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Air Intake Shaft Performance Tests (Shaft V): In Situ Data Report (May 1988 – July 1995)

Darrell E. Munson, David L. Hoag, John R. Ball, Glenn T. Baird, Robert L. Jones

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AIR INTAKE SHAFT PERFORMANCE TESTS (SHAFT V): IN SITU DATA REPORT (MAY 1988 - JULY 1995)

WASTE ISOLATION PILOT PLANT (WIPP) THERMAL/STRUCTURAL INTERACTIONS PROGRAM

Darrell E. Munson
Repository Isolation Systems Department
Sandia National Laboratories
P.O. Box 5800, Albuquerque, NM 87185

David L. Hoag and John R. Ball
RE/SPEC Inc.
4775 Indian School NE, Albuquerque, NM 87110

Glenn T. Baird and Robert L. Jones
Tech. Reps., Inc.
5000 Marble Avenue NE, Albuquerque, NM 87110

ABSTRACT

Data are presented from the Air Intake Shaft Test, an in situ test fielded at the Waste Isolation Pilot Plant (WIPP). The construction of this shaft, well after the initial three access shafts, presented an unusual opportunity to obtain valuable detailed data on the mechanical response of a shaft for application to seal design. These data include selected fielding information, test configuration, instrumentation activities, and comprehensive results from a large number of gages. Construction of the test began in December 1987; gage data in this report cover the period from May 1988 through July 1995, with the bulk of the data obtained after obtaining access in November, 1989 and from the heavily instrumented period after remote gage installation between May, 1990, and October, 1991.

ACKNOWLEDGMENTS

There were a number of organizations and people that made significant contributions to the fielding and operation of this large in situ test. To the people who were involved we owe a great deal and wish to thank them for their dedication and hard work, which assured that the results of the test were absolutely outstanding.

The Waste Isolation Pilot Plant (WIPP) Project is under the auspices of the Carlsbad Area Office of the Department of Energy (DOE/CAO), which has overall responsibility for the WIPP Program. As scientific advisor, Sandia National Laboratories (SNL) is responsible for the required technology development, which involves the in situ tests. Construction of the Air Intake Shaft (AIS) presented a significant opportunity to obtain needed data for the project and resulted in the Air Intake Shaft Test.

The required mining for the entries and shaft station was done by Westinghouse, the operating contractor for the WIPP. Shaft construction was by Frontier-Kemper through a contract with Westinghouse. Shaft outfitting was directly through Westinghouse using subcontractors, as necessary. Instrument hole drilling was done by Westinghouse. Cabling, instrument shed construction, and data acquisition were handled by SNL personnel with the support of contract personnel. All site aspects of gage installation were the responsibility of RE/SPEC Inc., a contractor to SNL, utilizing the support of additional contract personnel. Geotechnical crews were formed under the auspices of Westinghouse. Responsibility for daily test operation and maintenance was with Westinghouse, with overall test supervision by SNL and SNL support contractors.

Special thanks go to W. DeYouge, B. Stensen, and D. Schiermeister (all RE/SPEC) and R. Matalucci, D. Fulton and J. Mercer (all SNL).

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1 INTRODUCTION

In 1981 the Waste Isolation Pilot Plant (WIPP) Project, under the direction of the U.S. Department of Energy (DOE), began construction of a facility in southeastern New Mexico to develop the technology for disposing of radioactive waste from U.S. defense programs. This facility may eventually become a repository for defense transuranic (TRU) wastes, provided that the facility can demonstrate compliance with the regulatory requirements promulgated by the Environmental Protection Agency (EPA). Although the complete facility includes both surface and underground construction, the Repository Isolation Systems Department under the direction of the WIPP Project Management Department of Sandia National Laboratories (SNL) is primarily concerned with developments in the underground portion of the facility; we focus on that portion of the facility in this report.

Underground construction was divided into three phases: (1) the Site and Preliminary Design Validation phase, requiring the construction of two shafts and shaft stations, a limited entry system, the TRU Test Panel, and an exploratory drift (South Drift) to the southern extremity of the facility; (2) the Experimental Area, requiring the construction and fielding of several large research and development (R&D) Technology Development Program test rooms and the expansion of the shaft system; and (3) the TRU Waste Storage Area, requiring construction of shafts, entries, and storage panels for the operation of the disposal system, and which, if this facility is shown to be in compliance with the EPA regulations, will be used for storage of contact-handled (CH) and remote-handled (RH) TRU radioactive waste. The first two construction phases are complete, and extensive data have been acquired for facility design validation and for technology development. Further construction of the third phase is currently awaiting the demonstration of compliance with regulations to permit initial receipt of waste.

In addition to these initially planned phases, other construction occurred as necessary. One important construction activity for rock mechanics testing was the Air Intake Shaft (AIS). The decision was taken to construct an additional shaft to permit a better separation of the radiation and clean air flows of the ventilation system in the facility. It also gave an important opportunity, not previously possible, to fully instrument and test in the shaft from the time of its construction.

The experimental activities conducted in the underground facility are the responsibility of SNL. These in situ activities consist of several very large-scale tests and many small-scale experiments to address important technology issues related directly to the repository isolation systems, disposal room systems, and fluid flow and transport programs. The WIPP in situ testing addresses specifically the disposal of wastes generated from current and past defense programs. All of these tests, most of which were initially defined in a detailed planning document [1], were carried forward by individual test plans defining the implementation and fielding activities for each specific test. The technology issues currently address the disposal of TRU CH and RH wastes, which are directly relevant to the proposed disposal of TRU wastes at the WIPP. Although some tests initially addressed the disposal of defense high level waste (DHLW), DHLW is currently slated for disposal in a commercial repository. However, the heated tests remained in operation for their planned duration and have supplied supplemental information on the behavior of WIPP salt, which has strengthened our knowledge base.

This report is specific to the Thermal Structural Interactions (TSI) in situ tests of the Experimental Area. Within the main TSI tests are six major tests which involve some four rooms or room complexes. These are: (1) the 18 W/m^2 Mockup for Defense High Level Waste in Rooms A1, A2, and A3; (2) the Overtest for Simulated Defense High-Level Waste (DHLW) in Room B; (3) the Geomechanical Evaluation Test in Room G; (4) the In Situ Stress Field (Hydrofrac) Test in Room G; (5) the Heated Axisymmetric Pillar Test in Room H; and (6) the Clay Seam Shear Test. The Clay Seam Shear Test is not yet fielded. Although not a part of the original TSI series of tests, in situ data are also being obtained from: (1) Room D, an early excavation for facility ventilation; (2) Room Q, a horizontal cylindrical brine inflow test room; (3) the Intermediate Scale Borehole Test, an intermediate scale hole emplaced in the pillar between Rooms C1 and C2; and most recently (4) the Air Intake Shaft (Shaft V), a cylindrical, vertical shaft configuration. A number of documents have discussed planning, implementation, and fielding of TSI in situ tests [2-4] and the reader is referred to the original documents for more detailed information on these subjects.

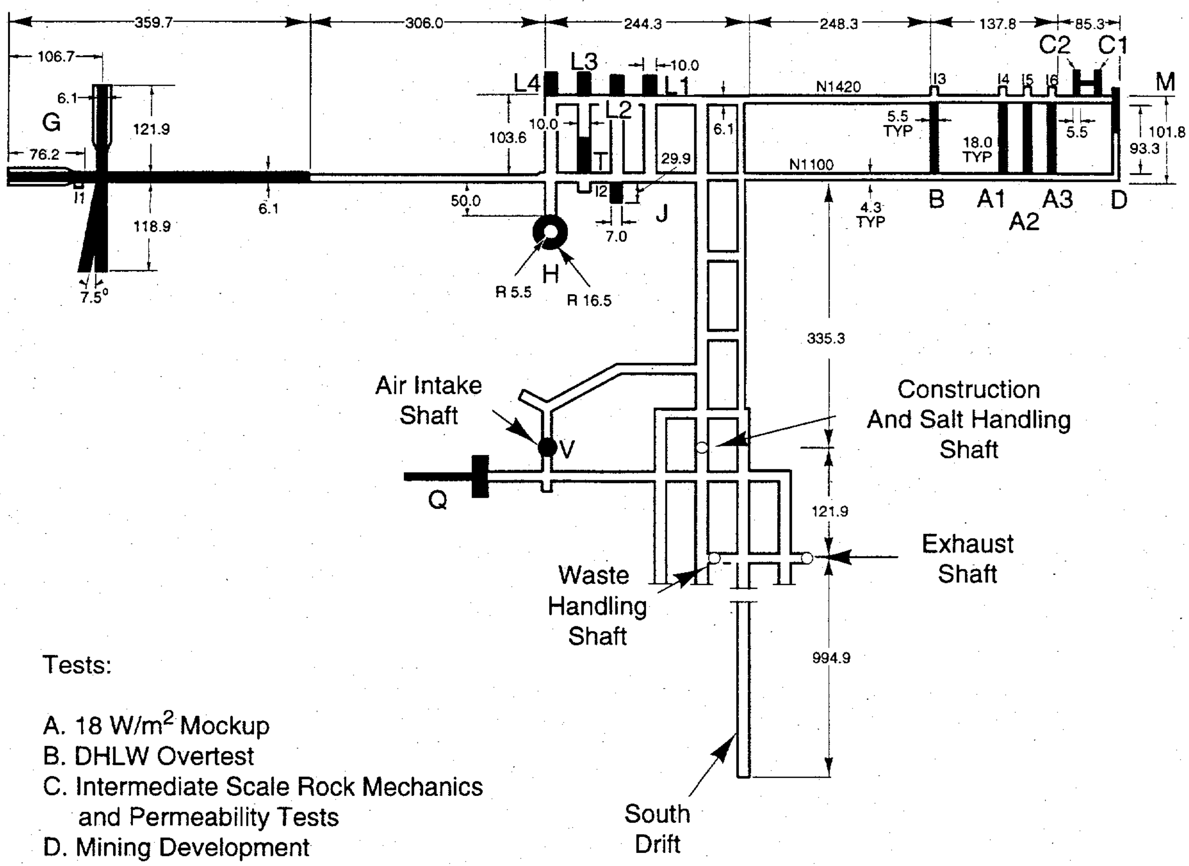
This data report is one of a series intended to document the data obtained from the TSI in situ tests and to make these data available to potential users. Other data reports include those for the Mining Development Test (Room D) [5], the Heated Axisymmetric Pillar Test (Room H) [6], the Overtest for Simulated Defense High Level Waste (Room B) [7], the 18 W/m^2 Mockup for Defense High Level Waste (Rooms A) [8, 9], the Geomechanical Evaluation (Room G) [10], and the Intermediate Scale Borehole (Rooms C) [11]. These data are supplemented by the report of the manual mining sequence closure data [12].

This report presents the data for the Air Intake Shaft Test fielded in the central portion of the WIPP. It specifically focuses on mechanical and thermal response data acquired from April 1988 to July 1995, but with the majority of data collected between May, 1990, when the remote gages at the upper principal shaft stations were installed, and July 1995, which is the cut-off date for this report. The remote gages at the lower principal shaft station were not installed until October, 1991.

2 EXPERIMENT DESCRIPTION

As given in the test plan [13], the Air Intake Shaft Test (Shaft V) was designed to investigate the response of WIPP shafts with regard to geomechanical response, and a number of other geophysical and hydrological processes. Note that each test was assigned an alphabetical designation; hence the "vee" for the AIS test. The geomechanical (rock mechanics) objectives of the test were to determine the shaft creep closure history of the salt beginning with the early measurements taken during the shaft excavation process. These data will be used as supporting information for the development of a model for long-term shaft creep closure predictions and will apply to seal design and performance assessments.

Three of the four shafts of the WIPP facility were constructed to provide initial access to the underground for personnel and equipment and for ventilation. These shafts are located as shown in Figure 2.0.1. Only one of the initial shafts, the Construction and Salt Handling (C&SH) Shaft, was instrumented for hydrological and geomechanical response, primarily for verification of the repository design and site performance. Shaft instrumentation was by D'Apalonia, which later became International Technologies (IT) Corporation, to provide data for eventual use of the architect/engineer, Bechtel International. Although these instruments gave adequate data [14], the experience suggested further improvements would be possible. At a later date, when it was decided that a fourth shaft was needed to provide improved ventilation, it was realized that this was the last opportunity to collect improved quantitative data on shaft behavior and performance for use in technology development. As a result, the AIS which is located slightly to the west in the central portion of the underground facility, was heavily instrumented. The TSI



Tests:

A. 18 W/m^2 Mockup
B. DHLW Overtest
C. Intermediate Scale Rock Mechanics and Permeability Tests
D. Mining Development
G. Geomechanical Evaluation
H. Heated Pillar
J. Simulated CH TRU Tests (Wet) and Materials Interface Interactions Test (MIIT)
L. Plugging and Sealing
M. Small Scale Seal Performance Tests
T. Simulated CH and RH Tests
Q. Circular Brine Room Tests
V. Air Intake Shaft Performance Tests
WPP. Waste Package Performance, Simulated DHLW (B, A1)

N

Notes:
1. All Dimensions in Meters
2. Not to Scale

TRI-6346-30-0

Figure 2.0.1. Plan View of the WIPP Shaft Locations and Experimental Area

testing consisted of instrumenting the shaft with early closure gages as it was being excavated to evaluate the early time creep closure of the shaft. Then, after the shaft was completely excavated and outfitted for normal manned access, a number of closure, extensometer, and temperature gages were installed at several discrete stations along the length of the lower portion of the shaft; i.e., in the salt beds.

The complete AIS test plan consisted of a collection of separate tests, involving different hydrological, geophysical, and geomechanical objectives, as outlined in the test plan [13]. In this report only the geomechanical, TSI, portion of the plan will be treated. Although not detailed in the test plan, the TSI test actually involved two phases, which were made possible by the unique raise-boring method of shaft construction. The first phase was the installation of an early set of closure points positioned just below and immediately after the passage of the raise-boring head during shaft excavation. This phase is described elsewhere [15]. The second phase consisted of the installation of gages in the shaft after it was outfitted for access [13].

Further relevant information is contained in either published or in preparation documents on the instrumentation, data acquisition system [16] and the overall WIPP In Situ Data Acquisition, Analysis, and Management (WISDAAM) System [17]. Some limited information from these documents is required for our purposes here. Consequently, in this section we briefly discuss the test configuration, mining, and special features of the AIS Test as background for the experimental data presented in this report.

2.1 Test Configuration

2.1.1 Physical: The shaft extends from the ground surface to a depth of 655.3 m (2150 ft) where it connects to the underground facility. It is a uniform 6.20 m (20.33 ft) in diameter. The shaft penetrates the three geologic formations present at the WIPP site; the Dewey Lake Red Beds, the Rustler Formation, and the Salado Formation. All the TSI experiment instruments are located in the Salado Formation salt.

2.1.2 Gages: Instruments in the TSI experiment consisted of the following:

(1) Temporary, manually read, horizontal closure gages established concurrently with excavation of the air intake shaft (these are referred to as either "early closure point or mining sequence" gages).

(2) Permanent, manually read, horizontal closure gages to measure diametrical closure of the shaft.

(3) Permanent, remotely read, extensometers specifically designed to measure radial displacement of the salt.

(3) Permanent, remotely read, thermocouples originating from selected stations along the shaft to monitor the temperature of the rock mass

(4) Permanent, remotely read, thermocouples originating from selected stations along the shaft to monitor the temperature of the intake airstream in the shaft.

The gages described above can be classified according to gage type and manufacturer. Most of the gages were devoted to displacement measurements which, along with the temperature measurements, were considered to be the highest priority in the experiment. The gage types that are presented in this report are as follows:

(1) Early Closure Points or Mining Sequence, Early closure point emplacement machine, and subsequently hand-held carpenter's tape,

manually read, drill hole emplacements;

(2) Closure, Sinco tape extensometer, manually read, anchored-pin emplacements;

(3) Extensometers, Irad 4000 series, linear-potentiometer, multipoint (5 anchors) remotely read stainless steel rod units;

(4) Thermocouples: Chromel-Constantan, fully jacketed, multipoint (6 points) remotely read junctions, grouted into place;

(5) Thermocouples: Chromel-Constantan, fully jacketed, single point remotely read junctions, suspended in the airstream.

Table 2.1.1 summarizes the quantities of each of these gage types that were installed in the AIS experiment. Note that each unit may contain several individual gages.

Each gage has a unique designation code. Gage designations (numbers) were configured to convey information about the gage. The designation code is a set of seven alphanumeric characters (for example, VT301-1) which contains several useful pieces of information. The first character is a letter representing the specific test room (in this example, "V"). The next character field indicates a subtest of the overall test program (here "T" for the thermal structural program). The gage type is given by the first of the next 3 numeric characters: "1xx" are manual closure units, "3xx" are extensometers units, and "7xx" and "9xx" are thermocouple units. Special gages added after completion of the test plan, if any, have a gage type with an initial alphabetic character keyed to the type of unit, in this case an "M" for early closure point or mining sequence. The sixth alphanumeric character is the subunit designation. In the AIS test we encounter only one type of subunit indicated with a "-" which tells us that the gages of the subunit are all contained in the same borehole.

Table 2.1.1. TSI Gage Summary for Air Intake Shaft

	INSTRUMENT UNITS									DRILLING	
	6 GAGES/UNIT	5 GAGES/UNIT	4 GAGES/UNIT	3 GAGES/UNIT	2 GAGES/UNIT	1 GAGES/UNIT	0 GAGES/UNIT	TOTAL UNITS	TOTAL GAGES	NUMBER OF HOLES	METERS OF HOLE
EXTENSOMETER	—	12	—	—	—	—	—	12	60	12	183
CLOSURE											
TEMPORARY	—	—	—	—	—	10	—	10	10	20	3
PERMANENT [1]	—	—	—	—	—	6	—	6	6	0	0
MINING SEQUENCE	—	—	—	—	4	—	—	4	8	8	1
THERMOCOUPLES											
ROCKMASS	6	—	—	—	—	—	—	6	36	6	91
AIRSTREAM	—	—	—	—	—	6	—	6	6		
ULTRASONIC [2]	—	—	—	—	—	—	9	9	—	9	41
TOTAL	**6**	**12**	**—**	**—**	**4**	**22**	**9**	**53**	**126**	**55**	**319**

[1] Installed on flanged pipe collars of opposing extensometers.

[2] Data are not included in this report.

Finally, the last numeric character is the specific gage within the unit. Gages of a unit or subunit may range from 0 to 9. Some units, such as closure and airstream types, have only 1 gage.

The location of each gage is specified, within the construction tolerance limits, in terms of the room cylindrical coordinate system of R (radius), T (theta, an angle taken positive counterclockwise from the due east base line), and Z (vertical depth in the shaft, with the origin at ground surface of the shaft and taken as positive in the up direction). In general, the gage location is given by pairs of coordinates which specify the two end locations of the gage. For gages set into boreholes, the first coordinate set (R_1,T_1,Z_1) defines the collar and the second set (R_2,T_2,Z_2) defines the point at depth. For a single point gage, the sets are duplicates. For closure gages, the theta coordinates will show a difference of 180 degrees with nominally the same R and Z coordinates.

Because of the normal peculiarities of excavation of the underground test rooms in a slightly dipping geology, two pairs of "Z" values were used in underground tests. However, for the configuration and limited extent of the stations involved in the AIS test configuration, there is an insignificant dip across the shaft diameter to require this correction. As a result for the AIS test, on pair of values is the location in terms of the test room coordinate system; the other pair of values is a deviation from the local midheight origin of the gage station (stations and principal stations are discussed in Section 2.3.1).

Gage or unit (a collection of gages) locations for the gages measuring the response of the in situ material and the borehole are shown in the elevation view for the air intake shaft in Figure 2.1.1. The view shows

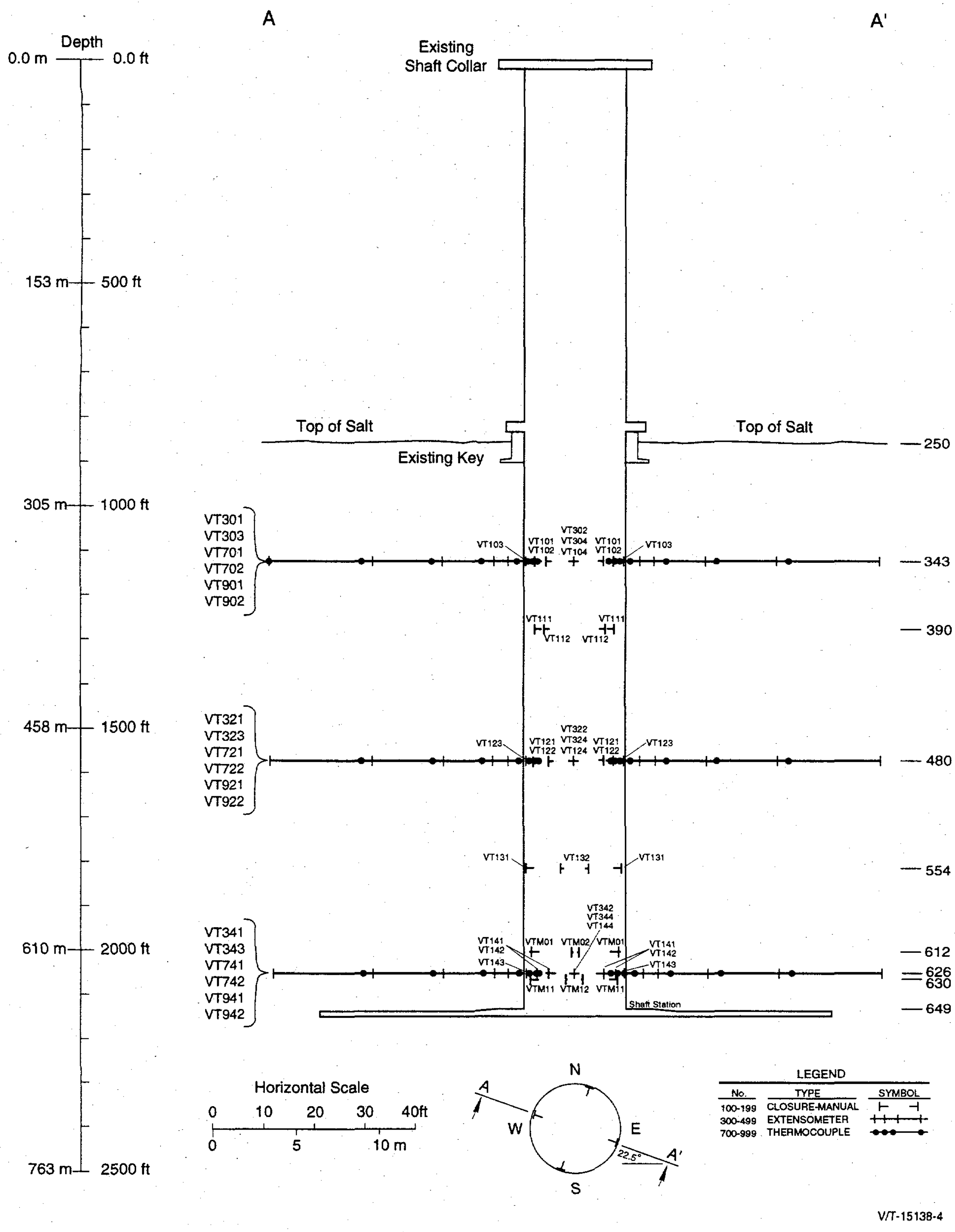


Figure 2.1.1. Vertical Cross Section of Shaft Stations

the concentration of gages at the principal stations of the test.

Cross section views of the principal stations are given for the early closure point station in Figure 2.1.2 and for the permanent stations in Figures 2.1.3a-c. As is apparent, the arrangement of gages in any cross section is generally orthogonal, except that orientations of north-south and east-west which one would normally assume have been shifted off that orientation. The shift was necessary to eliminate interference of the manual closure measurements by the guide cables of the hoist.

2.2 Construction

For this report, construction activities are summarized in abbreviated form. Only those activities relevant to this data report are noted. Construction activities are divided into mining, instrumentation, and operation. Full construction details are contained in a separate document which is in preparation.

2.2.1 Mining and Geology: The excavation of the AIS was by the raise-boring method which typically requires three or more operations. The first operation was the conventional drilling of a 228.6 mm (9.0 in.) pilot hole from the ground surface to a depth of 655.3 m (2150 ft). This pilot hole intersected a shaft station drift mined at the elevation of the underground facility. The pilot hole was then enlarged in the second operation by conventional reaming methods to a diameter of 368.3 mm (14.5 in.). The pilot hole and first reaming operations were performed between December, 1987, and April, 1988.

The third operation, using a single pass of a very large raise-boring head, was the excavation that enlarged the shaft to its final diameter. The raise-boring machine on the ground surface supplied power for both rotation and upward pull applied through a drill stem to the raise-boring

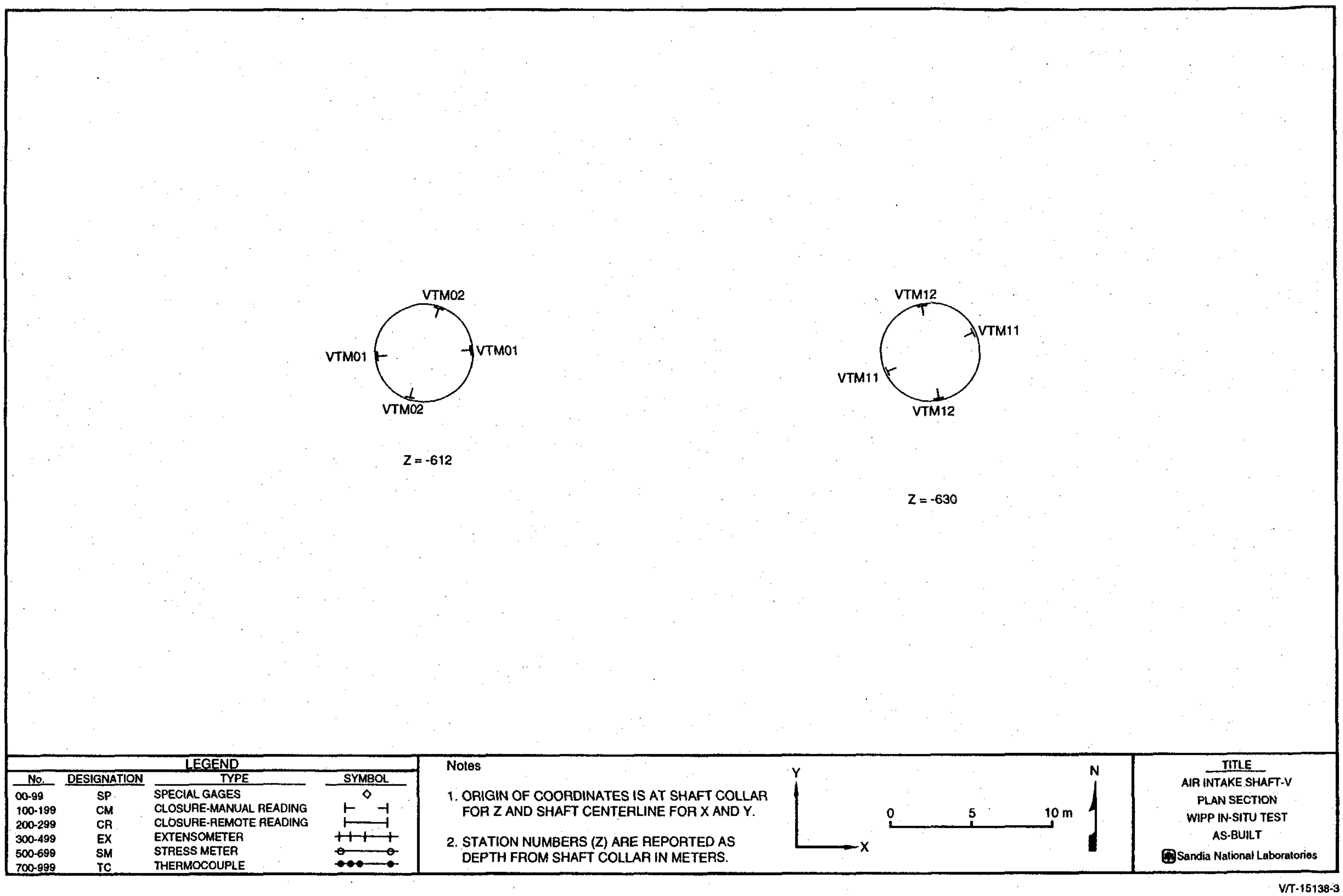


Figure 2.1.2. Cross Sections at Early Closure Stations -612 m and -630 m

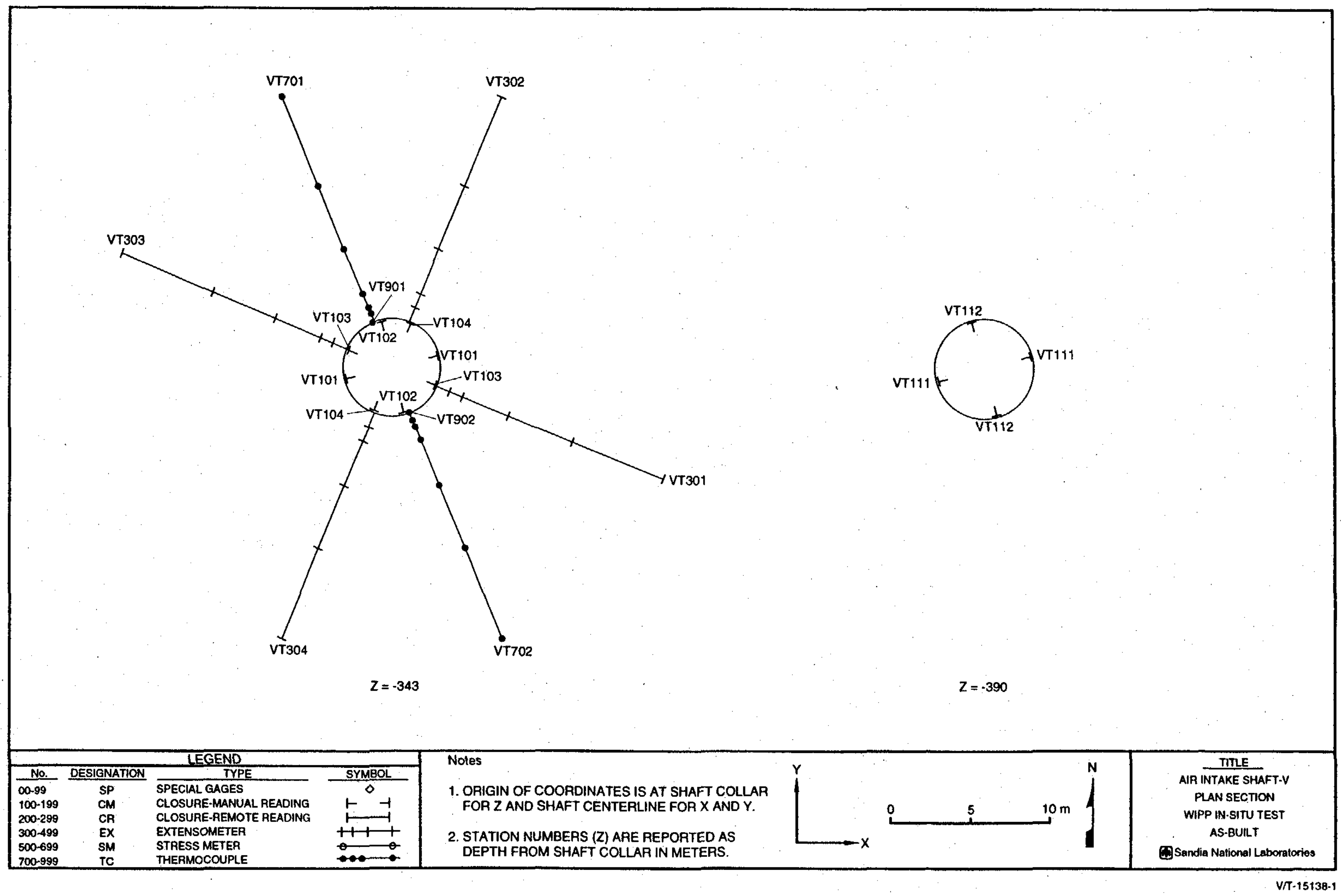


Figure 2.1.3a. Cross Sections at Stations -343 m and -390 m

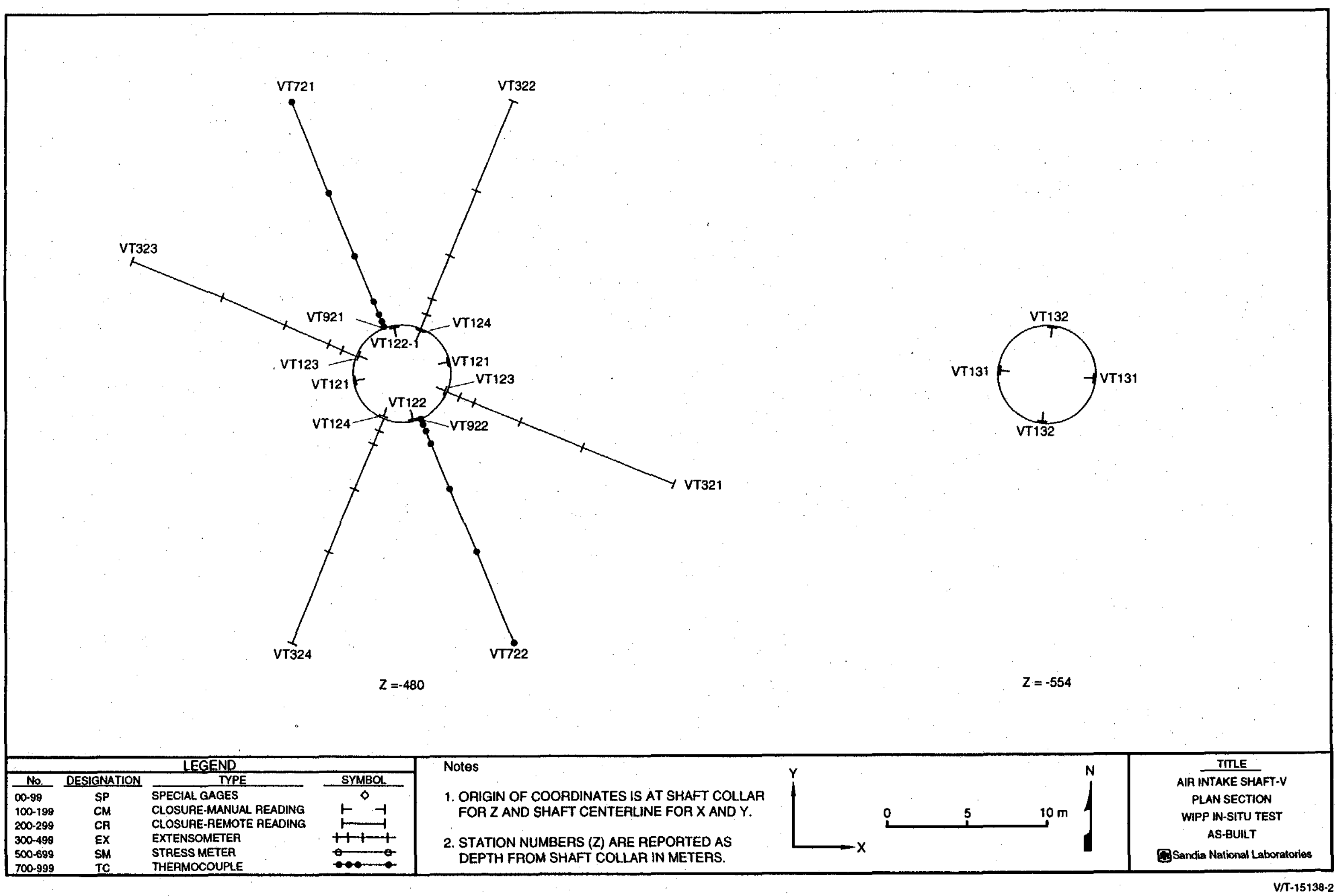


Figure 2.1.3b. Cross Sections at Stations -480 m and -554 m

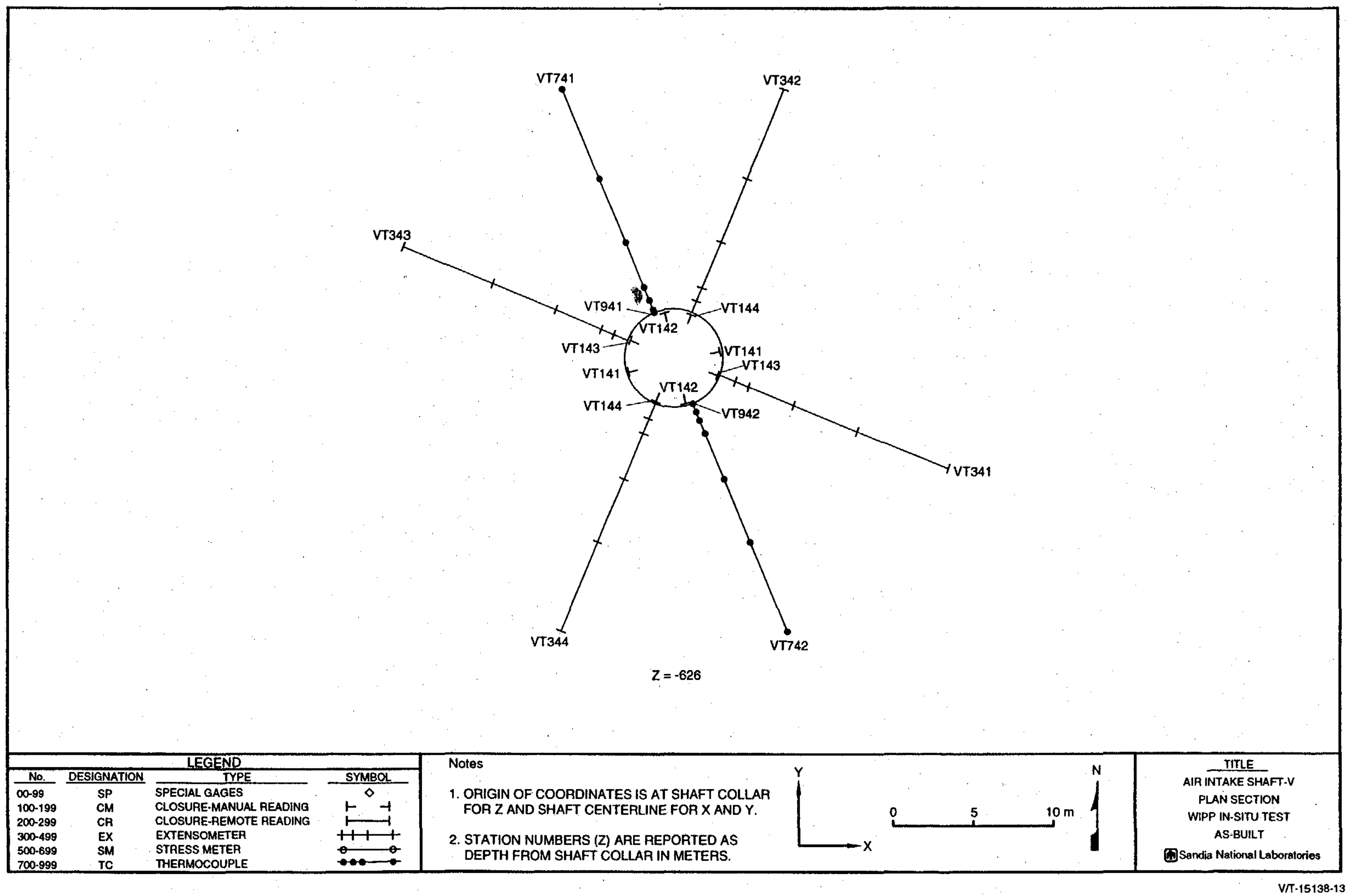


Figure 2.1.3c. Cross Sections at Station -626 m

head underground. In this manner, the shaft was progressively excavated from the shaft station to the ground surface. Figure 2.2.1 is a schematic of the shaft excavation. Figure 2.2.2 shows that the face advance of the air intake shaft initially averaged 374.9 mm (1.23 ft) per hour in the salt using the boring head. However, eventually, dull rotary bits caused the advance rate to decrease with time, especially when excavation was in the overlying, non-salt layers. The halt in advancement rate is due to the time required to replace the rotary bits. The raise-boring operation began on May 1, 1988, and was stopped for thirty days to replace the worn drilling bits. Raise-boring was then completed on August 25, 1988.

The detailed geology of the bedded stratigraphy through which the shaft was constructed is quite complicated. In the initial selection of "as-requested" instrument stations for the TSI test, a stratigraphy obtained from the earlier shafts was used to assure the stations were located in relatively thick layers of salt. Most of the salt layers were thought to be argillaceous. When the actual instrument stations were installed, the elevation was adjusted to assure the station was centered within a thick salt layer. This final selection process involved the Principal Investigator (PI) for the TSI experiment physically inspecting the shaft and individually placing each station. The stations were kept near the test plan location, if possible, and there was no intentional selection of either clean or argillaceous salt layer in this process. For the description of the stratigraphy, we will now use the actual stratigraphy as mapped for the Air Intake Shaft [18].

Although the need to know the entire stratigraphy of the shaft is important, for our purposes only the local stratigraphy at individual stations is required. Based on the elevations, or station Z coordinates,

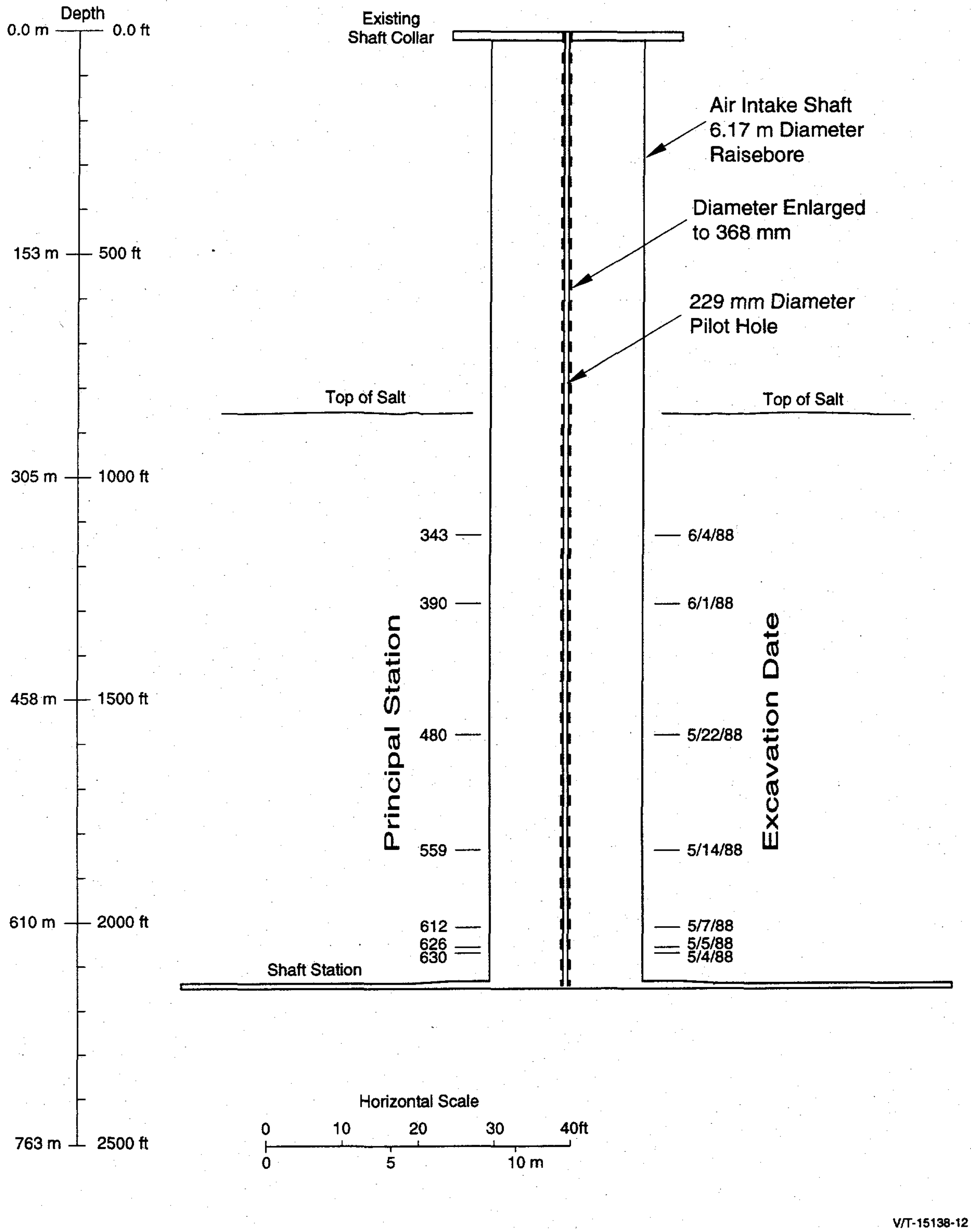


Figure 2.2.1. Schematic Drawing of the Excavation of the Shaft

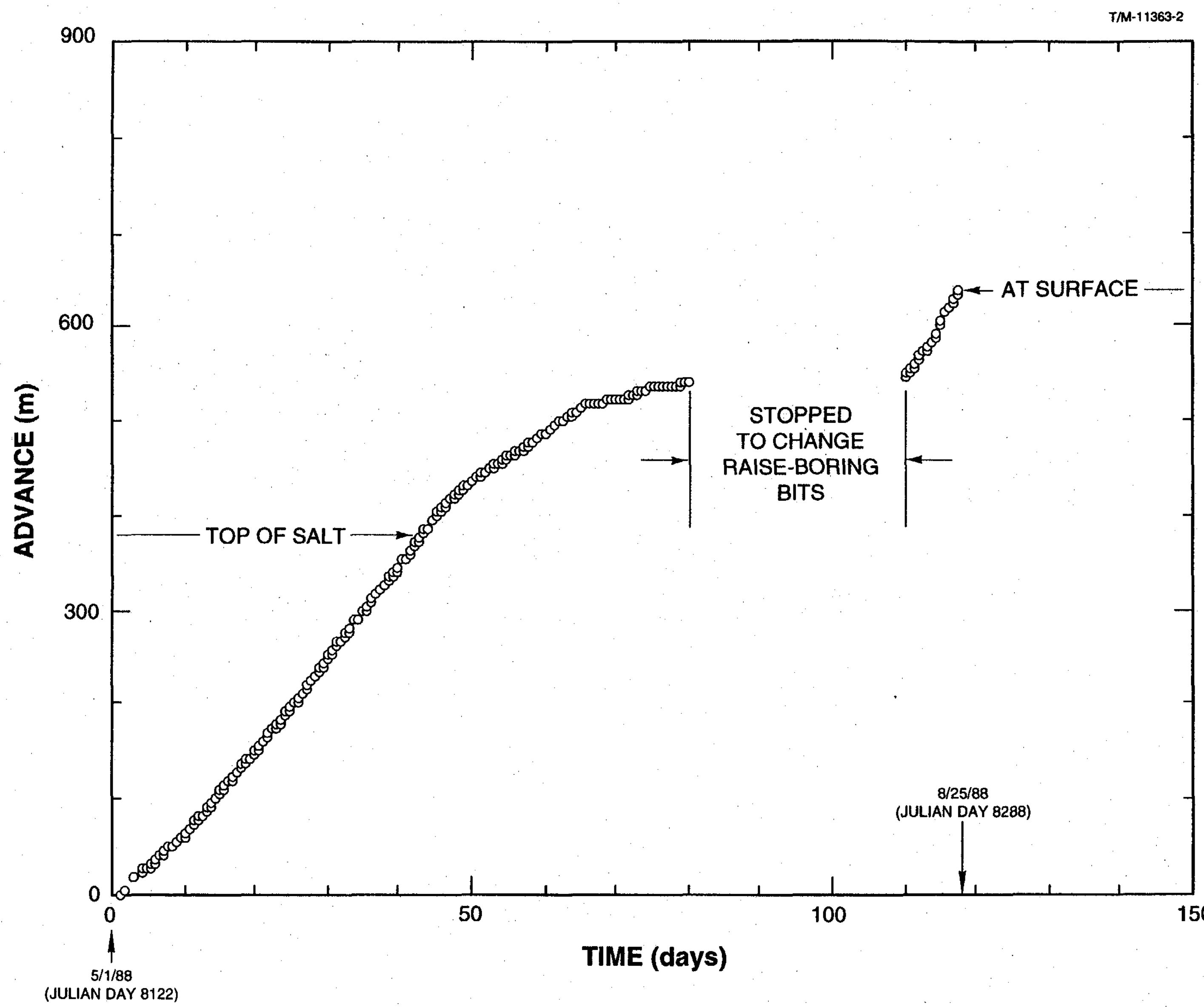


Figure 2.2.2. Advance Rate for Excavation of the Shaft

the stratigraphy immediately adjacent to the early closure point stations is given in Figures 2.2.3a-b, and to the permanent stations in Figures 2.2.4a-e. Registry between the depths of the stratigraphic mapping and the locations of the stations was obtained by using the depth markings emplaced on the shaft wall at the time of the mapping. It must be noted that the extensive (excessive) detail of the shaft mapping gives the impression of an extremely complicated structure; however, the features that give rise to this detail actually amount to only a few percent of second phase particles or clay impurities, or to just depositional variations. Visual estimates were made of the concentration of the impurities [18]. While such estimates may be in some error, the amounts given are consistent with quantitative solution residue determinations giving less than five percent clay and anhydrite by weight [19]. Most of the layers along the shaft would be considered argillaceous salt.

The simplified stratigraphy, derived from the geologic mapping [18], around the early closure point stations, which eventually became permanent closure stations, are given in Figures 2.2.3a and 2.2.3b. Station -612 is located between Marker Bed (MB) 135, which is a relatively thin anhydrite layer located some 6.7 m (22 ft) above, and MB 136, which is a quite thick anhydrite and polyhalite layer about 4.9 m (16 ft) below the station. The visual estimates of clay content are within the range of five percent. Station -630 is just 3.7 m (12 ft) below Principal Station -626 and the behavior at the two stations should act as a check on each other. The early closure Station -630 is located 9.1 m (30 ft) below MB 136, and just below the expected location of the missing MB 137, and well above the very thin MB 138 which is 9.8 m (32 ft) away. Again the salt bed contains a small amount of clay and polyhalite, estimated as less than one percent.

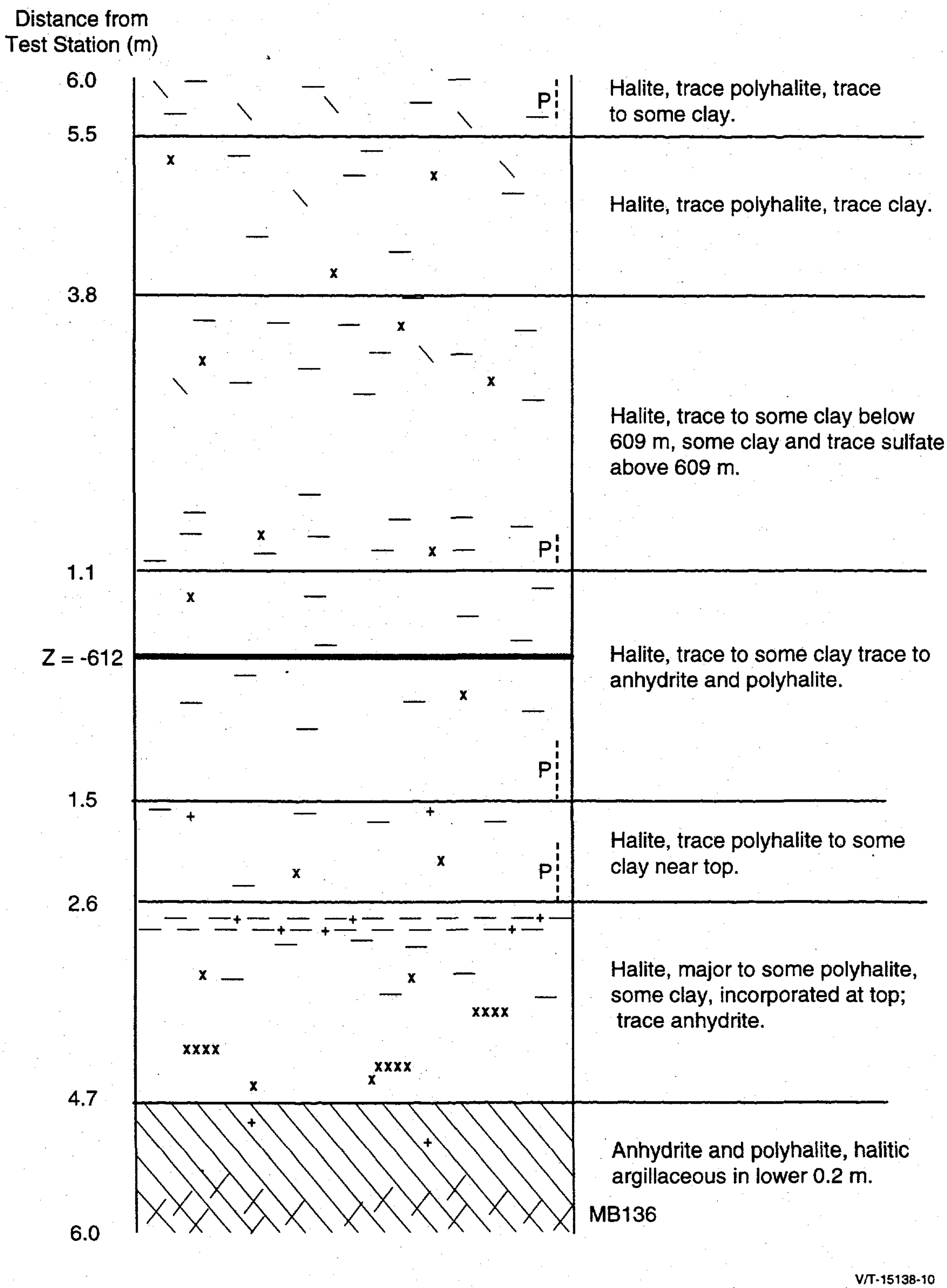


Figure 2.2.3a. Local Stratigraphy [18] at Early Closure Station -612

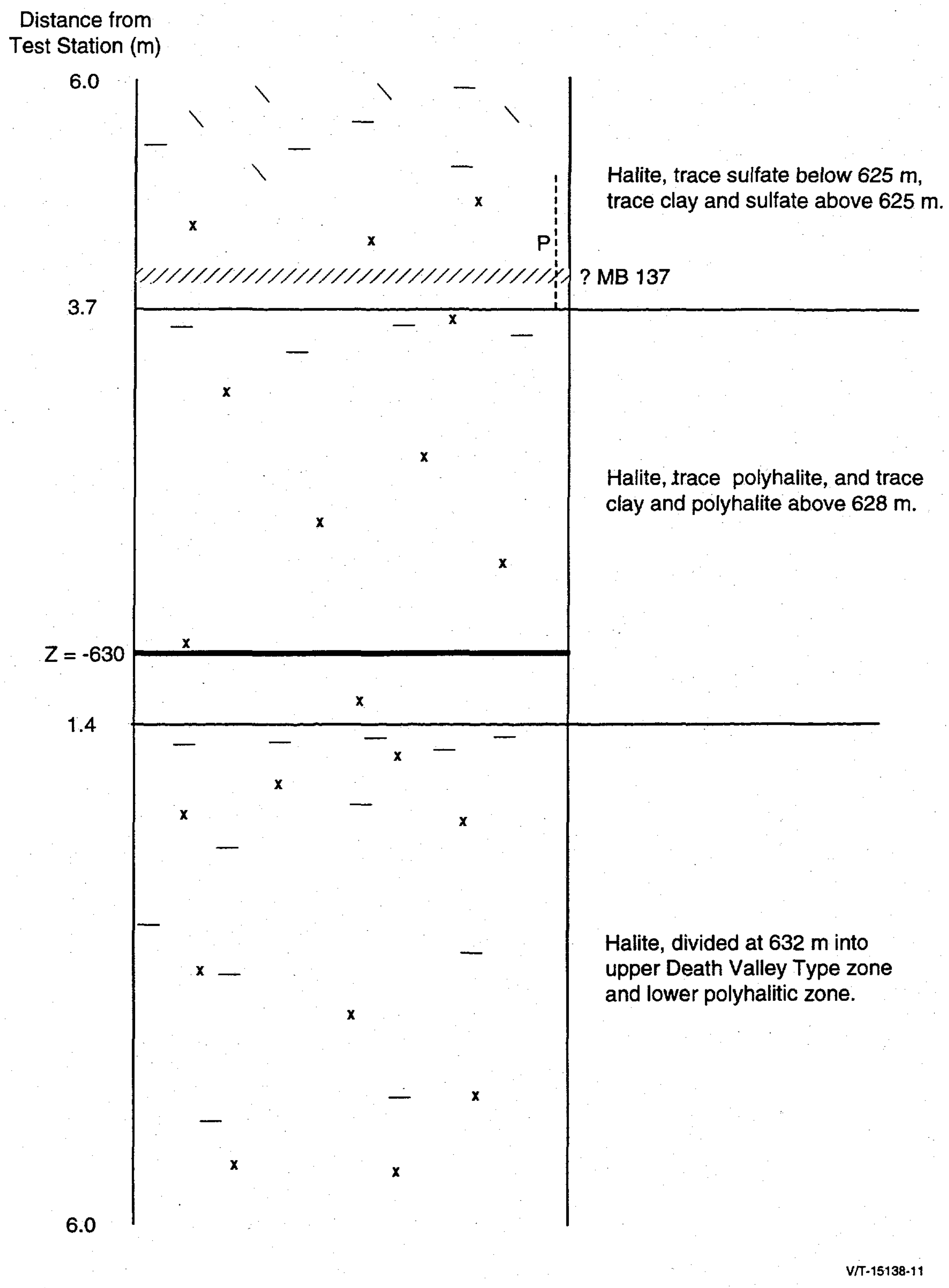


Figure 2.2.3b. Local Stratigraphy [18] at Early Closure Station -630

The stratigraphy on either side of, +/-3.0 m (+/-10 ft), Principal Station -343 is halite with less than one percent polyhalite, anhydrite and clay impurities, as shown in Figure 2.2.4a. The station is between the quite indistinct and thin MB 108 some 1.5 m (5 ft) above and the massive MB 109 below. It is however well removed, by about 4.7 m (15 ft), from MB 109. Station -390 is halite with much less than one percent polyhalite and clay, as shown in Figure 2.2.4b. This station is well removed from any anhydrite layers, with MB 112 some 13.7 m (45 ft) above and MB 115 some 12.2 m (40 ft) below. A thin polyhalite layer however is within 1.5 m (5 ft). Station -480 is halite with, again, less than one percent clay or polyhalite, as shown in Figure 2.2.4c. This station is some 12.2 m (40 ft) below the Union Anhydrite layer and roughly the same distance above MB 123 The impurity content in the intervening halite is generally less than one percent. Station -554 stratigraphy, as shown in Figure 2.2.4d, is quite consistent in configuration to the other stations, being in halite with less than one percent polyhalite and clay. This station is some 7.6 m (25 ft) below MB 130 and 13.1 m (43 ft) above MB 131. Although Station -626 appears to fall at the anticipated location of MB 137 as indicated in Figure 2.2.4e, the mapping apparently did not detect any notable anhydrite layer at this location. Instead, the data show mainly halite throughout the section, with less than one percent polyhalite, clay, and sulphur impurities. The nearest anhydrite is MB 136 some 5.2 m (17 ft) above and a very thin MB 138 (about 155 mm (6 in.)) some 13.7 m (45 ft) below the station. It is possible that the marker beds can disappear locally, which may have happened in this case.

In general, it can be concluded that the stations were all essentially located in argillaceous halite and sufficiently removed from significant

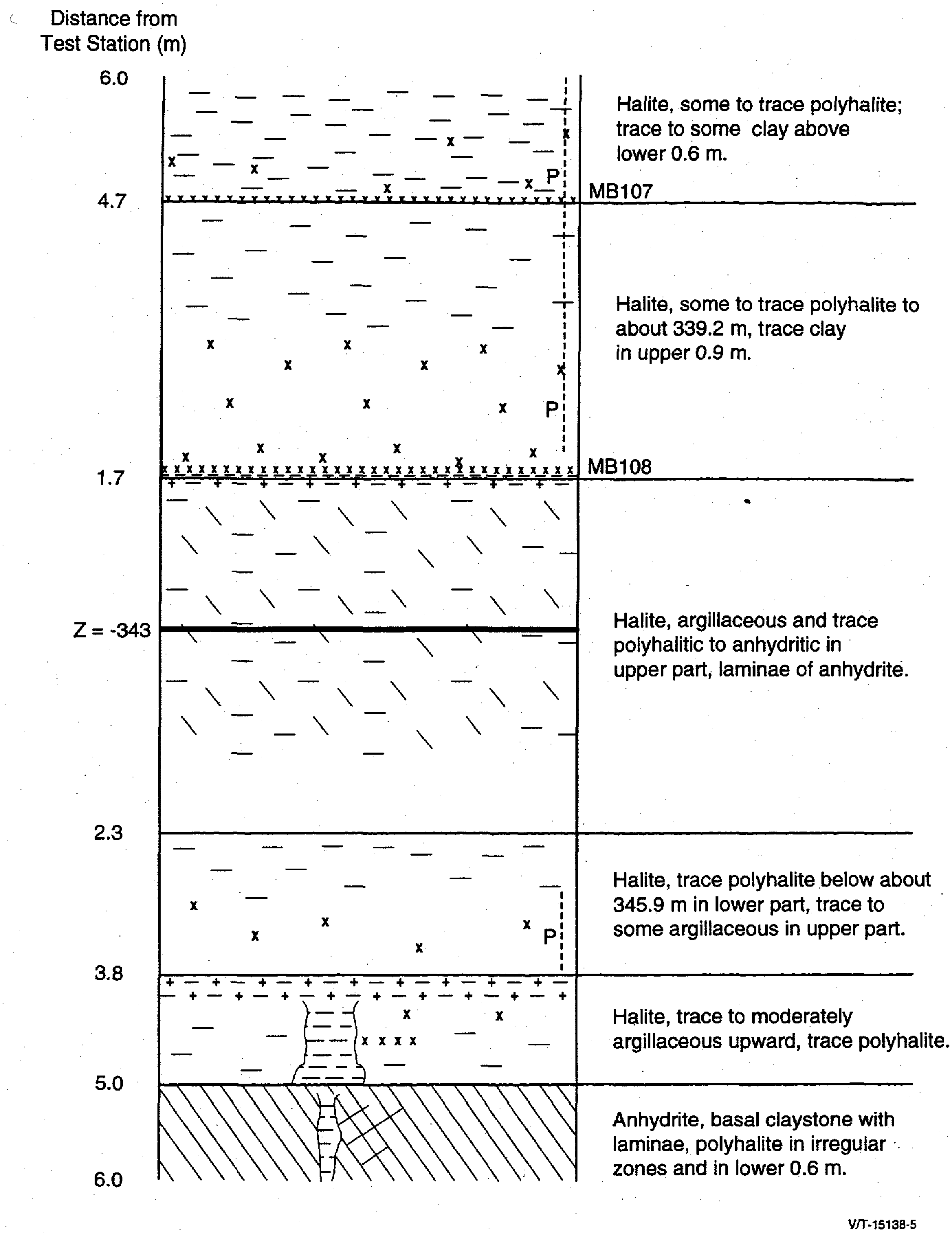


Figure 2.2.4a. Local Stratigraphy [18] at Principal Station -343

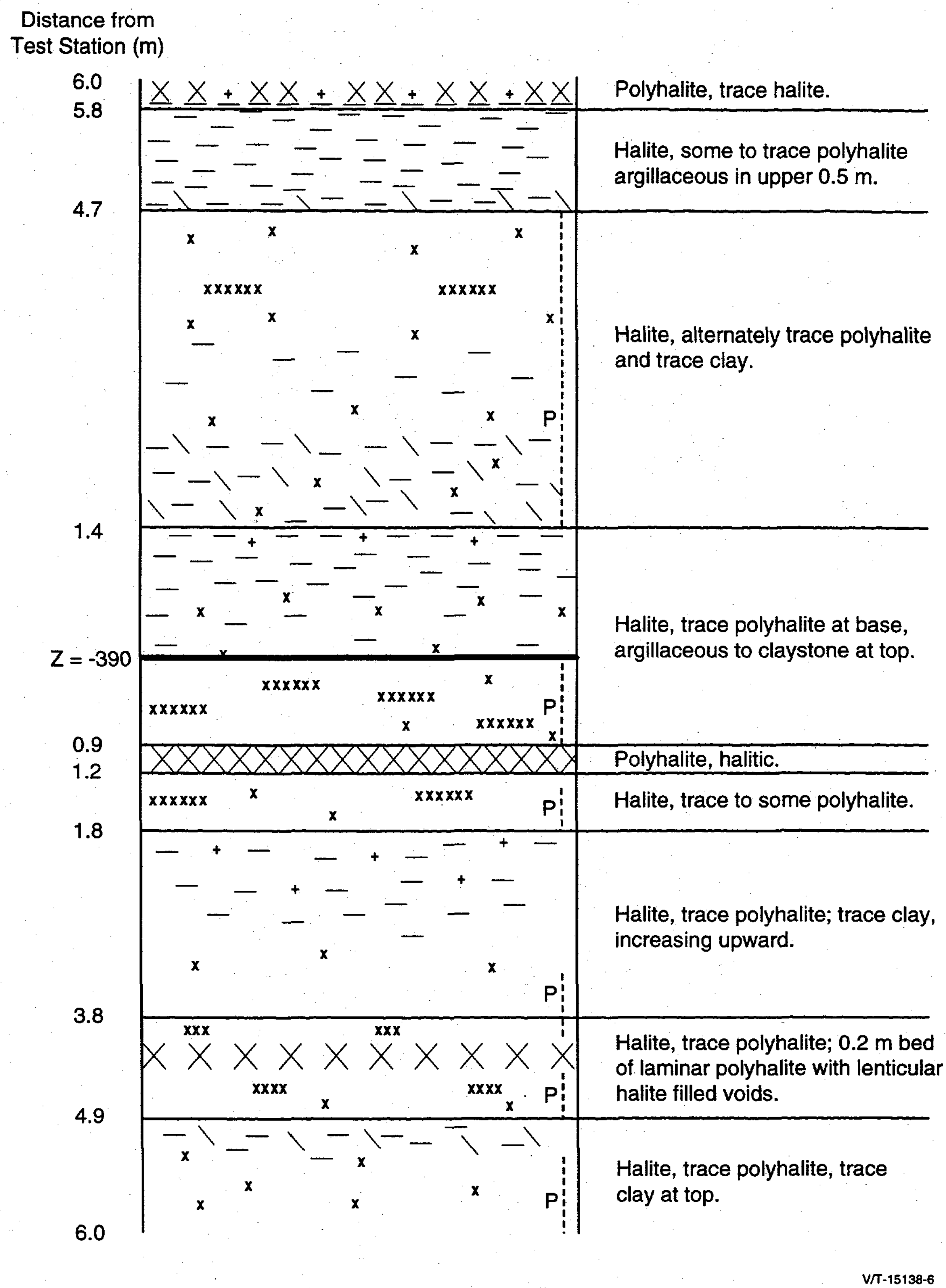


Figure 2.2.4b. Local Stratigraphy [18] at Principal Station -390

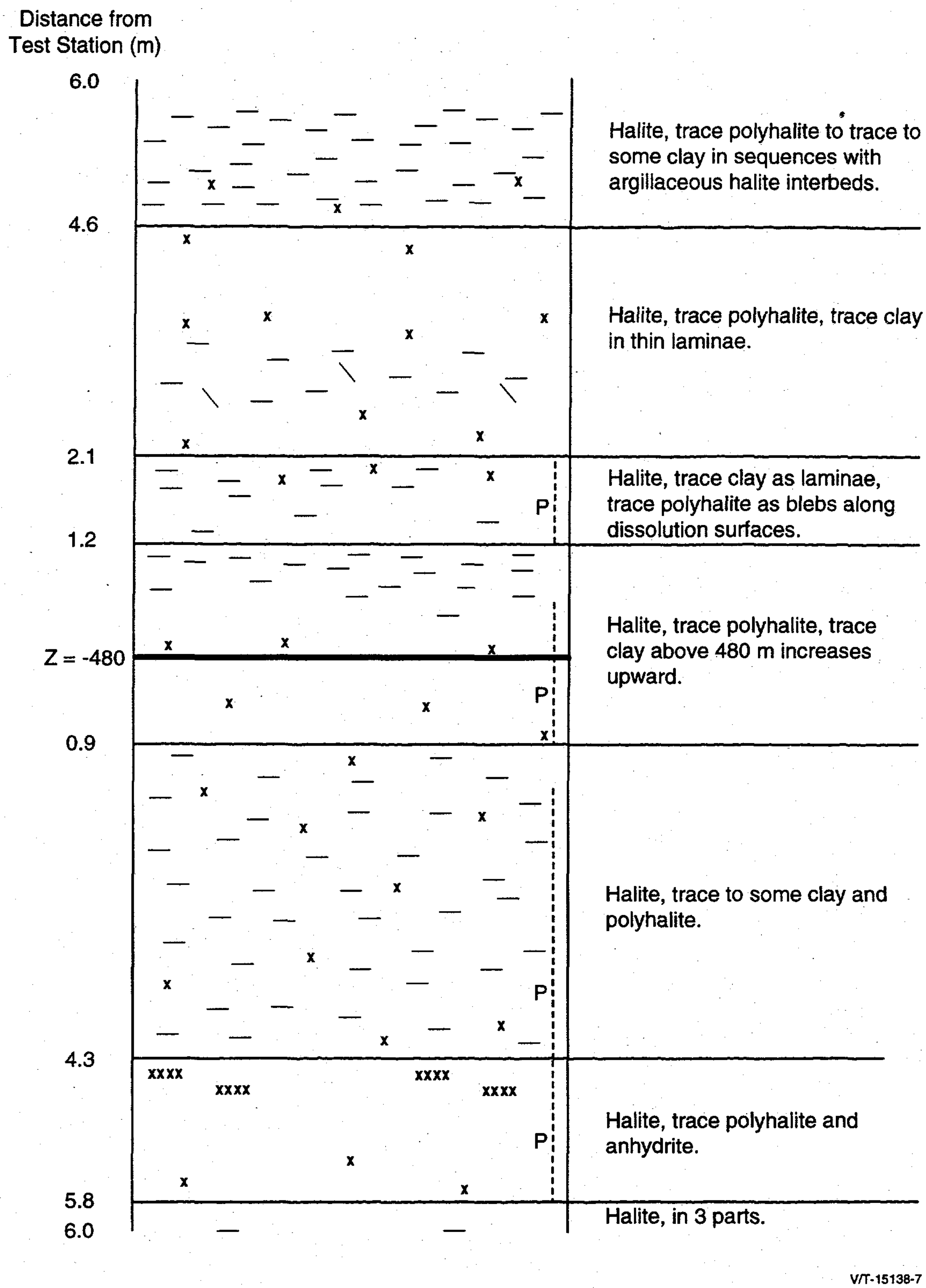


Figure 2.2.4c. Local Stratigraphy [18] at Principal Station -480

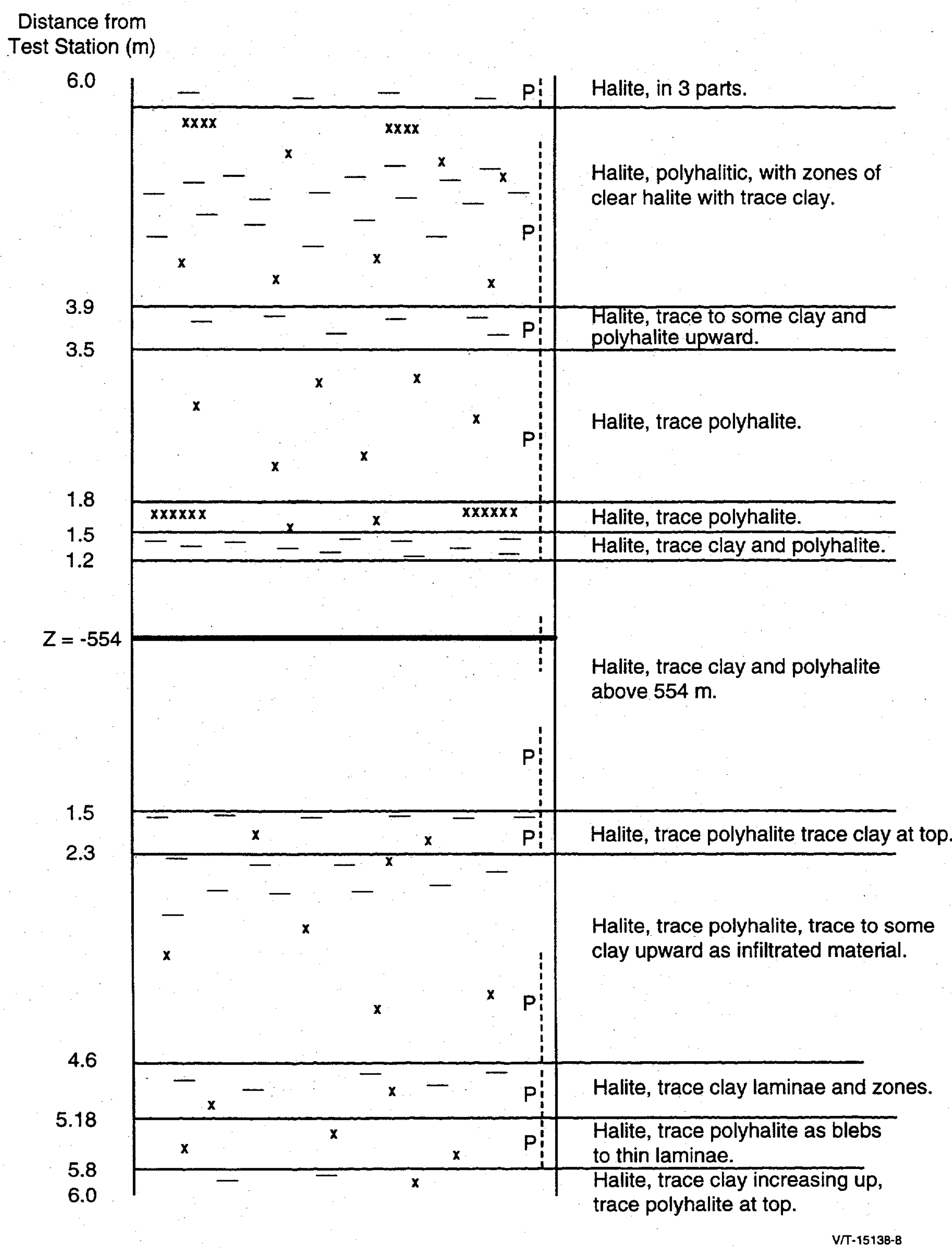


Figure 2.2.4d. Local Stratigraphy [18] at Early Closure Station -554

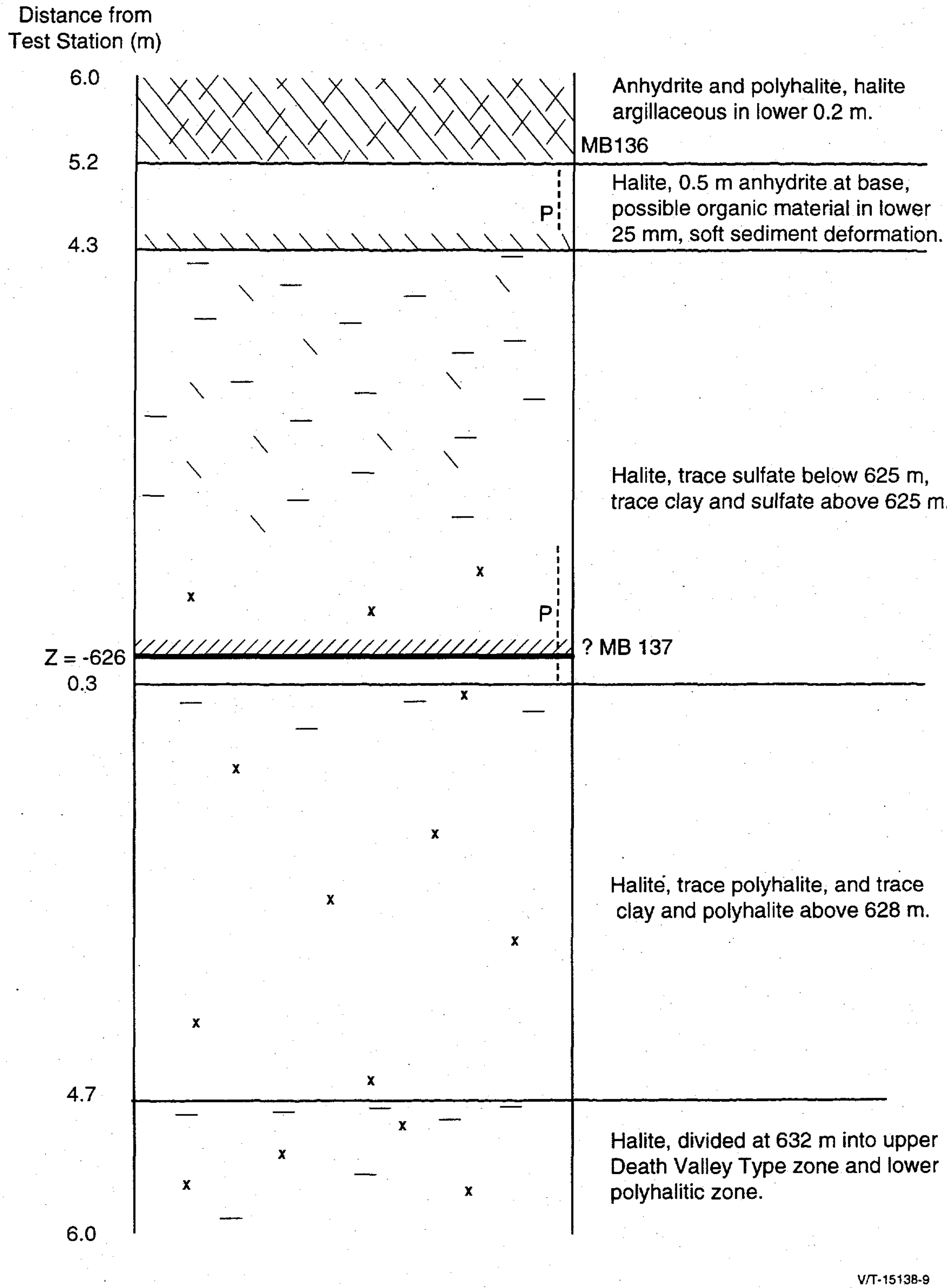


Figure 2.2.4e. Local Stratigraphy [18] at Early Closure Station -626

anhydrite beds to give unperturbed closure measurements. The only questionable locations could be Station -343, which is within about 1.5 m (5 ft) of a reasonably massive anhydrite layer, and Station -390 which is a similar distance from a relatively thin, and hence less influential, polyhalite layer.

Visual estimates of the impurity contents are thought to be self consistent and to reflect the relative amounts correctly. However, they could be somewhat in error. The visual estimations of impurity content are basically consistent with the measured content of argillaceous salt layers at the facility horizon, even though the measured content is from 2.5-3.5 percent clay, rather than one percent obtained from the visual estimates. Everything considered, this is probably too fine a judgment on the relative accuracy of the content measures; regardless of these judgments, the layers would clearly be considered as argillaceous salt.

2.2.2 Instrumentation: Installation of the early closure gages was coordinated with the raise-boring operations [15]. During excavation of the air intake shaft, the raise-boring head was advanced upward for a distance of 45.7 m (150 ft) past the first intended early closure station at -630.0 m (-2067 ft). At this point the head was lowered a distance of 7.6 m (25 ft) to prevent the head from seizing in the shaft by creep closure of the salt. A cable was lowered through the drill stem from a hoist truck on the ground surface to the facility level. This cable then picked up a specially designed closure point emplacement machine (Figure 2.2.5). Then the emplacement machine was raised into the shaft to level of the location of the closure station. The closure point emplacement machine consisted of two electric hammer drills mounted on hydraulic cylinders. Using remote controls safely located in the shaft station

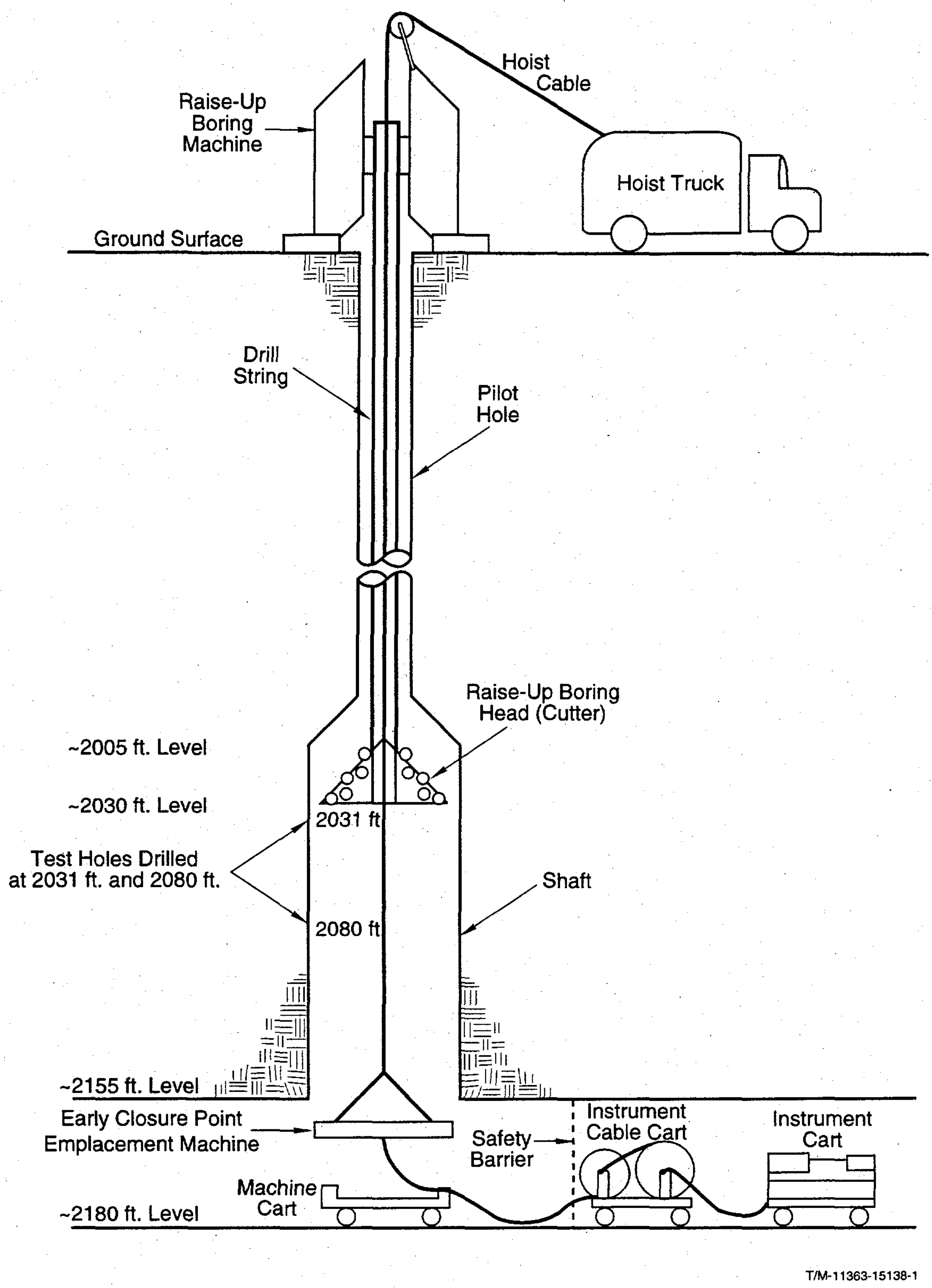


Figure 2.2.5. Schematic of the Emplacement of Early Closure Points

some 30.5 m (100 ft) from the shaft opening, it was possible to activate and advance the drills into the salt. Microswitches mounted on the drills permitted monitoring of the amount of travel for each drill. Drilling was stopped when the switches indicated the drills had advanced approximately 200 mm (8.0 in.). A calibrated linear potentiometer mounted between the drills was then used to obtain a measurement of the distance between the two emplacement drill points. After completion of the measurement, the drills were withdrawn and the sequence repeated to locate a second set of closure points orthogonal to the first set. Hydraulic cylinder pressure was monitored to ensure that the closure measurements were taken at the same static pressure. The emplacement machine was also equipped with lights and video cameras to monitor the drilling operations and a level indicator to ensure that the machine was horizontal. The sequence was repeated to locate another two orthogonal sets of closure points at the second early closure station at -611.7 m (-2007 ft). Both sets of early closure points were installed on May 8, 1988, approximately 108 hours after excavation of the -630.0 m (-2067 ft) location and about 43 hours after excavation of the -611.7 m (-2007 ft) location.

Some 18 months after these early closure points were installed, when access to the shaft was available, supplemental sets of closure points were installed at the same stations. The time delay was required for the hoist outfitting of the shaft for access and testing for proper air flow. <u>However, the readings taken during the installation of the early closure station points provided the zero displacement of these gages and all of the subsequent readings are complete closure displacements regardless of the delay in obtaining shaft access for installation of permanent closure gages.</u>

When shaft access was available, Sandia-controlled instrumentation teams were responsible for installing all permanent gages. These gages were closure gages, extensometers, and temperature gages. Installation crews were lowered to the desired shaft station elevations by hoist and then worked off of a work platform. Permanent gages were installed at the early closure stations in November 1989, with the balance of the permanent gages installed over an extended time interval, from May, 1990, to October, 1991. Permanent remote and manual gages were installed at -343 m (-1124 ft), -480 m (-1574 ft), and -626 m (-2054 ft), nominally, with additional manual closure gages installed at -390 m (-1279 ft) and -554 m (-1819 ft), again nominally. At this time a set of permanent manual gages were also installed, duplicating the early closure stations' points at -612 m (-2007 ft) and -630 m (-2067 ft). These locations were all designated as Principal Stations. When completed, seven principal stations along the air intake shaft were instrumented.

2.2.3 Operation: The test has provided data since the day the first early closure gage was installed, May 8, 1988. In practice both the permanent manual and early closure points were routinely read. However, the majority of the data are obtained from the permanent gages installed between November, 1989, and October, 1991. Routine operation of the shaft test continues and involves any necessary maintenance of gages, including repair or replacement, if possible. It also involves the continued collection of data from the test. The frequency of manual readings has diminished with time because of rather erratic accessibility of the shaft for work by the geotechnical crews. The frequency of remote reading of all active remote gages remains at the initial frequency of a reading every four hours.

2.3 Special Features

Certain special features of the fielding of the in situ tests relate directly to the analysis of the data presented here. In the AIS test, all of the gages were fielded in groupings at "principal stations," and many of the displacement gages were "linked" together, both physically and in time. As a further refinement of the AIS Test, gages are almost always related to each other by their radial or diametrical emplacement in the highly symmetrical shaft; and therefore a system of checks on gage response through gage redundancy is readily established for the test. In the AIS Test, the closure measurements at each station were redundant in that the gages were both duplicated for a given orientation and also were redundant based on symmetry for different sets of gages located at right angles to each other. The extensometers had a four-fold symmetry and the thermocouples a two-fold symmetry.

2.3.1 Principal Stations: Historically, for typical in situ tests involving underground rooms, the tests were designed assuming an ideal, flat-lying, bedded-salt stratigraphy, which is also an assumption required for analysis using two dimensional numerical models. In these cases, it was necessary to adapt the ideal design conditions appropriately to the actual field conditions of slightly dipping beds. As noted earlier, the field conditions for the excavation of rooms required following the beds because of clear partings in the roof. Actually, following the beds conforms to two-dimensionality because it preserves the fixed location of the opening with respect to the stratigraphy. However, location and installation of the gages over the total length of the room presented a problem. To minimize the problem, collections of gages were located relative to a local reference, called a principal station. Thus, it was possible to create a local reference at the principal station that was a flat-lying coordinate system with the origin centered vertically at a principal station.

For a vertical shaft, many of these concerns stated above are of little importance. The shaft penetrates normal to the beds and has such a small diameter as to make the bed dip from one side of the shaft to the other insignificant. However, we still retain the concept of a principal station for this TSI experiment. The local coordinate system is an orthogonal system in the R (radius), T (angle), and Z (vertical) directions according to the dip of the stratigraphy. Gages located within about 1 m (3 ft), sometimes somewhat more, of the principal station are designated as belonging to that principal station. This implies that the gages are all in the same geological unit or bed.

Although the details of gages shown in the cross sections of Figures 2.1.1, 2.1.2, and 2.1.3a-c are related to the principal stations, and some indication of the gages associated with the stations can be determined from the figures, Table 2.3.1 organizes the gages according to their actual groupings as they were emplaced. The table also gives the WISDAAM System directory name of the principal station as contained in the data base management system.

2.3.2 Gage Linking: All TSI experiments, including the AIS Test, were designed to obtain a complete closure data history, insofar as possible. To do this, we linked the gages in both time sequence and physical sequence. Permanent closure gage stations were located in close proximity to the early emplacement closure gage stations. As a result of this time linking, the very early closure values obtained manually at the early closure station can be linked to the later values obtained. The

Table 2.3.1 Gages Grouped By Principal Station

Station Principal (m)	(ft)	Actual Z (m)	Type	Units (Gages)
-343	(-1124)	-342.6	Closure(M)	VT101, VT102, VT103, VT104
			Extensometer	VT301, VT302, VT303, VT304
			Temperature	VT701, VT702, VT901, VT902
-390	(-1279)	-389.8	Closure(M)	VT111, VT112
-480	(-1574)	-479.7	Closure(M)	VT121, VT122, VT123, VT124
			Extensometer	VT321, VT322, VT323, VT324
			Temperature	VT721, VT722, VT921, VT922
-554	(-1819)	-554.4	Closure(M)	VT131, VT132
-612	(-2007)	-611.7	Closure(Early)	VTM01-1, VTM02-1
			Closure(M)	VTM01-2, VTM02-2
-626	(-2054)	-626.0	Closure(M)	VT141, VT142, VT143, VT144
			Extensometer	VT341, VT342, VT343, VT344
			Temperature	VT741, VT742, VT941, VT942
-630	(-2067)	-630.0	Closure(Early)	VTM11-1, VTM12-1
			Closure(M)	VTM11-2, VTM12-2

distances between these different gage stations were intentionally minimized so as to introduce as little error as possible when the data were linked to give the complete history of salt displacement at a given station. Time linking of closure data is discussed in terms of analysis in earlier papers [20, 21], and is not treated further in this report.

Physical linking of the gages pertains only to permanent displacement gages associated with a given principal station. Physical linking originates in the details of gage installation in collared holes. All of the permanent gages were installed on 0.533 m (21.0 in.) long flanged pipe collars grouted 0.457 m (18.0 in.) into the salt. The outer flange surface of the collars served as the reference surface from which all distances for installation, as-built surveys, and displacement were measured. In the case of the multipoint extensometers, the gage or unit was attached to or measured at the collar reference flange surface. In the case of closure gages, the gage point was placed on the reference collar. The sharing of a common reference surface means that the displacements measured by the appropriate linked gage at a principal station are in a continuous system, directly related to each other.

The AIS TSI experiments, as noted earlier, did not include any permanently installed remote closure gages because these would interfere with normal operation of the hoisting system.

Measurement of the distance between the closure points installed with the early emplacement machine was taken using a standard carpenter's visual tape measure and drill bits used as pins inserted into the drill holes. Measurements of the permanent manual closure gages were taken using calibrated extensometer tape measures. The conditions of taking such measurements from an unstable platform of the cage, with guide cables and cage equipment obstructing easy access, where the gage points are not in easy reach, and in the very strong wind of the air flow made the physical process of measuring difficult. As a result, the closure measurements may contain some additional scatter in the data, which is not typical of the normal TSI closure data.

It should be noted that the other subtests, such as permeability, ultrasonic, etc., were often placed in close proximity to the TSI gages. The intent was to have the TSI subtest provide supporting data to these other measurements, where it was possible and important to do so.

<u>2.3.3 Special Gage Groups:</u> There are collections of gages that have special relationships to each other, even though they may be distributed

throughout the test configuration. These gages form logical groups that are treated as an analysis entity because they describe an important material behavior, a room response, or a necessary parameter of the experiment. The early closure point gage emplacements when taken with the mining sequence gages installed at the same locations might be considered as a special group because of the unusual method of installation, and the fact that they represent nearly the complete displacement history. This makes them equivalent to the special group of mining sequence gages from the other TSI tests [12].

3 DATA REDUCTION PROCESS

The critical nature of data used in any development or process involving repositories for the disposal of radioactive waste requires that all data collection, reduction, and analysis must be formally documented. This documentation formalism is certainly necessary for the Research and Development (R&D) activities of the technology development program, of which the TSI in situ tests are a part. As the TSI Program was implemented, it expanded to include any TSI tests that were fielded in addition to the original plan. As a result, all of the procedures and methods apply to the Air Intake Shaft Test. Data reduction for this test forms a special part of a larger data collection, analysis, management, and documentation system developed for all the TSI in situ tests. This system is the WIPP In Situ Data Acquisition, Analysis, and Management (WISDAAM) System [17]. The important parts of the WISDAAM system applicable for this data report are the data reduction and the Quality Assurance (QA) procedures [22].

3.1 WISDAAM System Functions

The WISDAAM System forms the framework for the collection of data from the in situ tests. Input to the raw data base is either in the form of manual (handwritten) or remote (obtained by computer) records. Both types of records have large associated data bases. Incorporating them into a single, quality-controlled, reduced data base requires considerable care and effort.

3.1.1 Manual Data: Manual data are the handwritten records concerning nearly all aspects of the in situ test; these include far more than just the actual gage data. Although all of these records are necessary for the test results, for this report, however, only the actual gage data concern us. These data are collected from the in situ test and placed on special forms by the especially trained geotechnical teams. The forms are filed into the QA-controlled WISDAAM Notebook System as raw data. This Notebook System, which is considered as an appendix to the Test Plan for the Air Intake Shaft Performance Test [13], is maintained in the WIPP Central Files of the Waste Management Technology Library at SNL. From the raw data base, the data are entered into a computer-based data management system using dBase III. These data are then reduced at individual IBM-AT computers. The result of the data reduction process is Certified Data, which indicates that proper QA practice has been applied to the data collection and reduction. These certified data are transferred to the overall data base management MicroVAX III computer. Detailed explanations of the reduction process and the exact procedures for manual data are available [23].

3.1.2 Remote Data: The remotely collected data are obtained by the automated data acquisition system at the WIPP site [16]. Analog voltage data from individual gages are periodically interrogated by digital voltmeters located in underground instrument sheds adjacent to the in situ test. The digital data are transmitted by wire from the underground shed to a ModComp Classic 7840 computer at ground surface. These data constitute the raw remote data base. Raw engineering values are then calculated from raw voltages, gage calibrations, and conversion factors, and are stored as part of the raw data base. Periodically, the data are transferred to magnetic tape and transported to the central WISDAAM System data management MicroVAX III computer. The electronic volume of the remote data base is extremely large and can be handled only through the WISDAAM system. These tapes are considered part of the QA-controlled

WISDAAM Notebook System and are also retained in the SNL WIPP Central File. After the tapes are read by the MicroVAX III computer system, the engineering raw data are compressed and then reduced at terminals linked directly to the MicroVAX III computer system, and the resulting certified reduced data are stored in the MicroVAX III computer. Descriptions of the computer software, the data reduction system UNDERDOG, and the procedures for reduction of remote data are available [24].

3.2 Quality Assurance (QA) Requirements

Extensive QA procedures have been in practice before, during, and after fielding of the in situ tests. These QA procedures begin with the SNL Quality Assurance Program Plan [22] for the Waste Isolation Pilot Plant (WIPP), which includes all aspects of the Program, and especially those specific QA requirements of the individual test plans for the TSI in situ tests. The data in this report have been qualified through the use of an independent review team according to the Quality Assurance Procedure (QAP) 20-3 for qualifying existing data.

Although the overall QA plan has many implications for the data, we are concerned here only with the specific practices that relate to the data reduction process. The reduction process is compatible with overall QA requirements, but includes specific QA features peculiar to a working data reduction system and the WISDAAM System. As a necessary requirement of the QA practice, all the raw and reduced data bases are periodically archived on special long-life (about 25 years), maintenance-free, optical disks.

3.2.1 Reduction Levels: Because of the massive amount of raw data, the high level of overall QA, and the need to document the reduction process, the project has defined several levels of data reduction that are associated with very specific activities that govern the treatment of data:

Level 0 ---- Raw data in the form of magnetic tape or paper records. Remote raw data are stored in the MicroVAX III computer; the manual raw data in the WISDAAM Notebook System.

Level 1 ---- Remote data compressed by removing non-data zeros, system flags, and redundant data (values identical within the least significant figure); and manual data entered into the MicroVAX III computer data base.

Level 2 ---- All documented known-cause corrections to the manual and remote data are made and noted.

Level 3 ---- All undocumented known-cause corrections to the manual and remote data are made and noted.

QA Stamped-- Level 3 data that are PI approved as Certified Data, published in a data report, and available for analysis.

Level 1 data reduction is relatively straightforward. Because raw remote data are collected on a very frequent schedule, many data change only in the places beyond the least significant figure. The Level 1 activity for remote data retains only one reading when readings are identical to the place of the least significant figure. The Level 1 activity for raw manual data is its transfer under close QA checks to a computer data base.

Level 2 data reduction for both remote and manual data are the corrections taken when a planned or inadvertent human activity involving the gage or data acquisition system alters the gage reading(s). Examples are power failure, gage maintenance, gage replacement, and intentional or accidental disconnection of a gage. Because of the QA requirement to document that activity, the exact time and the exact activity are known. Correction procedures for Level 2 data reduction are thus determined by the activity which altered the gage reading.

Level 3 data reduction activities are basically routine and involve a known problem of the gage response that is not the result of a planned or accidental human action. These problems result from gage peculiarities or uncontrolled events. Examples are gage hysteresis, an unpredictable event controlled by the gage; low-resistance shorts to ground because of collection of moisture; an undetected reading error; or a necessary routine reconstruction of zeros because of destruction of a gage point. When these events occur, it is apparent from a characteristic signature of the gage response; thus corrective data reduction actions can be determined and applied routinely.

In developing the data reduction procedures, we were extremely careful to assure that no activity was in the realm of analysis. In other words, no modifications or corrections were made during data reduction that required the application of abstract concepts, scientific judgments, or fundamental interpretations. Reduction levels were applied rigorously throughout the entire data reduction process for this report. All data reduction was documented by level for each gage, and these records form an important part of the data base.

3.2.2 Certified Data: After data reduction has been applied to a given gage and the data have progressed to the completion of Level 3, the PI carefully checks to determine that (1) all reduction activities are proper, (2) all relevant data for the gage are included in the records, and (3) all necessary QA requirements as specified by the Air Intake Shaft Performance Test Plan [13] according to the SNL Department 6330 WIPP Quality Assurance Program Plan [22] have been fulfilled. When it is clear that all three conditions have been satisfied, the PI is responsible for application of the PI Level 3 QA Stamp to the data, which then becomes Certified Data. Certified Data are available to analysts for their use. All the data in this report are Certified.

4 REDUCED DATA PRESENTATION

Presentation of the large quantity of data from the Air Intake Shaft (Shaft V) Test, in exactly the manner matched to the needs of any specific analyst, is quite difficult. We can, however, present the data in a reasonable form and provide several keys that permit the analyst to find readily the desired collection of data. These keys will become apparent as the data are presented.

The first key is found in Table 2.3.1. Because an analysis might logically center on a principal station or special group, all gages belonging to a principal station or a special group are shown in this table to give the analyst a comprehensive overview of the location of instruments in the test. Analysis might also logically center on a gage type or gage orientation. As noted previously, the gage number (or gage designation) contains specific gage information which indicates the test room, gage type, unit number, and gage number. Thus, it is possible to determine the gage type directly from the gage number. Another key at the beginning of each of the sections is a location guide table showing the schematic location of each of the gages of that type by principal station. The guide permits identification of specialized gages peculiar to the needs of the analyst. Also, gage numbering generally follows a systematic pattern as an aid to identifying direction or location.

All the data are presented in sections according to individual gage type, beginning with manual closure data, and then remote extensometer and temperature data. All data in each section are presented by gage number in ascending order.

The format for each unit (in most cases a unit consisting of several gages) includes first the PI Comments on the quality and important aspects of the data reduction and the Location table specifying location and other relevant information concerning the unit (gages). The location of the gage is given in both shaft and principal station coordinates. Data for the gage(s) are then shown graphically. An explanation of each format item listed above is provided in the remainder of this chapter.

First let us consider only the remote gages. Several items in the PI Comments on remote gages require some explanation. The comments indicate the date of the evaluation, the initials of the person(s) responsible for the data reduction, and a ranking of the gage. The ranking relates to the quality of collection of the data, but not to the correctness of the data. In other words, the data could have very little meaning in terms of analysis and physical correctness and still have a high rank. Thus, the rank is actually a measure of the number of reduction actions taken during the reduction process and the severity of these actions. A specific scale based on the type, degree, and effect of the reduction activities was used to determine the gage rank value:

Rank 10 Outstanding. Very minor shifts or deletions of data, of which 95% or better are at Level 2, or data retention of 95% or better.

Rank 09 Exceptional. Reinstallation shifts and minor shifts and deletions of data, of which 90% or better are at Level 2, or data retention of 90% or better.

Rank 08 Excellent. Some additional minor deletion of data because of hysteresis at Level 3, or data retention of 80% or better.

Rank 07 Very good. All reduction actions to some degree, including up to 30% at Level 3, or data retention of 70% or better.

Rank 06 Good. All reduction actions, with marked deletions because of hysteresis, or data retention of 60% or better.

Rank 05 Fair. Marked shifts and deletions of data because of hysteresis, with up to 50% at Level 3, with some of the major shifts undocumented at Level 2 (called arbitrary), and possible swapping of data channels or entanglement of wires, or data retention of 50% or better.

Rank 04 Marginal. Marked arbitrary shifts, major deletions of hysteresis, and unknown scatter, or apparently entangled gages requiring adjustment according to other gages, or data retention at only 40% or better.

Rank 03 Poor. Required excessive reduction, with adjustments according to other gages and sources, or data retention of only 30% or better.

Rank 02 Very poor. Excessive reduction, with reporting of data only for possible supporting information, or data retention at 20% or better.

Rank 01 Unacceptable. Reported primarily to show experimental problems, data retention less than 20%.

Rank 00 No Data. No data reduction possible for gage.

The PI Comments conclude with the Level 1 compression ratio for the unit or gage, which is the ratio of the number of raw data points to the number of Level 1 data points. The completely automatic Level 1 reduction for remote gages incorporates data compression. This is necessary because of the extremely large data base involved. Data are compressed according to three rules: (1) data that are identical to within the significant figure (range) are redundant, and only one data point needs to be retained; (2) a data point will be retained every 3 days even though it may be redundant; (3) if a data point is retained on any gage of a unit, all comparable data points on that unit are retained.

For all of TSI remote-gage data obtained from the Air Intake Shaft Test (Shaft V), the least significant figures (ranges) are given by the following:

Time:	0.01 Jday (15 min).
Closure (displacement):	0.10 mm (0.004 in.).
Extensometer (displacement):	0.10 mm (0.004 in.).
Temperature:	0.1 °C (0.056 °F).

Note that an option in Level 3 data reduction permits a compression of data similar to the Level 1 compression. This recompression option does not however affect the previous Level 1 compression ratio. The option is often applied to units where data scatter on one gage causes excessive retention of redundant data on the other gages of the unit. It is also applied to the data of gages where the least significant figure was made intentionally small. Intentionally small significant figures were usually chosen when it was not possible to set a reliable initial value for a given gage type. In some cases, after the first reduction, the observed scatter may suggest a reasonable recompression for that gage. However, it was possible to assigned a least significant figure for all of the data types of this test.

PI Comments for the manual data differ from those for remote gages. The manual gage data were not ranked since reduction actions were quite limited and involved few data. This made the meaning of ranking of less importance. Also, there was no Level 1 compression of these data, and so the compression ratio of 1:1 applies.

The Location information gives the Z coordinate of the principal station designation and the actual station for the unit or gages. Then tabular entries present the gage number and type, initial gage status (permanent or temporary), recording method (remote or manual), direction (vertical, horizontal, or diagonal), the R, T, Z coordinate pairs for both ends of the gage with a value of Z in just station coordinates (for the special conditions of this specific test), gage manufacturer, initial installation date, purchase order and item number, and comments.

Facing the PI Comments and Location page is a graph of the data for the unit or gage. Several items are included to aid the viewer. The room, gage (or unit) number, type of gage, station and principal station are shown in the upper left corner. In most cases, a cartoon cross section showing the physical location of the gage(s) is given in the upper right corner. The cartoon gives the symbol legend for the gages. Thus, a square symbol is always gage 1, a diamond gage 2, an "x" gage 3, a triangle gage 4, a circle gage 5, and a "+" gage 6. In some cases the cartoon is replaced by a conventional symbol legend. Also, the origin is linked to the calendar and Julian day (Jday) on which the gage was installed. An abbreviated form of Julian day is used in which the first two numbers are the number of years since 1980 and the remaining numbers are the total days of the year to that day. Consequently, it is possible to arithmetically manipulate Julian days in modulo 365 (leap year 366).

All the reduced manual data are included on the graphs of these data. However, to make the graphs of the remote data clearer, we eliminated many of the actual data points so that the symbols are distinct. The increased clarity is illustrated by comparing Figure 4.0.1, which is an extensometer plot containing all of the Level 3 data points, and Figure 4.0.2, which is

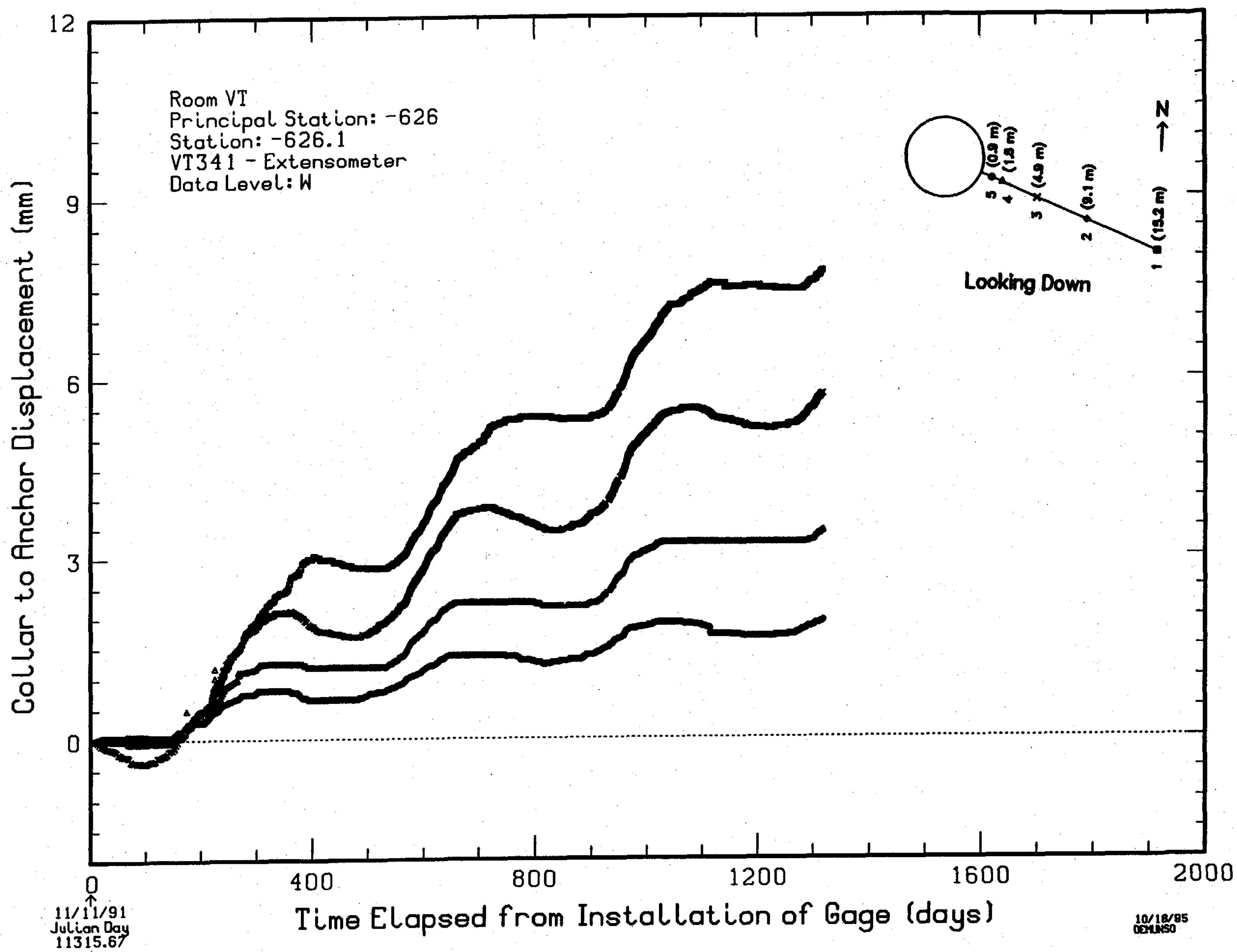


Figure 4.0.1. Extensometer Data Including All Level 3 Points (Failed Gage 2 Does Not Appear)

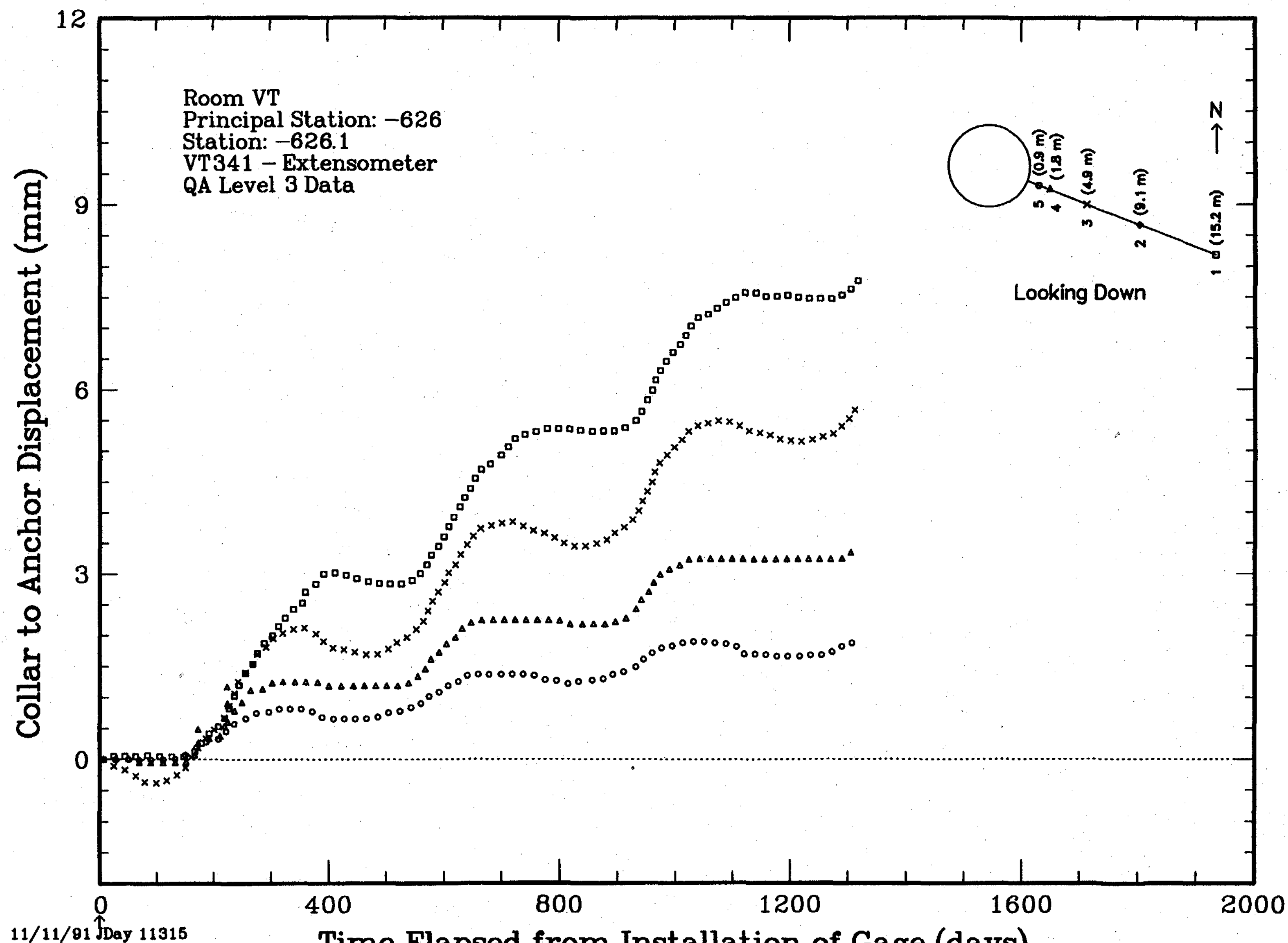


Figure 4.0.2. Extensometer Data with Overlapping Points Removed (Failed Gage 2 Does Not Appear)

the same plot after the elimination of overlapping data points. If this were not done, the data would have been so dense that the symbols would be completely illegible. This presentation clarification process is again not a true Level 1 compression. Another potentially useful feature of the graphs is that the displacements, and also temperatures, are plotted to identical (standard) scales and can therefore be easily compared directly by overlaying them.

5 REDUCED DATA

Before we discuss the data of each gage type, please note a very significant appraisal of data quality: the data to be presented are of truly high quality. This is noteworthy because they were obtained from a large-scale underground field experiment under harsh and congested environmental conditions and under occasionally difficult operational constraints, as is especially true for the shaft during construction and while in continuous operation. They would be judged of superior quality even against typical laboratory data obtained under ideal conditions. With time, of course, deterioration of the experiment is expected through gage failure, which means the gage cannot be repaired or replaced. For these reasons, the test was designed with at least a twofold, and most often a fourfold, redundancy.

The Air Intake Shaft Test was unique in the TSI experimental program due to the fact that remote closure gages did not supplement or replace the manual closure gages after some period of time. All of the closure measurements were taken using the special closure point installation equipment previously described or manually with a tape extensometer. As a result, only the extensometers and thermocouples were recorded remotely.

Although the shaft was not a heated experiment, thermocouples were installed as a necessary part of the experiment. This is because the intake ventilation temperature varies significantly seasonally as well as diurnally. These variations also influence the mechanical measurements.

The early closure point gages have been operational since installation on April 8, 1988, the manual closure gages since November, 1989, some extensometers since May, 1990, and the thermocouples since March, 1991.

The amount of data return was also remarkable, by any measure. Of 60 mechanical remote gages (extensometer gages), 42 temperature gages (rock mass and airstream), and 24 manual closure gages that were fielded, every gage initially produced data.

If we consider failure as a nonmaintainable condition leading to obviously incorrect data and the involuntary discontinuation of gage recording, then the gage failure rate for the remote extensometer gages in the shaft was about 26% for the period of March 1991 to July 1995. This represents 11 of the 60 gages initially active in this category. An additional 3 gages are producing little data and 2 gages have portions of data missing. All of the 48 rock mass and airstream thermocouples and the closure gages remained fully operational as of July 1995.

5.1 Displacement Measurements

Displacement measurements were from manual readings of the early emplacement closure gages installed during the raise-boring process and from permanent closure gages installed after the shaft had been outfitted for access. Displacement measurements were also obtained remotely from extensometers installed in the shaft wall after the shaft had been outfitted for access. Because of the logistics of working in the shaft while other testing was in progress, the time interval from initial gage installation to final installation of the permanent gages was quite long.

In this test, the early closure gage emplacement took the place of the mining sequence gages of the other TSI tests. These results originally were reported and analyzed in a separate publication [15] and are repeated here for completeness. They do not appear in the mining sequence gage data report [12] because they were unavailable at that time. Their inclusion here makes this report a complete record of TSI portion or subtest of the AIS Test.

5.1.1. Manual Shaft Closure Displacements: A location guide showing the schematic location of manually read gages is given in Table 5.1.1. This table shows the vertical location, and the general radial direction, of both the "early" closure point stations and permanent closure stations. The early closure point stations at two depths, -611.7 m (-2007 ft) and -630.0 m (-2067 ft), were emplaced during the raise-boring operation and are equivalent to the mining sequence gages of the other in situ tests. Station -2007 was emplaced some 43 hrs after excavation and Station -2067 was emplaced some 108 hrs after excavation.

This portion of test was unusual in that the early closure points were not part of the formal test plan. In fact, these installations were made possible only as the result of the selection of the contractor, who made the choice of the raise-boring method of excavation. Use of this method suggested the need, as well as the opportunity, to emplace these early closure stations rather than the anticipated mining sequence stations. Although the early closure point gages were not assigned any special designation, eventually, they were assigned the "M" or mining sequence designation of VTMxx-1. Thus, the early closure point stations became synonymous with the mining sequence stations of the other TSI tests.

Although the initial intent was to replace, when personnel access was possible, these early closure point stations with more substantial mining sequence type stations, this did not occur in practice. The mining sequence closure stations were not installed until shaft outfitting was completed, which was approximately 1.5 yrs after excavation. These mining sequence stations were established immediately adjacent to the early closure point stations as soon as possible. In fact, however, rather than discontinuing the measurements of the early closure stations, both sets of

Table 5.1.1. Manual Closure Units (Gages) Location Guide

Depth m (ft)	Station	Gages
0.0 (0.0)	Ground Surface	
-342.6 (-1124)	-343	[VT101 VT103 + VT104 *] [VT102]
-389.8 (-1279)	-390	[VT111 + *] [VT112]
-479.7 (-1574)	-480	[VT121 VT123 + VT124 *] [VT122]
-554.4 (-1819)	-554	[VT131 + *] [VT132]
-611.7 (-2007)	-612	[VTM01-1 + VTM01-2 *] [VTM02-2 VTM02-1]
-626.0 (-2054)	-626	[VT141 VT143 + VT144 *] [VT142]
-630.0 (-2067)	-630	[VTM11-1 + VTM11-2 *] [VTM12-2 VTM12-1]
		Shaft Station

closure points were measured. As a consequence, we have designated the initial early closure points as gage -1 and the later installed mining sequence closure points as gage -2.

Gage designations also suggest both the vertical location and orientation of the gage. Northwest-southeast oriented closure gages in the shaft are always designated VTMx1, where the final "1" is the critical indicator. The northeast-southwest oriented gages all carry a final "2" as an orientation indicator.

The appropriate early closure gage information is given in Table 5.1.2a-d and the early closure data are displayed in Figures 5.1.1a-d. These data have a significantly larger scatter when compared with other, more typical, in situ displacement data. This is a result of the rather difficult conditions under which these data are obtained. The early closure gage points for gages -1 are actually 25.4 mm (1.0 in.) drill holes in the wall of the shaft. In simulation of the original emplacement method, subsequent measurements are taken by inserting sharp pointed rods of known length into the opposing drill holes and then using a carpenter's tape to measure between the ends of the opposing rods. All of this is made more difficult by the interference of hoisting system cables and cage frame, and moreover, the cage could both swing and rotate slightly in the shaft. However, it is evident an acceptable representative average closure curve can be obtained. A more satisfactory measurement method was eventually established at these stations through permanent mining sequence emplacements. Thereafter, these mining sequence gages were measured with conventional tape extensometers. As already noted, the initial 2.6 years of data from the two early closure stations has been analyzed successfully using numerical code simulations [15]. (text continues on page 66)

Table 5.1.2a. Early Closure (Mining Sequence) Gages VTM01

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+--------------------+
|    Gage:  VTM01    |
+--------------------+
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***** VTM01 PI Comments *****

08/16/95 RLJ [94%] THIS CLOSURE GAGE WAS ORIGINALLY INSTALLED AT THE LOWER MEASUREMENT LEVELS IN THE SHAFT WITH THE EARLY POINT CLOSURE MACHINE. EIGHTEEN MONTHS LATER, CREWS GAINED SHAFT ACCESS ENABLING THEM TO MEASURE THE EARLY POINTS (DATA PLOTTED AS SQUARES) AND TO ESTABLISH NEW POINTS (EYEBOLTS) THAT COULD BE MEASURED WITH A TAPE EXTENSOMETER (DATA PLOTTED AS DIAMONDS). PLOTS SHOW MORE DATA SCATTER THAN OTHER MANUAL CLOSURE READINGS ACQUIRED IN UNDERGROUND TEST ROOMS BECAUSE THE TAPE EXTENSOMETERS WERE IMPACTED BY THE STRONG AIR FLOW. TYPICALLY, TWO TAPE EXTENSOMETERS WERE USED ON A GIVEN DAY TO RECORD DATA THEREBY EXPLAINING DUAL POINTS SHOWN AT A SINGLE TIME (X) VALUE. (DEM)

***** VTM01 Location *****

Principal Station -612
Station -611.5

								Gage Coordinates							
								Prin Stat		Room					
Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Z1 (m)	Z2 (m)	Z1 (m)	Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VTM01-1	CONV	T MAN	H	3.06	3.05	5.10	182.56	-0.3	-0.3	-611.5	-611.5	SNL	05/08/88	T91025-00	
VTM01-2	CONV	T MAN	H	3.06	3.07	4.30	183.62	0.0	0.0	-611.9	-611.9	SNL	11/22/89	T91025-00	

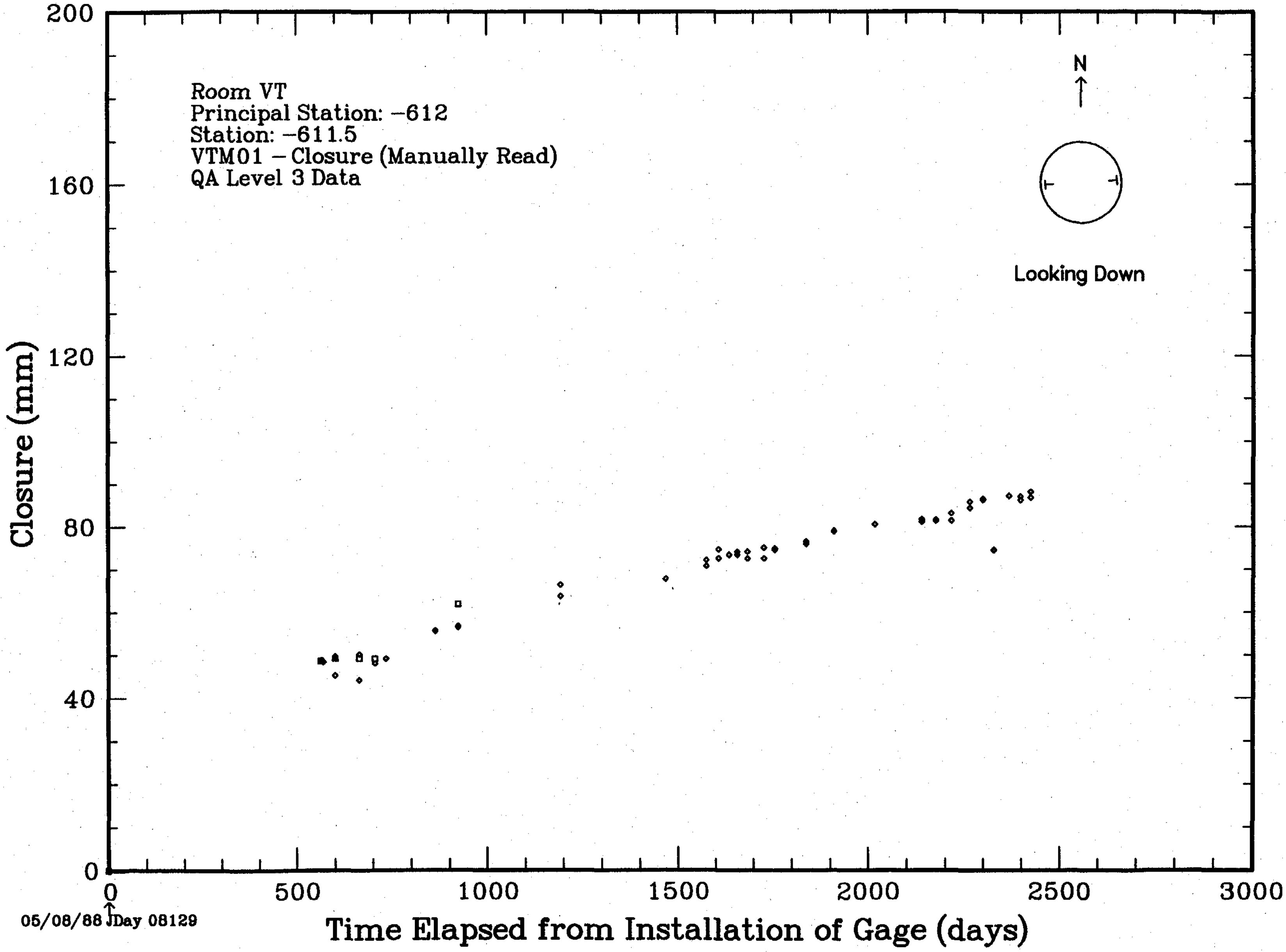

Figure 5.1.1a. Early Closure (Mining Sequence) Gages VTM01

Table 5.1.2b. Early Closure (Mining Sequence) Gages VTM02

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+--------------------+
|    Gage:  VTM02    |
+--------------------+
**********************
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***** VTM02 PI Comments *****

08/16/95 RLJ [96%] THIS CLOSURE GAGE WAS ORIGINALLY INSTALLED AT THE LOWER MEASUREMENT LEVELS IN THE SHAFT WITH THE EARLY POINT CLOSURE MACHINE. EIGHTEEN MONTHS LATER, CREWS GAINED SHAFT ACCESS ENABLING THEM TO MEASURE THE EARLY POINTS (DATA PLOTTED AS SQUARES) AND TO ESTABLISH NEW POINTS (EYEBOLTS) THAT COULD BE MEASURED WITH A TAPE EXTENSOMETER (DATA PLOTTED AS DIAMONDS). PLOTS SHOW MORE DATA SCATTER THAN OTHER MANUAL CLOSURE READINGS ACQUIRED IN UNDERGROUND TEST ROOMS BECAUSE THE TAPE EXTENSOMETERS WERE IMPACTED BY THE STRONG AIR FLOW. TYPICALLY, TWO TAPE EXTENSOMETERS WERE USED ON A GIVEN DAY TO RECORD DATA THEREBY EXPLAINING DUAL POINTS SHOWN AT A SINGLE TIME (X) VALUE. (DEM)

***** VTM02 Location *****

Principal Station -612
Station -611.9

Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Gage Coordinates Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VTM02-1	CONV	T MAN	H	3.04	3.08	71.58	252.09	0.0	0.0	-611.9	-611.9	SNL	05/08/88	T91025-00	
VTM02-2	CONV	T MAN	H	3.06	3.08	71.42	251.95	0.3	0.3	-612.2	-612.2	SNL	11/22/89	T91025-00	

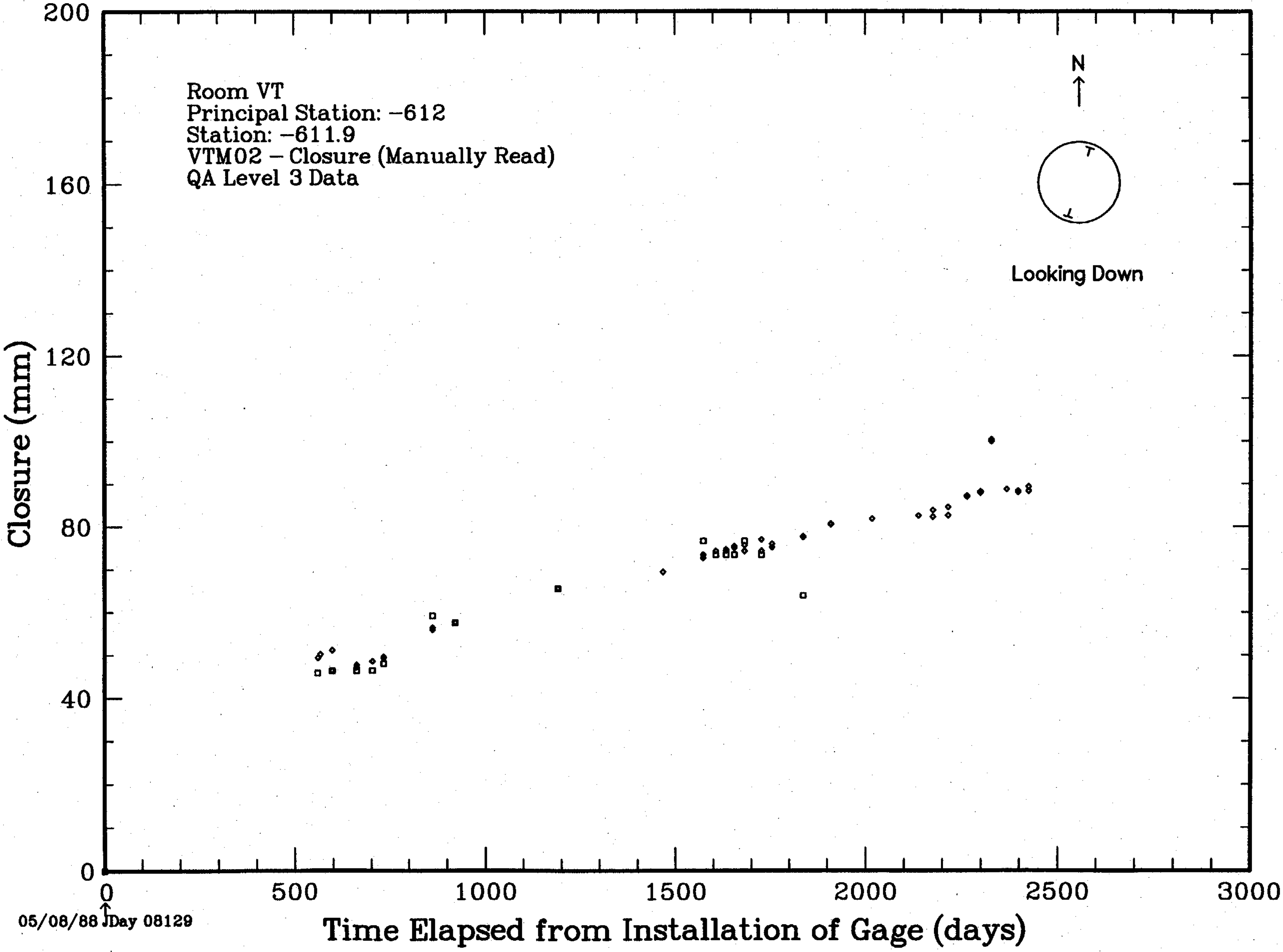

Figure 5.1.1b. Early Closure (Mining Sequence) Gages VTM02

Table 5.1.2c. Early Closure (Mining Sequence) Gages VTM11

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+--------------------+
|    Gage:  VTM11    |
+--------------------+
**********************
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***** VTM11 PI Comments *****

08/16/95 RLJ [99%] THIS CLOSURE GAGE WAS ORIGINALLY INSTALLED AT THE LOWEST MEASUREMENT LEVELS IN THE SHAFT WITH THE EARLY POINT CLOSURE MACHINE. EIGHTEEN MONTHS LATER, CREWS GAINED SHAFT ACCESS ENABLING THEM TO MEASURE THE EARLY POINTS (DATA PLOTTED AS SQUARES) AND TO ESTABLISH NEW POINTS (EYEBOLTS) THAT COULD BE MEASURED WITH A TAPE EXTENSOMETER (DATA PLOTTED AS DIAMONDS). A VERTICAL SHIFT OF DATA UPWARD ACCOUNTS FOR 25.4 MM (1 IN.) OF LOST CLOSURE WHEN CREWS RINSED OUT THE EARLY POINT HOLES WITH PRESSURIZED WATER (ONLY VTM11). PLOTS SHOW MORE DATA SCATTER THAN OTHER MANUAL CLOSURE READINGS ACQUIRED IN UNDERGROUND TEST ROOMS BECAUSE THE TAPE EXTENSOMETERS WERE IMPACTED BY THE STRONG AIR FLOW. TYPICALLY, TWO TAPE EXTENSOMETERS WERE USED ON A GIVEN DAY TO RECORD DATA THEREBY EXPLAINING DUAL POINTS SHOWN AT A SINGLE TIME (X) VALUE. (DEM)

***** VTM11 Location *****

Principal Station -629
Station -629.4

Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Gage Coordinates Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VTM11-1	CONV	T MAN	H	3.11	3.00	27.78	196.49	-0.3	-0.3	-629.4	-629.4	SNL	05/08/88	T91025-00	
VTM11-2	CONV	T MAN	H	3.18	3.06	24.69	203.52	-0.3	-0.3	-629.4	-629.4	SNL	11/20/89	T91025-00	

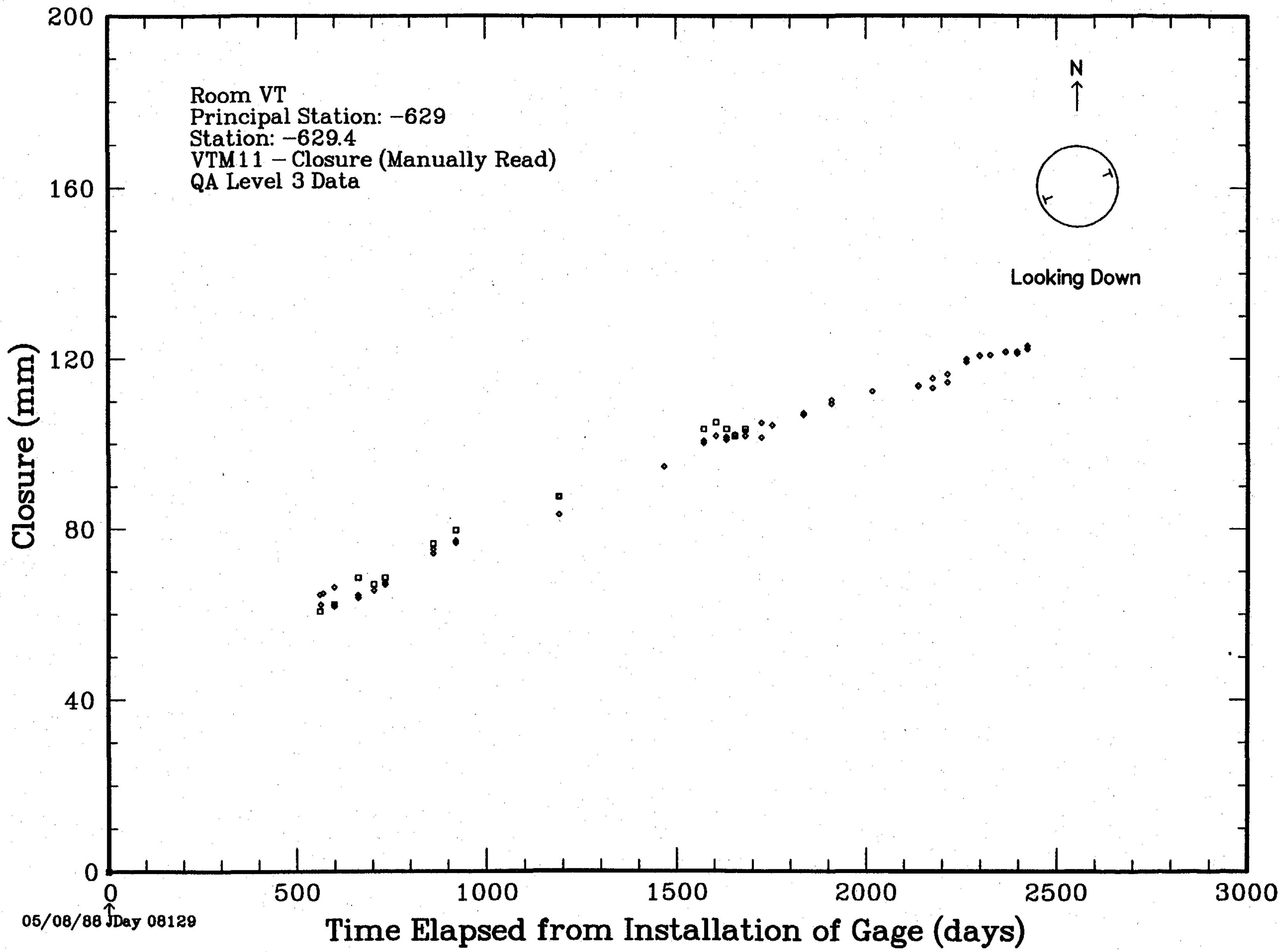

Figure 5.1.1c. Early Closure (Mining Sequence) Gages VTM11

Table 5.1.2d. Early Closure (Mining Sequence) Gages VTM12

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+---------------------+
|    Gage:  VTM12     |
+---------------------+
***********************
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***** VTM12 PI Comments *****

08/16/95 RLJ [99%] THIS CLOSURE GAGE WAS ORIGINALLY INSTALLED AT THE LOWEST MEASUREMENT LEVELS IN THE SHAFT WITH THE EARLY POINT CLOSURE MACHINE. EIGHTEEN MONTHS LATER, CREWS GAINED SHAFT ACCESS ENABLING THEM TO MEASURE THE EARLY POINTS (DATA PLOTTED AS SQUARES) AND TO ESTABLISH NEW POINTS (EYEBOLTS) THAT COULD BE MEASURED WITH A TAPE EXTENSOMETER (DATA PLOTTED AS DIAMONDS). PLOTS SHOW MORE DATA SCATTER THAN OTHER MANUAL CLOSURE READINGS ACQUIRED IN UNDERGROUND TEST ROOMS BECAUSE THE TAPE EXTENSOMETERS WERE IMPACTED BY THE STRONG AIR FLOW. TYPICALLY, TWO TAPE EXTENSOMETERS WERE USED ON A GIVEN DAY TO RECORD DATA THEREBY EXPLAINING DUAL POINTS SHOWN AT A SINGLE TIME (X) VALUE. (DEM)

***** VTM12 Location *****

Principal Station -630
Station -630.0

Gage Number	Gage Type	Rec	Dir	Gage Coordinates R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VTM12-1	CONV	T MAN	H	2.99	3.10	278.76	101.96	0.3	0.3	-630.0	-630.0	SNL	05/08/88	T91025-00	
VTM12-2	CONV	T MAN	H	3.02	3.11	280.78	98.93	0.3	0.3	-630.0	-630.0	SNL	11/20/89	T91025-00	

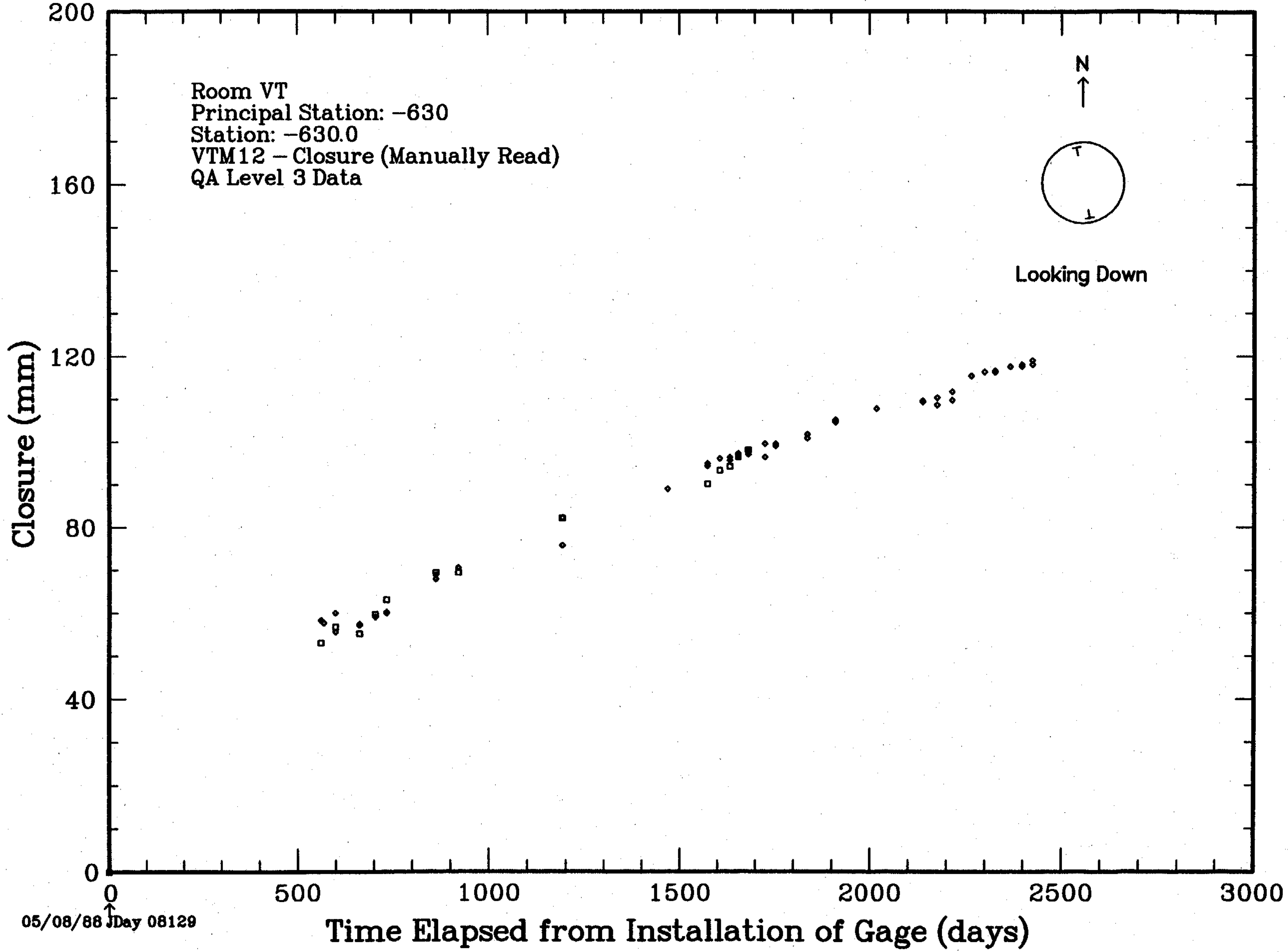

Figure 5.1.1d. Early Closure (Mining Sequence) Gages VTM12

Between about 2.9 and 3.5 years after the excavation of the shaft, subsequent to the outfitting of shaft and emplacement of the gage signal cables, the permanent gage stations were installed. All of these stations are in the salt formation. These gage locations are given schematically in Figure 5.1.1. The installations are at five stations, -342 m (-1124 ft), -389.8 m (-1275 ft), -479.7 m (-1574 ft), -554.4 m (-1815 ft), and -626.0 m (-2054 ft). As in the case of the mining sequence stations, installation of the permanent stations differed from the normal practice. Because of the difficulties in working in the shaft, typical temporary closure point installations were initially made at all five station locations. They were installed such that they are evenly distributed at 90^{o} intervals around the wall of the shaft. The units are oriented in the northwestern-southeastern (VT1x1) and northeastern-southwestern (VT1x2) directions, with designations related to the direction in the pattern noted. Later, when the extensometer gages were installed at three of these stations, -342.6 m (-1124 ft), -479.7 m (-1574 ft), and -626.0 m (-2054 ft), an additional set of permanent closure points were established on the collars of the extensometer installations, in what would be normal practice. The closure units established on the extensometer collars are colinear with the extensometers at a station. These gages are oriented in essentially the same northwestern-southeastern (VT1x3) and northeaster-southwestern (VT1x4) directions.

Data from these gages were taken by conventional tape extensometers. However, at the extensometer stations, both the initial temporary and the permanent closure points were routinely read as though they were permanent gages. At the two remaining stations, the initial temporary gages were routinely read as though they were permanent gages.

Here again, the difficulties introduced by interference of shaft cabling and the working environment resulted in considerable scatter. However, the results are actually quite adequate to show the relevant shaft closure displacements. Hidden within the scatter, and perhaps contributing to the appearance of scatter, is a sinusoidal variation of the displacement caused by the seasonal variation in temperature. As the mean intake air temperature changes, the salt in the shaft wall responds thermally. This produces cyclic variations in the measured closure that are superimposed on the long term creep closure. Although not at all clear in the closure measurements, this effect is more apparent in the displacements measured in the extensometers, where the physical measurement difficulty is not so pronounced.

The permanent closure gage information is given in Tables 5.1.3a-p and the corresponding data are found in Figures 5.1.2a-p. The data cover the time from emplacement (2.8 years) to the cut-off date for this report (7.4 years) or a duration of about 4.6 years.

Because of the differences in the installation times of the various closure gages, one must be careful in making direct comparisons of the measured closures. However, as is expected, the closure is a marked function of the vertical location of the gage. Closure at the bottom of the shaft (Station -626) is considerably larger than at the top of the shaft (Station -343). This occurs because the creep processes controlling the closure are strong functions of the stress and the stress increases with the vertical depth into the shaft. The displacement at a given time is related to the depth in the shaft taken to the 5.0 power [15], as was determined through the theoretical creep equations [25, 26].

(text continues on page 100)

Table 5.1.3a. Closure Gage VT101

```
+---------------------+
|    Gage:  VT101     |
+---------------------+
***********************
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***** VT101 PI Comments *****

08/15/95 RLJ [96%] THIS CLOSURE GAGE WAS INSTALLED AT THE UPPERMOST MEASUREMENT LEVEL IN THE SHAFT. PLOTS SHOW MORE DATA SCATTER THAN OTHER MANUAL CLOSURE READINGS ACQUIRED IN UNDERGROUND TEST ROOMS BECAUSE THE TAPE EXTENSOMETERS WERE IMPACTED BY THE STRONG AIR FLOW. TYPICALLY, TWO TAPE EXTENSOMETERS WERE USED ON A GIVEN DAY TO RECORD DATA THEREBY EXPLAINING DUAL POINTS SHOWN AT A SINGLE TIME (X AXIS) VALUE. (DEM)

***** VT101 Location *****

Principal Station -343
Station -342.8

Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Gage Coordinates Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT101-1	CONV T	MAN	H	3.11	3.11	14.28	193.69	0.0	0.1	-342.8	-342.8	SNL	11/28/89	T91025-00	

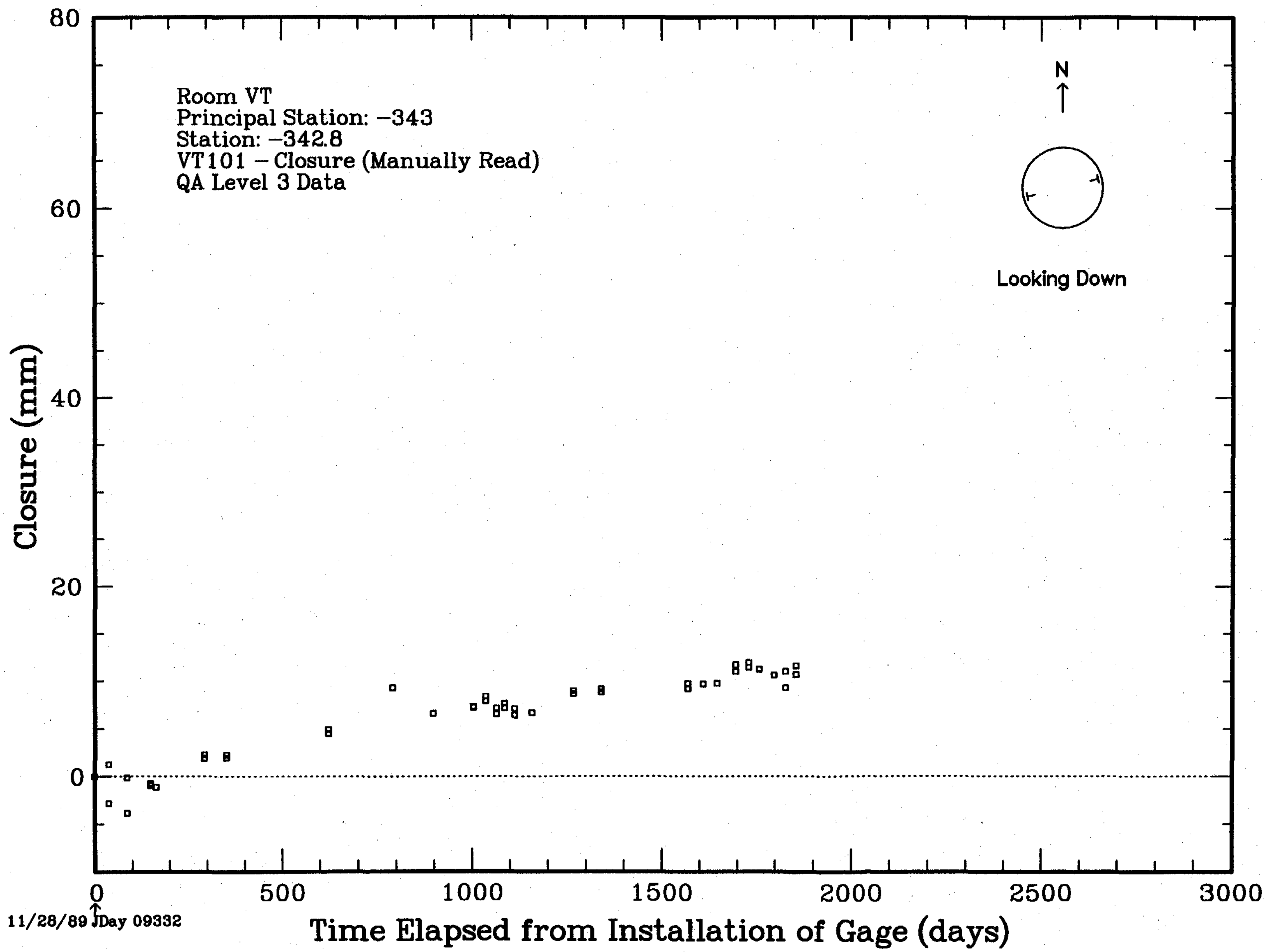

Figure 5.1.2a. Closure Gage VT101

Table 5.1.3b. Closure Gage VT102

```
+--------------------+
|    Gage:  VT102    |
+--------------------+
**********************
```

***** VT102 PI Comments *****

08/15/95 RLJ [98%] THIS CLOSURE GAGE WAS INSTALLED AT THE UPPERMOST MEASUREMENT LEVEL IN THE SHAFT. PLOTS SHOW MORE DATA SCATTER THAN OTHER MANUAL CLOSURE READINGS ACQUIRED IN UNDERGROUND TEST ROOMS BECAUSE THE TAPE EXTENSOMETERS WERE IMPACTED BY THE STRONG AIR FLOW. TYPICALLY, TWO TAPE EXTENSOMETERS WERE USED ON A GIVEN DAY TO RECORD DATA THEREBY EXPLAINING DUAL POINTS SHOWN AT A SINGLE TIME (X AXIS) VALUE. (DEM)

***** VT102 Location *****

Principal Station -343
Station -342.8

				Gage Coordinates											
								Prin Stat		Room					
Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Z1 (m)	Z2 (m)	Z1 (m)	Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT102-1	CONV T	MAN	H	3.12	3.09	285.18	103.20	0.0	0.0	-342.8	-342.8	SNL	11/28/89	T91025-00	

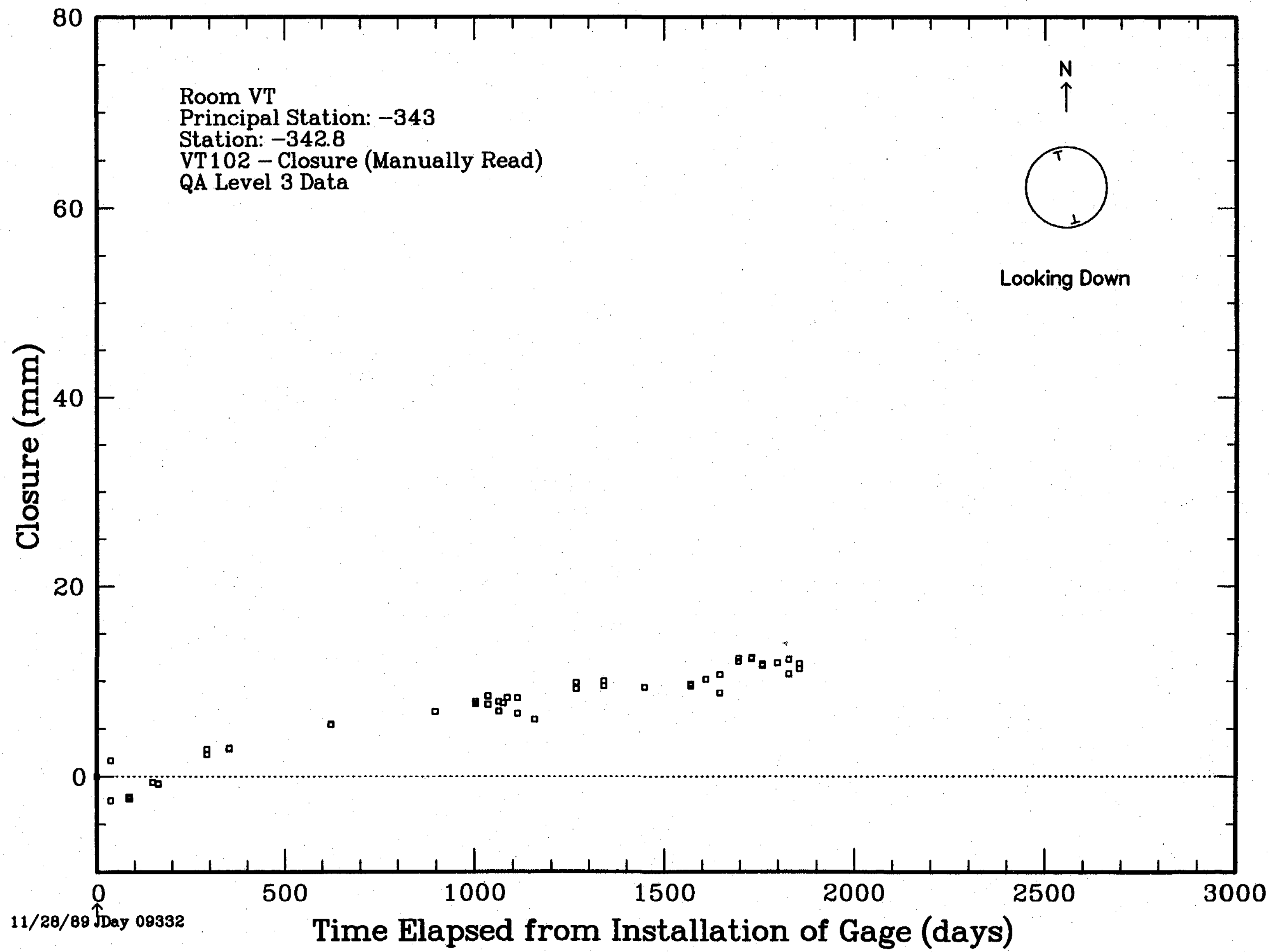

Figure 5.1.2b. Closure Gage VT102

Table 5.1.3c. Closure Gage VT103

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+--------------------+
|    Gage:  VT103    |
+--------------------+
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***** VT103 PI Comments *****

08/15/95 RLJ [100%] THIS CLOSURE GAGE WAS INSTALLED AT THE UPPERMOST MEASUREMENT LEVEL IN THE SHAFT. PLOTS SHOW MORE DATA SCATTER THAN OTHER MANUAL CLOSURE READINGS ACQUIRED IN UNDERGROUND TEST ROOMS BECAUSE THE TAPE EXTENSOMETERS WERE IMPACTED BY THE STRONG AIR FLOW. TYPICALLY, TWO TAPE EXTENSOMETERS WERE USED ON A GIVEN DAY TO RECORD DATA THEREBY EXPLAINING DUAL POINTS SHOWN AT A SINGLE TIME (X AXIS) VALUE. VT103 WAS INSTALLED DIRECTLY ON THE COLLARS OF HOLES VT301 AND VT303. (DEM)

***** VT103 Location *****

Principal Station -343
Station -342.7

Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Gage Coordinates Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT103-1	CONV	P MAN	H	3.07	3.08	157.21	337.77	0.0	0.0	-342.7	-342.7	SNL	05/07/90	T91025-00	

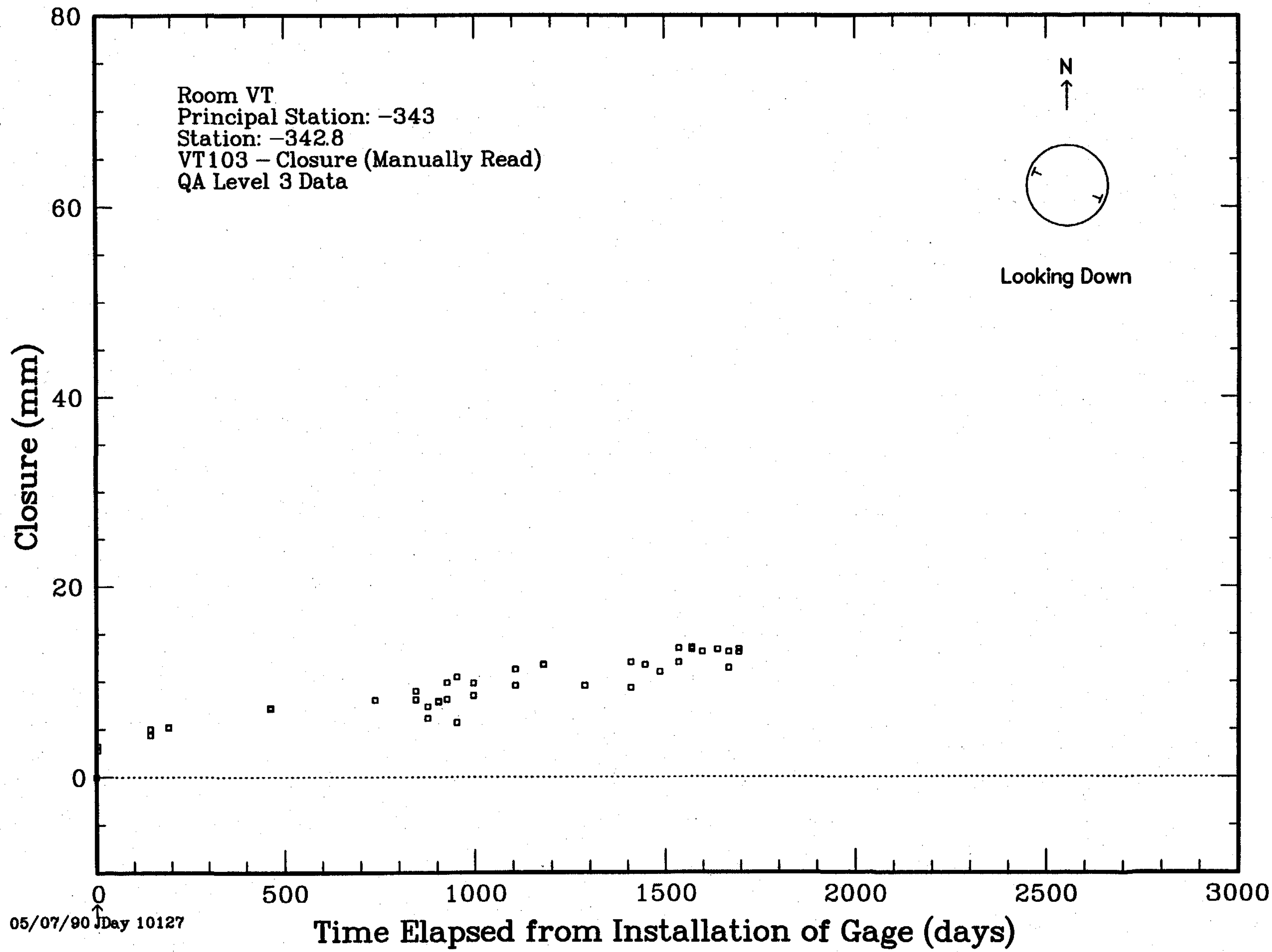

Figure 5.1.2c. Closure Gage VT103

Table 5.1.3d. Closure Gage VT104

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+--------------------+
|    Gage:  VT104    |
+--------------------+
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***** VT104 PI Comments *****

08/15/95 RLJ [100%] THIS CLOSURE GAGE WAS INSTALLED AT THE UPPERMOST MEASUREMENT LEVEL IN THE SHAFT. PLOTS SHOW MORE DATA SCATTER THAN OTHER MANUAL CLOSURE READINGS ACQUIRED IN UNDERGROUND TEST ROOMS BECAUSE THE TAPE EXTENSOMETERS WERE IMPACTED BY THE STRONG AIR FLOW. TYPICALLY, TWO TAPE EXTENSOMETERS WERE USED ON A GIVEN DAY TO RECORD DATA THEREBY EXPLAINING DUAL POINTS SHOWN AT A SINGLE TIME (X AXIS) VALUE. VT104 WAS INSTALLED DIRECTLY ON THE COLLARS OF HOLES VT302 AND VT304. (DEM)

***** VT104 Location *****

Principal Station -343
Station -342.7

Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Gage Coordinates Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT104-1	CONV	P MAN	H	3.09	3.06	247.44	67.54	0.0	0.0	-342.7	-342.7	SNL	05/07/90	T91025-00	

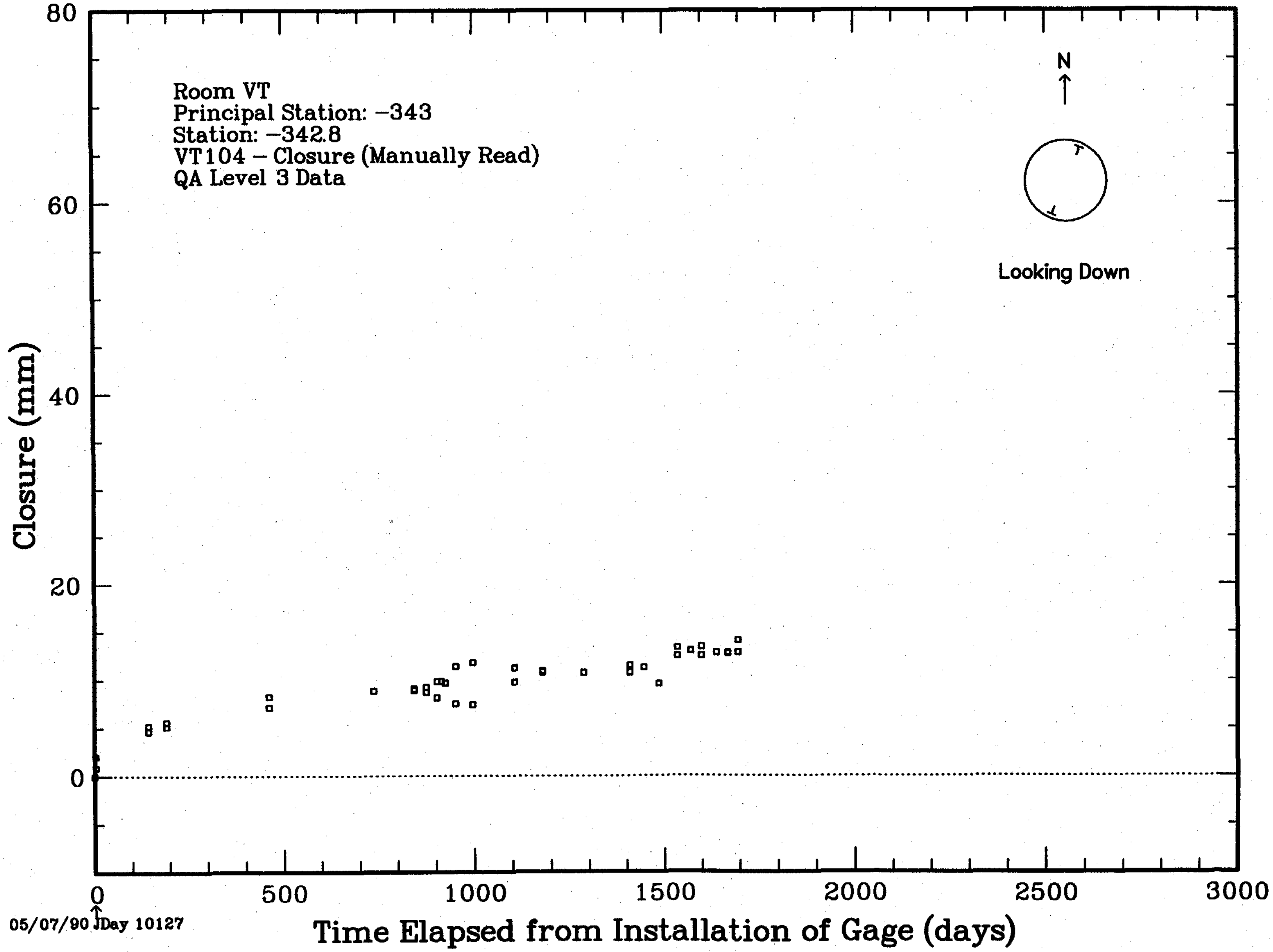

Figure 5.1.2d. Closure Gage VT104

Table 5.1.3e. Closure Gage VT111

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+---------------------+
|   Gage:  VT111      |
+---------------------+
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***** VT111 PI Comments *****

08/15/95 RLJ [98%] THIS CLOSURE GAGE WAS INSTALLED AT THE 2nd HIGHEST MEASUREMENT LEVEL IN THE SHAFT. PLOTS SHOW MORE DATA SCATTER THAN OTHER MANUAL CLOSURE READINGS ACQUIRED IN UNDERGROUND TEST ROOMS BECAUSE THE TAPE EXTENSOMETERS WERE IMPACTED BY THE STRONG AIR FLOW. TYPICALLY, TWO TAPE EXTENSOMETERS WERE USED ON A GIVEN DAY TO RECORD DATA THEREBY EXPLAINING DUAL POINTS SHOWN AT A SINGLE TIME (X AXIS) VALUE. (DEM)

***** VT111 Location *****

Principal Station -390
Station -390.0

Gage Number	Gage Type	Rec	Dir	Gage Coordinates R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT111-1	CONV T	MAN	H	3.08	3.11	15.52	195.72	0.0	0.1	-390.0	-390.0	SNL	11/27/89	T91025-00	

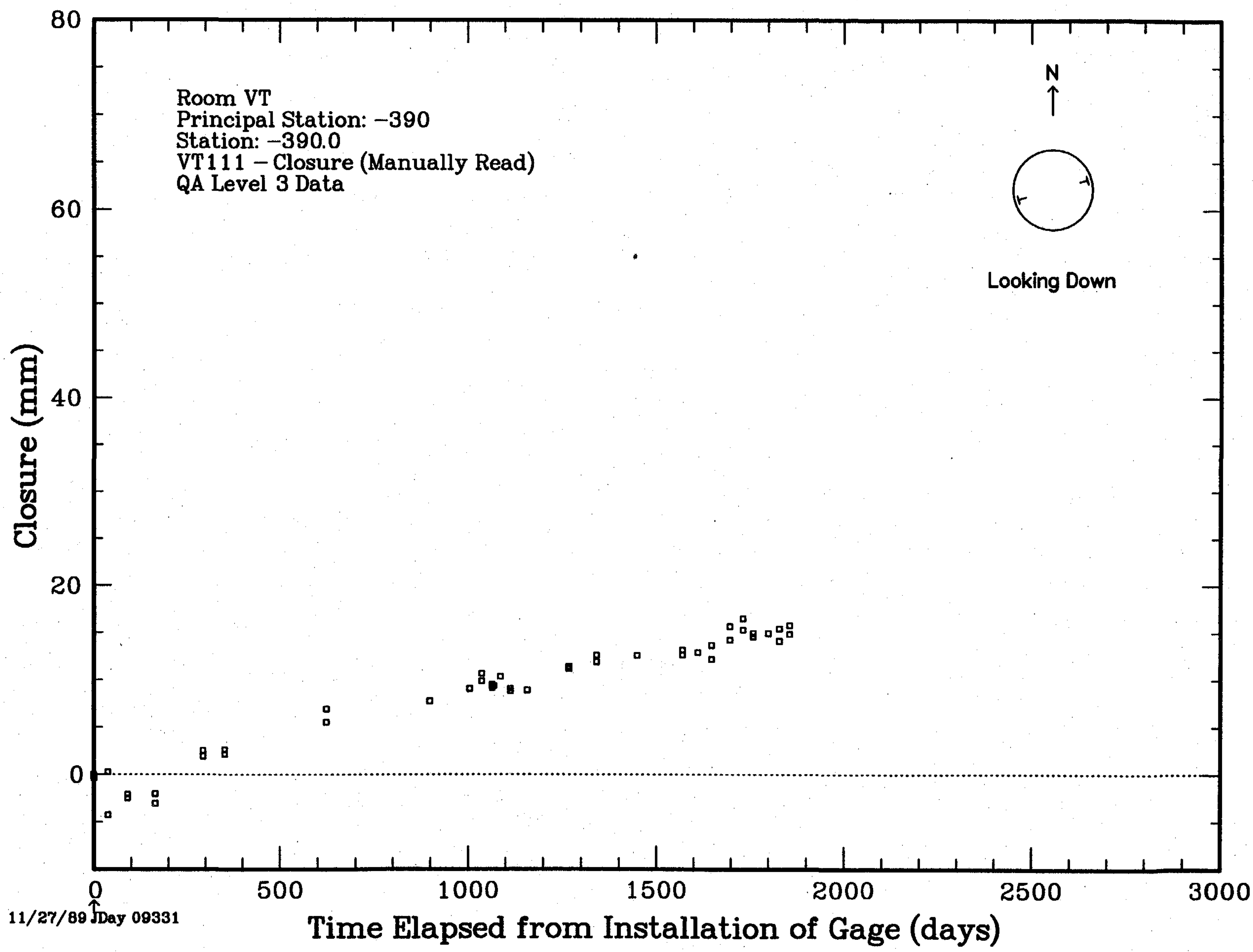

Figure 5.1.2e. Closure Gage VT111

Table 5.1.3f. Closure Gage VT112

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+--------------------+
|    Gage:  VT112    |
+--------------------+
**********************
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***** VT112 PI Comments *****

08/15/95 RLJ [98%] THIS CLOSURE GAGE WAS INSTALLED AT THE 2nd HIGHEST MEASUREMENT LEVEL IN THE SHAFT. PLOTS SHOW MORE DATA SCATTER THAN OTHER MANUAL CLOSURE READINGS ACQUIRED IN UNDERGROUND TEST ROOMS BECAUSE THE TAPE EXTENSOMETERS WERE IMPACTED BY THE STRONG AIR FLOW. TYPICALLY, TWO TAPE EXTENSOMETERS WERE USED ON A GIVEN DAY TO RECORD DATA THEREBY EXPLAINING DUAL POINTS SHOWN AT A SINGLE TIME (X AXIS) VALUE. (DEM)

***** VT112 Location *****

Principal Station -390
Station -390.0

Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Gage Coordinates Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT112-1	CONV T	MAN	H	3.10	3.09	285.32	105.96	0.0	0.0	-390.0	-390.0	SNL	11/27/89	T91025-00	

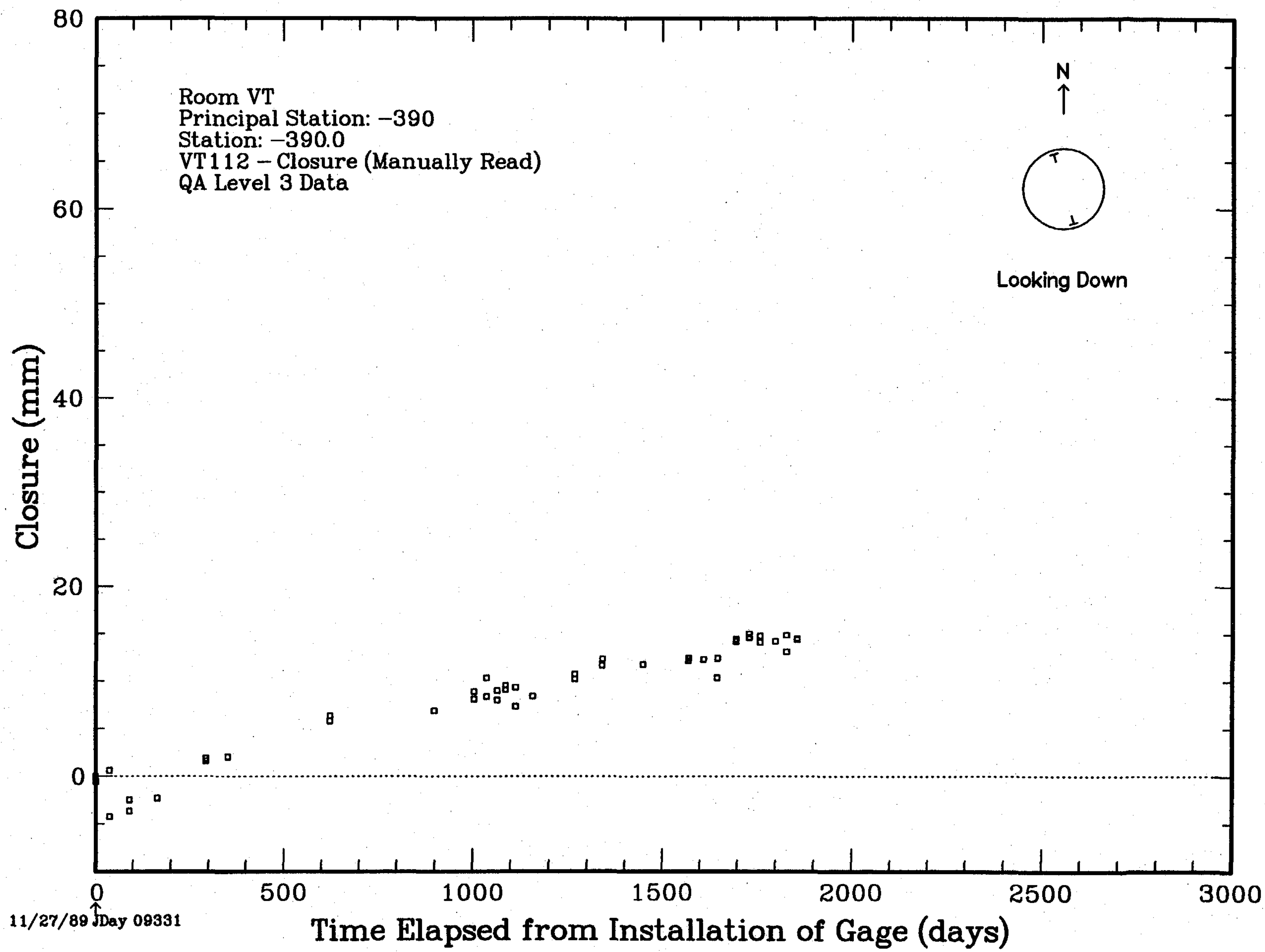

Figure 5.1.2f. Closure Gage VT112

Table 5.1.3g. Closure Gage VT121

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+--------------------+
|    Gage:  VT121    |
+--------------------+
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```

***** VT121 PI Comments *****

08/15/95 RLJ [100%] THIS CLOSURE GAGE WAS INSTALLED AT THE CENTRAL MEASUREMENT LEVEL IN THE SHAFT. PLOTS SHOW MORE DATA SCATTER THAN OTHER MANUAL CLOSURE READINGS ACQUIRED IN UNDERGROUND TEST ROOMS BECAUSE THE TAPE EXTENSOMETERS WERE IMPACTED BY THE STRONG AIR FLOW. TYPICALLY, TWO TAPE EXTENSOMETERS WERE USED ON A GIVEN DAY TO RECORD DATA THEREBY EXPLAINING DUAL POINTS SHOWN AT A SINGLE TIME (X AXIS) VALUE. (DEM)

***** VT121 Location *****

Principal Station -480
Station -479.8

Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Gage Coordinates Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT121-1	CONV T	MAN	H	3.06	3.14	11.42	192.91	0.1	0.1	-479.8	-479.8	SNL	11/27/89	T91025-00	

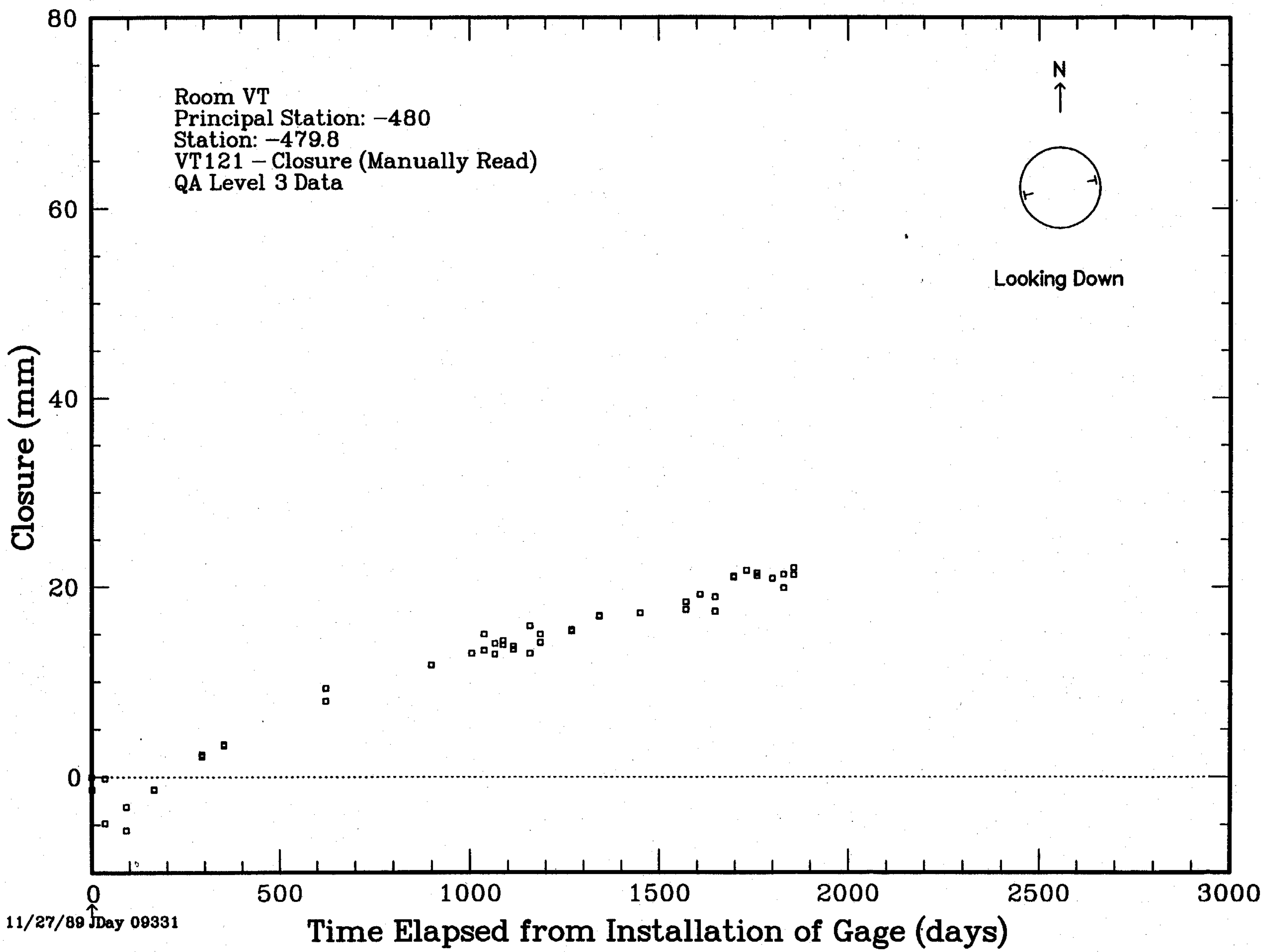

Figure 5.1.2g. Closure Gage VT121

Table 5.1.3h. Closure Gage VT122

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+--------------------+
|    Gage:  VT122    |
+--------------------+
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***** VT122 PI Comments *****

08/15/95 RLJ [100%]   THIS CLOSURE GAGE WAS INSTALLED AT THE CENTRAL MEASUREMENT LEVEL IN THE SHAFT. PLOTS SHOW MORE DATA SCATTER THAN OTHER MANUAL CLOSURE READINGS ACQUIRED IN UNDERGROUND TEST ROOMS BECAUSE THE TAPE EXTENSOMETERS WERE IMPACTED BY THE STRONG AIR FLOW. TYPICALLY, TWO TAPE EXTENSOMETERS WERE USED ON A GIVEN DAY TO RECORD DATA THEREBY EXPLAINING DUAL POINTS SHOWN AT A SINGLE TIME (X AXIS) VALUE. (DEM)

***** VT122 Location *****

Principal Station -480
Station -479.7

Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Gage Coordinates Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT122-1	CONV	T MAN	H	3.08	3.10	282.04	101.01	0.0	0.0	-479.7	-479.8	SNL	11/27/89	T91025-00	

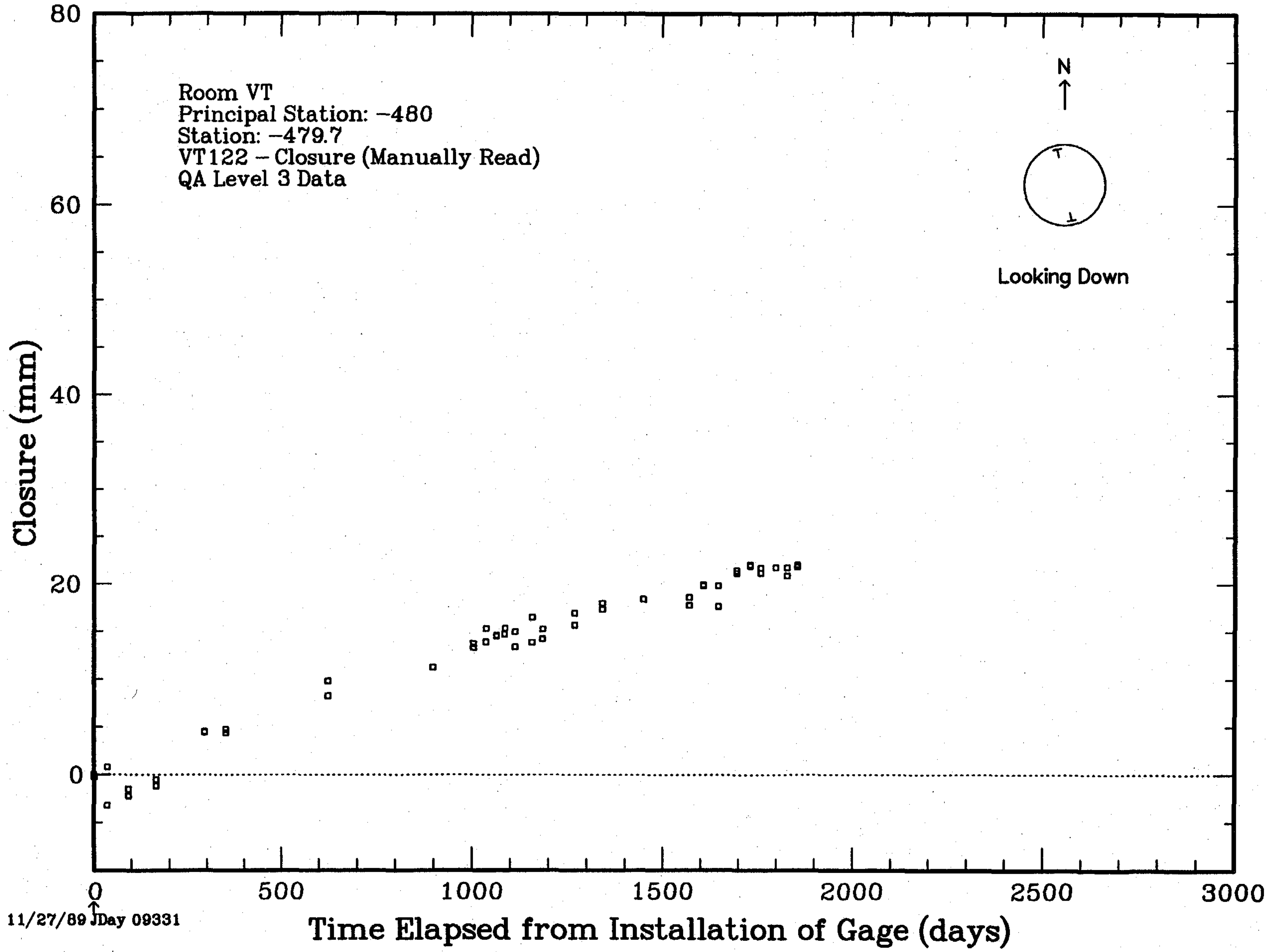

Figure 5.1.2h. Closure Gage VT122

Table 5.1.3i. Closure Gage VT123

```
+---------------------+
|    Gage:  VT123     |
+---------------------+
***********************
```

***** VT123 PI Comments *****

08/15/95 RLJ [100%] THIS CLOSURE GAGE WAS INSTALLED AT THE CENTRAL MEASUREMENT LEVEL IN THE SHAFT. PLOTS SHOW MORE DATA SCATTER THAN OTHER MANUAL CLOSURE READINGS ACQUIRED IN UNDERGROUND TEST ROOMS BECAUSE THE TAPE EXTENSOMETERS WERE IMPACTED BY THE STRONG AIR FLOW. TYPICALLY, TWO TAPE EXTENSOMETERS WERE USED ON A GIVEN DAY TO RECORD DATA THEREBY EXPLAINING DUAL POINTS SHOWN AT A SINGLE TIME (X AXIS) VALUE. VT123 WAS INSTALLED DIRECTLY ON THE COLLARS OF HOLES VT321 AND VT323. (DEM)

***** VT123 Location *****

Principal Station -480
Station -479.7

Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Gage Coordinates Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT123-1	CONV	P MAN	H	3.04	3.09	157.88	337.12	0.0	0.0	-479.7	-479.7	SNL	09/28/90	T91025-00	

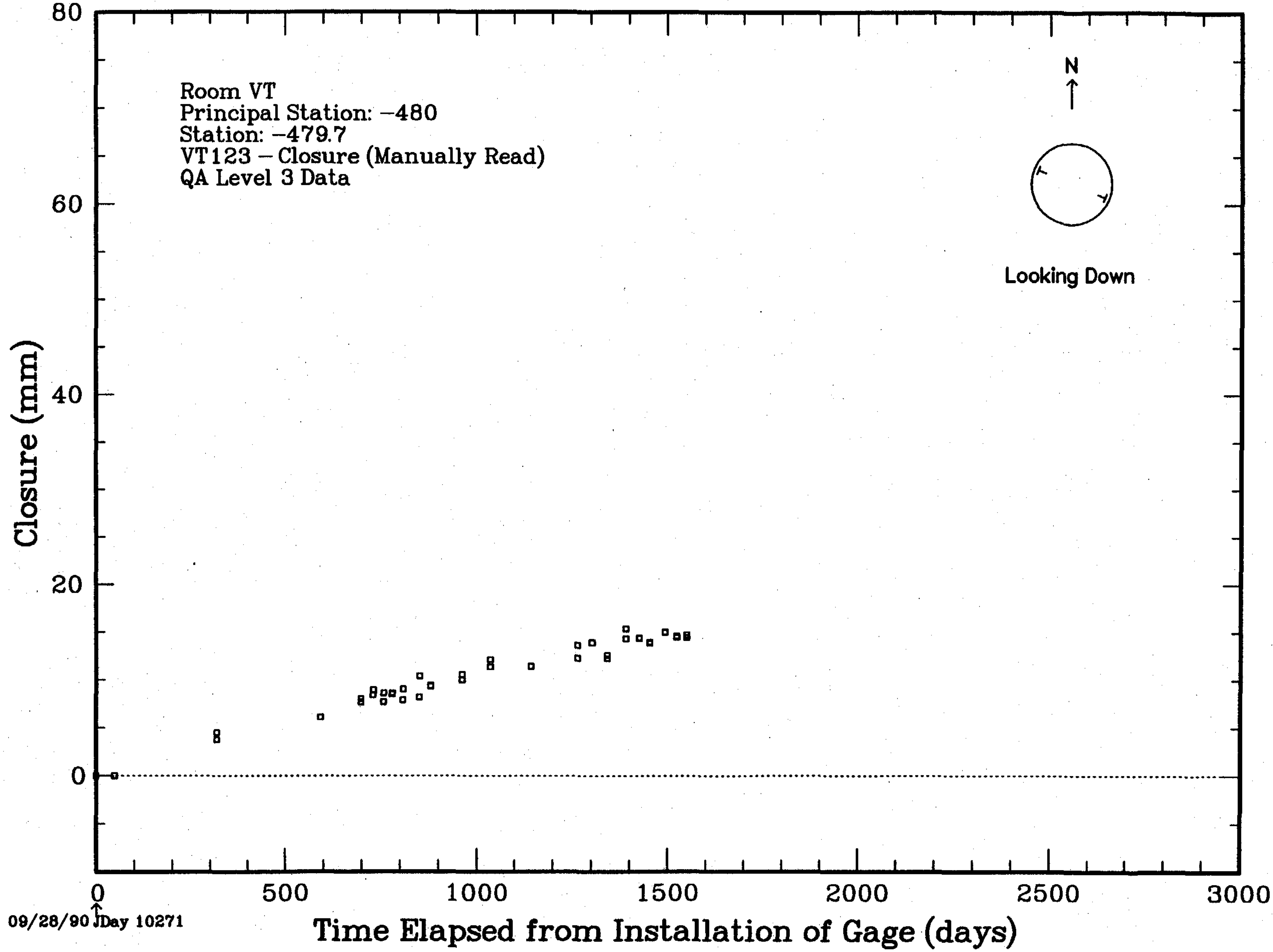

Figure 5.1.2i. Closure Gage VT123

Table 5.1.3j. Closure Gage VT124

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+--------------------+
|   Gage:  VT124     |
+--------------------+
**********************
```

***** VT124 PI Comments *****

08/15/95 RLJ [100%] THIS CLOSURE GAGE WAS INSTALLED AT THE CENTRAL MEASUREMENT LEVEL IN THE SHAFT. PLOTS SHOW MORE DATA SCATTER THAN OTHER MANUAL CLOSURE READINGS ACQUIRED IN UNDERGROUND TEST ROOMS BECAUSE THE TAPE EXTENSOMETERS WERE IMPACTED BY THE STRONG AIR FLOW. TYPICALLY, TWO TAPE EXTENSOMETERS WERE USED ON A GIVEN DAY TO RECORD DATA THEREBY EXPLAINING DUAL POINTS SHOWN AT A SINGLE TIME (X AXIS) VALUE. VT124 WAS INSTALLED DIRECTLY ON THE COLLARS OF HOLES VT322 AND VT324. (DEM)

***** VT124 Location *****

Principal Station -480
Station -479.7

Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Gage Coordinates Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT124-1	CONV	P MAN	H	3.05	3.09	247.09	67.93	0.0	0.0	-479.7	-479.7	SNL	09/28/90	T91025-00	

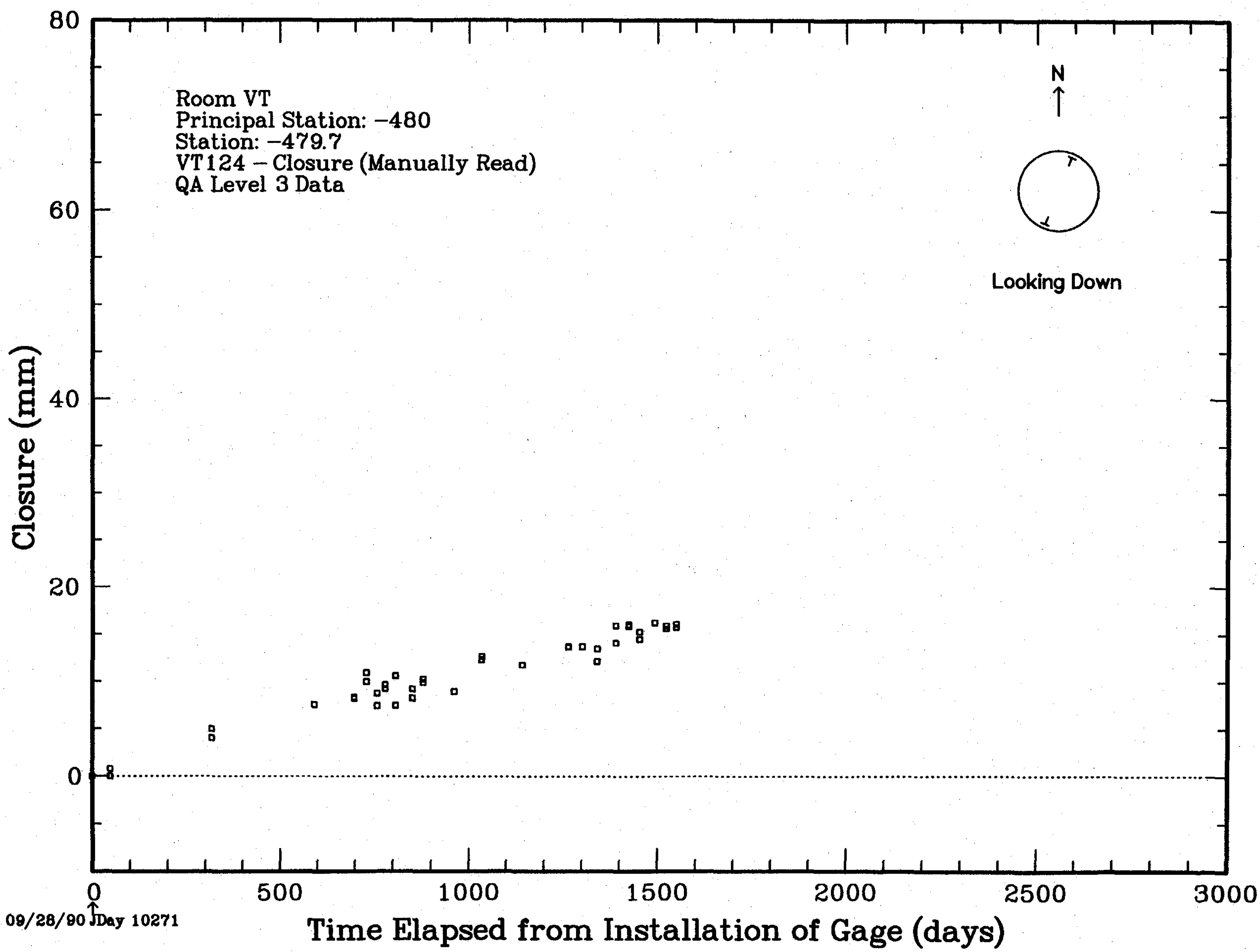

Figure 5.1.2j. Closure Gage VT124

Table 5.1.3k. Closure Gage VT131

```
+--------------------+
|   Gage:  VT131     |
+--------------------+
**********************
```

***** VT131 PI Comments *****

08/15/95 RLJ [100%] THIS CLOSURE GAGE WAS INSTALLED AT THE FOURTH MEASUREMENT LEVEL IN THE SHAFT. PLOTS SHOW MORE DATA SCATTER THAN OTHER MANUAL CLOSURE READINGS ACQUIRED IN UNDERGROUND TEST ROOMS BECAUSE THE TAPE EXTENSOMETERS WERE IMPACTED BY THE STRONG AIR FLOW. TYPICALLY, TWO TAPE EXTENSOMETERS WERE USED ON A GIVEN DAY TO RECORD DATA THEREBY EXPLAINING DUAL POINTS SHOWN AT A SINGLE TIME (X AXIS) VALUE. (DEM)

***** VT131 Location *****

Principal Station -554
Station -554.4

								Gage Coordinates							
								Prin Stat		Room					
Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Z1 (m)	Z2 (m)	Z1 (m)	Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT131-1	CONV	T MAN	H	3.12	3.05	354.58	174.35	-0.1	0.0	-554.4	-554.5	SNL	11/22/89	T91025-00	

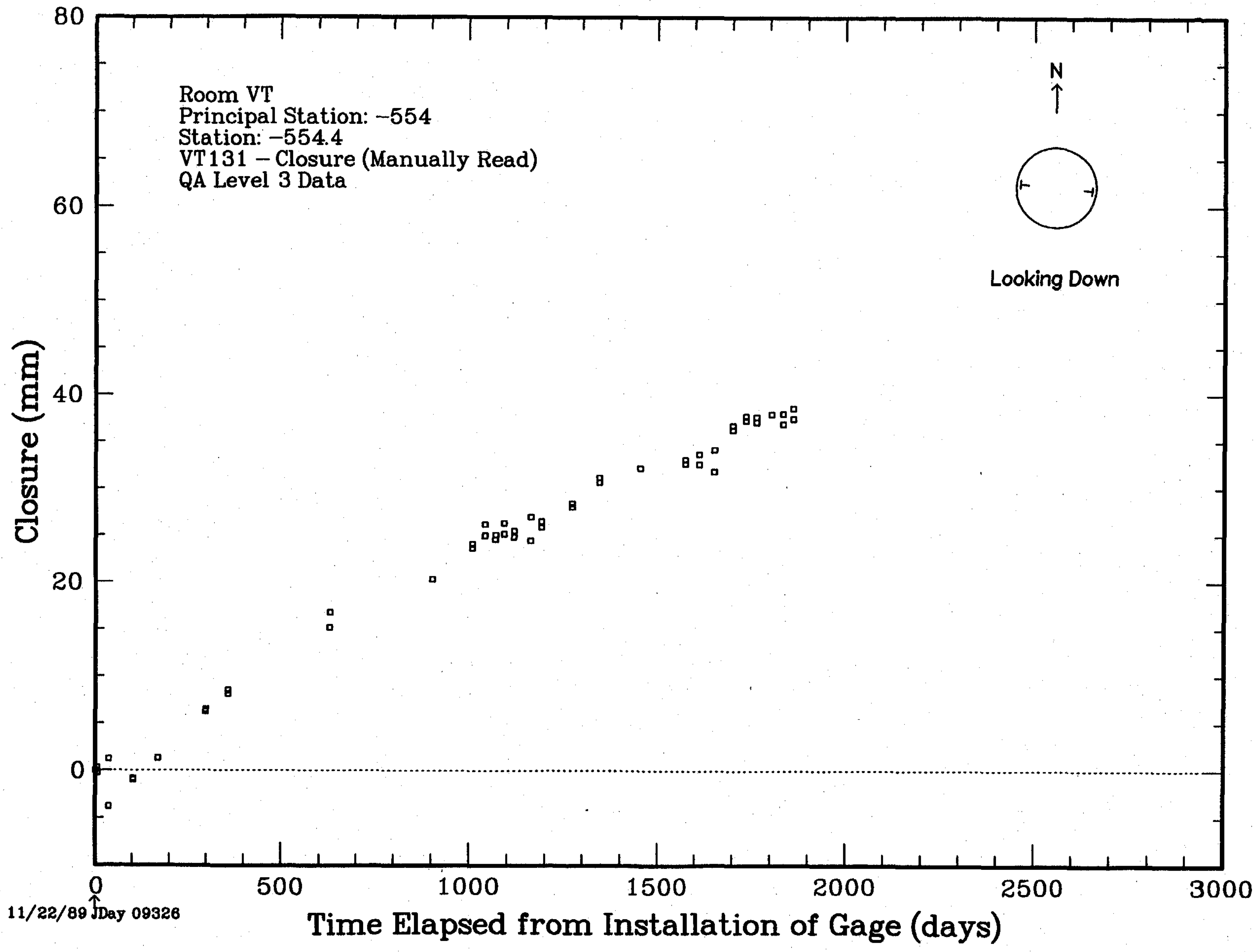

Figure 5.1.2k. Closure Gage VT131

Table 5.1.31. Closure Gage VT132

```
+---------------------+
|    Gage:  VT132     |
+---------------------+
***********************
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***** VT132 PI Comments *****

08/15/95 RLJ [100%] THIS CLOSURE GAGE WAS INSTALLED AT THE FOURTH MEASUREMENT LEVEL IN THE SHAFT. PLOTS SHOW MORE DATA SCATTER THAN OTHER MANUAL CLOSURE READINGS ACQUIRED IN UNDERGROUND TEST ROOMS BECAUSE THE TAPE EXTENSOMETERS WERE IMPACTED BY THE STRONG AIR FLOW. TYPICALLY, TWO TAPE EXTENSOMETERS WERE USED ON A GIVEN DAY TO RECORD DATA THEREBY EXPLAINING DUAL POINTS SHOWN AT A SINGLE TIME (X AXIS) VALUE. (DEM)

***** VT132 Location *****

Principal Station -555
Station -554.5

				Gage Coordinates											
								Prin Stat		Room					
Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Z1 (m)	Z2 (m)	Z1 (m)	Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT132-1	CONV	T MAN	H	3.08	3.09	84.90	263.65	0.0	0.1	-554.5	-554.5	SNL	11/22/89	T91025-00	

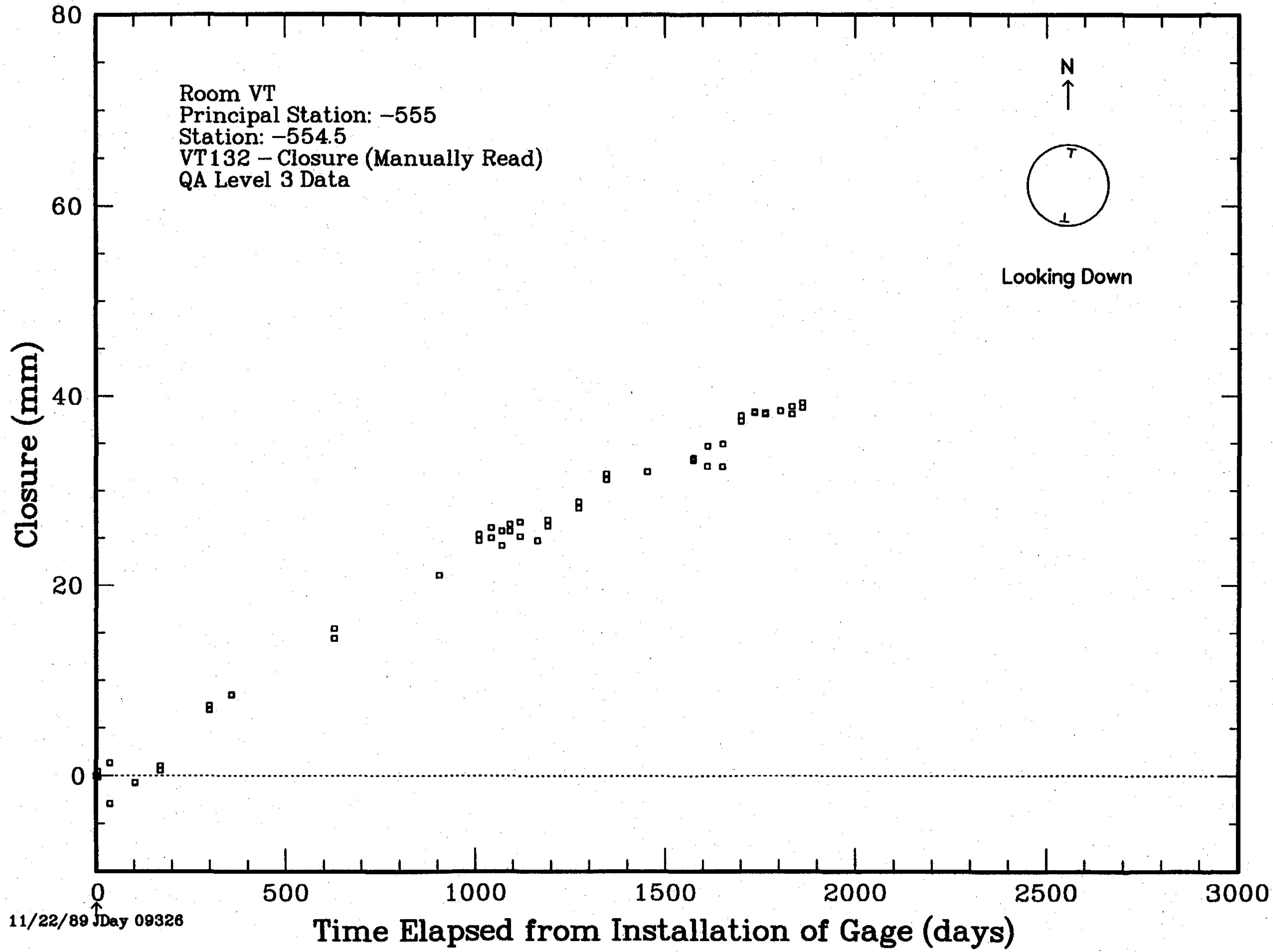

Figure 5.1.21. Closure Gage VT132

Table 5.1.3m. Closure Gage VT141

```
+--------------------+
|    Gage:  VT141    |
+--------------------+
**********************
```

***** VT141 PI Comments *****

08/15/95 RLJ [100%] THIS CLOSURE GAGE WAS INSTALLED AT THE LOWER MEASUREMENT LEVEL IN THE SHAFT. PLOTS SHOW MORE DATA SCATTER THAN OTHER MANUAL CLOSURE READINGS ACQUIRED IN UNDERGROUND TEST ROOMS BECAUSE THE TAPE EXTENSOMETERS WERE IMPACTED BY THE STRONG AIR FLOW. TYPICALLY, TWO TAPE EXTENSOMETERS WERE USED ON A GIVEN DAY TO RECORD DATA THEREBY EXPLAINING DUAL POINTS SHOWN AT A SINGLE TIME (X AXIS) VALUE. (DEM)

***** VT141 Location *****

Principal Station -626
Station -626.2

Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Gage Coordinates Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT141-1	CONV	T MAN	H	3.09	3.08	14.69	190.83	0.1	0.0	-626.2	-626.1	SNL	11/21/89	T91025-00	

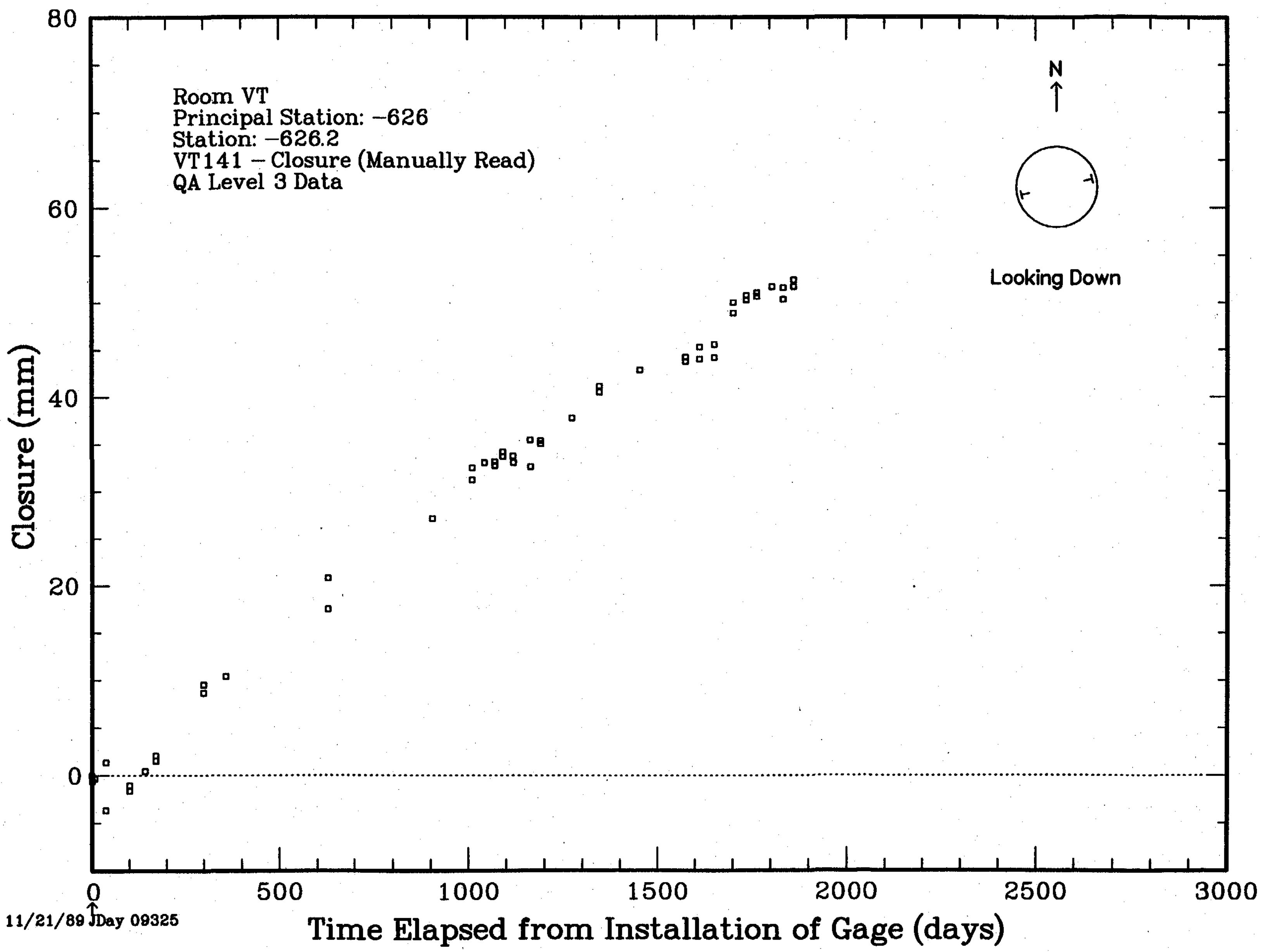

Figure 5.1.2m. Closure Gage VT141

Table 5.1.3n. Closure Gage VT142

```
+--------------------+
|    Gage:  VT142    |
+--------------------+
**********************
```

***** VT142 PI Comments *****

08/15/95 RLJ [100%]   THIS CLOSURE GAGE WAS INSTALLED AT THE LOWER MEASUREMENT LEVEL IN THE SHAFT. PLOTS SHOW MORE DATA SCATTER THAN OTHER MANUAL CLOSURE READINGS ACQUIRED IN UNDERGROUND TEST ROOMS BECAUSE THE TAPE EXTENSOMETERS WERE IMPACTED BY THE STRONG AIR FLOW. TYPICALLY, TWO TAPE EXTENSOMETERS WERE USED ON A GIVEN DAY TO RECORD DATA THEREBY EXPLAINING DUAL POINTS SHOWN AT A SINGLE TIME (X AXIS) VALUE. (DEM)

***** VT142 Location *****

Principal Station -626
Station -626.2

Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Gage Coordinates Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT142-1	CONV	T MAN	H	3.15	2.98	283.84	101.65	0.1	0.1	-626.2	-626.2	SNL	11/21/89	T91025-00	

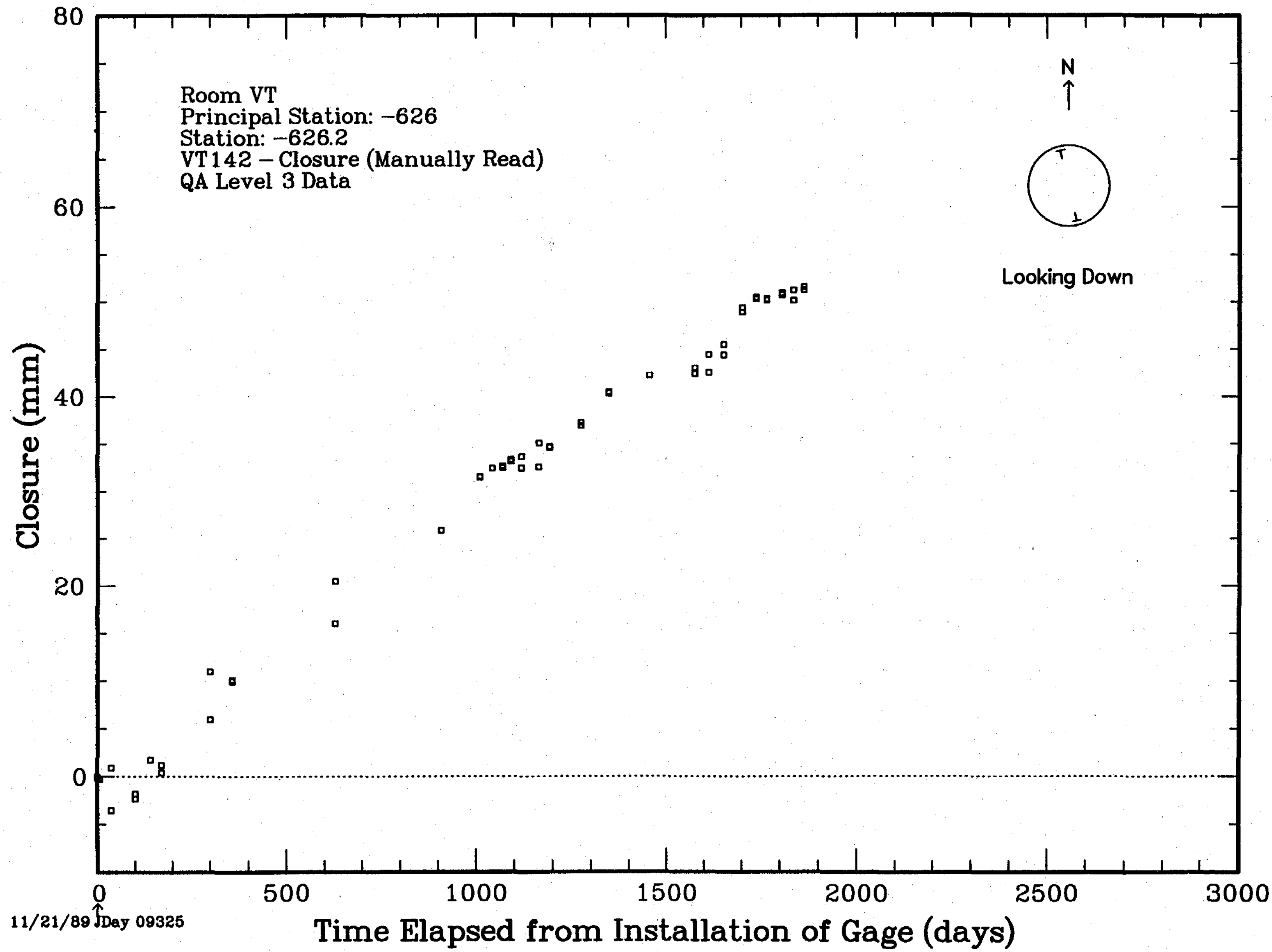

Figure 5.1.2n. Closure Gage VT142

Table 5.1.3o. Closure Gage VT143

```
+---------------------+
|    Gage:  VT143     |
+---------------------+
**********************
```

***** VT143 PI Comments *****

08/15/95 RLJ [94.7%] THIS CLOSURE GAGE WAS INSTALLED AT THE LOWER MEASUREMENT LEVEL IN THE SHAFT. PLOTS SHOW MORE DATA SCATTER THAN OTHER MANUAL CLOSURE READINGS ACQUIRED IN UNDERGROUND TEST ROOMS BECAUSE THE TAPE EXTENSOMETERS WERE IMPACTED BY THE STRONG AIR FLOW. TYPICALLY, TWO TAPE EXTENSOMETERS WERE USED ON A GIVEN DAY TO RECORD DATA THEREBY EXPLAINING DUAL POINTS SHOWN AT A SINGLE TIME (X AXIS) VALUE. VT143 WAS INSTALLED DIRECTLY ON THE COLLARS OF HOLES VT341 AND VT343. (DEM)

***** VT143 Location *****

Principal Station -626
Station -626.1

Gage Number	Gage Type	Rec	Dir	Gage Coordinates R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT143-1	CONV	P MAN	H	3.02	3.12	155.82	339.13	0.0	0.0	-626.1	-626.1	SNL	05/14/92	T91025-00	

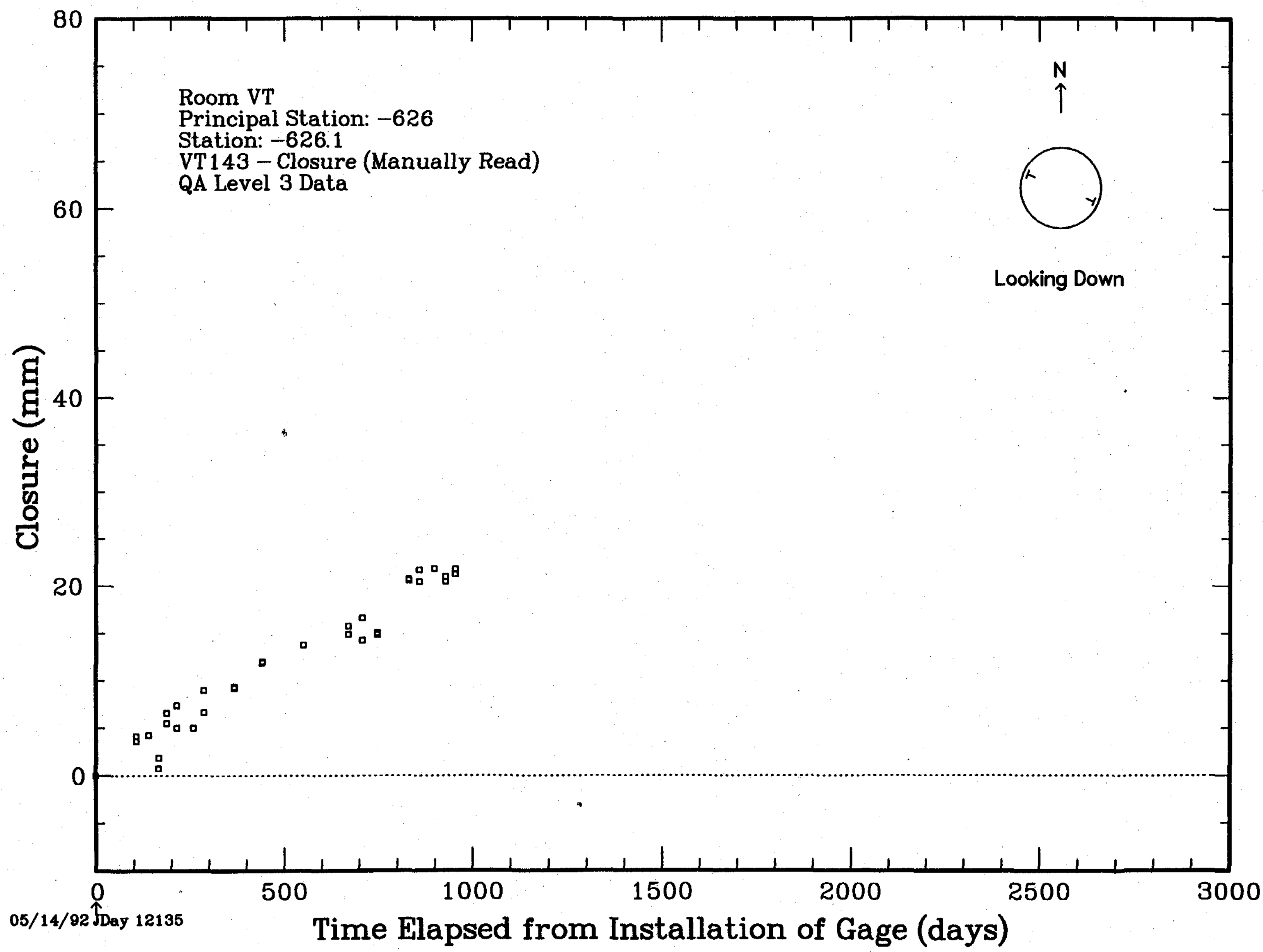

Figure 5.1.2o. Closure Gage VT143

Table 5.1.3p. Closure Gage VT144

```
+--------------------+
|    Gage:  VT144    |
+--------------------+
**********************
```

***** VT144 PI Comments *****

08/15/95 RLJ [88%] THIS CLOSURE GAGE WAS INSTALLED AT THE LOWER MEASUREMENT LEVEL IN THE SHAFT. PLOTS SHOW MORE DATA SCATTER THAN OTHER MANUAL CLOSURE READINGS ACQUIRED IN UNDERGROUND TEST ROOMS BECAUSE THE TAPE EXTENSOMETERS WERE IMPACTED BY THE STRONG AIR FLOW. TYPICALLY, TWO TAPE EXTENSOMETERS WERE USED ON A GIVEN DAY TO RECORD DATA THEREBY EXPLAINING DUAL POINTS SHOWN AT A SINGLE TIME (X AXIS) VALUE. VT144 WAS INSTALLED DIRECTLY ON THE COLLARS OF HOLES VT342 AND VT344. (DEM)

***** VT144 Location *****

Principal Station -626
Station -626.1

				Gage Coordinates												
								Prin Stat		Room						
Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Z1 (m)	Z2 (m)	Z1 (m)	Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT144-1	CONV	P	MAN	H	3.14	2.96	246.61	68.45	0.0	0.0	-626.1	-626.1	SNL	01/28/93	T91025-00	

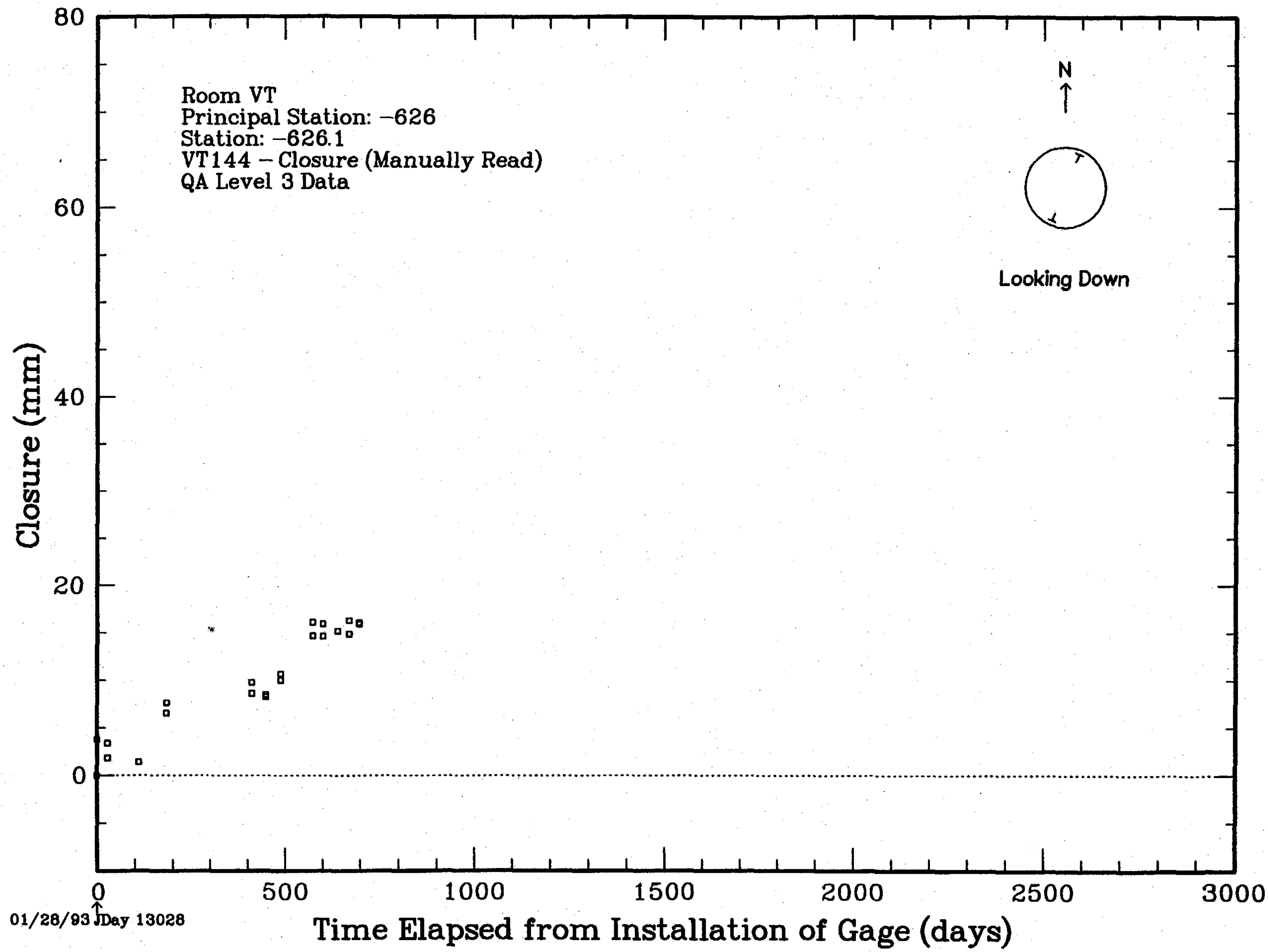

Figure 5.1.2p. Closure Gage VT144

5.1.2 Remote Extensometer Measurements: A guide to the location of all extensometer units is given in Table 5.1.4. This table indicates schematically the stations in the shaft, and hence the depth below ground level, at which the extensometers were emplaced. The installations are located at three stations, -343 m (-1124 ft), -480 m (-1574 ft), and -626 m (-2054 ft). At each station, four extensometer units are located so that they are evenly distributed at 90° intervals radially around the wall of the shaft. The units are oriented in the southeastern (VT3x1), northeastern (VT3x2), northwestern (VT3x3), and southwestern (VT3x4) directions, with designations related to the direction in the pattern noted. Also, the orientation of the opposing pairs of units are colinear with the manual closure gages at the station. In fact, as is typical of these installations, the collars of the extensometer emplacements are the reference for the closure measurements. Each unit has five anchors at depths of 15.2, 7.6, 3.0, 1.5, and 0.9 m (50, 25, 10, 5, and 3 ft) into the salt.

Extensometers measure the relative displacements between the collar of the emplacement hole and the multiple anchors placed at several depths in the hole. The data have a wealth of information that is sometimes not straightforward in interpretation. In the case of the extensometers in the AIS, the unique conditions in the shaft affect markedly the measured response of the gages. Large volumes of air flow past the measurement heads of the gages. The air velocity in the shaft is also quite high, approximating 6.1 m/s (13.6 miles/hr). This air has the current ambient temperature, which exhibits both diurnal and annual cyclic variation. It is thought the high air velocity and the open instrument holes probably assures that the extensometer gage components are at or near the current

Table 5.1.4. Extensometer Units (Gages) Location Guide

Depth m (ft)	Station			
0.0 (0.0)	Ground Surface			
-342.6 (-1124)	-343	VT303 + + + +	VT302 + VT304	+ + + + VT301
-479.7 (-1574)	-480	VT323 + + + +	VT322 + VT324	+ + + + VT321
-626.0 (-2054)	-626	VT343 + + + +	VT342 + VT344	+ + + + VT341
	Shaft Station			

air temperature. The consequence of these conditions is actually two fold. First, the thermal effects on the stainless steel rod connection between the gage head and anchor cause expansion and contraction with the changes in air temperature. Second, the changes in shaft wall temperature produce, through conduction, changes in the salt temperature radially away from the shaft. The first effect should appear as an oscillation of displacement in phase with the air temperature changes. Whereas, the second effect should have an oscillation that progressively becomes more out of phase with the air temperature as the anchor depth increases.

Descriptions, locations and PI comments for each extensometer are given in Tables 5.1.5a-l. Plots of the reduced data for the individual units are given in Figures 5.1.3a-l.

It is apparent the long-term creep deformation occurs as an increasing mean displacement with time; but, this mean displacement is modified by an oscillatory displacement. If the oscillations are removed from the records, there is an overall positive displacement as a result of salt creep. As is typical, the largest displacements are those associated with the deepest anchor. The oscillation frequency is directly related to the seasonal variation of the mean temperature. Interpretation of the records suggests that the displacement amplitude of the oscillations diminishes as the depth increases. Also, one could examine the data for a phase shift between the near surface behavior and that at depth. Such an effect would be some integration of the temperature influence on the connecting rod of the extensometer and the surrounding salt. Although these data do not apparently resolve this effect clearly, there does appear to be a slight shift (about 100 days) which delays the peak displacement amplitude of the deepest gage. Even though visual comparisons are interesting, a much more careful analysis would be required to make these statements with any certainty.

The portions of extensometer gage records which were eliminated during data reduction most commonly exhibited hysteresis effects. Often the negative part of the oscillatory cycle appears over a marked time interval as a flat, constant displacement. This is the result of gage hysteresis where either (1) the thermal expansion of the rod is accommodated by the reversal of the slack in the bayonet connecting joints between rod lengths or (2) the anchor was not "set" and slipped through out the history of the gage. While either of these is possible, the loss of predominantly the shallow gages suggests that anchor failure is the most likely process.

Again, as in the case of the closure measurements, the extensometer data reflect a marked increase of displacement rate with depth. The instantaneous creep rate was determined at the same total time after shaft excavation for the deepest anchor at each of the three stations. The stations reflect the depth which is directly related to the stress driving the creep process. It is necessary to draw the average displacement curve through the inflection points of the oscillations to obtain a correct creep displacement curve. When this is done, the rough displacement (creep) rates of the deepest anchors at about 2490 days (6.82 years) after shaft excavation are: 1.45 x E-3 /s at -343 m; 2.90 x E-3 /s at -480 m; and 7.09 x E-3 /s at -626 m. When the creep rate and depth are plotted on a double logarithmic plot, the slope is roughly 5.0. This agrees well with the theoretical value found from the constitutive model for salt creep proposed by Munson, et al. [25,26].

(text continues on page 128)

Table 5.1.5a. Extensometer VT301

Gage: VT301

****

***** VT301 PI Comments *****

08/04/95 DEM [RANK = 10(1),10(2),10(3),10(4),5(5)] THE DATA ARE OUTSTANDING FOR ALL GAGES EXCEPT GAGE 5 WHICH SHOWED EXCESSIVE SCATTER FROM UNKNOWN CAUSES AFTER DAY 525. THE SCATTER WAS DELETED. THE MARKED HYSTERISIS IN GAGE 1, ALTHOUGH SHOWN BY A NUMBER OF GAGES IN THE AIS TEST, IS RATHER UNUSUAL FOR A ROD EXTENSOMETER WHICH NORMALLY FOLLOWS DECREASES IN DISPLACEMENT. HOWEVER, AS THE DISPLACEMEMT RATE BECOMES POSITIVE, THE GAGE DISPLACEMENT EVENTUALLY AGAIN APPEARS TO RESPOND CORRECTLY WITH POSITIVE DISPLACEMENTS. THE SINUSOIDAL GAGE REPONSE AROUND THE MEAN DISPLACEMENT IS THE RESULT OF THE SEASONAL TEMPERATURE VARIATION OF THE INTAKE AIR. THE TOTAL DISPLACEMENTS ARE RELATIVELY SMALL BECAUSE THIS PRINCIPAL STATION IS AT THE TOP OF SALT WHERE THE OVERBURDEN STRESS IS THE LEAST OF ALL OF THE SHAFT STATIONS. [COMPRESSION = 6.42:1] (DEM)

***** VT301 Location *****

Principal Station -343
Station -342.7

Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Gage Coordinates Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT301-1	EXT	P REM	H	3.08	18.32	337.77	337.57	0.0	0.0	-342.7	-342.8	IRAD	05/07/90	57-4933	
VT301-2	EXT	P REM	H	3.08	12.22	337.77	337.60	0.0	0.0	-342.7	-342.8	IRAD	05/07/90	57-4933	
VT301-3	EXT	P REM	H	3.08	7.95	337.77	337.64	0.0	0.0	-342.7	-342.8	IRAD	05/07/90	57-4933	
VT301-4	EXT	P REM	H	3.08	4.90	337.77	337.69	0.0	0.0	-342.7	-342.8	IRAD	05/07/90	57-4933	
VT301-5	EXT	P REM	H	3.08	3.99	337.77	337.70	0.0	0.0	-342.7	-342.7	IRAD	05/07/90	57-4933	

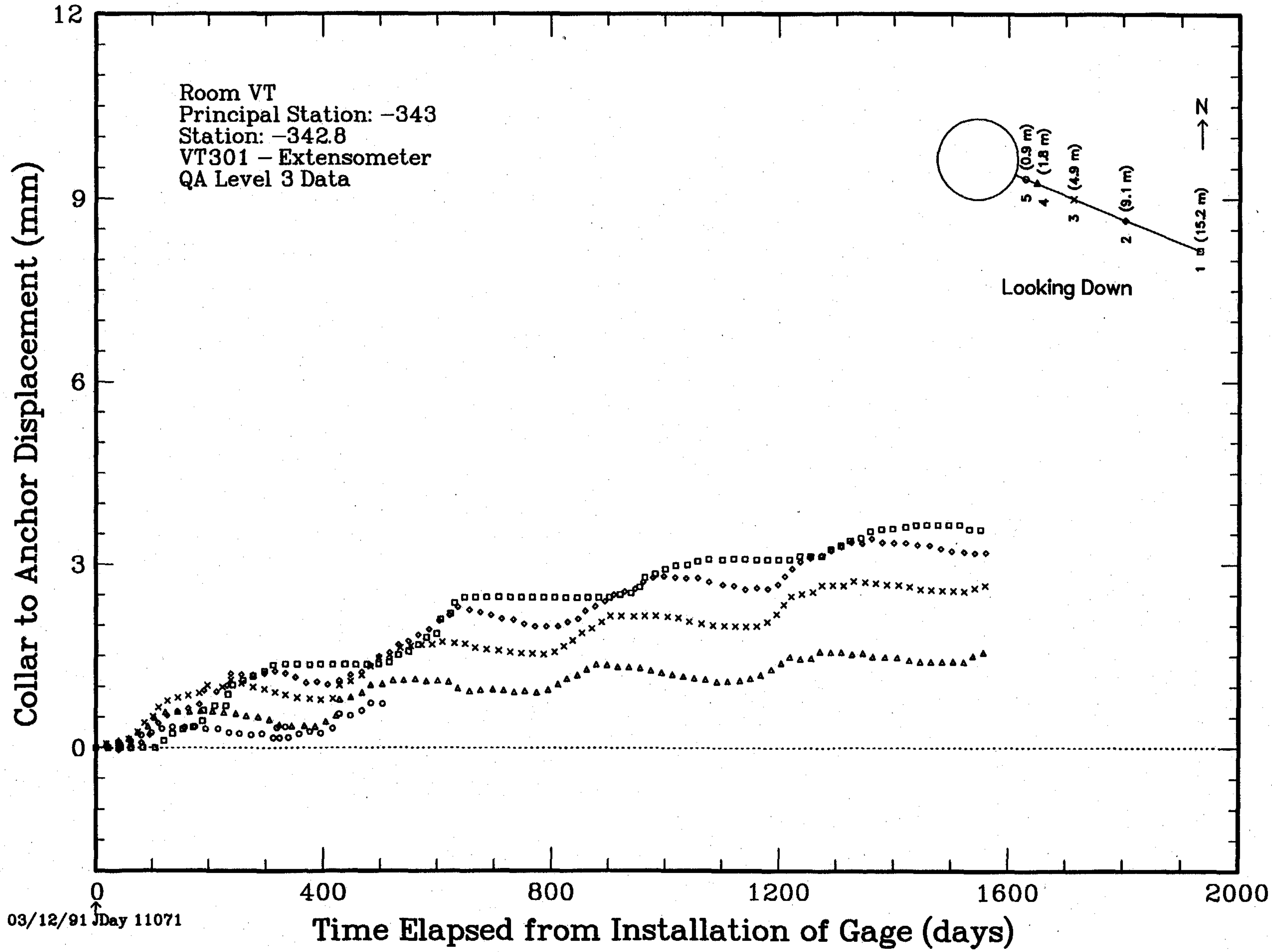

Figure 5.1.3a. Extensometer VT301

Table 5.1.5b. Extensometer VT302

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+---------------------+
|    Gage:  VT302     |
+---------------------+
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***** VT302 PI Comments *****

08/04/95 DEM [RANK = 10(1),3(2),10(3),10(4),10(5)] THE DATA ARE OUTSTANDING FOR ALL GAGES EXCEPT GAGE 2 WHICH SHOWED EXCESSIVE SCATTER FROM UNKNOWN CAUSES AFTER DAY 68. THE SCATTER WAS DELETED. THE SINUSOIDAL GAGE RESPONSE AROUND THE MEAN DISPLACEMENT IS THE RESULT OF THE SEASONAL VARIATION IN THE TEMPERATURE OF THE INTAKE AIR. THE TOTAL DISPLACEMENTS ARE RELATIVELY SMALL BECAUSE THIS PRINCIPAL STATION IS NEAR THE TOP OF THE SALT WHERE THE OVERBURDEN STRESS IS THE LEAST OF ALL OF THE SHAFT STATIONS. [COMPRESSION = 10.77:1] (DEM)

***** VT302 Location *****

Principal Station -343
Station -342.7

Gage Number	Gage Type	Rec	Dir	Gage Coordinates R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT302-1	EXT	P REM	H	3.06	18.30	67.54	67.63	0.0	-0.2	-342.7	-342.6	IRAD	05/03/90	57-4933	
VT302-2	EXT	P REM	H	3.06	12.20	67.54	67.62	0.0	-0.1	-342.7	-342.7	IRAD	05/03/90	57-4933	
VT302-3	EXT	P REM	H	3.06	7.94	67.54	67.62	0.0	-0.1	-342.7	-342.7	IRAD	05/03/90	57-4933	
VT302-4	EXT	P REM	H	3.06	4.89	67.54	67.59	0.0	0.0	-342.7	-342.7	IRAD	05/03/90	57-4933	
VT302-5	EXT	P REM	H	3.06	3.97	67.54	67.56	0.0	0.0	-342.7	-342.7	IRAD	05/03/90	57-4933	

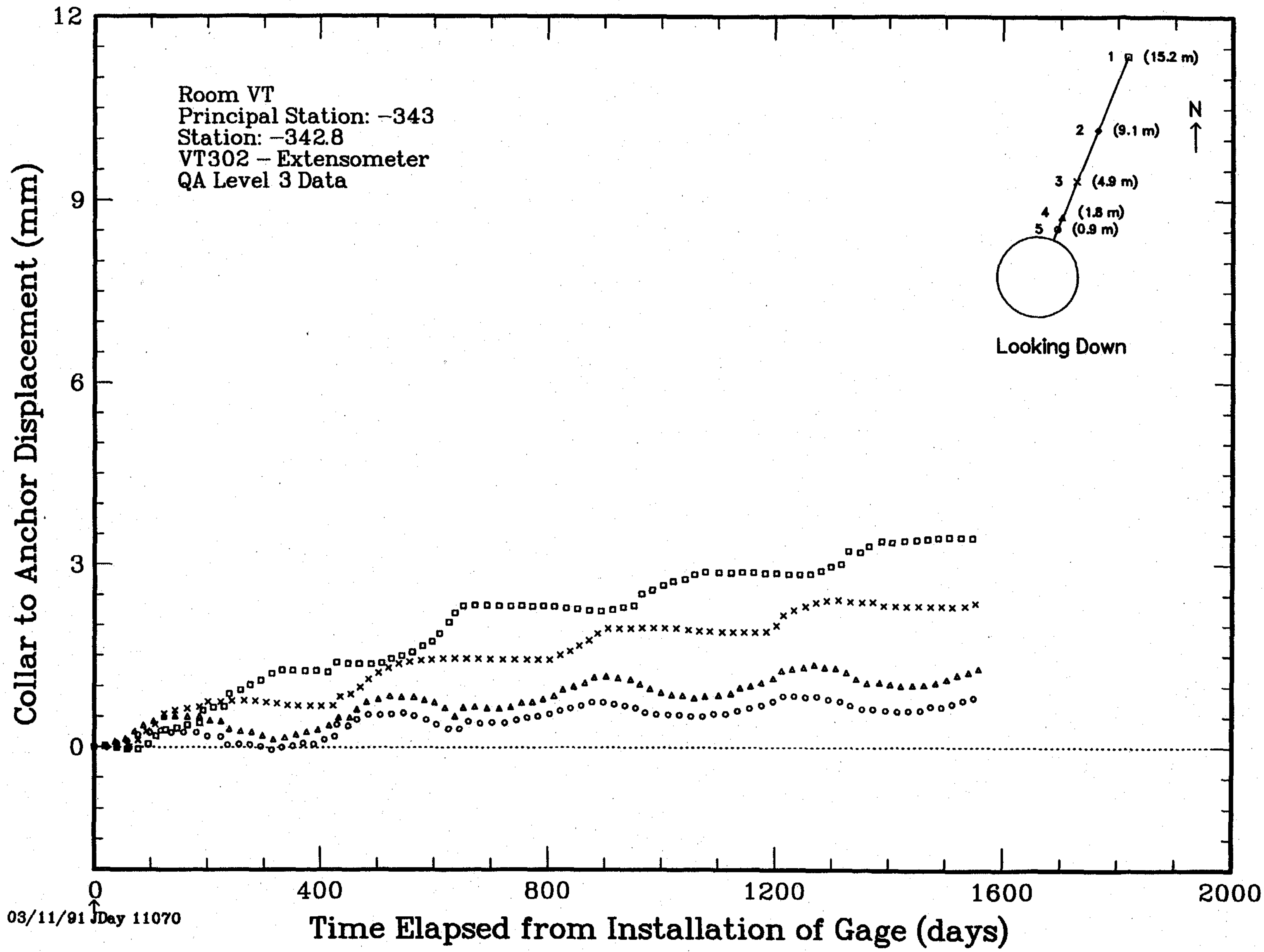

Figure 5.1.3b. Extensometer VT302

Table 5.1.5c. Extensometer VT303

Gage: VT303

***** VT303 PI Comments *****

08/04/95 DEM [RANK = 10(1),3(2),10(3),10(4),10(5)] THE DATA ARE OUTSTANDING FOR ALL GAGES EXCEPT GAGE 2 WHICH SHOWED EXCESSIVE SCATTER FROM UNKNOWN CAUSES. THE DATA RECORD FOR GAGE 2 WAS DELETED AFTER DAY 102. THE SCATTER SEVERITY CAUSED THE VERY LOW COMPRESSION RATIO FOR THE UNIT. THE SEASONAL VARIATION IN TEMPERATURE OF THE INTAKE AIR PRODUCED THE SINUSOIDAL BEHAVIOR IN DISPLACEMENT ABOUT THE MEAN DISPLACEMENT. THE SMALL TOTAL DISPLACEMENTS ARE THE RESULT OF RATHER SMALL OVERBURDEN STRESS AT THIS STATION NEAR THE TOP OF THE SALT. [COMPRESSION 1.59:1] (DEM)

***** VT303 Location *****

Principal Station -343
Station -342.7

Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Gage Coordinates Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT303-1	EXT	P REM	H	3.07	18.31	157.21	157.32	0.0	-0.1	-342.7	-342.7	IRAD	05/07/90	57-4933	
VT303-2	EXT	P REM	H	3.07	12.22	157.21	157.32	0.0	-0.1	-342.7	-342.7	IRAD	05/07/90	57-4933	
VT303-3	EXT	P REM	H	3.07	7.95	157.21	157.30	0.0	-0.1	-342.7	-342.7	IRAD	05/07/90	57-4933	
VT303-4	EXT	P REM	H	3.07	4.90	157.21	157.27	0.0	0.0	-342.7	-342.7	IRAD	05/07/90	57-4933	
VT303-5	EXT	P REM	H	3.07	3.98	157.21	157.26	0.0	0.0	-342.7	-342.7	IRAD	05/07/90	57-4933	

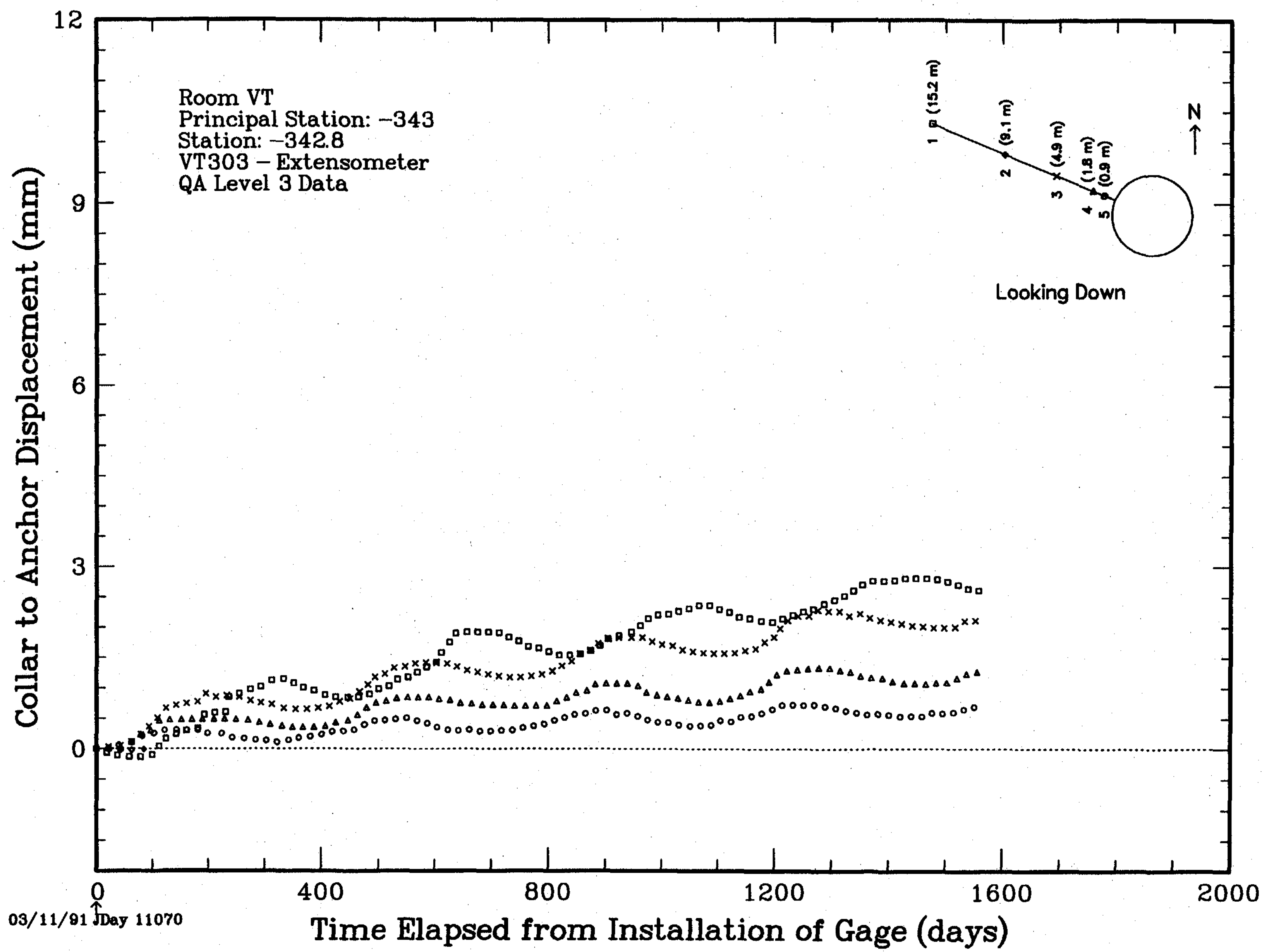

Figure 5.1.3c. Extensometer VT303

Table 5.1.5d. Extensometer VT304

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+--------------------+
|    Gage:  VT304    |
+--------------------+
**********************
```

***** VT304 PI Comments *****

08/04/95 DEM [RANK = 0(1),9(2),7(3),0(4),9(5)] THE DATA FROM THIS UNIT WAS ONLY GOOD OVER ALL. GAGE 1 DATA WAS LARGELY OBSCURED BY HYSTERESIS EFFECTS WHICH NEVER RECOVERED. GAGE 4 DATA WAS BADLY SCATTERED AND THE ENTIRE RECORD WAS DELETED. THE CAUSE OF THESE EFFECTS IS UNKNOWN. GAGE 3 ALSO CONTAINS MARKED HYSTERESIS, LIMITING THE CONFIDENCE IN THE MEASUREMENTS. GAGES 2, 3, AND 5 ALL REQUIRED SHIFTS IN THE DATA. BECAUSE THESE DATA SHIFTS WERE AT THE SAME TIME ON ALL OF THE DATA TRACES, THE CAUSE WAS PROBABLY AN UNDOCUMENTED IMPACTING OF THE UNIT DURING SHAFT ENTRY BY THE GALLOWAY. THE SINUSOIDAL VARIATION ABOUT THE MEAN DISPLACEMENT IS DUE TO THE SEASONAL VARIATION OF THE TEMPERATURE OF THE INTAKE AIR. THE DISPLACEMENTS ARE RATHER SMALL BECAUSE THE STRESS AT THIS STATION NEAR THE TOP OF SALT IS SMALL COMPARED TO THE DEEPER STATIONS. [COMPRESSION = 2.89:1] (DEM)

***** VT304 Location *****

Principal Station -343
Station -342.7

Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Gage Coordinates Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT304-1	EXT	P REM	H	3.09	18.33	247.44	247.92	0.0	0.1	-342.7	-342.9	IRAD	05/01/90	57-4933	
VT304-2	EXT	P REM	H	3.09	12.23	247.44	247.87	0.0	0.1	-342.7	-342.8	IRAD	05/01/90	57-4933	
VT304-3	EXT	P REM	H	3.09	7.97	247.44	247.79	0.0	0.0	-342.7	-342.8	IRAD	05/01/90	57-4933	
VT304-4	EXT	P REM	H	3.09	4.92	247.44	247.64	0.0	0.0	-342.7	-342.8	IRAD	05/01/90	57-4933	
VT304-5	EXT	P REM	H	3.09	4.00	247.44	247.58	0.0	0.0	-342.7	-342.8	IRAD	05/01/90	57-4933	

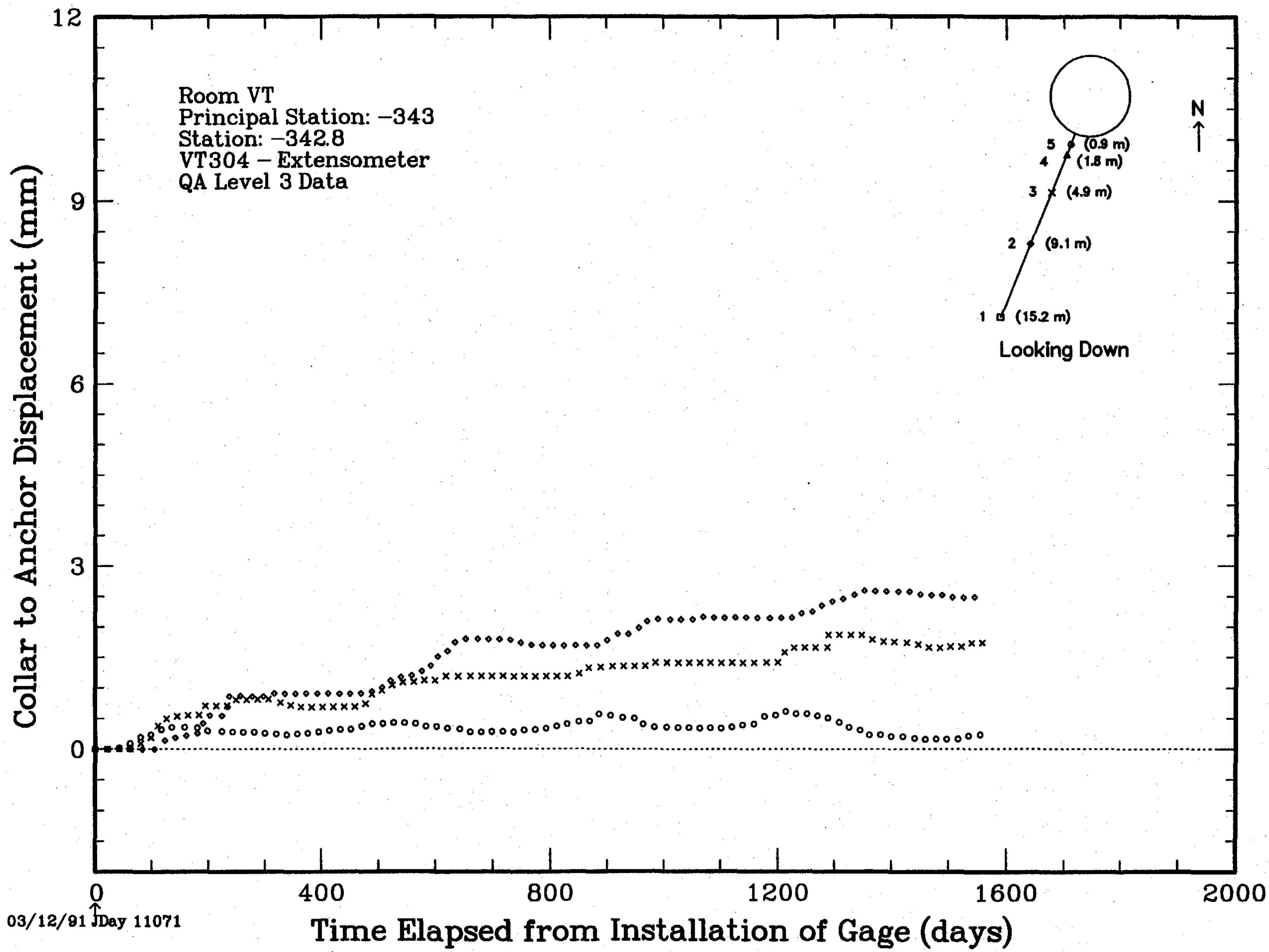

Figure 5.1.3d. Extensometer VT304

Table 5.1.5e. Extensometer VT321

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+--------------------+
|   Gage:  VT321     |
+--------------------+
**********************
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***** VT321 PI Comments *****

08/07/95 DEM [RANK = 8(1),10(2),10(3),10(4),0(5)] THREE OF THE GAGES WERE OUTSTANDING, WHILE GAGE 1 SHOWED SOME AMOUNT OF SCATTER WHICH WAS DELETED. GAGE 5 WAS DOMINATED BY HYSTERESIS, WITH EXCESSIVE SCATTER AT LATE TIMES. AS A CONSEQUENCE ALL OF GAGE 5 WAS DELETED. THE CAUSE OF THE HYSTERESIS IS NOT KNOWN, HOWEVER GAGE 5 OF THE UNITS SEEM TO SHOW THIS BEHAVIOR MORE THAN THE OTHER GAGES OF THE UNITS, SUGGESTING PERHAPS THAT THESE SHALLOW ANCHORS ARE OFTEN NOT FIRMLY PLACED. THE SINUSOIDAL BEHAVIOR ABOUT THE MEAN DISPLACEMENTS IS THE RESULT OF THE SEASONAL VARIATION IN THE INTAKE AIR TEMPERATURE. THIS UNIT WAS AT AN INTERMEDIATE DEPTH IN THE SHAFT. [COMPRESSION = 2.97:1] (DEM)

***** VT321 Location *****

Principal Station -480
Station -479.7

Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Gage Coordinates Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT321-1	EXT	P REM	H	3.09	18.33	337.12	337.44	0.0	0.2	-479.7	-479.9	IRAD	09/27/90	57-4933	
VT321-2	EXT	P REM	H	3.09	12.23	337.12	337.40	0.0	0.1	-479.7	-479.9	IRAD	09/27/90	57-4933	
VT321-3	EXT	P REM	H	3.09	7.96	337.12	337.36	0.0	0.0	-479.7	-479.8	IRAD	09/27/90	57-4933	
VT321-4	EXT	P REM	H	3.09	4.92	337.12	337.25	0.0	0.0	-479.7	-479.8	IRAD	09/27/90	57-4933	
VT321-5	EXT	P REM	H	3.09	4.00	337.12	337.20	0.0	0.0	-479.7	-479.7	IRAD	09/27/90	57-4933	

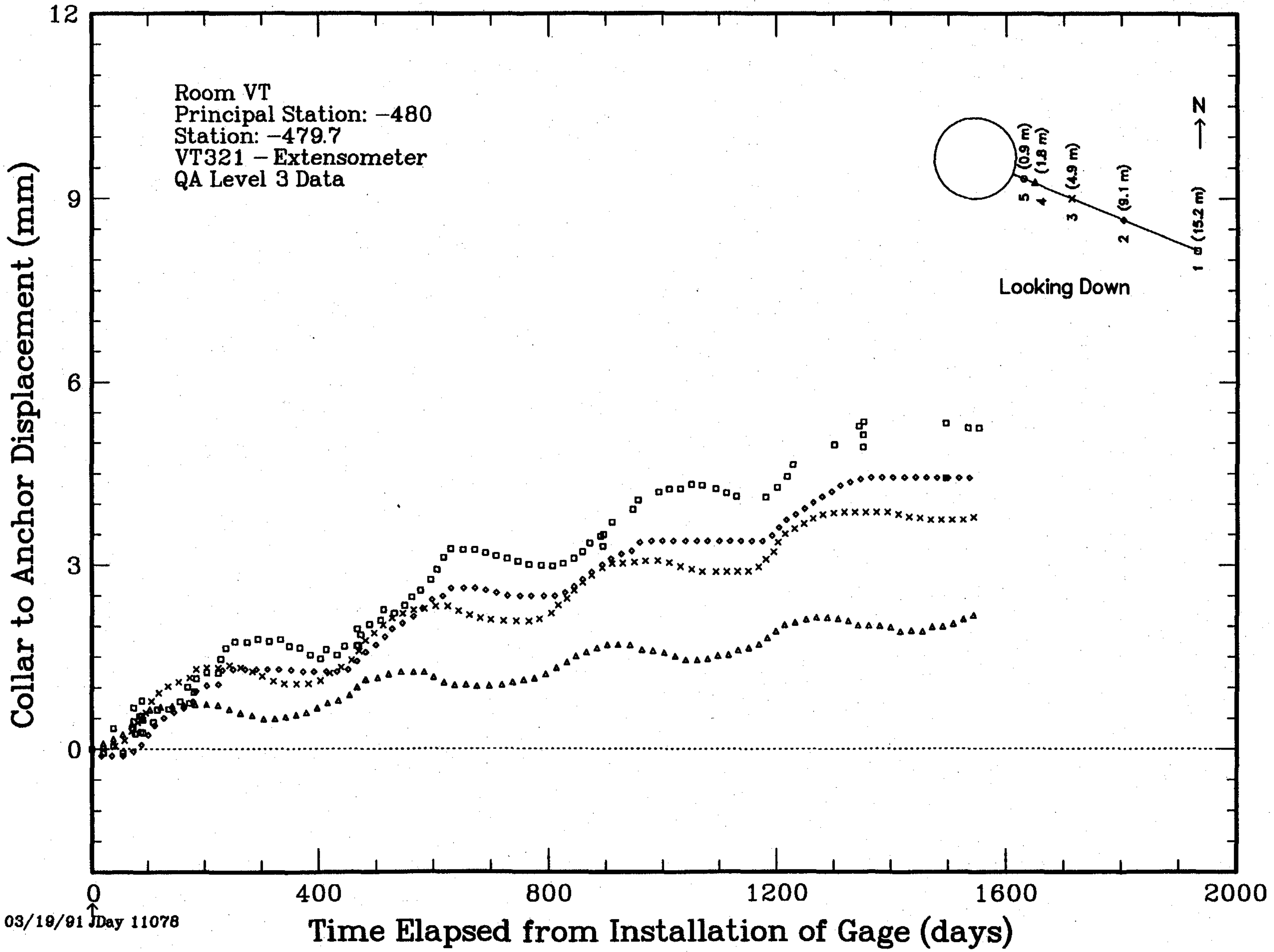

Figure 5.1.3e. Extensometer VT321

Table 5.1.5f. Extensometer VT322

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+---------------------+
|   Gage:  VT322      |
+---------------------+
***********************
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***** VT322 PI Comments *****

08/04/95 DEM [RANK = 0(1),10(2),3(3),10(4),10(5)] ALTHOUGH THE DATA FROM GAGES 2, 4, AND 5 ARE OUTSTANDING, THE DATA FROM BOTH GAGES 1 AND 3 ARE NOT USEFUL. BOTH OF THESE GAGES HAD SEVERE SCATTER FROM UNKNOWN CAUSES. GAGE 1 WAS DELETED IN ITS ENTIRETY, AND ONLY A SMALL PART OF THE GAGE 3 DATA BETWEEN DAY 711 AND DAY 1102 WAS THOUGHT TO BE USABLE. BECAUSE OF THE EXTREME SCATTER, THE RATIO FOR COMPRESSION WAS VERY SMALL AND THE DATA WERE RESIEVED. SEASONAL VARIATION CAUSED BY THE INTAKE AIR TEMPERATURE VARIATION IS EVIDENT. THIS SINUSOIDAL VARIATION OCCURS ABOUT THE MEAN MEASURED DISPLACEMENT. BECAUSE THIS GAGE IS AT AN INTERMEDIATE DEPTH IN THE SALT, THE STRESS IS INTERMEDIATE AND THE DISPLACEMENTS ARE ALSO INTERMEDIATE. [COMPRESSION = 1.10:1] (DEM)

***** VT322 Location *****

Principal Station -480
Station -479.7

Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Gage Coordinates Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT322-1	EXT	P REM	H	3.09	18.33	67.93	67.93	0.0	0.1	-479.7	-479.8	IRAD	09/25/90	57-4933	
VT322-2	EXT	P REM	H	3.09	12.23	67.93	67.93	0.0	0.0	-479.7	-479.8	IRAD	09/25/90	57-4933	
VT322-3	EXT	P REM	H	3.09	7.97	67.93	67.93	0.0	0.0	-479.7	-479.8	IRAD	09/25/90	57-4933	
VT322-4	EXT	P REM	H	3.09	4.92	67.93	67.94	0.0	0.0	-479.7	-479.7	IRAD	09/25/90	57-4933	
VT322-5	EXT	P REM	H	3.09	4.00	67.93	67.92	0.0	0.0	-479.7	-479.7	IRAD	09/25/90	57-4933	

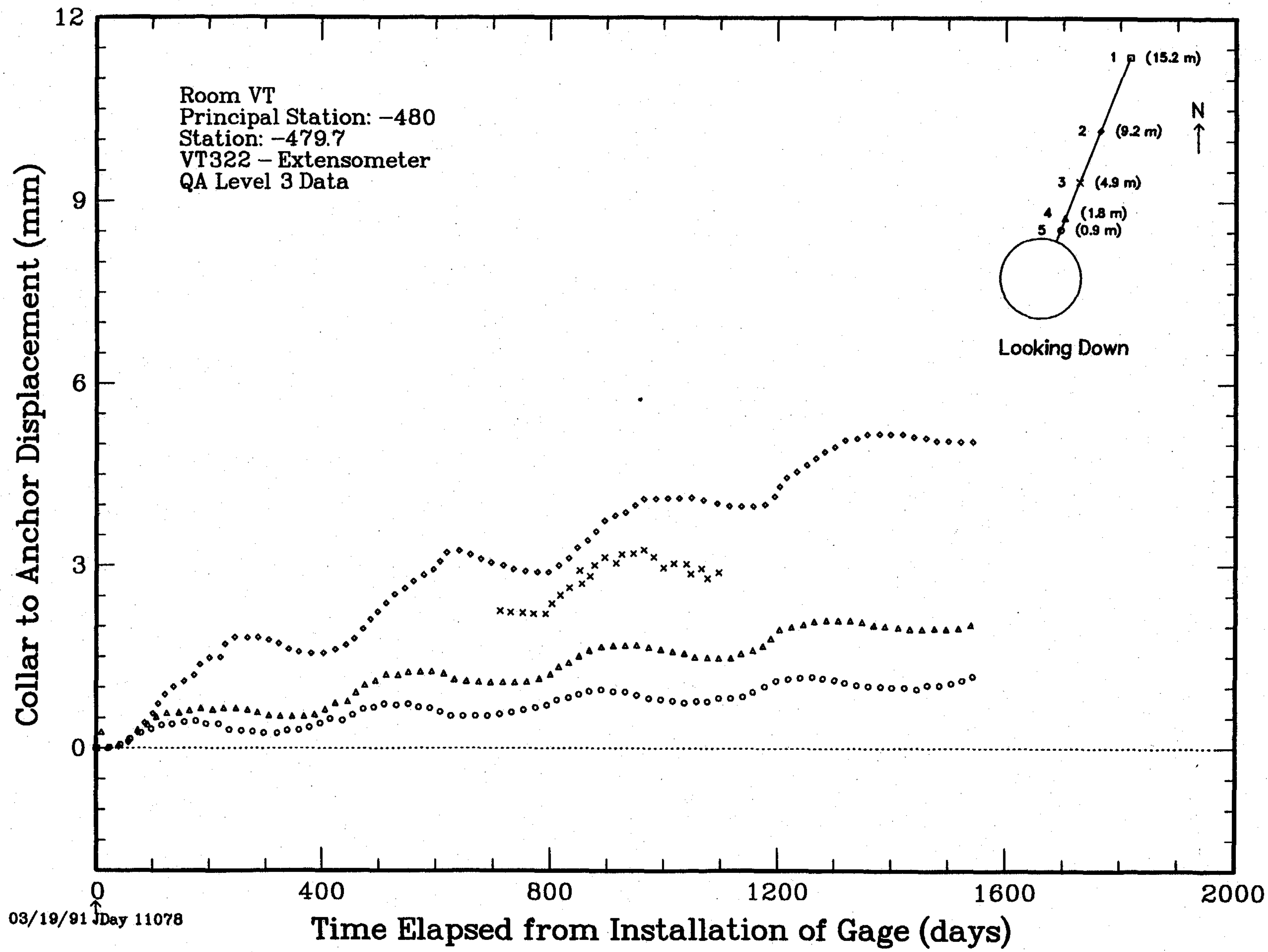

Figure 5.1.3f. Extensometer VT322

Table 5.1.5g. Extensometer VT323

```
+--------------------+
|   Gage:  VT323     |
+--------------------+
**********************
```

***** VT323 PI Comments *****

08/07/95 DEM [RANK = 10(1),10(2),8(3),10(4),9(5)] THREE OF THE GAGES GAVE OUTSTANDING DATA, WHILE GAGE 3 HAD SEVERAL RANGES OF SCATTER THAT WERE REMOVED AND GAGE 5 HAD ONE PERIOD OF DATA SCATTER REMOVED. THE SINUSOIDAL VARIATION ABOUT THE MEAN DISPLACEMENT BEHAVIOR IS THE RESULT OF THE SEASONAL VARIATION IN THE TEMPERATURE OF THE INTAKE AIR. THIS UNIT IS AT AN INTERMEDIATE DEPTH IN THE SHAFT. [COMPRESSION =12.66:1] (DEM)

***** VT323 Location *****

Principal Station -480
Station -479.7

Gage Number	Gage Type	Rec	Dir	Gage Coordinates R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT323-1	EXT	P REM	H	3.04	18.29	157.88	157.34	0.0	-0.1	-479.7	-479.7	IRAD	09/28/90	57-4933	
VT323-2	EXT	P REM	H	3.04	12.19	157.88	157.39	0.0	0.0	-479.7	-479.7	IRAD	09/28/90	57-4933	
VT323-3	EXT	P REM	H	3.04	7.92	157.88	157.48	0.0	0.0	-479.7	-479.7	IRAD	09/28/90	57-4933	
VT323-4	EXT	P REM	H	3.04	4.87	157.88	157.64	0.0	0.0	-479.7	-479.7	IRAD	09/28/90	57-4933	
VT323-5	EXT	P REM	H	3.04	3.96	157.88	157.74	0.0	0.0	-479.7	-479.7	IRAD	09/28/90	57-4933	

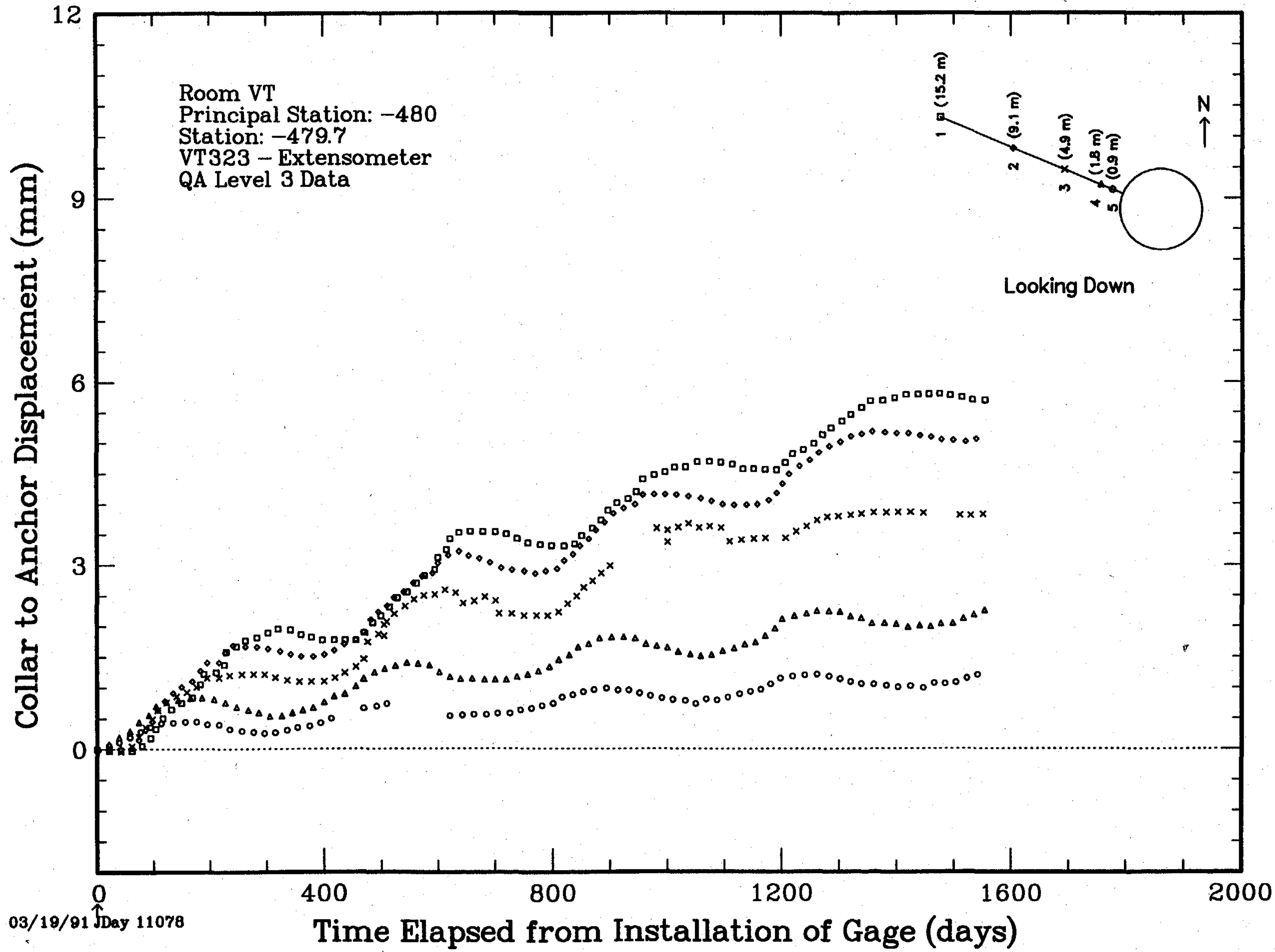

Figure 5.1.3g. Extensometer VT323

Table 5.1.5h. Extensometer VT324

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+--------------------+
|   Gage:  VT324     |
+--------------------+
**********************
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***** VT324 PI Comments *****

08/07/95 DEM [RANK = 10(1),10(2),3(3),10(4),0(5)] THREE OF THE GAGES GAVE OUTSTANDING DATA, WHILE GAGES 3 AND 5 ESSENTIALLY PRODUCED NO DATA. GAGE 3 SUFFERED FROM EXCESSIVE SCATTER. WHEN THIS WAS DELETED LITTLE MEANINGFUL DATA REMAINED. GAGE 5 SHOWED MARKED HYSTERESIS WITH SCATTER AT LATE TIMES. THIS IS OFTEN THE CASE WITH THESE GAGES IN THE UNITS, PERHAPS BECAUSE THEY HAVE SHALLOW ANCHORS THAT MAY NOT BE FIRM. THE ENTIRE DATA RECORD WAS DELETED. AS IS TYPICAL, THE SINUSOIDAL BEHAVIOR ABOUT THE MEAN DISPLACEMENT IS THE RESULT OF THE SEASONAL VARIATION OF THE TEMPERATURE OF THE INTAKE AIR. THIS UNIT IS AT AN INTERMEDIATE DEPTH IN THE SHAFT. [COMPRESSION = 5.83:1] (DEM)

***** VT324 Location *****

Principal Station -480
Station -479.7

Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Gage Coordinates Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT324-1	EXT	P REM	H	3.05	18.29	247.09	247.96	0.0	0.0	-479.7	-479.8	IRAD	09/27/90	57-4933	
VT324-2	EXT	P REM	H	3.05	12.19	247.09	247.86	0.0	0.0	-479.7	-479.8	IRAD	09/27/90	57-4933	
VT324-3	EXT	P REM	H	3.05	7.92	247.09	247.73	0.0	0.0	-479.7	-479.7	IRAD	09/27/90	57-4933	
VT324-4	EXT	P REM	H	3.05	4.88	247.09	247.47	0.0	0.0	-479.7	-479.7	IRAD	09/27/90	57-4933	
VT324-5	EXT	P REM	H	3.05	3.96	247.09	247.31	0.0	0.0	-479.7	-479.7	IRAD	09/27/90	57-4933	

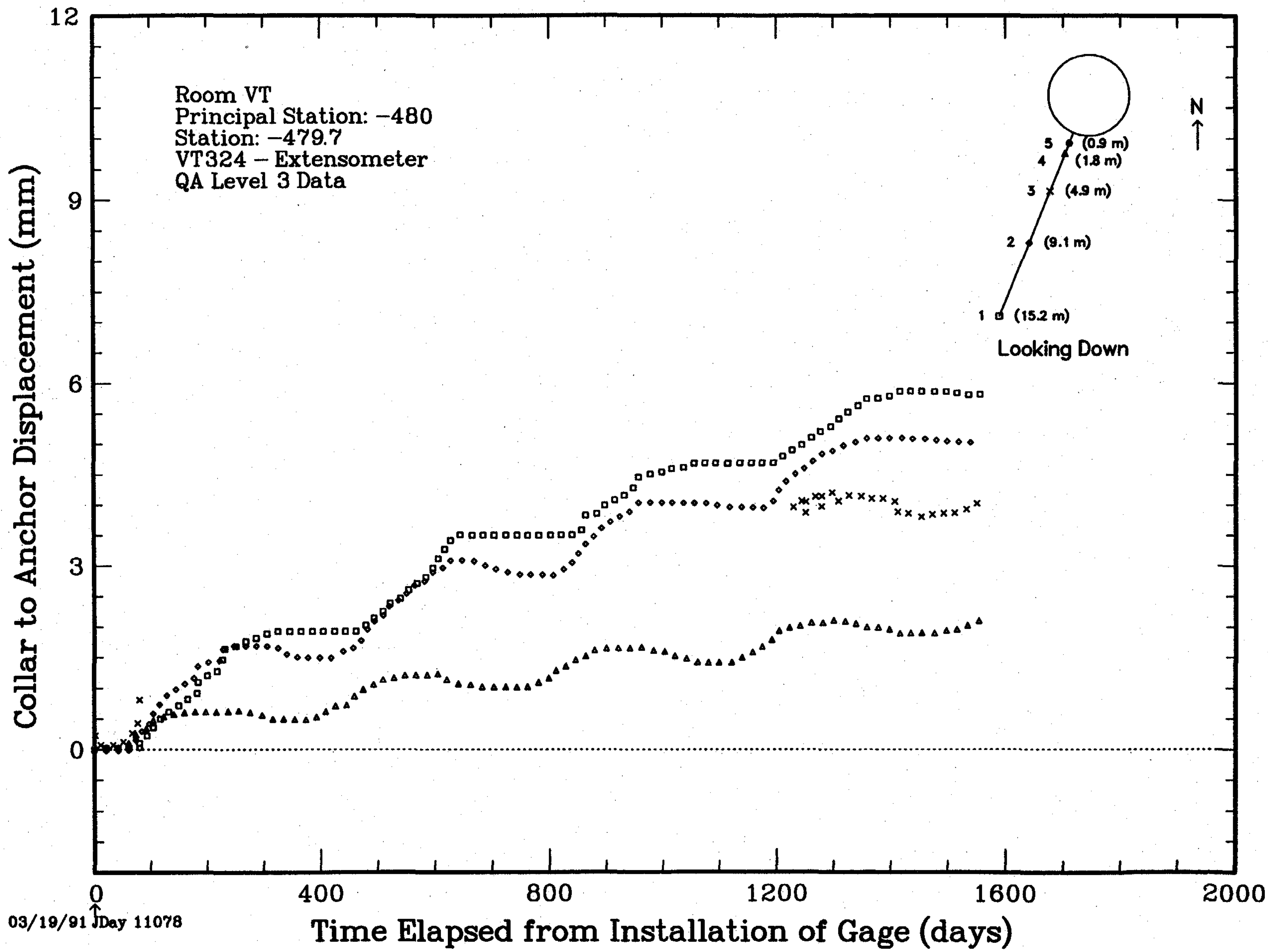

Figure 5.1.3h. Extensometer VT324

Table 5.1.5i. Extensometer VT341

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+--------------------+
|    Gage:  VT341    |
+--------------------+
**********************
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***** VT341 PI Comments *****

08/07/95 DEM [RANK = 9(1),0(2),9(3),9(4),9(5)] GAGE 2 SUFFERED FROM EXCESSIVE SCATTER, WHICH RESULTED IN THE ENTIRE GAGE RECORD BEING DELETED. ALL OF THE REMAINING GAGES GAVE EXCEPTIONAL DATA WITH EACH REQUIRING ONE SHIFT IN THE DATA, PROBABLY AS THE RESULT OF AN UNDOCUMENTED JARRING OF THE UNIT DURING MOVEMENT OF THE GALLOWAY. THE SINUSOIDAL VARIATION ABOUT THE MEAN DISPLACEMENT CURVE IS THE RESULT OF THE SEASONAL VARIATION IN THE INTAKE AIR TEMPERATURE. THIS UNIT IS NEAR THE MAXIMUM SHAFT DEPTH. [COMPRESSION = 2.79:1] (DEM)

***** VT341 Location *****

Principal Station -626
Station -626.1

Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Gage Coordinates Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT341-1	EXT	P REM	H	3.12	18.36	339.13	338.49	0.0	-0.1	-626.1	-626.0	IRAD	10/11/91	57-4933	
VT341-2	EXT	P REM	H	3.12	12.26	339.13	338.56	0.0	-0.1	-626.1	-626.0	IRAD	10/11/91	57-4933	
VT341-3	EXT	P REM	H	3.12	7.99	339.13	338.66	0.0	-0.1	-626.1	-626.0	IRAD	10/11/91	57-4933	
VT341-4	EXT	P REM	H	3.12	4.95	339.13	338.86	0.0	-0.1	-626.1	-626.1	IRAD	10/11/91	57-4933	
VT341-5	EXT	P REM	H	3.12	4.03	339.13	338.94	0.0	-0.1	-626.1	-626.1	IRAD	10/11/91	57-4933	

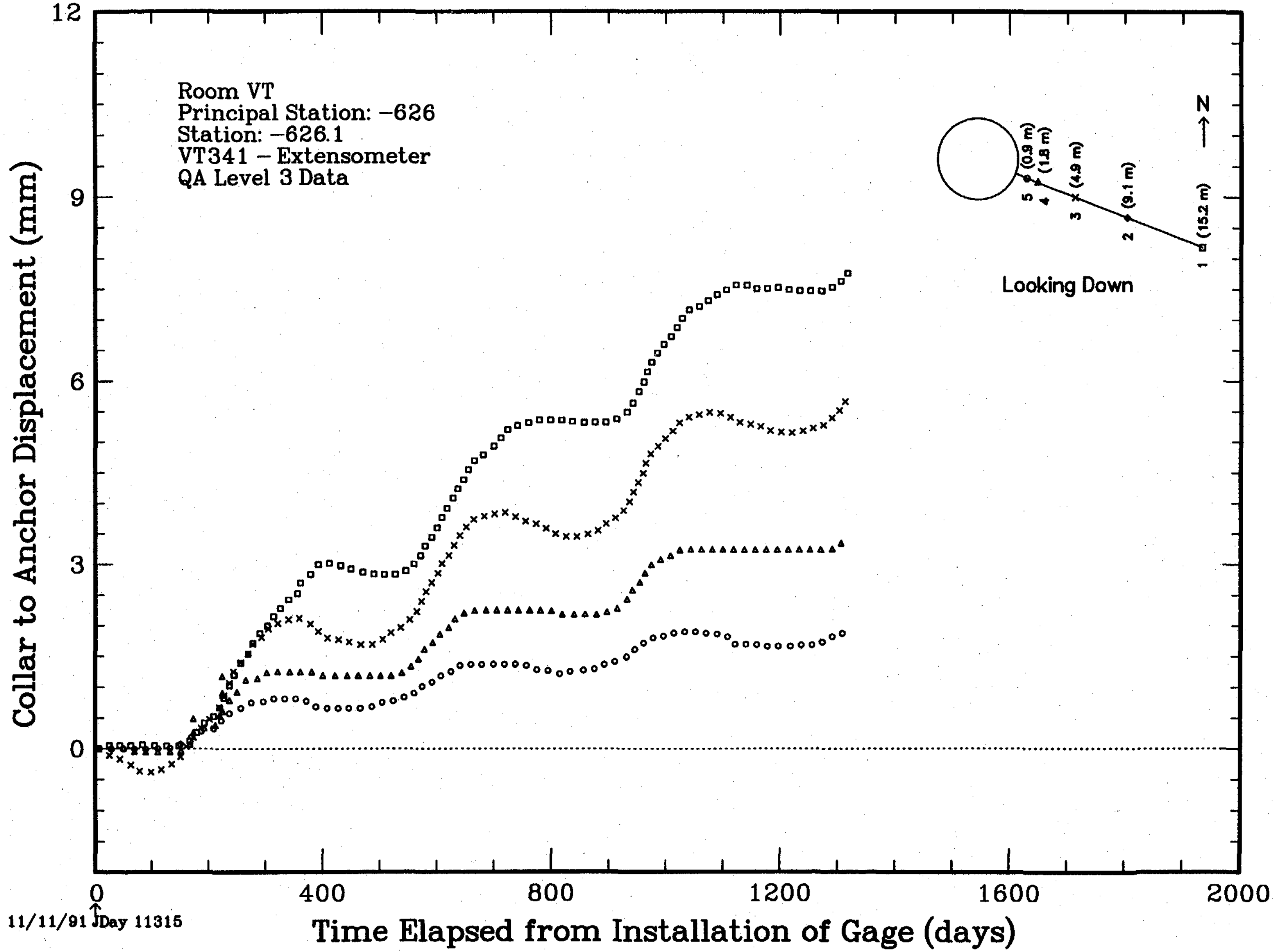

Figure 5.1.3i. Extensometer VT341

Table 5.1.5j. Extensometer VT342

+--------------------+
| Gage: VT342 |
+--------------------+
****

***** VT342 PI Comments *****

08/07/95 DEM [RANK = 10(1),5(2),10(3),10(4)10(5)] ALL GAGES GAVE OUTSTANDING DATA EXCEPT FOR GAGE 2 WHICH SUFFERED FROM EXCESSIVE SCATTER. THIS SCATTER WAS DELETED. THE OSCILLATIONS ABOUT THE MEAN DISPLACEMENT CURVE IS THE RESULT OF THE SEASONAL VARIATION IN THE TEMPERATURE OF THE INTAKE AIR. THIS UNIT IS NEAR THE FULL DEPTH OF THE SHAFT. [COMPRESSION = 5.22:1] (DEM)

***** VT342 Location *****

Principal Station -626
Station -626.1

Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Gage Coordinates Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT342-1	EXT	P REM	H	2.96	18.20	68.45	67.60	0.0	0.0	-626.1	-626.1	IRAD	09/11/91	57-4933	
VT342-2	EXT	P REM	H	2.96	12.10	68.45	67.68	0.0	0.0	-626.1	-626.1	IRAD	09/11/91	57-4933	
VT342-3	EXT	P REM	H	2.96	7.83	68.45	67.81	0.0	0.0	-626.1	-626.1	IRAD	09/11/91	57-4933	
VT342-4	EXT	P REM	H	2.96	4.79	68.45	68.07	0.0	0.0	-626.1	-626.1	IRAD	09/11/91	57-4933	
VT342-5	EXT	P REM	H	2.96	3.87	68.45	68.22	0.0	0.0	-626.1	-626.1	IRAD	09/11/91	57-4933	

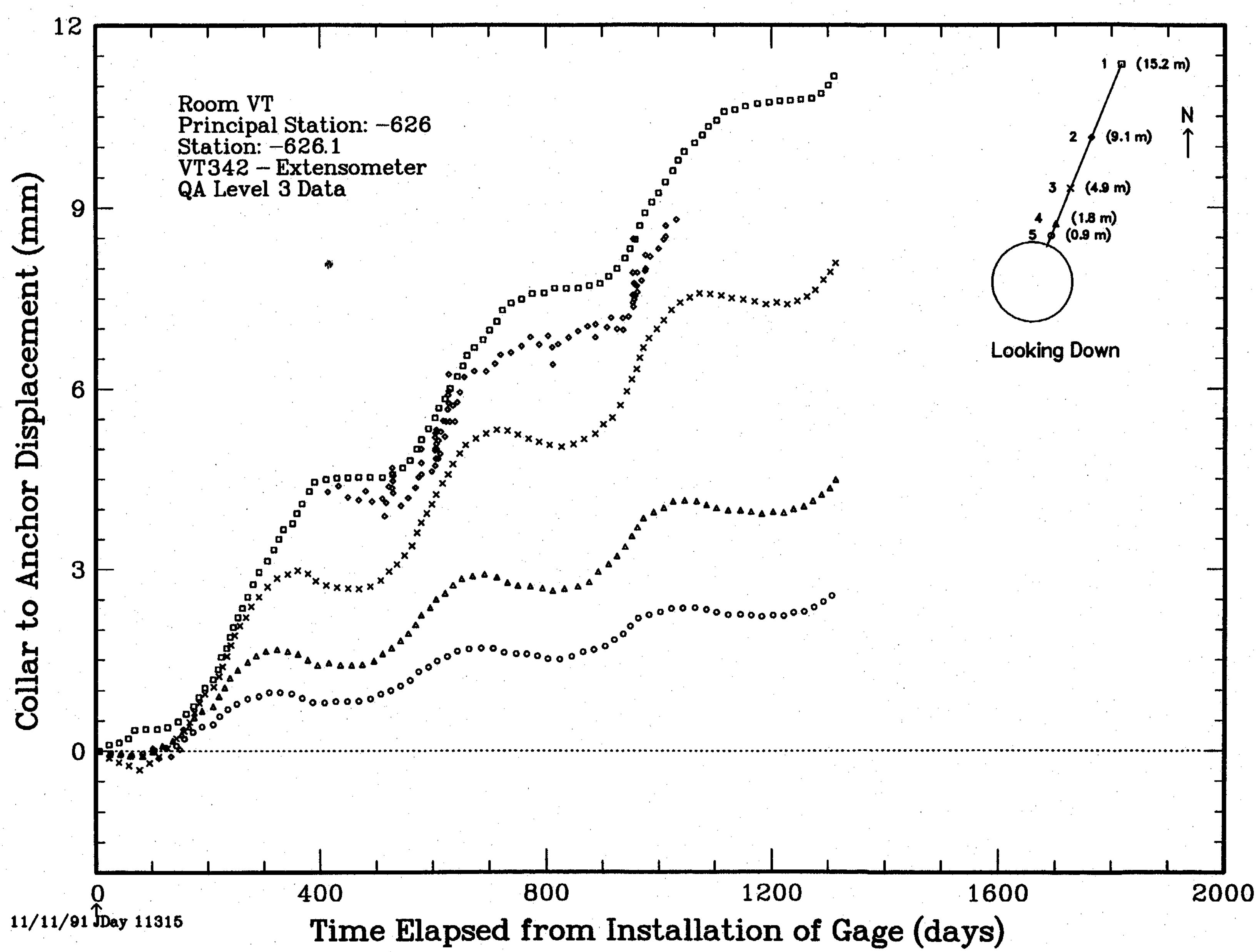

Figure 5.1.3j. Extensometer VT342

Table 5.1.5k. Extensometer VT343

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+---------------------+
|    Gage:  VT343     |
+---------------------+
***********************
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***** VT343 PI Comments *****

08/07/95 DEM [RANK = 0(1),10(2),10(3),10(4),10(5)] ALL OF THE DATA ARE RANKED AS OUTSTANDING EXCEPT FOR THAT OF GAGE 1, WHICH SHOWED EXCESSIVE SCATTER. AS A CONSEQUENCE, THE GAGE 1 RECORD WAS DELETED. THE OSCILLATIONS ABOUT THE MEAN DISPLACEMENT OF THE GAGES IS THE RESULT OF THE SEASONAL VARIATIONS IN THE AIR TEMPERATURE OF THE INTAKE AIR. THIS UNIT WAS NEAR THE FULL DEPTH OF THE SHAFT. [COMPRESSION = 7.11:1] (DEM)

***** VT343 Location *****

Principal Station -626
Station -626.1

				Gage Coordinates												
								Prin Stat		Room						
Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Z1 (m)	Z2 (m)	Z1 (m)	Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT343-1	EXT	P REM	H	3.02	18.26	155.82	157.39	0.0	-0.2	-626.1	-625.9	IRAD	10/09/91	57-4933	
VT343-2	EXT	P REM	H	3.02	12.16	155.82	157.24	0.0	-0.1	-626.1	-626.0	IRAD	10/09/91	57-4933	
VT343-3	EXT	P REM	H	3.02	7.89	155.82	156.98	0.0	-0.1	-626.1	-626.0	IRAD	10/09/91	57-4933	
VT343-4	EXT	P REM	H	3.02	4.85	155.82	156.51	0.0	-0.1	-626.1	-626.0	IRAD	10/09/91	57-4933	
VT343-5	EXT	P REM	H	3.02	3.93	155.82	156.25	0.0	-0.1	-626.1	-626.0	IRAD	10/09/91	57-4933	

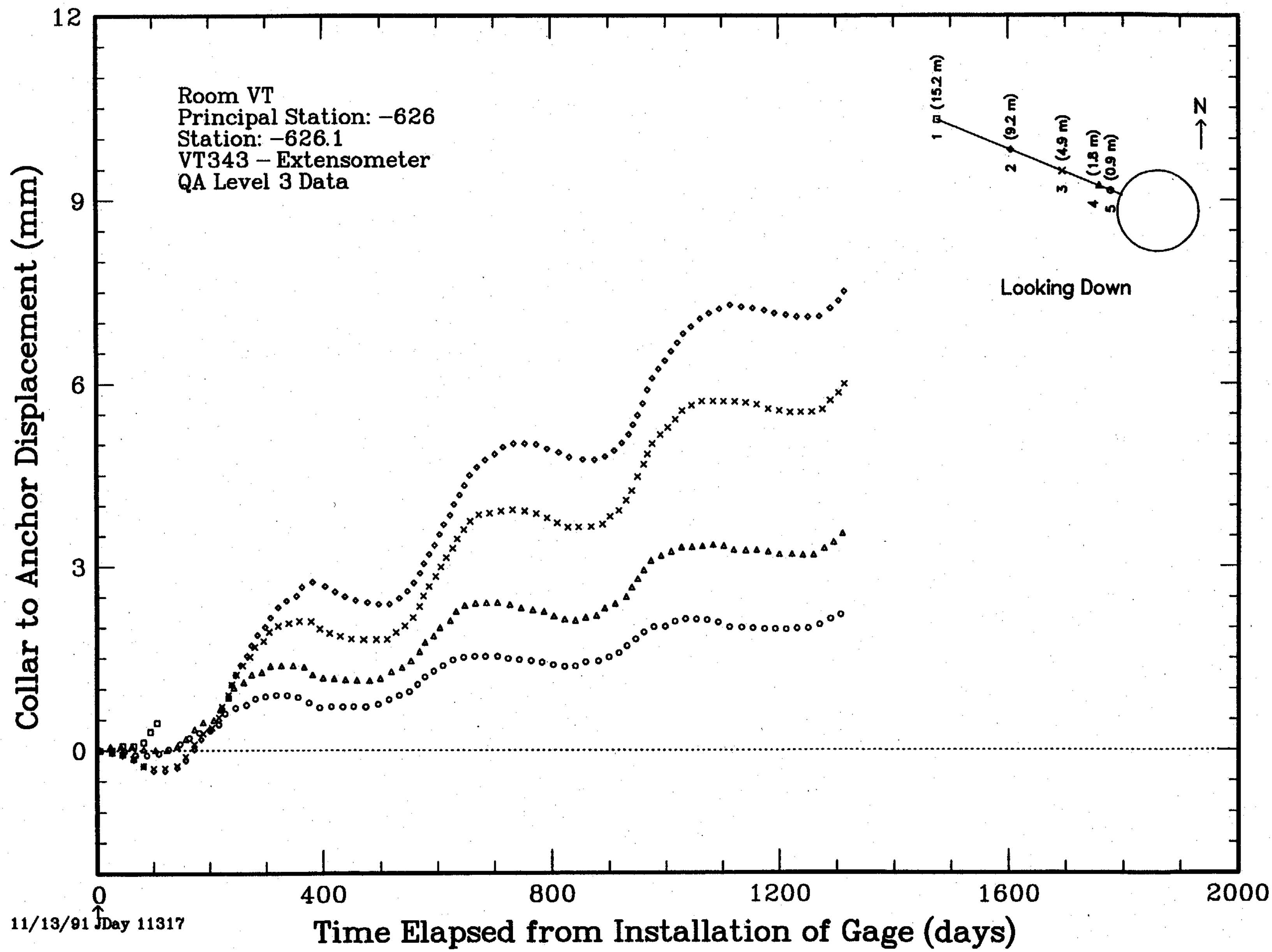

Figure 5.1.3k. Extensometer VT343

Table 5.1.51. Extensometer VT344

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+--------------------+
|   Gage:  VT344     |
+--------------------+
**********************
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***** VT344 PI Comments *****

08/07/95 DEM [RANK = 10(1),10(2),10(3),10(4),0(5)] THE DATA OF THIS UNIT ARE OUTSTANDING EXCEPT FOR GAGE 5 WHICH HAD EXCESSIVE SCATTER OVER ITS ENTIRE LIFE. GAGE 5 DATA WERE ENTIRELY DELETED. THE OSCILLATIONS ABOUT THE MEAN DISPLACEMENT CURVES ARE THE RESULT OF THE SEASONAL VARIATION IN THE INTAKE AIR TEMPERATURE. THIS UNIT WAS NEAR THE FULL DEPTH OF THE SHAFT. [COMPRESSION = 1.43:1] (DEM)

***** VT344 Location *****

Principal Station -626
Station -626.1

								Gage Coordinates							
								Prin Stat		Room					
Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Z1 (m)	Z2 (m)	Z1 (m)	Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT344-1	EXT	P REM	H	3.14	18.38	246.61	247.43	0.0	0.2	-626.1	-626.3	IRAD	09/12/91	57-4933	
VT344-2	EXT	P REM	H	3.14	12.28	246.61	247.35	0.0	0.1	-626.1	-626.2	IRAD	09/12/91	57-4933	
VT344-3	EXT	P REM	H	3.14	8.01	246.61	247.20	0.0	0.0	-626.1	-626.1	IRAD	09/12/91	57-4933	
VT344-4	EXT	P REM	H	3.14	4.97	246.61	246.96	0.0	0.0	-626.1	-626.1	IRAD	09/12/91	57-4933	
VT344-5	EXT	P REM	H	3.14	4.05	246.61	246.84	0.0	0.0	-626.1	-626.1	IRAD	09/12/91	57-4933	

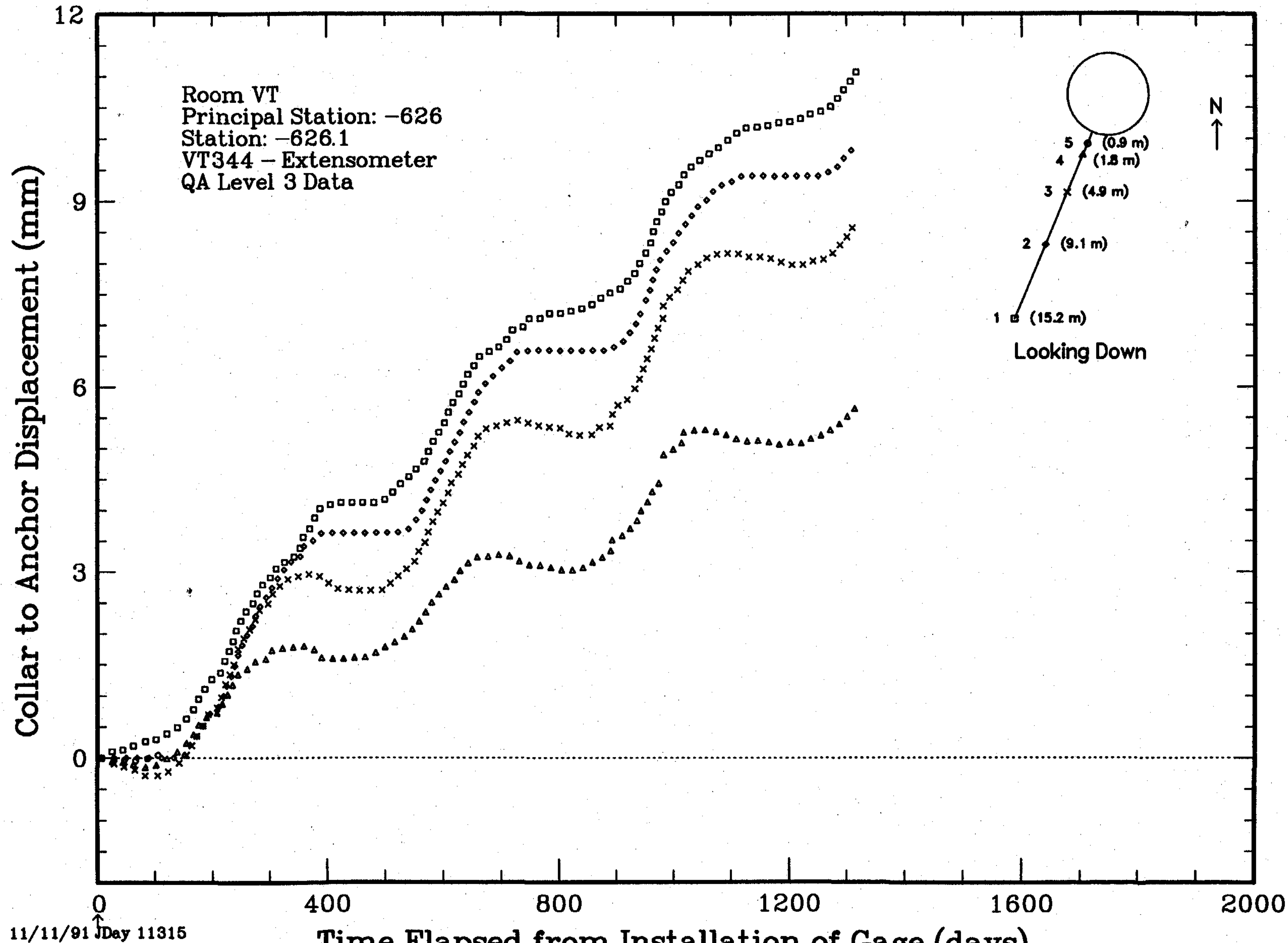

Figure 5.1.31. Extensometer VT344

5.2 Temperature Measurements: Temperature measurements were made with conventional thermocouples. There were essentially two different types of installations: single thermocouple junctions installed to measure the air temperature, and thermocouple units consisting of six gage junctions emplaced at different depths into the emplacement hole at approximately 15.2, 7.6, 4.6, 1.5, 0.9, and 0.5 m (50, 25, 15, 5, 3, and 1.5 ft) to measure the salt temperature in the shaft walls. The single thermocouple junctions measuring the air temperature were installed on the collars of the emplacement drill holes of the units measuring the salt temperature. The installations were at three stations, -343 m (-1124 ft), -479 m (-1574 ft), and -626 m (-2054 ft). At each station, two diametrically opposed units were located so that they split the angle between two of the extensometer units, essentially in the northwest-southeast orientation. Thus, there were two units measuring temperature into salt shaft wall at each of the three station locations. Typically, Unit VT7x1 was oriented to the northwest and VT7x2 to the southeast. The corresponding air temperature gages match the unit designations in style, being VT9x1 with VT7x1 and VT9x2 with VT7x2, respectively.

5.2.1 Airstream Temperature Measurements: The relative locations of the air temperature thermocouple units in the shaft are depicted in Table 5.2.1.

Descriptions, locations and PI comments for each thermocouple gage for air temperature are given in Tables 5.2.2a-f. Plots of the reduced data for the individual units are given in Figures 5.2.1a-f for air temperature gages. These airstream temperatures are presented before the salt rock mass temperature information because the airstream forms the basis for the behavior of the rock mass.

Table 5.2.1. Thermocouple Units (Gages) Location Guide

Depth m (ft)	Station	Gages
0.0 (0.0)	Ground Surface	
-342.6 (-1124)	-343	VT901 VT701 + VT702 VT902
-479.7 (-1574)	-554	VT921 VT721 + VT722 VT922
-626.0 (-2054)	-626	VT941 VT741 + VT742 VT942
		Shaft Station

Temperature measurements differ from the mechanical measurements in that the time of installation has little, if any, physical meaning. In the AIS, as noted previously, the installation of the -626 Station was some 237 days after the -343 and -480 Stations. As a result, the initial date of the plots of temperature from the -626 Station are all arbitrarily shifted by 237 days so that they coincide with the installation date of the first thermocouple unit to be installed. This procedure brings all of the thermocouple records into essentially the same time frame and makes correlation of responses much easier.

The temperature data, appear at first glance, to be quite scattered and uncertain. This would be an incorrect observation. In fact, they actually are quite accurate and contain a wealth of information. Because they are located in the shaft used as the air intake for the entire underground ventilation system, this environment accounts for their appearance. Under normal operating conditions a large volume of air (12,035 m^3/min (425,000 ft^3/min)) passes by these gage locations. This produces an equivalent velocity of about 6.1 m/s (13.6 miles/hr). Brief periods of reduced or quiescent flow because of testing or power outages occur, but total less than 5% of the time, and are considered insignificant. Depending upon the exact location of the thermocouple junction, its response will vary in accordance with the conditions in the intake air, and of its installation details.

Those gages directly in the airstream are very straightforward in their response. As is apparent, the temperature variation responds to both the diurnal, as well as the seasonal, variation in air temperature. The resultant data trace is then the superimposition of two sinusoidal type wave signals. The diurnal is the high frequency and the seasonal is the low frequency signal. Thus, the apparent large scatter of data, of about +/-9°C (+/-16°F), about the mean in these gages is actually equal to the daily temperature variations of the intake air. The long peak to trough variation is the seasonal cycle of the gages. At Station -343 the measurements indicate the average temperature is about 18°C (64.4°F), with the summer mean temperature of about 28°C (82.4°F) and with the corresponding winter mean temperature of about 10°C (50°F). The mean temperatures agree quite well with the regional temperatures, as would be expected. However, for some reason, not related to the accuracy of the gages, the extremes in temperature do not reflect the known regional values. This is probably caused by the inability of the reading frequency to adequately capture the extremes or, more probably, that this station is actually about half way down the shaft.

The fundamental temperature response is the same for the airstream gages at all of the stations, independent of depth of the station in the shaft. The only differences with depth being that the minimum peak temperature at Station -626 is some 5°C (9°F) warmer than the air at Station -343. The maximum peak temperatures remain nearly the same, however. It appears from these records that the summertime diurnal fluctuation is roughly 12°C (22°F), while the wintertime fluctuation is about 18°C (32°F).

Interestingly, both the peak summer high and peak winter low appear to progressively increase over the four year recording history, perhaps this is indicative of a somewhat normal long-term variation in regional temperature patterns.

(text continues on page 144)

Table 5.2.2a. Airstream Temperature Gage VT901

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+---------------------+
|    Gage:  VT901     |
+---------------------+
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***** VT901 PI Comments *****

08/09/95 DEM [RANK = 10(1)] THE DATA ARE OUTSTANDING. THIS THERMOCOUPLE GAGE IS DIRECTLY IN THE INTAKE AIR STREAM. AS A RESULT IT SHOWS THE EXPECTED LARGE DIURNAL CHANGES IN TEMPERATURE. THESE ARE SUPERIMPOSED ON THE SEASONAL CHANGES IN THE AIR TEMPERATURE. [COMPRESSION = 1.06:1] (DEM)

***** VT901 Location *****

Principal Station -343
Station -342.7

Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Gage Coordinates Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT901-1	TC	P REM	H	3.06	3.06	112.30	112.30	0.0	0.0	-342.7	-342.7	CGS	04/30/90	40-6791	

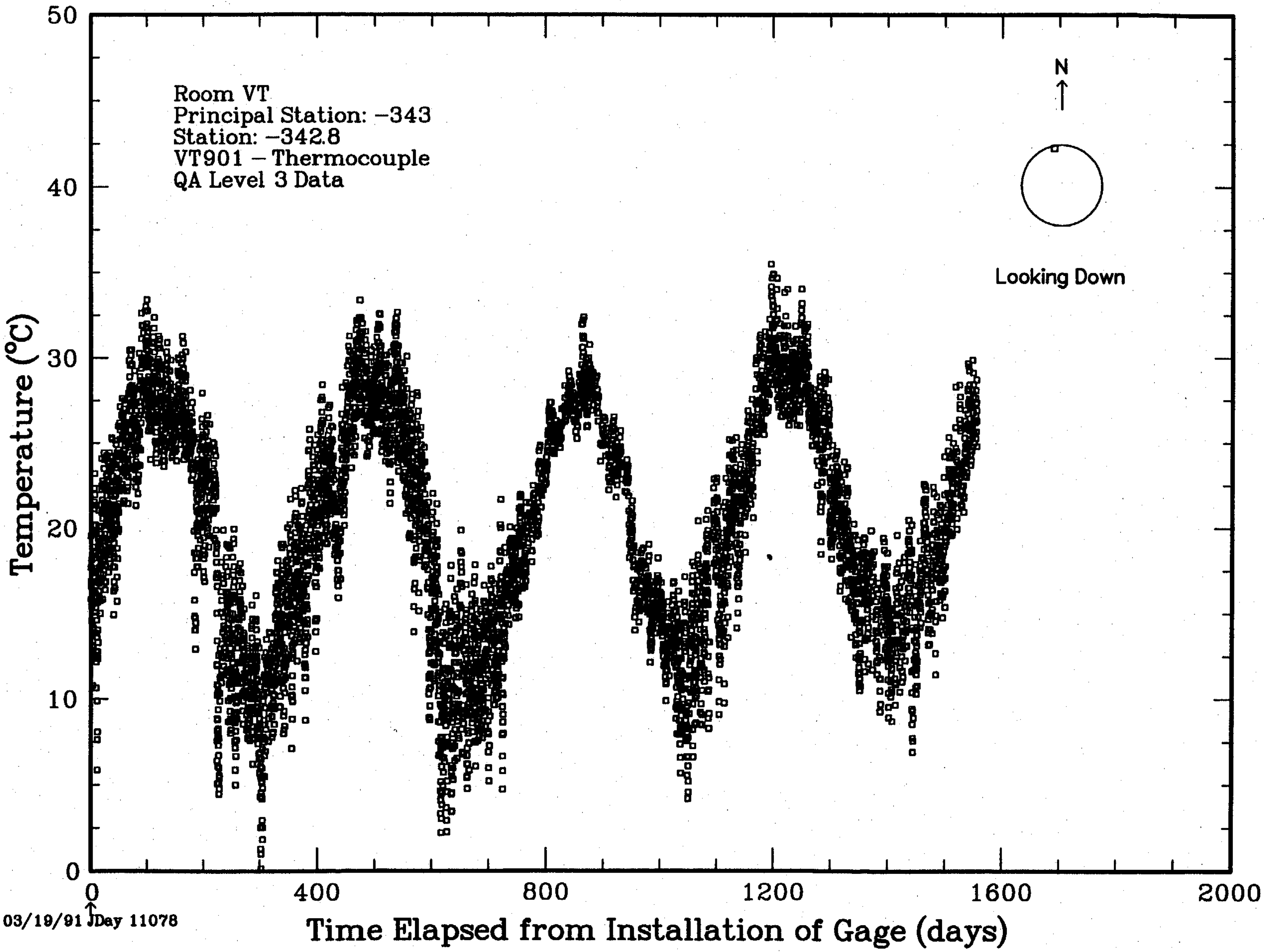

Figure 5.2.1a. Airstream Temperature Gage VT901

Table 5.2.2b. Airstream Temperature Gage VT902

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+--------------------+
|    Gage:  VT902    |
+--------------------+
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***** VT902 PI Comments *****

08/09/95 DEM [RANK = 10(1)] THE DATA ARE OUTSTANDING. THIS THERMOCOUPLE GAGE IS DIRECTLY IN THE INTAKE AIR STREAM. AS A RESULT IT SHOWS THE EXPECTED LARGE DIURNAL CHANGES IN TEMPERATURE. THESE ARE SUPERIMPOSED ON THE SEASONAL CHANGES IN THE AIR TEMPERATURE. [COMPRESSION = 1.06:1] (DEM)

***** VT902 Location *****

Principal Station -343
Station -342.7

Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Gage Coordinates Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT902-1	TC	P REM	H	3.09	3.09	292.66	292.66	0.0	0.0	-342.7	-342.7	CGS	04/30/90	40-6791	

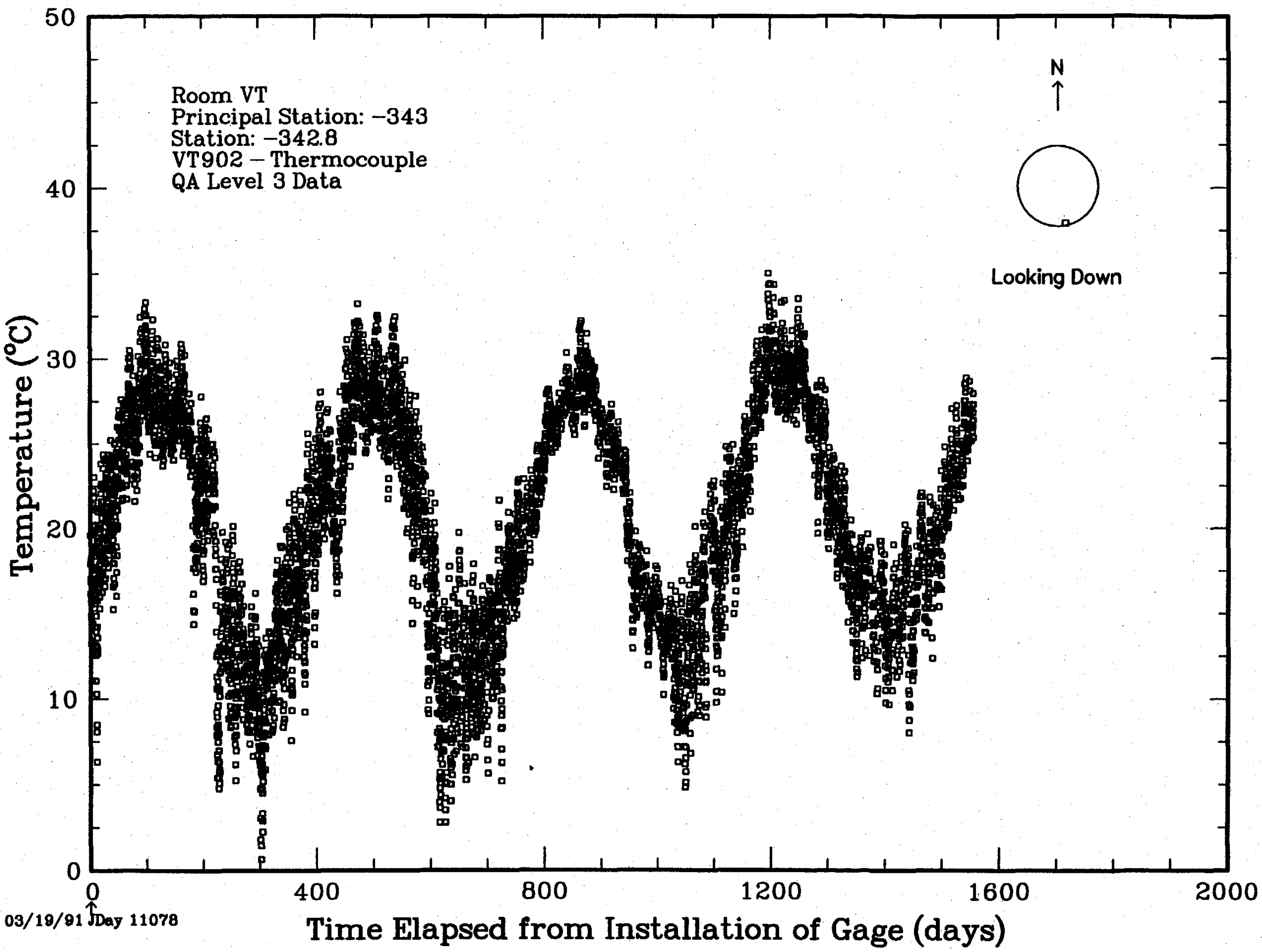

Figure 5.2.1b. Airstream Temperature Gage VT902

Table 5.2.2c. Airstream Temperature Gage VT921

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+---------------------+
|    Gage:  VT921     |
+---------------------+
***********************
```

***** VT921 PI Comments *****

08/09/95 DEM [RANK = 10(1)] THE DATA ARE OUTSTANDING. THIS THERMOCOUPLE GAGE IS DIRECTLY IN THE INTAKE AIR STREAM. AS A RESULT IT SHOWS THE EXPECTED LARGE DIURNAL CHANGES IN TEMPERATURE. THESE ARE SUPERIMPOSED ON THE SEASONAL CHANGES IN THE AIR TEMPERATURE. [COMPRESSION = 1.08:1] (DEM)

***** VT921 Location *****

Principal Station -480
Station -479.7

								Gage Coordinates							
								Prin Stat		Room					
Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Z1 (m)	Z2 (m)	Z1 (m)	Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT921-1	TC	P REM	H	3.07	3.07	113.06	113.06	0.0	0.0	-479.7	-479.7	CGS	09/20/90	40-6791	

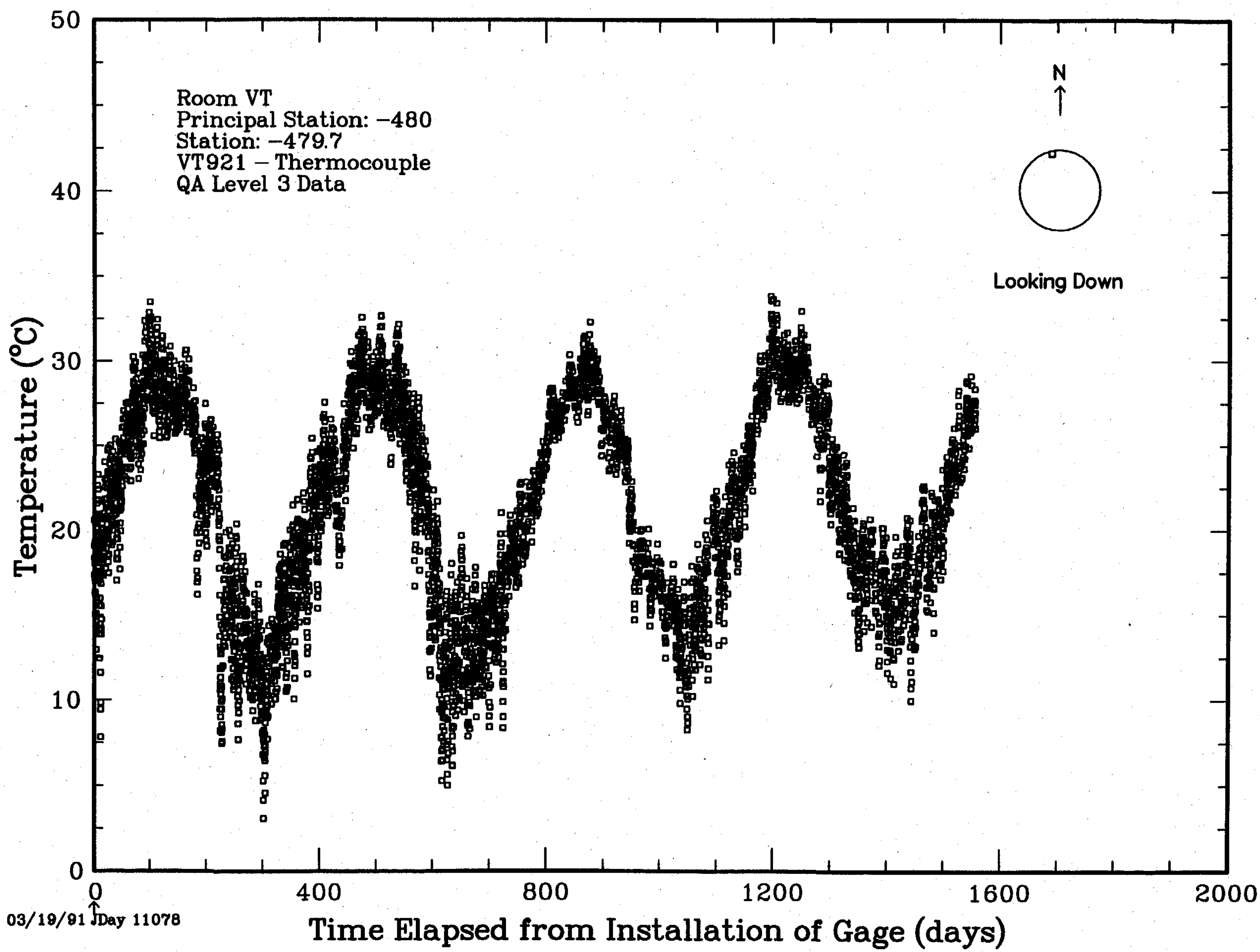

Figure 5.2.1c. Airstream Temperature Gage VT921

Table 5.2.2d. Airstream Temperature Gage VT922

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+--------------------+
|    Gage:  VT922    |
+--------------------+
**********************
```

***** VT922 PI Comments *****

08/09/95 DEM [RANK = 10(1)] THE DATA ARE OUTSTANDING. THIS THERMOCOUPLE GAGE IS DIRECTLY IN THE INTAKE AIR STREAM. AS A RESULT IT SHOWS THE EXPECTED LARGE DIURNAL CHANGES IN TEMPERATURE. THESE ARE SUPERIMPOSED ON THE SEASONAL CHANGES IN THE AIR TEMPERATURE. [COMPRESSION = 1.11:1] (DEM)

***** VT922 Location *****

Principal Station -480
Station -479.7

								Gage Coordinates							
								Prin Stat		Room					
Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Z1 (m)	Z2 (m)	Z1 (m)	Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT922-1	TC	P	REM	H 3.06	3.06	291.96	291.96	0.0	0.0	-479.7	-479.7	CGS	09/20/90	40-6791	

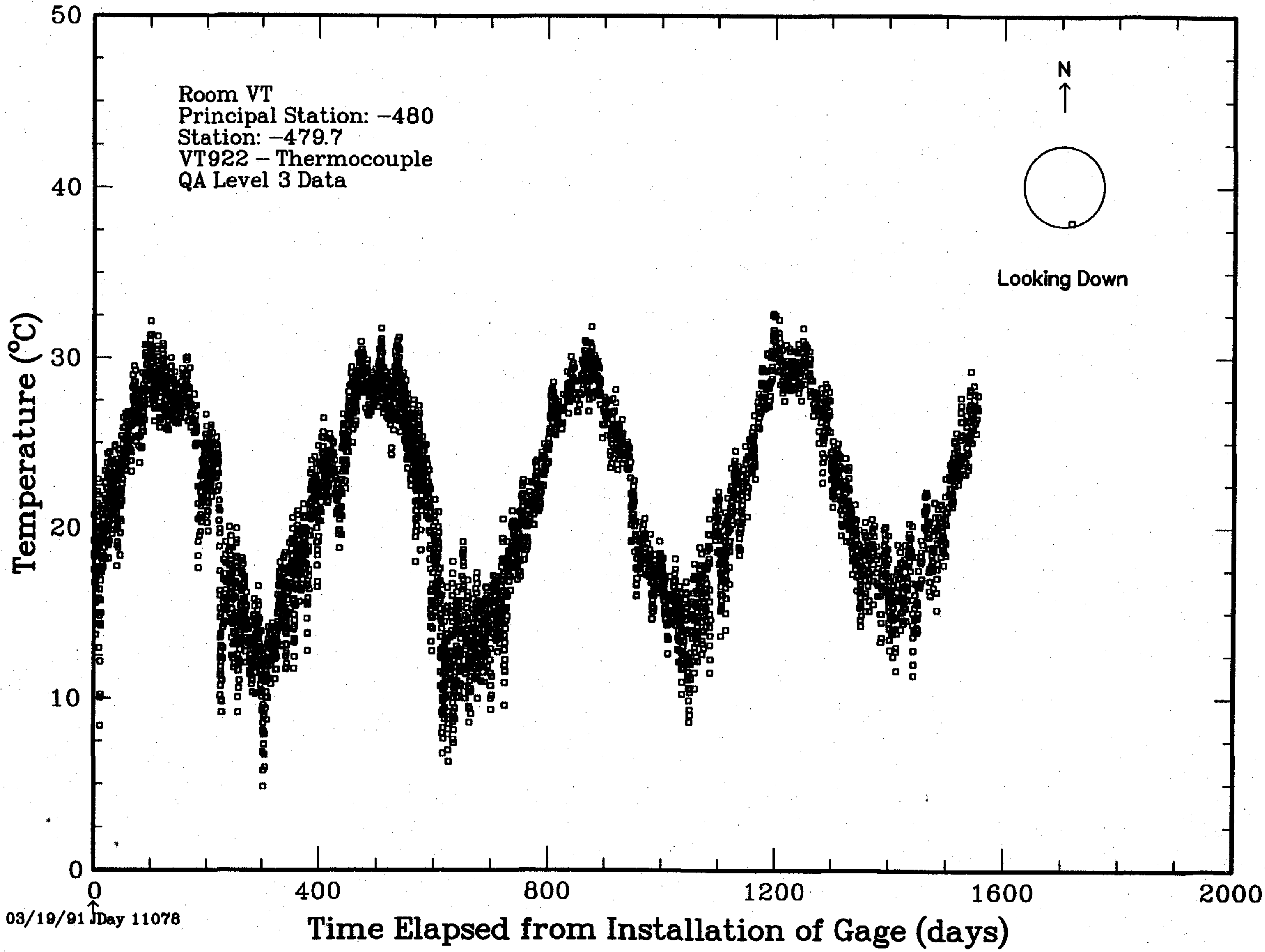

Figure 5.2.1d. Airstream Temperature Gage VT922

Table 5.2.2e. Airstream Temperature Gage VT941

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+--------------------+
|    Gage:  VT941    |
+--------------------+
**********************
```

***** VT941 PI Comments *****

08/09/95 DEM [RANK = 10(1)] THE DATA ARE OUTSTANDING. THIS THERMOCOUPLE GAGE IS DIRECTLY IN THE INTAKE AIR STREAM. AS A RESULT IT SHOWS THE EXPECTED LARGE DIURNAL CHANGES IN TEMPERATURE. THESE ARE SUPERIMPOSED ON THE SEASONAL CHANGES IN THE AIR TEMPERATURE. BECAUSE THE ZERO DATE FOR THE CONTINUOUS TEMPERATURE HISTORY IS ARBITRARY, THESE DATA HAVE BEEN SHIFTED BY 237 DAYS TO BRING THEM INTO REGISTRY WITH THE GAGES INSTALLED EARLIER AT THE UPPER SHAFT STATIONS. [COMPRESSION = 1.17:1] (DEM)

***** VT941 Location *****

Principal Station -626
Station -626.1

Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Gage Coordinates Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT941-1	TC	P REM	H	2.96	2.96	111.95	111.95	0.0	0.0	-626.1	-626.1	CGS	08/30/91	40-6791	

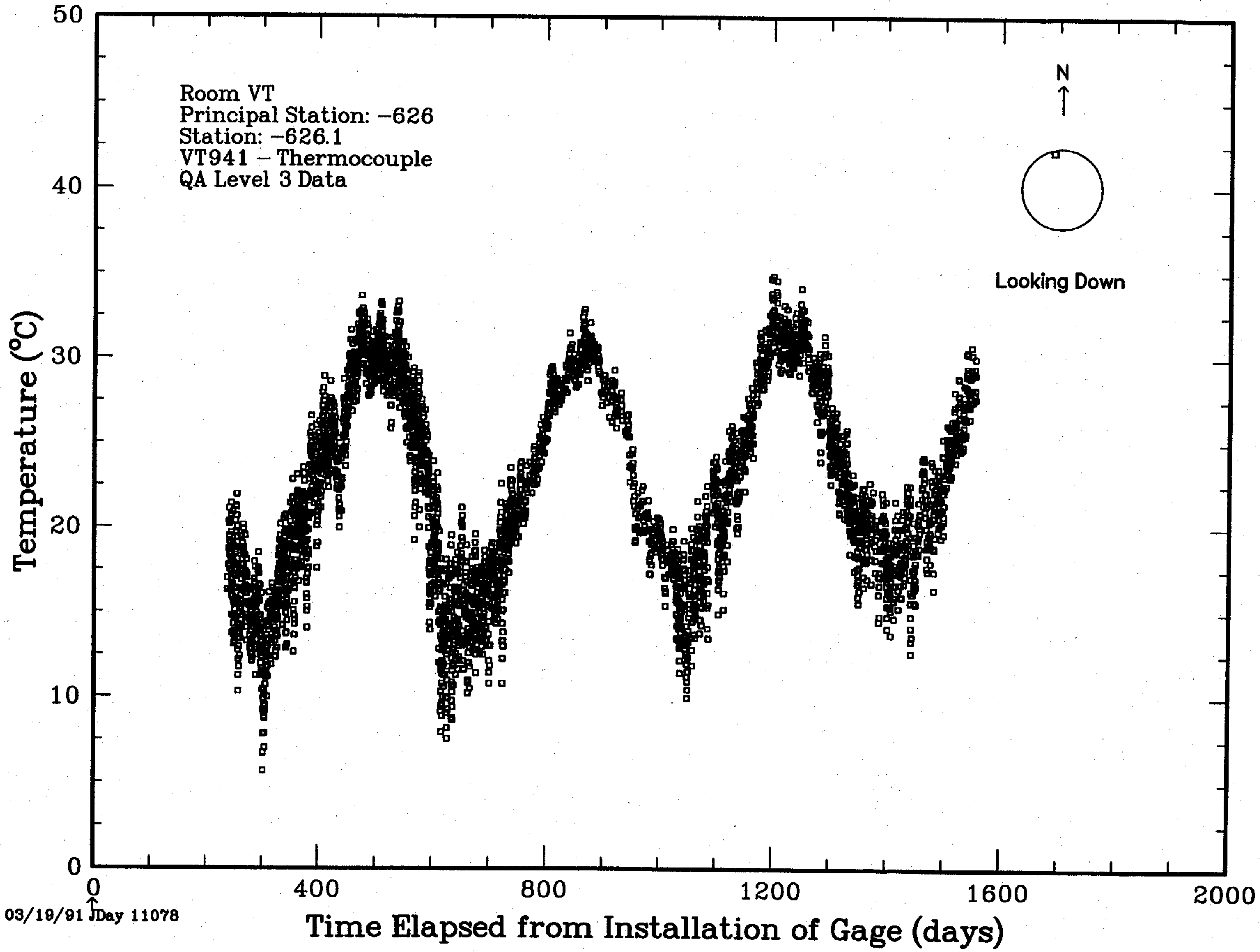

Figure 5.2.1e. Airstream Temperature Gage VT941

Table 5.2.2f. Airstream Temperature Gage VT942

```
+---------------------+
|   Gage:  VT942      |
+---------------------+
***********************
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***** VT942 PI Comments *****

08/09/95 DEM [RANK = 10(1)] THE DATA ARE OUTSTANDING. THIS THERMOCOUPLE GAGE IS DIRECTLY IN THE INTAKE AIR STREAM. AS A RESULT IT SHOWS THE EXPECTED LARGE DIURNAL CHANGE IN TEMPERATURE. THESE ARE SUPERIMPOSED ON THE SEASONAL CHANGES IN THE AIR TEMPERARTURE. BECAUSE THE ZERO DATE FOR THE CONTINUOUS TEMPERATURE HISTORY IS ARBITRARY, THESE DATA HAVE BEEN SHIFTED BY 237 DAYS TO BRING THEM INTO REGISTRY WITH THE GAGES INSTALLED EARLIER AT THE UPPER SHAFT STATIONS. [COMPRESSION = 1.19] (DEM)

***** VT942 Location *****

Principal Station -626
Station -626.1

Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Gage Coordinates Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT942-1	TC	P	REM H	3.13	3.13	293.04	293.04	0.0	0.0	-626.1	-626.1	CGS	08/30/91	40-6791	

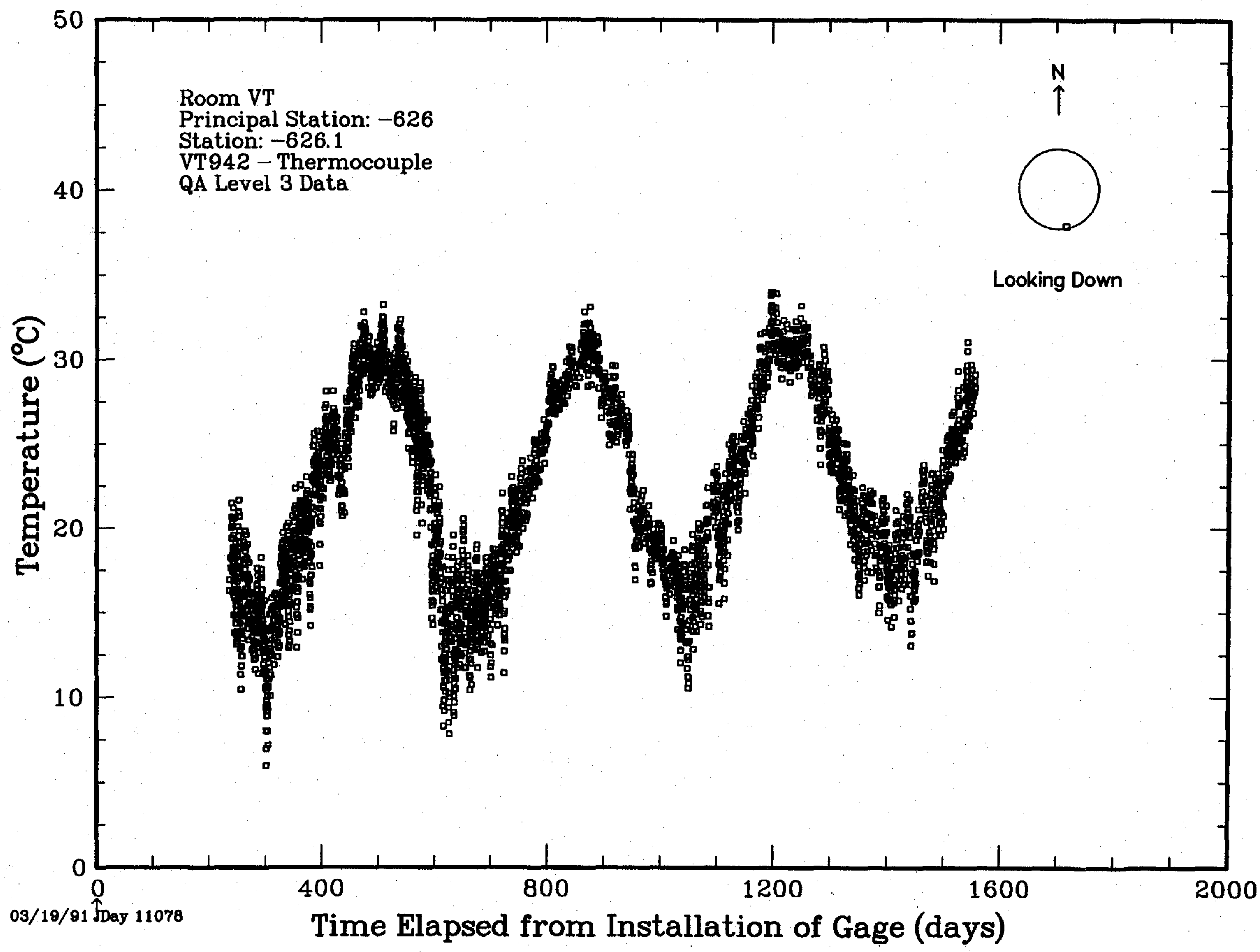

Figure 5.2.1f. Airstream Temperature Gage VT942

5.2.2 Rock Mass Temperature Measurements: The thermocouple units in the salt of the shaft wall show behavior, although somewhat more complex, which clearly reflects the airstream temperature. This is reasonable because the airstream temperature is driving the processes that occur around the salt mass units and within the salt mass itself.

The rock mass thermocouple units, as previously stated, consist of six individual gage junctions emplaced each at different depths into the hole, with depths of approximately 15.2, 7.6, 4.6, 1.5, 0.9, and 0.5 m (50, 25, 15, 5, 3, and 1.5 ft). These measured the salt temperature into the salt. The units were installations at three principal stations, -343 m (-1124 ft), -479 m (-1574 ft), and -626 m (-2054 ft). At each station, two diametrically opposed units were located in the northwest-southeast orientation so that they split the angle between two of the extensometer units. Thus, there were two units measuring temperature into the shaft wall at each of the three station locations, giving a two-fold redundancy.

As in the case of the airstream gages, the initial times obtained from installation have little meaning and 237 days have been added to the gages at principal station -626. This effectively brings these data into registry with the gages at stations -343 and -480, installed earlier.

The location guide found in Table 5.1.1 gives the location of the rock mass thermocouple units. The details related to the PI comments and relevant gage data are given, as usual, in Tables 5.2.3a-f. The plots of rock mass temperature output of the gages is given in Figures 5.2.2a-f.

Although it is clear that all of the gages in the unit exhibit the sinusoidal variations of the air temperature gages, the behavior is modified significantly. In fact, both the diurnal and seasonal variations diminish in amplitude with the depth of the gage in the emplacement hole.

At the maximum depth in the holes, the gages show essentially no diurnal variation and a markedly attenuated seasonal variation. There is also a diminishing of intensity of the sinusoidal changes with the increasing depth in the shaft. This is consistent with the diminished amplitude of the intake air temperature with depth (or travel) down the shaft.

The change in amplitude of the temperature variations with depth into the salt has several aspects related to the air stream temperature and the details of the gage installation. The indicated variation in both diurnal and seasonal is always smaller than the actual air temperature variation. Perhaps the most relevant reason for this is that the thermocouples are emplaced in imperfectly insulated emplacement drill holes which suggests that the air in the holes is either totally or somewhat quiescent, although the exact condition in not known.

As is equally apparent, the sinusoidal wave undergoes a phase shift with the depth of the thermocouple gage in the emplacement drill hole, again probably because of the conditions of the circulation of air in the hole. An indication of the effectiveness of the insulation is obtained by determining the phase shift of the seasonal waves with depth into the salt. If the insulation in the emplacement hole provides perfect suppression of convection, the change in temperature at depth depends solely on the conduction of heat in the salt and the phase shift is maximum. For the case of perfect convective heat transfer in the emplacement hole, there would be no phase shift in the data. Although the shift is difficult to quantify without precise analysis, it appears to be about 100 days, which is consistent with a similar shift thought to be caused by the temperature variations in the mechanical extensometer data.

(text continues on page 159)

Table 5.2.3a. Shaft Salt Temperature Unit VT701

Gage: VT701

***** VT701 PI Comments *****

08/07/95 DEM [RANK = 10(1),10(2),10(3),10(4),10(5),10(6)] NO REDUCTION ACTIONS WERE NECESSARY FOR THIS UNIT. THE APPARENT SCATTER IS ACTUALLY THE DIURNAL CHANGES IN AIR TEMPERATURE SUPERIMPOSED ON THE SEASONAL VARIATION IN INTAKE AIR TEMPERATURE. THE DATA SHOWS BOTH A DIMINISHED AMPLITUDE OF THE VARIATION AND A PHASE SHIFT WITH RADIAL DISTANCE INTO THE SALT AWAY FROM THE SHAFT. [COMPRESSION 1.38:1] (DEM)

***** VT701 Location *****

Principal Station -343
Station -342.7

Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Gage Coordinates Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT701-1	TC	P REM	H	3.06	18.30	112.30	112.40	0.0	0.0	-342.7	-342.7	CGS	04/30/90	40-6791	
VT701-2	TC	P REM	H	3.06	12.20	112.30	112.39	0.0	0.0	-342.7	-342.7	CGS	04/30/90	40-6791	
VT701-3	TC	P REM	H	3.06	7.93	112.30	112.37	0.0	0.0	-342.7	-342.7	CGS	04/30/90	40-6791	
VT701-4	TC	P REM	H	3.06	4.89	112.30	112.35	0.0	0.0	-342.7	-342.7	CGS	04/30/90	40-6791	
VT701-5	TC	P REM	H	3.06	3.97	112.30	112.32	0.0	0.0	-342.7	-342.7	CGS	04/30/90	40-6791	
VT701-6	TC	P REM	H	3.06	3.52	112.30	112.30	0.0	0.0	-342.7	-342.7	CGS	04/30/90	40-6791	

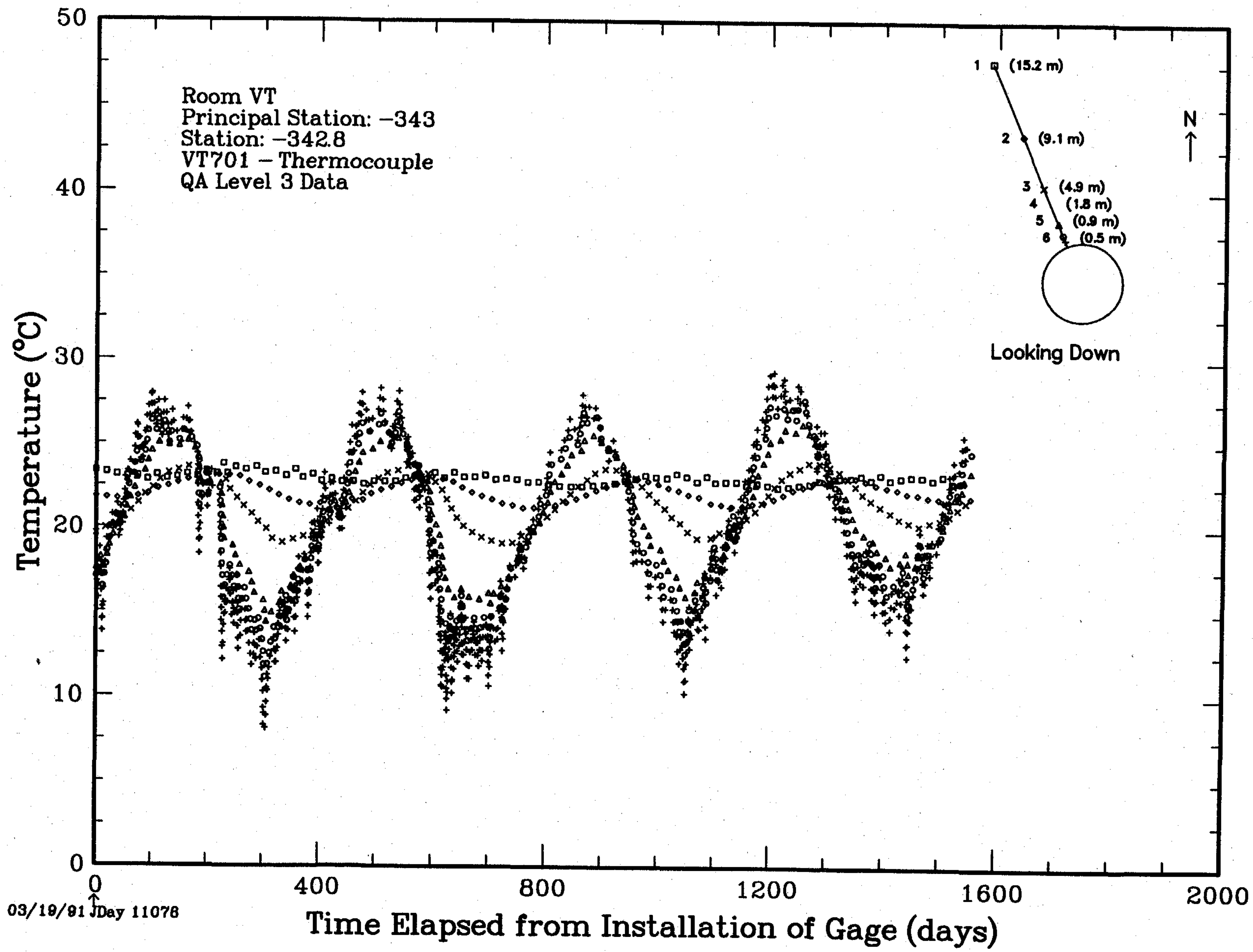

Figure 5.2.2a. Shaft Salt Temperature Unit VT701

Table 5.2.3b. Shaft Salt Temperature Unit VT702

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+--------------------+
|   Gage:  VT702     |
+--------------------+
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***** VT702 PI Comments *****

08/07/95 DEM [RANK = 10(1),10(2),10(3),10(4),10(5),10(6)] NO REDUCTION ACTIONS WERE NECESSARY FOR THIS UNIT. THE APPARENT SCATTER IS ACTUALLY THE DIURNAL CHANGES IN AIR TEMPERATURE SUPERIMPOSED ON THE SEASONAL VARIATION IN INTAKE AIR TEMPERATURE. THE DATA SHOWS BOTH A DIMINISHED AMPLITUDE OF THE VARIATION AND A PHASE SHIFT WITH RADIAL DISTANCE INTO THE SALT AWAY FROM THE SHAFT SURFACE. [COMPRESSION 1.36:1] (DEM)

***** VT702 Location *****

Principal Station -343
Station -342.7

				Gage Coordinates											
								Prin Stat		Room					
Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Z1 (m)	Z2 (m)	Z1 (m)	Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT702-1	TC	P REM	H	3.09	18.32	292.66	292.28	0.0	0.0	-342.7	-342.7	CGS	04/30/90	40-6791	
VT702-2	TC	P REM	H	3.09	12.23	292.66	292.38	0.0	0.0	-342.7	-342.7	CGS	04/30/90	40-6791	
VT702-3	TC	P REM	H	3.09	7.97	292.66	292.43	0.0	0.0	-342.7	-342.7	CGS	04/30/90	40-6791	
VT702-4	TC	P REM	H	3.09	4.92	292.66	292.51	0.0	0.0	-342.7	-342.7	CGS	04/30/90	40-6791	
VT702-5	TC	P REM	H	3.09	4.00	292.66	292.58	0.0	0.0	-342.7	-342.7	CGS	04/30/90	40-6791	
VT702-6	TC	P REM	H	3.09	3.55	292.66	292.61	0.0	0.0	-342.7	-342.7	CGS	04/30/90	40-6791	

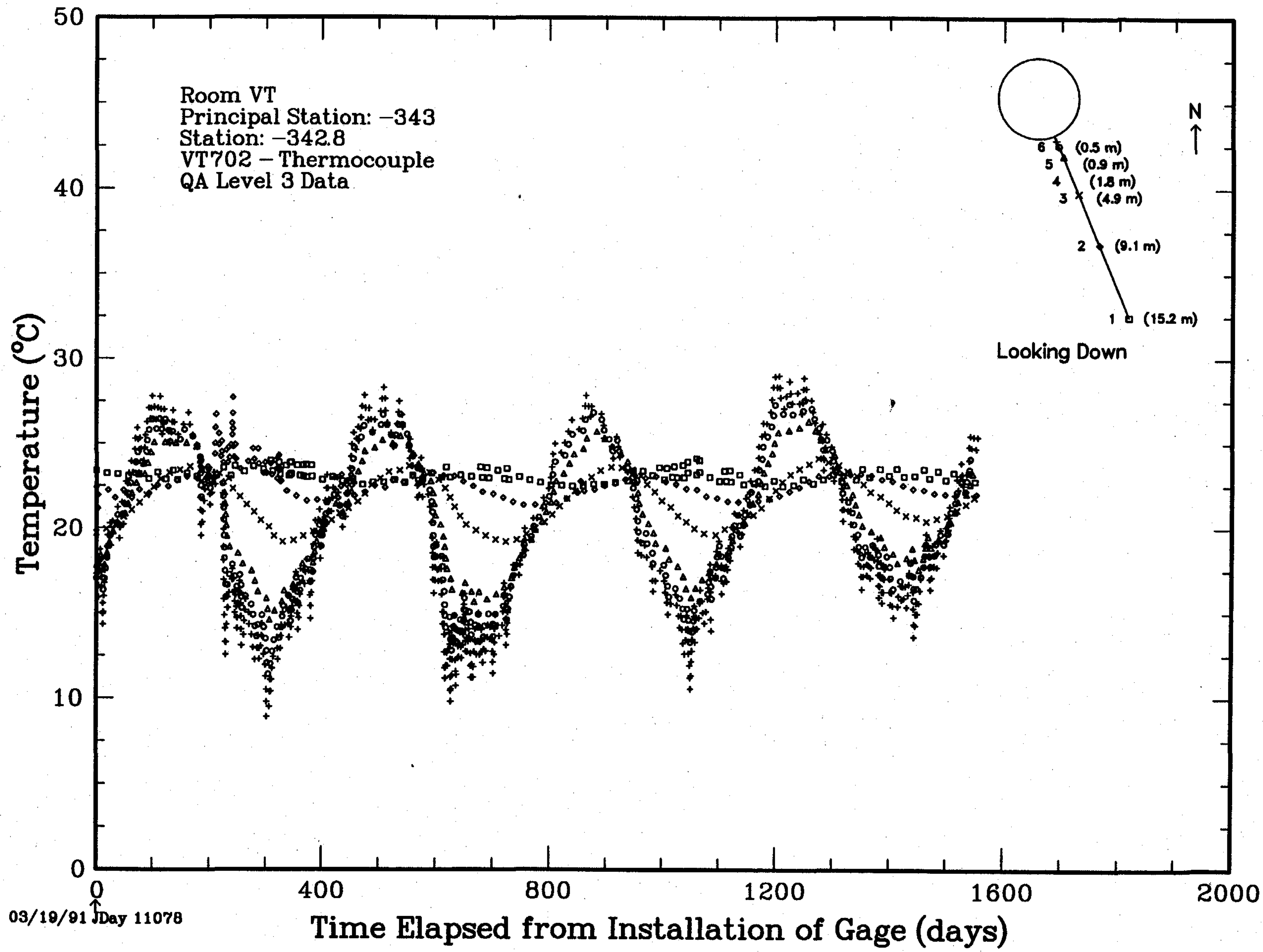

Figure 5.2.2b. Shaft Salt Temperature Unit VT702

Table 5.2.3c. Shaft Salt Temperature Unit VT721

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+--------------------+
|    Gage:  VT721    |
+--------------------+
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```

***** VT721 PI Comments *****

08/07/95 DEM [RANK = 9(1),10(2),10(3),10(4),10(5),10(6)] ONLY A FEW REDUCTION ACTIONS WERE POSSIBLE. THEY CONSISTED OF DELETION OF OBVIOUS SCATTER FROM PARTS OF GAGE 1. THIS WAS DIFFERENT FROM THE REAL DIURNAL CHANGES NATURALLY OCCURRING IN TEMPERATURE. DIURNAL CHANGES ARE SUPERIMPOSED ON THE SEASONAL VARIATION OF THE INTAKE AIR. THE DATA SHOWS BOTH THE DIMINISHED AMPLITUDE OF THE VARIATION AND A PHASE SHIFT WITH RADIAL DISTANCE INTO THE SALT AWAY FROM THE SHAFT WALL. [COMPRESSION = 1.53:1] (DEM)

***** VT721 Location *****

Principal Station -480
Station -479.7

Gage Number	Gage Type	Rec	Dir	Gage Coordinates R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT721-1	TC	P REM	H	3.07	18.31	113.06	112.28	0.0	0.0	-479.7	-479.7	CGS	09/20/90	40-6791	
VT721-2	TC	P REM	H	3.07	12.21	113.06	112.36	0.0	0.0	-479.7	-479.7	CGS	09/20/90	40-6791	
VT721-3	TC	P REM	H	3.07	7.94	113.06	112.50	0.0	0.0	-479.7	-479.7	CGS	09/20/90	40-6791	
VT721-4	TC	P REM	H	3.07	4.90	113.06	112.71	0.0	0.0	-479.7	-479.7	CGS	09/20/90	40-6791	
VT721-5	TC	P REM	H	3.07	3.98	113.06	112.85	0.0	0.0	-479.7	-479.7	CGS	09/20/90	40-6791	
VT721-6	TC	P REM	H	3.07	3.53	113.06	112.96	0.0	0.0	-479.7	-479.7	CGS	09/20/90	40-6791	

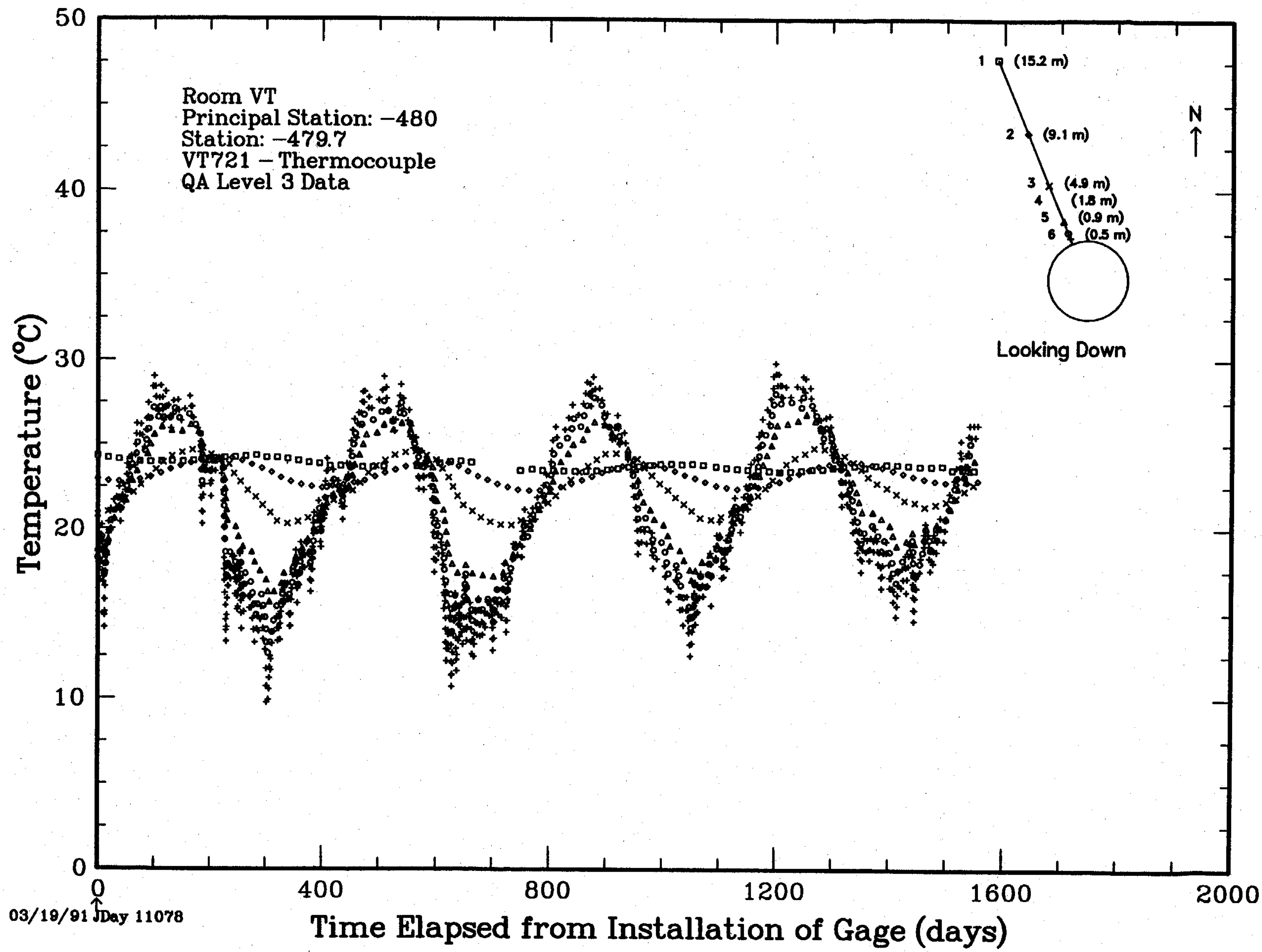

Figure 5.2.2c. Shaft Salt Temperature Unit VT721

Table 5.2.3d. Shaft Salt Temperature Unit VT722

+--------------------+
| Gage: VT722 |
+--------------------+
****

***** VT722 PI Comments *****

08/08/95 DEM [RANK = 8(1),9(2),10(3),10(4),10(5),10(6)] THERE WERE SOME UNUSUAL PROBLEMS WITH THIS UNIT. GAGES 4 AND 6 WERE OBVIOUSLY SWITCHED, PROBABLY AS THE RESULT OF INCORRECT CONNECTIONS OF THE LEADS. THIS WAS CORRECTED IN THE DATA REDUCTION PROCESS. OTHER REDUCTION ACTIONS INCLUDED REMOVAL OF MINOR SCATTER FROM GAGE 2. GAGE 1 HAD SCATTER AS WELL, ONLY SOME OF WHICH COULD BE REMOVED. SCATTER ON GAGE 1 AFTER ABOUT DAY 1250 COULD NOT BE REMOVED EASILY; HOWEVER, IT IS NOT TOO OBJECTIONABLE AND DOES NOT OBSCURE THE TEMPERATURE TREND. IN THE GAGES NEAR THE SHAFT SURFACE, THE NORMAL DATA SPREAD (APPARENT SCATTER) IS CAUSED BY THE DIURNAL CHANGES IN AIR TEMPERATURE. HOWEVER, IN THIS UNIT, ALTHOUGH IT WOULD BE VERY DIFFICULT TO DEMONSTRATE, GAGE 6 IS THOUGHT TO HAVE CONSIDERABLE REAL INSTRUMENT SCATTER. CERTAINLY, THE VERY LOW COMPRESSION SUGGESTS SIGNIFICANT REAL SCATTER AND CONSEQUENTLY MANY MORE DATA POINTS WERE RETAINED THAN NORMAL FOR THESE UNITS. THE RANGE OF THE DIURNAL VARIATION, PARTICULARILY IN GAGE 6, APPEARS EXCESSIVE BECAUSE OF SCATTER. THE EXCESSIVE RANGE ON GAGE 6 WOULD ALSO MANIFEST ITSELF AS AN APPARENT INCREASE IN AMPLITUDE OF THE SEASONAL VARIATION. THERE IS NO DATA REDUCTION METHOD TO REMOVE WELL DISTRIBUTED UNIFORM SCATTER. AS IS TYPICAL, DIURNAL CHANGES ARE SUPERIMPOSED ON THE SINUSOIDAL CHANGES OF THE SEASONAL VARIATION OF THE TEMPERATURE OF THE INTAKE AIR. THE DATA SHOW A DIMINISHED AMPLITUDE OF THE VARIATION AND A PHASE SHIFT WITH RADIAL DEPTH INTO THE SALT AWAY FROM THE SHAFT SURFACE. [COMPRESSION = 1.03:1] (DEM)

***** VT722 Location *****

Principal Station -480
Station -479.7

Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Gage Coordinates Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT722-1	TC	P REM	H	3.06	18.30	291.96	292.17	0.0	0.0	-479.7	-479.7	CGS	09/20/90	40-6791	
VT722-2	TC	P REM	H	3.06	12.21	291.96	292.14	0.0	0.0	-479.7	-479.7	CGS	09/20/90	40-6791	
VT722-3	TC	P REM	H	3.06	7.94	291.96	292.12	0.0	0.0	-479.7	-479.7	CGS	09/20/90	40-6791	
VT722-4	TC	P REM	H	3.06	4.89	291.96	292.05	0.0	0.0	-479.7	-479.7	CGS	09/20/90	40-6791	
VT722-5	TC	P REM	H	3.06	3.98	291.96	292.00	0.0	0.0	-479.7	-479.7	CGS	09/20/90	40-6791	
VT722-6	TC	P REM	H	3.06	3.52	291.96	292.00	0.0	0.0	-479.7	-479.7	CGS	09/20/90	40-6791	

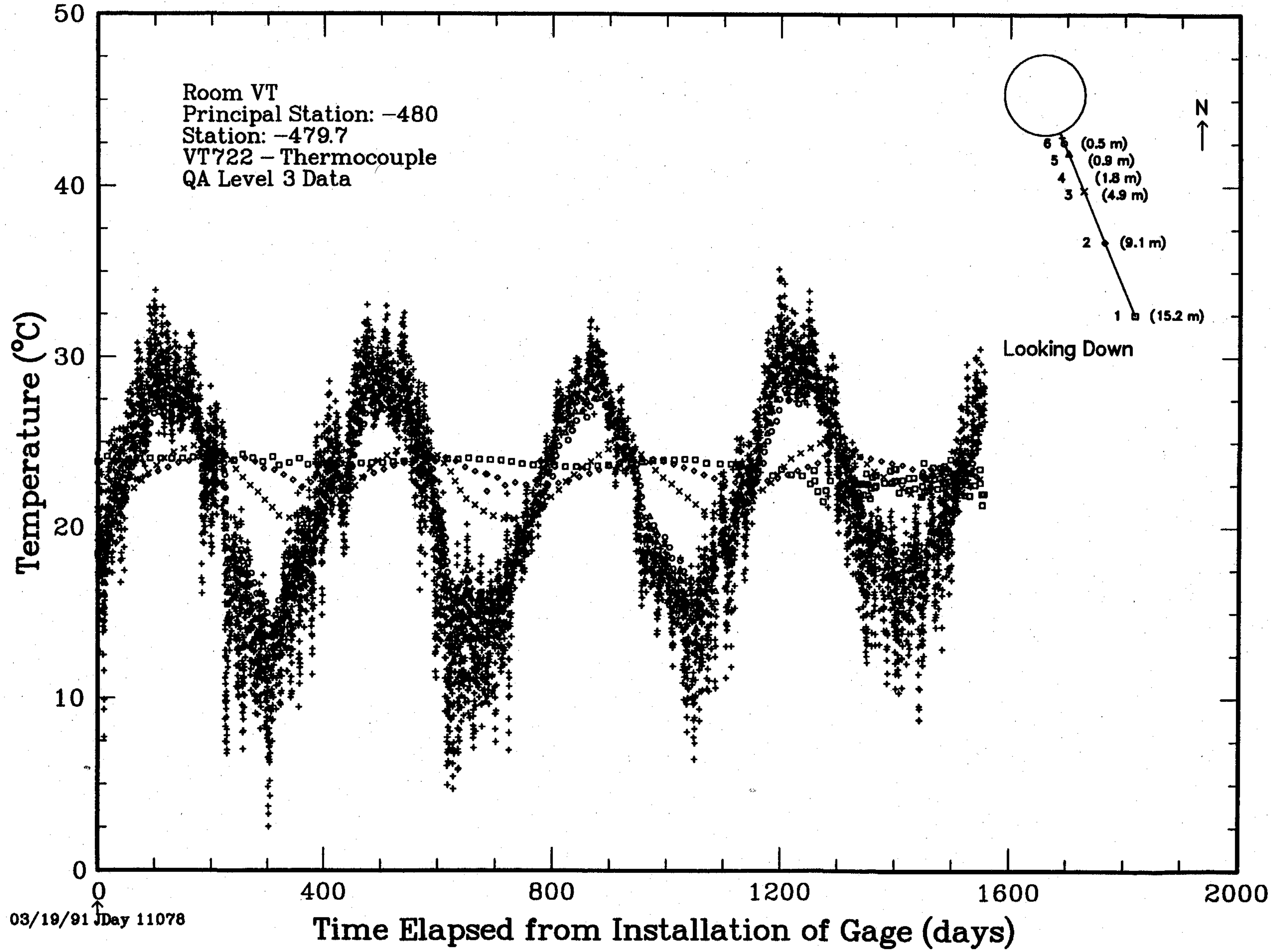

Figure 5.2.2d. Shaft Salt Temperature Unit VT722

Table 5.2.3e. Shaft Salt Temperature Unit VT741

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+--------------------+
|    Gage:  VT741    |
+--------------------+
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***** VT741 PI Comments *****

08/09/95 DEM [RANK = 10(1),9)2),10(3),10(4),10(5),10(6)] GAGE 2 SHOWS SOME MINOR SCATTER, WHICH WAS LARGELY DELETED. THE SCATTER AFTER DAY 1050, ALTHOUGH OBJECTIONABLE, COULD NOT BE REMOVED. IN GENERAL, THE SCATTER IS SUCH THAT IT DOES NOT OBSCURE THE TREND OF THE DATA. THE DATA SPREAD (APPARENT SCATTER) IS USUALLY THE RESULT OF THE DIURNAL CHANGES IN TEMPERATURE. THIS IS SUPERIMPOSED ON THE SEASONAL VARIATION IN THE AIR INTAKE TEMPERATURE. THE DATA SHOW A DIMINISHED AMPLITUDE OF THE VARIATION AND A PHASE SHIFT WITH RADIAL DEPTH INTO THE SALT AWAY FROM THE SHAFT SURFACE. BECAUSE THE ZERO DATE FOR THE CONTINUOUS HISTORY OF THE TEMPERATURE IS ARBITRARY, THESE DATA HAVE BEEN SHIFTED BY 237 DAYS TO BRING THEM INTO REGISTRY WITH THE GAGES INSTALLED EARLIER AT THE UPPER SHAFT STATIONS. [COMPRESSION = 2.02:1] (DEM)

***** VT741 Location *****

Principal Station -626
Station -626.1

Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Gage Coordinates Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT741-1	TC	P REM	H	2.96	18.20	111.95	112.17	0.0	-0.2	-626.1	-625.9	CGS	08/30/91	40-6791	
VT741-2	TC	P REM	H	2.96	12.11	111.95	112.15	0.0	-0.2	-626.1	-626.0	CGS	08/30/91	40-6791	
VT741-3	TC	P REM	H	2.96	7.84	111.95	112.12	0.0	-0.1	-626.1	-626.0	CGS	08/30/91	40-6791	
VT741-4	TC	P REM	H	2.96	4.79	111.95	112.07	0.0	-0.1	-626.1	-626.0	CGS	08/30/91	40-6791	
VT741-5	TC	P REM	H	2.96	3.88	111.95	111.99	0.0	-0.1	-626.1	-626.0	CGS	08/30/91	40-6791	
VT741-6	TC	P REM	H	2.96	3.42	111.95	112.00	0.0	-0.1	-626.1	-626.0	CGS	08/30/91	40-6791	

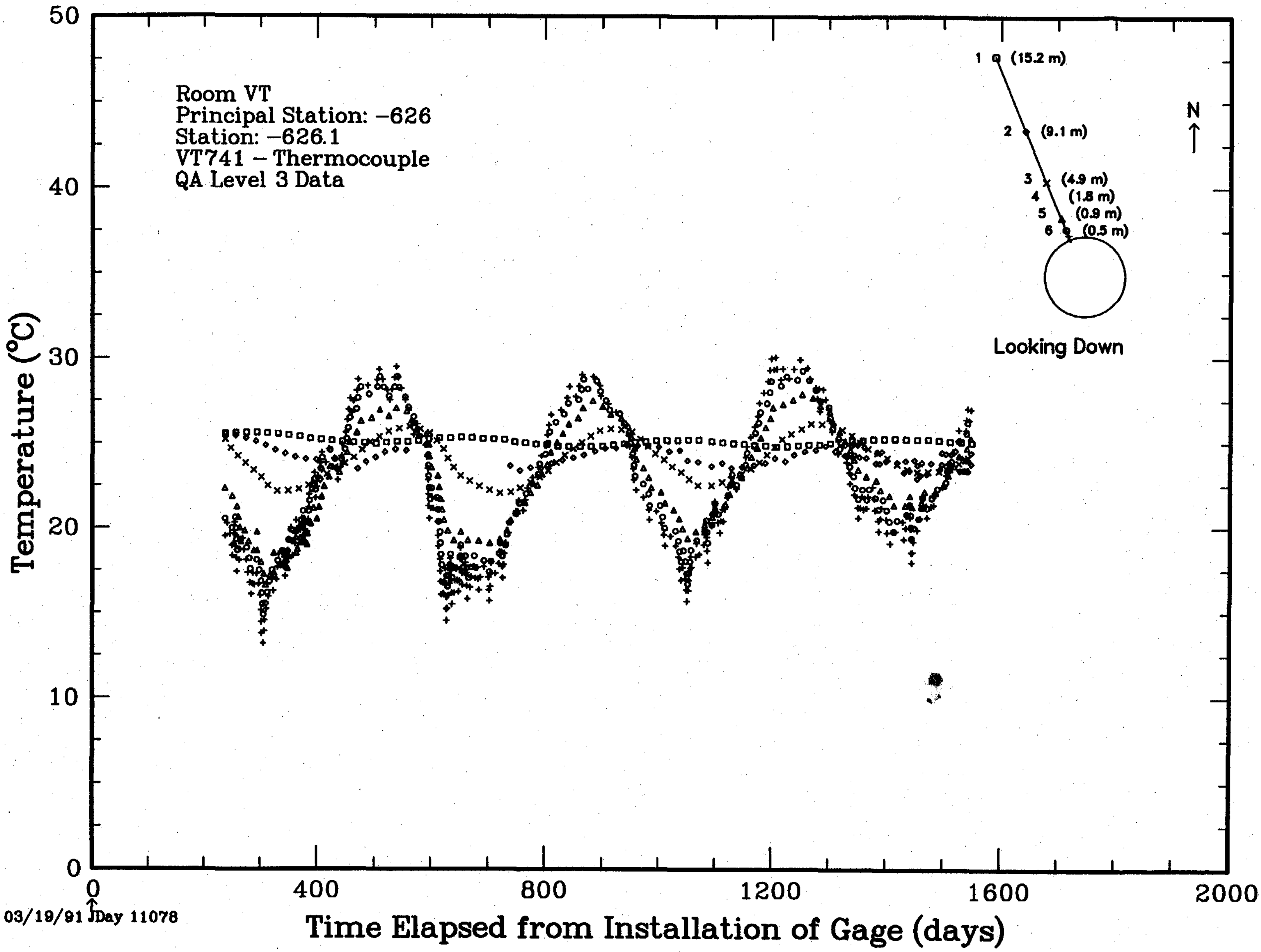

Figure 5.2.2e. Shaft Salt Temperature Unit VT741

Table 5.2.3f. Shaft Salt Temperature Unit VT742

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+--------------------+
|   Gage:  VT742     |
+--------------------+
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***** VT742 PI Comments *****

08/09/95 DEM [RANK = 10(1),10(2),10(3),10(4),10(5),10(6)] THE DATA ARE TRULY OUTSTANDING. THE APPARENT SCATTER IS ACTUALLY DIURNAL CHANGES IN TEMPERATURE. THIS IS SUPERIMPOSED ON THE SINUSOIDAL SEASONAL VARIATION OF THE INTAKE AIR TEMPERATURE. THE DATA SHOW BOTH THE DIMINISHED AMPLITUDE AND A PHASE SHIFT WITH RADIAL DISTANCE INTO THE SALT AWAY FROM THE SHAFT SURFACE. BECAUSE THE ZERO DATE FOR THE CONTINUOUS TEMPERATURE HISTORY IS ARBITRARY, THESE DATA HAVE BEEN SHIFTED BY 237 DAYS TO BRING THEM INTO REGISTRY WITH THE GAGES INSTALLED EARLIER AT THE UPPER SHAFT STATIONS. [COMPRESSION = 2.33:1] (DEM)

***** VT742 Location *****

Principal Station -626
Station -626.1

Gage Number	Gage Type	Rec	Dir	R1 (m)	R2 (m)	T1 (deg)	T2 (deg)	Gage Coordinates Prin Stat Z1 (m)	Prin Stat Z2 (m)	Room Z1 (m)	Room Z2 (m)	Gage Manuf	Inst Date	PO Item	Comments
VT742-1	TC	P REM	H	3.13	18.38	293.04	292.64	0.0	-0.2	-626.1	-625.9	CGS	09/03/91	40-6791	
VT742-2	TC	P REM	H	3.13	12.28	293.04	292.68	0.0	-0.2	-626.1	-626.0	CGS	09/03/91	40-6791	
VT742-3	TC	P REM	H	3.13	8.01	293.04	292.75	0.0	-0.1	-626.1	-626.0	CGS	09/03/91	40-6791	
VT742-4	TC	P REM	H	3.13	4.96	293.04	292.86	0.0	-0.1	-626.1	-626.0	CGS	09/03/91	40-6791	
VT742-5	TC	P REM	H	3.13	4.05	293.04	292.93	0.0	-0.1	-626.1	-626.0	CGS	09/03/91	40-6791	
VT742-6	TC	P REM	H	3.13	3.59	293.04	292.95	0.0	-0.1	-626.1	-626.0	CGS	09/03/91	40-6791	

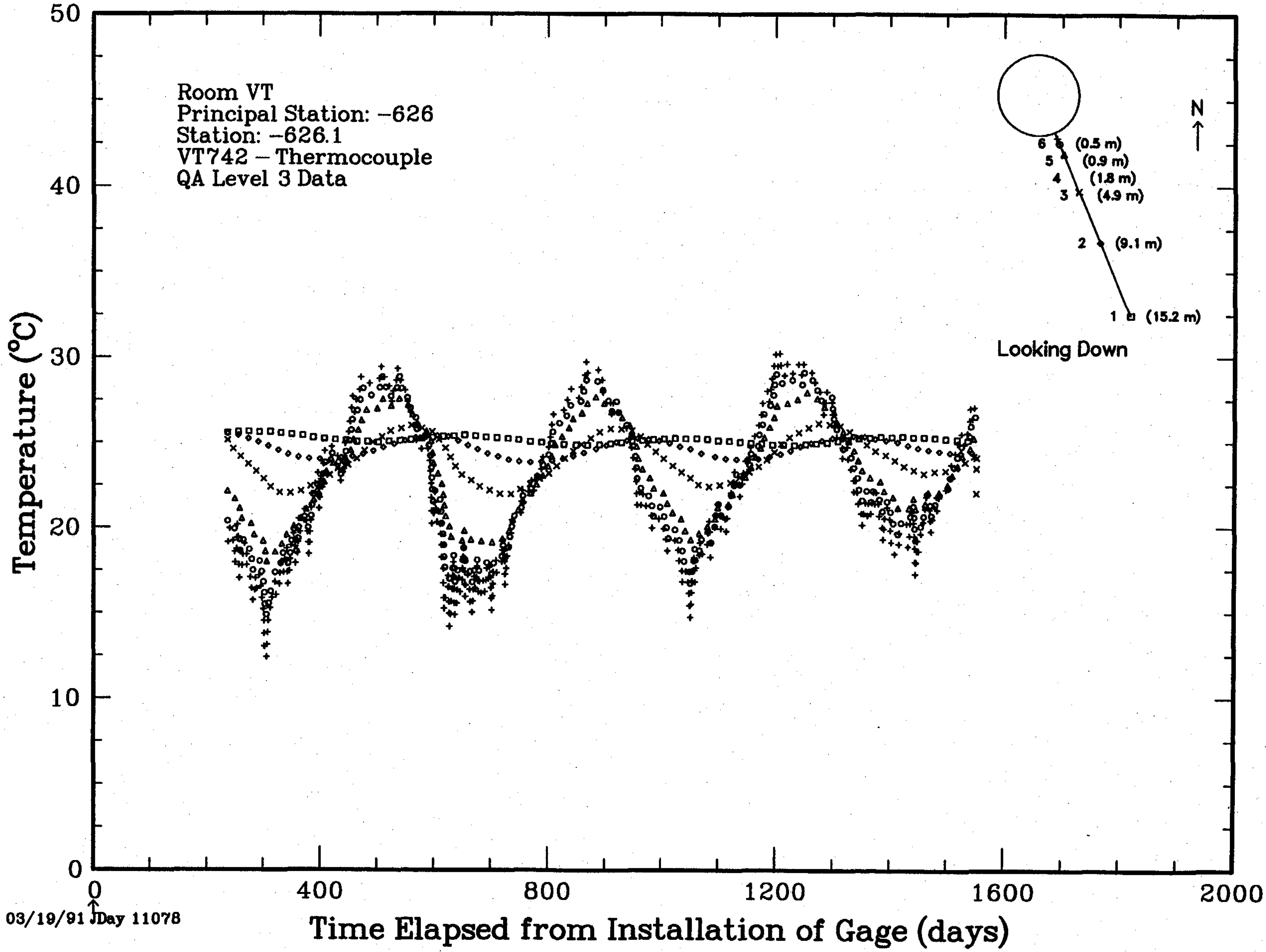

Figure 5.2.2f. Shaft Salt Temperature Unit VT742

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6 INTERPRETATION AIDS

Interpretation of data from the TSI in situ tests involves some interesting but often ignored or unrecognized factors related to the time-dependent response of salt. If these factors are not considered, failure to accurately predict observed in situ behavior may result. Certainly, ignoring these factors can be a source of confusion in interpretation of numerical studies. Therefore, before a meaningful analysis of the in situ data is undertaken, these factors must be understood.

First, the analyst should realize that in situ data represents only part of the displacements that have occurred during the excavation of an opening. Proper interpretation requires that the investigator or analyst avoids the temptation to assume virgin conditions before measurements began. Instead, the analyst must minimize the "lost" or "unmeasured" displacements as much as possible and recognize the influence of fielding activity on temperature measurements. In turn, the numerical analyst must become aware of the consequences of model abstractions and assumptions that have been introduced into calculations, but which may not adequately represent in situ conditions.

The displacement results in this report were obtained with every care taken to reduce the "lost" early time displacements to as small a quantity as possible. Furthermore, the interpretation recognizes where the lost displacements reside. Schematically, reconstruction of salt displacements for both closures and extensometers can be visualized in terms of the trajectory of a material point in the salt as the mining face of an opening approaches, passes, and recedes from the plane of the point. If the face velocity is not a function of time, the points move in time according to the constitutive laws for salt creep. (A nonconstant face velocity introduces an additional pseudo-time-dependent term.)

Figure 6.0.1 illustrates such a trajectory. The two material points marked E and C, represent an extensometer anchor and a closure point, respectively. Trajectory lines for vertical displacements are drawn through the two points. For both points E′ and C, it is seen that the points undergo displacements <u>before</u> the raise-boring face reaches them. These displacements are the result of the far-field stress-strain influence of the opening in the surrounding salt and can be measured only under very special conditions. Typically, they are unmeasured.

Notice that point C actually starts at a position above the eventual line of the opening, but as the face approaches the plane of the point, displacement brings the point down to become a surface point. The point displacements in advance of the raise-boring excavation face cannot be measured because the excavation operation essentially removes the displaced material. After the excavation face has passed, both points E′ and C continue to displace with time. Now, however, the investigator can install instruments to measure the displacements, provided there is access to the excavation face.

It is important to remember that the points continue to displace from creep even though the face advance may hesitate or stop. The affect of this can be illustrated by placing the time of gage installation on the material point trajectory. In the AIS, the early closure points were the first to be installed, but because of the raise-boring operation were several meters from the excavation face and were delayed about a day and a half after the station excavation, so some displacement of the material

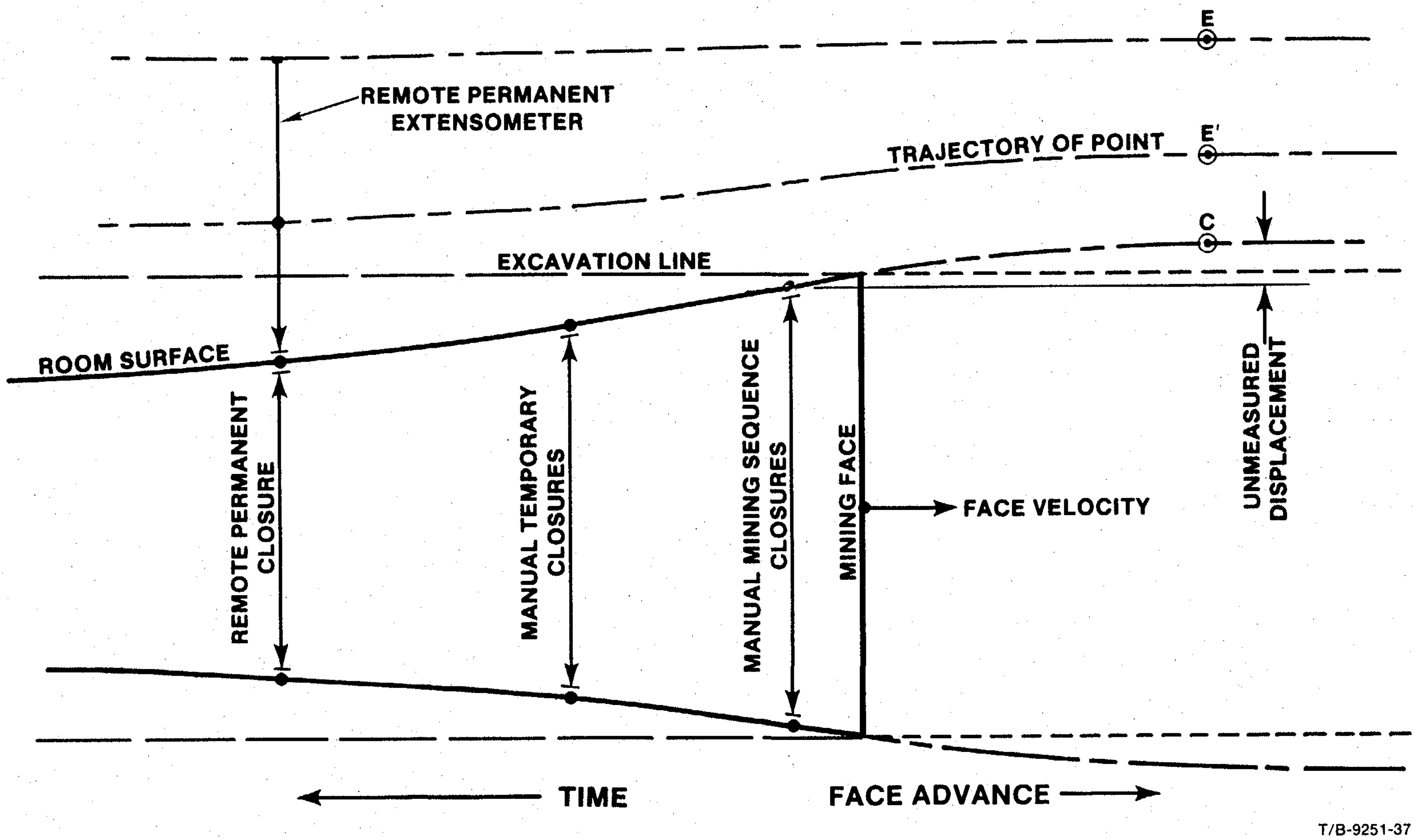


Figure 6.0.1. Particle Trajectories for Displacements during Raise-Boring

point were unmeasured. Again, as operations and hole drilling permitted, the permanent closure stations were established and, for the first time in this sequence, permanent extensometer installations were made. It is clear that the delay results in a significant "lost" displacement, as is apparent in the point E trajectory.

Recognizing the events described above permits the reconstruction of the measured and "unmeasured" displacements in an abstract sense. Such reconstructions are illustrated for closure measurements in Figure 6.0.2 and for extensometer measurements in Figure 6.0.3. Figure 6.0.3 adds an intermediate extensometer point, E', to show its treatment. It is often difficult in reconstruction of extensometer displacements to evaluate the unmeasured displacements, especially where there were significant delays in instrument installation. Even under optimum installation condition, the extensometers will have more unmeasured displacements and be more difficult to reconstruct than will closure displacements.

Because of the very extensive delay in gage installation at most of the stations, the lost displacements are considerable. However, the complete history was very adequately established for the deepest station through the early closure points emplaced during the raise-boring.

The success with which complete displacement curves are reconstructed may be the measure of the success of the analysis of the in situ data. As a corollary, numerical simulations that ignore the realities of field data collection may be less than successful.

Temperature measurements require few, if any, interpretation aids. Since the temperature measurements concern only the ambient temperatures and the effect of the thermocouple placements, the analysis is probably straightforward.

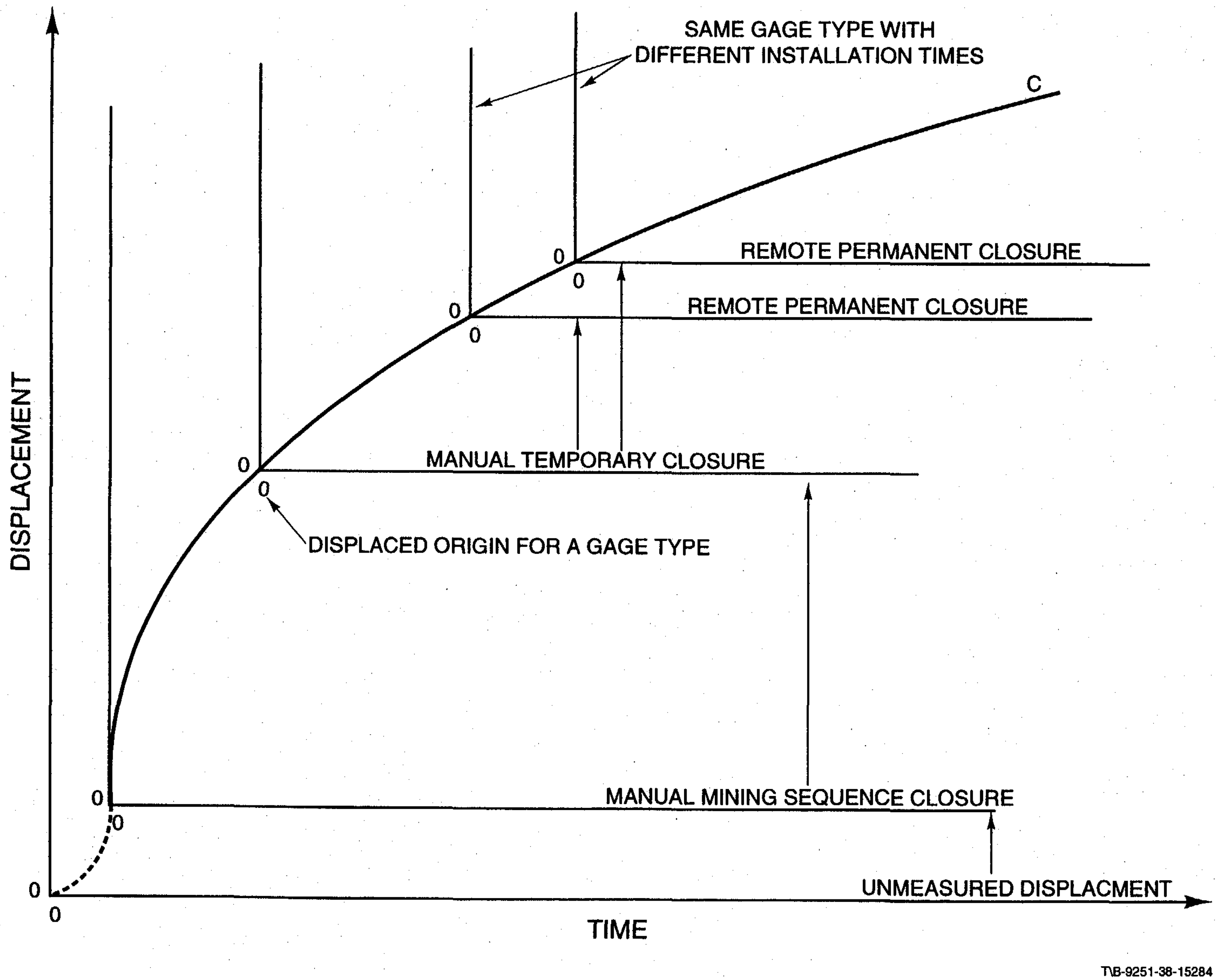


Figure 6.0.2. Reconstruction Schematic for Closure Measurements

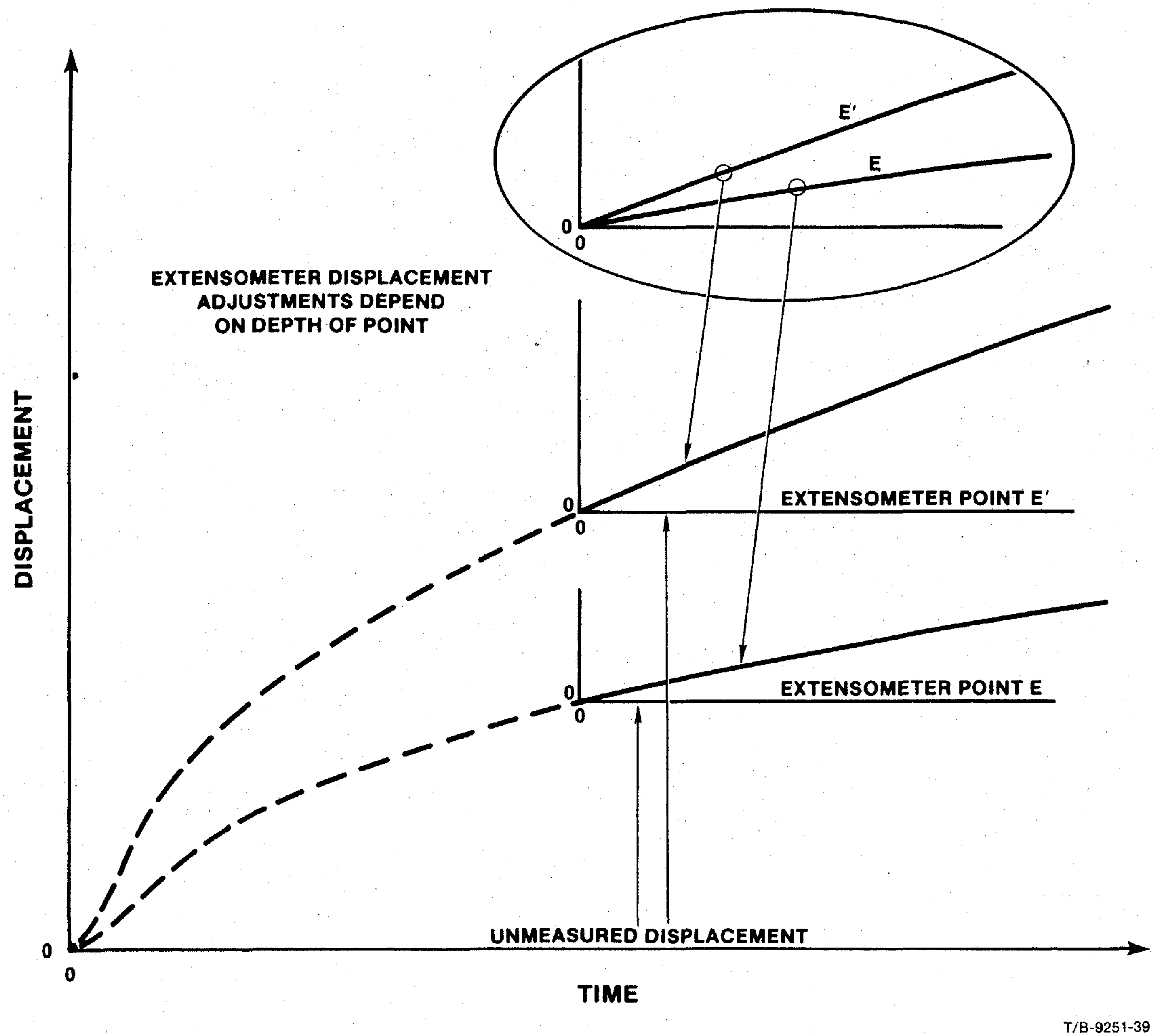


Figure 6.0.3. Reconstruction Schematic for Extensometer Measurements

7 SUMMARY

Of all of the tests for the thermomechanical/structural program, that in the Air Intake Shaft was perhaps the most difficult to field. However, even within this context, the measurements still appear quite acceptable and meaningful.

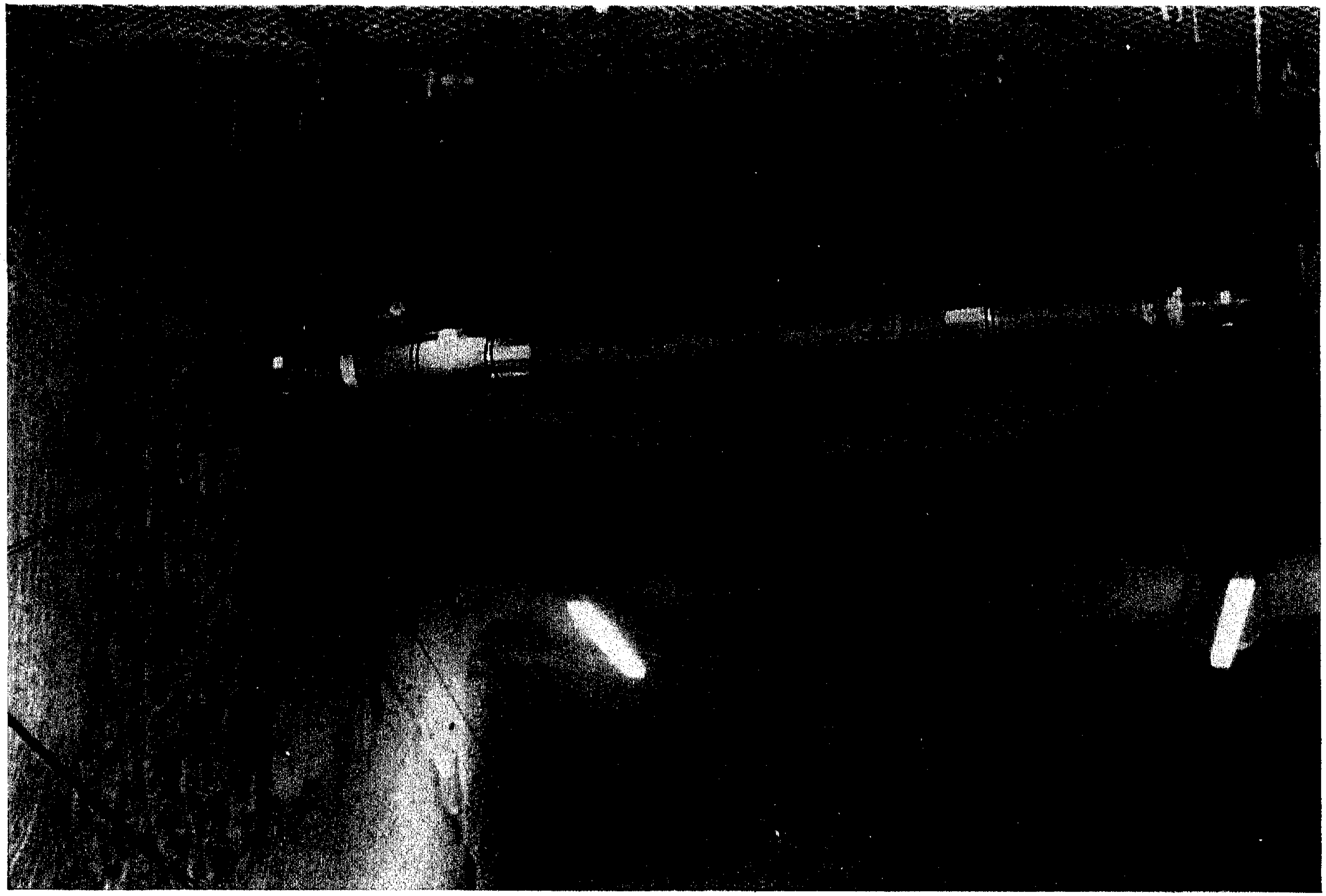
The measured sinusoidal variation in air stream temperatures in the shaft reflect accurately both the diurnal and seasonal changes in regional air temperature. Even though the velocity and volume of intake air is quite high, there is a distinct change of air temperature response as a function of the location (depth) of the gage station.

Seasonal variation in air stream temperature produces corresponding changes, although moderated, of the temperature of the surrounding salt as determined by thermocouple strings emplaced in drill holes in the salt of the shaft wall. While the sinusoidal character of temperature of the air stream is preserved in the temperatures measured by the shaft salt gages, the amplitude diminishes with depth into the salt. At the greatest gage depth, the seasonal variation has largely disappeared. The temperature variations are thought to be influenced by both convection in the drill hole and conduction in the salt. The separation of these effects is difficult; however, a distinct phase shift between the gages near the shaft surface and those at depth suggests at least part of the thermal response is by conduction through the salt. Again, because the details of the air stream temperature differ with depth in the shaft, the salt temperature response depends on the location of the measurement station.

The salt displacement measurements consist of shaft closure and extensometer measurements. Although it could be expected that both of these would be affected by the temperature, in fact only the extensometer measurements appear to be influenced. The closure measurements show a relatively large scatter, primarily as the result of the inherent difficulty in making measurements from a poorly controlled hoist cage. Perhaps this scatter masks the effect of temperature. Even with this relatively large data scatter, the results are quite consistent. The largest closures are measured at the deepest shaft station, as expected. The closure diminishes markedly at the shallow stations in accordance with the theoretical constitutive model of salt creep.

The influence of temperature variation on the extensometer results is pronounced. This is in contrast to the observed lack of any marked temperature influence on the closure measurements. This could be confusing. However, it shows that the influence is not primarily on the salt displacements. Rather, the temperature influence is on the thermal expansion of the rods of the extensometer gages and the surrounding salt. The result is that the measurements show a seasonal response related to the air stream temperatures. The extensometer records also suggest a distinct phase shift of effects of temperature with depth into the salt away from the shaft wall.

Flyleaf(a). View of Raise-Boring Head in Shaft Station (at Beginning of Construction)



Flyleaf(b). View of the Early Closure Point Emplacement Machine (Starting up the Shaft)

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Fuel Processing & Waste Mgmt. Division
785 DOE Place
Idaho Falls, ID 83402

US Environmental Protection Agency (2)
Radiation Protection Programs
Attn: M. Oge
ANR-460
Washington, DC 20460

Boards

Defense Nuclear Facilities Safety Board
Attn: D. Winters
625 Indiana Ave. NW, Suite 700
Washington, DC 20004

Nuclear Waste Technical Review Board (2)
Attn: Chairman
S. J. S. Parry
1100 Wilson Blvd., Suite 910
Arlington, VA 22209-2297

State Agencies

Attorney General of New Mexico
P.O. Drawer 1508
Santa Fe, NM 87504-1508

Environmental Evaluation Group (3)
Attn: Library
7007 Wyoming NE
Suite F-2
Albuquerque, NM 87109

NM Energy, Minerals, and Natural
Resources Department
Attn: Library
2040 S. Pacheco
Santa Fe, NM 87505

NM Environment Department (3)
Secretary of the Environment
Attn: Mark Weidler
1190 St. Francis Drive
Santa Fe, NM 87503-0968

NM Bureau of Mines & Mineral Resources
Socorro, NM 87801

NM Environment Department
WIPP Project Site
Attn: P. McCasland
P.O. Box 3090
Carlsbad, NM 88221

Laboratories/Corporations

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Attn: R. E. Westerman, MSIN P8-44
Battelle Blvd.
Richland, WA 99352

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1650 University Blvd. NE, Suite 300
Albuquerque, NM 87102

INTERA, Inc.
Attn: J. F. Pickens
6850 Austin Center Blvd., Suite 300
Austin, TX 78731

INTERA, Inc.
Attn: W. Stensrud
P.O. Box 2123
Carlsbad, NM 88221

Los Alamos National Laboratory
Attn: B. Erdal, INC-12
P.O. Box 1663
Los Alamos, NM 87544

RE/SPEC, Inc. (8)
Attn: Angus Robb
D. L. Hoag (5)
D. A. Labreche
J. R. Ball
4775 Indian School NE, Suite 300
Albuquerque, NM 87110-3927

RE/SPEC, Inc. (3)
Attn: J. L. Ratigan
G. D. Callahan
K. L. DeVries
P.O. Box 725
Rapid City, SD 57709

Southwest Research Institute (2)
Center for Nuclear Waste Regulatory Analysis
Attn: P. K. Nair
6220 Culebra Road
San Antonio, TX 78228-0510

Southwest Research Institute
Material Engineering and
Technology Division
Attn: K. S. Chan
6220 Culebra Road
San Antonio, TX 78228-0510

Tech Reps, Inc. (6)
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T. Peterson (2)
G. T. Baird
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5000 Marble NE, Suite 222
Albuquerque, NM 87110

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Attn: Library
J. Epstein
J. Lee
B. A. Howard
R. Kehrman
P.O. Box 2078
Carlsbad, NM 88221

S. Cohen & Associates
Attn: Bill Thurber
1355 Beverly Road
McLean, VA 22101

National Academy of Sciences, WIPP Panel

Howard Adler
Oxyrase, Incorporated
7327 Oak Ridge Highway
Knoxville, TN 37931

Ina Alterman
Board of Radioactive Waste Management
GF456
2101 Constitution Ave.
Washington, DC 20418

Rodney C. Ewing
Department of Geology
University of New Mexico
Albuquerque, NM 87131

Charles Fairhurst
Department of Civil and Mineral Engineering
University of Minnesota
500 Pillsbury Dr. SE
Minneapolis, MN 55455-0220

B. John Garrick
PLG Incorporated
4590 MacArthur Blvd., Suite 400
Newport Beach, CA 92660-2027

Leonard F. Konikow
US Geological Survey
431 National Center
Reston, VA 22092

Carl A. Anderson, Director
Board of Radioactive Waste Management
National Research Council
HA 456
2101 Constitution Ave. NW
Washington, DC 20418

Christopher G. Whipple
ICF Kaiser Engineers
1800 Harrison St., 7th Floor
Oakland, CA 94612-3430

John O. Blomeke
720 Clubhouse Way
Knoxville, TN 37909

Sue B. Clark
University of Georgia
Savannah River Ecology Lab
P.O. Drawer E
Aiken, SC 29802

Konrad B. Krauskopf
Department of Geology
Stanford University
Stanford, CA 94305-2115

Della Roy
Pennsylvania State University
217 Materials Research Lab
Hastings Road
University Park, PA 16802

David A. Waite
CH_2 M Hill
P.O. Box 91500
Bellevue, WA 98009-2050

Thomas A. Zordon
Zordan Associates, Inc.
3807 Edinburg Drive
Murrysville, PA 15668

Universities

University of New Mexico
Geology Department
Attn: Library
141 Northrop Hall
Albuquerque, NM 87131

University of Washington
College of Ocean & Fishery Sciences
Attn: G. R. Heath
583 Henderson Hall, HN-15
Seattle, WA 98195

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325 Don Gaspar
Santa Fe, NM 87503

New Mexico Tech
Martin Speere Memorial Library
Campus Street
Socorro, NM 87810

WIPP Public Reading Room
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101 S. Halagueno St.
Carlsbad, NM 88220

Foreign Addresses

Studiecentrum Voor Kernenergie
Centre d'Energie Nucleaire
Attn: A. Bonne
SCK/CEN Boeretang 200
B-2400 Mol, BELGIUM

Atomic Energy of Canada, Ltd.
Whiteshell Laboratories
Attn: B. Goodwin
Pinawa, Manitoba, CANADA R0E 1L0

Francois Chenevier (2)
ANDRA
Route de Panorama Robert Schumann
B. P. 38
92266 Fontenay-aux-Roses, Cedex
FRANCE

Claude Sombret
Centre d'Etudes Nucleaires de la Vallee Rhone
CEN/VALRHO
S.D.H.A. B.P. 171
30205 Bagnols-Sur-Ceze, FRANCE

Commissariat a L'Energie Atomique
Attn: D. Alexandre
Centre d'Etudes de Cadarache
13108 Saint Paul Lez Durance Cedex
FRANCE

Bundesanstalt fur Geowissenschaften und Rohstoffe (2)
Attn: M. Langer
Postfach 510 153
D-30631 Hannover 51, GERMANY

Bundesministerium fur Forschung und Technologie
Postfach 200 706
5300 Bonn 2, GERMANY

Institut fur Tieflagerung
Attn: K. Kuhn
Theodor-Heuss-Strasse 4
D-3300 Braunschweig, GERMANY

Gesellschaft fur Anlagen und Reaktorsicherheit (GRS)
Attn: B. Baltes
Schwertnergasse 1
D-50667 Cologne, GERMANY

Physikalisch-Technische Bundesanstalt
Attn: P. Brenneke
Postfach 3345
D-3300 Braunschweig, GERMANY

Shingo Tashiro
Japan Atomic Energy Research Institute
Tokai-Mura, Ibaraki-Ken, 319-11
JAPAN

Netherlands Energy Research Foundation ECN
Attn: L. H. Vons
3 Westerduinweg
P.O. Box 1
1755 ZG Petten
THE NETHERLANDS

Svensk Karnbransleforsorjning AB
Attn: F. Karlsson
Project KBS (Karnbranslesakerhet)
Box 5864
S-102 48 Stockholm
SWEDEN

Nationale Genossenschaft fur die Lagerung
Radioaktiver Abfalle (2)
Attn: S. Vomvoris
P. Zuidema
Hardstrasse 73
CH-5430 Wettingen
SWITZERLAND

AEA Technology
Attn: J. H. Rees
D5W/29 Culham Laboratory
Abington, Oxfordshire OX14 3DB
UNITED KINGDOM

AEA Technology
Attn: W. R. Rodwell
044/A31 Winfrith Technical Centre
Dorchester, Dorset DT2 8DH
UNITED KINGDOM

AEA Technology
Attn: J. E. Tinson
B4244 Harwell Laboratory
Didcot, Oxfordshire OX11 ORA
UNITED KINGDOM

D. R. Knowles
British Nuclear Fuels, plc
Risley, Warrington, Cheshire WA3 6AS
1002607 UNITED KINGDOM

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