N.28

# UNDERGROUND COAL GASIFICATION FIRST TRIAL IN THE FRAMEWORK OF A COMMUNITY COLLABORATION

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## TECHNICAL REPORT JULY 1994 - DECEMBER 1994


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## Summary

The main activities during the period of this report were the completion design and the drilling of the two remaining process wells, the recovery well[RW(ET5)] and the transverse injection well[IW2(ET6)], and the detailed engineering design of surface plant, including the Product Gas Analysis Unit, the Data Acquisition/Control System Unit and the Fibre Optic System.

KAWASAKI THERMAL SYSTEMS, the manufacturers of THERMOCASE, the insulated tubing foreseen for the recovery well, was sold to another company in USA, which, at August 1994, was unable to give a commitment to manufacture the required tubing, and a decision was taken to proceed with an alternative completion configuration. The choice of alternative design was assisted by further runs of a recovery well computer simulation performed by the UNIVERSITY OF LOUVAIN(Belgium).

The two remaining process wells, the recovery well[RW(ET5)] and the transverse injection well[IW2(ET6)], were drilled in December 1994. The trajectory objectives of these wells were fully achieved, although surveys of injection well[IW2(ET6)] indicated the upper coal seam to be located at a depth approx. 5 metres higher than expected from the prognosis given by other wells. The two wells were partially completed by the installation and cementing of casing to the design depths.

Phase 2 of the Surface Plant Engineering continued by SERELAND and orders for critical path items of plant(oxygen and nitrogen plants, boiler, gas combustor and flare, dosing pump units) were placed. Contracts for the detailed design of Product Gas Analysis and Data Acquisition/Control System Units were placed with DUMEZ COPISA SISTEMAS(Gas Analysis) and HONEYWELL(Data Acquisition/Control) - contracts which continued at the end of the period of this report. Final specification of the Fibre Optic System was defined and the order for the System was placed with YORK SENSORS, LTD(UK).

Work on two projects continued in the supporting programme. INSTITUTO DE CARBOQUIMICA continued the development of a computer programme simulation to predict maximum reaction zone temperatures; TU. DELFT in the Netherlands continued work on the thermomechanical behaviour of adjacent strata, and modelling of the underground gasification process.


## 1. INTRODUCTION

This report is the sixth technical report of the Underground Coal Gasification project being conducted in North Teruel, Spain, with financial support under the EU's THERMIE energy programme.

Key points in well design and construction were the decision to proceed with a non-THERMOCASE solution to the recovery well[RW(ET5)] design following the inability to procure the special insulated tubing foreseen within an acceptable time scale, and the successful drilling of the two remaining process wells, the recovery well[RW(ET5)] and the transverse injection well[IW2(ET6)].

The two process wells, recovery well[RW(ET5)] and transverse injection well [IW2(ET6)], were drilled in sequence with the same rig and service contractors, separated only by the rig move between spud locations on site. Operations were planned in this way in order to incur only one rig mobilisation/ demobilisation charge for the two wells.

Detailed engineering design of surface plant continued via a contract with SERELAND, in parallel with contracts with DUMEZ COPISA SISTEMAS for the design of the Product Gas Analysis Unit, and with HONEYWELL for the design of the Data Acquisition/Control System Unit. Orders were placed for critical items of the surface plant(oxygen and nitrogen plants, boiler, gas combustor and flare, dosing pump units) and for the Fibre Optic System.

## 2. RECOVERY WELL[RW(ET5)]

*Unless otherwise stated, all depths given in Sections 2 and 3 of this report are* ***Depths from Ground Level****(i.e. from the concrete platforms).*

### 2.1 TARGET OBJECTIVES - DIRECTIONAL DATA

The target objective of recovery well[RW(ET5)] was defined as a point one metre further along the trajectory of the injection well[IW1(ET4)] from the surveyed location of the 6.5/8" liner shoe with entry to the coal seam at/or near vertical(see Figures 1a and 1b). The intention of this objective was to minimise the separation of recovery well to injection well in order to maximise the ability to subsequently connect/link these two wells prior to the channel gasification operations.

The surface(spud) location of the well was not revised from that originally planned and for which civil works for rig placement had been conducted previously, and the trajectory of recovery well[RW(ET5)] was therefore an 'S', or relief well, trajectory.

Although this trajectory involved a greater offset than for the original 'vertical' well, the costs of directional drilling were no greater, because directional drilling would have been required to achieve verticality in the original programme. The following objectives were therefore set for the trajectory of the recovery well[RW(ET5)]:

- Target location at a point 1 metre in front of 6 5/8" liner shoe of the deviated injection well[IW1(ET4)]

- Target accuracy +/- 2 metres from target X, Y co-ordinates

- Type of Profile — 'S' or relief profile
  Kick-off Point(KOP) — +/- 200 m MD
  Build up rate — +/- 2.2 degrees / 30 metres
  Inclination at end of build — +/- 8 degrees
  Tangent Section(hold) — from +/- 309 m MD to +/- 431 m MD
  Drop-off rate — +/- 2.2 degrees / 30 metres
  End of drop-off — +/- 540 m MD
  Inclination at end of drop-off — +/- 0 degree
  Total Depth(+/- 6 m below coal seam) — +/- 584.5 m MD
  Well azimuth — +/- 340.3° relative to UTM North
  Horizontal displacement — +/- 32.1 metres

- Target UTM co-ordinates(1 metre in front of 6.5/8" liner shoe location)

| | | | |
|---|---|---|---|
| Spud | X: 718560.68 | Y: 4532575.70 | Z: 663.68(ref. sea level) |
| Target | X: 718549.86 | Y: 4532605.93 | Z: 88.18 |

## 2.2 WELL DETAILS - COMPLETION DESIGN

In August 1994, TUBE-ALLOY CORPORATION, the purchasers of KAWASAKI THERMAL SYSTEMS, informed UGE of their intention to relocate their manufacturing facility within USA, and that they were unable to provide tubing to meet UGE's procurement schedule. The decision was taken to proceed with the alternative non-THERMOCASE configuration described in the previous technical report.

The final design of the tubing arrangement within the wellhead and the well is shown in Figures 2 and 3. Further runs(see Table I) of a computer model of the well were performed by the UNIVERSITY OF LOUVAIN to represent the performance of the selected configuration.

The analyses revealed that the design was effective both in delaying the onset of condensation in, and reducing the wetted length of, recovery well production tubing. Nevertheless, it is impossible to prevent a total absence of condensation in all flow conditions/phases. The study also revealed that the double annulus system will require more sparge water for a given high temperature product gas flow, the sparge water being in this case at higher temperature at well bottom.

Orders were placed for all components, the longest procurement period being 9 - 10 months for the special alloy tubing strings, leading to an expected delivery date for these items of June - July 1995.

In view of the long procurement time for completion materials and the need to establish the ability to achieve accurate placement of this important well, it was decided to drill and case the well first, and to workover the well subsequently for final completion once all the completion materials were available. Further, in order to minimise the cost of process well drilling, it was decided to drill ET5 and ET6 with the same rig, only rig relocation on-site separating the two drilling operations.

In accordance with standard practice, the well was designed from the bottom up, the hole diameter in the coal dictating completion requirements and controlling drilling and casing diameters at higher intervals.

Casing Programme

| Hole (inches) | Casing (inches) | Shoe MD(m) |
|---|---|---|
| 17.1/2 | 13.3/8 | 60 |
| 12.1/4 | 9.5/8 | 576(+/- 0.3 m below seam roof) |

Casing Specification

| | |
|---|---|
| 13.3/8" | 54.5 PPF - K55 - BTC |
| 9.5/8" | 40 PPF - N80 - BTC<br>(2 last joints in 40 PPF - INCONEL 625 - BTC) |

Casings to be run with centralisers, float collars and shoes. 9.5/8" float shoe made of INCONEL 625 and 9.5/8" casing string to be cemented with THERMOCEMOIL high temperature cement.

This casing programme is only part of the completion, the remaining elements to be installed in subsequent workover operations.

## 2.3 DRILLING PROGRAMME, BITS AND FLUIDS

The planned drilling programme was as follows:

| | |
|---|---|
| 17.1/2" drilling | Rotary |
| 13.3/8" plug/casing shoe | Rotary |
| 12.1/4" to KOP | Rotary |
| 12.1/4" build/tangent/drop-off | 8" DHM/MWD(oriented/rotation) |
| 8.1/2" coring | Rotary |
| 12.1/4" hole opening | Rotary |
| 12.1/4" re-drilling after cement plug | Rotary |

In order to precisely locate the roof of the seam for subsequent casing placement/setting, drilling at 12.1/4" diameter was planned to stop some 10 m above the coal roof, at which point coring would take place through and into the floor of the coal seam(+/- 6 m). The programme then involved hole opening to +/- 1.5 m below coal seam roof, setting a cement plug, and re-drilling to +/- 0.3 m into the top of the seam. This procedure was employed to attempt to protect the coal seam from excessive pressure during casing cementing.

Bits

The bits were selected on base of the previous experience of ET4 drilling. Conventional rock roller bits were selected, standard tooth for the vertical section to KOP and protected insert for the deviated interval. A diamond crown bit was used for coring

Fluids

Similar programme to the programme applied for the ET4 drilling was adopted for the drilling of ET5.

Bentonitic spud mud was specified for the initial 17.1/2" interval from surface to 60 m MD.

From the 13.3/8" casing shoe, the vertical and deviated sections would be drilled with a non-dispersed KCl polymer mud with additives for clay inhibition, fluid loss control, etc.. Target KCl mud properties were:

| | |
|---|---|
| Density | 1.05 - 1.12 kg/l |
| Yield Point | 20 - 25 lb / 100 $ft^2$ |
| Filtrate | $<$ 5 $cm^3$ / 30 min API |
| Sand content | $<$ 2% |
| $K^+$ | 45 - 55 g/l |
| pH | 8 - 9 |

## 2.4 SERVICE CONTRACTORS

The following contractors were selected for the operations, services and equipment involved in the realisation of the recovery well[RW(ET5)]:

| | |
|---|---|
| • Civil Works | MAURICIO VENTURA |
| Concrete platform for the derrick | |
| Cellar and guide tube | |
| Channels for mud drainage | |
| • Drilling(Rig and Crew) | COFOR |
| Drilling 17.1/2" | |
| Casing and cementing 13.3/8" | |
| Drilling 12.1/4" | |
| Casing 9.5/8" installation | + WEATHERFORD |
| Coring 8.1/2" | + BAKER HUGHES |
| • Directional Drilling & MWD | ANADRILL SCHLUMBERGER |

| | |
|---|---|
| • Fluids(Mud)<br>Provision of drilling fluids<br>Fluids engineering | MATRIX / MGA |
| • Casing | |
| Supply of 13.3/8" and 9.5/8" casing | VALLOUREC |
| Supply of 9.5/8" casing(Inconel 625) | INCO ALLOY |
| Supply of 9.5/8" shoe(Inconel 625) | HALLIBURTON |
| • Cementing 9.5/8" casing<br>+ Supply of float collars and shoes | HALLIBURTON |
| • Logging<br>Cement Bond Log (CBL) | SCHLUMBERGER |
| • Bits | SMITH / BAKER HUGHES |

## 2.5 OPERATIONS AND WELL COMPLETION

### 2.5.1 Site Preparation, Procurement and Mobilisation

The site was prepared to accept the COFOR rig, the same MASSARENTI 7000 MR Trailer rig which had drilled the deviated injection well[IW1(ET4)], with double derrick capacity, 300,000 LB hookload, Triplex pumps.

UGE had requested COFOR to improve the mud system of the rig over that employed in drilling ET4 in order to try to avoid the shaker screen overflow problems experienced in that well.The rig was equipped with a Brandt dual-tandem shaker(previously Sweco LM3 tandem) and mud cleaner capacity was doubled by installing a second raw of 8 cones.

Although the rig was available to drill the well in October 1994, the manufacture of special Inconel casing components for the lower section of the well was delayed and the order to mobilise the rig could not be given until late November.

Further, although ANADRILL had proposed the use of their Powerpak A800 steerable motors for the job, customs problems were experienced in the return of the 8" motors from Algeria in time for the beginning of ET5 operations and ANADRILL were forced to rent two equivalent 7.3/4" F2000S steerable motors from HALLIBURTON as replacements.

### 2.5.2 Rig Operations

The rig arrived on site 30 November 1994 and the well was spudded 6 December 1994. The operations performed were:

| | | | |
|---|---|---|---|
| - Drilling | 17.1/2" | 0 - 68.3 m | 6 Dec. - 7 Dec. |
| - Casing/cementing | 13.3/8" | 0 - 68.3 m | 8 Dec. |
| - Drilling | 12.1/4" | 68.3 - 570.0 m | 9 Dec. - 14 Dec. |
| - Coring | 8.1/2" | 570.0 - 582.3 m | 15 Dec. |
| - Hole opening | 12.1/4" | 570.0 - 582.3 m | 15 Dec. |
| - Setting cement plug | | 552.0 - 582.3 m | 16 Dec. |
| - Re-drilling | 12.1/4" | to 577.06 m | 16 Dec. |
| - Casing/cementing | 9.5/8" | to 576.90 m | 17 Dec. |
| - Drilling cement plugs | 8.1/2" | to 575.5 m | 18 Dec. |
| - CBL log | | TD to surface | 18 Dec. |

Actual depth/time progress is compared to the pre-spud estimate in Figure 4. Operating time distribution is given in Table II. The total time to complete all operations was 13 days(approx. 3 days greater than anticipated), the additional time being a consequence of MWD failures, and generally slow working due to communication difficulties between the French drillers and other crew members recruited by COFOR from within Spain.

### 2.5.3 Vertical Interval 0 m - 68.3 m MD, 17.1/2" diam.

This interval was drilled in rotary mode with a standard pendulum assembly:

17.1/2" Bit
Bit Sub
17.1/2" Stabiliser
X-Over
8" Monel Drill Collar
17.1/2" Stabiliser
8" Drill Collar to surface

Drilling parameters were:

| | |
|---|---|
| Weight On Bit(WOB) | 1 - 7 tonnes |
| Rotary Speed | 100 - 110 RPM |
| Flow rate | 1600 - 1700 l/min |
| Standpipe pressure | 35 kg/cm$^2$ |

The interval was drilled without difficulty, the Brandt dual-tandem shale shaker working much more effectively than the Sweco linear shale shaker used in drilling injection well[IW1(ET4)]. Inclination from vertical was 1/4° from vertical by TOTCO survey. 13.3/8" casing was installed and cemented.

### 2.5.4 Vertical Interval 68.3 m - 194.9 m MD, 12.1/4" diam.

The following assembly was used to drill the cement plugs and the vertical interval to 194.9 m MD:

12.1/4" Bit
12.3/16" Near Bit Stabiliser with Float

Slim Landing Sub / TOTCO Ring
8" Monel Drill Collar with Slim MWD
12.3/16" Stabiliser
8" Drill Collar(4 joints)
7.3/4" Flex Joint
7.3/4" Jar
8" Drill Collar
X-Over
5" HWDP(12 joints)
5" Drill Pipe to surface

| Drilling parameters were: | Cement plug | Out of 13.3/8" casing |
|---|---|---|
| WOB | 3 - 4 tonnes | 6 - 7 tonnes |
| Rotary Speed | 60 - 70 RPM | 100 - 110 RPM |
| Flow rate | 1600 - 1700 l/min | 1800 - 2200 l/min |

Shaker screens were 30 mesh square(upper) and 20x40 mesh(equiv. 60 mesh) rectangular(lower). Screen overflows began soon after the start of drilling, at approx. 77 m MD, at which point mud funnel viscosity was reduced from 60 to 47 sec / qt. No further overflows occurred.

The interval was drilled without difficulty, rate of penetration varying between 4 and 10 m/h, the lower rate relating to the presence of occasional hard zones.

MWD surveys were taken every 2 joints, the final survey in the interval at 177.4 m MD indicating an inclination of 0.4° from vertical.

### 2.5.5 "S" Type Directional Interval 194.9 m - 570.0 m MD, 12.1/4" diam.

The bent housing of the 7.3/4" steerable motor was set to 1° to achieve kick-off and the required build rate, and this and a bit for motor operation were made up in the following bottom hole assembly:

12.1/4" Bit
7.3/4" Steerable DHM, 1° bent
8" Monel Short Collar
Float Sub
12.1/8" Non-mag. Stabiliser
8" Orienting Sub
8" Monel DC with Slim MWD
8" Drill Collar(4 joints)
7.3/4" Flex Joint
7.3/4" Jar
8" Drill Collar
X-Over
5" HWDP(12 joints)
5" Drill Pipe to surface

| Drilling parameters were: | Oriented | Rotating |
|---|---|---|
| WOB | 5 - 8 tonnes | 3 - 12 tonnes |
| Rotary Speed | | 50 - 70 RPM |
| Motor Speed | 120 RPM | 120 RPM |
| Flow rate | 1800 - 2200 l/min | 1800 - 2200 l/min |

Drilling from KOP at 194.9 m MD was in oriented mode with Tool Face set to achieve the target azimuth. The intention was to survey at the end of every joint but surveys were not possible at the end of the first two joints, the signals being affected by interference. Surveys were achieved subsequently(from 222.8 m MD) by shutting down one of the mud pumps during the survey period.

Drilling continued, partly in oriented mode and partly in rotation, to achieve the required average build rate, with no difficulty in surveying until 259.6 m MD at which point survey data from the MWD could not be received, a failure of the MWD survey tool suspected. Efforts were made to fish the MWD tool with the sand line but these proved to be unsuccessful, and a decision to trip and replace the MWD tool was taken.

MWD surveys were restored and drilling resumed without difficulties to the end of the "S" section at 570 m MD(including wiper trips at 381.0 m MD, 455.9 m MD and TD). End of build was at 305.9 m MD, start of drop-off at 427.4 m MD, and end of drop-off at 530.4 m MD.

The Cenomanian was entered exactly at the expected depth of 413.5 m MD, with resultant reduced rate of penetration. The Albian was entered at 464.5 m MD also as expected; this point confirmed by a sudden increase of rate of penetration from +/- 1 m/h at the lower part of the Cenomanian to +/- 13 m/h in the Albian.

The whole interval from KOP was drilled with a single bit, which on inspection on POOH at TD was found to be in good condition but slightly under gauge.

Excellent accuracy was achieved in directional control, the final location in the X-Y plane at TD being within 0.5 m from target(see Figures 5a and 5b).

### 2.5.6 Coring Interval 570.0 - 582.3 m MD 8.1/2" diam.. Hole opening 12.1/4" diam. and final operations.

As mentioned earlier, coring was conducted to locate precisely the roof of the seam for subsequent casing placement/setting.

During the coring interval and subsequent operations in ET5, water was injected into well ET4 in order to ensure that no mud or debris entered this well, the pressures in ET5 during coring, hole opening and cementing being greater than the hydrostatic pressure in the coal seam. A flow rate of 700 - 900 l/h was initiated at the ET4 wellhead.

Coring was effected without difficulty, although only 11.85 m of core was recovered from a cored length of 12.3 m, the lost 0.45 m of core being thought most likely to have been from the coal floor/limestone interface or transition zone. The coring revealed:

| | |
|---|---|
| Start of coring: | 570.00 m MD |
| Coal Roof: | 576.66 m MD |
| Coal Floor: | 578.58 m MD |
| Top Limestone | 578.92 m MD |

The core section through the coal seam of 1.92 m is less than expected, although lower quality carbonaceous material is present below the seam.

Erosion by sand above the coal is confirmed by the presence of coal inclusions in the seam roof, and clear visual evidence of erosive contact at sand-coal boundary.

Excellent correlation was achieved between the coal seam positions in wells ET4 and ET5(see Figure 5b)

An increase of pressure to 9 - 10 bar(approx. the pressure difference existing between both wells - mud density plus well level difference) was observed at the ET4 wellhead at the time at which the coring bit passed through the coal seam, an indication that some form of connection between ET4 and ET5 was established. On this observed increase in pressure, a by-pass of water return via the annulus of ET4 was begun in order to ensure clean conditions through the ET4 shoe and to avoid contamination of ET5 drilling mud by the water injected in ET4.

The hole was opened to 12.1/4" diam. to 582.3 m MD, approx. 4.5 m below the floor of the seam, and, following circulation, a cement plug was set(to theoretical top plug depth 554 m MD, assuming no caving), subsequently drilled out to 577.06 m MD, 0.4 m below the seam roof.

The 9.5/8" casing string with centralisers was installed to 576.9 m MD, 0.16 m less than TD, the last two joints requiring circulation. Table III gives the 9.5/8" casing components and the corresponding levels/positions in the well.

The casing was cemented by HALLIBURTON, a lead slurry of 1.77 kg/l for the upper section of the well and a tail slurry of 1.8 kg/l, THERMOCEMOIL cement being used for both upper and lower sections. The cementing plugs were then drilled out to 575.5 m MD, followed by circulation, 8 $m^3$ of viscous water and 25 $m^3$ packer fluid(water plus caustic soda). A CBL log(*) was run by SCHLUMBERGER, and indicated good cement bond over the whole section except for intervals 0 - 80 m and 405 - 427 m MD.

The well was closed prior to workover operations for final completion to be carried out at a later date.

* A second CBL log using a crane was run in ET5 during the drilling operations of ET6, to record the evolution of cement integrity. The results were similar to those of the first log, with only minor changes at particular locations.

## 3. TRANSVERSE INJECTION WELL[IW2(ET6)]

### 3.1 TARGET OBJECTIVES - DIRECTIONAL DATA

The target objective of transverse injection well[IW2(ET6)] was defined as a point off-set laterally by 30 metres from a position approximately half way along the channel gasifier to be developed in the in-seam interval of the injection well[IW1(ET4)], and with entry to the coal seam at/or near vertical(see Figures 6a and 6b).

The surface(spud) location of the well was not revised from that originally planned and for which civil works for rig placement had been conducted previously, and the well trajectory was also therefore an 'S', or relief well, trajectory, as was the case for recovery well[RW(ET5)].

The trajectory of the transverse injection well[IW2(ET6)] therefore had the following objectives:

- Target location at 30 metres lateral off-set from a point situated approx. half way of the channel gasifier to be developed along the in-seam interval of the injection well[IW1(ET4)]

- Target accuracy +/- 5 metres from target X, Y co-ordinates

- | | |
  |---|---|
  | Type of Profile | 'S' or relief profile |
  | KOP | +/- 201 m MD |
  | Build up rate | +/- 2.2 degrees / 30 metres |
  | Inclination at end of build | +/- 8 degrees |
  | Tangent Section(hold) | from +/- 310 m MD to +/- 416 m MD |
  | Drop-off rate: | +/- 2.2 degrees / 30 metres |
  | End of drop-off | +/- 525 m MD |
  | Inclination at end of drop-off | +/- 0 degree |
  | Total Depth(+/- 5 m below coal seam) | +/- 558.0 m MD |
  | Well azimuth | +/- 330.5° relative to UTM North |
  | Horizontal displacement: | +/- 30 metres |

- Target UTM co-ordinates(30 m lateral off-set from channel gasification mid-point)

| | | | |
|---|---|---|---|
| Spud | X: 718532.54 | Y: 4532621.19 | Z: 660.26(ref. sea level) |
| Target | X: 718517.81 | Y: 4532647.25 | Z: 112.30 |

## 3.2 WELL DETAILS - COMPLETION DESIGN

The well is the smallest and simplest of the three process wells in terms of completion design. The tubing arrangement and wellhead for transverse injection well[IW2(ET6)] are shown in Figures 7 and 8.

As mentioned in Section 2.2 of this report, ET5 and ET6 were to be drilled with the same rig, only rig relocation on-site separating the two drilling operations. As for well ET5, it was decided to drill and case the well, and to carry out workover operations subsequently for final completion.

Casing Programme

| Hole (inches) | Casing (inches) | Shoe MD(m) |
|---|---|---|
| 8.1/2 | 7 | 60 |
| 6.1/8 | 4.1/2 | 558(+/- 5 m below seam floor) |

Casing Specification

| | |
|---|---|
| 7" | 26 PPF - N80 - NEW VAM Special Clearance(SC) |
| 4.1/2" | 12.6 PPF - N80 - NEW VAM SC<br>(2 last joints in 11.6 PPF - VS 22 - NEW VAM SC) |

Casings to be run with centralisers, float collars/shoes, and 4.1/2" casing to be cemented with THERMOCEMOIL high temperature cement.

This casing programme is only part of the completion, the remaining elements to be installed in a subsequent workover operation.

## 3.3 DRILLING PROGRAMME, BITS AND FLUIDS

The planned drilling programme was as follows:

| | |
|---|---|
| 8.1/2" drilling | Rotary |
| 7" plug/casing shoe | Rotary |
| 6.1/8" to KOP | Rotary |
| 6.1/8" build/tangent/drop-off | 4.3/4" DHM/MWD(oriented/rotation) |
| 5.7/8" coring | Rotary |
| 6.1/8" hole opening | Rotary |

Bits

Conventional rock roller bits were also selected, standard tooth for the vertical section to KOP and protected insert for the deviated interval. A diamond crown bit was used for coring

Fluids

Drilling fluid specifications were as for ET5. KCl polymer mud used previously to drill ET5(+/- 40 $m^3$) was re-used as spud mud during the 8.1/2" drilling phase instead of Bentonitic mud.

## 3.4 SERVICE CONTRACTORS

Services and equipment were provided by the same contractors involved in recovery well ET5.

## 3.5 OPERATIONS AND WELL COMPLETION

### 3.5.1 Site Preparation, Mobilisation and Procurement

The site was prepared to accept the COFOR rig, which was moved to the spud location of ET6 from that of ET5 over a period of 3 days. During rig re-location, ANADRILL replaced the directional drilling equipment used in ET5 with the smaller diameter equipment required for ET6. Schoeller Bleckmann(SBS) 4.3/4" Flex Drill Series P150 motors were supplied to drill the directional interval.

### 3.5.2 Rig Operations

The well was spudded 22 December 1994. The operations performed were:

| | | | |
|---|---|---|---|
| - Drilling | 8.1/2" | 0 - 60.80 m | 22 Dec. |
| - Casing/cementing | 7" | 0 - 60.80 m | 23 Dec. |
| - Drilling | 6.1/8" | 60.8 - 545.30 m | 23 Dec. -27 Dec. |
| - Coring | 5.7/8" | 545.30 - 552.85 m | 28 Dec. |
| - Reaming/Drilling | 6.1/8" | 545.30 - 554.85 m | 28 Dec. |
| - Logging open hole | | TD to 236.53 m | 29 Dec. |
| - Casing/cementing | 4.1/2" | to 554.29 m | 29 Dec. |
| - Drilling cement plugs | 3.3/4" | to 552.60 m | 30 Dec. |
| - CBL log | | TD to surface | 30 Dec. |

Actual depth/time progress is compared to the pre-spud estimate in Figure 9. Operating time distribution is given in Table IV. The total time to complete all operations was 9 days(as anticipated).

### 3.5.3 Vertical Interval 0 m - 60.8 m MD, 8.1/2" diam.

This interval was drilled in rotary mode with a standard pendulum assembly:

8.1/2" Bit
Bit Sub
8.1/2" Stabiliser
6.1/2" Drill Collar
8.1/2" Stabiliser
6.1/2" Drill Collar(3 joints)
X-Over
5 " Drill Pipe to surface

The interval was drilled without difficulty, although mud losses to surface formation of 1.5 - 3 $m^3$/h began at approx. 27 m MD. Medium mica was added to the mud to control circulation losses although a total of 22 $m^3$ of mud was lost to the formation during this interval. 7" casing was installed and cemented without problem.

### 3.5.4 Vertical Interval 60.8 m - 197.8 m MD, 6.1/8" diam.

The following assembly was used to drill the cement plugs and the vertical interval to 197.8 m MD:

6.1/8" Bit
Bit Sub
6.1/8" Stabiliser
4.3/4" Drill Collar
6.1/8" Stabiliser
4.3/4" Drill Collar(19 joints)
5" Drill Pipe to surface

| Drilling parameters were: | Cement plug | Out of 7" casing |
|---|---|---|
| WOB | 1 tonne | 4 tonnes |
| Rotary Speed | 60 - 70 RPM | 90 - 120 RPM |
| Flow rate | 500 - 900 l/min | 500 - 900 l/min |

The interval was drilled without difficulty, rate of penetration varying between 4 and 10 m/h, the lower rate relating to the presence of occasional hard zones.

### 3.5.5 "S" Type Directional Interval 197.8 m - 545.3 m MD, 6.1/8" diam.

The bent housing of the 4.3/4" steerable motor was set to 1.15° to achieve kick-off and the required build rate, and this and a bit for motor operation were made up in the following bottom hole assembly:

6.1/8" Bit
4.3/4" Steerable DHM, 1.15° bent
X-over
5.7/8" Stabiliser
4.3/4" Orienting Sub
4.3/4" Monel Short Collar
4.3/4" Monel DC with Slim MWD
4.3/4" Drill Collar(8 joints)
4.3/4" Flex Joint
4.3/4" Jar
4.3/4" Drill Collar
3.1/2" HWDP(15 joints)
3.1/2" Drill Pipe to surface

| Drilling parameters were: | Oriented | Rotating |
|---|---|---|
| WOB | 5 - 6 tonnes | 2 - 6 tonnes |
| Rotary Speed | | 50 - 60 RPM |
| Motor Speed | 180 RPM | 180 RPM |
| Flow rate | 700 - 900 l/min | 700 - 900 l/min |

Although the MWD surface test was not totally satisfactory, it was decided to continue to make-up the string and to test the MWD again outside the 7" shoe. This test failed and the string was POOH to replace the MWD pulser and associated electronics.

The subsequent surface test of the new assembly was satisfactory but the MWD failed again outside the 7" shoe, the signal arriving "inverted". A decision was taken to replace the complete MWD unit, and the string was POOH again.

The third MWD test was successful and drilling began after having lost a total of approx. 8 hours time due to the two MWD failures.

MWD surveys were taken on RIH to KOP, inclinations from vertical ranging from 0.6° at 70.0 m MD to 1.0° at 191.0 m MD. Drilling from KOP at 197.8 m MD was in oriented mode with Tool Face set to achieve the target azimuth, and MWD surveys taken at the end of every joint. Drilling continued without difficulty to the end of the build section(sliding plus rotation), and partly through the hold section(rotary only) to 354.8 m MD, when a wiper trip back to 200 m MD was effected, continuous drilling having been conducted for over 18 hours. No over-pull was observed during the trip, indicating good hole condition.

Drilling resumed in rotary mode to the end of the hold section(in the Cenomanian), ROP over the last few joints in this section being very low, which together with low torque suggested bit deterioration.

A decision was taken to trip to examine the condition of bit and DHM and the string was POOH. The motor bearings were in good condition, the bit was found to be partially worn and was replaced before RIH to continue drilling. Drilling resumed in oriented mode to the end of the drop-off section. End of build was at 290.0 m MD, start of drop off at 430.4 m MD, and end of drop off at 519.8 m MD.

Excellent accuracy in directional control was also achieved in this well, the final location in the X-Y plane at TD being within 1 m from target(see Figures 10a and 10b).

### 3.5.6 Coring Interval 545.30 - 552.85 m MD 5.7/8" diam.. Subsequent re-drilling 6.1/8" diam. to 554.85 m, and final operations.

Coring was conducted in order to locate precisely the seam limits for casing placement and subsequent perforation. Initial cuttings on the shaker during the coring phase were coaly indicating that the seam had been entered higher than anticipated, a situation confirmed by the appearance of limestone(from below the seam floor) and low ROP at a depth of only 547.8 m MD.

Coring was terminated at 552.85 m MD and the drill string was POOH. A tight point was experienced at 522.3 m MD during the withdrawal of the string. On examination of the core at surface, coal was found immediately at the beginning of the core section to 545.3 m MD(possibly with more coal above the coring point ?), indicating the presence of the coal seam approx. 5.3 m higher than expected from the prognosis from previous wells(see Figure 10b).

A total length of 7.29 m of core was recovered from a cored length of 7.55 m, the lost core thought most likely to have been from the section between the coal seam floor and the hard limestone(carbonaceous clay) and/or the starting of the coring(top of the coal seam). The coring revealed:

| | |
|---|---|
| Start of coring: | 545.30 m MD |
| Coal Roof: at depth less than | 545.30 m MD |
| Coal Floor: | 547.47 m MD |
| Top limestone: | 547.83 m MD |

Due to the difficulties to interpret accurately the coring information, a decision was taken to log the well to TD to confirm the presence and extent of the coal interval. The cored section was opened to 6.1/8" diam. and drilling continued to 554.85 m MD, approx. 7 m below the seam floor, in order to obtain a subsequent combined lithodensity/neutron log across the full coal thickness. Logging was performed by SCHLUMBERGER and the log revealed:

| | |
|---|---|
| Coal Roof: | +/- 545.6 m MD |
| Top limestone: | +/- 548.4 m MD |

Comparison of log analysis with coring showed: a higher seam(coal plus carbonaceous clay) thickness(2.8 m in front of the 2.53 m revealed by the coring) and a greater measured depth for the top limestone(548.4 m MD in front of the 547.83 m MD revealed by the drill pipe length).

The difference in seam thickness(+/- 0.3 m) may be explained by the loss of core(as mentioned above). The difference in measured depths(+/- 0.6 m) is probably coming from the length measurement inaccuracy(drill pipe cumulated lengths in front of wire-line length in a relief well).

The 4.1/2" casing string with centralisers was installed to 554.29 m MD(0.56 m above TD). On running casing, the centraliser clamps failed to operate satisfactorily and the decision was taken to use the couplings as stop collars. Table V gives the 4.1/2" casing components and the corresponding levels/positions in the well. The casing was cemented by HALLIBURTON with a slurry of 1.8 kg/l THERMOCEMOIL cement for the complete section.

The cementing plugs were then drilled out with a 3.3/4" Economill and 2.3/8" drill string to 552.3 m MD, followed by circulation, 8 $m^3$ of viscous water and 25 $m^3$ packer fluid(water plus caustic soda). A CBL log was then run by SCHLUMBERGER, and indicated good cement bond over the whole section.

The well was closed prior to workover operations for final completion, to be carried out at a later date.

# 4. ENGINEERING

## 4.1 WORKOVERS AND WELL COMPLETION

Workover and completion of wells MW1(ET1), MW2(ET2), IW1(ET4), RW(ET5) and IW2(ET6) will be carried out prior to gasification operations as follows:

- ET1: Installation of thermocouples clamped to a tubing string and cementing(see Figure 11).
- ET2: Short-radius drilling extension(workover) followed by the installation of a coiled tubing equipped with thermocouples and fibre optics, and cementing(see Figure 12).
- ET4: Installation of a small tubing equipped with burner/injection head, macaroni and thermocouples followed by the installation of coiled tubing(see Figure 13).
- ET5: Cement plug re-drilling to design depth, water breakthrough/linking operations, bottom well cleaning/reaming followed by liner installation, and installation of tubing strings(3 strings in total) equipped with thermocouples, fibre optics, macaroni and burner(see Figures 2 and 3).
- ET6: Perforation of casing in front of the coal seam followed by the installation of a small tubing string equipped with thermocouple, macaroni and burner(see Figures 7 and 8).

The design of the coiled tubing system for ET2 will be finalised early 1995 and the manufacture of the flat-pack instrumentation for this well will control the timing of this workover operation, together with the availability of suitable workover rigs and short radius directional drilling equipment and services.

ET1 workover will be realised with a small rig prior to ET2 workover in order to realise the cementing operations at the same time(only one mobilisation/demobilisation cost for both cementing operations).

ET4, ET5 and ET6 workover and completion operations will be conducted once all the special alloy tubing strings, liner completion components, protectors/centralisers, clamps and burners for these wells are delivered - expected Summer 1995.

## 4.2 SURFACE PLANT

### 4.2.1 Site Layout

The basic design of the site layout realised by JOHN BROWN SENER was previously described in the fourth technical report(July 1993 - December 1993). From the first design, few modifications were applied to the basic principles/specifications. The final site layout produced by SERELAND is shown in Figure 14.

The site comprises 3 platforms with levels increasing in height from north to south, on which plant and equipment will be grouped according to the location of process wells and activities. A main north-south pipe rack will be constructed to convey the process and utility fluids to all platforms. East-west branches will also be realised to make final connection to the wells and equipment. The precise location of components is controlled by safety, environmental and logistical factors, including hazardous area requirements.

The location of plant and equipment on platforms is as follows:

<u>Injection/Utility Area(lowest platform - northernmost):</u>

Deviated Injection Well[IW1(ET4)]
Vertical Monitoring Well[MW1(ET1)]
Argon Analyser Unit
Process Water Pumping Unit
Coiled Tubing Control Unit
Coiled Tubing Injection Unit
Propane Storage/Heaters
Equipment Storage/Workshop
Instrument Air Unit
Emergency Group
Injection Manifold of Well[IW1(ET4)]
Nitrogen and Oxygen Plant
Sparge Water Pumping Unit
Fire Water Pumping Unit
Utility Water Pumping Unit
Foam Pumping Unit
Steam Boiler Plant
Water Storage Tanks(Process/Fire)
Transformer
Helium Injection Vessels

Office/Control Area(intermediate platform - central):

Transverse Injection Well[IW2(ET6)]
Deviated Monitoring Well[MW2(ET2)]
Staff Accommodation Shelters
Equipment Storage
Injection Manifold of Well[IW2(ET6)]
Data Acquisition/Control System Unit
Parking

Product Gas Analysis/Disposal Area(highest platform - southernmost):

Recovery Well[RW(ET5)]
Pressure Letdown Stations
Flow-metering Units
Gas Combustor
Foul Water Tanks
Injection Manifold of Well[RW(ET5)]
Product Gas Analysis Unit
Heat Exchangers
Flare

### 4.2.2 Process and Utility Plant/Unit Description

The surface plant, designed first by JOHN BROWN SENER(basic design - phase 1) and secondly by SERELAND(detailed design - phase 2), will be built to handle with a maximum degree of turndown and flexibility the process phases of the trial described in detail in Appendix B of the third technical report(January 1993 - June 1993).

The process flow diagram, shown in Figure 15, indicates the four main blocks of the process: (i) the injection facilities including the oxygen and nitrogen plant, the argon analyser unit, the process water and foam pumping units, and the injection manifolds, (ii) the process wells and the underground reactor, (iii) the product gas/liquid facilities including the letdown stations, the heat exchangers, the flow-metering units, the product gas analysis unit, the flare, the gas combustor and the foul water tanks, and (iv) the sparge water pumping unit.

Nitrogen and oxygen will be stored on site as liquids in cryogenic storage tanks and pumped in the liquid form prior to vaporisation in steam fed heat exchangers. Pressures of nitrogen and oxygen inside surge vessels will be maintained between controllable levels by means of on/off pumping actions. The flow diagrams for the oxygen and nitrogen supply units are shown in Figure 16.

Nitrogen, oxygen, water and foam are supplied to the wellheads of the two injection wells[IW1(ET4)] and [IW2(ET6)] to achieve fluid injections for the various process phases including gasification. Nitrogen, oxygen and sparge water are supplied to the recovery well[RW(ET5)] to meet specific process phase requirements such as bottom well cooling, liquid/gas lift, purging and reverse combustion ignition.

Nitrogen and oxygen are transferred from the surge vessel to the wellhead areas(injection manifolds) where flows are controlled via control valves. Water and foam are directly controlled from the units via adjustable stroke dosing pumps. Both the control valves and the adjustable stroke dosing pumps are designed to achieve high flow control and stability.

From the recovery well[RW(ET5)], product gases/liquids are passed to a gas combustor or a flare, and foul water tanks for certain operational phases, via pressure letdown stations and heat exchangers. The heat exchangers installed in the low and high flow product gas lines will ensure that the products are maintained in the gaseous phase for gas analysis.

Figure 17 shows the flow diagram of the different product gas/liquid lines. The diagram shows also the sizes and materials of the different lines, material selection being determined by the corrosion resistance requirements at anticipated temperatures and pressures.

The gas combustor will ensure complete combustion of products from the recovery well, and will be to a design which ensures that the dilution and dispersion of combustion products meet statutory "inmision" regulations. The results of the emission/deposit study are given in a report prepared by PROYCE on the basis of calculations realised by the CENTRO POLITECNICO SUPERIOR of the UNIVERSITY OF ZARAGOZA. The flare will be used to burn high quality products from the gasifier or in case of failure of the gas combustor.

Utilities include steam, compressed air for instrumentation, low pressure nitrogen and water, propane and electricity. A fire water system and an emergency electrical generator will also be provided.

### 4.2.3 Detailed Engineering(Phase 2) Status

The detailed engineering design of the surface plant(Phase 2) continued by SERELAND throughout the whole period of this report. Although completion of this work was originally foreseen early 1995, delays are expected as a result of the need to obtain competitive tenders and to conduct equipment selection in difficult areas such as process instrumentation and control, and heat exchangers. Nevertheless, due to other delays (procurement of well completion materials and time to design the Product Gas Analysis Unit), the surface plant detailed engineering and procurement is not the critical path of the project.

The remit to SERELAND comprises two tasks: (i) engineering and detailed design of the surface facility including the preparation of specifications for all surface plant and equipment and (ii) equipment selection and analysis of competitive tenders for plant and equipment for procurement by UGE. The construction of the facility(Engineering contract - Phase 3) will be initiated /conducted at the end of Phase 2 when the majority of the equipment will be ordered.

Progress at the end of the report period is as follows:

### i) Preparation of drawings, specifications and data sheets

- Drawing Preparation

| Item | Progress |
|---|---|
| P& ID | 80 % |
| Plot Plan | 100 % |
| Key Plan | 80% |
| Piping Drawings | 0 % |
| Manifold Drawings | 50 % |
| Mechanical Drawings | 0 % |
| Fire Fighting | 80 % |
| Electricity Drawings | 0 % |
| Hazardous Area Plan | 80 % |
| Hook-up | 0 % |
| Control/Inst. Drawings | 0 % |

- Specification, Data Sheet and List Preparation

| Item | Progress |
|---|---|
| Equip. Spec. for Tendering | 65 %(see progress in tendering) |
| Drawing List | 30 % |
| Line List | 60 % |
| Equipment List | 20 % |
| Piping Spec. | 20 % |
| Electricity Cable List | 0 % |
| Inst. Cable List | 0 % |
| Instrument List | 40 % |

### ii) Tendering and equipment selection

- Equipment ordered:

| Item | Company | Delivery Date |
|---|---|---|
| Electricity Transformer | ERSA | December 1994 |
| Gas combustor/flare | PROYCE | April 1995 |
| Steam Boiler | GEVAL | April 1995 |
| $O_2$ and $N_2$ Plant | CARBUROS METALICOS | June 1995 |
| $H_2O$/Foam Dosing Pumps | BRAN / LUEBBE | June 1995 |

- Equipment under tender evaluation

| | |
|---|---|
| Flow-metering Devices | Pressure and Temperature Transmitters |
| Fire Fighting System | HP Choke and Manual Valves |

| | |
|---|---|
| $O_2$ Analysers | Safety and Automatic On/off Valves |
| Tracer Bottles/Vessels | Utility Water Pressure Group |
| Heat Exchangers | Propane Storage/Heaters |
| Control Valves | |

- Equipment/services still to be tendered

| | |
|---|---|
| Argon Analyser | Injection and Ignition Manifolds |
| Civil Works | Pressure and Temperature Indicators |
| Electricity Installation | Instrumentation Installation |
| Pipe Construction | Emergency Group |

Globally, SERELAND has evaluated the progress of the detailed engineering phase at the end of the report period to be 52 %.

## 4.3 PRODUCT GAS ANALYSIS UNIT

As mentioned in the previous technical report for January 1994 - June 1994, DUMEZ COPISA SISTEMAS was selected for the detailed design(Phase 1) of the Product Gas Analysis Unit and a contract was placed with the company in July 1994.

The contract covers specifications of equipment, safety requirements, and a cost estimate for Phase 2, proposed as a turnkey contract for the procurement of equipment and construction of the complete Unit. Work on the Phase 1 contract by DUMEZ COPISA SISTEMAS continued throughout the whole period of this report, being close to completion at end - December 1994.

Work outstanding on the Phase 1 contract comprises mechanical and electrical layout/design which should be complete in February 1995. Procurement of components and construction of the complete Unit(Phase 2) will be initiated following acceptance of the final design specification.

The Product Gas Analysis Unit is required to provide continuous analytical composition measurement of the product gas stream and continuous liquid collection during the different phases of operation for both process control and accurate mass balance calculation.

UCG process control requires on line analysis of methane, carbon monoxide, carbon dioxide, hydrogen, hydrogen sulphide, oxygen and dry gas/liquid ratio.

Accurate mass balance calculation requires analysis of additional components such as argon, nitrogen, ethane, propane, heavy hydrocarbons, ammonia, carbonate/bicarbonate, sulphate/sulphide and phenols(including some subsequent laboratory analysis).

Helium will be injected and its content in the product gas will be measured for analysis of the residence time distribution inside the underground reactor.

A block diagram of the complete Gas Analysis System - from product gas flow lines to analysers - is shown in Figure 18. A major part of the system is involved in conditioning the samples prior to entry to the dry gas analysers.

Samples of the product gas will be taken via retractable sampling probes in the product gas streams, and particles will be removed by cyclones and filters installed in heated boxes close to the sampling points.

After transport via heated lines to the main Analysis Unit, wet flow rate will be measured prior to gas cleanup in which cooling/condensation will be effected for dry gas/liquid ratio analysis. The liquid accumulated inside the condensate pot(level will be measured) will be sampled from time to time for further analysis of water/liquid ratio and liquid content.

After removal of additional heavy hydrocarbons, the flow rate of clean, dry gas from the cleanup section will be measured prior to its distribution to individual analysers via their respective dedicated(additional) sample conditioning systems. The complete conditioning system from sampling point to dry flow measurement will be duplicated to enable analysis to continue during the maintenance or repair of elements due to blockage or failure.

The proposed analysers for process control are: (i)a para-magnetic analyser for oxygen, (ii)a multiway infra-red analyser for carbon monoxide, carbon dioxide and methane, (iii) an ultra-violet analyser for hydrogen sulphide and (iv) a gas chromatograph for hydrogen.

The decision to analyse the hydrogen sulphide after the water/liquid condenser(dry basis) was based on the results of gas/liquid composition calculations realised at the UNIVERSITY OF LIEGE.

A mass spectrometer will provide redundancy for process control as well as concentration measurements of argon, helium, nitrogen, ethane, propane, ammonia, heavy hydrocarbons($C_4$, $C_5$, $C_6^+$) for mass balance calculations and tracer test interpretation.

The dry gas/liquid ratio will be measured by difference between the wet flow rate(before cooler/condenser) and the dry flow rate(after cooler/condenser). Liquid samples will be sent to specialist laboratories for analysis of water/liquid ratio and liquid content.

Temperature and moisture detectors will be installed to protect analysers and other system components from improper conditioning of the product gas in terms of particle/liquid content e.g. on process start-up, other cool/high liquid/dirty phases, and to give warning of invalid analysis conditions.

With the exception of the local boxes, all elements of the Product Gas Analysis Unit will be constructed as a mobile unit with the ability to be stored, and transported to other sites. The analyser house or shelter will be approx. 4 metres length by 3 metres width and 2 metres height.

The shelter will be installed with a redundant forced ventilation system, and explosive and toxic($CO/H_2S$) gas detectors. These will guard against explosive/toxicity hazards and will shut-off sample inlet and electrical apparatus to the shelter on positive detection.

## 4.4 DATA ACQUISITION AND CONTROL UNIT

### 4.4.1 Requirements

Process phases of the trial will be directly managed via control of the injected flows, reactor back pressure and pressure let-down, and the product well bottom hole temperature.

Product gas composition, and simple mass and energy balances will be used indirectly to manage process phases(gasification efficiency, control of water influx and/or gas losses, heat losses).

Information from tracer test and fibre optic measurements will be used to control the underground cavity growth.

The Data Acquisition/Control System will present a single window to plant operation, adapted in accordance with process phase, and will manage the basic functions:

- Control and indication of process variables
- Display and monitoring of strategic point alarms
- Control loop tuning
- Data processing, storage and reporting

The Control System will be modular with a field control input/output unit including all necessary equipment to capture, send, control and digitise data input and output from/to the field instruments(transmitters and control devices) i.e. power supply, controllers, analogue/digital converters, relay multiplexers, in/out interface with processor, etc.

The Control Strategy is based on classical closed-loop controls. Flow correction for temperature and pressure will be applied, together with flow ratio control and annular purge control where set point will be adapted as a function of well pressure variation($Flow = Flow_{set} + c^{ste} \bullet dp/dt$).

Some advanced Control Strategies(such as feedforward, cascade) will be used in heat exchanger and recovery well temperature control, these being considered necessary because of the uncertainty of product gas parameters(flow, temperature and composition)

The Data Acquisition System will acquire, store, process, visualise and/or print data from a large number of surface and subsurface instruments. Its primary task is to scan/store data from sensors and to display/update subsets for operational monitoring.

The scan/storage capacity of the System will provide updating each minute, with hourly and daily mean values of each measurement point.

The Data Acquisition System will be supplied with all necessary software to capture and digitise data input, and in addition to basic software such as the Operating System, communication/interface drivers, compilers, etc., will include the following minimum software:

- Data Base - Hierarchical storage of all data input and provision/ organisation of access for subsequent data processing, visualisation and printing.
- Scanning - Initialisation/co-ordination of scanning tasks with the field input unit, fibre optic distributed temperature controller and gas analysis controller.
- Alarms - Low/high alarm settings and alarm message management.
- Calculation - Calculations such as mass/energy balances, flow compensation, residence time.
- Graphics - Screen/printer displays of data on real time/historical bases
- Network - Access to the Data Base from the network

### 4.4.2 System/Contractor Selection

A total of 13 tenders were received for the design and construction of the Unit. Proposals within the tenders were similar at the Controller level, but fell into two main categories at the level of the database/user interface, these being PC based systems, and RISC workstation based systems.

The workstation solution provides greater power/performance than a PC based solution but has the disadvantage of being linked to the manufacturer both for hardware and software. The PC based system is less powerful but offers greater flexibility and a wider range of software applications.

The tender offers comprised a wide range of system structure sophistication and prices. Analysis of the suitability/capability of the offers revealed that a well structured PC based solution was adequate for the tasks required, and as mentioned in the previous technical report(January 1994 - June 1994), the HONEYWELL PC based proposal was selected.

A contract for the detailed design/engineering of the Data Acquisition and Control System(Phase 1) was placed in July 1994.

### 4.4.3 System Engineering

The System will be based on HONEYWELL SCAN 3000 Base Software operating with a UNIX Operating System, with two Dell 486DX2/66 PC's as Master/Operator stations linked via Ethernet to two 9000 Controllers.

The System will also be linked via modem to a remote terminal and a modelling computer in UGE offices(see Figure 19).

The complete Unit will be housed as a mobile shelter/container for storage or transportation to other sites, air conditioned for optimum operation under all expected climatic conditions. An Uninterrupted Power Supply(UPS) will also be installed to maintain the control of process and safety in case of transformer/electricity failure.

The detailed engineering design of the Data Acquisition and Control Unit was nearing completion by HONEYWELL at end-December 1994.

## 4.5 FIBRE OPTIC SYSTEM

Wells[IW1(ET4)], [MW2(ET2)] and [RW(ET5)] will be equipped with Optical Fibres using a system for Distributed Temperature Sensing(DTS) and length measurement developed by YORK SENSORS, LTD.

In wells[IW1(ET4)] and [MW2(ET2)], the System will be used to obtain information on axial and lateral cavity growth respectively, via temperature measurement and the length of the fibre optic sensors as they are destroyed by the combustion process.

In well[RW(ET5)], the System will provide temperature information along the recovery well production tubing to guard against excessive temperatures at well bottom, to confirm the extent of sparge cooling, and to warn of low temperature wet corrosion conditions in the upper section.

The YORK System is based on Optical Time Domain Reflectometry using multi-mode optical fibre sensors. The System is claimed to have the ability to provide temperature versus distance information to a resolution better than $1^{\circ}C$, and spatial resolution of less than 1 metre.

The System comprises the fibre optic cable, an optical fibre interface(laser source and receptor), optical to digital information conversion, and computer interfaces. Data from the System will be input to the HONEYWELL Data Acquisition/Control System Unit.

Optical fibre cables for the three wells and the surface equipment(including software for interface with the Data Acquisition/Control System Unit) were ordered in September 1994.

## 5. SUPPORTING PROGRAMME

INSTITUTO DE CARBOQUIMICA completed work on "El Tremedal" coal reactivity determination and the predictive modelling of maximum in-seam temperatures in the combustion zone as a function of operating conditions. Experimental results of reactivity of char combustion and gasification with $CO_2$, $H_2O$ and $H_2$ were delivered.

These results as well as the pyrolysis results were included inside the predictive model and provide estimates of the effect of oxygen/water ratio on the combustion/gasification temperatures at the underground gasifier wall, and optimum conversion conditions.

A final report was received from INSTITUTO DE CARBOQUIMICA on the three elements of work performed - the above mentioned work on modelling, and the previous laboratory measurements of pyrolysis and coal char reactivities of the "El Tremedal" coal.

The conclusions of the report can be summarised as follows:

- **Pyrolysis Experiment**

  - temperatures up to 800 °C favour the formation of water, gas and tar
  - maximum amount(+/- 5 %) of char recovered around 600 - 700 °C
  - pressure favours the retention of sulphur in char

- **Reactivity Experiment**

  "El Tremedal" coal shows high reactivity(normal for Teruel basin coal)

- **Modelling**

  - internal water coming from drying and pyrolysis is sufficient to maintain a "self-gasification" of the "El Tremedal" coal
  - ash softening in the combustion/gasification zone is not expected
  - pressure is an important parameter of reaction mechanisms(especially for the formation of $CH_4$)
  - thermomechanical behaviour of the coal will be the dominant factor in cavity growth

Work on UCG process behaviour by TU. DELFT continued and a number of papers on the work of the group were received. A meeting to discuss the status of the thermomechanical stability analysis and process modelling will be held early in 1995.

## 6. PROJECT DIRECTION

### 6.1 ADMINISTRATION

No additional staff were recruited in the period of this report. The vacancy in Process Control/ Analysis remained unfilled. Current complement of the team is 13 full-time personnel.

### 6.2 PROBLEMS/DIFFICULTIES

The most important technical problem resulted from the sale of KAWASAKI THERMAL SYSTEMS, with the consequent decision to proceed with an alternative less satisfactory non-THERMOCASE design for the completion for the recovery well[RW(ET5)].

The apparent divergence of coal location in ET6 from that anticipated could be due to the presence of a small fault between ET6 and the line of ET4. Further analysis will be carried out to assess the scale of such faulting and the impact on process planning/operations.

Delays are expected to obtain competitive tenders and to conduct equipment selection in difficult areas of the surface plant such as process instrumentation and control, and heat exchangers.

Other delays in procurement of well completion materials in special alloys are also expected. The critical path has become the procurement of special alloy well equipment - expected delivery Summer 1995.

### 6.3 CHANGES IN TECHNICAL STRATEGY

The main change in technical strategy involved the decision to proceed with the alternative recovery well completion design mentioned in Problems/Difficulties above.

### 6.4 FUTURE WORK

Workover operations on the wells ET1, ET2, ET4, ET5 and ET6 will be performed following the delivery of tubings, liner components and thermocouples, and the design and delivery of coiled tubing components(ET2 and ET4).

Contracts for the construction of the Product Gas Analysis and Data Acquisition/Control System Units will be placed as soon as the detailed engineering design contracts for these Units are complete.

Orders for remaining surface plant components will be placed following confirmation of their design specifications by the engineering contractor SERELAND and acceptance by UGE.

## 6.5 CONFERENCES, PUBLICATIONS AND REPORTS

- "Final Report of Works performed by INSTITUTO DE CARBOQUIMICA in support of the El Tremedal Trial"
  by J. Adanez, F. Garcia-Labiano and R. Moliner(INSTITUTO DE CARBOQUIMICA)
  (UGE ref. 54)

- "Estudio Impacto Ambiental Inmisiones - Quemador"
  Report prepared by PROYCE on the basis of calculations realised by the CENTRO POLITECNICO SUPERIOR of the University of ZARAGOZA
  (UGE ref. 55 and 56)

- "Recovery Well Heat Losses and Pressure Changes"
  Reports prepared by Ph. de Ro and Prof. J. Patigny(IDGS)
  (UGE ref. 44, 48, 49 and 51)

- "ET5 and ET6 Drilling and MWD Survey End of Well Report"
  Report prepared by ANADRILL SCHLUMBERGER
  (UGE ref. 53)

- "ET5 and ET6 Final Mud Report"
  Report prepared by MGA
  (UGE ref. 62)

- "Field Trial of Underground Coal Gasification by Underground Gasification Europe, Teruel, Spain"
  Second progress report prepared by ETSU

- "Transport Phenomena in UCG Channels"
  by R.A. Kuiper(TU. DELFT)
  (UGE ref. 52)

- THERMIE Exhibition, Berlin. UGE Poster Session Presentation

| Run Cases | | | Flows(kg/h) | | | | Temperature(°C) | | | | | | | Condensation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | UCG Product Gas | Sparge Water | Nitrogen Purge | Gas Mixture Outlet | UCG Product Gas | Sparge Water | | Nitrogen Purge | | Gas Mixture Outlet | | |
| | | | | | | | | Bottom | Top | Bottom | Top | Bottom | Top | |
| INSULATED TUBING | High Flow - High Temp. Case | 1.2 day | 12240 | 4014 | 126 | 16380 | 800 | 58 | 25 | 216 | 25 | 309 | 288 | NO |
| | | 11.6 days | 12240 | 4014 | 126 | 16380 | 800 | 61 | 25 | 220 | 25 | 310 | 290 | NO |
| | Medium Flow - Low Temp. Case | 1.2 day | 4320 | 0 | 126 | 4446 | 250 | - | - | 234 | 25 | 245 | 214 | NO |
| | | 11.6 days | 4320 | 0 | 126 | 4446 | 250 | - | - | 241 | 25 | 245 | 226 | NO |
| DOUBLE ANNULUS | High Flow - High Temp. Case | 1.2 day | 12240 | 4536 | 72 | 16848 | 800 | 123 | 25 | 235 | 25 | 302 | 236 | NO |
| | | 11.6 days | 12240 | 4536 | 72 | 16848 | 800 | 133 | 25 | 247 | 25 | 309 | 245 | NO |
| | Medium Flow - Low Temp. Case | 1.2 day | 4320 | 0 | 72 | 4392 | 250 | - | - | 234 | 25 | 250 | 206 | YES Liq. Fraction=0.3 Wet length= +/- 222 m |
| | | 11.6 days | 4320 | 0 | 72 | 4392 | 250 | - | - | 244 | 25 | 250 | 226 | NO |

**Table I .** Data of the Recovery Well Computer Model run by UNIVERSITY OF LOUVAIN

| Day | | Drilling / Coring | Stop/Main-tenance | Mud Prep./ Circulation | Casing Setting | Cementing / Waiting | Plug/Shoe Drilling + Reaming | Survey + Logging | Rig Manoeuvre | Others |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | VERTICAL | 6.00 | | 3.00 | | | | | 3.00 | 8.00 |
| 2 | | 19.75 | | 1.75 | | | | 0.25 | 2.25 | |
| 3 | | | | | 6.25 | 16.50 | | | 1.25 | |
| 4 | | 9.50 | | 4.00 | | | 4.25 | | 6.25 | |
| 5 | | 13.75 | | 0.75 | | | | 1.00 | 7.75 | 0.75 |
| 6 | RELIEF | 14.50 | 3.25 | | | | | 1.75 | 4.50 | |
| 7 | | 20.50 | | 1.00 | | | | | 2.50 | |
| 8 | | 19.75 | 1.00 | 1.00 | | | | 1.00 | 1.25 | |
| 9 | | 15.25 | | 1.50 | | | 0.75 | 0.75 | 5.75 | |
| 10 | | 5.00 | 0.25 | 0.25 | | | 3.50 | | 12.50 | 2.50 |
| 11 | | | | 3.00 | | 11.00 | 3.25 | | 6.75 | |
| 12 | | | | 1.00 | 10.25 | 10.00 | | | 2.75 | |
| 13 | | | | 0.75 | | 8.00 | 3.25 | 0.75 | 9.75 | 1.50 |
| 14 | | | | | | | | 3.25 | 1.00 | |
| Total | | 124.00 | 4.50 | 18.00 | 16.50 | 45.50 | 15.00 | 8.75 | 67.25 | 12.75 |

**Table II .** ET5 Operating Time Distribution(hours)

| Nº | Description | Length(m) | Bottom Measured Depth(m) |
|---|---|---|---|
| 46 | Casing Joint(N80) (*)<br>(cut 50 cm above GL) | 13.04<br>(6.94) | - 6.44 |
| 45 | Casing Joint(N80) (*) | 13.34 | - 19.78 |
| 44 | Casing Joint(N80) (*) | 13.13 | - 32.91 |
| 43 | Casing Joint(N80) (*) | 13.31 | - 46.22 |
| 42 | Casing Joint(N80) nº 44 | 13.67 | - 53.89 |
| 41 | Casing Joint(N80) nº 42 | 11.25 | - 71.14 |
| 40 | Casing Joint(N80) nº 40 | 13.50 | - 84.64 |
| 39 | Casing Joint(N80) nº 39 | 13.47 | - 98.11 |
| 38 | Casing Joint(N80) nº 38 | 13.67 | - 111.78 |
| 37 | Casing Joint(N80) nº 37 | 13.38 | - 125.16 |
| 36 | Casing Joint(N80) nº 36 | 13.41 | - 138.57 |
| 35 | Casing Joint(N80) nº 35 | 13.66 | - 152.23 |
| 34 | Casing Joint(N80) nº 34 | 13.64 | - 165.87 |
| 33 | Casing Joint(N80) nº 33 | 13.66 | - 179.53 |
| 32 | Casing Joint(N80) nº 32 | 13.62 | - 193.15 |
| 31 | Casing Joint(N80) nº 31 | 13.64 | - 206.79 |
| 30 | Casing Joint(N80) nº 30 | 13.66 | - 220.45 |
| 29 | Casing Joint(N80) nº 29 | 13.64 | - 234.09 |
| 28 | Casing Joint(N80) nº 28 | 12.09 | - 246.18 |
| 27 | Casing Joint(N80) nº 27 | 13.63 | - 259.81 |
| 26 | Casing Joint(N80) nº 26 | 13.67 | - 273.48 |
| 25 | Casing Joint(N80) nº 25 | 13.64 | - 287.12 |
| 24 | Casing Joint(N80) nº 24 | 13.29 | - 300.41 |
| 23 | Casing Joint(N80) nº 23 | 13.36 | - 313.77 |
| 22 | Casing Joint(N80) nº 22 | 13.66 | - 327.43 |
| 21 | Casing Joint(N80) nº 21 | 13.68 | - 341.11 |
| 20 | Casing Joint(N80) nº 20 | 13.66 | - 354.77 |
| 19 | Casing Joint(N80) nº 19 | 13.33 | - 368.10 |
| 18 | Casing Joint(N80) nº 18 | 13.68 | - 381.78 |
| 17 | Casing Joint(N80) nº 17 | 13.67 | - 395.45 |
| 16 | Casing Joint(N80) nº 16 | 13.60 | - 409.05 |
| 15 | Casing Joint(N80) nº 15 | 13.68 | - 422.73 |
| 14 | Casing Joint(N80) nº 14 | 13.61 | - 436.34 |
| 13 | Casing Joint(N80) nº 13 | 13.66 | - 450.00 |
| 12 | Casing Joint(N80) nº 12 | 13.59 | - 463.59 |
| 11 | Casing Joint(N80) nº 11 | 13.68 | - 477.27 |
| 10 | Casing Joint(N80) nº 10 | 13.40 | - 490.67 |
| 9 | Casing Joint(N80) nº 9 | 12.22 | - 502.89 |
| 8 | Casing Joint(N80) nº 8 | 13.64 | - 516.53 |
| 7 | Casing Joint(N80) nº 5 | 13.63 | - 530.16 |
| 6 | Casing Joint(N80) nº 4 | 13.59 | - 543.75 |
| 5 | Casing Joint(N80) nº 3 | 12.26 | - 556.01 |
| 4 | Float Collar(N80) | 0.41 | - 556.42 |
| 3 | Casing Joint(Inconel 625) nº 2 | 10.01 | - 566.43 |
| 2 | Casing Joint(Inconel 625) nº 1 | 10.01 | - 576.44 |
| 1 | Float Shoe(Inconel 625) | 0.46 | - 576.90 |

**Table III .** 9.5/8" Casing String Components of ET5
(Depth relative to Ground Level)

(*) Casing joints in excess of previous ET4 casing installation

| Day | Drilling / Coring | Stop/Main-tenance | Mud Prep./ Circulation | Casing Setting | Cementing / Waiting | Plug/Shoe Drilling + Reaming | Survey + Logging | Rig Manoeuvre | Others |
|---|---|---|---|---|---|---|---|---|---|
| 1 VERT. | 16.50 | | 0.50 | 0.50 | | | | 2.50 | 4.00 |
| 2 | 1.75 | | 0.50 | 1.00 | 16.00 | 2.75 | | 2.00 | |
| 3 | 16.00 | | 0.50 | | | | | 7.50 | |
| 4 REL. | 15.00 | | | | | | 0.50 | 8.50 | |
| 5 | 18.50 | | 1.25 | | | | 1.00 | 3.25 | |
| 6 | 11.25 | | 1.50 | | | | 0.25 | 9.25 | 1.75 |
| 7 | 8.25 | | 1.25 | | | 1.75 | | 12.50 | 0.25 |
| 8 | | | 0.75 | 5.25 | 12.00 | | 4.00 | 0.50 | 1.50 |
| 9 | | | 0.50 | | 4.00 | 9.50 | | 7.25 | 2.75 |
| 10 | | | | | | | 4.50 | 1.00 | 0.50 |
| Total | 87.25 | 0.00 | 6.75 | 6.75 | 32.00 | 14.00 | 10.25 | 54.25 | 10.75 |

**Table IV .** ET6 Operating Time Distribution(hours)

| Nº | Description | Length(m) | Bottom Measured Depth(m) |
|---|---|---|---|
| 47 | Casing Head | 0.14 | 0.26 |
| 46 | BT Pin - BT Pin Joint | 0.32 | -0.06 |
| 45 | X-over New Vam/BT (*) | 0.88 | - 0.94 |
| 44 | Casing Joint(N80) nº 41 (*) | 13.13 | - 14.07 |
| 43 | Pup Joint(N80) (*) | 2.98 | - 17.05 |
| 42 | Casing Joint(N80) nº 40 (*) | 13.52 | - 30.57 |
| 41 | Casing Joint(N80) nº 39 (*) | 13.54 | - 44.11 |
| 40 | Casing Joint(N80) nº 38 (*) | 13.53 | - 57.64 |
| 39 | Casing Joint(N80) nº 37 (*) | 13.48 | - 71.12 |
| 38 | Casing Joint(N80) nº 36 (*) | 13.54 | - 84.66 |
| 37 | Casing Joint(N80) nº 35 (*) | 13.52 | - 98.18 |
| 36 | Casing Joint(N80) nº 34 (*) | 13.36 | - 111.54 |
| 35 | Casing Joint(N80) nº 33 (*) | 13.53 | - 125.07 |
| 34 | Casing Joint(N80) nº 32 (*) | 13.51 | - 138.58 |
| 33 | Casing Joint(N80) nº 31 (*) | 13.53 | - 152.11 |
| 32 | Casing Joint(N80) nº 30 (*) | 13.47 | - 165.58 |
| 31 | Casing Joint(N80) nº 29 (*) | 13.52 | - 179.10 |
| 30 | Casing Joint(N80) nº 28 (*) | 13.42 | - 192.52 |
| 29 | Casing Joint(N80) nº 27 (*) | 13.45 | - 205.97 |
| 28 | Casing Joint(N80) nº 26 (*) | 13.52 | - 219.49 |
| 27 | Casing Joint(N80) nº 25 (*) | 13.22 | - 232.71 |
| 26 | Casing Joint(N80) nº 24 (*) | 13.49 | - 246.20 |
| 25 | Casing Joint(N80) nº 23 (*) | 13.50 | - 259.70 |
| 24 | Casing Joint(N80) nº 22 (*) | 13.51 | - 273.21 |
| 23 | Casing Joint(N80) nº 21 (*) | 12.46 | - 285.67 |
| 22 | Casing Joint(N80) nº 20 (*) | 13.50 | - 299.17 |
| 21 | Casing Joint(N80) nº 19 (*) | 13.53 | - 312.70 |
| 20 | Casing Joint(N80) nº 18 (*) | 13.26 | - 325.96 |
| 19 | Casing Joint(N80) nº 17 (*) | 13.22 | - 339.18 |
| 18 | Casing Joint(N80) nº 16 (*) | 13.51 | - 352.69 |
| 17 | Casing Joint(N80) nº 15 (*) | 13.51 | - 366.20 |
| 16 | Casing Joint(N80) nº 14 (*) | 13.42 | - 379.62 |
| 15 | Casing Joint(N80) nº 13 (*) | 13.48 | - 393.10 |
| 14 | Casing Joint(N80) nº 12 (*) | 13.50 | - 406.60 |
| 13 | Casing Joint(N80) nº 11 (*) | 13.49 | - 420.09 |
| 12 | Casing Joint(N80) nº 10 (*) | 13.49 | - 433.58 |
| 11 | Casing Joint(N80) nº 9 (*) | 13.45 | - 447.03 |
| 10 | Casing Joint(N80) nº 8 (*) | 13.52 | - 460.55 |
| 9 | Casing Joint(N80) nº 7 (*) | 13.50 | - 474.05 |
| 8 | Casing Joint(N80) nº 6 (*) | 13.54 | - 487.59 |
| 7 | Casing Joint(N80) nº 5 (*) | 13.34 | - 500.93 |
| 6 | Casing Joint(N80) nº 4 (*) | 13.32 | - 514.25 |
| 5 | Casing Joint(N80) nº 3 (*) | 13.47 | - 527.72 |
| 4 | Float Collar | 0.36 | - 528.08 |
| 3 | Casing Joint(VS22) nº 2 (*) | 12.98 | - 541.06 |
| 2 | Casing Joint(VS22) nº 1 (*) | 12.83 | - 553.89 |
| 1 | Float Shoe | 0.40 | - 554.29 |

**Table V .** 4.1/2" Casing String Components of ET6
(Depth relative to Ground Level)

(*) Casing joints/X-over recovered from the contingency programme of ET4

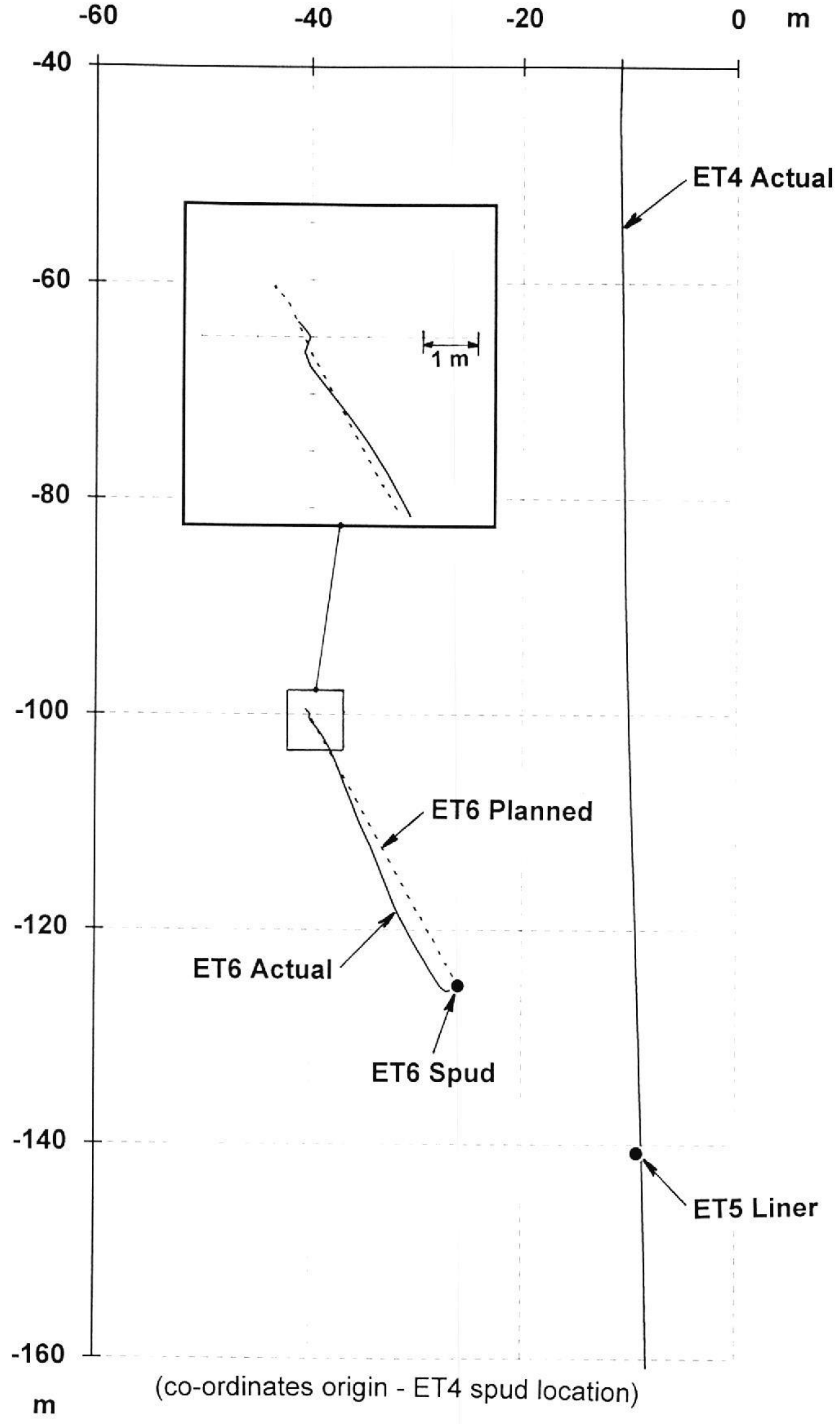


**Figure 10a .** Comparison of ET6 Planned and Actual Trajectories (Horizontal Section in Area of ET4 In-seam Interval)

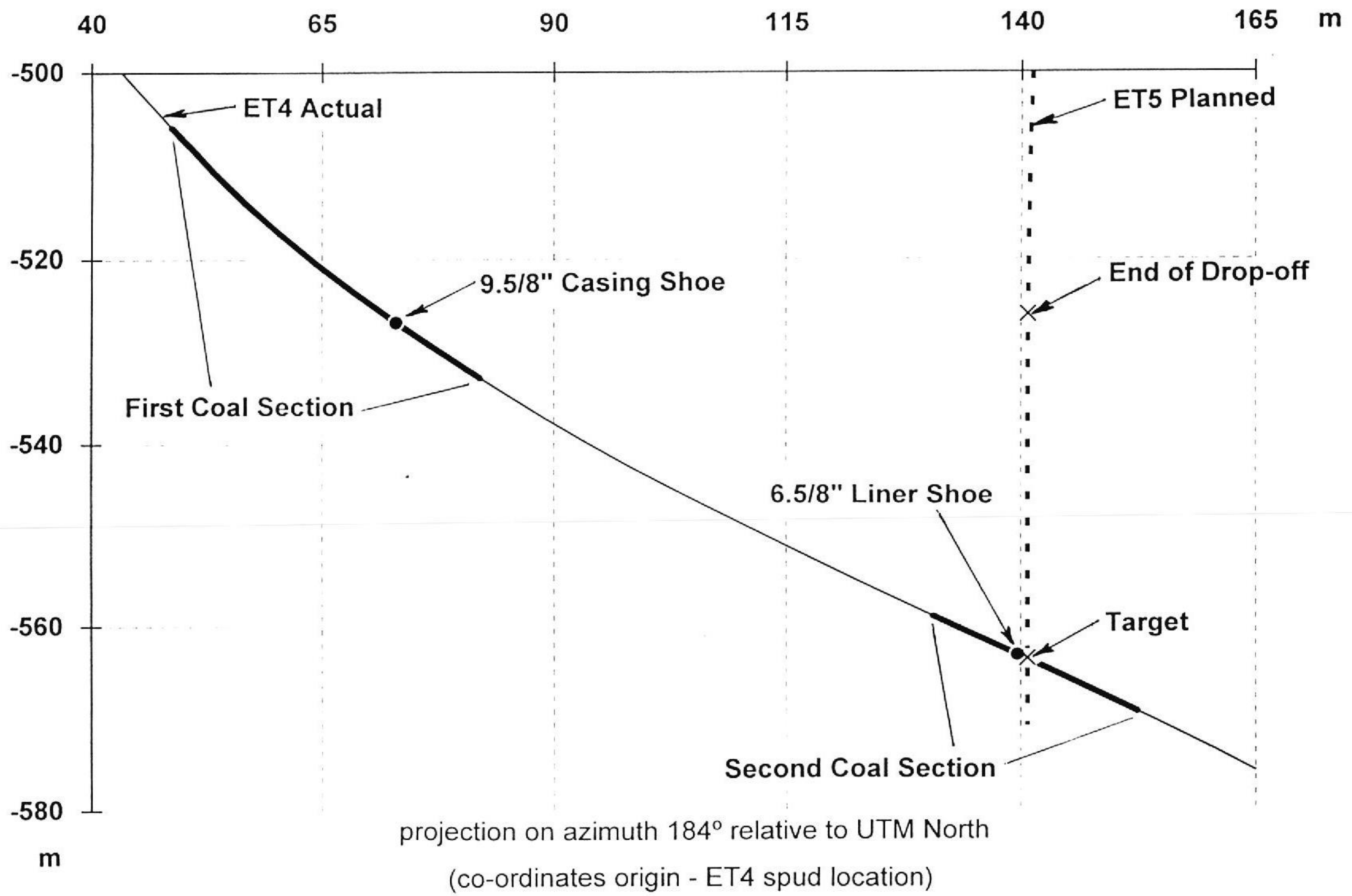


**Figure 1b .** ET5 Planned Trajectory and ET4 Actual Trajectory
(Vertical Section in Area of ET4 In-seam Interval)

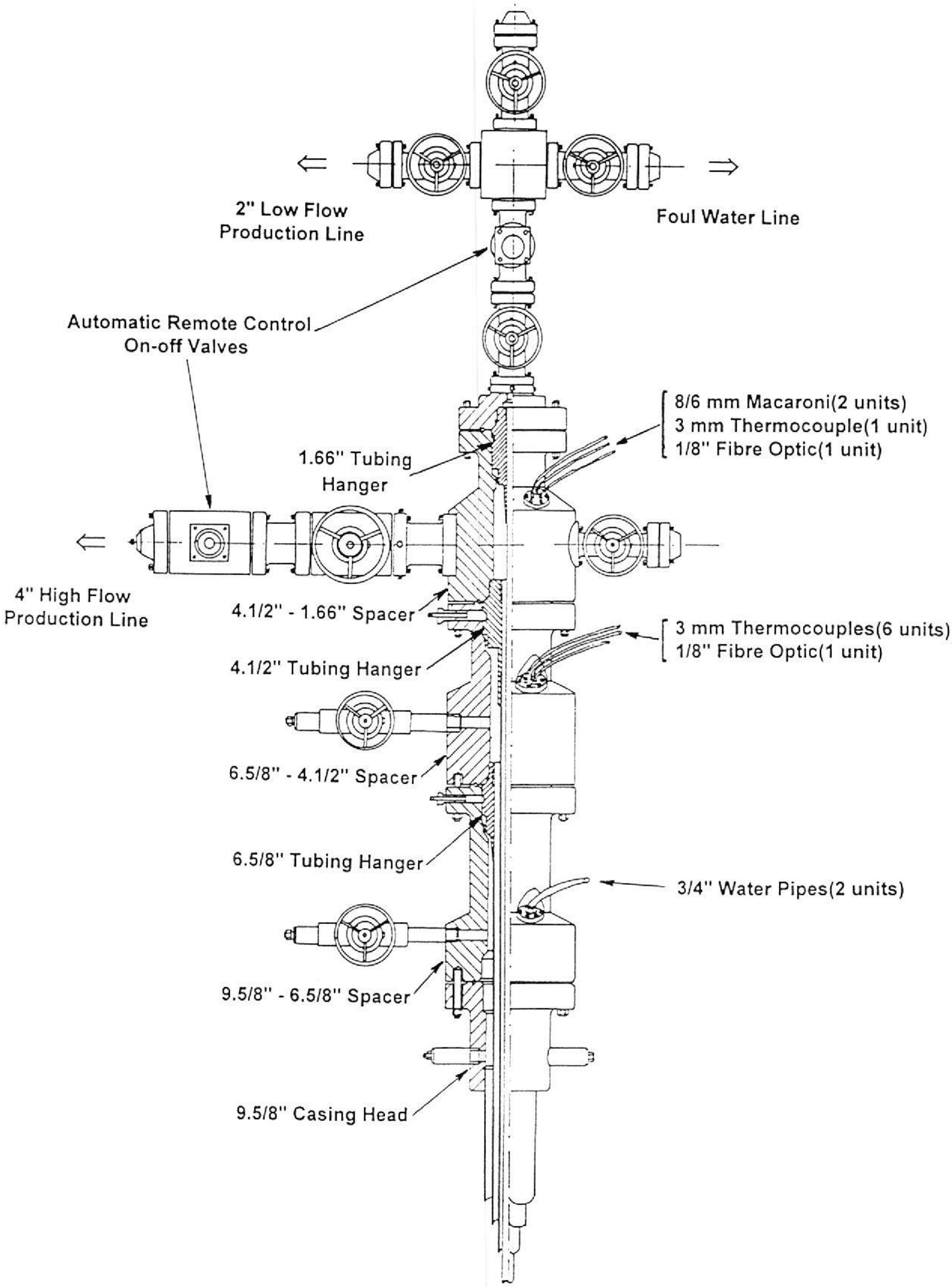


**Figure 2 .** ET5 Wellhead Assembly

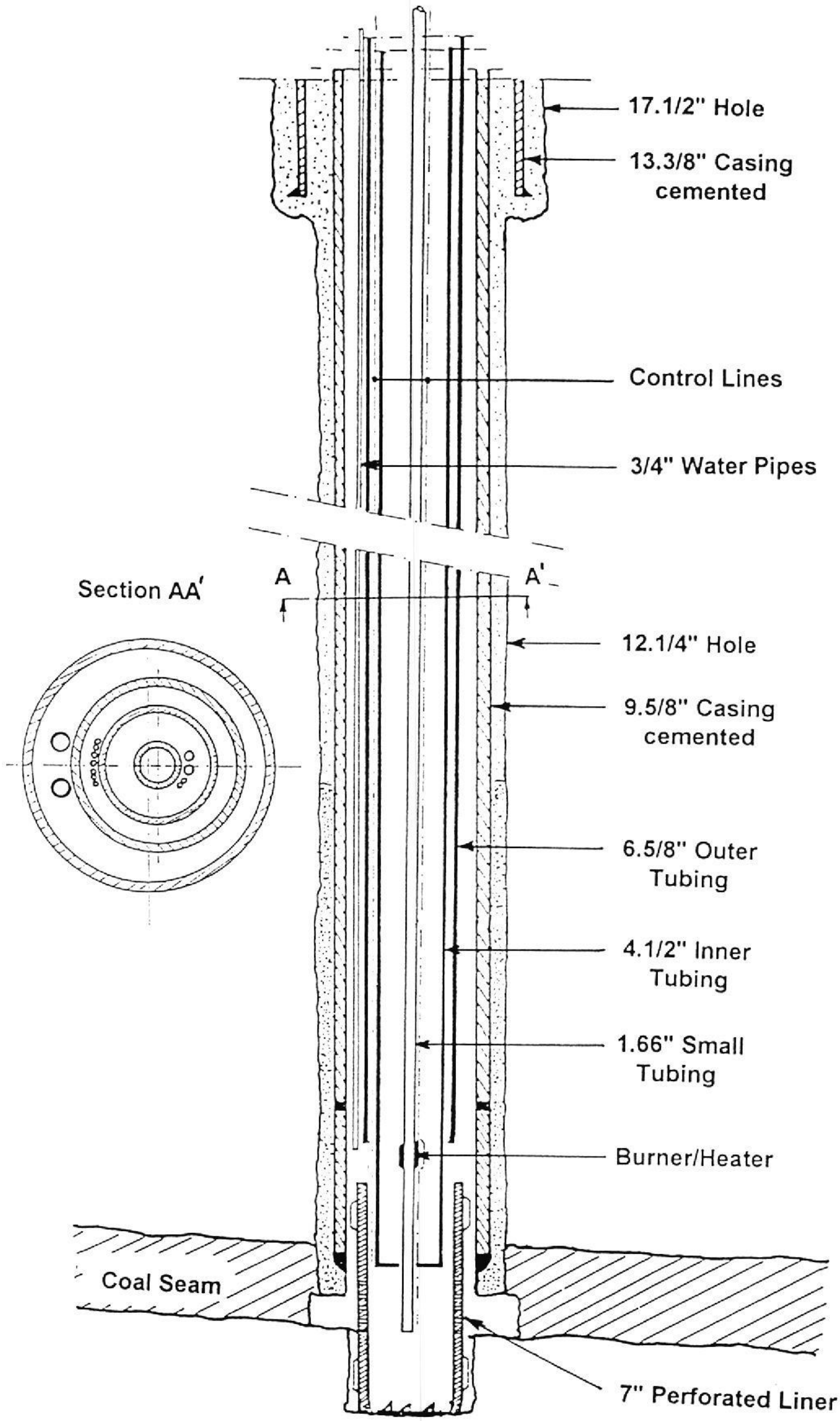


**Figure 3 .** ET5 Well Completion

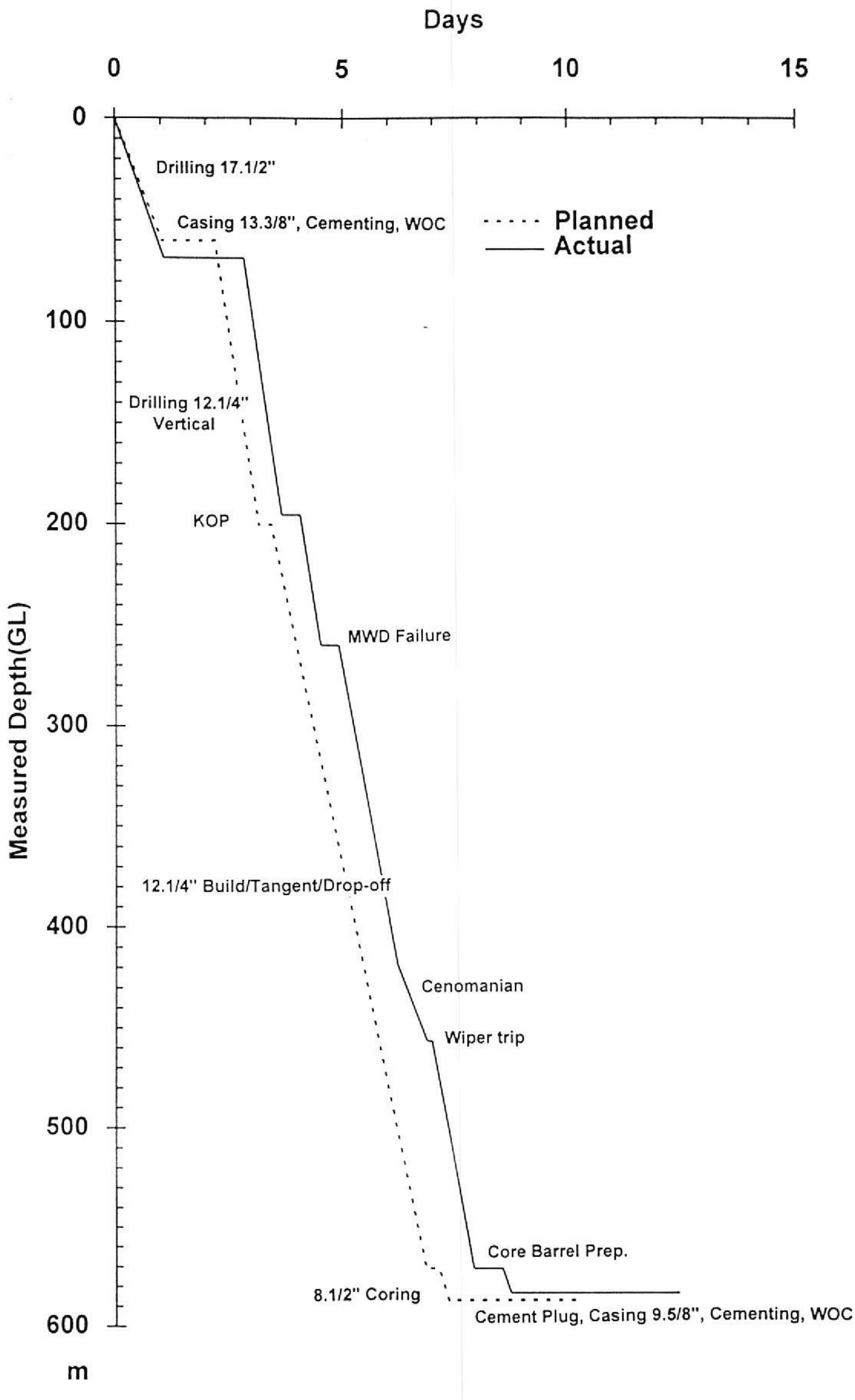


**Figure 4** . ET5 Depth/Time Progress compared to Pre-spud Estimate

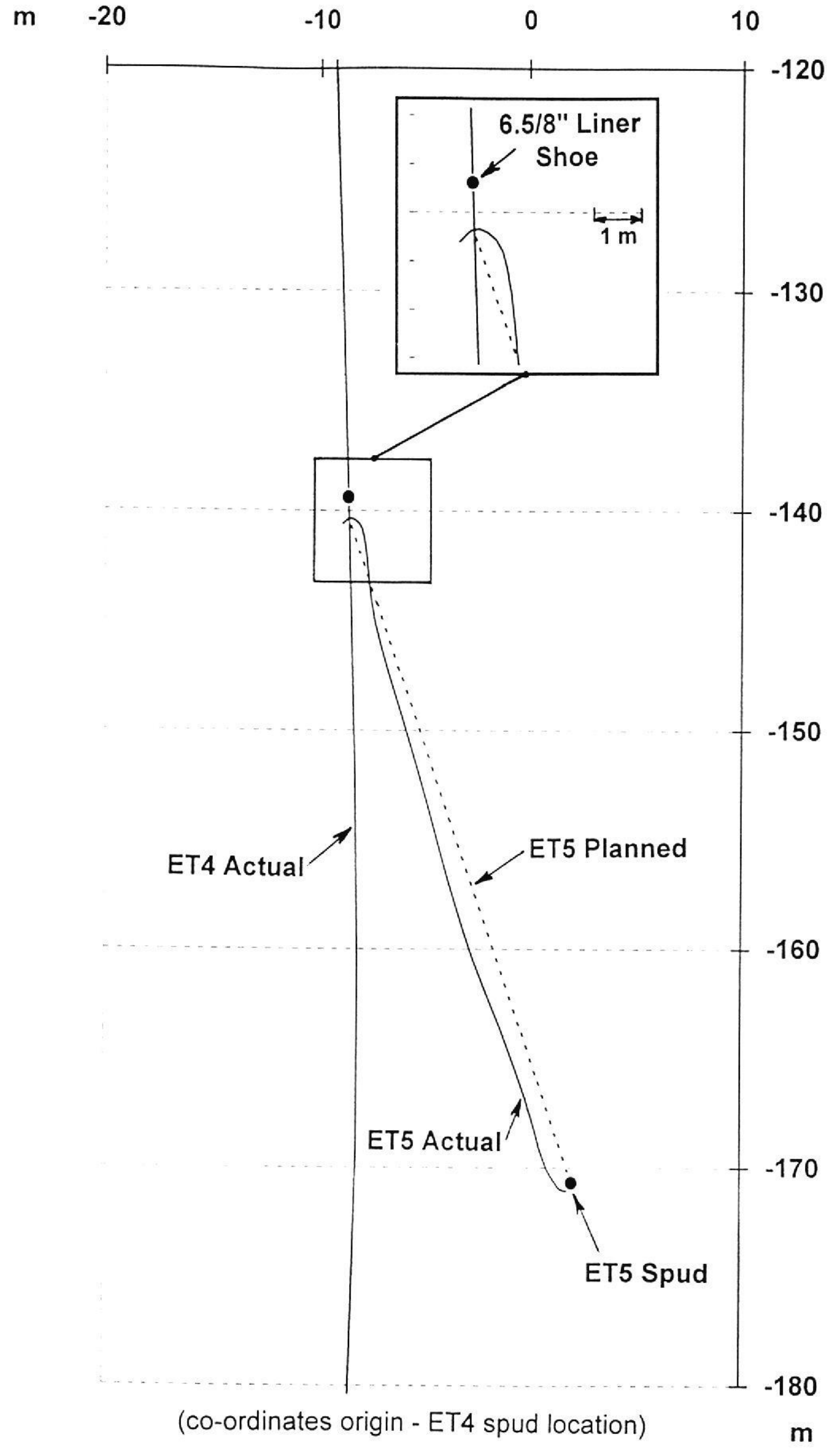


**Figure 5a .** Comparison of ET5 Planned and Actual Trajectories (Horizontal Section in Area of ET4 6.5/8" Liner Shoe)

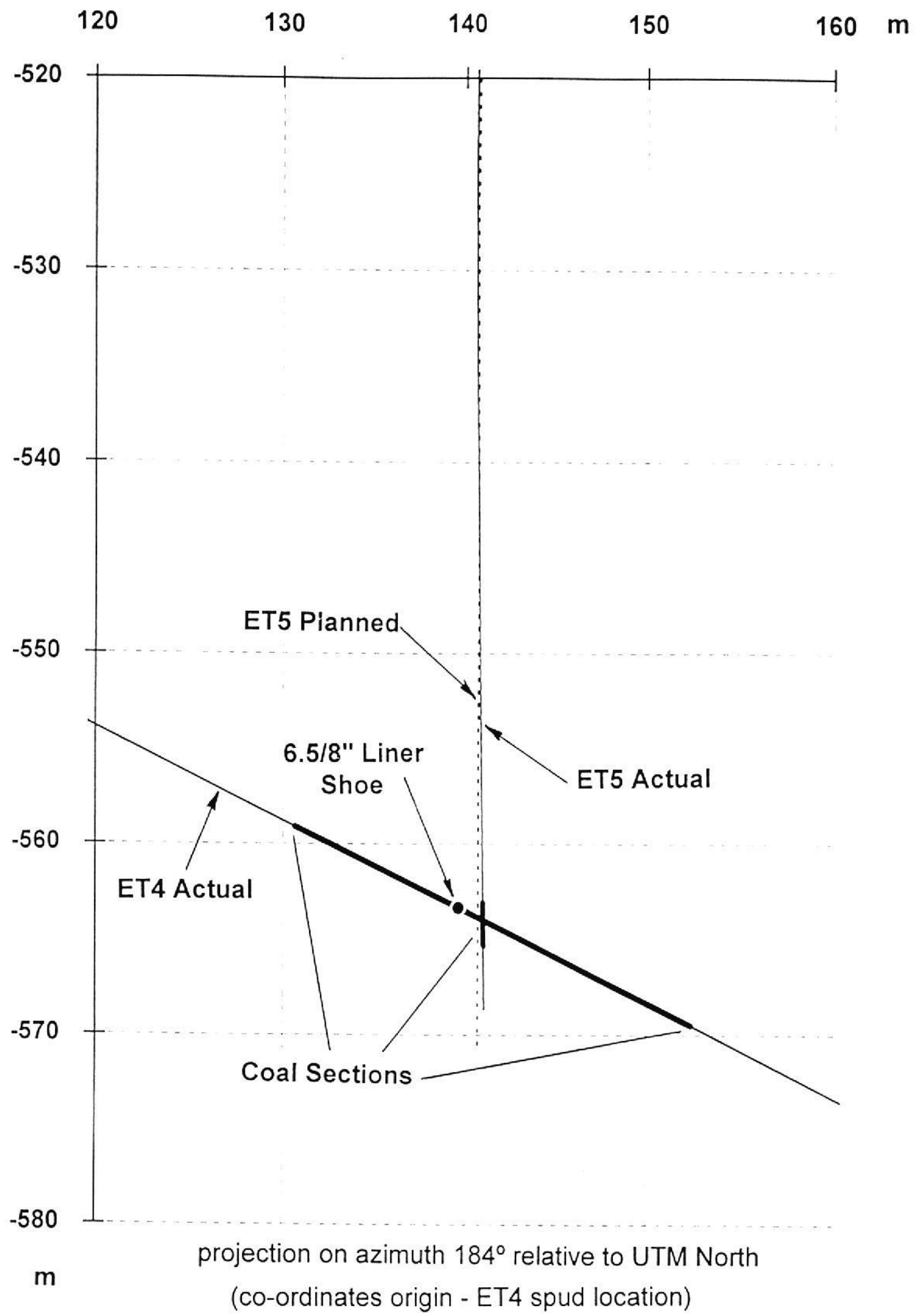


**Figure 5b .** Comparison of ET5 Planned and Actual Trajectories (Vertical Section in Area of ET4 6.5/8" Liner Shoe)

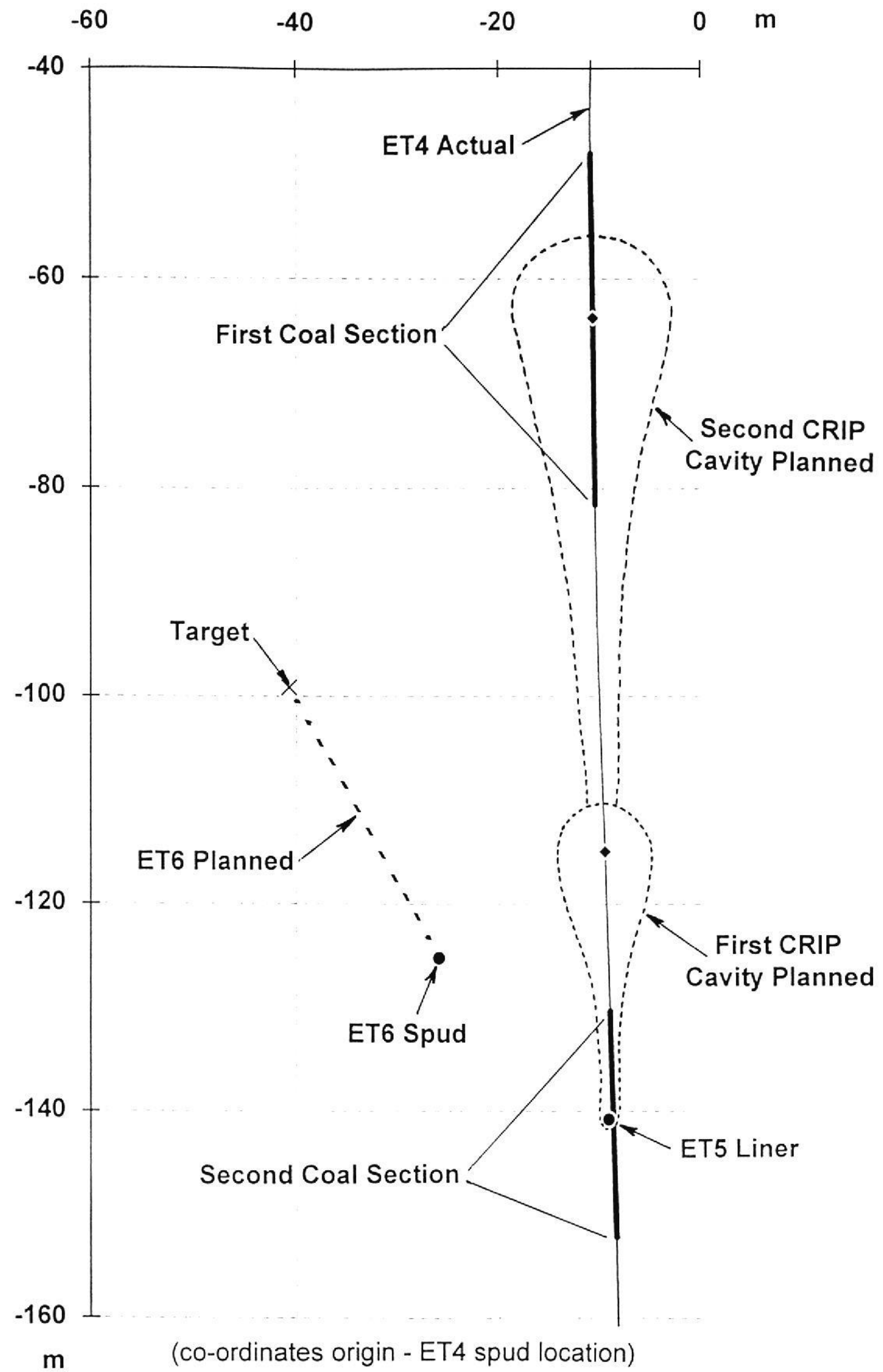


**Figure 6a .** ET6 Planned Trajectory and ET4 Actual Trajectory
(Horizontal Section in Area of ET4 In-seam Interval)

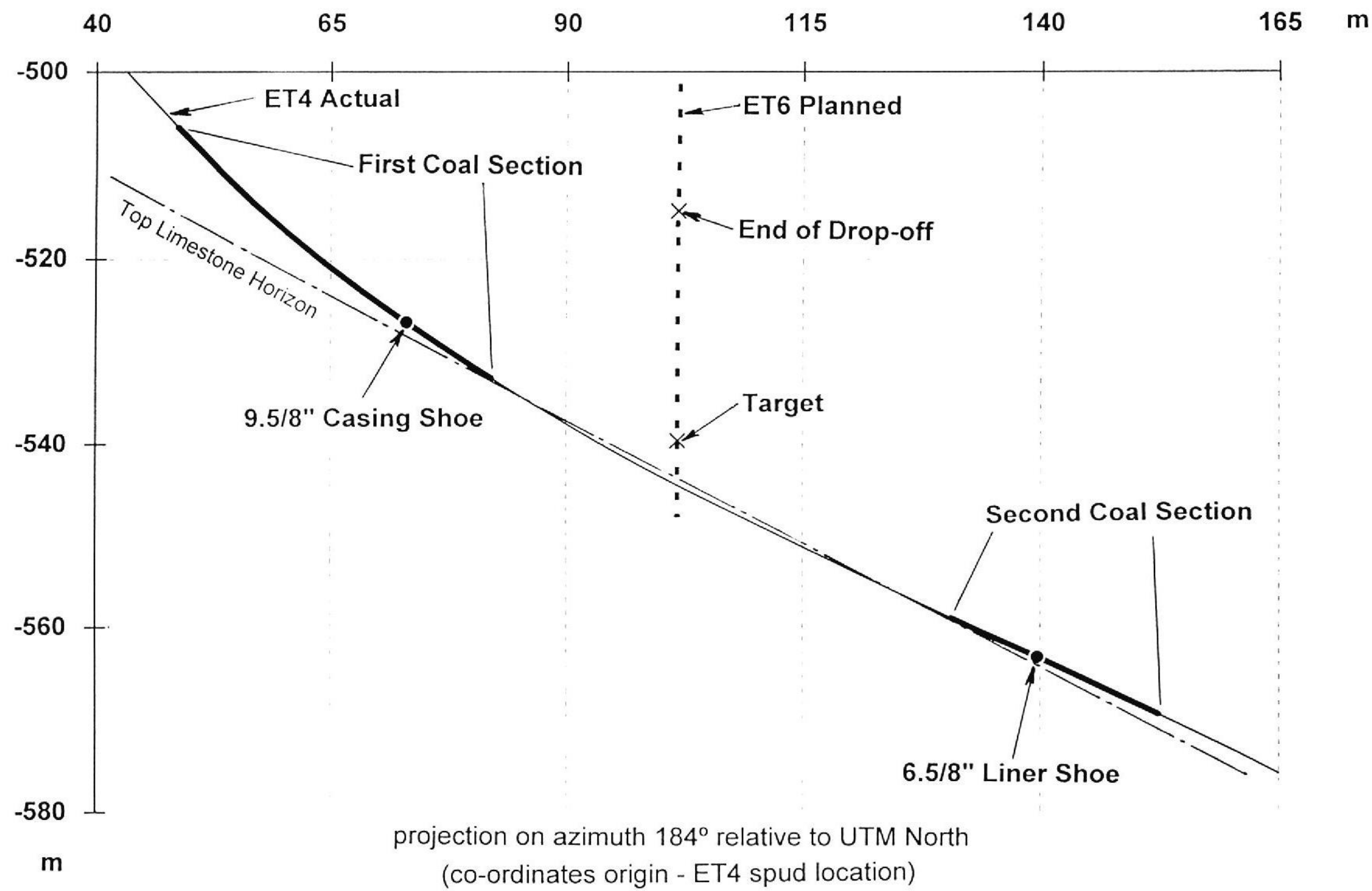


**Figure 6b .** ET6 Planned Trajectory and ET4 Actual Trajectory
(Vertical Section in Area of ET4 In-seam Interval)

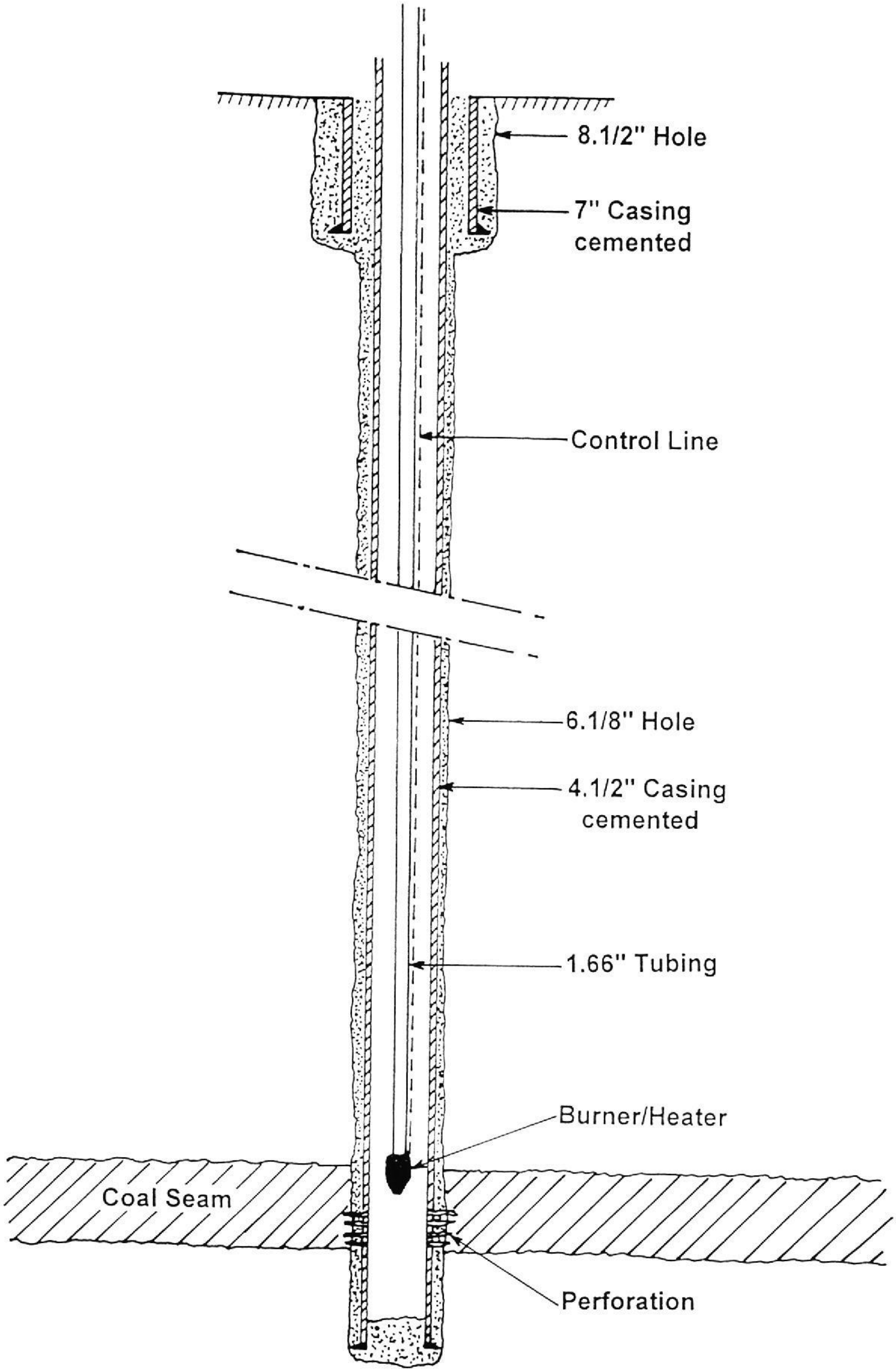


**Figure 7 .** ET6 Well Completion

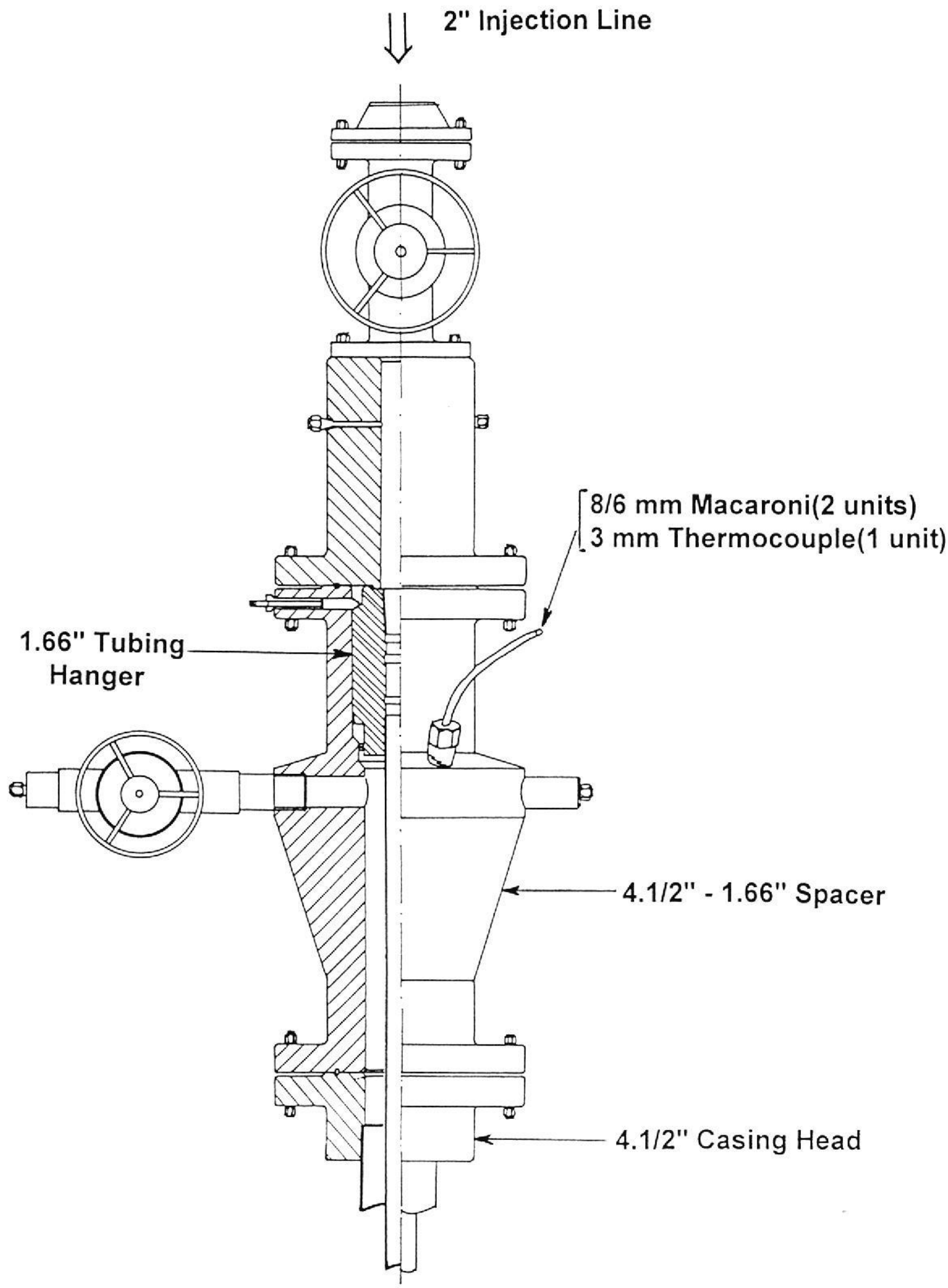


**Figure 8 .** ET6 Wellhead Assembly

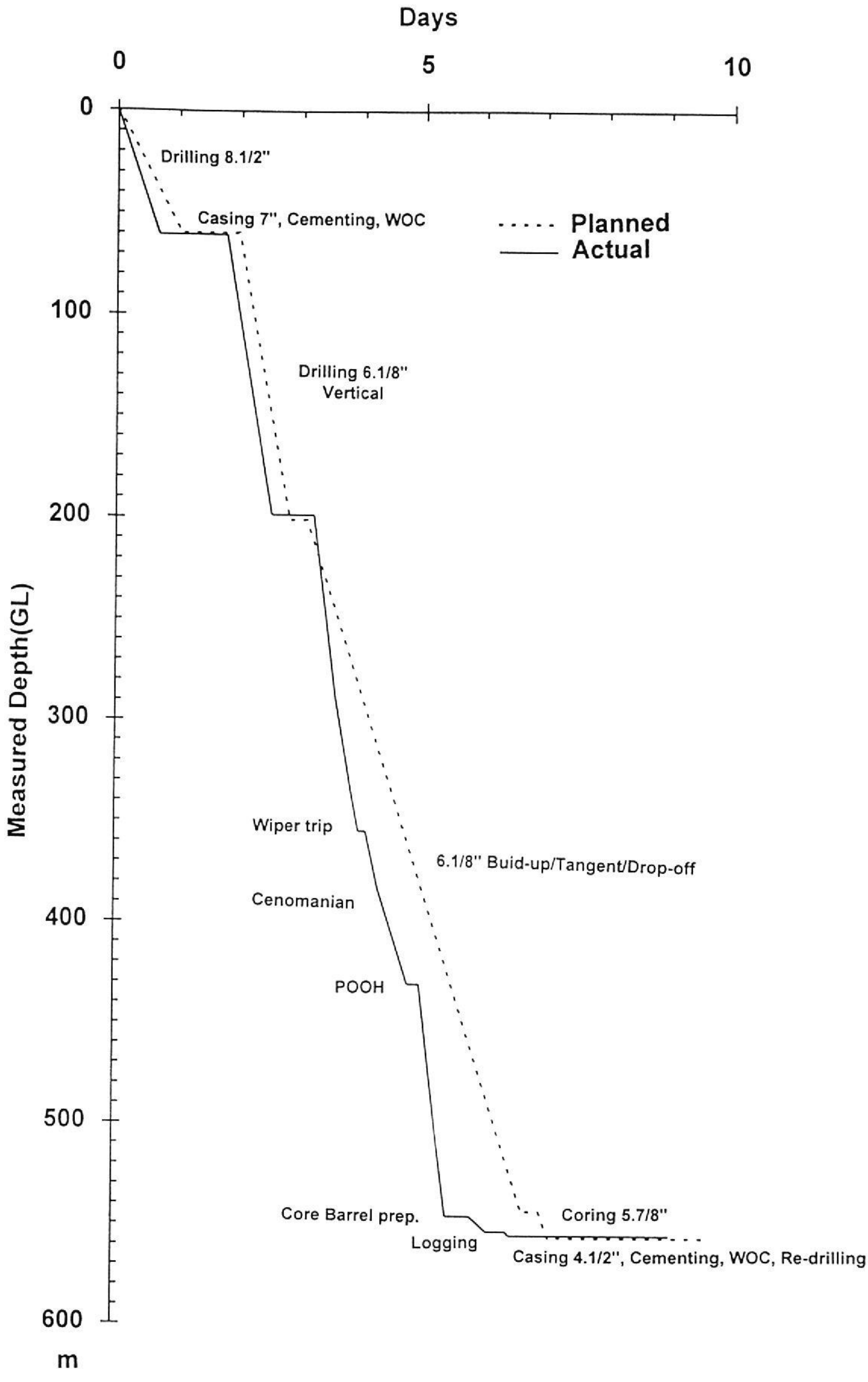


**Figure 9 .** ET6 Depth/Time Progress compared to Pre-spud Estimate

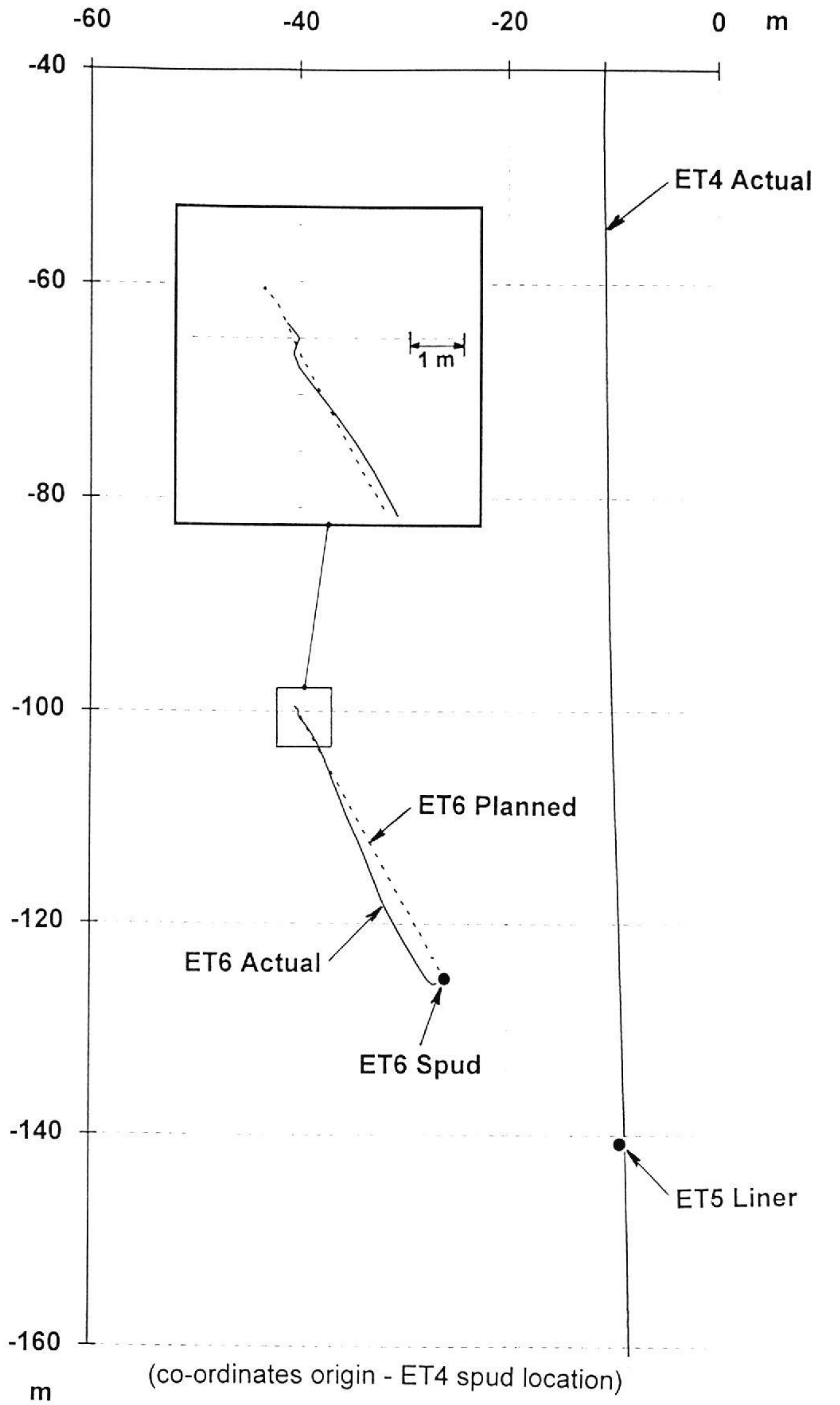


**Figure 10a .** Comparison of ET6 Planned and Actual Trajectories (Horizontal Section in Area of ET4 In-seam Interval)

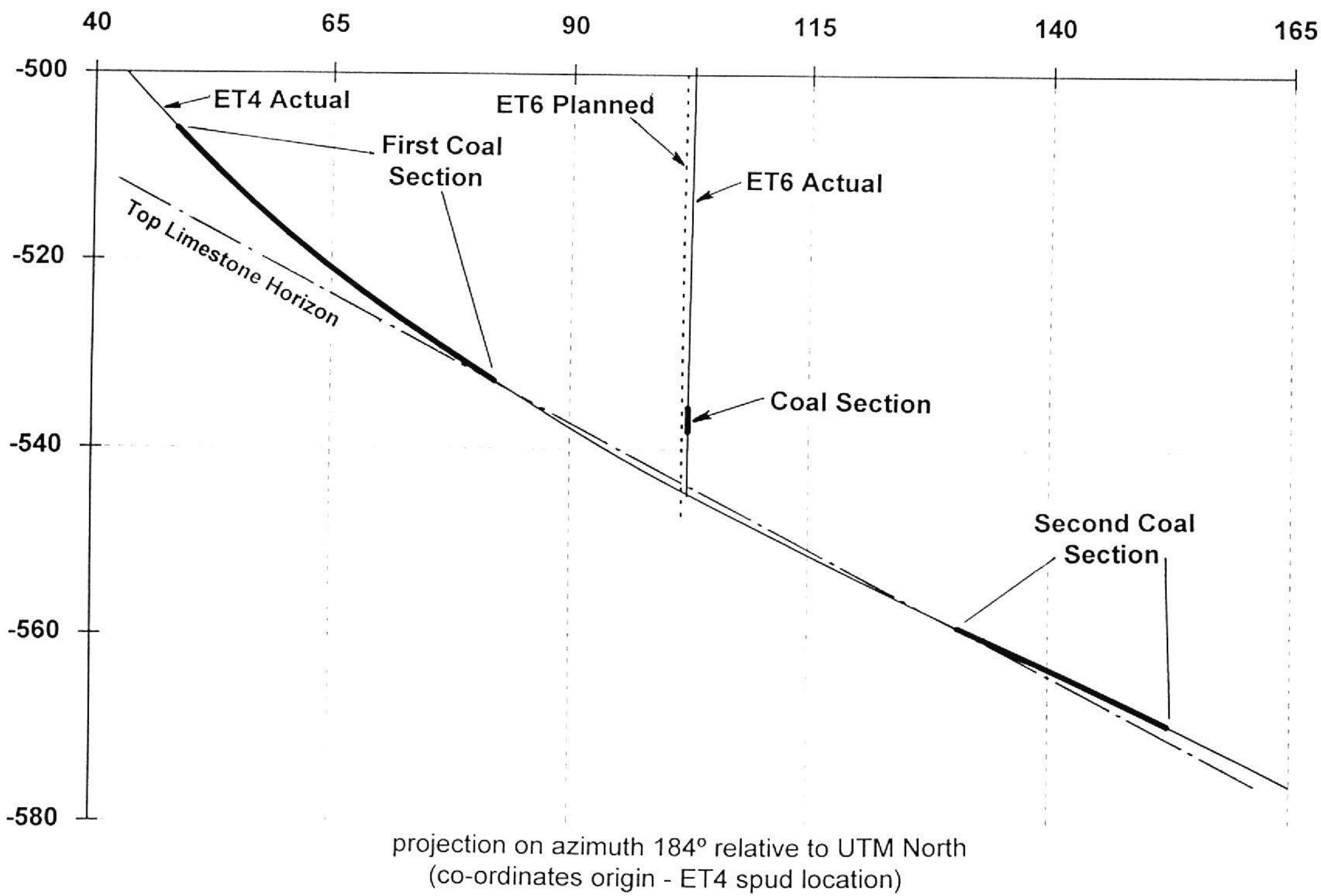


**Figure 10b .** Comparison of ET6 Planned and Actual Trajectories
(Vertical Section in Area of ET4 In-seam Interval)

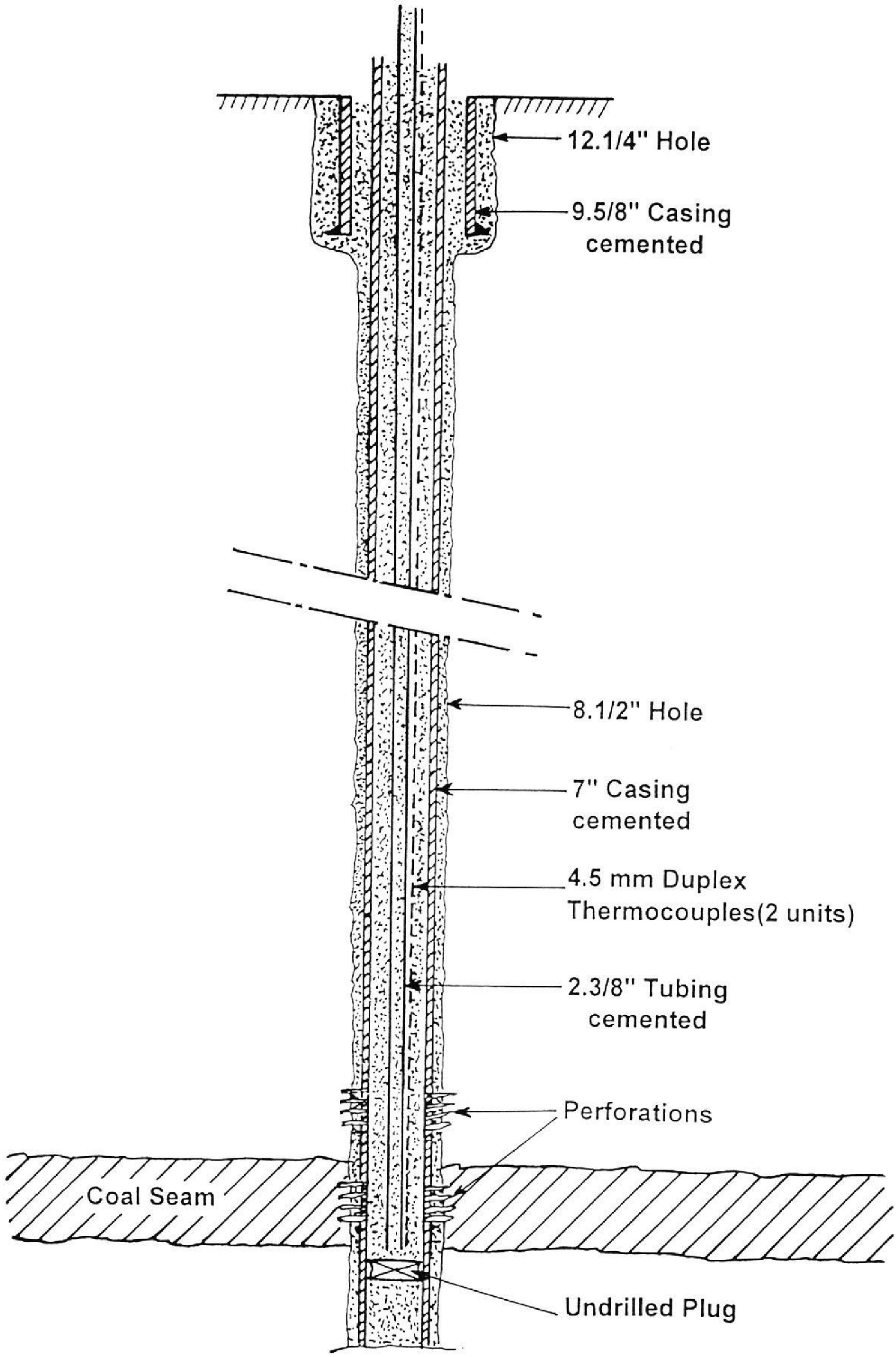


**Figure 11 .** Completion of Vertical Monitoring Well[MW1(ET1)]

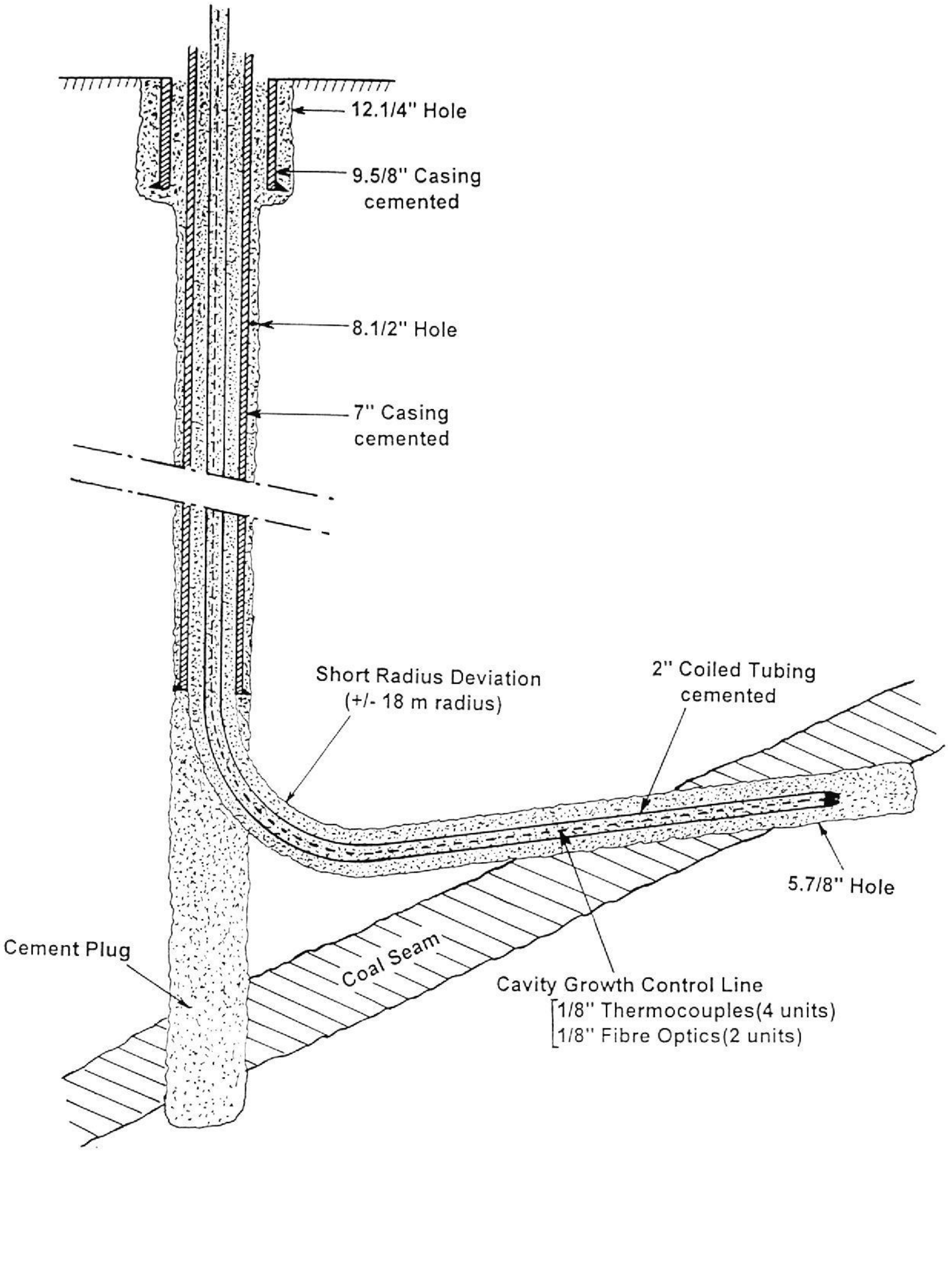


**Figure 12 .** Completion of Deviated Monitoring Well[MW2(ET2)]

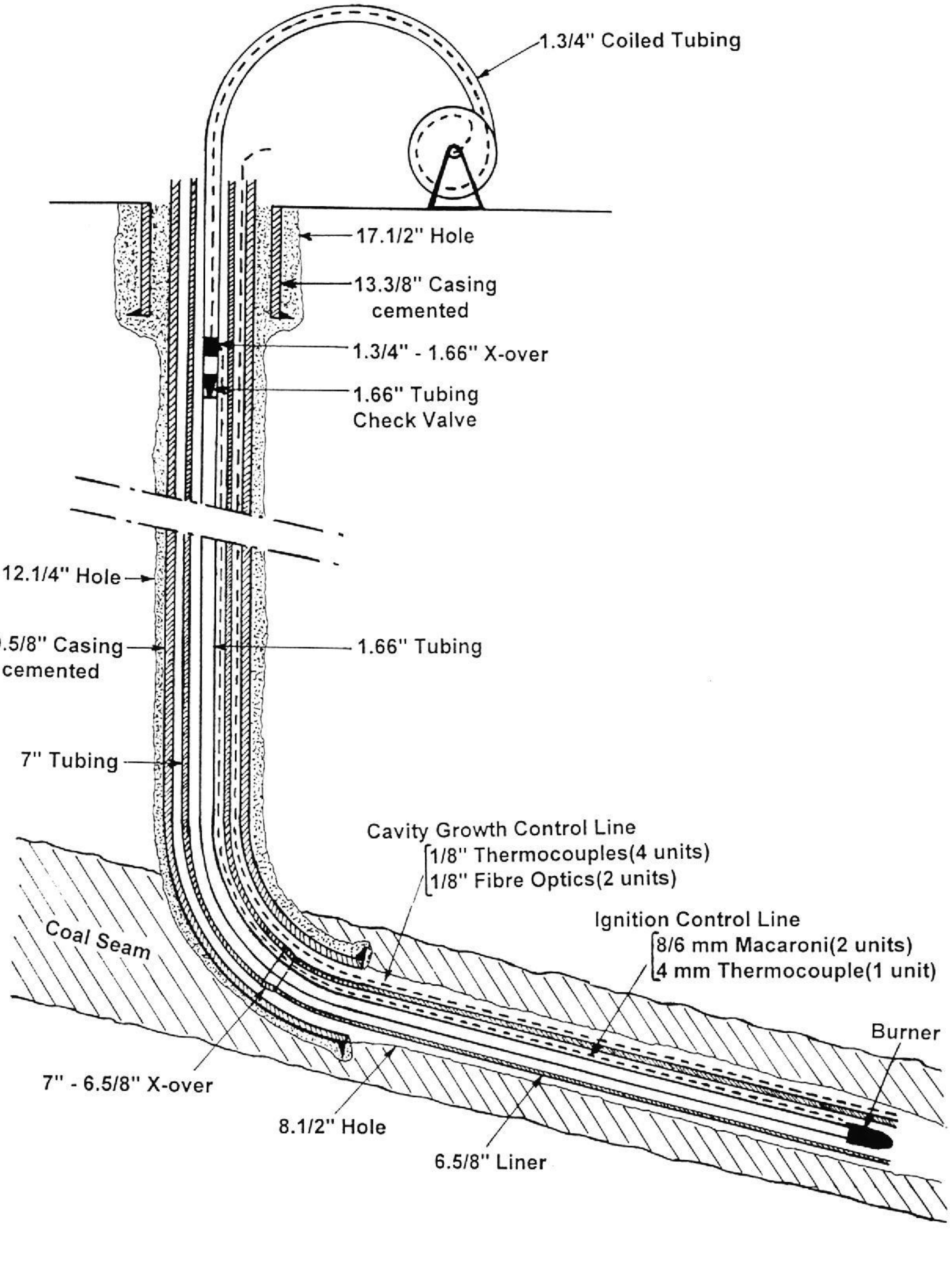


**Figure 13 .** Completion of Deviated Injection Well[IW1(ET4)]

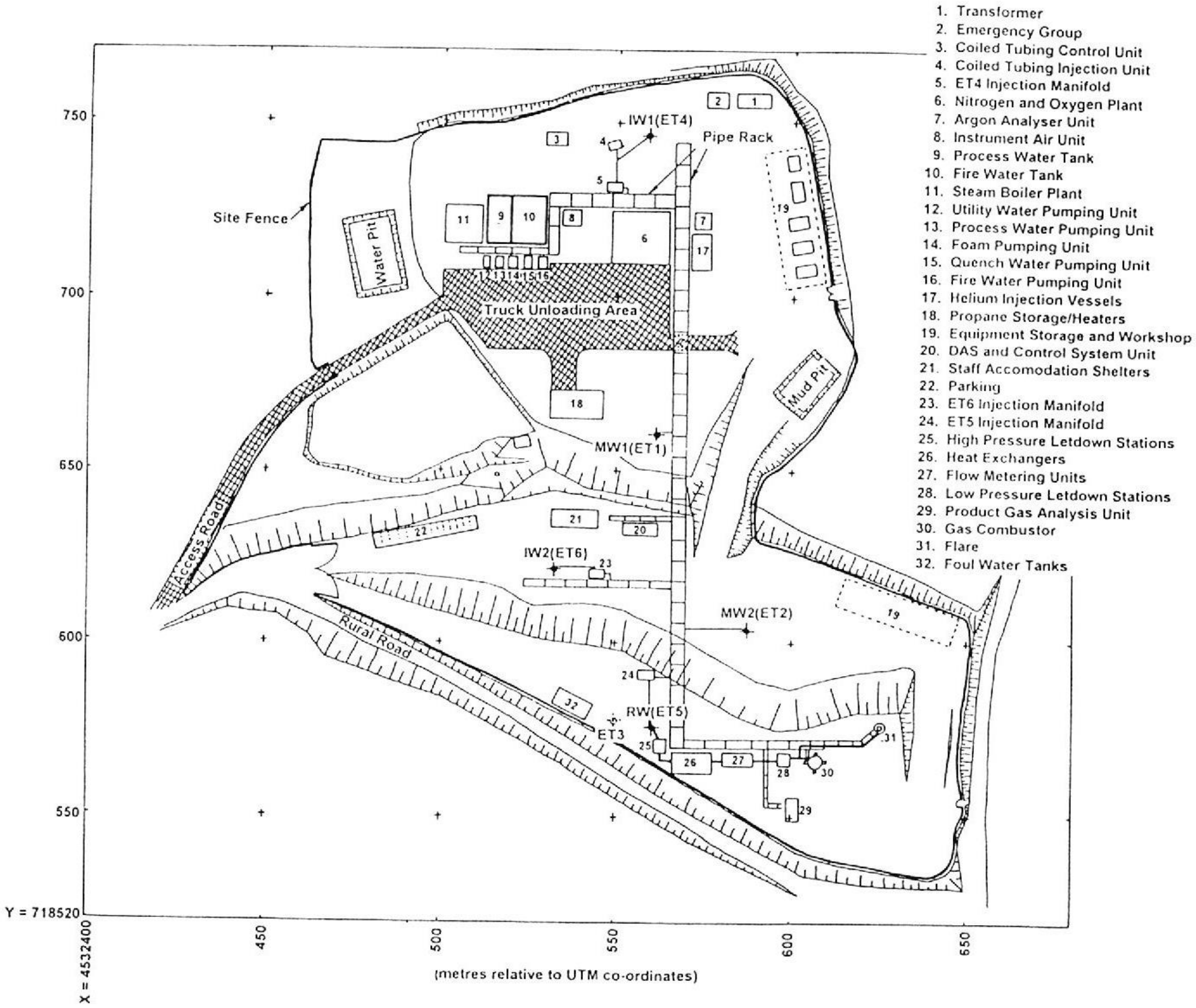


**Figure 14 .** "El Tremedal" Site Layout

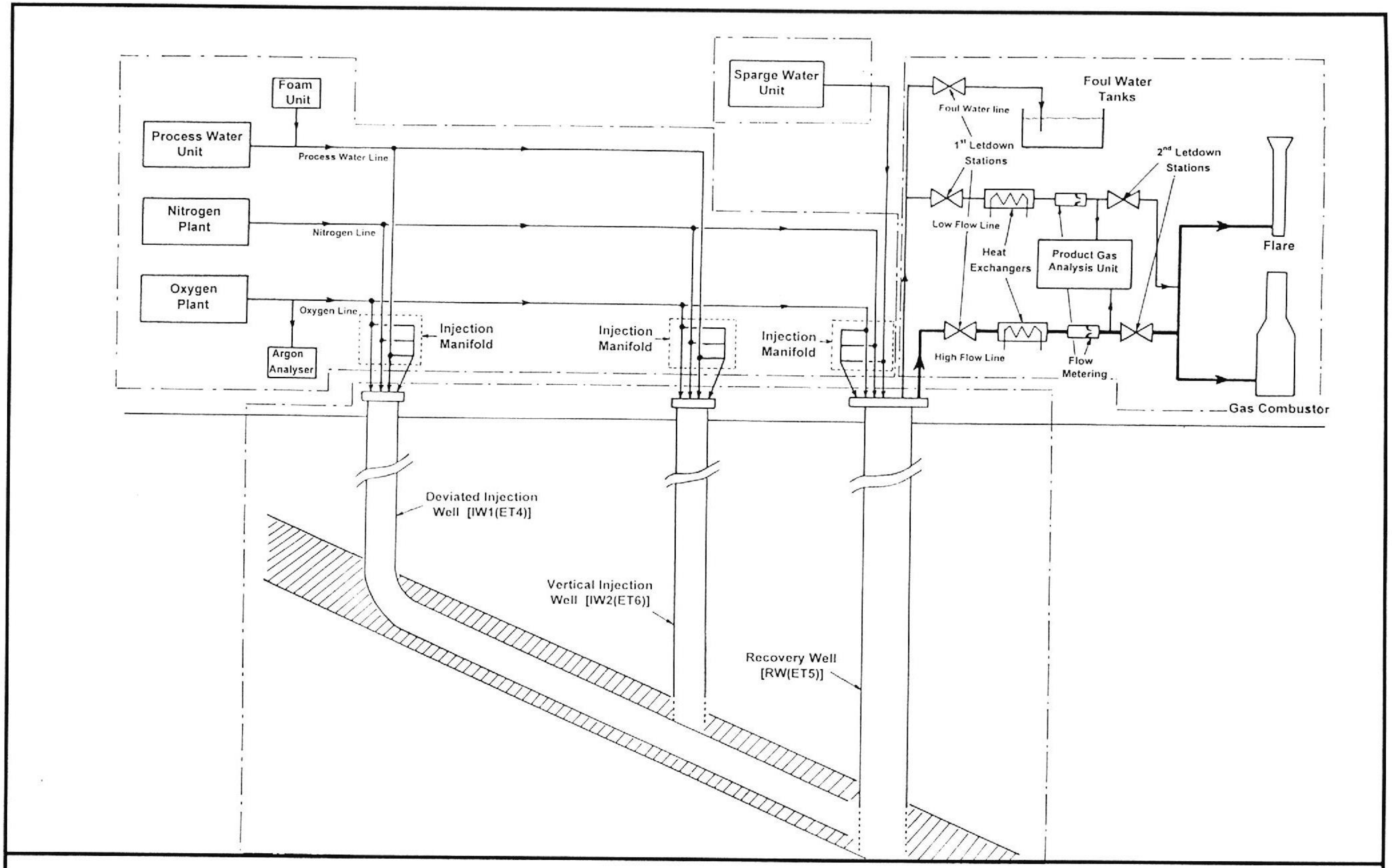


**Figure 15 .** "El Tremedal" UCG Trial - Process Flow Diagram

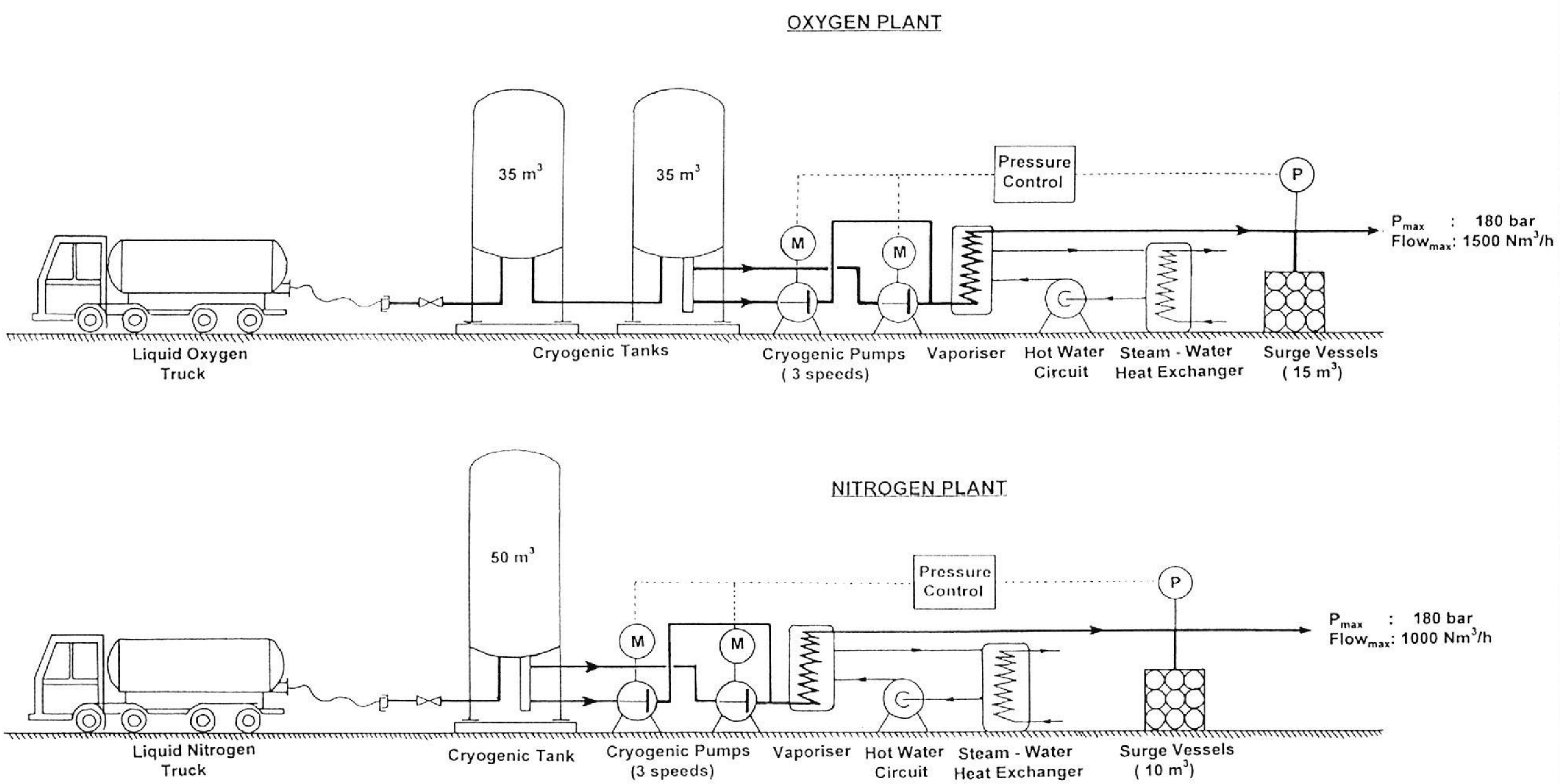


**Figure 16** . "El Tremedal" UCG Trial - Oxygen and Nitrogen Plants

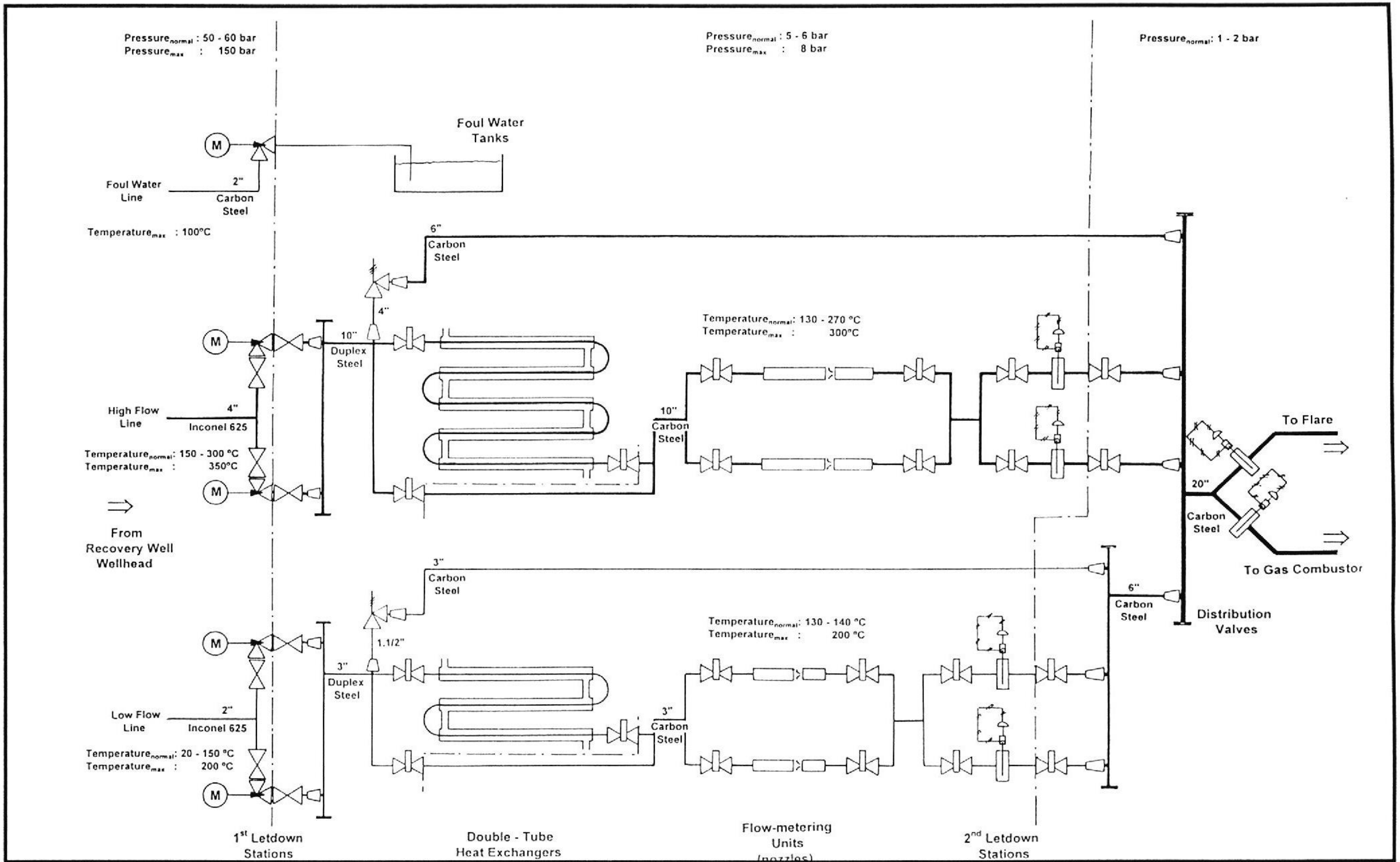


**Figure 17** . "El Tremedal" UCG Trial - Production Line Flow Diagram

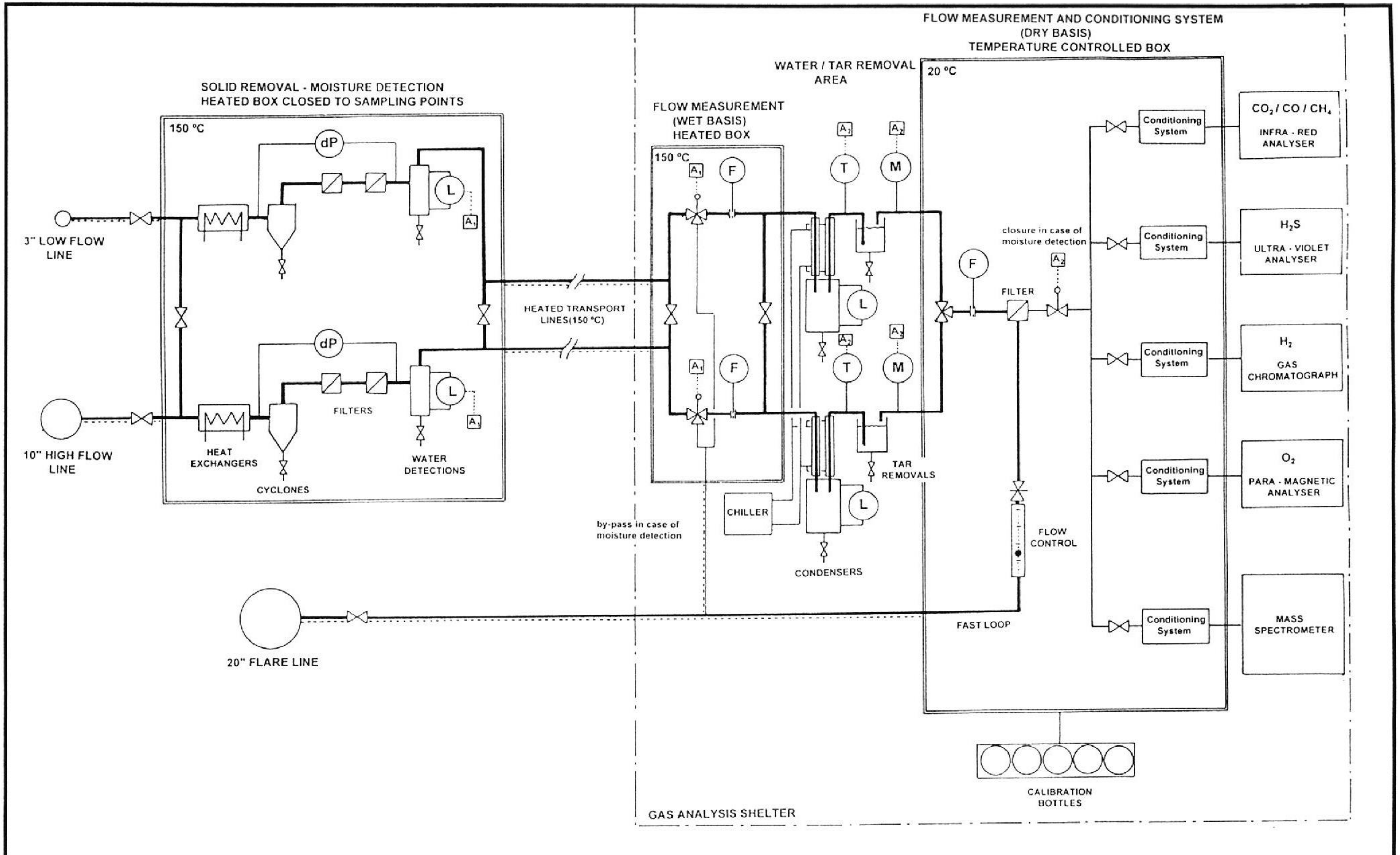


**Figure 18 .** "El Tremedal" UCG Trial - Gas Analysis System Flow Diagram

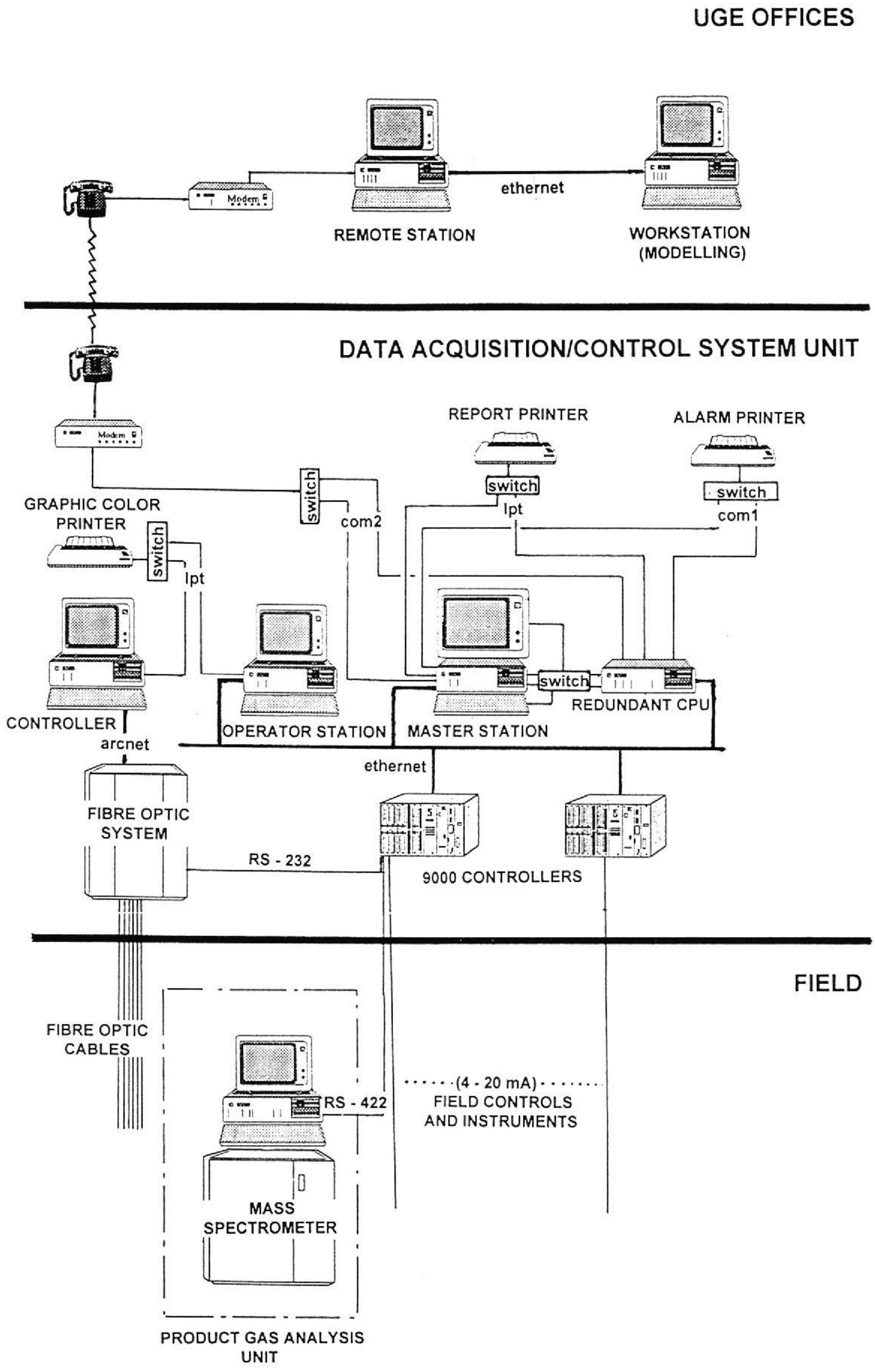


**Figure 19 .** Data Acquisition and Control System Architecture