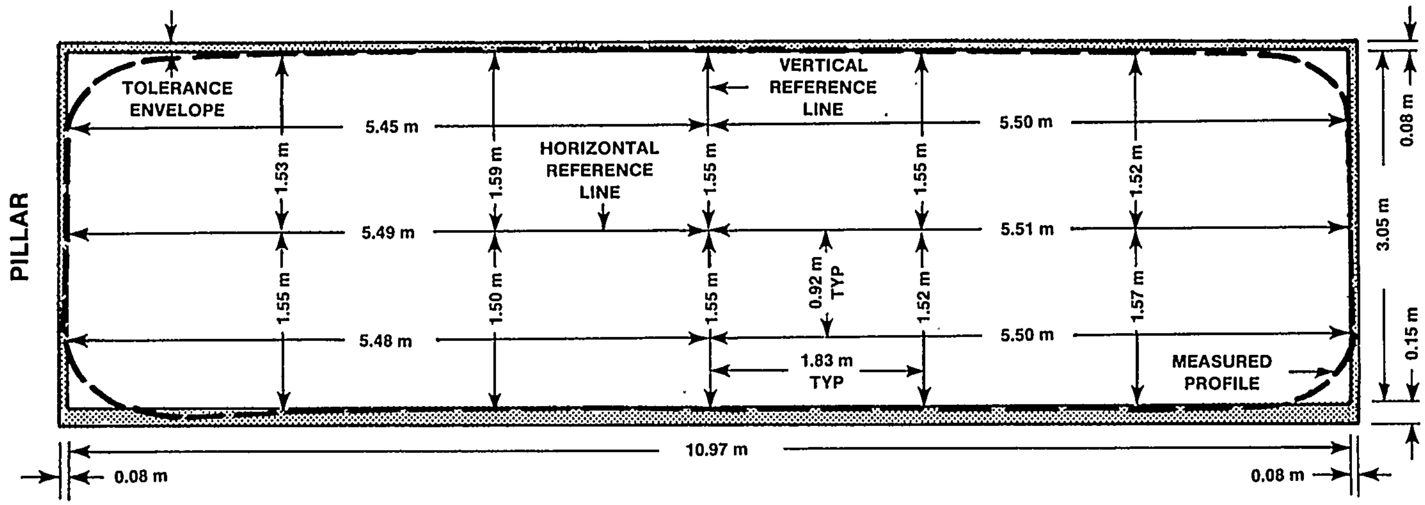


Figure H-3a. As-Built Cross Section of Station 0°, Room H

T/H-5352-2



MINING COMPLETE
2/10/85 (JULIAN DAY 5041)

SURVEYED
2/12/85 (JULIAN DAY 5043)

ROOM H

STATION 45°

meters
0 1 2

Figure H-3b. As-Built Cross Section of Station 45°, Room H

T/H-5354-1

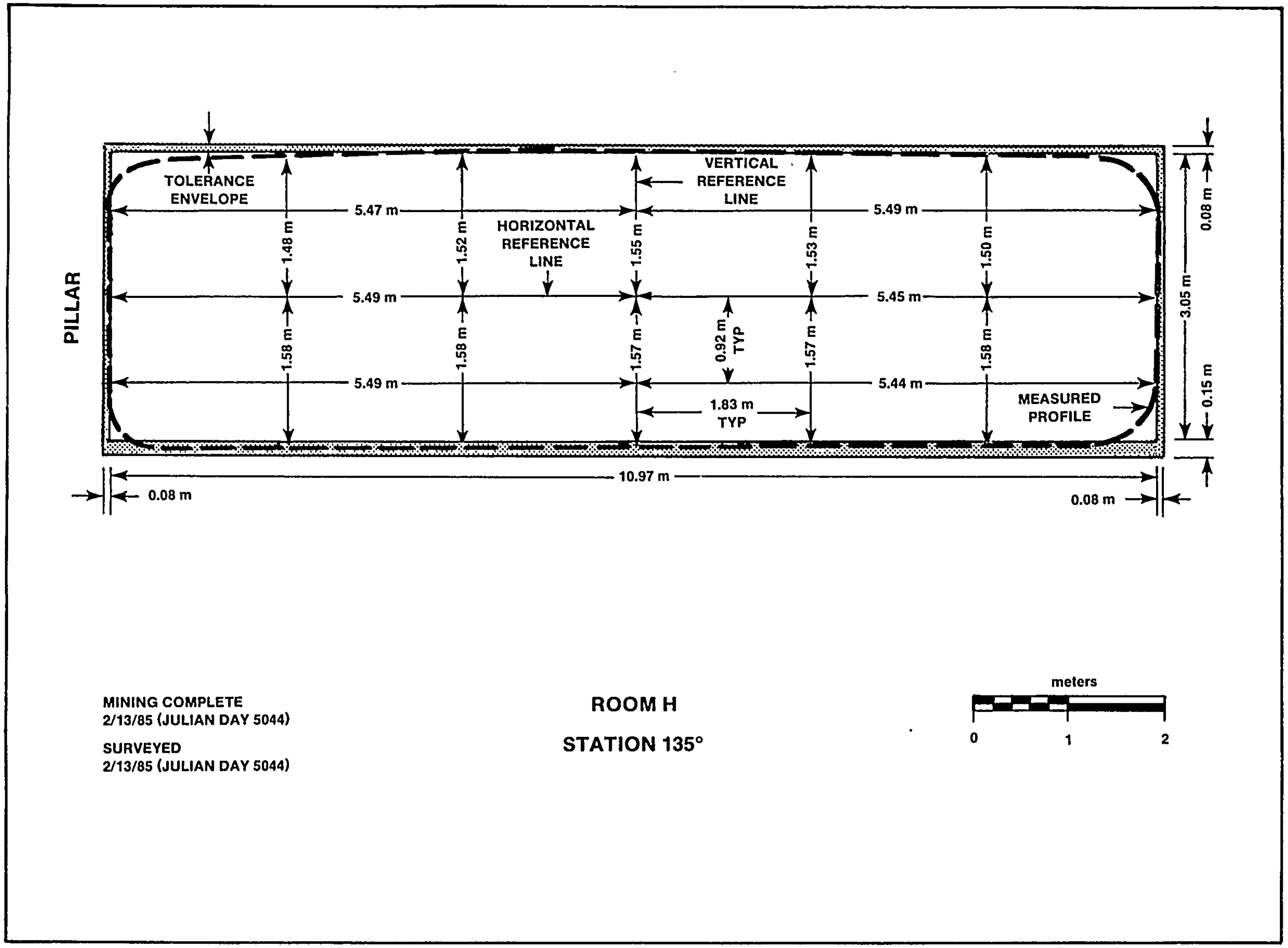


Figure H-3c. As-Built Cross Section of Station 135°, Room H

T/H-5354-2

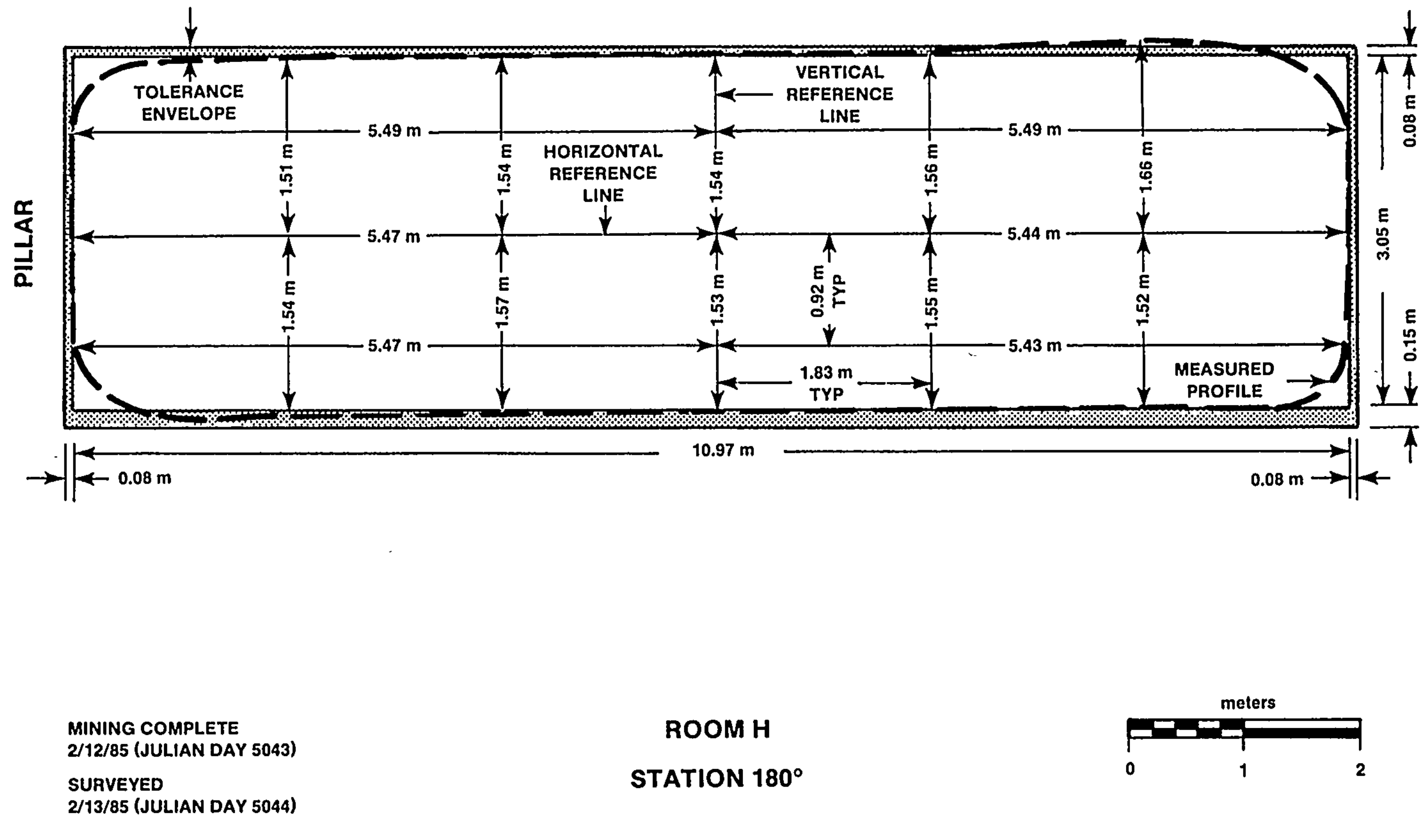


Figure H-3d. As-Built Cross Section of Station 180°, Room H

T/H-5357-1

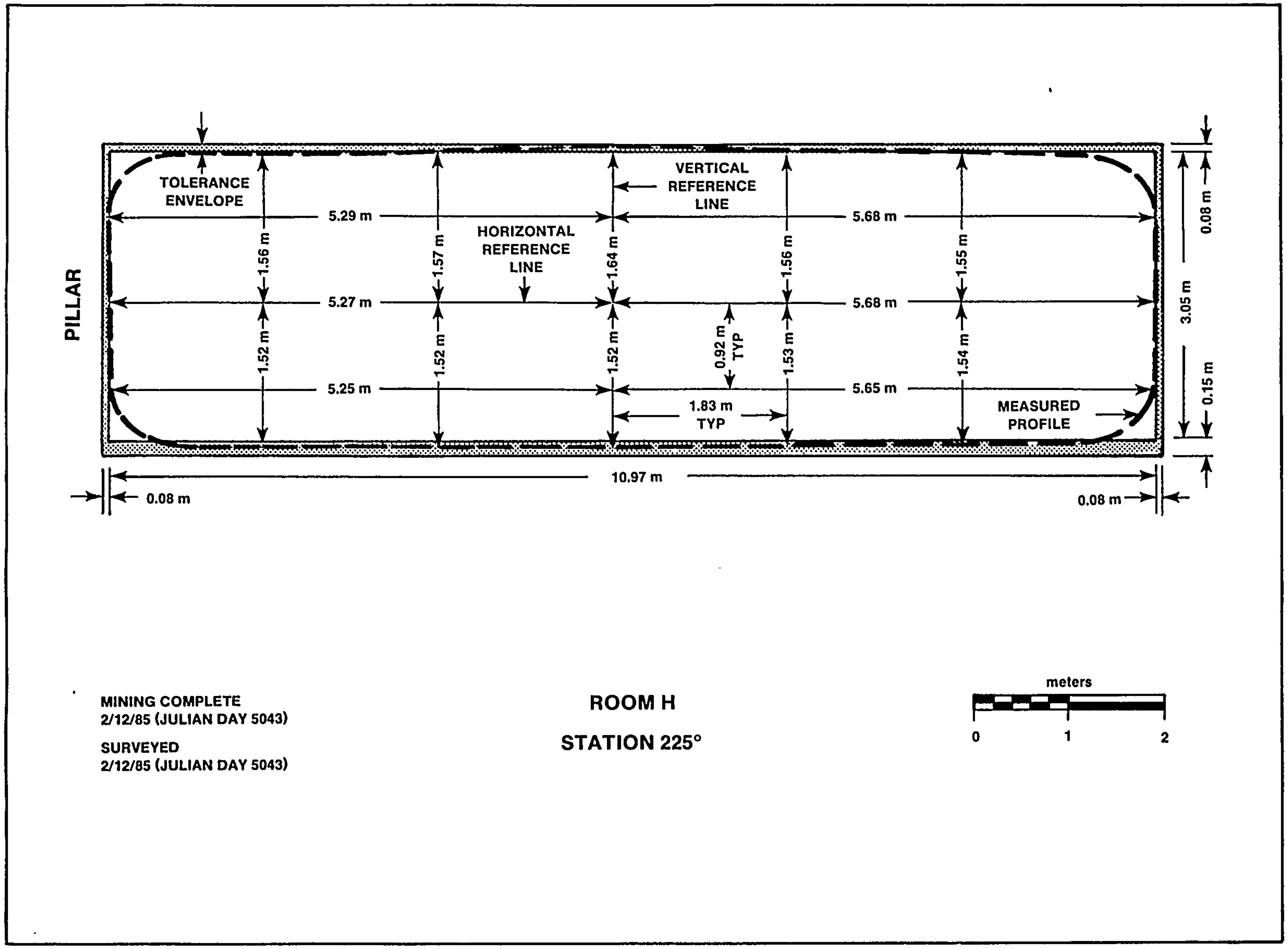


Figure H-3e. As-Built Cross Section of Station 225°, Room H

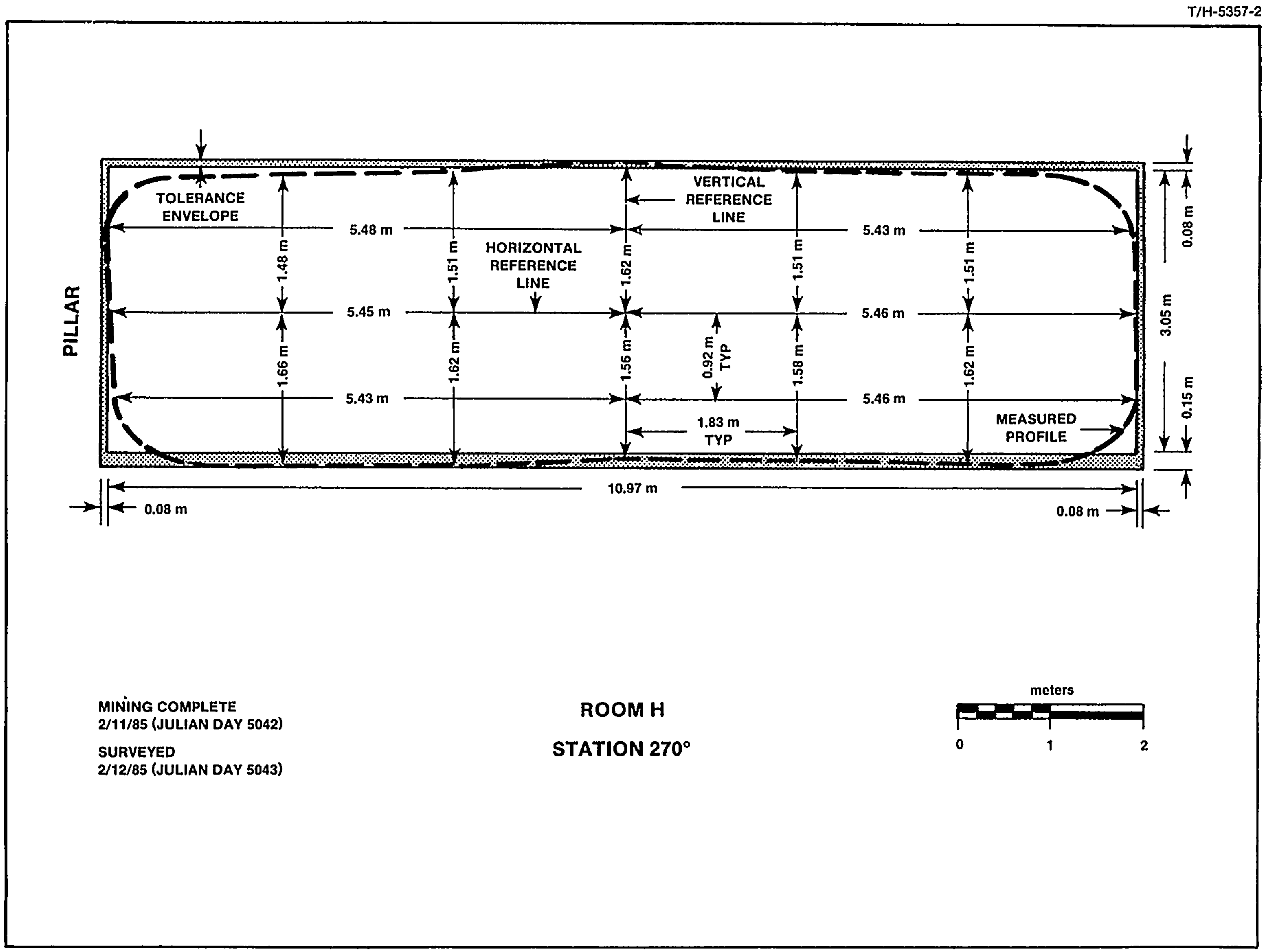


Figure H-3f. As-Built Cross Section of Station 270°, Room H

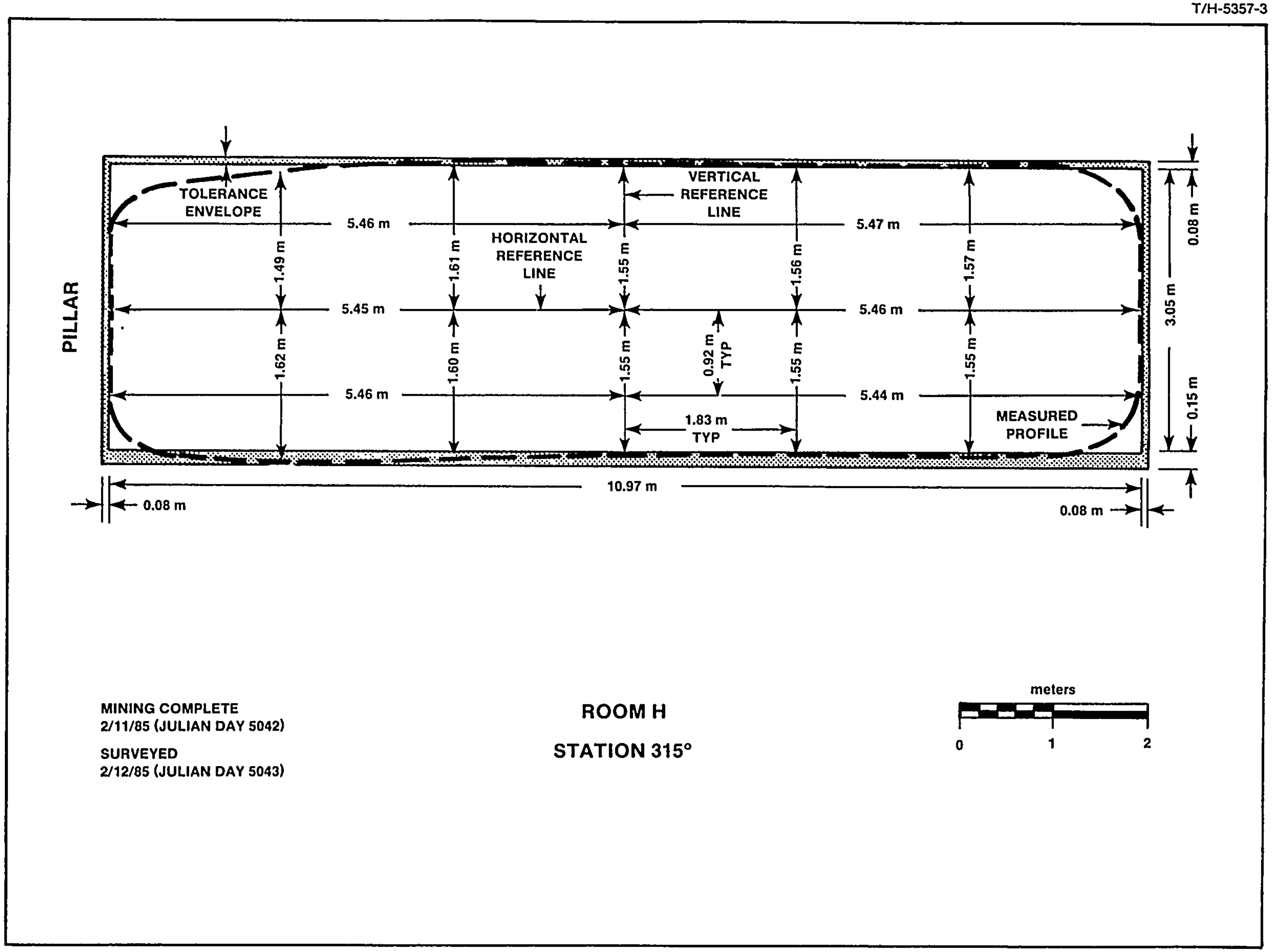


Figure H-3g. As-Built Cross Section of Station 315°, Room H

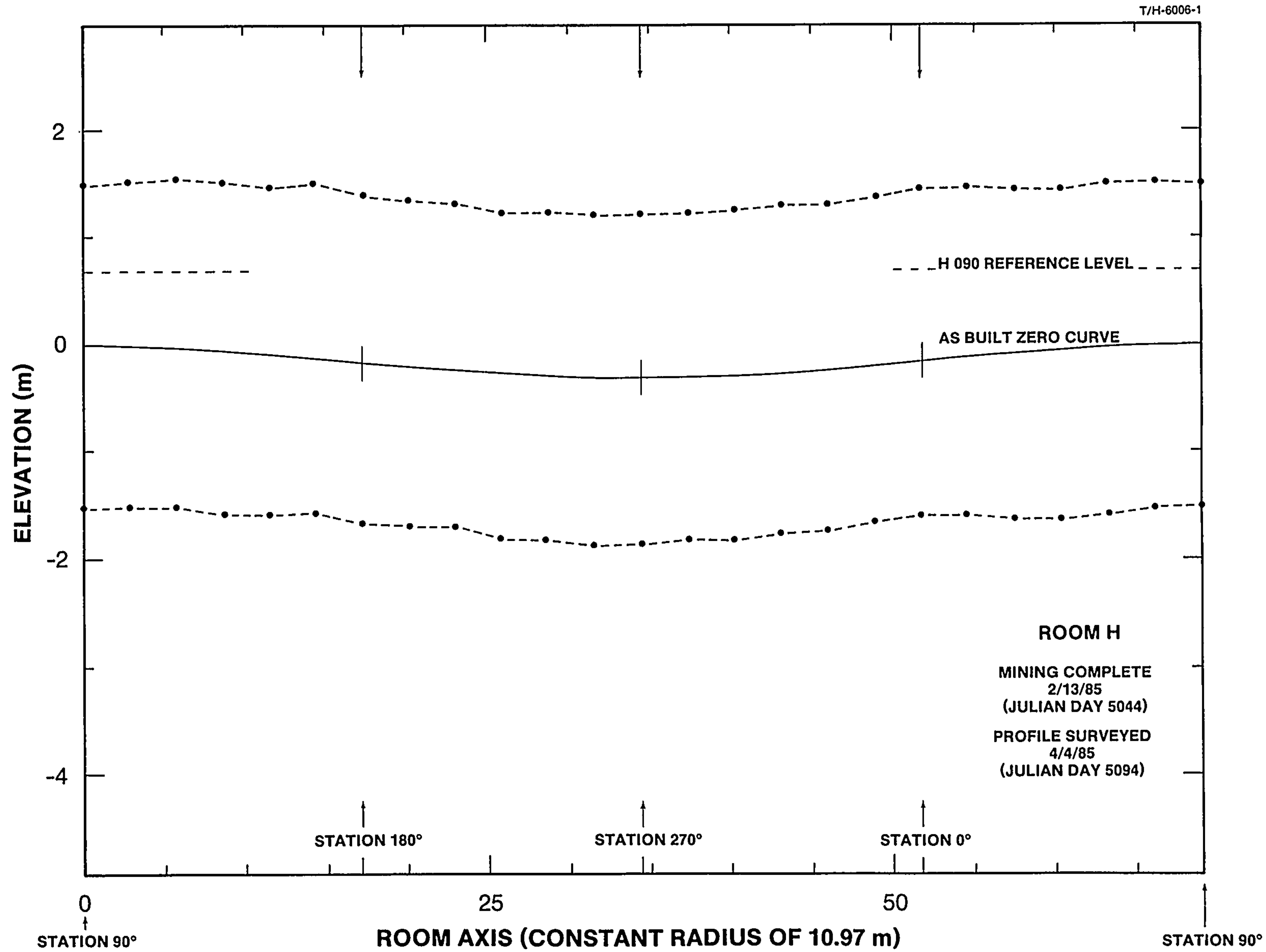


Figure H-4. As-Built Profile of Room H

APPENDIX Q: TEST ROOM Q AS-BUILT DRAWINGS

LIST OF FIGURES FOR APPENDIX Q

T/Q-10310-2-12269

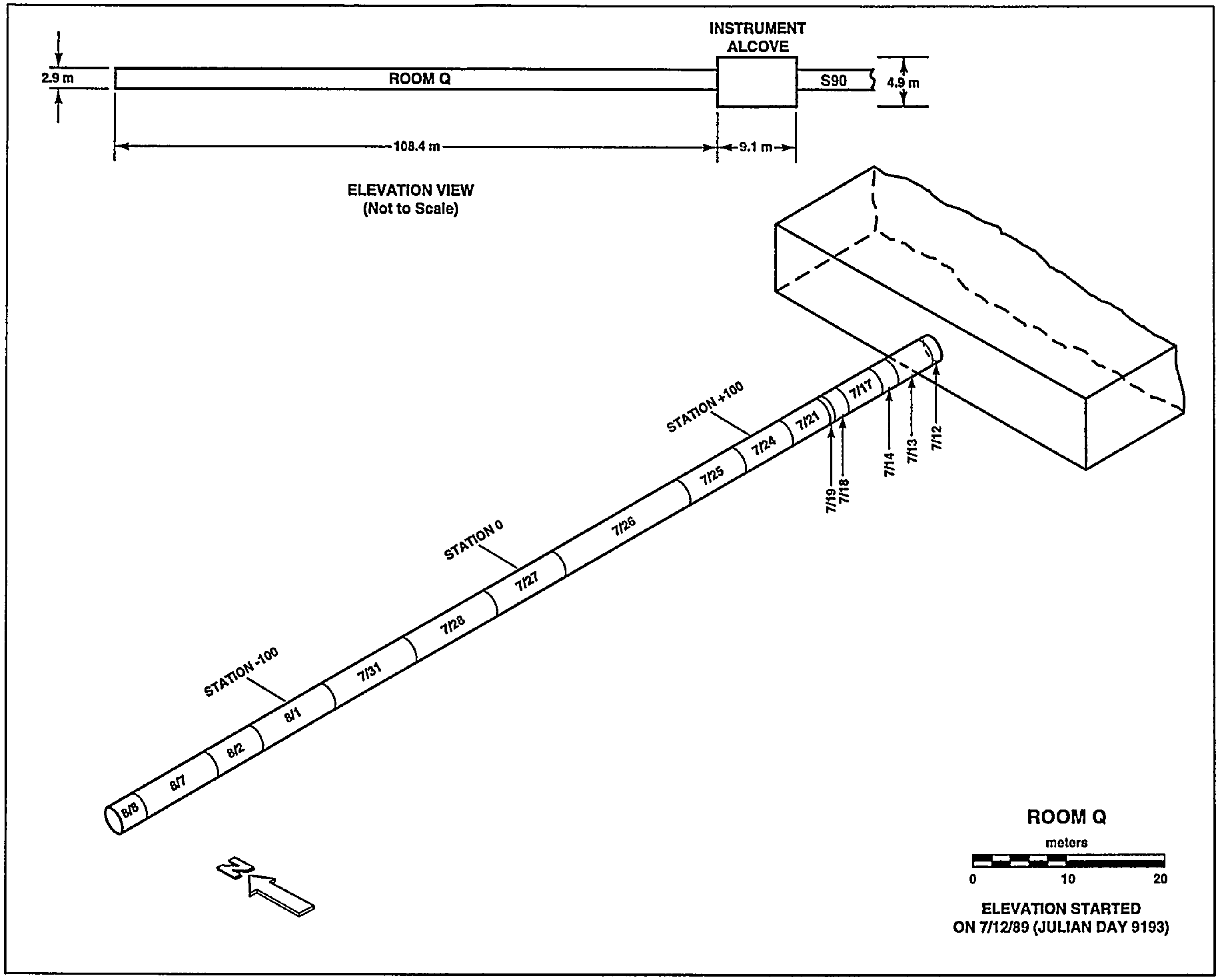


Figure Q-1. Isometric View of Excavation Progress, Room Q

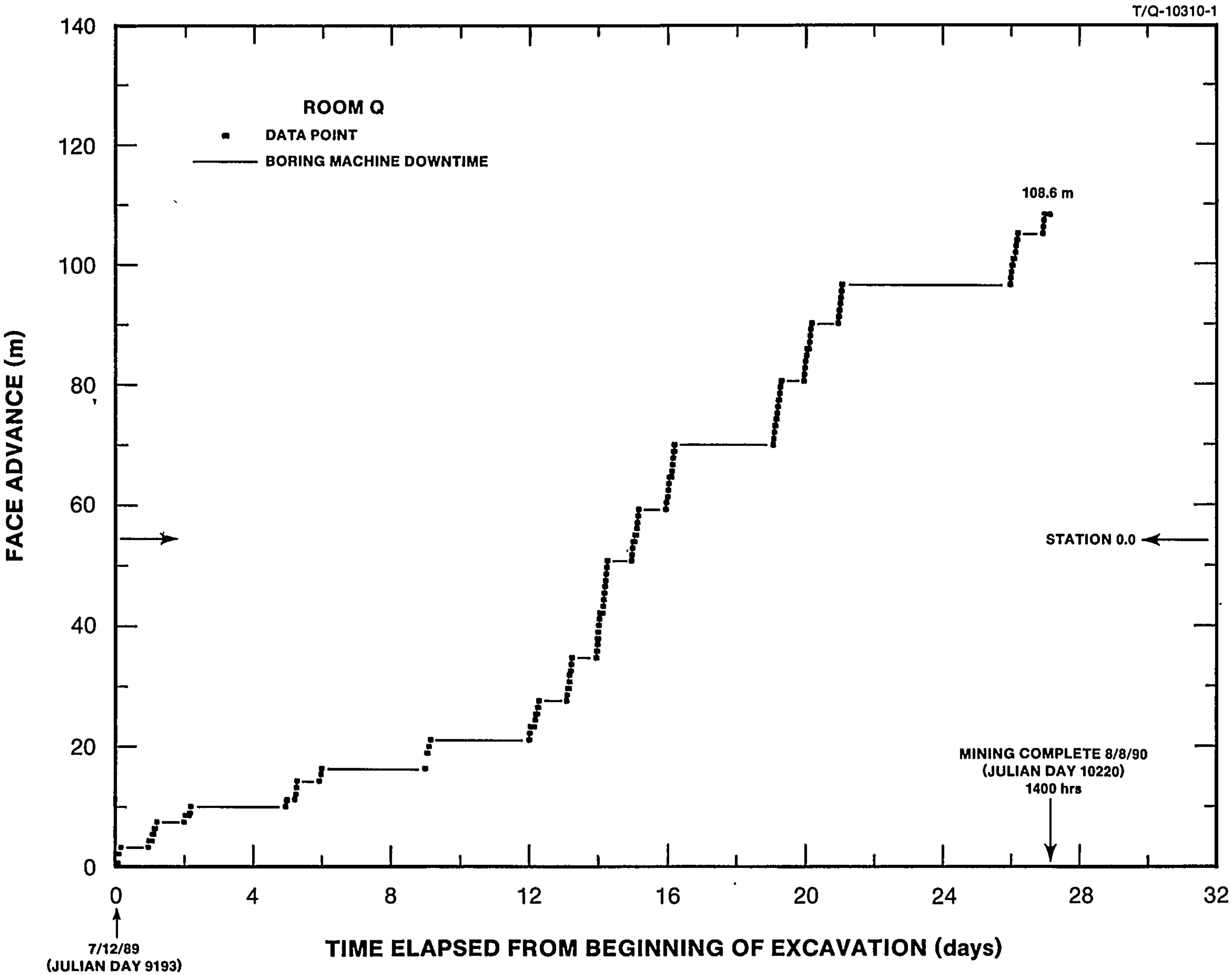


Figure Q-2. Face Advance During Excavation, Room Q

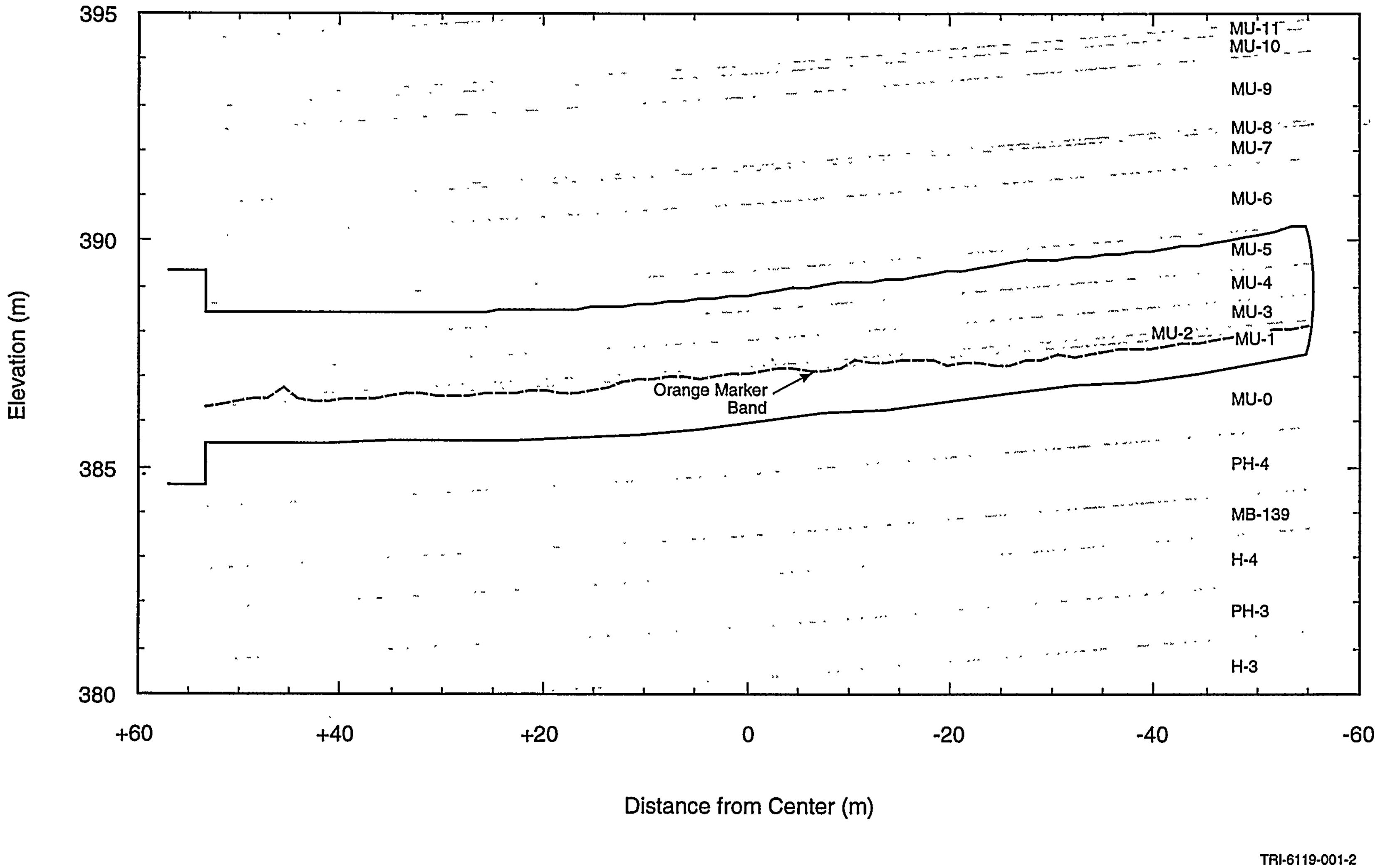


Figure Q-3. As-Built Profile of Room Q

APPENDIX V: SHAFT V AS-BUILT DRAWINGS

LIST OF FIGURES FOR APPENDIX V

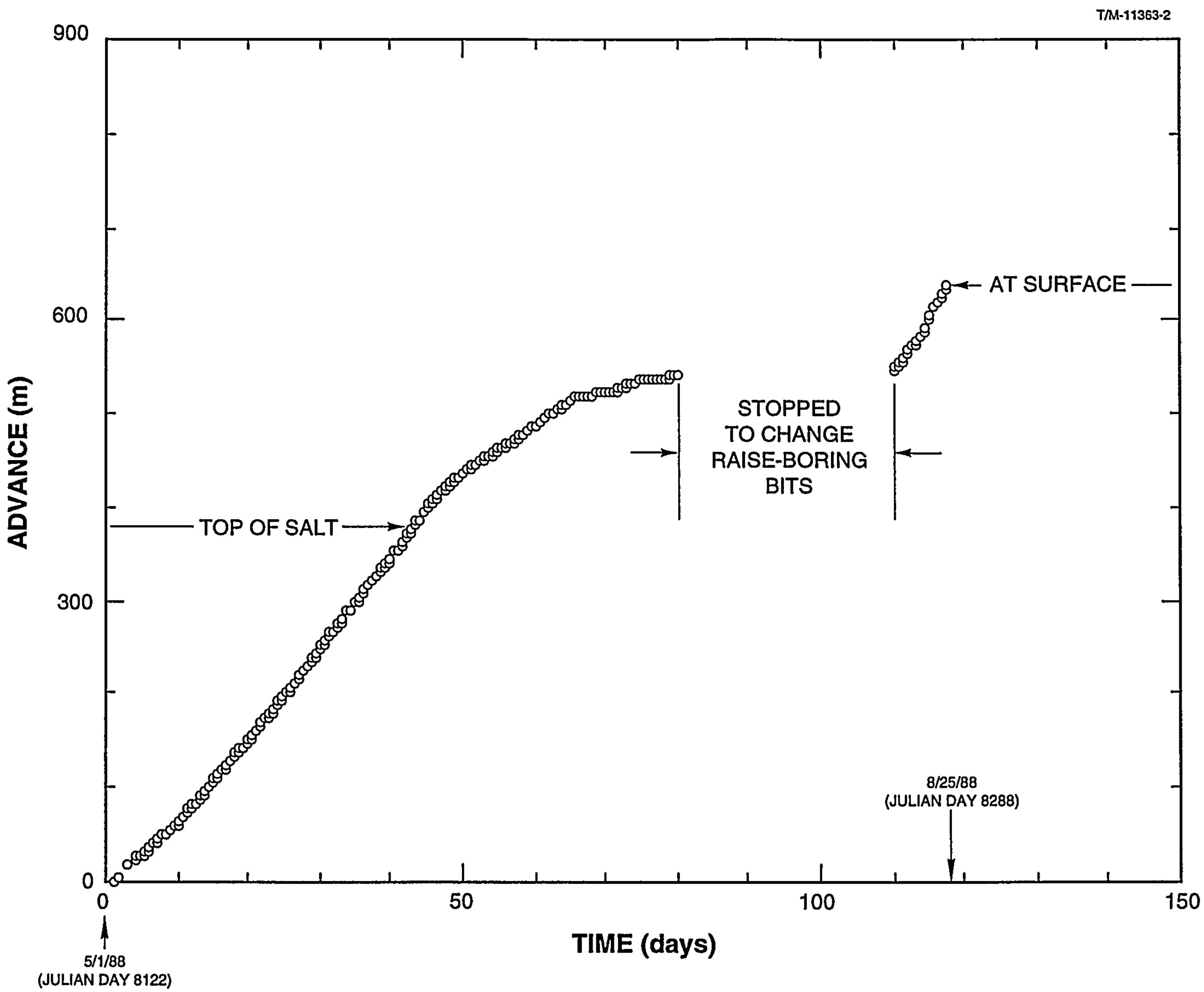


Figure V-1. Shaft Advance During Excavation, Shaft V

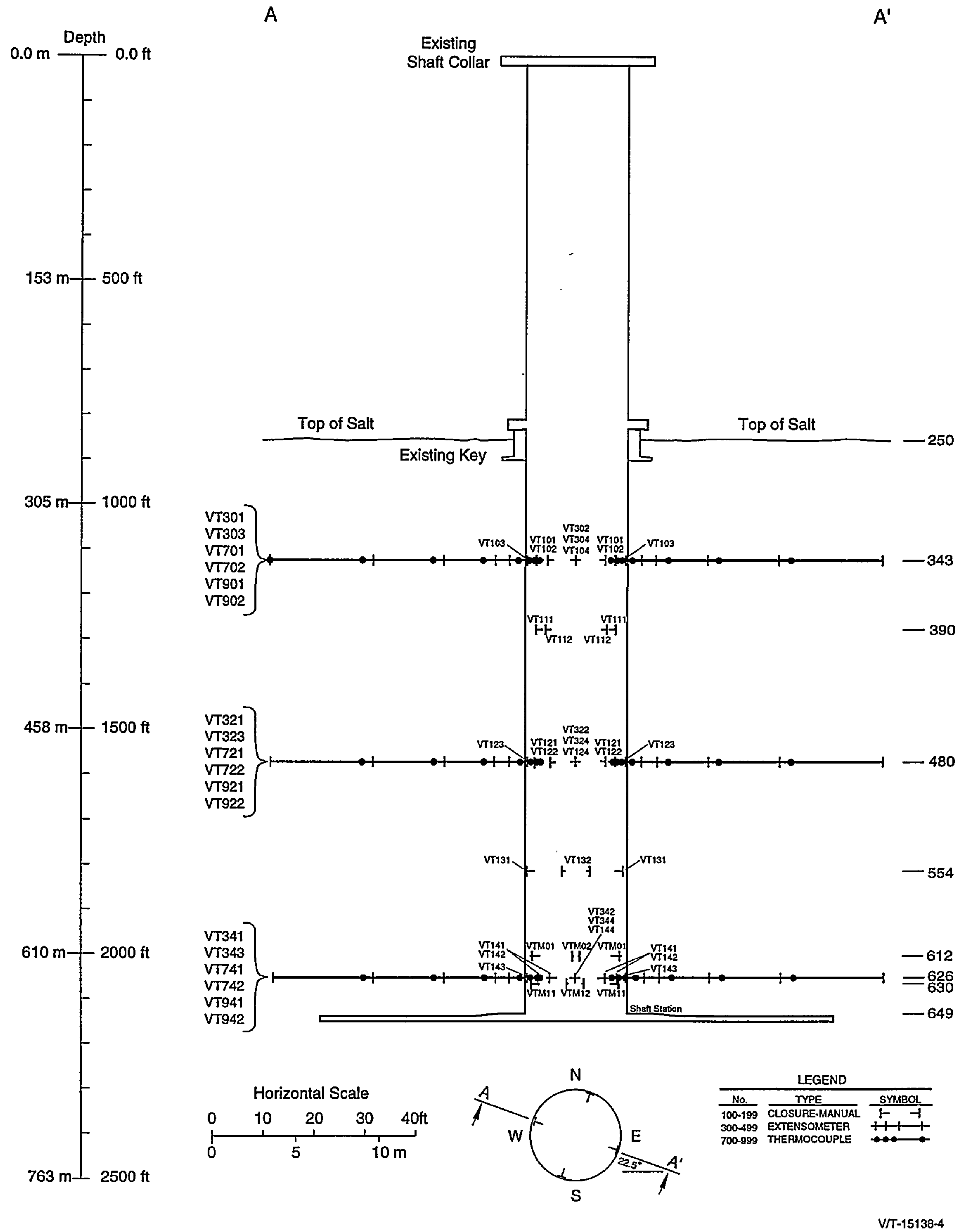


Figure V-2. Profile of the Air Intake Shaft

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Idaho Operations Office
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785 DOE Place
Idaho Falls, ID 83402

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ANR-460
Washington, DC 20460

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Washington, DC 20004

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Attn: Chairman
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Arlington, VA 22209-2297

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Santa Fe, NM 87504-1508

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Suite F-2
Albuquerque, NM 87109

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Attn: Library
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Santa Fe, NM 87505

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Secretary of the Environment
Attn: Mark Weidler
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Santa Fe, NM 87503-0968

NM Bureau of Mines & Mineral Resources
Socorro, NM 87801

NM Environment Department
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