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STERLING REENTRY

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Contents

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Abstract

The Sterling Event was a 380-ton nuclear detonation conducted in the cavity remaining from the Salmon Event at a depth of 2717 ft in the Tatum salt dome near Hattiesburg, Miss.

The reentry operation was undertaken thru a request by the Advanced Research Projects Agency (ARPA) to determine the general cavity conditions post Sterling, i.e., shape, temperature, pressure and radiation levels.

The cavity investigation was conducted by reentry thru the 9-5/8-in. Sterling emplacement casing into the standing cavity. The original emplacement hole (Sta 1-A) as represented by the conditions in the 9-5/8-in. casing still has good integrity.

The cavity was found to have a slight positive pressure (under 2 psig) upon reentry. Temperatures and radiation levels were obtained by in-hole geophysical logging tools. The levels measured were as predicted for temperatures ranging in the mid 150°F. The radiation levels in the cavity ranged from 25 to 45 mR/hr increasing as the detector approached the cavity bottom from 2660 to 2742 ft. A local high radiation level was found between the open cavity and the bottom of the diagnostic canister, i.e., the conical collapse zone from 2640 ft to 2660 ft in the hole. This level peaked at about 250 mR/hr in this region.

The general shape of the post Sterling cavity is the same as the pre Sterling configuration except for a rubble pile in the center of the floor covering perhaps some 50 ft in diameter and approximately 11 ft high in the center of the floor tapering to the original floor level at the outside of the 50-ft diameter.

A volume approximation was obtained by pressurization and flow test in the cavity. This indicated a volume of 630,000 ± 50,000 cu ft. This volume falls within the variation of a similar measurement made on the pre Sterling cavity.

Gas samples in the cavity were obtained and analyzed. These analyses showed the cavity gas is similar to normal air with no hazardous environmental conditions.

The cavity floor was cored to a depth of 2762 ft. No recovery was obtained through the 11 ft of rubble. Approximately 8 ft of core was recovered from the area below the rubble. In this core the Sterling melt is represented in the first foot with the remaining showing some slight mixing of Sterling debris/Salmon melt and unaffected Salmon melt.

The cavity was photographed using a downhole 35 mm camera system functioning thru the downhole TV camera and cable. A total of 48 color photos were taken covering the top, middle and bottom of the cavity and 360° around the cavity.

Introduction

The Sterling Event was a 380-ton nuclear detonation in the Tatum salt dome near Hattiesburg, Miss., at a depth of 2717 ft (see Fig. 1). The detonation occurred in the standing cavity remaining from the Salmon Event.[1] The explosive was emplaced and detonated in the center of the Salmon cavity on 3 December 1966, at 12:15:00 GMT (0615 CST). The specific objectives[2,3] of Project Sterling were: (1) Determine the extent of the decoupling of a sprung cavity in salt; specifically, determine the decoupling ratio as a function of frequency. (2) Determine the validity of decoupling calculations for a sprung cavity. (3) Define any operational problems associated with the use of such a cavity.

Sterling Reentry Objectives

The objectives of the Sterling Reentry Program were to determine the shape, temperature, pressure, and radiation levels of the post Sterling cavity as shown in Fig. 2. To accomplish these objectives, Sterling reentry included within its scope the construction and use of a chip processing plant, reentry drilling, temperature and gamma logging, gas sampling, coring of the cavity floor, TV and photographic viewing of the cavity, and pressure flow testing to estimate the cavity size.

<u>Emplacement Hole Selection</u>

There were three holes, Station 1-A, PS-I, and PS-II, that entered the original cavity as shown in Figs. 3 and 4. PS-I and PS-II were instrumentation holes that have been cemented to the surface. Station 1-A, the emplacement hole (see Fig. 5) was selected because it had provision for cavity reentry through a drill string which had a 9-5/8-in. o.d. and a 8-7/8-in. i.d., and a casing with threaded joints. The outer annulus of the emplacement hole had a 20-in. o.d. casing down to

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[1] D. Rawson, P. Randolph, C. Boardman and V. Wheeler, <u>Post Explosion Environment Resulting from the Salmon Event</u>, Lawrence Radiation Laboratory, Livermore, Rept. UCRL-14280, Rev. II (1966).

[2] C. J. Sisemore, L. A. Rogers and W. R. Perret, <u>Project Sterling—Subsurface Phenomenology Measurements Near a Decoupled Nuclear Event</u>, LRL/Sandia Laboratory Rept. VUF-3025 (1967).

[3] D. Springer, M. Denny, J. Healy and W. Mickey, <u>The Sterling Experiment: Recoupling of Seismic Waves By A Shot-Generated Cavity</u>, Lawrence Radiation Laboratory, Livermore, Rept. VUF-3026 (1968).

2202 ft and was uncased from there to the top of the cavity (~2660 ft).

Sterling Reentry (See Appendix A)

The following is a brief summary of the Sterling Reentry Program.

We began reentry procedures on 9 March 1968, with mobilization of the drill rig, compressors, and blowout preventer. Sand removal and reentry drilling began on 14 March 1968 and continued until 22 March 1968, when communication with the cavity was achieved at a depth of 2640 ft.

During reentry drilling, we utilized the chip processing plant (see Appendix B) to trap all particulates—from the drilling returns—larger than 0.3 microns, and to dilute and disperse the remaining effluent into the atmosphere as shown in Fig. 6.

With the exception of TV coverage, we performed all diagnostics after reentry into the cavity was accomplished.

CAVITY CONDITIONS

TV and Photography (see Appendix C)

We made the first TV run when

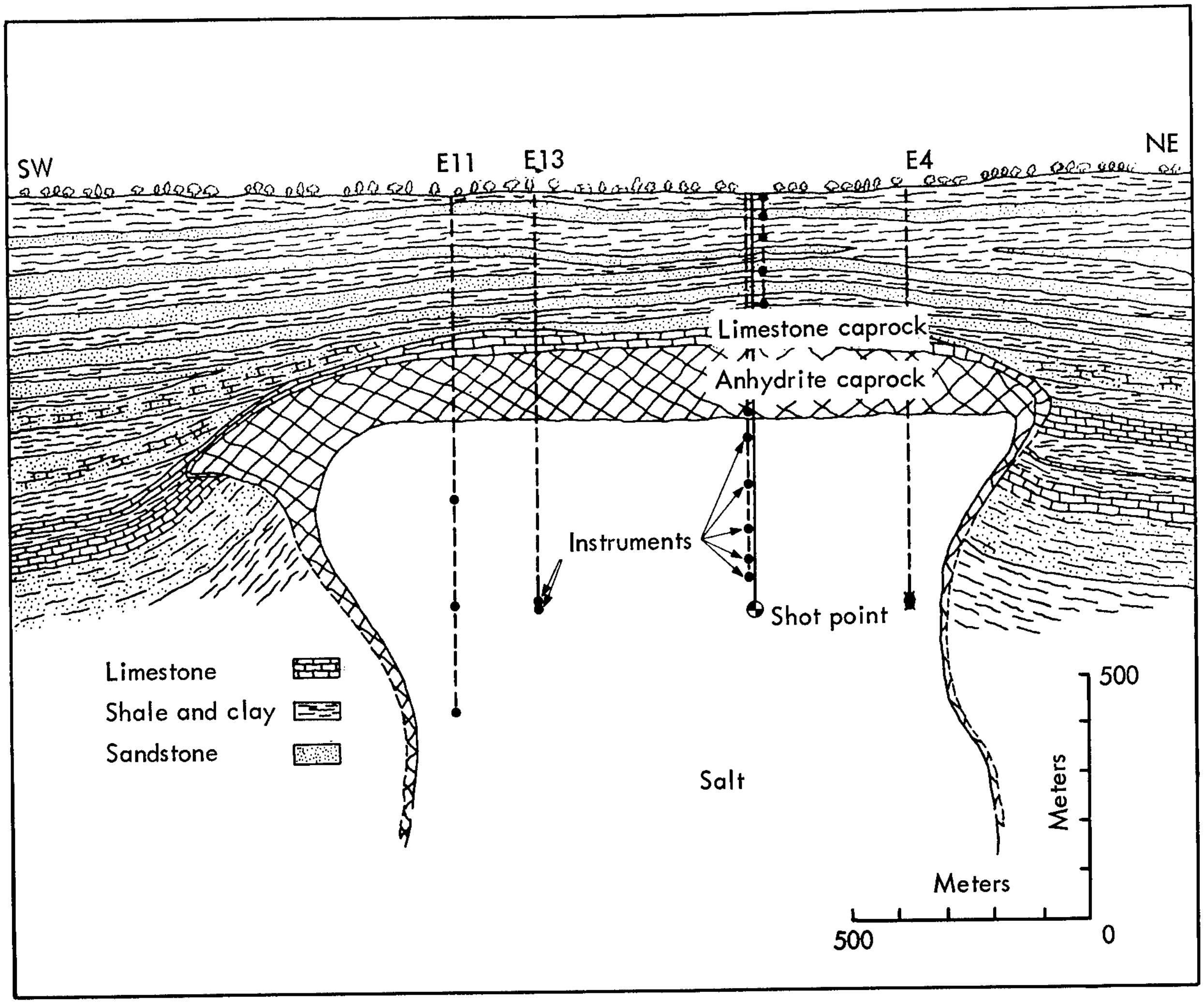

Fig. 1. Cross-section of the Tatum-dome test site.

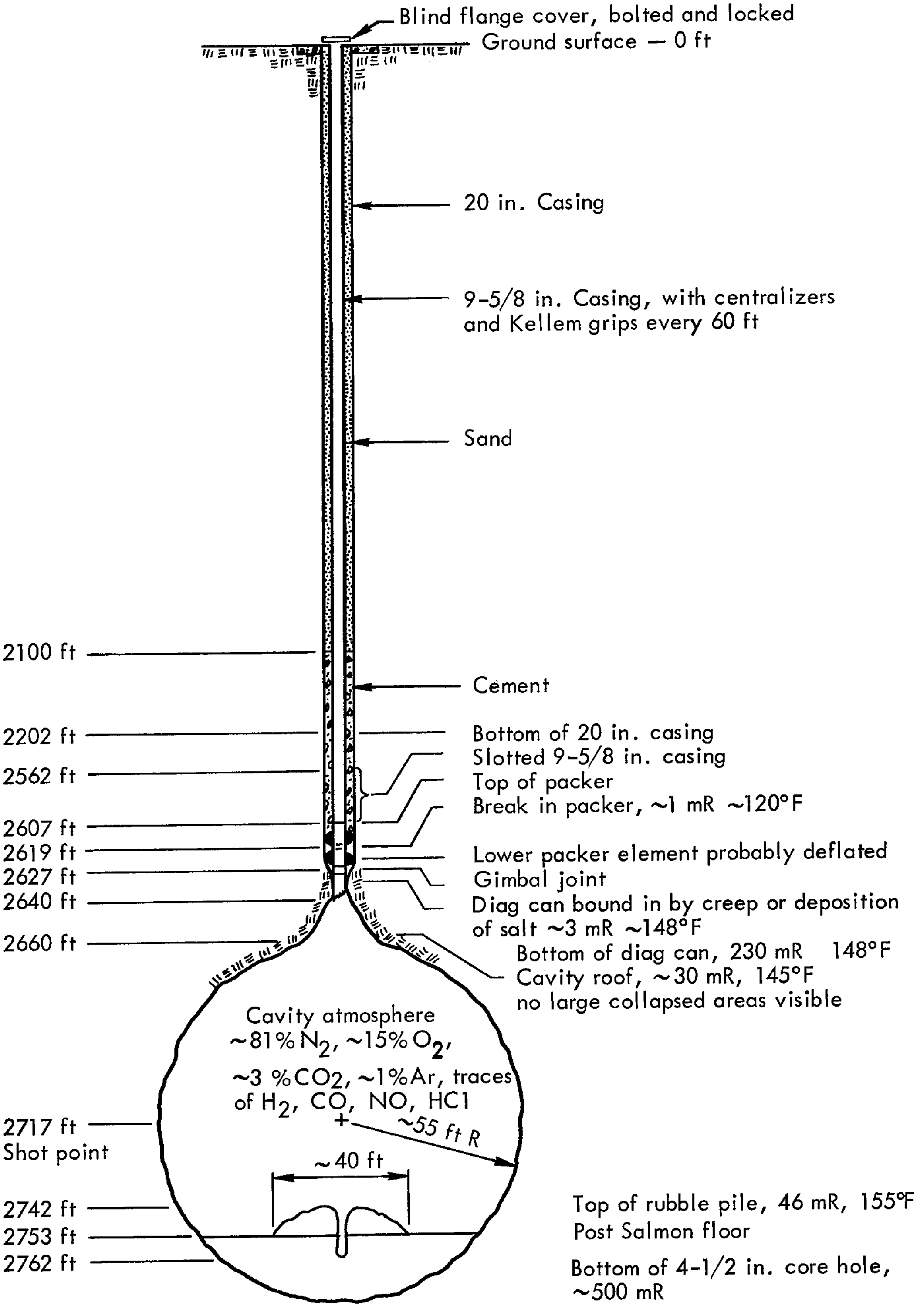

Fig. 2. Post-Sterling emplacement hole and cavity conditions.

drilling reached the top of the packer. We observed water dribbling down the casing (see Fig. 7) possibly from a water leak through the cementing slot on the hole bottom—but it appeared to be condensate rather than leakage. At the bottom (which appeared bubbly because of the water) there was a puddle, but its level did not rise. Reentry milling was continued even though it was not determined from where the excess water was originating. If water was entering the cavity outside the 9-5/8-in.

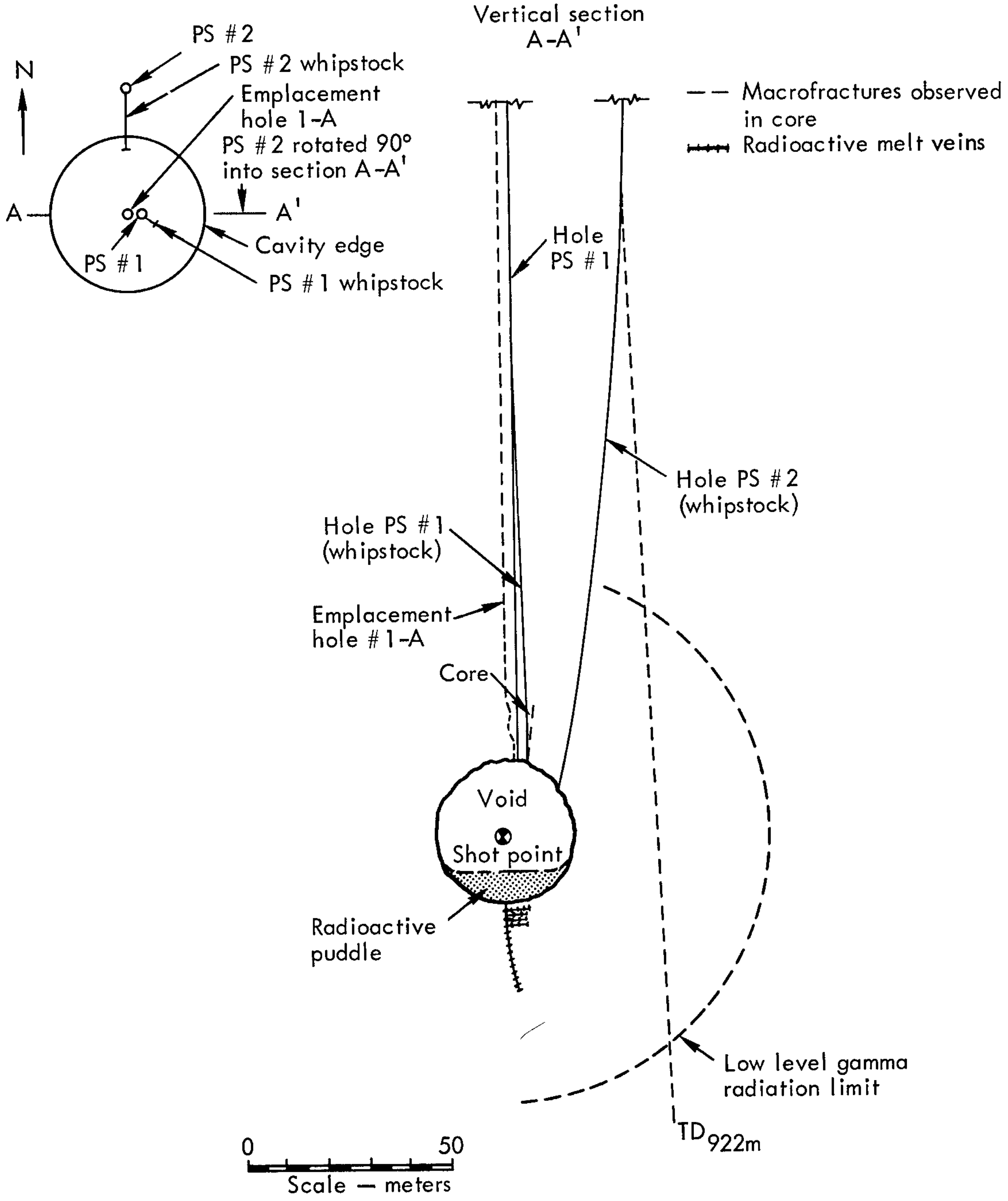

Fig. 3. Vertical section of Sterling emplacement and drill holes.

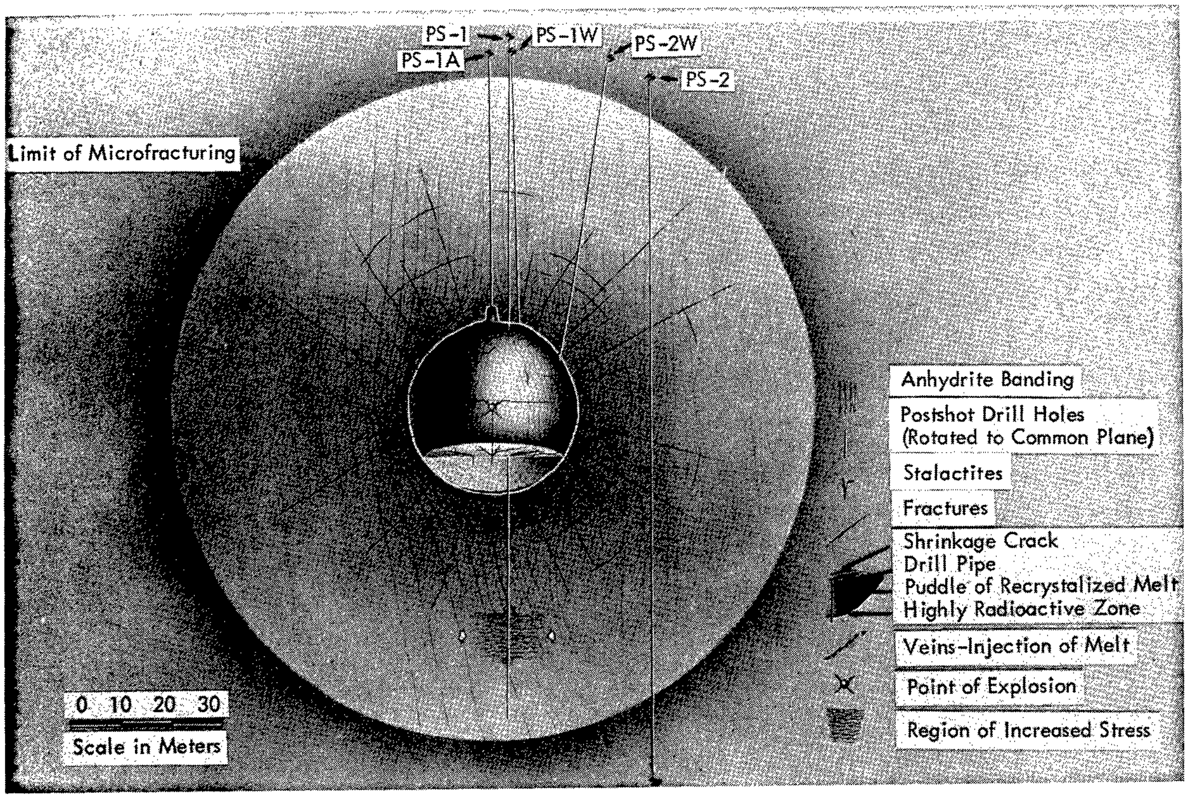

Fig. 4. Pre-Sterling cavity with micro-fracturing conditions.

casing (the only place where an effective seal could be made) it was decided nothing could be lost by continuing the milling process.

Another attempt was made to determine the problem in the packer. We found that the 9-5/8-in. casing was cut in two at ~2619-2621 ft. However, we were unable to lower the camera into the bottom section of the packer as shown in Fig. 8A.

A leading centralizer guide was built to solve the problem of the obstruction by the broken packer. On the third attempt, the TV camera passed through the casing. The hole bottom had the appearance of the first TV run, i.e., a bubbling effect. However, the casing was dry. The slot (which might have been the source of water during the first run) was now dry (see Fig. 8B). There was a definite possibility that the water was refluxing in the hole, i.e., not leaking into the cavity in any great quantity.

Milling continued until cavity communication was complete. The hole was bled and cleared, and we proceeded with a TV run with the down-looking camera, where a limited view of the bottom of the cavity was obtained (see Fig. 9). This entry revealed the top of a rubble pile at 2742 ft, or about 11 ft above the post Salmon cavity floor. The rubble appeared to be wet, and small puddles were visible. The horizontal extent of the rubble pile was beyond the camera's view. During this TV run, there was less water trickling down the 9-5/8-in. casing than in previous runs, and there was no water coming out of the cementing slot that had previously appeared to be leaking.

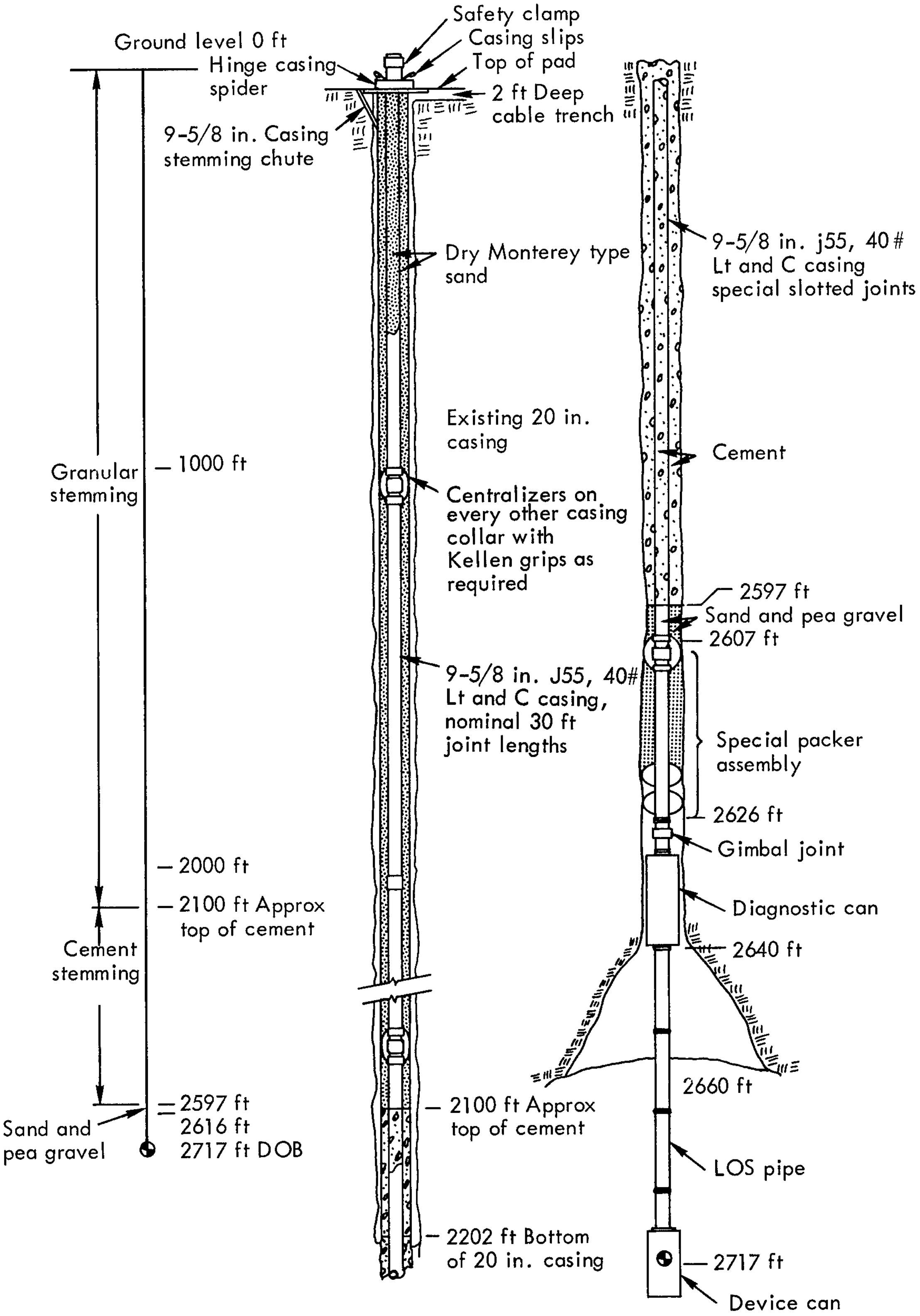

Fig. 5. Station 1-A emplacement and stemming plan.

We lowered the side-looking camera, but no view of the cavity was obtained because of fogging and mud-spatter on the mirror. Additional TV runs failed because the lenses or mirror was splattered with water, fogged over, or the cavity itself was fogged. These failures led to a series of "fixes" which included: (1) placing a 7-in. diam. liner in the packer-diagnostic can area of the hole to prevent splatter and snaggling (2) providing better centralizers and antidrip hoods for the TV cameras (3) installation of a heater behind the side-looking camera mirror to prevent condensation on its surface and (4) ventilating the cavity in hopes of reducing any fog. After making these improvements several TV tape recordings and movie films were obtained of the cavity.

However, these rather limited views revealed that the rubble pile was about 50-ft in diameter, and no areas in

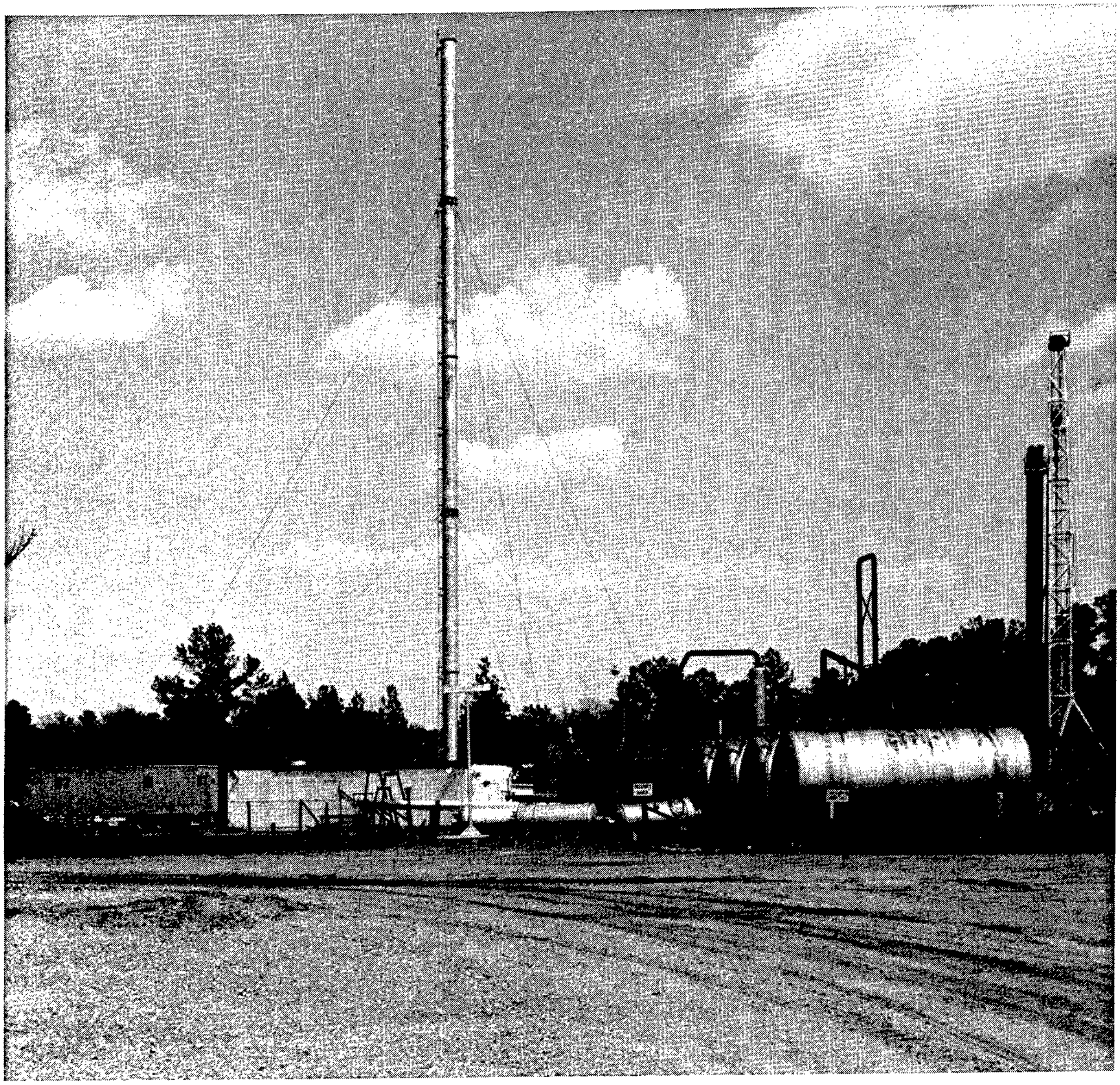

Fig. 6. Reentry chip processing plant.

Fig. 7. TV photo of casing at 2620 ft showing water (white streaks) inside casing.

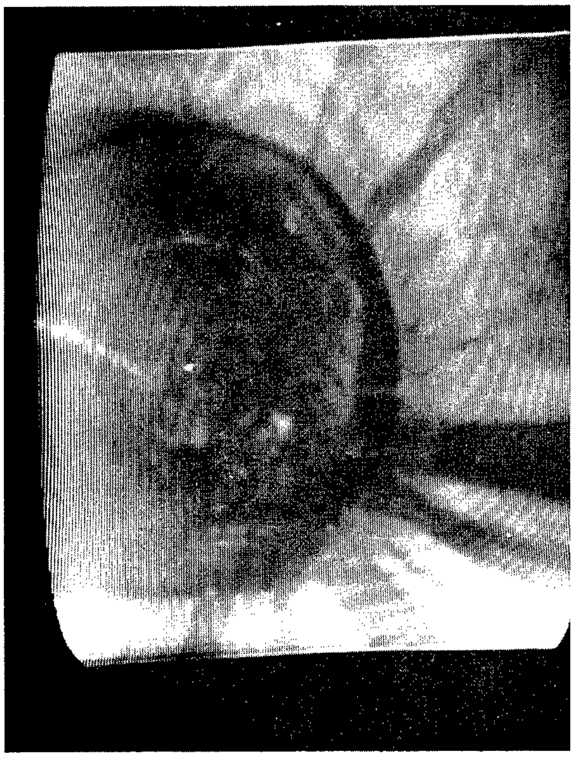

Fig. 8A. TV photo showing milled casing (dark angular ring).

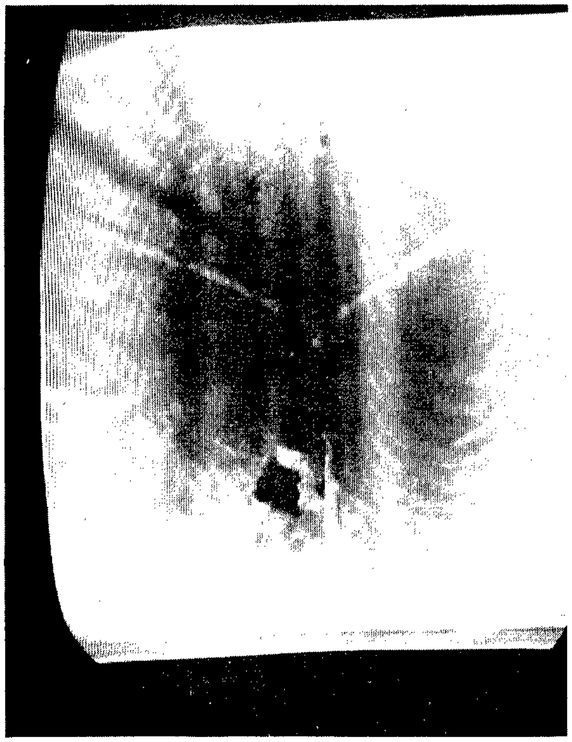

Fig. 8B. TV photo at 2605 ft showing slots in casing suspected of leaking water.

Fig. 9. TV photo of rubble pile in cavity at approximate depth of 2742 ft.

the roof could be positively identified as the source of the rubble.

We then constructed a special lighting system and camera package for Sterling reentry. It consisted of a cylinder about 7½-in. in diameter by 7 ft long, the upper nine-tenths of which was occupied by capacitors and a strobe light, while the lower part formed a housing for either a 35mm camera or a stereo camera. This package was hung beneath the down-looking TV camera and was powered and controlled through channels available in the TV cable. The cameras were mounted so that the axis of their view was horizontal. The planning capability of the TV camera permitted aiming the photo cameras in all directions.

The enlarged 35mm photos shown in Figs. 10 through 12 were dark, but the roof and floor areas were visible. There were no collapsed areas distinguishable in the roof. The floor was dry and the rubble pile appeared to cover about the center one-third of the diameter of the floor.

The stereo camera photos were all completely fogged, because of etching of the lenses by the corrosive atmosphere.

The TV and camera systems were very useful for gathering information. During the first TV run, we could determine the extent of damage to the diagnostic can. The inside of the diagnostic can was very rough. Each section was clearly definable, i.e., top section full of fuzed lead shot, dog house No. 1 through No. 4 and a section of the line of site pipe 5 ft long (very ragged) below the diagnostic can.

We were able to get a good view of the floor directly below the 9-5/8-in. casing. The following determinations were made: (1) material was identified as to relative size (2) we could see where rubble samples and coring had taken place (3) floor conditions were not visible beyond a 10 to 12 ft diam which is the field of view of the down-looking TV camera

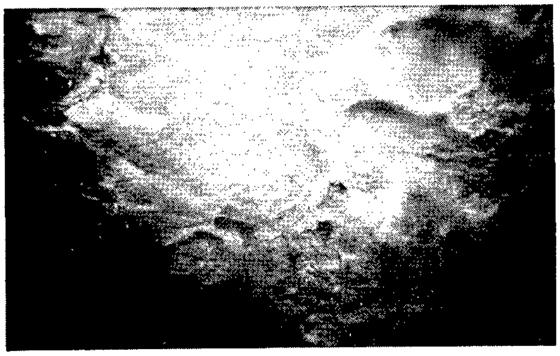

Fig. 10. Cavity roof at approximate depth of 2665 ft.

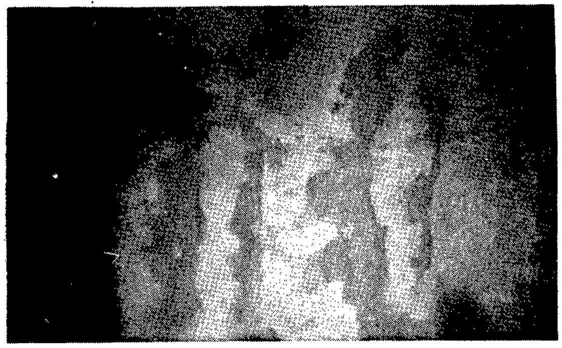

Fig. 11. Cavity side wall at approximate depth of 2720 ft.

Fig. 12. Cavity floor showing rubble pile and wall-to-floor transition.

(4) there was only limited visibility of the conical section above the cavity (2645 ft to 2655 ft) (5) the cavity floor was viewed from approx. 2736 ft (6) Water was dripping by the camera into the rubble pile on the floor, creating small puddles in the depressions in the rubble.

Shut-in Pressure Measurements

To measure the cavity shut-in pressure upon reentry, we installed an absolute pressure gage on the chip process line at the well head, and a compound gage on the downhole side of the blow-out preventer rams.

In drilling from 2620 ft to attempt reentry, on two occasions we thought we had cavity communication, but on opening the system into the chip process plant the slight pressure which had developed dropped very rapidly. These slight pressures probably represent some pressuring of the semi-permeable material between the 9-5/8-in. casing and the 20-ft hole from 2607 ft (packer top) on down.

The first definitely noticeable communication with the cavity took place during a trip to replace a mill that had reached to within $2\frac{1}{2}$ ft of the bottom of the diagnostic can. We shut in the system as soon as the condition was observed and the pressure measured at 4.2 psig. There is no way to determine how much of this pressure was attributable to drilling air. When the mill penetrated the bottom of the diagnostic can on 22 March at 1800 hr, the system was again shut-in and the pressure measured at $2\frac{1}{4}$ psi. The system held this pressure to 0700 hr on 23 March. When the system was opened to the chip process system, more than $3\frac{1}{2}$ hr were required to relieve the pressure to atmospheric.

The best that can be said regarding cavity pressure is that it was probably slightly more than atmospheric. Therefore, the "natural" cavity pressure was never clearly established.

Proper metering was not available so we made no attempt to estimate the cavity volume from this data.

Gamma and Temperature Logging

We started the logging program at approximately 1600 hr, 23 March and completed it at approximately 1600 hr, 26 March 1968.

Schlumberger Well Surveying Corp. was the contractor selected to perform the logging services because: (1) This firm provides the capability of recording gamma radiation in excess of levels anticipated within the drill hole and the cavity (300 mR/hr). (2) No problems were expected with the temperature logging because Schlumberger commonly records higher temperatures in oil wells than were predicted in the cavity (200-300°F).

Radiation Log (Gamma)

The Schlumberger sonde had been calibrated to record radiation in American Petroleum Institute units, which is an arbitrary scale devised to evaluate the very low level of natural state radiation in rocks. Since the levels of radiation anticipated in the drill hole and cavity were several orders of magnitude greater than the natural state of most rocks, we recalibrated the sonde.

We accomplished calibration by placing a 100-mR/hr source at varying distances from the detector (G-M tubes) in the sonde and reading the amount of gamma radiation recorded on a calibrated geiger counter at equal distances from the source. We then set the Schlumberger instruments to read values equal to those recorded on the geiger counter. Different levels of radiation could be obtained by varying the proximity of the source to the detectors. Distances were varied to permit calibration at the following radiation levels: (1) background (zero on log) (2) 10 mR/hr (3) 30 mR/hr (4) 50 mR/hr.

We made six in-runs and out-runs at varying logging speeds and recording sensitivities. The interval logged was from approximately 2620 ft (depth from ground level) to the top of the rubble pile on the floor of the cavity at a depth of 2742 ft. The rubble pile was encountered at the same depth on all in-runs, and the sonde was allowed to sit on the top of the rubble for two minutes time on each run to record any variation of radiation. Reproducibility of all logging profiles was exceptionally good.

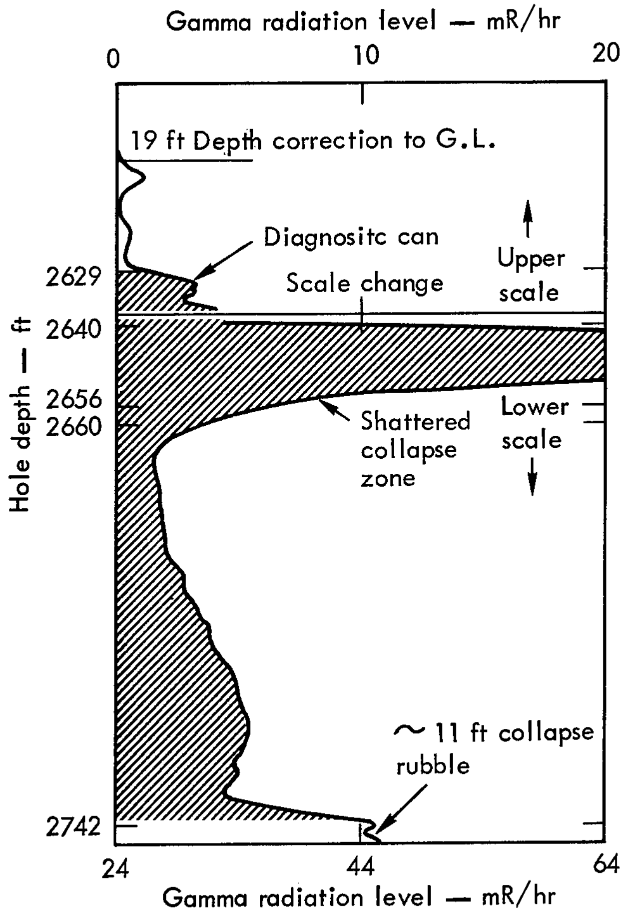

Fig. 13. Gamma radiation log (high intensity).

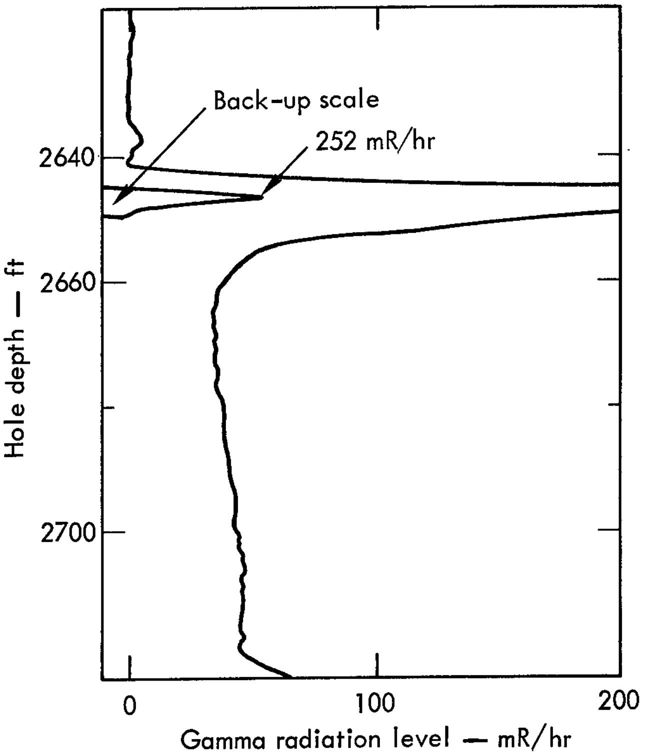

Fig. 14. Gamma radiation log (low intensity).

Figures 13 and 14 are reproductions of a portion of the radiation log. Both a high and a low intensity record are shown to better define four distinct radiation zones:

(1) Lower portion of diagnostics canister left in the hole after milling through the package (2629 ft-2640 ft). The maximum reading was 3.25 mR/hr.

(2) Shattered collapse zone, an essentially conical region extending from the roof of the cavity (~2660 ft) to an apex of ~2640 ft. The base diameter of this

cone is about 10-12 ft, and the surrounding salt is very highly fractured, primarily as a result of the Salmon detonation. Maximum radiation in this region was 252 mR/hr. A "best guess" explanation of the high radioactivity would be that radioactive products, resulting from the Sterling detonation, were injected and trapped along the existing fractures of the surrounding salt. Although some of the highly fractured material subsequently collapsed into the cavity, forming the rubble pile on the floor of the cavity, enough radioactive material remained trapped in the fractures to produce this high zone.

(3) Cavity Void—The degree of radiation within the cavity consistently increases downward from a low at the top of 27 mR/hr, neglecting the anomalously high zone above, to a high of 35 mR/hr at a point approx 20 ft above the rubble pile. The radiation trend then reverses to a value of 33 mR/hr about 7 ft above the rubble pile.

This reversal reflects the shielding effect of the rubble pile geometry. If one looks at the estimated size of the rubble pile top and base from 2735 ft on down (see Fig. 15), the sonde will be in the shadow of the rubble from the Sterling melt puddle, assuming it has more or less uniform distribution over the floor.

In the lowermost 7 ft of the cavity void, the radiation intensity increases constantly to a cavity maximum of 45-46 mR/hr when the logging sonde is in contact with the rubble pile. This value correlates very closely with more sophisticated analyses at a later date made on recovered samples of rubble.

(4) Rubble Pile—This zone is essentially a flattened cone approximately 15-16 ft in diameter and extending about 11 ft above the top of the Salmon-Sterling puddles at its apex. The material comprising the pile is primarily fragments of salt that have fallen from the shattered collapse zone described above. It is also expected that portions of the line of site emplacement casing that survived could be part of the rubble.

Based on the exacting calibration of the radiation sonde and the continuous

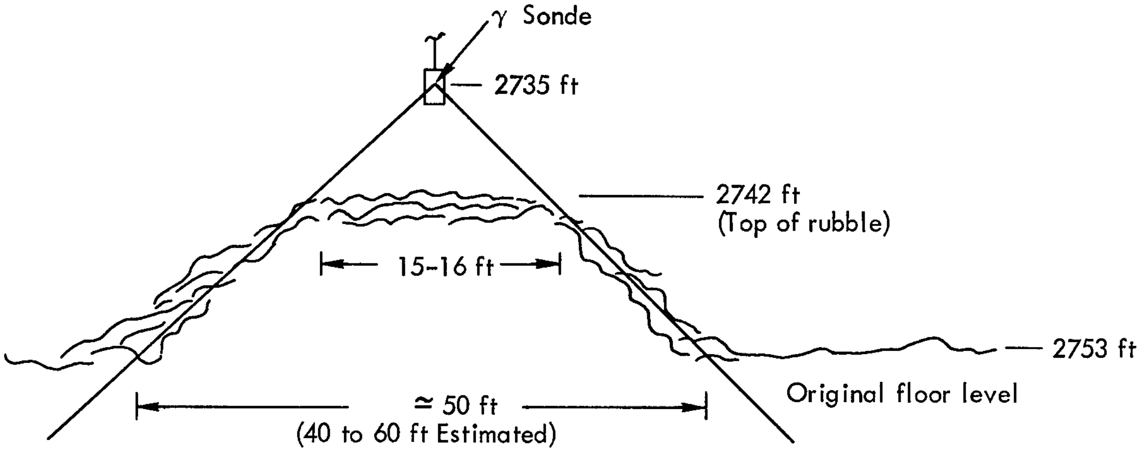

Fig. 15. Sketch of rubble pile.

reproducibility of the six in-runs and out-runs, the reliability of this log is extremely high.

Temperature Log

The temperature sonde used by Schlumberger was a conventional, continuously recording, thermocouple type instrument used for in-hole probing. The maximum temperature capability of the instrument was approximately 375°F. Before the sonde was run in the hole, a calibration of the tool at the surface was conducted. This process consisted of immersing the sonde in a bucket of hot water and taking simultaneous readings on an analytical thermometer and the Schulmberger instruments. After each reading was made, a small portion of crushed ice was added to the hot water and allowed to melt. Then the water was mixed thoroughly before a new reading was made.

We made four in-runs and out-runs at varying logging speeds, ranging from 34 ft/min to 10 ft/min. Generally, the upper portion of the drill hole exhibited a normal geothermal gradient and was logged at higher speeds than the induced heat region. Since the geothermal gradient was normal in the upper part of the hole, this region was logged during the first in-run and the last out-run only. The other in-runs and out-runs were utilized primarily for reproducibility of the induced temperature profile in the cavity and lower portion of the drill hole.

On each in-run, the temperature sonde was left in contact with the rubble pile to record any variability of temperature.

The following statements relating to the interpretation of these data appear valid:

1. The geothermal gradient is somewhat higher than normal for a sedimentary sequence of rocks, probably in the order of one-half again as great. This is typical of salt domes in general. A comparison to other temperature logs run in conjunction with other programs at Tatum dome test site (TDTS) in the past, shows an almost identical geothermal gradient as that obtained during the logging program.
2. The first noticable effect of temperature increase because of the Salmon

Table I. Summary of temperature results.

Thermometer Reading °C	Thermometer Reading °F	Schlumberger instruments °F	Difference (Schlum.-therm.) °F	Comments
1.0	33.8	34	+0.2	surface air
22.0	71.5	73	+1.5	
30.0	86.0	84.5	+1.5	
38.8	101.8	100	-1.8	
44.5	112.1	112	-0.1	
60.0	140.0	136.5	-3.5	
79.0	174.2	173.5	-0.7	

Table II. A summary of the data from the log.

Depth interval (ft)	Temp @ top (°F)	Temp @ base (°F)	Difference top - base (°F)	Gradient (°F/100 ft)
0 - 200	69.5	75.5	6.0	3.0
200 - 400	75.5	79.5	4.0	2.0
400 - 600	79.5	86.0	6.5	3.25
600 - 800	86.0	88.0	2.0	1.0
800 - 1000	88.0	94.0	6.0	3.0
1000 - 1200	94.0	98.0	4.0	2.0
1200 - 1400	98.0	99.0	1.0	0.5
1400 - 1600	99.0	103.5	4.5	2.25
1600 - 1800	103.5	107.25	3.75	1.87
1800 - 2000	107.25	113.5	1.5	0.75
2000 - 2200	108.75	113.5	5.25	2.67
2200 - 2400	113.5	117.5	4.0	2.0
2400 - 2600	117.5	130.0	12.5	6.25
2600 - 2743 (Total depth)	130.0	153.5	23.5	11.75

and/or Sterling Events, occurs at approximately 2380 - 2420 ft.

3. The maximum temperature recorded was encountered at the top of the rubble pile on the bottom of the cavity. This temperature was 153.5°F.
4. A possible zone of condensation of water vapor from the cavity in the drill hole was observed during the logging program. However, between the first in-run and the last out-run this zone, represented by a reversal in the gradient, appears to have migrated up the drill hole and decreased in magnitude and intensity. On the first in-run, this zone extended from 2150-2370 ft and had an average magnitude of approx 1°F. The last out-run showed a normal gradient in the same region, but the zone 1850-1936 ft showed an average reversal of gradient of < 1°F. No explanation of this phenomenon is proposed, other than continued adjustment of the drill cavity system to the atmosphere.
5. All anomalous intervals above 1400 ft can be related to lithology breaks and/or aquifer occurrences. Almost identical anomalous zones appear on other temperature logs made during other programs at TDTS.
6. Because of the good calibration of sonde, the good reproducibility of the temperature profile on the in-runs and out-runs, and the good correlation to previous temperature logs, the reliability of this log is extremely high.

Rubble Sampling

On 25 March, before actual coring was done, two core-like samples were obtained from of the rubble pile by rotating a wash-over shoe and junk catcher in the top of the rubble pile (2742 ft) without air, until no further advance could be made. We retrieved about 1 ft of sample material both times unconsolidated, with grain sizes from 4 in. chucks to powder. The relatively large pieces were yellow to white (minor radiation effect) salt interspaced with yellow to red-brown salt (damaged more by radiation) in smaller sizes. No layering or gross variations were visible in either sample, which were wet throughout. The average gamma intensity was from 30 to 35 mR/hr at the end of the shoe and 100 mR/hr on contact with the core.

Coring

On 28 March, we made an attempt to obtain a large rubble plus melt core using a drag bit and a 40 ft by $4\frac{1}{2}$-in. diam core barrel. The entire operation took 8 hr, and we had no great trouble with the barrel sticking or encountering any metal debris in the rubble. The air supply for this coring was reduced to one 400-cfm compressor but this was enough to apparently blow away the material in the rubble pile portion of the core (~11 ft), for none was recovered. Coring was completed at a depth of 2762 ft (see Figs. 16A and B) with about 8 to 10 ft of core recovered from the area below the rubble pile. A detailed analysis of this core can be found in UCRL-50535 (Classified).

The core was polycrystalline, slightly vesicular salt varying from yellow-orange with dark inclusion at the top (est. ≃2753 ± 1 ft) through dark graying very vesiculated salt to a gray polycrystalline slightly vesiculated material typical of the Salmon melt on the bottom (2762 ft). The maximum length of a single core piece was less than 1 ft; the majority of the pieces were 2 to 4 in. long.

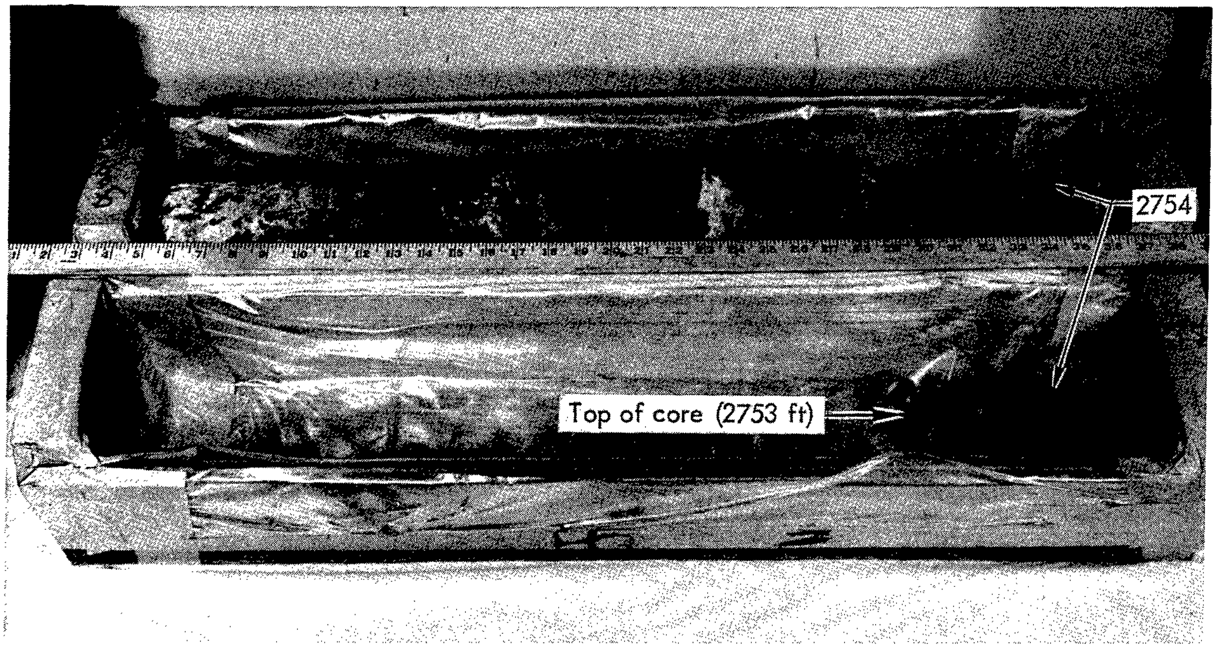

Fig. 16A. Recovery core samples from 2753 to 2757 ft.

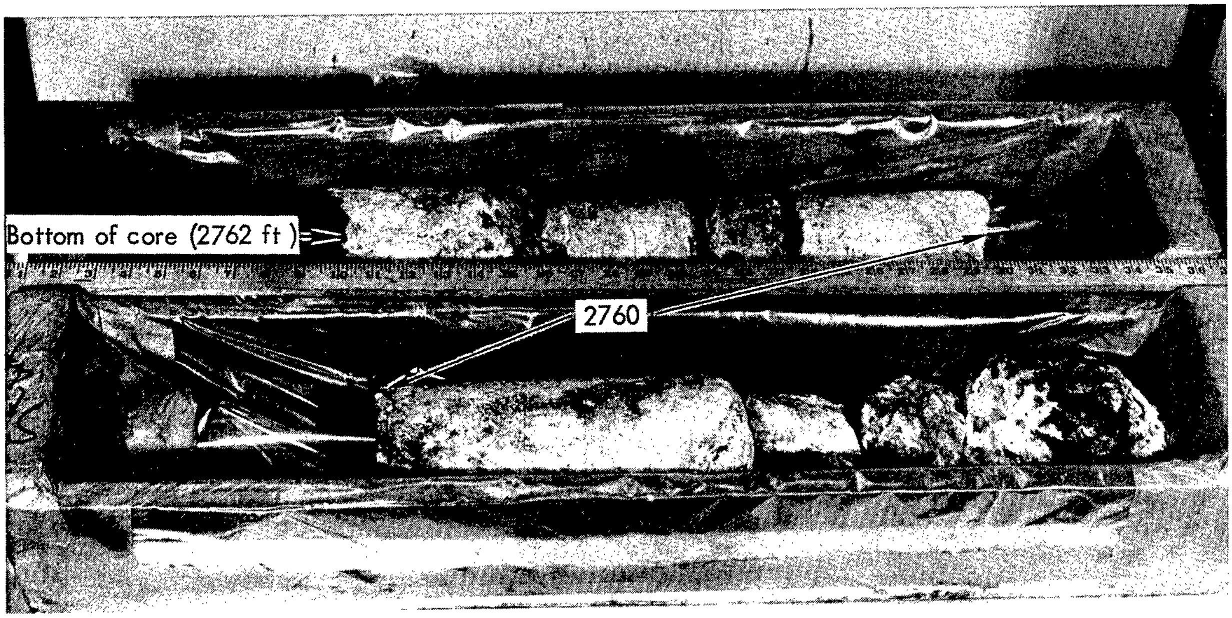

Fig. 16B. Recovery core samples from 2757 to 2762 ft.

Analysis of this core indicated that the Sterling melt most likely is in the top portion of the core. Only this area contains Zr^{95}, with a peak value at about 8 in. down the core. Ru^{106} is found in a similarly confined area. Both of these isotopes can be attributed to Sterling debris. The marked rise in Sb^{125} and Ce^{144} in this area can also be attributed to Sterling.

Cs^{137}, from Salmon, showed a marked decrease near the surface probably because of the effect that the Sterling Event had on this volatile isotope in the original top of the Salmon melt.

Only the top part of the core showed any alpha activity. Judging from the activity levels in this area of the core and the totals available from the Sterling Event, we concluded that this alpha activity represented a more or less uniform layer of Sterling debris over the floor diameter.

Because no rubble was recovered, no estimates are available about the melt conditions at the time the rubble pile formed or the relative effect that the rubble could have on the melt in this area.

Cavity Volume

On 30 March, we conducted a flow test to obtain data from which we could estimate the cavity volume. The cavity was pressurized through the drill string into the cavity to +7.6 psig. The pressure was then bled down through the annulus of the drill string and 9-5/8 in. emplacement casing through the chip process plant and metered. A total of 175,000 cu ft of air released from the cavity brought the pressure to 3.4 psig. Correcting for cavity conditions, this pressure corresponds to an estimated cavity volume of 630,000 cu ft.

With possible variations and uncertainties in the metering and condition determination, this number is estimated to be accurate to about ±50,000 cu ft. This result falls within the same range and error of the preshot determination.

Upon completion of this test, we demobilized the drill rig and compressors and removed them from the surface area of Station 1-A.

Downhole Gas Sampling

The downhole gas sample bottles (see Fig. 17) were designed and built by LRL with requirements for cleaning, bakeout, and pumpdown to a hard vacuum as dictated by the type of gas analysis to be accomplished. The predicted gases were very similar to normal air with very low radioactivity levels. Pressure predictions were for below ambient, thus the bottles were built to operate at normal atmospheric conditions. The bottles were essentially evacuated steel cylinders with solenoid operated inlet valves.

The gas sample system was used with the Schlumberger logging truck. On 24 March, we ran six sample bottles into the cavity with the logging cable serving as messenger and operating cable. Prior to the first downhole sample, we found it necessary to modify some Schlumberger equipment and downhole tools to ensure proper functioning of the sample bottle through the logging cable.

The cavity gases were sampled at four levels with repeated samples at two of the four levels. The levels were: 2677 ft—one sample; 2694 ft—two samples; 2710 ft—two samples; and 2727 ft—one sample. The first sample at each location was taken in descending elevations, the repeats in ascending elevations.

Of the six samples, one of the repeats had some leaking prior to sampling that effectively changed the O_2 and CO_2 balance for this sample. The remaining five samples were almost identical, having the following composition:

Gas	%
CO_2	2.76
Ar	0.96
O_2	15.4
N_2	80.7
NO	0.01
H_2	0.13
CO and HCl	trace

Since the gas composition of the samples through the 50-ft span of the cavity were almost identical we can assume that the cavity gas is of uniform composition throughout the void area, i.e., no layering of gases within the cavity at the time of sampling, and no particularly hazardous chemical conditions (e.g., explosive, strong acid or caustic).

CHIP COLLECTION SYSTEM (See Appendix B)

The Sterling chip collection system provided for control of radioactivity brought to the surface in air drilling returns and subsequent flows, is any, for cavity pressure equilibration and cavity flushing. The system also provided for collection of radioactive particulates in scrubbing or settling tanks and filters and for dispersal of radioactive gases via a stack. The chip collection system had been designed to receive either soluble salt chips or insoluble chips. The tanks were large enough to allow chip accumulation throughout the final phase of reentry drilling.

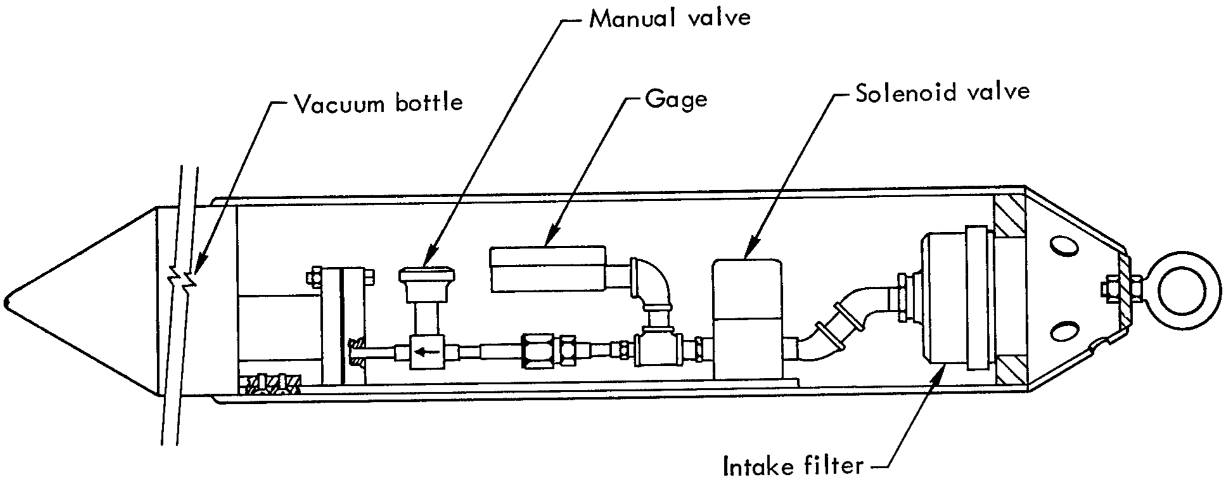

Fig. 17. Drawing of gas sample bottle.

TERMINATION STATUS

The Sterling reentry work was completed on 5 April and the hole was left capped with a cover bolted and locked to the 9-5/8-in. casing, but otherwise open from ground surface to the cavity. The 7-in. liner previously installed in the lower 73 ft of the hole was removed.

The filter plant was left intact, with clean filters installed, and a blind flange closing the upstream end of the pipe.

SUMMARY OF RESULTS

The following is a summary of the results:

- Pressure in the cavity on reentry—about 2 psig above atmospheric.
- Temperature in the cavity— 150°F to 155°F.
- Radiation readings in the cavity—35 mR/hr to 47 mR/hr.
- Radiation readings in the conical part at the top of the cavity (between 2640 ft and 2655 ft)—218 mR/hr to 252 mR/hr.
- Volume and general shape — substantially unchanged from the pre-Sterling condition. The result of a pressurization and flow test indicates a volume of 630,000 ± 50,000 cu ft, or within the errors of a preshot determination.
- Water content—a few small areas of standing water on the floor were seen in the early TV runs which were thought to have been introduced into the cavity during the stemming of Sterling. The casing appears to be intact, and we do not believe water is entering the cavity.
- Cavity floor— photographs taken of the cavity floor show the presence of a rubble mound roughly conical in shape, between 40 and 60 ft diam at its base, and about 10 to 11 ft high at its apex. Little of this material was recovered during coring; its origin is most likely the conical void below the Sterling diagnostic can, and perhaps some isolated slabbing from other sections of the roof.

Acknowledgments

The success of the Sterling Reentry was only possible through cooperative efforts of a large number of people representing various organizations and agencies. The work was sponsored by the Advance Research Project Agency of the Department of Defense, and the Atomic Energy Commission field work was conducted under the auspices of the Nevada Operations Office of the Atomic Energy Commission with technical direction by the Lawrence Radiation Laboratory.

Exceptional contributions to this success were made by representatives of Big Chief Drilling Company; representatives of Fenix and Scission, in particular, M. Hazlett; representative of Schlumberger Well Surveying Corporation; representative of EG&G, Inc., in particular, W. Lightcap, C. Donsi, W. Johnson, and R. Roeder; numerous staff members of the Nevada Operations Office of the Atomic Energy Commission, in particular, D. Magnetti, Project Manager Representative, and K. Devine, Project Engineer, and various representatives of Reynolds Electric and Engineering Company.

The author wishes to express his special appreciation to colleagues at the Lawrence Radiation Laboratory for their unstinting efforts and cooperation.

Appendix A

REENTRY DRILLING

The drilling contractor was the Big Chief Drilling Company of Oklahoma City. Reentry was affected by using a 131-ft Moore derrick of 440,000 lb capacity, and a $4\frac{1}{2}$-in. drill pipe with six $7\frac{1}{2}$-in. collars to remove the stemming from the 9-5/8-in. Sterling emplacement casing and milling through the packer and diagnostic can.

Mobilization of the drill rig, compressors, and blowout preventor equipment was completed by 13 March 1968.

0-2100 ft	Sand, which was dry and easily blown out in 22 hr total time.
2100-2607 ft	Cement, which was drilled through in 25 hr.
(2202 ft)	Bottom of 20-in. casing.
(2652-2607 ft)	Slotted 9-5/8-in. casing.
2607-2626 ft	Below the cement was the 19 ft long, double element Lynes packer.

About 48 hr of milling was required to penetrate its length. During this time, a TV run revealed that the packer was separated between its upper and lower elements, so the Schlumberger Corp. attempted to perforate the bottom packer in hopes that it would then fall away or could be driven down. But after an hour of jarring on the supposedly deflated lower packer element, no effect was observed, so milling was continued on through the packer.

The material retrieved from the junk baskets during the milling operation in the Lynes packer was wet, but no drilling difficulty was experienced that would indicate that there was a large amount of water in the hole. During milling in the last few feet of the packer, oil was observed in return air and junk basket material, indicating that the lower packer probably was perforated successfully.

2627 ft

Below the packer was a gimbal joint from which the diagnostic can was suspended. It had been hoped that when this gimbal joint was milled through, the diagnostic can would fall away. However, the diagnostic can was firmly bound and it was necessary to mill and fish for junk entirely through the can. The material retrieved from this area was moist, but definitely not wet like it had been in the packer.

2660 ft

About 107 hr total was consumed in this milling before reentry to the cavity was achieved at 6 P. M., 22 March 1968.

Appendix B

CHIP PROCESSING PLANT

The chip processing plant was designed to trap all particulates from the drilling returns larger than 0.3 microns and to dilute and disperse the remainder in the atmosphere.

The essential components of the system were a 25,000 gallon dry settling tank, a 25,000 gallon wash tank, two banks of filters, and a blower which gave 2000 to 1 dilution and exhausted the flow through a 120-ft stack.

We started test runs on 13 March 1968. The tests required for the system consisted of a pressure test with air and a leak test. Since the drill rig was not yet ready for operation, we rented two portable 600 scfm compressors for predrilling tests.* All predrilling tests were satisfactory.

We made a dry run test in sand while drilling at approx 250 ft depth. The system worked satisfactorily. This test, however, pointed out the fact that the pressure alarm should be at the first tank (settling tank) instead of the well head. We changed the pressure reading guage (P2) from downstream of the water wash tank (Tank No. 2) to the top of the settling tank (Tank No. 1) to allow monitoring of the pressure drop along the long horizontal pipe run. These were the only "as built" changes except that we connected the well head dilution blower from the existing plant into the line for the added flexibility it would allow, i.e., test runs, and operation while the drilling air was shut down. The blower would not operate, and the above-mentioned rental compressors were continued in use with the system.

We determined during the dry run test that neither the rental compressors nor the well head dilution compressor were required to supplement air flow, i.e. to maintain suspension of particles in the in the long horizontal pipe run or otherwise aid satisfactory operation of the plant to handle drilling returns. We therefore discontinued use of the compressors.

We made a dry run test of approximately 15 ft of concrete at a starting depth of 2224 ft on 15 March 1968. The system worked well, and we went on standby.

Although there was as yet no definite requirement based on detection of radioactivity in drilling returns, as a precautionary measure, we put the plant "on stream" at a depth of 2515 ft at 0030 hr 16 March 1968. All drilling air and/or flushing air passed through the plant from this time on, with the exception of that gas that was allowed to escape.* This was necessary because of the depth of the water in the water wash tank (approx 2 ft) and the lack of a bypass line and valve to allow the gas to go directly to the stack without passing through the water. REECo-Rad-Safe, and LRL Hazards Control monitored this gas and decided that it was not necessary to install the bypass line and valve for this operation.

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*To confirm plant and operational performance with air flow only.

*After gas pressure from the well became too low (less than 1 psig) to flow through the water in the wash tank.

We processed a total of approximately 395 ft of material in the 9-5/8-in. pipe through the chip collection system. This corresponds to approximately 165 cu ft of material. We obtained very little information prior to the plant design as to the expected particle size and particle size distribution of the chips from this type of drilling. The number of filters required for the operation was almost impossible to estimate with the unknowns existing, including:

- Total number of feet of material to be processed.
- Particle size range and distribution.
- Actual air flow (it was assumed at the time of the plant design that it would be between 1200 and 1800 scfm — actual used 1200 scfm rated).
- Quantity of entrained water droplets.

Enough filters were available for several complete changes. However, in actual practice, no filter changes were required.

We took samples from the settling tank, and from the water wash tank. We also shipped back the filters.* We recommend the following changes to this plant to make it more useful and efficient:

(1) Install the above-mentioned bypass line and valve to allow complete bleed down of the cavity.

(2) Take the relative humidity and temperature of the air between the compressors and the well head.

(3) Take the relative humidity and temperature as it comes from the well head with provisions for taking total water content if there are indications that water droplets are being transported up the pipe.

(4) Install an accurate gas meter in the line (i.e., positive displacement recording type).

Items (2) and (3) would be of interest to the Technical Director and the drilling engineer if they are correlated with TV runs to determine the total water being eliminated from the hole.

The gas meter would allow more exact determination of when contact was made with the cavity, and could be used in conjunction with time-pressure readings to determine cavity volume.

When the drilling reached a depth of 2517 ft we closed the blooie line and all returns were run through the processing plant. The plant worked very effectively, trapped most of the particulates in the settling and wash tanks; only one bank of filters was used, no change of filters was required.

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*For inspection and a more sensitive measurement of collected radioactivity than was possible with field survey instruments. Field measurements indicated 1 mR/hr or less.

Appendix C

TV AND PHOTOGRAPHY

The TV and camera system was composed of LRL owned components housed in AEC vehicles operated by EG&G personnel. The system included a down-looking camera system, a side-looking camera system, appropriate monitors, videotape, kineoscope capabilities, and 3000 ft of special TV cable with a winch truck and a TV van truck housing all the equipment.

We used the TV system to:

(1) Aid in identifying and assessing problems that could develop during the reentry drilling.

(2) View the cavity to assess any changes in size, shape, etc.

(3) Provide support to lower and operate 35mm color and stereo color cameras to photograph the cavity.

A total of 23 downhole runs were made in Station 1-A over a three week period. The first seven runs were in conjunction with the reentry drilling; i.e., inspecting broken 9-5/8 in. casing inside packer, looking for water entering 9-5/8 in. casing, identifying and assessing milling problems, and installing the 7-in. casing and casing hanger. The additional sixteen runs were into the cavity for TV coverage and in support of the photo systems.

The TV system was very useful for relatively close-in information, i.e., that data obtained using the down-looking system in general. Eventually, we were able to get a good view of the floor directly below the 9-5/8-in casing. We could identify material as to relative size, and we could see where rubble samples and coring had taken place. Normally we were unable to see beyond 10 to 12 ft across the floor. This was in part due to the camera's field of view and in part due to the limited illumination used on this system.

Environmental problems plagued the camera systems. Water dripping through the broken casing section at 2619 to 2624 ft usually caused drops on mirrors and lens. Sometimes this completely clouded the system, other times it only degraded the video quality. Cavity temperatures were 150-156°F range. The TV cameras, after about one hour at these temperatures (those in excess of 125°F) would become erratic and have to be taken out of the hole for cooling. The water in the lower casing and vapors in the cavity were acidic (HCl at pH of 3). These fluids attacked mirrors, lens coatings, camera internal wiring, lights, etc., to such a point that on each successive run another problem with one or a number of these components would arise. Unfortunately, we consumed much time and manpower in looking for and repairing these maladies.

The TV crew fabricated a number of field expedient devices, which enabled them to maintain a downhole TV capability, even with all these problems.

All attempts to obtain acceptable coverage of the cavity sidewalls with our system failed. The coverage of the cavity roof was somewhat successful as were attempts to see beyond the floor area. We were able to confirm that the basic cavity seemed relatively unchanged. We obtained video tap and kinescope film for each meaningful downhole run.

After we dismantled and moved the drill rig, we used the TV systems to provide support for the photo system. We made a total of four runs with the combined TV-photo systems (which comprised the down-looking TV and the 35mm wide angle Leica camera system).

We made the first run on 2 April 1968. When the combined systems were inside the cavity, we found that the photo-illumination system wouldn't function. The combined systems were taken from the hole and the problem isolated and corrected.

We made the second run on 3 April 1968. All components functioned properly. We took a total of 38 photos of the cavity; 13 each around the cavity at 2670 ft; 13 each at 2735 ft and 12 each at 2717 ft. Of the 38 taken, 33 provided very good color photographs of the various areas of the cavity.

We made the third run on 4 April 1968. This was to be a repeat of the second run with some changes in camera settings. We positioned the system at 2737 ft and 10 photos were taken around the cavity. We moved the system to 2705 ft and planned for 10 photos at this depth. After three photos at this location, the camera system wouldn't function. The system was pulled from the cavity and repair attempted on a faulty film advance mechanism.

We made the fourth and final run on 4 April 1968, using the same TV system with a stereo camera in place of the 35mm wide angle. Before making the run, we found it was necessary to modify the hardware holding the camera, enabling the stereo camera to fit the structure. After these changes, we positioned the combined system at 2738 ft in the hole and obtained five photos. We then raised the camera to 2707 ft, and after taking three more photos, the camera again failed to function. We pulled the system from the hole and found that the camera operating mechanisms were jammed. No capability existed in the field for their repair.

This concluded all downhole investigation.

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