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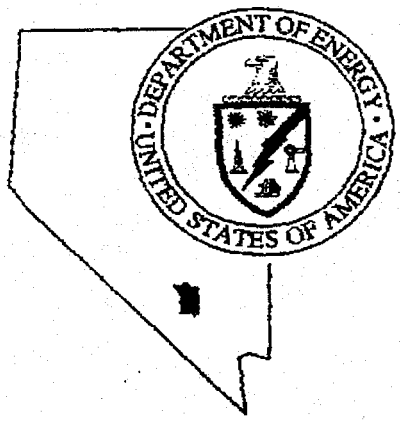

Recompletion Report for BILBY

February 1998

Environmental Restoration
Division

U.S. Department of Energy
Nevada Operations Office

DOE/NV--500
UC-700

RECOMPLETION REPORT FOR BILBY

Prepared for:

DOE Nevada Operations Office
Las Vegas, Nevada

February 1998

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Recompletion Report for BILBY

Approved by: Robert M. Bangerter Jr. Date: 2/26/98
Robert M. Bangerter, Project Manager,
Underground Test Area Subproject

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List of Acronyms and Abbreviations

BN	Bechtel Nevada
cm	Centimeters
DOB	Depth of burial
DOE/NV	U.S. Department of Energy, Nevada Operations Office
ft	Foot (feet)
gal	Gallon(s)
HGU	Hydrogeologic Unit
HP	Horsepower
hrs	Hours
id	Inside diameter
in.	Inch(es)
IT	IT Corporation
m	Meter(s)
m^3	Cubic meters
NTS	Nevada Test Site
od	Outside diameter
pCi/L	PicoCurie(s) per liter
TD	Total depth
UGTA	Underground Test Area
USGS	U.S. Geological Survey
WP	Working Point

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1.0 Introduction

1.1 Project Description

The BILBY recompletion project was conducted in December 1996 and January 1997 for the U.S. Department of Energy, Nevada Operations Office (DOE/NV) in support of the Nevada Environmental Restoration Project at the Nevada Test Site (NTS), Nye County, Nevada. This project is part of the DOE's Underground Test Area (UGTA) subproject at the NTS. The primary UGTA tasks include collecting geological, geophysical, and hydrological data from new and existing wells to define groundwater quality and to determine pathways and rates of groundwater migration at the NTS. A program of drilling or recompleting wells near the sites of selected underground nuclear tests (near-field studies) was implemented as part of the UGTA subproject to obtain site-specific data on the nature and extent of migration of radionuclides produced by an underground nuclear detonation.

The BILBY project is named for the underground nuclear test conducted in Emplacement Hole U-3cn in 1963. The BILBY site is located in Area 3 of the NTS, in the central portion of Yucca Flat (Figures 1-1 and 1-2). The site consists of a collapse sink (centered on the collar of the original emplacement hole) and several wells collared within the sink (Figure 1-3). Two of the wells were recompleted for this project. Postshot Hole U-3cn PS#2 was drilled through the chimney rubble into the explosion cavity to a depth of 793.4 meters (m) (2,603 feet [ft]) soon after the detonation in 1963. Hydrologic Test Hole U-3cn#5 was drilled outside but near the chimney two years after the nuclear test to a total depth (TD) of 923.5 m (3,030 ft).

Data from the original studies in these two wells are not adequate for use in making projections of the present condition of the groundwater system around the BILBY site because of various uncertainties related to the test conditions (low pumped volumes, low gradient) and because of unanswered questions about how radionuclides migrated within fracture systems. Although no rapid or extensive migration of radionuclides was found in the original studies, scientists can not determine the current status with the existing data set (Buddemeier and Isherwood, 1985). However, a large volume of geologic and baseline hydrologic data is available for the BILBY site. Thus, the UGTA Technical Working Group, a committee of experts on NTS geology and the weapons testing program (consisting of DOE, Lawrence Livermore National Laboratory, Los Alamos National Laboratory, and contractor personnel), selected the BILBY site as a near-field study project because important questions about radionuclide migration might be answered

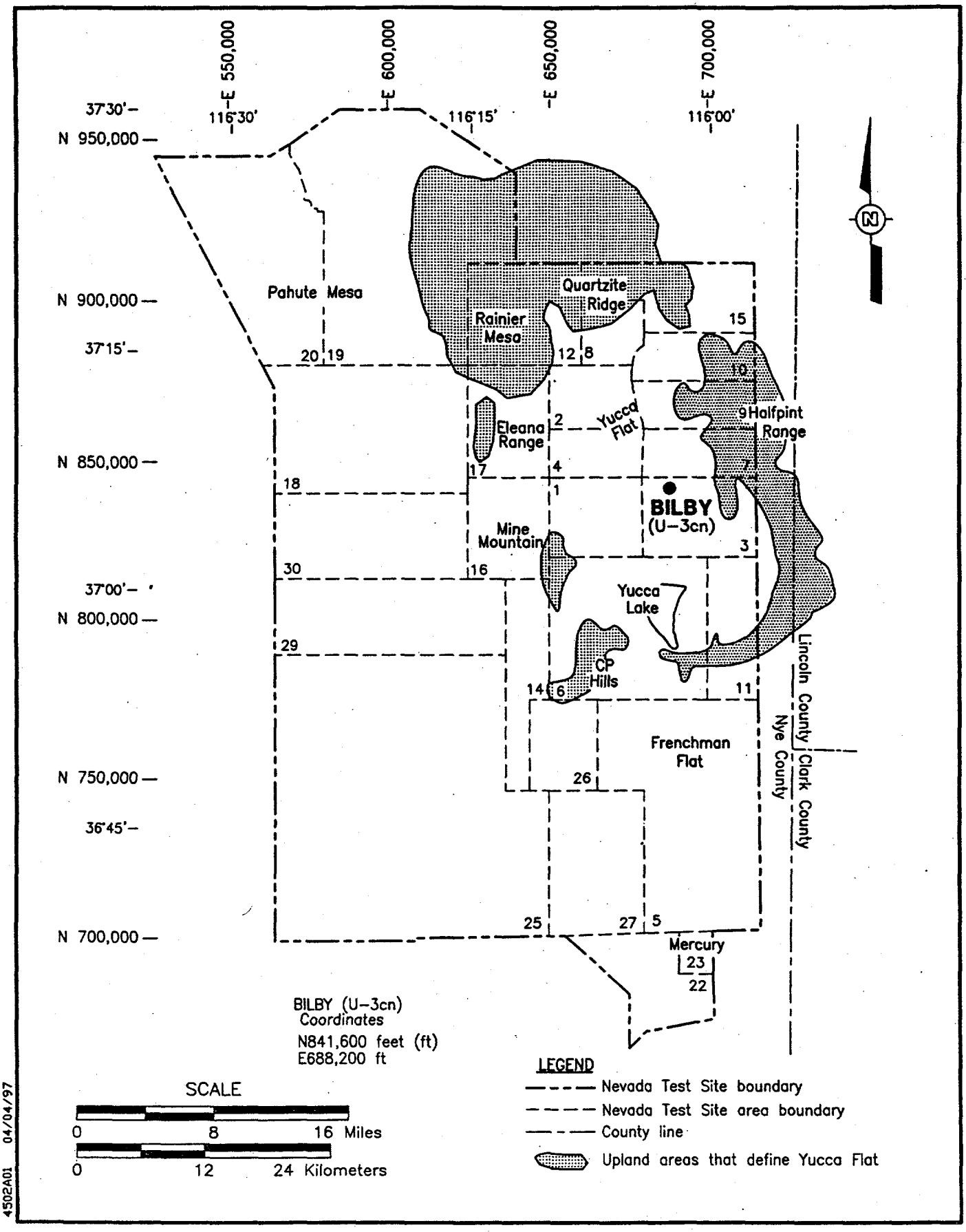

Figure 1-1
Location of BILBY (U-3cn)

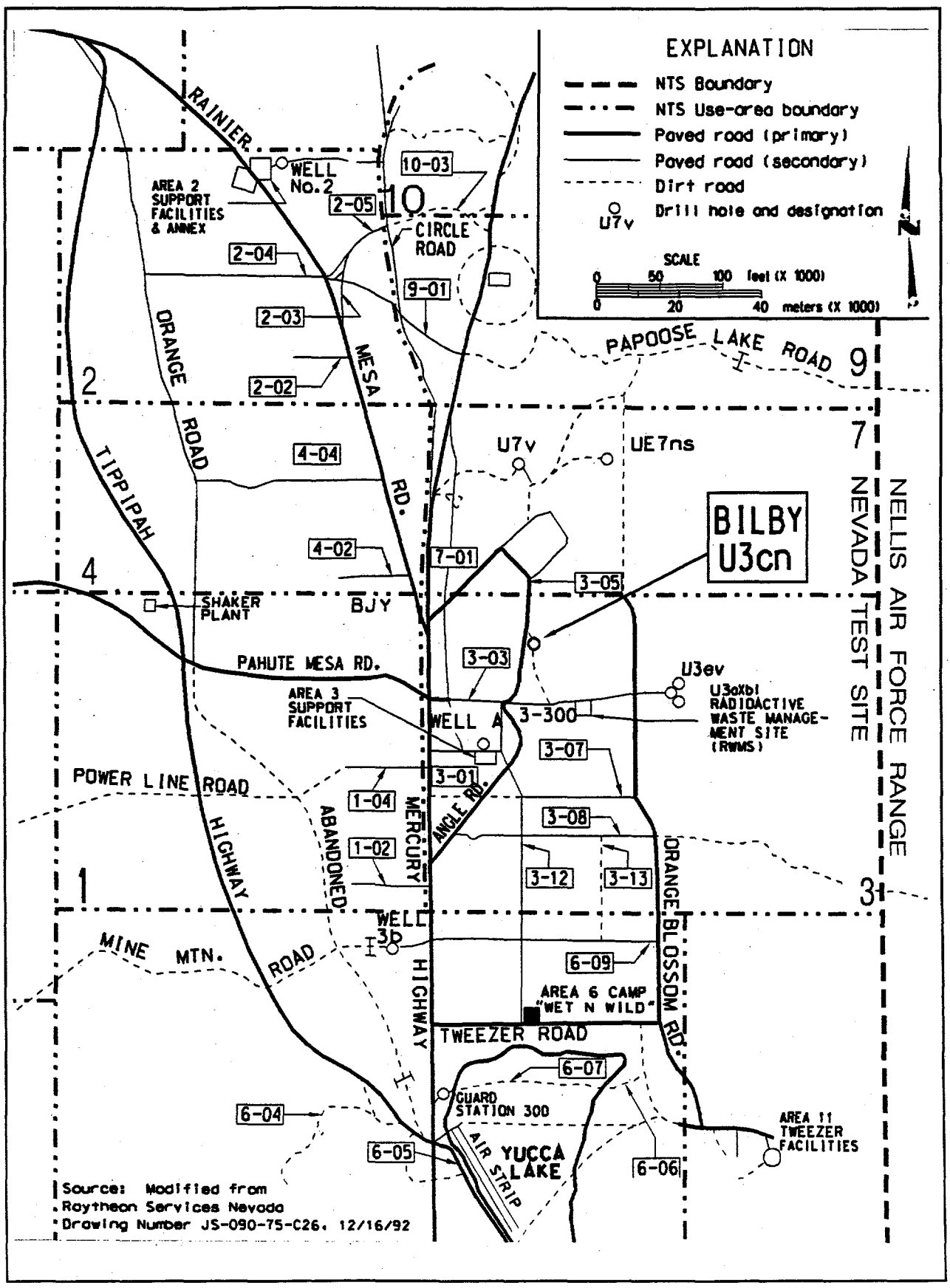

Figure 1-2
Area Map for U-3cn BILBY Recompletion Project

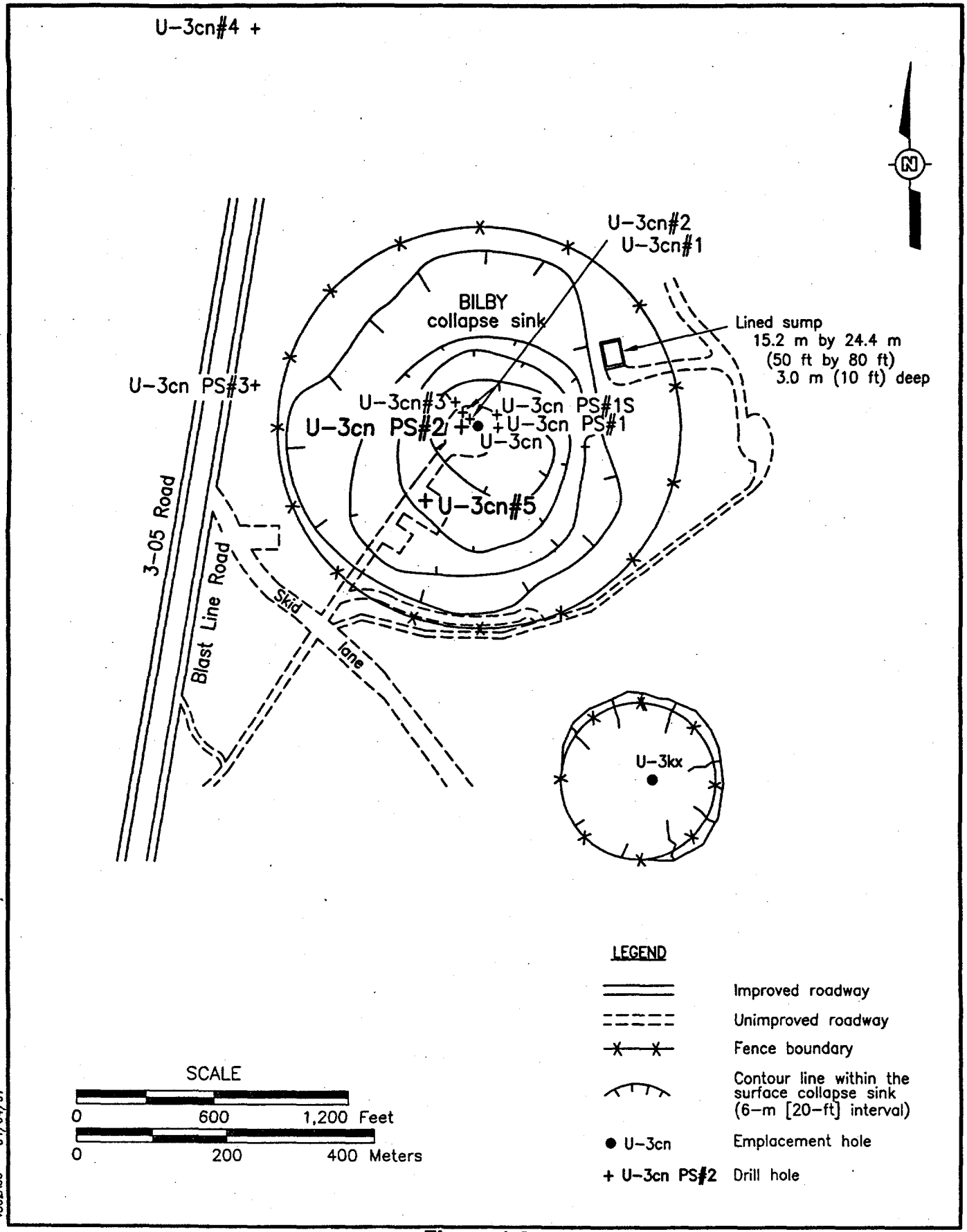

Figure 1-3
BILBY (U-3cn) Site Layout

simply by replacing well hardware, conducting hydrologic tests, and monitoring groundwater quality.

The initial phase of this project (through January 1997, reported here) consisted of the evaluation, rehabilitation, and sampling of Hydrologic Test Hole U-3cn#5 and Postshot Hole U-3cn PS#2. The Nevada State Planar Coordinates and elevation of both well collars are provided in Table 1-1, along with additional site summary and survey information.

Table 1-1
BILBY Recompletion Site Summary

Hole Designation		Hydrologic Test Hole U-3cn#5	Postshot Hole U-3cn PS#2
Site Coordinates[a]	Central Nevada State Planar (ft)	N841,255 E687,998	N841,600 E688,169
	Universal Transverse Mercator (Zone 11) (m)	N4,101,713.7 E586,921.8	N4,101,819.0 E586,973.6
Surface Elevation[b]		1,222.9 m (4,012 ft)	1,217.4 m (3,994 ft)
Drilled Depth		923.5 m (3,030 ft)	793.4 m (2,603 ft)
Fluid-Level Depth		493.9 m[c] (1,620 ft)	472.4 m[d] (1,550 ft)
Fluid-Level Elevation		729.1 m (2,392 ft)	744.9 m (2,444 ft)

Sources: RSN (1991); BN (1996).

[a] 1927 North American Datum. Measurement made by Holmes & Narver Survey.
[b] 1929 North American Vertical Datum. Measurement by Homes & Narver Survey.
[c] Measurement by USGS, December 1996 (Trudeau, 1997).
[d] Fluid level from logs by Birdwell in 1977 (Arteaga *et al.* [1991]).

IT Corporation (IT) was the principal environmental contractor for the project. Engineering, well-site support, inspection, and geotechnical services were provided by Bechtel Nevada (BN). The work planned to accomplish the recompletions is described in BN Drilling Program Number D-012-001.96 (BN, 1996). Descriptions of the BILBY site, summaries of previous studies, and preconstruction conditions are provided in the *Bilby Recompletion Criteria Technical Letter* (IT, 1995). The UGTA fluid-management plan (DOE, 1994a) provided guidelines for handling potentially radioactive fluids produced during pumping and sampling of these holes.

This document presents well-design and recompletion data for the two BILBY wells that were pumped and sampled for this project. Some summary data on geology, hydrology, and previous activities at the site are also included here for the convenience of the reader. The results of pumping and sampling activities will be presented in a separate report.

1.2 Hydrologic Effects of Nuclear Tests

1.2.1 Phenomenology

Underground nuclear explosions cause physical changes in the near field as a result of ground shock, cavity growth, and chimney formation. Temporary increases in temperature and fluid pressure, and in some cases the groundwater level, have been observed. More permanent changes expected in the near field include enhanced fracture permeability, increased porosity due to bulking of broken material in the cavity/chimney area, and the creation of a potentially permeable vertical conduit between aquifers through the chimney material (Garber, 1971a; Brikowski, 1991).

1.2.2 BILBY

The BILBY underground nuclear test, executed in Emplacement Hole U-3cn on September 13, 1963, was the first nuclear explosion conducted below the water table at the NTS. See Table 1-2 for a summary of data for the BILBY nuclear test. Observations made following previous underground explosions indicated that groundwater levels near test locations could be affected, at least temporarily, so the BILBY test plan included "real-time" monitoring of groundwater levels to determine if the explosion caused any such changes. Also, because of BILBY's relatively large yield (249 kilotons [DOE, 1994b]) and because the explosion cavity was located close to the lower carbonate aquifer, scientists thought that radionuclides released by the explosion could possibly have been introduced into this regional aquifer. Thus, several studies were conducted in the years following the test to try to develop an understanding of the close-in effects of nuclear tests on the groundwater system and the distribution of explosion-produced radioactivity in the environment. Data from the postshot hole provided valuable information on the recovery of the water table after the explosion and on the hydrologic characteristics of the chimney rubble (Garber, 1971b; Buddemeier and Isherwood, 1985). Data from the hydrologic test hole indicated that as of 1981 no radionuclides had been detected in the regional aquifer in that area.

Detailed reports on the drilling and testing of these two holes can be found in Hale *et al.* (1963), Garber and Johnston (1967), and Garber (1971b). An evaluation of the results from all the data available from this site through 1984 can be found in Buddemeier and Isherwood (1985).

Table 1-2
Synopsis of Pertinent Data for the BILBY Underground Nuclear Test

Emplacement Hole Designation	U-3cn
Central Nevada State Planar Coordinates	N841,600 ft E688,200 ft
Surface Elevation	1,241.8 m (4,074 ft)
Drilled Depth	785.5 m (2,577 ft)
Water-Table Depth	502.9 m (1,650 ft)
Water-Table Elevation	738.8 m (2,424 ft)
Test Date	September 13, 1963
Announced Yield	249 kilotons
Depth of Burial (DOB)	713.2 m (2,340 ft)
Geologic Medium at DOB	Zeolitized, nonwelded ash-flow tuff
Estimated Cavity Radius	87 m (285 ft)
Surface Collapse Sink Depth North-south diameter East-west diameter	 24.7 m (81 ft) at maximum 487.7 m (1,600 ft) 457.2 m (1,500 ft)

Sources: DOE (1994b) and Williams (1964).

1.3 Objectives

The primary objective of the BILBY recompletion project was to reestablish a means of investigating the impact of the BILBY underground nuclear test on the lower carbonate aquifer in southern Yucca Flat. The rehabilitation of the submersible pumps in Hydrologic Test Hole U-3cn#5 and Postshot Hole U-3cn PS#2 is expected to enable long-term monitoring of groundwater near the BILBY test.

1.4 Project Summary

This section briefly summarizes drilling and completion data for the BILBY site. A summary of the geology and hydrology, and the details of the recompletion activities are given in Sections 2 and 3 of this report.

Prior to work on the pumps in Wells U-3cn#5 and U-3cn PS#2 a new, lined sump and fences were constructed at the BILBY site, and an exclusion zone was established. Appropriate barriers

such as plastic linings were installed at the wellheads to prevent soil contamination by lubricants and other fluids from the equipment.

1.4.1 Hydrologic Test Hole U-3cn#5

Hydrologic Test Hole U-3cn#5, located approximately 40 m (130 ft) outside the BILBY collapse chimney at closest approach (drill-hole depth of approximately 695 m [2,280 ft]), was drilled to the depth of 923.5 m (3,030 ft) in 1966, and completed with a submersible pump and an access line. The hole was cased to a depth of 863 m (2,832 ft), leaving the lower 60.4 m (198 ft) of the hole open to Paleozoic-age carbonate rocks of the lower carbonate aquifer. The well was used for hydrologic testing and sampling through 1981 when the pump failed, but the U.S. Geological Survey (USGS) continues to measure water levels intermittently.

A Franks 300 drill rig was used to pull the existing pump string for evaluation on January 15-16, 1997. Forty-two joints of the existing 2⅞-inch (in.) pump string were replaced due to excessive rust. A 50-horsepower (HP) Centrilift™ tandem pump was lowered on the refurbished pump string, and set with its bottom at 691.3 m (2,268.1 ft) on January 23, 1997. The pump intake is located at 687.6 m (2,255.8 ft). The existing 2⅜-in. access tube was left in place with its bottom set at 701.0 m (2,300 ft). After the new pump was installed, a 46-hour pumping test was conducted and water samples were taken for analysis. Pumping and sampling of Hydrologic Test Hole U-3cn#5 were concluded on January 30, 1997.

1.4.2 Postshot Hole U-3cn PS#2

Postshot Hole U-3cn PS#2 was drilled through the rubble of the BILBY collapse chimney and into the explosion cavity in 1963. The total depth of the original hole was 793.4 m (2,603 ft), and the hole was cased to 792.2 m (2,599 ft). This 4½-in. casing was perforated in the interval 579.1 to 792.2 m (1,900-2,599 ft), but the casing soon pinched off or collapsed at approximately 587 m (1,926 ft). A packer was set at 561.4 m (1,842 ft), and additional perforations were made at 512.1 to 527.0 m (1,680-1,729 ft); now only the rubble-chimney environment can be sampled in this configuration. The original submersible pump was located at a depth of 520.9 m (1,709 ft), but failed and was replaced. An 8.9-centimeter (cm) (3½-in.) 10-HP Reda ™ submersible pump was installed in September 1977 on 1⅔-in. Hydril™ tubing, with the intake at 503.5 to 504.7 m (1,652-1,656 ft). The well was sampled intermittently through 1984.

The existing pump was tested on January 9, 1997 and found to be operable. A 140-hour pumping test was conducted and water samples were taken for analysis. Pumping and sampling of Postshot Hole U-3cn PS#2 were concluded on January 22, 1997.

1.5 Project Manager

Inquiries regarding the BILBY recompletion project should be directed to the UGTA Project Manager:

Environmental Restoration Division
DOE/Nevada Operations Office
Post Office Box 98518
Las Vegas, Nevada 89193-8518

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2.0 Geology and Hydrology of the U-3cn BILBY Site

2.1 Geology

The geology of the BILBY site in central Yucca Flat is well known from extensive geologic studies associated with underground nuclear testing in the area, and from analyses of data obtained during the drilling and sampling of the original BILBY holes themselves (Emplacement Hole U-3cn, Well U-3cn#4, Hydrologic Test Hole U-3cn#5, Postshot Hole U-3cn PS#2). Data from the BILBY holes are presented in various USGS reports and summarized in the *Bilby Recompletion Criteria Technical Letter* (IT, 1995). Features that are relevant to the UGTA near-field program are described in the following paragraphs. No new geologic data were collected during the BILBY recompletion activities.

2.1.1 Geologic Setting

Yucca Flat is an arid, intermontane valley typical of the Basin and Range province of Nevada. The valley was formed by faulting of the Paleozoic-age sedimentary rocks, and has been filled with tuffs and alluvium. The alluvium consists of tuffaceous sands and gravels at the BILBY site, and ranges in thickness from about 260 to 290 m (850-950 ft). The alluvium is underlain by a series of Tertiary-age ash-flow tuffs and bedded tuffs approximately 536 m (1,760 ft) thick, which are separated from the underlying Paleozoic-age carbonate rocks by a colluvial layer approximately 41 m (135 ft) thick at BILBY. The upper 108 m (355 ft) of the volcanic section is vitric, but the volcanic rocks become zeolitized below about 282 m (925 ft) below the surface. The Paleozoic rocks immediately beneath the BILBY site are mainly dolomites and dolomitic quartzites of the lower carbonate aquifer.

A west-east hydrogeologic cross section, constructed at approximately right angles to the local structural fabric through the BILBY site, is presented in Figure 2-1. As can be seen, no major faults are projected to pass closer than about 457 m (1,500 ft) from the edge of the BILBY explosion cavity.

2.1.2 Update of Original Geologic Data

The USGS conducted the original geologic studies at the BILBY site, as described in Williams and Hoover (1963); Garber and Johnston (1967); Garber (1971b); and Dixon *et al.* (1973). However, recent work on the stratigraphy of the Tertiary volcanic rocks of the NTS area has required that the original logs be updated to incorporate the latest stratigtraphic nomenclature. A listing of stratigraphic units present at the BILBY site, with map symbols, lithology, and

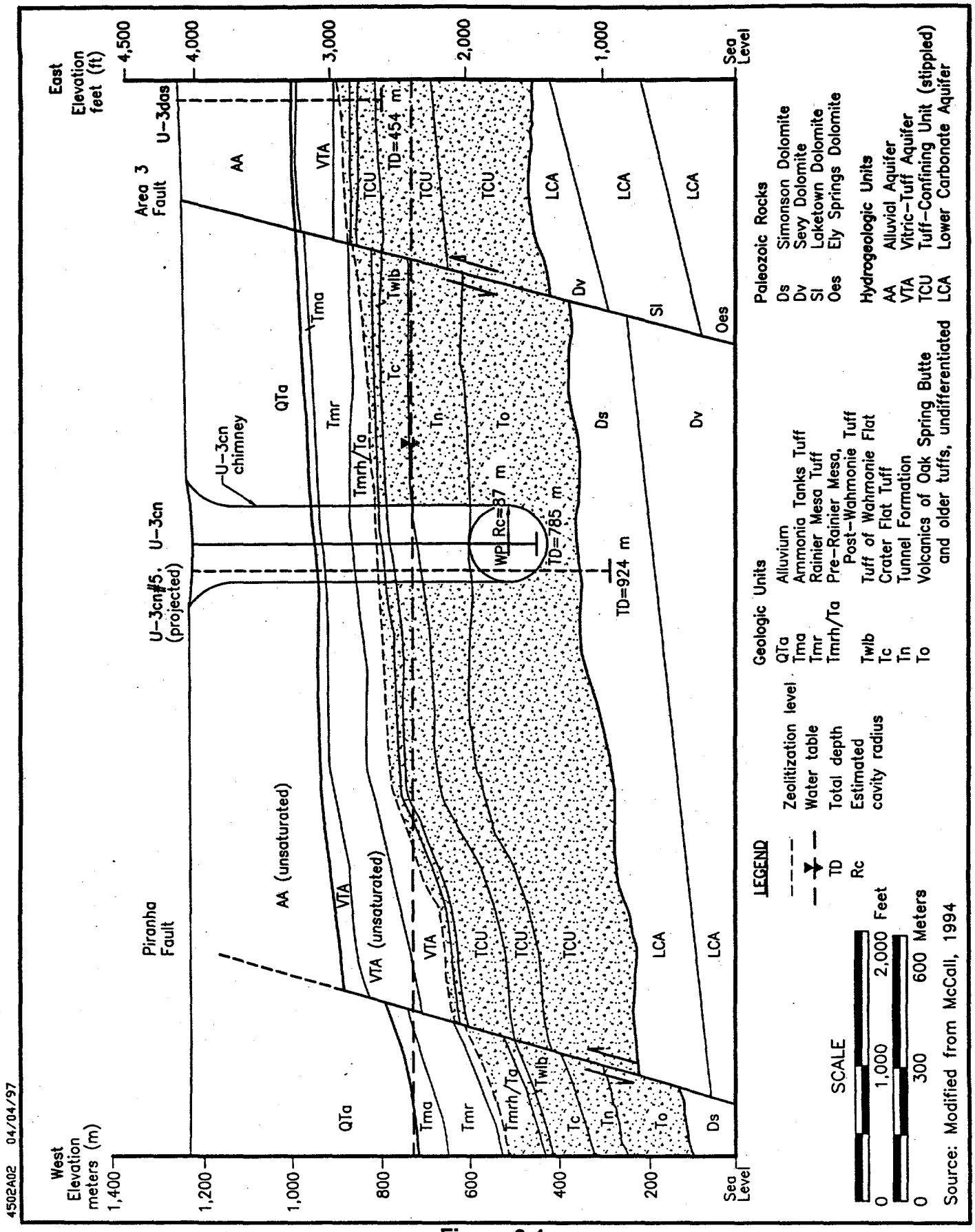

Figure 2-1
West-East Hydrogeologic Cross Section Through the BILBY Area

hydrogeology, is given in Table 2-1. The updated stratigraphic and lithologic logs for Hydrologic Test Hole U-3cn#5 are given in Appendix B. Because Postshot Hole U-3cn PS#2 was drilled through the BILBY chimney rubble, no lithologic log is provided. Depths to selected formation tops and other drill hole information are presented for Emplacement Hole U-3cn, Hydrologic Test Hole U-3cn#5, and Postshot Hole U-3cn PS#2 in Table 2-2.

Lists of geophysical logs, conventional cores, and sidewall cores from Hydrologic Test Hole U-3cn#5 can be found in Garber and Johnston (1967) and in the drill hole history (F&S, 1966a). Descriptions of sidewall cores taken after drilling Postshot Hole U-3cn PS#2 are given in Garber (1971b).

2.2 Hydrology

The hydrology of the BILBY site is summarized in the following paragraphs.

2.2.1 Hydrogeologic Setting

The rocks in the BILBY area can be divided into four hydrogeologic units (HGUs) that are distinguished by their differing abilities to transmit groundwater. These HGUs are defined on the basis of primary lithologic properties, degree of fracturing, and secondary mineral alteration. See Winograd and Thordarson (1975) and Laczniak *et al.* (1996) for more discussion of the hydrogeologic units in the NTS region.

Alluvial aquifer and vitric-tuff aquifer units are present above the static water table at BILBY, to a depth in Hydrologic Test Hole U-3cn#5 of approximately 364 m (1,195 ft). Below the water table the mostly zeolitized volcanic rocks and paleocolluvium are classified as a tuff confining unit. The BILBY detonation point (Working Point or WP) was located in a saturated, zeolitized, nonwelded ash-flow tuff of this tuff confining unit. The pre-Tertiary rocks, encountered at the depth of 860 m (2,821 ft) (approximately 166 m [545 ft] below the BILBY WP), are classified as lower carbonate aquifer. All of these HGUs are listed with the stratigraphic units on Table 2-1 and illustrated on Figure 2-1.

Table 2-1
Stratigraphic, Lithologic, and Hydrogeologic Units at the U-3cn BILBY Site

Stratigraphic Group or Formation	Member or Unit	Symbol[a]	Typical Lithology[b]	Hydrogeologic Unit
Alluvium	Alluvium	Qta	Sands and gravels	Alluvial aquifer
Timber Mountain Group	Ammonia Tanks Tuff	Tma	Nonwelded ash-flow tuff	Vitric-tuff aquifer
	Rainier Mesa Tuff	Tmr	Nonwelded ash-flow tuff	
	Tuff of Holmes Road	Tmrh	Vitric bedded tuff	
	Pre-Rainier Mesa, Post-Wahmonie tuffs, undifferentiated	Tmrh/Ta	Zeolitized bedded tuff	Tuff confining unit
Wahmonie Formation	Tuff of Wahmonie Flat	Twlb	Zeolitized bedded tuff and tuffaceous sandstone	
Crater Flat Group	Crater Flat Tuff, undifferentiated	Tc	Zeolitized bedded tuff	
Tunnel Formation	4 Member and older tuffs, undifferentiated	Tn/To	Zeolitized ash-flow and bedded tuffs	
Volcanics of Oak Spring Butte	Redrock Valley Tuff	Tor	Nonwelded to partially welded, devitrified to zeolitized ash-flow tuff	
	Tuff of Twin Peaks	Tot	Nonwelded, devitrified ash-flow tuff	
	Older tuffs, undifferentiated	To	Zeolitized and argillized bedded tuff	
Paleocolluvium	Paleocolluvium	Tl	Gravel in calcareous, clay-rich matrix; tuffaceous beds	
Simonson Dolomite	Simonson Dolomite	Ds	Dolomite and dolomitic quartzite	Lower carbonate aquifer

Source: Modified from IT (1995)

[a] Symbols by Ferguson *et al.* (1994).

[b] See Appendix B for detailed lithology and stratigraphy.

Table 2-2
Depth to Selected Formation Tops and General Drill Hole Information for Drill Holes U-3cn, U-3cn#5, and U-3cn PS#2

	U-3cn		U-3cn#5		U-3cn PS#2	
	feet	meters	feet	meters	feet	meters
Northing [a]	841,600	256,520.2	841,255	256,415.0	841,600	256,520.2
Easting [a]	688,200	209,763.8	687,998	209,702.2	688,169	209,754.3
Ground Elevation	4,074	1,241.8	4,012	1,222.9	3,994	1,217.4
TD	2,577	785.5	3,030	923.5	2,603	793.4
Tma	910	277.4	925	281.9	ND [b]	ND
Tmab	ND	ND	945	288.0	ND	ND
Tmr	ND	ND	955	291.1	ND	ND
Tmrh	1,170	356.6	1,165	355.1	ND	ND
Tw	ND	ND	1,395	425.2	ND	ND
Tc	ND	ND	1,430	435.9	ND	ND
Tn4	ND	ND	1,655	504.4	ND	ND
Tn4E	ND	ND	1,801	548.9	ND	ND
Tor	ND	ND	2,102	640.7	ND	ND
Tot	ND	ND	2,250	685.8	ND	ND
To	ND	ND	2,565	781.8	ND	ND
Tl	---- [c]	----	2,685	818.4	----	----
Pz	----	----	2,821	859.8	----	----
Pz Fm	----	----	Simonson Dolomite (?)		----	----
Static Water Level	1,569 [d]	478.2	1,620 [e]	493.9	1550 [f]	472.4
Top of Zeolitization	1,274	388.3	1,280	390.1	ND	ND
Bed Dip	ND	ND	10° at 1,422 15° at 2,030	10° at 433.4 15° at 618.7	ND	ND
Faults	ND	ND	1,798? 2,280? 2,924?	548.0? 694.9? 891.2?	ND	ND

Source: Drellack and Thompson (1990).

See Table 2-1 for key to formation symbols.

[a] Central Nevada State Planar Coordinates
[b] Not defined.
[c] Formation not encountered.
[d] Garber and Johnston (1967)
[e] Measurement by USGS, December 1996 (Trudeau, 1997).
[f] Fluid level from logs by Birdwell in 1977 (Arteaga *et al.* [1991]).

2.2.2 Results of Previous Hydrologic Investigations

The local hydrology at the BILBY site was altered in the short term as a result of the explosion. As detailed in Hale *et al.* (1963), measurements made in nearby wells immediately after the explosion indicated that water levels rose significantly within the wells, presumably in response to the pressure pulse associated with displacement of rock around the shot point. Measurements in a nearby well that penetrated the underlying Paleozoic sedimentary rocks suggested that the rapid increase of hydraulic pressure also occurred within the lower carbonate aquifer as well. However, by the time water-level measurements could be made in Postshot Hole U-3cn PS#2, two months after the explosion, the water level in the chimney rubble was approximately 96 m (315 ft) lower than the pre-test level. Measurements made in the postshot hole over the next several years indicated that it took approximately five years for the water level to recover to the pre-test level (Garber, 1971b; Buddemeier and Isherwood, 1985). Numerous fluid samples were collected from the postshot hole, and the chemistry data for these samples are listed in Beetem *et al.* (1965) and Garber (1971b), and summarized in Buddemeier and Isherwood (1985).

When last measured, the elevation of the water level in Hydrologic Test Hole U-3cn#5, completed in the lower carbonate aquifer, was approximately 15.8 m (52 ft) lower than the water level in Postshot Hole U-3cn PS#2, which did not penetrate the carbonate. This difference is consistent with the observation that fluid levels measured in wells completed in the lower carbonate aquifer are typically lower than wells completed in the tuff confining unit in Yucca Flat (Winograd and Thordarson, 1975).

During the drilling of Hydrologic Test Hole U-3cn#5 radiation above background levels was observed on gamma and gamma-neutron logs in the interval 679.7 to 710.8 m (2,230-2,332 ft) (Garber and Johnston, 1967). It was determined at that time that the radionuclides were present along fracture planes in the welded tuff in this interval. Garber and Johnston (1967) ruled out radionuclide migration via groundwater because the hydraulic gradient at that time was away from the test hole, toward the chimney. They suggest that the radionuclides could have been emplaced by prompt injection at the time of the detonation. No radionuclides were found in fluids from this well during monitoring over the next ten years (Buddemeier and Isherwood, 1985). A summary of hydraulic tests conducted at Hydrologic Test Hole U-3cn#5 is given in Table 2-3.

Table 2-3
Summary of Hydraulic Tests at Hydrologic Test Hole U-3cn#5

Depth Interval Tested meters (m) (feet [ft])	Date	Stratigraphic Unit [a]	Lithology	Hydrogeologic Unit [b]	Specific Capacity
551.7 to 603.5 m (1,810 to 1,980 ft)	1965 and 1966	Tn4E	Ash-flow tuff, partially-welded, zeolitized	TCU	0.11 m^2/day [c] 0.006 gpm/ft [d] and 0.18 m^2/day 0.01 gpm/ft
603.5 to 655.3 m (1,980 to 2,150 ft)	1965 and 1966	Tn, undiff.	Ash-flow and bedded tuffs, zeolitized	TCU	
670.6 to 726.9 m (2,200 to 2,385 ft)	1965 and 1966	Tot	Ash-flow tuff, nonwelded to moderately-welded, zeolitized	TCU	0.11 m^2/day 0.006 gpm/ft
864.4 to 907.1 m (2,836 to 2,976 ft)	1966	Pz	Mostly dolomite, quartzite below 892 m (2,925 ft)	LCA	7.2 m^2/day 0.4 gpm/ft
864.4 to 922.9 m (2,836 to 3,028 ft)	1966	Pz	Dolomite and quartzite	LCA	

Source: Garber and Johnston (1967). Stratigraphy and lithology modified from Dixon *et al.* (1973) and Drellack and Thompson (1990).

[a] Tn4E - Tunnel Formation, 4 Member, Bed 4E; Tn-Tunnel Formation 3 and 4 undifferentiated; Tot - Tuff of Twin Peaks; Pz - Paleozoic rocks, undifferentiated
[b] TCU - Tuff-confining unit; LCA - Lower-carbonate aquifer
[c] Meter squared per day
[d] Gallon per minute per foot of drawdown

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3.0 Hydrologic Test Hole U-3cn#5

3.1 Introduction

The history of Well U-3cn#5 is well documented, as described in Section 2 of this report. A synopsis of the drilling and original completion activities is given in the *Bilby Recompletion Criteria Technical Letter* (IT, 1995), where summaries of the original hydrologic studies are also provided. This section summarizes pertinent drilling data, describes how the recompletion was conducted, and presents the current status of the well.

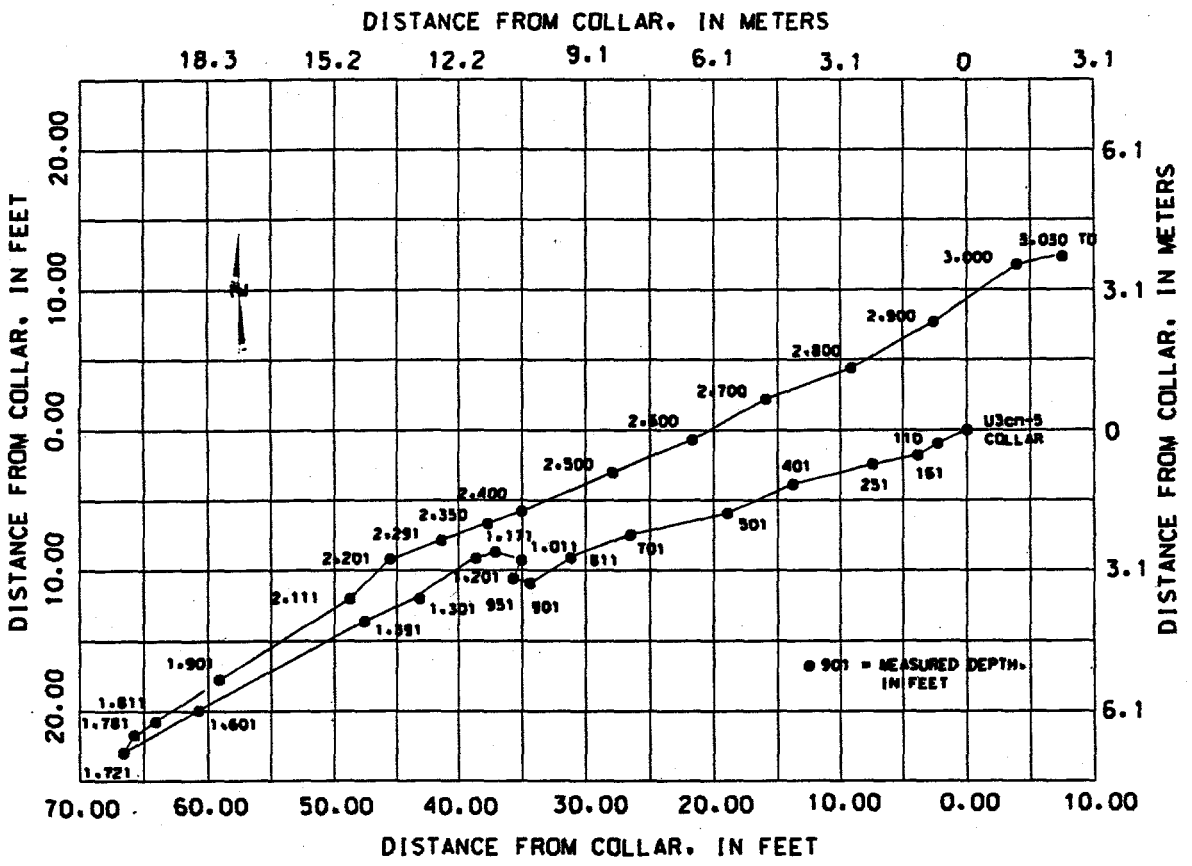
3.2 Activities Summary for Hydrologic Test Hole U-3cn#5

The drilling of Hydrologic Test Hole U-3cn#5 in 1965/66 is summarized for the convenience of the reader in Section 3.2.1, and Section 3.2.2 describes the recent recompletion activities.

3.2.1 Summary of Original Work

Details of the drilling and original completion operations are documented in the hole history (F&S, 1966a) and in Garber and Johnston (1967). The drilling of Hydrologic Test Hole U-3cn#5 began in September 1965. The borehole was drilled and cored in several stages to a TD of 923.5 m (3,030 ft) using conventional drilling techniques, and was completed in February 1966 (the operation was prolonged due to a labor strike). Conductor casing with an outside diameter (od) of 20 in. was set at 11 m (36 ft), and drilling of a 44.5-cm (17½-in.) hole continued to 435.3 m (1,428 ft) where the drill bit assembly and two drill collars were lost. The hole was cemented and then side-tracked from 289.9 to 324.3 m (951-1,064 ft), leaving the lost tools in the hole. After drilling and coring reached the depth of 542.5 m (1,780 ft) the hole was again cemented (to 434.6 m [1,426 ft]) and redrilled to stop caving of the borehole. The 13⅜-in. casing was set from the surface to the depth of 432 m (1,418 ft), and the annulus of this casing was cemented from the bottom of the hole to the depth of 356.6 m (1,170 ft). The hole was then cored and reamed to 25.1 cm (9⅞-in.) diameter to the depth of 609.6 m (2,000 ft) where it was discovered that borehole deviation had become severe (see Figure 3-1 for a plot of the borehole deviation). An effort was made to correct this by again cementing and redrilling the hole.

Coring and drilling continued to 731.5 m (2,400 ft), when drilling stopped for hydrologic testing. The hole was then opened to 31.1 cm (12¼ in.), and the 9⅝-in. casing was set at 726.9 m (2,385 ft). Its annulus was cemented, though not successfully. When drilling resumed, circulation was immediately lost so that further geologic data were obtained only by drilling sidewall and conventional cores.



Measured depth = 923.5 m (3,030 ft). True vertical depth = 922.5 m (3,026.5 ft).
Horizontal displacement at total depth = 3.8 m (12.6 ft) north; 2.1 m (6.8 ft) east.

Source: Garber and Johnston (1967), Figure 3.

Figure 3-1
Graph of Directional Survey in Hydrologic Test Hole U-3cn#5

It was verified by coring that at the depth of 863.2 m (2,832 ft) the hole had penetrated dolomitic limestone. To isolate the lower portion of the hole (after geophysical logging) a 6⅝-in. liner was hung from the 9⅝-in. casing to the depth of 863.2 m (2,832 ft), and the annulus of the lower part of the liner was cemented. Coring resumed, with pauses occasionally to obtain samples of the fluid from the Paleozoic rocks exposed in the open hole below the liner. After the hole reached TD in Paleozoic quartzite at the depth of 923.5 m (3,030 ft) in February 1966, additional hydraulic testing was conducted and a pump was installed. The pump was replaced in 1973 and again in 1976. The last pump failed in 1981.

3.2.2 Recompletion Activities

No new drilling or logging was conducted for the Well U-3cn#5 recompletion project. All field work was done on a one-shift-per-day basis (four ten-hour days per week). Information presented here was obtained from the BN NTS Daily Rig Operations reports. The daily recompletion activities for Hydrologic Test Hole U-3cn#5 are listed in Appendix A-1, and Table 3-1 presents abridged drill hole statistics, incorporating the original drilling and casing data with the final recompletion configuration.

The BILBY site was prepared for the recompletion operation in December 1996, concurrently with preparations for activities at Postshot Hole U-3cn PS#2. These preparations primarily consisted of construction of one lined sump and perimeter fences, dressing of existing roads and pads, and installation of work trailers, power, phones, and tanks for water and fuel. Replacement tubing in storage was cleaned and brought to the location in case it was needed.

A Franks 300 rig was set up over the wellhead on January 9, 1997 after discharge piping was removed to make room for it. After the drill crew made a few minor repairs and de-iced the equipment, the rig became operational on the afternoon of January 14, 1997. The uppermost 0.5 m (1.5 ft) of the 9⅝–in. casing was cut off to permit access for removal of the pump string. It was verified that the pump string and access line were not attached to each other and that the pump was not attached to the bottom of the access line. The crew began to pull the pump string on January 15, 1997, leaving the access line in place.

Personnel donned anti-contamination clothing on January 16, 1997, after 50 joints of tubing had been removed, in anticipation of encountering contaminated fluid. A sample of fluid dripping from one of the joints was found to contain low levels of tritium, so a 3.8-cm by 1.5-m (1½-in. by 5-ft) steel bar was dropped to open any bleeder valve that might be present within the tubing. Fluid subsequently drained from the tubing, thus reducing the chance of personnel contamination as the rest of the string was pulled. The bleeder valve and pump assembly were removed from the well and laid down on January 21, 1997. The joint above the old pump was found to be partially plugged with rust, and the suction screen was 90% plugged with rocks and pump debris.

A new Centrilift™ 50-HP tandem pump assembly was installed in the well. It was found that the wrong size suction screen had been sent with the pump, so in-stock pump screen was field-fitted to the pump intake opening. As the new pump was lowered into the well on the original tubing, each joint was examined for damage and rust. A total of 42 joints of old tubing were replaced

Table 3-1
Abridged Drill Hole Statistics for Hydrologic Test Hole U-3cn#5

LOCATION DATA	Coordinates:	
	Central Nevada State Planar:	N841,255, E687,998 ft
	Universal Transverse Mercator:	N4,101,713.7, E586,921.8 m
	Ground elevation:	1,222.9 m (4,012 ft)
	Distance from BILBY (Emplacement Hole U-3cn):	122 m (400 ft) on a bearing of S30.4°W from U-3cn
DRILLING DATA		
Spud Date:	9-26-65	
Completion Date:	2-9-66	
Recompletion Date:	1-23-97	
Total Depth (TD):	923.5 m (3,030 ft)	
Hole Diameters:	66.0-cm (26-in.) hole to 11 m (36 ft) 44.5-cm (17½-in.) hole to 435.3 m (1,4278 ft) 31.1-cm (12¼-in.) hole to 731.5 m (2,400 ft) 14.6-cm (5¾-in.) hole to 922.9 m (3,028 ft) 13.0-cm (5⅛-in.) hole to 923.5 m (3,030 ft) (TD)	
Cores:	Conventional cores were cut in the following intervals: 11 to 61 m (36 to 200 ft); 518.2 to 731.5 m (1,700 to 2,400 ft); 818.4 to 819.6 m (2,685 to 2,689 ft); 861.7 to 863.2 m (2,827 to 2,832 ft); and 882.4 to 923.5 m (2,895 to 3,030 ft). Sidewall cores were also taken at various depths to supplement the above cored intervals (F&S, 1966b; Garber and Johnston, 1967).	
Drilling Problems (1965/66):	Hole sloughing and lost circulation problems below about 457.2 m (1,500 ft); poor core recovery. The hole was cemented back and redrilled three times to sidetrack around lost drilling tools, to stop borehole caving, and to try to straighten the hole.	
CASING DATA	20-in. od conductor casing set at 0 to 11 m (0-36 ft) 13⅜-in. od casing set at 0 to 432 m (0-1,418 ft) 9⅝-in. od casing set at 0 to 727 m (2,385 ft) 6⅝-in. od liner set at 707 to 863 m (2,321 to 2,832 ft)	
WELL COMPLETION DATA		
Open Borehole:	863.2 m to 923.5 m (2,832 to 3,030 ft) (TD)	
Downhole Pump:	50-horsepower Centrilift™ tandem pump landed at 691.3 m (2,268.1 ft) with pump intake at 687.6 m (2,255.8 ft). Pump hangs on 2⅞-in. od tubing inside the 9⅝-in. casing.	
Access Line:	2⅜-in. od tubing set at 0 to 701.0 m (2,300 ft)	
Fluid Level[a]:	493.9 m (1,620 ft)	

Sources: F&S (1966a); Garber and Johnston (1967); RSN (1991)

[a] Measured by USGS, December 1996 (Trudeau, 1997).

with good, used, washed tubing. The pump was landed on January 23, 1997 at the depth of 691.3 m (2,268.1 ft).

After the landing assembly for the pump string was welded onto the wellhead, a tubing manifold with a pressure gauge and valves was made up, and a flow line was connected. The pump was started mid-day on January 27, 1997, but was found to be running backward, so it was shut down, reversed, and restarted. The pump was found to work properly, and was allowed to run for approximately 42 minutes to flush any debris from the line; it was then shut down again to repair a small leak at the wellhead. Pumping and sampling then began at 1400 hours (hrs), and the crew began to disassemble the drill rig. The pump was allowed to run continuously while IT personnel collected fluid samples, until 1215 hrs on January 29, 1997, when it was shut down after a total of approximately 46 hours pumping time.

Following pumping and sampling operations, the discharge hose and manifold were flushed with water tagged with lithium bromide. After the equipment was checked and found to be free of contamination, laborers removed the discharge line and other equipment.

3.3 Fluid Management

Effluent from Hydrologic Test Hole U-3cn#5 was monitored as prescribed in the *Fluid Management Plan for the Underground Test Area Operable Unit* (DOE, 1994a). All fluids produced during pumping and sampling were routed to a lined sump. Information on the volumes and quality of fluids pumped for this project will be presented in a separate report.

3.4 Hydrology

The latest water-level data for Hydrologic Test Hole U-3cn#5 were obtained in December 1996, when the depth to water was measured by the USGS at 493.9 m (1,620 ft) (Trudeau, 1997). No new hydrologic testing was conducted or fluid-level tags made during recompletion operations. Approximately 440 cubic meters (m^3) (116,346 gallons [gal]) of fluid were pumped from Hydrologic Test Hole U-3cn #5 into the lined sump during this activity (BN, 1997).

Fluid samples from Hydrologic Test Hole U-3cn#5 were taken during replacement of the pump string and pumping operations. The results of field analyses indicated tritium activities ranging from approximately 8,000 picoCuries per liter (pCi/L) for samples taken from the old equipment as it was drawn from the well, to near zero following pumping activities (BN, 1997). The results of analyses on these and other samples will be reported in a separate document.

3.5 Recompletion

The recompletion undertaken at Hydrologic Test Hole U-3cn#5 was planned to include only replacement of the existing pump and limited sampling. The goal of the operation was to provide for long-term monitoring of the quality of groundwater from the lower carbonate aquifer near the BILBY site. Figure 3-2 is a schematic of the final well-completion design for Hydrologic Test Hole U-3cn#5, and Figure 3-3 shows a plan and profile view of the wellhead configuration.

3.5.1 Planned Recompletion Design

The recompletion design, as described in the *Well Recompletion and Testing Program* (BN, 1996), specified that the existing inoperable pump be replaced, with the intake of the new pump located at approximately the same depth as that of the old pump, 693.4 m (2,275 ft). The pump string was to be run without a check-valve so that water in the flowline will drain back into the well when the pump is turned off. The original tubing was to be used in the pump string, except that which must be replaced due to damage or excessive rust.

3.5.2 As-Built Recompletion Design

As described in the draft *Bilby Recompletion Criteria Technical Letter* (IT, 1995), a 22.7-cm (8.92-in.) inside-diameter (id) casing is cemented in the hole from the surface to the depth of 726.9 m (2,385 ft). A 15.0-cm (5.92-in.) id liner, set in the hole from 707.4 to 863.2 m (2,321-2,832 ft), is attached to the 9⅝-in. casing with a lead seal, and its annulus cemented to isolate the bottom of the hole. The bottom 60.4 m (198 ft) of the hole, 14.6 cm (5¾ in.) in diameter, was originally left open to the dolomite formation. A 2⅜-in. access line was originally installed next to the pump string, and has been left in place. The new tandem pump was installed on 2⅞-in. carbon-steel tubing, with the intake at 687.6 m (2,255.8 ft). The string compositions are listed in Table 3-2 and tubing materials are given in Appendix A-2.

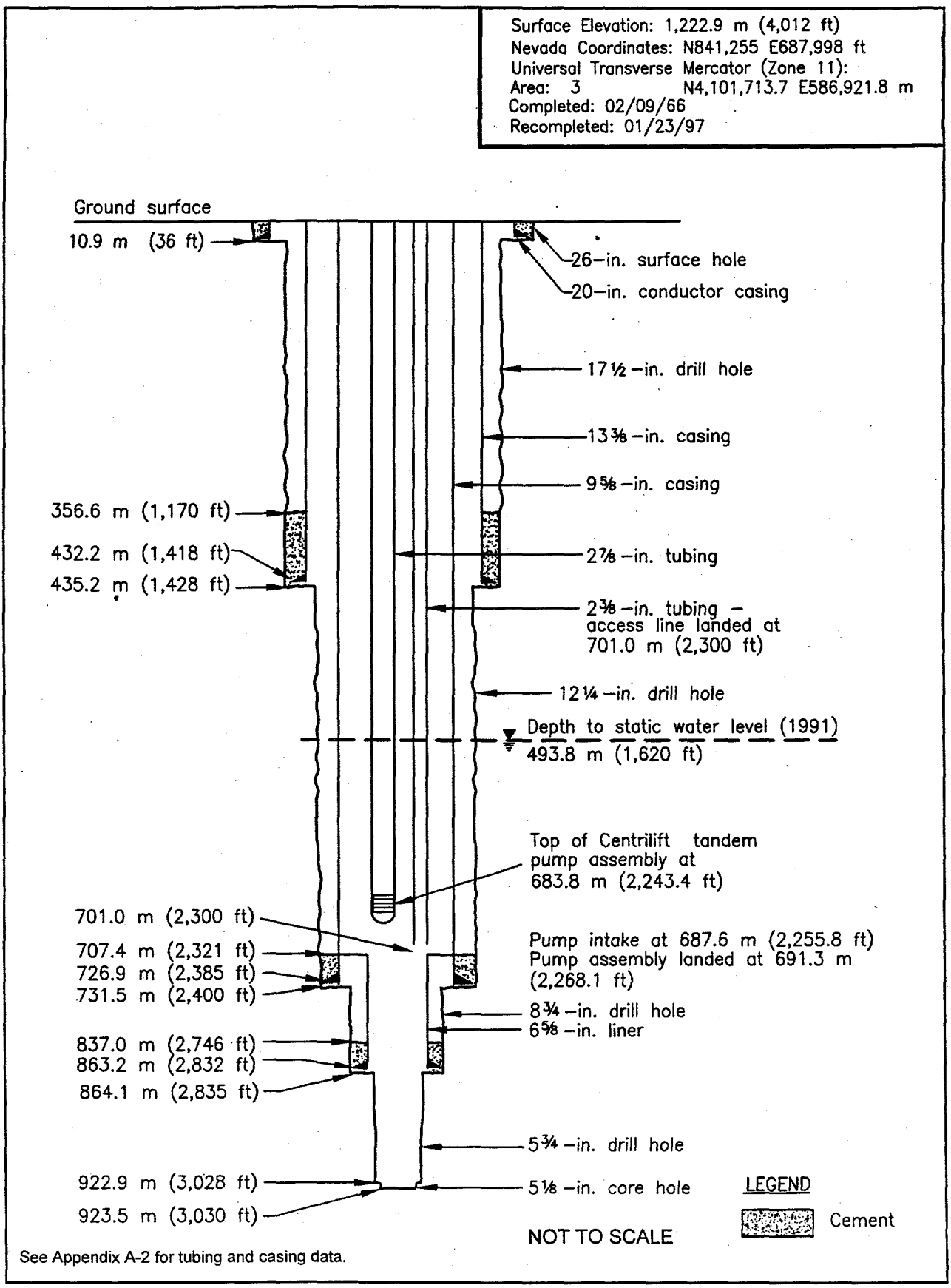


Figure 3-2
Recompletion Diagram for Hydrologic Test Hole U-3cn#5

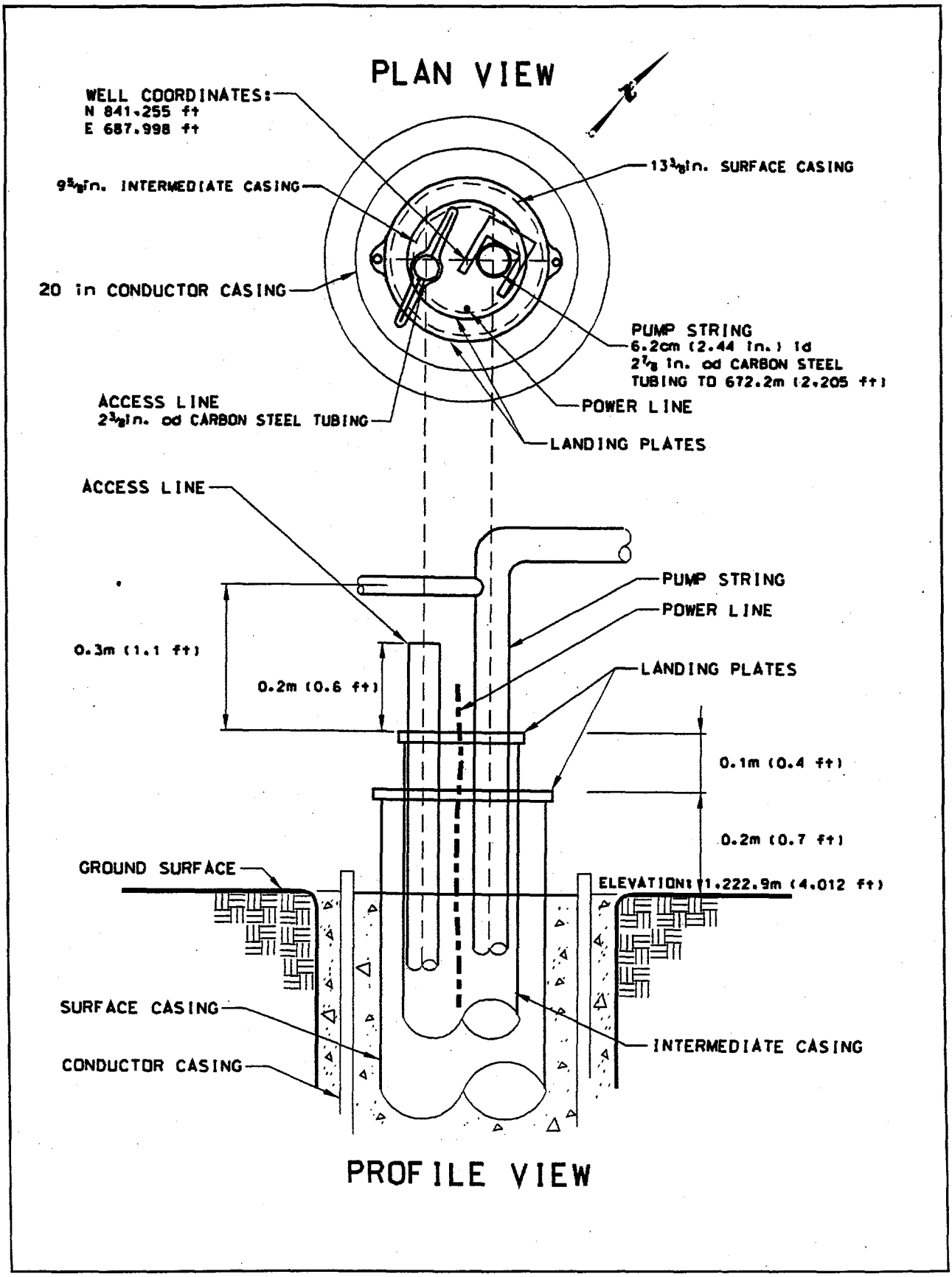


Figure 3-3
Wellhead Diagram for Hydrologic Test Hole U-3cn#5

Table 3-2
Hydrologic Test Hole U-3cn#5 Construction Summary

Completion String	Configuration	Cement[a]
9⅝-inch carbon-steel casing	Ground surface to 726.9 m (2,385 ft)	Annulus tack-cemented 708.1 to 731.5 m (2,323 to 2,385 ft)
6⅝-inch carbon-steel liner	Attached to bottom of 9⅝-inch casing with lead seal 707.4 to 863.2 m (2,321 to 2,832 ft)	Annulus cemented from 837.0 to 863.2 m (2,746 to 2,832 ft)
Pump string: 2⅞-inch carbon-steel tubing	Inside 9⅝-inch casing/liner Ground surface to 683.8 m (2,243.4 ft)	Not cemented
Pump Assembly:		Not cemented into well.
Tandem pumps	683.8 to 687.6 m (2,243.4 to 2,255.8 ft)	
Seal	687.6 to 689.5 m (2,255.8 to 2,262.1 ft)	
Motor	689.5 to 691.3 m (2,262.1 to 2,268.1 ft)	
Access line: 2⅜-inch carbon-steel tubing	Ground surface to 701.0 m (2,300 ft) Bottom open	Not cemented into well.

Sources: F&S (1966a); BN (1997)
[a] Precise cement compositions not available.

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4.0 Postshot Hole U-3cn PS#2

4.1 Introduction

The history of Postshot Hole U-3cn PS#2 is well documented, as described in Section 2 of this report. A synopsis of the drilling and original completion activities is given in the *Bilby Recompletion Criteria Technical Letter* (IT, 1995), where summaries of the original hydrologic studies are also provided. This section briefly summarizes the original work conducted at Postshot Hole U-3cn PS#2, documents the activities conducted for the BILBY recompletion project, and describes the current status of the well.

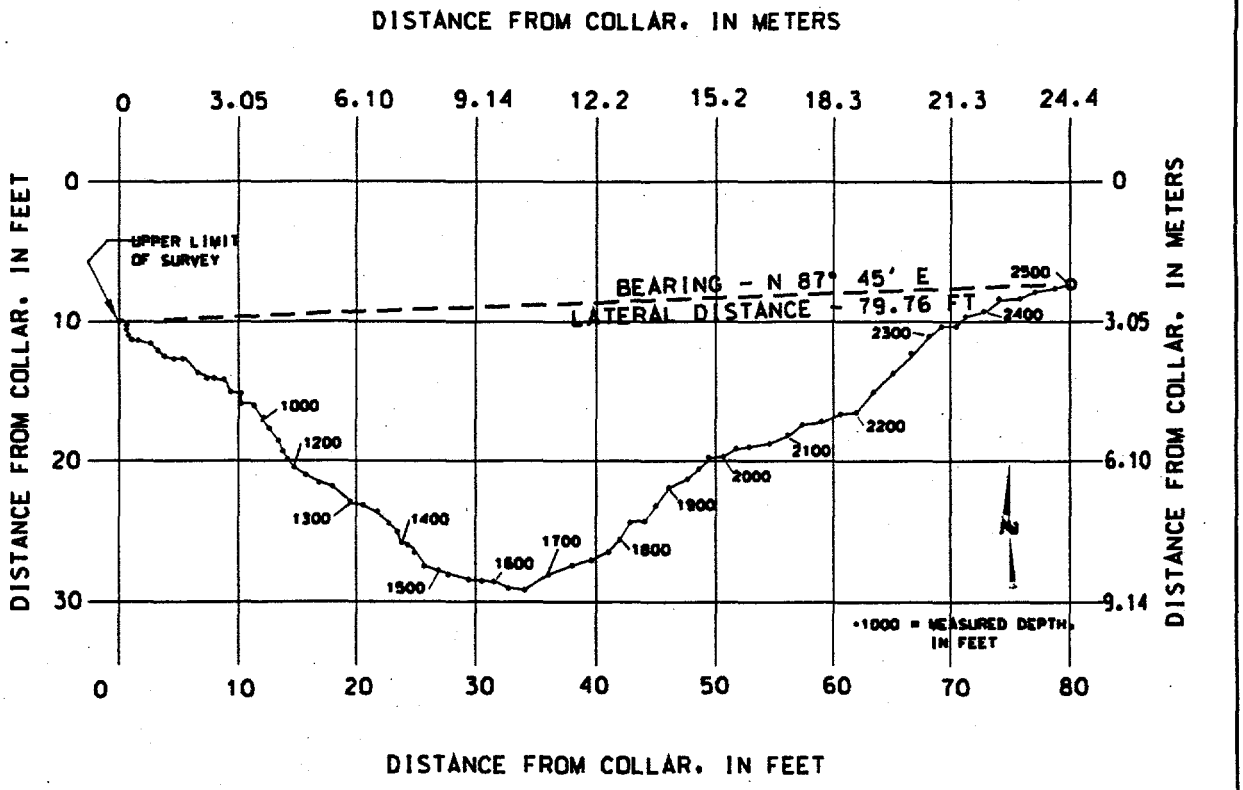
4.2 Activities Summary for Postshot Hole U-3cn PS#2

The drilling of Postshot Hole U-3cn PS#2 in 1963 is summarized for the convenience of the reader in Section 4.2.1, and Section 4.2.2 describes the current recompletion activities.

4.2.1 Summary of Original Work

Details of the drilling and original completion operations at this well can be found in the drill hole history (F&S, 1966b) and in Garber (1971b). Drilling of Postshot Hole U-3cn PS#2 through the BILBY chimney began ten days after the detonation, in September 1963. A 10¾-in. casing was set in the 38.1-cm (15-in.) borehole at 182.6 m (599 ft) and its annulus was cemented to the surface. Drilling of a 24.4-cm (9⅝-in.) borehole continued to the TD of 793.4 m (2,603 ft), which was reached in October 1963. Several voids were encountered during drilling, but the use of heavy drilling mud apparently sealed off any gases (Garber, 1971b). Sidewall samples were taken from the interval 734.0 to 755.9 m (2,408-2,480 ft), just below the original WP. A diagram of the measured borehole deviation is given in Figure 4-1. A 4½-in. casing was installed and perforated from near the estimated top of the explosion cavity to the hole TD. The fluid level was determined to be below 591.3 m (1,960 ft) during this operation. Radioactive gas was produced during perforating operations (Garber, 1971b).

Six days after perforation of the casing in Postshot Hole U-3cn PS#2 measurements indicated that the casing had collapsed near the top of the perforated interval, presumably by shifting of blocks within the chimney rubble (Garber, 1971b). Hydrologic studies that continued at the well over the next eight months indicated that the fluid level was slowly rising (Garber, 1971b). In June 1964 a pair of packers was inserted into the casing to seal the casing above the damaged interval. The casing was perforated again above the packer, and a pump was installed. Pumping, sampling, and testing continued intermittently at the well through 1984, though the pump was



Measured depth at bottom of survey run = 762.0 m (2,500 ft).
True vertical depth at bottom of survey run = 761.3 m (2,497.8 ft).

Source: Garber (1971b), Figure 2.

Figure 4-1
Graph of Directional Survey in Postshot Hole U-3cn PS#2

replaced in 1977. During pump replacement operations it was noted that the top of the 4½-in. casing was located approximately 7.9 m (26 ft) below the ground level, and care had to be taken to assure that equiment lowered into the hole went into the casing rather than into the annulus (F&S, 1977). The ½-in. air line planned for use in making water-level tags was not run at that time (Ortego, 1977).

4.2.2 Recompletion Activities

No new drilling or logging was conducted for the Well U-3cn PS#2 recompletion project. All field work was done on a one-shift-per-day basis (four ten-hour days per week). Information presented here was obtained from the BN NTS Daily Rig Operations reports. The daily recompletion activities for Postshot Hole U-3cn PS#2 are listed in Appendix A-1, and Table 4-1 presents abridged drill hole and completion statistics.

Table 4-1
Abridged Drill Hole Statistics for Postshot Hole U-3cn PS#2

LOCATION DATA:		
Coordinates:	Central Nevada State Planar:	N841,600, E688,169 ft
	Universal Transverse Mercator:	N4,101,819.0, E586,973.6 m
Ground Elevation:		1,217.4 m (3,994 ft)
Distance from BILBY (U-3cn)		9.4 m (31 ft) due west of Emplacement Hole U-3cn
DRILLING DATA:		
Spud Date:		9/23/63
Completion Date:		10/14/63
Total Depth:		793.4 m (2,603 ft)
Hole Diameters:		38.1-cm (15-in.) diameter borehole to 182.9 m (600 ft) 24.4-cm (9⅝-in.) diameter borehole to 562.7 m (1,846 ft) 22.9-cm (9-in.) diameter borehole to 793.4 m (2,603 ft)
CASING DATA:		
		10¾-in. od casing set at 182.6 m (599 ft) 4½-in. od casing (drill pipe) set at 792.2 m (2,599 ft). Top of casing noted to be at 7.9 m (26 ft) below surface in 1977.
WELL COMPLETION DATA:		
Perforations:		512.1 to 527.0 m (1,680 to 1,729 ft)
Downhole Pump:		10-horsepower Reda™ submersible pump installed in September 1977 at 509 m (1,670 ft) with pump intake at 503.5 to 504.7 m (1,652-1,656 ft). Pump hangs on 1⅝-in. od tubing.
Access Line:		None. One ½-in. od access port is installed at the surface.
Comments:		Casing pinched or collapsed at 587.0 m (1,926 ft) depth. A packer is set at 561.4 m (1,842 ft) inside the 4½-in. casing, which isolates the original perforations (at 579.1 to 792.2 m [1,900-2,599 ft]) from a second set, listed above. The condition of the pump was listed as unknown in 1984 (Buddemeier and Isherwood, 1985) but was found to operate adequately in January 1997.
Fluid Level[a]:		472.4 m (1,550 ft)

Sources: F&S (1966b); RSN (1991); Garber (1971b).

[a] Fluid level from logs by Birdwell in 1977 (Arteaga *et al.* [1991]).

The BILBY site was prepared in December 1996, as described in Section 3.2 of this report. Other work conducted in preparation for work at Postshot Hole U-3cn PS#2 included installation of an electrical panel for wiring of the pump and installation of hoses for discharge of fluids to the lined sump.

The existing pump was successfully tested and allowed to run for 23 minutes on January 9, 1997. The next two days were spent preparing for the pumping test, as IT personnel rigged up and tested their equipment. Pumping began at 1600 hrs on January 16, 1997 after time was spent that morning rigging up and thawing the flow lines. Sampling of fluid from the well began on Friday, January 17, 1997, and continued unit 1530 hrs on January 22, 1997. The pump was allowed to run nearly continuously, for a total pumping time of approximately 140 hours.

Following the pumping and sampling, the discharge hose and manifold were flushed with water tagged with lithium bromide. After the equipment was checked and found to be free of contamination, laborers removed the discharge line and other equipment.

4.3 Fluid Management

Effluent from Postshot Hole U-3cn PS#2 was monitored as prescribed in the *Fluid Management Plan for the Underground Test Area Operable Unit* (DOE, 1994a). All fluids produced during pumping and sampling were routed to a lined sump. Information on the volumes and quality of fluids pumped for this project will be presented in a separate report.

4.4 Hydrology

The most recent measured fluid level in Postshot Hole U-3cn PS#2 was at 472.4 m (1,550 ft), as determined from geophysical logs in 1977 when the pump was replaced (Arteaga *et al.*, 1991). No new hydrologic testing was conducted or fluid-level tags made during the 1997 recompletion operations at BILBY.

Approximately 286 m^3 (75,514 gal) of fluid were pumped from the well in January 1997. Preliminary results of field analyses made on this fluid indicated tritium activities ranging from approximately 12.0 to 13.7 million pCi/L (BN, 1997). Final water-quality data will be presented in a separate report.High levels of tritium were detected in the early groundwater studies at Postshot Hole U-3cn PS#2. Other radionuclides including ruthenium-106, cobalt-60, antimony-125, cerium-144, and cesium-137 have also been detected. These data are summarized in Table 4-2.

Table 4-2
Dissolved Radionuclides in Groundwater
Samples from Postshot Hole U-3cn PS#2 (through 1965)

Radionuclide	^{3}H	^{106}Ru	^{60}Co	^{125}Sb	^{144}Ce	^{137}Cs
Activity (picocuries per liter)	2.3×10^{8}	3,800	210	660	65	3

Sources: Beetem *et al.* (1965) as summarized by Borg *et al.* (1976), Table 17.

4.5 Recompletion

4.5.1 Planned Recompletion Design

The recompletion project undertaken at Postshot Hole U-3cn PS#2 was planned to include only replacement of the existing pump, if necessary, followed by pumping and limited sampling. The existing pump was found to be operable, so no equipment was removed from the well for examination or verification. Thus, the following section describes the existing completion configuration, as it is known from available records. Figure 4-2 is a schematic of the final well-completion design for Postshot Hole U-3cn PS#2 and Figure 4-3 shows plan and profile views of the wellhead configuration.

4.5.2 As-Built Completion Design

As described in the original drill hole history (F&S, 1966b), a 4½-in. casing was installed from the surface to 792.2 m (2,599 ft) soon after drilling in 1963. The 4½-in. casing was perforated in October 1963, between the depths of 579.1 and 792.2 m (1,900-2,599 ft). However, it was soon found that the casing was collapsed or pinched at 587.0 m (1,926 ft). A pair of inflatable packers in tandem was installed in June 1965, with the top packer set at 561.4 m (1,842 ft). Additional perforations were made with a jet tool between 512.1 and 527.0 m (1,680-1,729 ft). Two 0.95-cm (⅜-in.) diameter holes were made per foot of casing (Garber, 1971b). The existing 10-HP Reda™ pump was installed new in 1977. It was lowered on a string of 1⅔-in. tubing to 509.3 m (1,670.8 ft), with its intake at 503.5 to 504.7 m (1,652-1,656 ft). No access line is believed to be installed in the well, though a ½-in. access port is visible at the wellhead. The string composition is listed in Table 4-3, and tubing materials are given in Appendix A-2

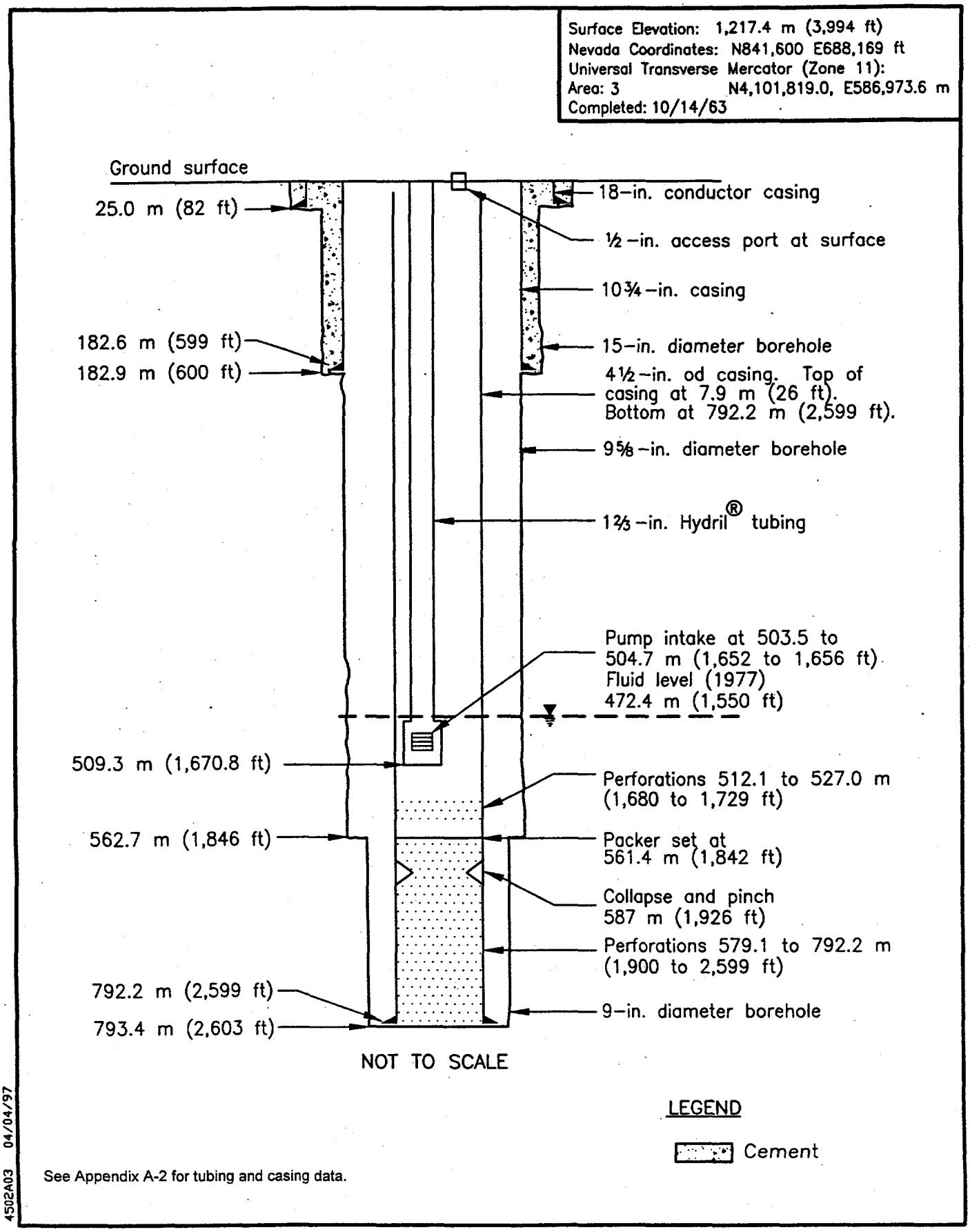


Figure 4-2
Completion Diagram for Postshot Hole U-3cn PS#2

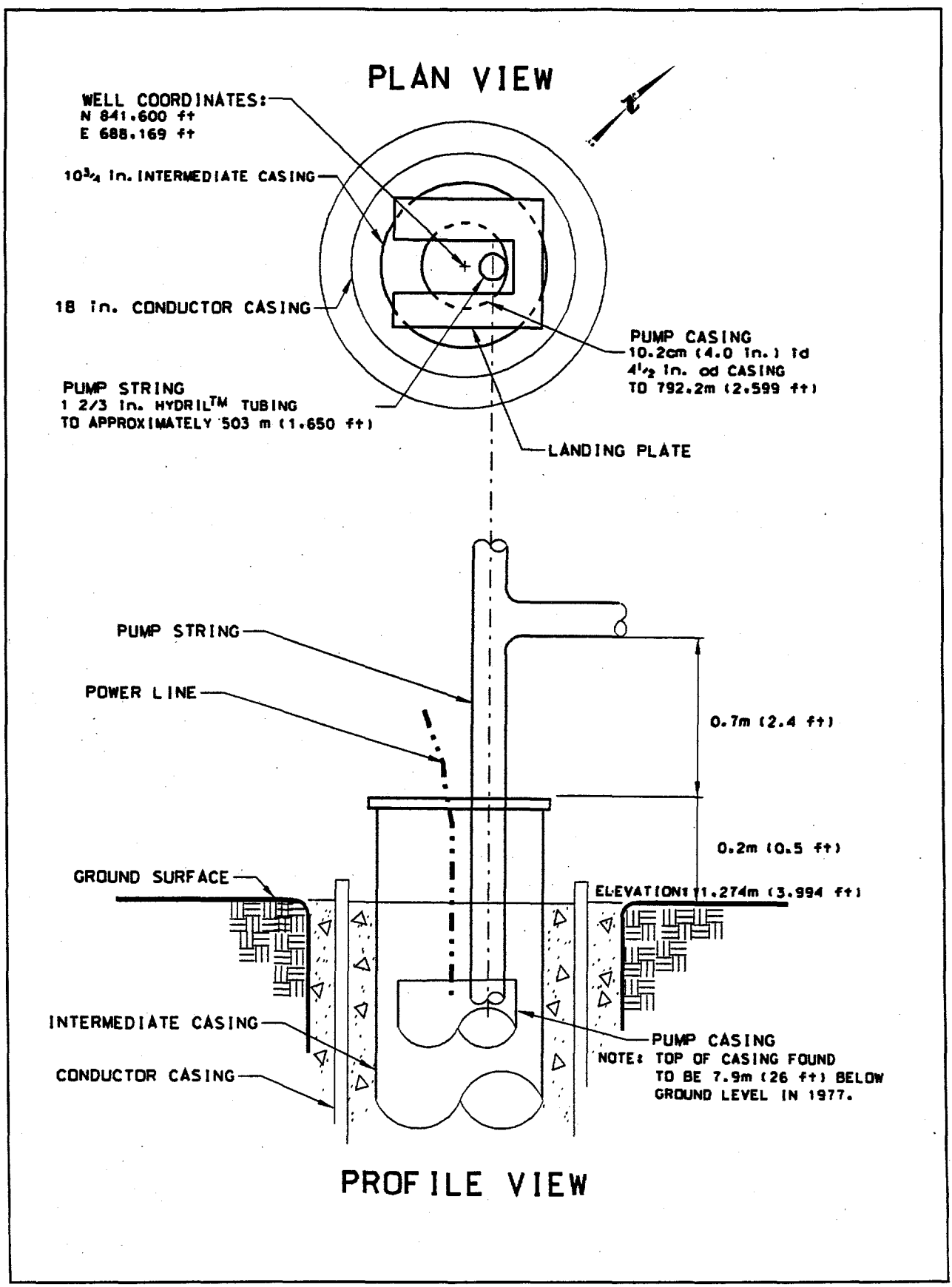


Figure 4-3
Wellhead Diagram for Postshot Hole U-3cn PS#2

Table 4-3
Postshot Hole U-3cn PS#2 Construction Summary

Completion String	Configuration	Cement
4½-inch casing	7.9 to 792.2 m (26 to 2,599 ft) Top of packer at 561.4 m (1,842 ft) Perforated at 512.1 to 527.0 m (1,680 to 1,729 ft)	Not cemented
1⅔-inch Hydril ™ tubing: Installed inside 4½-inch casing	Ground surface to approximately 502.9 m (1,650 ft) 10-HP pump hanging on end of tubing, with its intake at 503.5 to 504.7 m (1,652 to1,656 ft)	Not cemented

Sources: F&S (1966b; 1977); BN (1997)

5.0 Summary, Recommendations, and Lessons Learned from the BILBY Recompletion Operation

5.1 Summary

BILBY (U-3cn) was the first underground nuclear test conducted below the water table at the Nevada Test Site, and numerous studies were conducted in the 1960s and 1970s to determine the effects of the explosion on the groundwater. Several holes were drilled to study the near-field hydrology of the BILBY site, and two of these were evaluated for recompletion in January 1997. Hydrologic Test Hole U-3cn#5 had been drilled approximately 40 m (130 ft) from the edge of the chimney, into the regional carbonate aquifer, and Postshot Hole U-3cn PS#2 had been drilled within the collapse-chimney rubble. The original studies conducted through years of pumping and sampling these wells demonstrated that the groundwater table dropped locally as an immediate result of the explosion, but recovered to near pre-test levels in about five years. In addition, after pumping for more than ten years on the hydrologic test hole, which remained open to the lower carbonate aquifer, no radionuclides were found to have migrated outside the collapse chimney. However, due to the nature of these early tests and because of the time that has passed since either hole was sampled, scientists could not rule out the possibility that some radionuclides might have migrated into the lower carbonate aquifer. The positions of these two holes and the abundance of data available for the site made the BILBY site an ideal location for near-field monitoring studies. The Technical Working Group determined that valuable information about radionuclide migration might be obtained simply by replacing well hardware and monitoring groundwater quality, so the two holes were targeted for recompletion.

Hydrologic Test Hole U-3cn#5 is cased to the depth of 863 m (2,832 ft), with the lower 60.4 m (198 ft) of the hole open to Paleozoic-age sedimentary rocks of the lower carbonate aquifer. The existing inoperable pump was replaced with a new 50-HP tandem pump in January 1997. The existing open-ended access line was left in place. This pump was operated for 46 hours and groundwater samples were taken for analysis.

Postshot Hole U-3cn PS#2 was drilled in the BILBY collapse chimney rubble. The existing pump was found to be operable, but there appears to be no access line for water-level tags. The borehole is fully cased, but a packer isolates a 15-m (49-ft) perforated section that is open only to the rubble above the original explosion cavity, but below the water table. The pump in the postshot hole, originally installed in 1977 and last operated in 1984, was run for 140 hours in January 1997. Groundwater samples were taken for analysis.

No new drilling or geophysical logging was conducted for the BILBY recompletion project, but the geologic characteristics of the site are well known from previous studies. Figure 5-1 illustrates the site geology, the BILBY collapse chimney, and the two wells, showing the positions of the pump intakes and the portions of the holes that are open to the surrounding medium.

Samples of fluid from both holes were analyzed for tritium at the site during the recompletion project. Only very low levels of tritium were encountered in Hydrologic Test Hole U-3cn #5, and these dropped to near zero during pumping. Tritium activity of approximately 12.0 to 13.7 million pCi/L was encountered in fluid from Postshot Hole U-3cn PS#2.

5.2 Recommendations for Additional Data Interpretation

No plans exist at this time for additional interpretation of data from the BILBY site. The site remains available for future groundwater monitoring operations.

5.3 Lessons Learned

Although no drilling or testing was conducted at BILBY for this project, the work conducted for this recompletion project offers a few lessons for future operations, as listed below:

- Construction of the lined sump (estimated to take two weeks) was conducted over several weeks because sufficient labor resources were not available when work began. This intermittent work schedule resulted in lost efficiency, including extra travel time for numerous short work periods and time spent waiting for crews when the start of one operation was dependent on the completion of another. In the future, work should not begin until full resources are available to provide a continuous work force to complete the job.

- This operation provided a rare opportunity to inspect an old monitoring well. Evaluation of this information might provide insight to ways of improving the construction designs of long-term monitoring wells constructed in support of the DOE Environmental Restoration Program.

- Although significant data on the hydrology of nuclear test areas were obtained over a period of nearly twenty years at BILBY, it was still difficult to find and verify the most recent construction data for the wells at this site. As already begun for other UGTA projects, the effort to document all field activities adequately must continue.

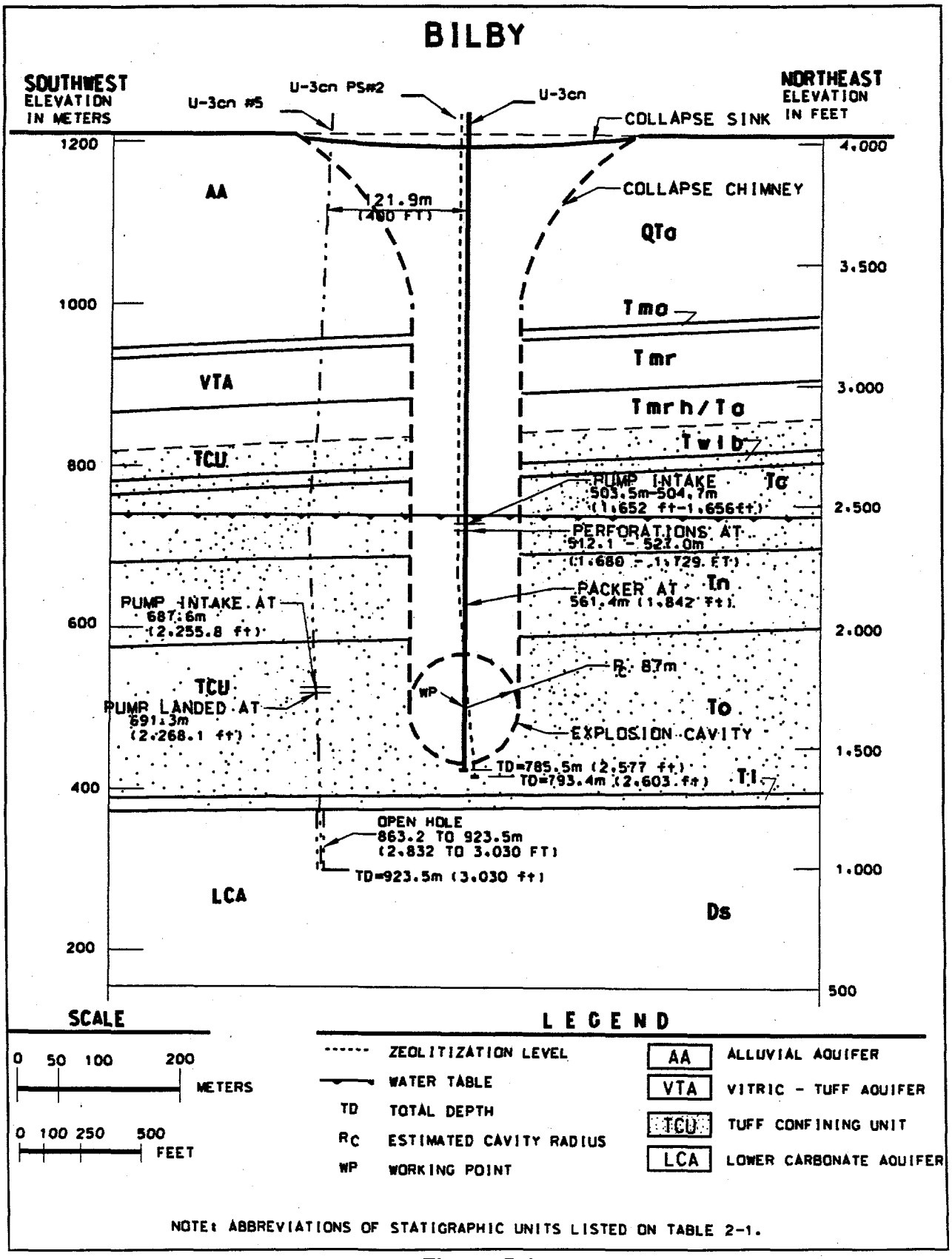


Figure 5-1
Southwest-Northeast Diagrammatic Cross Section Through BILBY and Hydrologic Test Hole U-3cn#5

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Appendix A
Completion and Recompletion Data

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Appendix A-1
Recompletion Histories for Hydrologic Test Hole U-3cn#5 and Postshot Hole U-3cn PS#2

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Table A-1-1
Hydrologic Test Hole U-3cn#5 Recompletion History

All work was conducted on 10-hours-per-day, 4-days-per week basis.

Source: Bechtel Nevada NTS Daily Rig Operations Reports

Activities at the BILBY site common to both Hydrologic Test Hole U-3cn#5 and Postshot Hole U-3cn PS#2:

Date	Day	Activity
11-6-96	(1)	Begin work on site construction: road dressing, etc.
11-7-96	(2)	Work on Sump #1 excavation.
11-12-96	(3)	Work on Sump #1 excavation.
11-13-96	(4)	Work on Sump #1 excavation
11-14-96	(5)	Work on Sump #1 excavation.
11-18-96	(6)	Work on Sump #1 excavation.
11-19-96	(7)	Work on Sump #1 excavation. Sand hauled to line sump.
11-20-96	(8)	Work on Sump #1 excavation
11-21-96	(9)	Begin digging sump liner trench.
11-25-96	(10)	Installing sand in liner trench; plastic liner delivered.
11-26-96	(11)	Installing sand in liner trench; dig "diverter" trench.
12-2-96	(12)	Install 40-mil liner in Sump #1; backfill trench to secure liner; install escape ladders.
12-3-96	(13)	Construct fences, dress road, build pads for parking, trailers, generators, etc.
12-4-96	(14)	Finish fences.
12-5-96	(15)	Build generator pad; work on parking area. Build perimeter fence for exclusion zone around U-3cn#5 and U-3cn PS#2.

Activities at Hydrologic Test Hole U-3cn#5:

Date	Day	Activity
12-9-96	(16)	Rig up and auger-drill 35.5-centimeter (14-inch [in]). anchor hole to 3 meters (m) (10 feet [ft]). Finish work on pads and parking.
12-10-96	(17)	Install anchor for Franks 300 rig. Move rig to location. Complete perimeter fences.
12-11-96	(18)	Cut, place, and secure 40-mil plastic protective sheet. Park rig on sheet.
12-12-96	(19)	Subdock crew lays out 70 joints (± 640.1 m [2,100 ft]) of 2⅞-in. 8Rd tubing and 120 joints (± 1,097.3 m [3,600 ft]) of 1.6-in. Hydril tubing for cleaning as time permits.
12-18-96	(20)	Transport equipment from ER-20-6 site. Set up water tank.
		Operation shut down for holidays, 12-19-96 through 1-5-97.
1-6-97	(21)	Continue site preparation (fencing, field offices, phone lines, etc.).

Hydrologic Test Hole U-3cn#5 Recompletion Activities, continued.

Date	Day	Activities
1-7-97	(22)	Continue site preparation.
1-8-97	(23)	Fencing continues; continue wiring transportainers; lay out discharge hoses from sump to well.
1-9-97	(24)	Continue wiring up support buildings. Remove insulation and discharge piping from wellhead. Spot rig over well; begin rigging up. Tubing determined not to be tied together. Lay down 35 joints (±324.6 m [±1,065 ft]) of 2⅞-in. tubing.
1-14-97	(25)	De-ice and repair rig. Rig operational at 1530 hours (hrs).
1-15-97	(26)	Cut 0.5 m (1.5 ft) off 9⅝-in. casing to lower the 2⅞-in. pump string and monitoring string to a workable level for the removal of the pump string. The two strings of tubing not attached together.
1-16-97	(27)	Lay down Joints #36-50 of 2⅞-in. pump string. Don anti-Cs; continue pulling tubing. Fluid leaking from Joint #52 is sampled and tritium level found to be 4,800 disintegrations per minute. Drop 3.8-centimeter by 1.5-m (1.5-in. by 5-ft) steel bar to open bleeder valve down hole; fluid drains from pipe. Lay down tubing Joints #53-70. Lay down bleeder valve. Lay down full Joint #71 and disconnect electric cable. Land pump assembly in the hole on the 5-ft pup joint.
1-21-97	(28)	Continue laying down pump assembly. Joint above pump partially plugged with rust; suction screen 90% plugged with rocks and pump debris. Lay out and measure pump string.
1-22-97	(29)	Pick up new 50-horsepower Centrilift™ pump; assemble tandem pump assembly. Screen shipped with pump too small; welder spot welds a suction screen to the pump and seals flanges. Pick up and run 2⅞-in. tubing, hitting joints with hammer to check for rust. Run pump on same (to Joint #19 at 443 ft). Lay down Joint #6 due to excessive rust inside.
1-23-97	(30)	Continue running pump. Lay down Joints #32, #35, and #38-55 due to excessive rust. Replace Joints #38-79 with good used, washed tubing. Strip on landing plate and land pump with bottom at 691.3 m (2,268.1 ft). IT Corporation (IT) personnel and laborers rigging up discharge flowline to sump and rigging up "sample manifold." Construct "mini sumps" under each connection.
1-27-97	(31)	Welder fabricates 2⅞-in. tubing landing assembly on wellhead. Make up tubing manifold; connect flowline. IT completes installation of flow monitoring equipment. Start pump at 1127 hrs; determine that it is running backwards. Shut down at 1139 hrs and reverse pump; restart at 1147 hrs; fluid to surface in 5 minutes. Small leak at wellhead sampled by RadSafe. Shut down pump at 1229 hrs after running flow directly into sump to flush any debris from line. Repair leak at wellhead. Restart pump at 1351 hrs. Fluid to surface in 5 minutes. Pumping and sampling test begins at 1400 hrs. Rig down Franks rig. IT allows flow to go into sump, waiting for it to clear before running it through flowmeter. Fluid directed through flowmeter at 1517 hrs though still rusty in color (41 gallons per minute [gpm]). Electricians move equipment out.

Hydrologic Test Hole U-3cn#5 Recompletion Activities, continued.

Date	Day	Activity
1-28-97	(32)	Pumping continuously since 1517 hrs on 1-27-97. IT collects grab samples. Remove some equipment from site. At 1515 hrs, total pumped = 62,684 gallons.
1-29-97	(33)	Continue pumping till 1215 hrs. IT collects grab samples. Total pumped during test = 116,346 gallons. Backflushed discharge line and sampling equipment with 40 bbl water tagged with LiBr. Continue moving out equipment.
1-30-97	(34)	Complete moving out equipment, leaving only IT sample van, transportainer, hose stands, and empty waste barrels (left per IT instruction).

Table A-1-2
Well U-3cn PS#2 Recompletion History

All work conducted on 10-hours-per-day, 4-days-per week basis.

See Table A-1-1 for activities at the BILBY site common to recompletion effort at both Hydrologic Test Hole U-3cn#5 and Postshot Hole U-3cn PS#2.

Source: Bechtel Nevada NTS Daily Rig Operations Reports

Date	Day	Activity
12-18-96	(20)	Install 40-mil plastic sheet for generator.
Operation shut down for holidays, 12-19-96 through 1-5-97.		
1-6-97	(21)	Bring generator from U-7ba to site. Attempt to start same with no success.
1-7-97	(22)	Install electrical backboard.
1-8-97	(23)	Install pump control box to backboard; wire up generator to the control box. Lay out discharge hoses from sump to well.
1-9-97	(24)	Finish installing discharge hose, with "mini" lined sumps under each connection; drain valve and pressure gauge installed at the wellhead to drain the line after the pump test, if needed. Set up exclusion zone; lay plastic liner around wellhead. Start pump at 1513 hours (hrs); fluid to sump in 17 minutes. Shut off pump at 1536 hrs. Drain hose back into well.
1-14-97	(25)	Wiring power to IT transportainer and working on automatic low-flow shut-off switch. IT rigs up flow meter. Repair IT generator.
1-15-97	(26)	IT continues rigging up. Lay auto-shut-off cable from sump to generator. Lay liner for extra fuel tank. Thaw discharge lines.
1-16-97	(27)	Wiring up low-flow switch. Try to thaw flow line; start pump in attempt to push ice out of line: no success. Continue trying to thaw line. Off-load and connect fuel tank. Start pump at 1440 hrs; fluid reaches sump in 19 minutes. Fluid allowed to run back through the pump. Restart pump at 1542 hrs; fluid to sump in 15 minutes. Pump test begins at 1600 hrs. Low-flow switch activated and set at 1.5 gallons per minute.
1-21-97	(28)	Pump test and sampling continue (since 1-16-97). IT takes samples and RadSafe monitors and analyzes.
1-22-97	(29)	IT takes samples. Pump shut off at 1330 hrs. Rig up and flush discharge hose and manifold with LiBr-tagged water. Drain hoses and roll them up. RadSafe checks of connections show no contamination.

Appendix A-2
Casing and Tubing Data for Hydrologic Test Hole U-3cn#5 and Postshot Hole U-3cn PS#2

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Table A-2-1
Casing and Tubing Data for Hydrologic Test Hole U-3cn#5

CASING	Depth Interval meters (feet)	Type	Grade	Outside Diameter (inches)	Inside Diameter centimeters (inches)	Wall Thickness centimeters (inches)	Weight per Foot pound/foot
Conductor casing	0 to 11.0 (0 to 36)	?	?	20	49.53 (19.5)	0.635 (0.25)	52.73
Surface casing	0 to 432.2 (0 to 1,418)	Carbon steel	J-55	13⅜	32.04 (12.615)	0.965 (0.38)	54.5
Intermediate casing	0 to 726.9 (0 to 2,385)	Carbon steel	J-55	9⅝	22.66 (8.921)	0.894 (0.352)	36.0
Liner	707.4 to 863.2 (2,321 to 2,832)	Carbon steel	J-55	6⅝	15.04 (5.921)	0.894 (0.352)	23.6
TUBING							
Pump string	0 to 672.2 (0 to 2,205.5)	Carbon steel	N-80?	2⅞	6.20 (2.441)	0.551 (0.217)	6.5
Access line	0 to 701.0 (0 to 2,300)	Carbon steel?	?	2⅜	?	?	?

Source: F&S (1966a); BN (1997)
Note: Records cannot be found to verify data marked with "?".

Table A-2-2
Casing and Tubing Data for Postshot Hole U-3cn PS#2

CASING	Depth Interval meters (feet)	Type	Grade	Outside Diameter (inches)	Inside Diameter centimeters (inches)	Wall Thickness centimeters (inches)	Weight per Foot pound/foot
Conductor casing	0 to 24.4 (0 to 80)	?[a]	?	18	43.8 (17.25)	0.953 (0.375)	70.59
Intermediate casing	0 to 91.1 (0 to 599)	Carbon steel	J-55	10¾	25.5 (10.05)	0.889 (0.35)	40.5
Pump casing	0 to 792.2 (0 to 2,599)	?	?	4½	10.16 (4.0)	0.635 (0.25)	?
TUBING							
Pump string[b]	0 to ~503 (0 to ~1,650)	Hydril™	J-55	1⅔	?	?	2.4

Source: F&S (1966b); F&S (1977); BN (1997)
[a] Records cannot be found to verify data marked with "?".
[b] Pump string replaced in 1977. Record of exact tubing length not found, but top of pump intake noted at 503.5 m (1,652 ft).

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Appendix B
Stratigraphic and Lithologic Logs for Hydrologic Test Hole U-3cn#5

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Stratigraphic Log of Hydrologic Test Hole U-3cn#5

Depth Meters	Depth Feet	Lithology	Stratigraphic Unit	Symbol	Thickness Meters	Thickness Feet
0 - 281.9	0- 925	**Alluvium:** Fine-grained; friable; calcareous; sandy.	Alluvium	QTa	281.9	925
281.9 - 291.1	925 - 955	**Ash-Flow Tuff and underlying Bedded Tuff:** Nonwelded; vitric.	Ammonia Tanks Tuff, Timber Mountain Group	Tma	9.2	30
291.1 - 355.1	955 - 1,165	**Ash-Flow Tuff:** Nonwelded; vitric to devitrified.	Rainier Mesa Tuff, Timber Mountain Group	Tmr	64	210
355.1 - 364.2	1,165 - 1,195	**Bedded Tuff:** Vitric.	Tuff of Holmes Road	Tmrh	9.1	30
364.2 - 425.2	1,195 - 1,395	**Bedded Tuff:** Devitrified to zeolitized.	Pre-Rainier Mesa, Post-Wahmonie Bedded Tuffs, Undifferentiated	Tmrh/Ta	61	200
425.2 - 435.9	1,395 - 1,430	**Bedded Tuff and Tuffaceous Siltstone:** Zeolitized.	Tuff of Wahmonie Flat	Twlb	10.7	35
435.9 - 548.9	1,430 - 1,801	**Bedded Tuff:** Zeolitized.	Crater Flat Bedded Tuffs, Undifferentiated	Tc	113	371
548.9 - 611.7	1,801 - 2,007	**Ash-Flow Tuff:** Partly welded; zeolitized.	Tunnel Formation (Possibly Bed 4E)	Tn	62.8	206
611.7 - 640.7	2,007 - 2,102	**Bedded Tuff:** Zeolitized.	Tunnel Formation and Older Tuffs, Undifferentiated	Tn	29	95
640.7 - 685.8	2,102 - 2,250?	**Ash-Flow Tuff:** Nonwelded to partially welded; devitrified to zeolitized.	Redrock Valley Tuff	Tor	45.1	148
685.8 - 781.8	2,250? - 2,565	**Ash-Flow Tuff:** Nonwelded; devitrified.	Tuff of Twin Peaks	Tot	96	315
781.8 - 818.4	2,565 - 2,685	**Bedded Tuff:** Clay alteration.	Older Tuffs, Undifferentiated	To	36.6	120
818.4 - 859.8	2,685 - 2,821	**Colluvium:** Gravel in calcareous, clay-rich matrix; tuffaceous beds.	Paleocolluvium	Tl	41.4	136
859.8 - 923.5 (Total Depth)	2,821 - 3,030 (Total Depth)	**Dolomite and Dolomitic Quartzite:** Dense; highly fractured; some calcite seams.	Simonson Dolomite	Ds	>32	>105

See U-3cn#5 lithologic log.
Stratigraphic nomenclature from Ferguson and others (1994).

Lithologic Log of Hydrologic Test Hole U-3cn#5
(Logged by W.J. Carr, U.S. Geological Survey)

Source: Dixon and others (1973). Stratigraphic nomenclature updated by Bechtel Geology, 1996.

Depth Meters/(Feet)	Lithologic Description	Stratigraphic Unit
0 - 281.9 m (0 - 925 ft)	**Alluvium:** Fine-grained; friable; calcareous; sandy, particularly lower part.	Alluvium
281.9 - 288.0 m (925 - 945 ft)	**Nonwelded Ash-Flow Tuff:** Very light-gray to yellowish-gray; vitric; contains abundant quartz, feldspar, and biotite.	Ammonia Tanks Tuff, Timber Mountain Group
288.0 - 291.1 m (945 - 955 ft)	**Bedded Tuff:** White; friable; fine-grained; contains abundant shards.	
291.1 - 304.8 m (955 - 1,000 ft)	**Nonwelded Ash-Flow Tuff:** Gray to pinkish-gray; vitric; shard-rich; contains quartz, feldspar, and biotite.	Rainier Mesa Tuff, Timber Mountain Group
304.8 - 312.4 m (1,000 - 1,025 ft)	**Nonwelded Ash-Flow Tuff:** Light-brown, vitric, shard-rich; contains a few small lithic fragments	Rainier Mesa Tuff, Timber Mountain Group
312.4 - 318.5 m (1,025 - 1,045 ft)	**Nonwelded Ash-Flow Tuff:** Light-gray to pinkish-gray; vitric	Rainier Mesa Tuff, Timber Mountain Group
318.5 - 330.7 m (1,045 - 1,085 ft)	**Nonwelded to Partly Welded Ash-Flow Tuff:** Light-pink; devitrified to vapor-phase crystallization; contains quartz, feldspar, and biotite.	Rainier Mesa Tuff, Timber Mountain Group
330.7 - 355.1 m (1,085 - 1,165 ft)	**Nonwelded Ash-Flow Tuff:** Light-pink, vitric; contains common dark glass shards.	Rainier Mesa Tuff, Timber Mountain Group
355.1 - 364.2 m (1,165 - 1,195 ft)	**Bedded Tuff:** Very light gray to light-tan; vitric; contains abundant white pumice and abundant quartz, feldspar, and biotite. May be bedded tuff or basal ash-flow of Rainier Mesa Tuff.	Tuff of Holmes Road
364.2 - 373.4 m (1,195 - 1,225 ft)	**Bedded Tuff:** Light-gray; slightly zeolitized; contains small dark lithic fragments, biotite, quartz, and feldspar.	Pre-Rainier Mesa, Post-Wahmonie Bedded Tuffs, Undifferentiated
373.4 - 388.6 m (1,225 - 1,275 ft)	**Bedded Tuff:** Pinkish-tan; devitrified; fine-grained, crystal-poor; contains small white pumice, and small lithic fragments.	Pre-Rainier Mesa, Post-Wahmonie Bedded Tuffs, Undifferentiated

Lithologic Log of Hydrologic Test Hole U-3cn#5

(Logged by W.J. Carr, U.S. Geological Survey)

(Page 2 of 3)

Depth Meters/(Feet)	Lithologic Description	Stratigraphic Unit
388.6 - 390.1 m (1,275 - 1,280 ft)	**Bedded Tuff:** Very light-gray; devitrified; contains abundant large biotite flakes.	Pre-Rainier Mesa, Post-Wahmonie Bedded Tuffs, Undifferentiated
390.1 - 422.1 m (1,280 - 1,385 ft)	**Bedded Tuff:** Tan to light-gray; zeolitized; friable; contains rare biotite, feldspar, and quartz.	Pre-Rainier Mesa, Post-Wahmonie Bedded Tuffs, Undifferentiated
422.1 - 425.2 m (1,385 - 1,395 ft)	No cuttings available.	Pre-Rainier Mesa, Post-Wahmonie Bedded Tuffs, Undifferentiated
425.2 - 435.9 m (1,395 - 1,430 ft)	**Bedded Tuff and Tuffaceous Siltstone:** Light-gray to light-pink; zeolitized; contains abundant biotite, feldspar, and altered light-green pyroxene. Dip of beds at 433.4 m (1,422 ft) is 10°.	Tuff of Wahmonie Flat
435.9 - 504.4 m (1,430 - 1,655 ft)	**Bedded Tuff:** Yellow to light-brown; zeolitized; fine-grained; contains some biotite, quartz, feldspar, and small lithic fragments.	Crater Flat Bedded Tuffs, Undifferentiated
504.4 - 548.9 m (1,655 - 1,801 ft)	**Bedded Tuff:** Pink, light-gray to yellowish-gray and white; zeolitized; contains rare to common crystals of quartz, feldspar, and biotite; small 0.6 - 0.3 cm (¼ - ⅛ in.) Dark volcanic lithic fragments are common. Zone 546.8 - 548.9 m (1,794 to 1,801 ft) contains much broken rock and clay, it is stained red and yellow and may be a fault zone or possibly a clay enrichment zone at top of the underlying ash-flow tuff. Thin section taken from 541.6 m (1,777 ft).	Crater Flat Bedded Tuffs, Undifferentiated
548.9 - 611.7 m (1,801 - 2,007 ft)	**Partly Welded Ash-Flow Tuff:** Light-gray to yellowish-gray; contains 10 percent phenocrysts of quartz, feldspar, and hornblende, and 5-10 percent gray and purple lithic fragments 0.2 - 1.3 cm (1/16 - 1/2 in.) In diameter. Pumice is pink and yellow. Thin sections taken from 568.5 m (1,865 ft), 576.7 m (1,892 ft), and 586.4 m (1,924 ft).	Tunnel Formation (Possibly Bed 4E)
611.7 - 640.7 m (2,007 - 2,102 ft)	**Bedded Tuff:** Red, light-tan and light orange-brown, fine- to medium-grained; most beds contain common biotite, quartz, and feldspar; rare to common dark volcanic and locally Paleozoic lithic fragments. Dip of bedding at 618.7 m (2,030 ft) is 15°.	Tunnel Formation and Older Tuffs, Undifferentiated

Lithologic Log of Hydrologic Test Hole U-3cn #5

(Logged by W.J. Carr, U.S. Geological Survey)

Depth Meters/(Feet)	Lithologic Description	Stratigraphic Unit
640.7 - 685.8 m (2,102 - 2,250? ft)	**Nonwelded to Moderately Welded Ash-Flow Tuff:** Light-gray to pink, devitrified to zeolitized; contains 5-10 percent phenocrysts of quartz, feldspar, and biotite; also contains rare dark purple porphyritic lithic fragments as large as 2.5 cm (1 in.). Thin sections taken from 641.9 m (2,106 ft) and 664.5 m (2,180 ft).	Redrock Valley Tuff
685.8 - 781.8 m (2,250? - 2,565 ft)	**Nonwelded Ash-Flow Tuff:** Light-gray; devitrified; contains common feldspar and biotite with rare quartz; phenocrysts more common at 757.4 - 765.0(?) m (2,485 - 2,510 ft). Locally contains abundant lithic fragments. Possible fault zone near or at top of unit 691.9(?) - 698.0(?) m (2,270[?] - 2,290[?] ft) may be contact between Redrock Valley Tuff and Tuff of Twin Peaks. Thin sections taken from 688.8 m (2,260 ft), 701.0 m (2,300 ft), and 730.0 m (2,395 ft).	Tuff of Twin Peaks
781.8 - 818.4 m (2,565 - 2,685 ft)	**Bedded Tuff with Clayey Alteration:** Light-gray to reddish-brown; Clayey alteration contains rare to common feldspar, quartz, and biotite.	Older Tuffs, Undifferentiated
818.4 - 859.8 m (2,685 - 2,821 ft)	**Colluvium:** Very light-gray to reddish-brown; rich in clay; tuffaceous fragments and Paleozoic rock fragments. Rock consists largely of a colluvial gravel in weakly cemented calcareous and clayey matrix. Fragments are gray dolomite and limestone, and light-gray quartzite; unsorted. Fragments are subangular to subrounded 1.3 - 7.6 cm (½ - 3 in.) In diameter. Interval contains rare 15.2 - 25.4 cm (6 - 10 in.) Thick beds of pink to tan clayey tuffaceous sandstone. Core at 835.2 - 840.9 m (2,740 - 2,759 ft) contains somewhat more rounded gray to olive-green fragments of slightly calcareous, poorly indurated clayey sandstone. Common black carbonaceous plant remains.	Paleocolluvium
859.8 - 891.5 m (2,821 - 2,925 ft)	**Dolomite:** Light and medium gray to light brownish-gray; fine- to medium-grained; dense; locally contains seams of calcite. Fractures present at 863.5 m (2,833 ft), 864.4 m (2,836 ft), 866.2 (2,842 ft); rock is highly fractured between 868.7 and 876.3 m (2,850 and 2,875 ft).	Paleozoic Rocks, Simonson Dolomite?
891.5 - 923.5 m (2,925 - 3,030 ft) (Total Depth)	**Dolomitic Quartzite:** Light tan; fairly well sorted, contains 50 percent subrounded quartz grains; locally contains reddish-brown stains; fairly well indurated. Thin sections taken from 892.5 and 923.5 m (2,928 and 3,030 ft). Small fault at top of interval.	

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