SUMMARY REPORT OF PREDICTIONS

DRIBBLE SERIES

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Roland F. Beers, Inc.
813 North Royal Street
Alexandria, Virginia

MASTER

Prepared for the U. S. Atomic Energy Commission
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SUMMARY REPORT OF PREDICTIONS

DRIBBLE SERIES

January 10, 1964
Revised May 8, 1964
Revised June 15, 1964

Contract AT(29-2)-1163

Roland F. Beers, Inc.
813 North Royal Street
Alexandria, Virginia

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SUMMARY REPORT OF PREDICTIONS
DRIBBLE SERIES

January 10, 1964
Revised May 8, 1964
Revised June 15, 1964

1.C INTRODUCTION

The Summary Report of January 10, 1964 was submitted in order to provide a useful document which summarized and updated, where required, all results of previous predictions and evaluations for the DRIBBLE series. Following review by the NVOO Operational Safety staff, NVO¹ suggested consideration of certain refinements, as well as updating in accordance with more recent developments. These consisted of various difficulties experienced during the drilling, casing and grouting of Station 1 - Emplacement Hole, Station 3 - Vent and Access Holes, and E-14 - Instrument Hole. To aid in the evaluation of the influences of the difficulties upon operational safety, NVOO transmitted two recently completed Fenix and Scisson reports². Additionally, an excerpt from revised specifications for drilling of a new emplacement hole, designated

¹ OSA:RLK-2336, dated February 20, 1964, Subject: Summary Report of Predictions - DRIBBLE SERIES.

² Historical Report, E-14 Complex, Project DRIBBLE, Lamar County, Mississippi, dated November 18, 1963, and Project DRIBBLE, Critical Hole Summary, dated January 1964.

as Station 1A, was furnished. This excerpt consisted of PART V, TECHNICAL PROVISIONS, of the subject specifications.

The present report constitutes a revision of that prepared in January and reflects the NVOO suggestions. Predictions have been revised as necessary on the basis of the correlation of data contained within the foregoing documents. Subsequent to the aforementioned letter, NVOO letter³ requested attendance at a meeting to be held at NVOO on March 13, 1964, for the purpose of presenting the results of investigations specifically requested by this same letter. These results are also reflected in this revision.

During the preparation of this May 8th report, changes in the basis of predictions have been made. For the January 10th report, pressure predictions obtained from hydrodynamic calculations served as a major factor in the prediction of effects; however, analyses of data from recent events have prompted a reconsideration of some of the procedures employed. This study is still in process, and its results are not reflected in this May 8th report. Predictions have,

³ OSA:RLK-2378, dated March 6, 1964, Subject: Meeting of Project Review Panel - DRIBBLE.

therefore, been obtained using alternate procedures, thereby resulting in changes to the figures previously quoted in the January 10th report.

The format for this report has been established with the objective of presenting the essential data in a manner suitable for ready use by the Operational Safety Division. Accordingly, tabulations of numerical values and conclusions are stated in brief form in the Abstract of Predictions which follows. The procedures used to obtain the values therein are expanded in the main body of the report and will be of interest if additional treatment of the subject matter is desired.

To obviate any future doubt, on the part of others referring to this report, as to what data might have constituted the basis for preparation, it is emphasized that the date of currency of the report is May 8, 1964. It is presumed that all available data have been transmitted to Roland F. Beers, Inc. previous to such date. As additional data become available and new evaluations are accomplished, appropriately dated replacement pages will be distributed.

The conditions upon which the predictions have been made are as follow:

1. Emplacement Hole	- Station 1A
2. Station 1A Coordinates	- N537,358.14,
E269,540.96
3. Yield	- 5 KT
4. Medium	- Salt
5. Chamber Size	- 17 $\frac{1}{2}$ -inch diameter
uncased hole
6. DOB	- 2,700 feet
7. Stemming	- Pea-sized gravel
from surface to
depth of 2,100 feet;
grout from 2,100 feet
to a depth slightly
in excess of 2,700
feet

2.0 ABSTRACT OF PREDICTIONS

2.1 Phenomenology and Containment

Radius of Cavity	Most probable	62 feet
	Maximum probable	97 feet
Cracking Radius	Most probable	190 feet
	Maximum probable	300 feet
Radius of Radiation Injection into Cracks	Most probable	152 feet
	Maximum probable	240 feet
Height of Chimney	Most probable	<279 feet
	Maximum probable	<435 feet
Depth of Spalling		131 feet
Thickness of Undisturbed Rock		2,134 feet
Radius of Spalling		<1,000 feet
Elastic Radius		387 feet

Stemming - The stemming plan is considered to be adequate to prevent immediate release of radioactive products.

Possibility of Secondary Explosions - No hazards to containment are anticipated from the entry of water into the post-shot cavity.

Estimate of Prompt Venting of Gaseous Isotopes - It is estimated that the probability of prompt venting to the surface through existing and shot-induced fractures is very small.

Damage to Grout Seals and Aquifer Contamination - Relative motion of casing and surrounding media would not damage the seal if properly cemented in place. The communication of hazardous quantities of radioactive products to aquifers is not likely.

Containment - Under the proposed emplacement and stemming plan, the SALMON detonation at a yield of 5 KT will be essentially contained.

2.2 Predictions of Amplitudes of Ground Motion

TABLE 2.2.1

Surface Peak Particle Motions SALMON Event

Horizontal Range From Surface Zero (miles)	Acceleration (g)	Velocity (cm/sec)	Energy Ratio	Displacement (cm)
0	10.4	232	2340	5.3
.062	10.2	228	2260	-
.95	1.8	38	69	-
1.3	1.2	25.0	25	-
1.7	.80	17	12	-
2.2	.50	12	6.0	.26
2.3	.45	11	5.0	-
2.7	.34	8.4	3.0	-
3.5	.19	5.4	1.3	-
3.8	.16	3.8	1.0	.14
4.5	.10	3.6	.60	-
5.0	.079	3.1	.42	-
5.7	.056	2.5	.27	-
6.1	.047	2.3	.21	.10
30	.001	-	-	-

TABLE 2.2.2

Surface Peak Particle Motions

TAR Event

Horizontal Range From Surface Zero (miles)	Peak Particle Velocity (cm/sec)
1.0	4.4
1.2	3.4
1.4	2.7
1.6	2.2
1.8	1.8
2.0	1.5
2.2	1.3
2.4	1.1
2.6	1.0

The ground motion predictions tabulated above are based on cube root scaling of GNOME data measured in salt. Surface predictions were obtained by applying a transmission coefficient to the subsurface values scaled to 5 KT for SALMON and .1 KT for TAR. Consideration of the stratigraphy directly above the shot indicates that at surface zero the transmission coefficient has a magnitude of 3.52. At very short horizontal distances from surface zero the transmission coefficient will remain essentially unchanged. However, at larger distances (arbitrarily greater than

350 feet) the coefficient begins to decrease due to the changing angle of incidence. Because of the geologic complexity near the edges of the dome it is not possible to determine precisely the manner in which the transmission coefficient will vary. Therefore, it has been assumed that, except for points of interest very close to surface zero, surface predictions will be twice the subsurface values scaled from GNOME data.

The surface acceleration predictions were made using Figure 2.2.1 which is a graph of observed scaled subsurface (in salt) acceleration at GNOME versus scaled distance. Accelerations obtained from this graph were multiplied by a factor of 2.0 at all distances except near surface zero where a factor of 3.5 was applied.

The other parameters (particle velocity, energy ratio, and displacement) were calculated using the following equations. Derivations of these equations are given in Section 6.

$$u = 5.74 \times 10^6 W^{.55} R^{-1.64} \text{ (at surface zero)} \quad (2.2.1)$$

$$u = 3.26 \times 10^6 W^{.55} R^{-1.64} \text{ (all other locations)} \quad (2.2.2)$$

$$ER = \frac{4\pi^2 u^2}{(30.48)^2} \quad (2.2.3)$$

$$d = \frac{u^2}{980a} \quad (2.2.4)$$

a = Peak surface acceleration in units of gravity (g);

u = Peak surface particle velocity in centimeters/
second;

ER = Energy ratio in (feet/second)²;

d = Peak surface displacement in centimeters;

R = Distance in meters;

W = Yield in kilotons.

FIGURE 2.2.2
SALMON Event
PREDICTED SURFACE ACCELERATION
Versus
HORIZONTAL DISTANCE
Roland F. Beers, Inc.
Alexandria, Virginia
May 8, 1964

FIGURE 2.2.3

SALMON Event
PREDICTED SURFACE PARTICLE VELOCITY
Versus
HORIZONTAL DISTANCE
Roland F. Beers, Inc.
Alexandria, Virginia
May 8, 1964

FIGURE 2.2.5
SALMON Event
PREDICTED ENERGY RATIO
Versus
HORIZONTAL DISTANCE
Roland F. Beers, Inc.
Alexandria, Virginia
May 8, 1964

FIGURE 2.2.6

SALMON Event
PREDICTED SURFACE PARTICLE DISPLACEMENT
Versus
HORIZONTAL DISTANCE
Roland F. Beers, Inc.
Alexandria, Virginia
May 8, 1964

3.0 DRIBBLE GEOLOGIC EVALUATION

3.1 Location and Topography

The proposed site for the DRIBBLE series is within the Tatum Salt Dome, Lamar County, southern Mississippi.

The Tatum area is about 250 to 350 feet above sea level, and is moderately dissected with narrow, flat-topped ridges rising about 100 feet above intervening valleys. The hills are well drained, but usually the bottomlands are wet during most of the year. The principal streams in the area are Half Moon and Grantham Creeks which flow into Lower Little Creek about a mile north of the dome (Reference 2). The area immediately over the dome is a topographic low.

3.2 Geologic Setting

All formations outcropping in the State of Mississippi are of upper Cretaceous and Tertiary age. The older formations, exposed along the northern edge of the State, are overlain to the south-southwest by progressively younger beds, which outcrop in roughly parallel bands. In general, the formations thicken to the south-southwest. Younger beds dip about 10 feet per mile to the south whereas dips on the base of the older, deeper Eocene beds are about 35 feet per mile southward (Reference 2).

Tatum dome is a large buried salt stock that has pierced sedimentary deposits of early Cretaceous to Oligocene (middle Tertiary) age. Sediments of Miocene age surround and overlie the dome but are thinner over the dome than in the surrounding area. Rocks of Eocene age are absent on the crest of the dome (Reference 3). Regional strikes and dips are locally disturbed around the dome.

3.3 Local Stratigraphy and Lithology

Stratigraphic relations over and around the dome are shown in the attached cross section (Figure 3.3.1) extending southwest through the dome. Figure 3.3.2 shows the location of this section and all drill holes presently in the dome area.

Figure 3.3.3 is a generalized stratigraphic section through Station 1, the former location of the SALMON Event. A section through Station 3, the location of the SAND Event, is shown in Figure 3.3.4. Lithologic descriptions of the various rock types in the dome area are given on this figure. The sediments over the dome are mainly sands, clays and silts in varying mixtures. The true caprock which underlies the Catahoula Sandstone is composed of two dominant lithologic units. The upper unit is gray to brown, fine- to medium-grained, crystalline limestone. The limestone contains

Adapted by U.S. Geological Survey from
"Composite Site Map, Project Dribble,
number 4, 1962, by Holmes & Narver, Inc.

FIGURE 3.3.2

Redrafted by GKNell,
Roland F. Bears, Inc.
Alexandria, Virginia
May 20, 1964

GENERALIZED STRATIGRAPHIC SECTION **SAND (STATION 3)**

N 537,198.21 E 267,553.84

SCALE 1" = 400'

ROLAND F. BEERS, INC.

ALEXANDRIA, VIRGINIA

JANUARY 10, 1964

zones of high permeability, in which varying quantities of drilling fluid were reported lost while drilling. It also contains some lenses of gray to brown, medium-grained, calcareous, loose sand. This sand may be either contained as lenses within the limestone or as interfingering lenses of the Catahoula Sandstone with the caprock limestone (Reference 4). In some places, the limestone has been leached, forming channels and vugs. The lower 20 feet of the limestone (in WP-4) consists of vuggy brecciated black calcitic limestone. The limestone at its base grades into several feet of gypsum which in turn grades down into the anhydrite which composes lower dominant lithologic unit of the caprock. The anhydrite is medium gray, hard, and finely crystalline. In WP-4, the upper part of the anhydrite has been highly fractured, and gypsum veins line the slickensided surfaces. Its basal contact with the salt is sharp. The salt varies from gray to very light gray, anhydrite-bearing halite to transparent, very coarse crystalline, almost pure halite. The salt is banded with nearly vertical alternating thin bands of anhydrite-bearing halite and almost pure halite (Reference 5).

Tabulations of drill hole information and lithologic logs are shown in Tables 3.3.1 and 3.3.2. Lithologic logs are

TABLE 3.3.1. DRILL HOLES OF TATUM SALT DOME AREA, MARCH 1964 (All measurements in feet.)

Hole	Coordinates (New)		Elevation (Datum) GL- Ground Level C - Collar	Total Depth (Measured from Datum)	Limestone Caprock		Anhydrite		Salt	Reference
					Depth of Top Below Sea Level	Thickness	Depth of Top Below Sea Level	Thickness		
E-1	N635,240.99	E267,506.33	267 GL	4503	669	120	789	440	1229	DR-8
E-2	N535,590.86	E268,672.29	259 GL	1679 ^c	645	>80	no samples		1226	DR-16
E-3	N536,395.03	E270,833.63	250 GL	1535 ^c	696	129	825	404	1229	DR-17
E-4	N537,915.26	E270,425.47	246 GL	4512	694	133	827	403	1230	DR-12
E-5	N537,880.71	E267,162.10	252 GL	3513	701	95	796	438	1234	DR-13
E-6	N538,050.45	E268,734.48	240 GL	2991	630	152	782	450	1232	DR-14
E-7	N535,597.66	E268,698.34	259 GL	3542	635	345 ^a	980 ^a	245 ^a	1225	DR-16
E-9	N536,390.38	E270,916.59	248 GL	3511	728	99	827	405	1232	DR-17
E-11	N536,856.87	E267,585.96	277 C	3540	673				1237	
E-12	N537,330.87	E267,623.85	282 C	2882	658				1228	
E-13	N537,047.73	E268,098.43	271 C	2871	659				1230	
E-14	N537,199.25	E269,006.28	242 C	4005	654				1233	
E-15	N537,414.13	E269,491.64	241 C	2550	638	137	775	453	1228	Densilog
E-16 ^b	N537,414.35	E269,591.63	proposed							
E-8	N538,530	E271,160	proposed							
E-14T	N537,199.25	E268,986.28	242 C	1670	644				1229	
E-14B	N537,121.75	E269,026.12	242 C	3360	662				1235	
HT-1	N539,390	E272,660	315 GL	2610	off	dome				DR-6
HT-1A ^d	N539,540	E272,400	283 C	1096	off	dome				
HT-1B ^d	N539,810	E271,880	272 C	889	off	dome				
HT-2	N532,750	E265,455	295 GL	2615	off	dome				DR-7
HT-2A ^e	N532,610	E265,830	294 C	1080	off	dome				
HT-2B ^e	N532,380	E266,380	292 C	1005	off	dome				DR-37
HT-3	N535,800	E268,730	267 GL	1052	675 ⁺					DR-31, 37
HT-4	N535,800	E268,770	266 C	475	does	not reach caprock				Sonic Log
HT-5	N535,780	E268,730	264 C	680	does	not reach caprock				
HT-6	N535,800	E268,780	266 C	812	does	not reach caprock				DR-37
HT-7	N535,790	E268,680	265 C	882	does	not reach caprock				

Notes: a. 800-980', fault zone

b. E-16 conductor pipe was cemented in
and abandoned; elevation top of pad - 241.13'

c. Abandoned

d. HT-1A and -1B are observation wells 1
and 2 respectively.e. HT-2A and 2B are observation wells 3
and 4 respectively.

TABLE 3.3.2.

DRILL HOLES OF TATUM SALT DOME AREA, MARCH 1964 (All measurements in feet.)

Hole	Coordinates (New)		Elevation (Datum) GL - Ground Level C - Collar RT - Rotary Table	Total Depth (Measured from Datum)	Limestone Caprock		Anhydrite		Salt	Reference
					Depth of Top Below Sea Level	Thickness	Depth of Top Below Sea Level	Thickness		
FS #1	N534,820	E268,545	288 GL	1587	1094	67	1161	97	1258	f,h,1
FS #2	N534,540	E266,940	277 GL	2029	1499	89 ^g	1507	60	off dome	f,h,1
FS #3	N537,010	E268,110	288 GL	1540	671	104	778	461	1237	f,h,1
FS #4	N537,550	E269,740	247 GL	1041	617	146	763	> 31		f,h,1
FS #5	N538,325	E268,190	249 GL	1095	648	124	772	> 74		f,h,1
FS #6	N535,820	E266,940	285 GL	1546	891	216	1107	112	1219	f,h,1
FS #7	N535,090	E270,830	252 GL	2087	off dome					f,h,1
FS #8	N536,020	E270,120	248 GL	1215	705	68	773	>194		f,h,1
FS #9	N539,150	E268,210	260 GL	1562	893	127	1020	215	1235	f,h,1
FS #10	N537,400	E266,910	271 GL	1291	723	125	848	>172		f,h,1
Shell										
Hibernia #1	N536,740	E265,400	338 RT	9565	1447	160 ^g				DR-1,h,1
Humble										
Hibernia #1	N533,760	E272,840	333 GL	5998	off dome					h,1
Willmut #1	N535,680	E268,450	275 GL	1959	723	100	823	416	1239	DR-1,h,1
Willmut #2	N533,310	E273,020	370 RT	8080	off dome					h,1
Willmut #3	N534,220	E266,670	286 RT	6956	off dome				6600	DR-29,h,1
Willmut #4	N533,850	E269,890	265 GL	4726	off dome					h,1
WP-1	N537,263.56	E267,949.31	271 GL	3501	650	119	769	461	1230	DR-15
WP-4	N536,303.98	E269,172.86	244 GL	3500	679	86	765	467	1232	DR-19
STA. 1 ^j	N537,328.14	E269,540.96	241 C	1650 [±]						
STA. 1A	N537,358.14	E269,540.96	241 C	incomplete						
STA. 2	N537,011.77	E268,228.55	proposed	2000 ^k						
STA. 3 ⁱ	N537,198.21	E267,553.84		2000 ^k						
Vent	N537,180.52	E267,544.51	284 C	2680						
Access ^j	N537,273.38	E267,593.51	283 C	950 [±]	does not reach caprock					

Notes:

- f. H & N Drawing E-055-C4, 4/10/61
g. Caprock overhang
h. Letter: OSA:RLK 923, Enclosure:
"Tabulation Pre-Dribble Holes"

- i. Subsurface W. P.
j. Abandoned
k. Proposed depth, LRL drawing, L6-15364, 10/31/62
l. H & N drawing, E-055-C3, 4/19/61

available for the following holes on or near Tatum Salt
Dome:

WP-1	DR-15
WP-4	DR-19
E-1	DR-8
E-2	DR-16
E-3	DR-17
E-4	DR-12
E-5	DR-13
E-6	DR-14
E-7	DR-16
E-9	DR-17
HT-1	DR-6, DR-32, DR-40
HT-2	DR-7, DR-32, DR-40
HT-3	DR-31

3.4 Physical Properties

Physical properties for the salt and surrounding sediments are compiled in Tables 3.4.1 and 3.4.2.

3.5 Structure

Physical properties applied to calculation of the compound transmission coefficient in a vertical section at HT-3 are shown on Table 3.5.1. The enclosed cross section (Figure 3.3.1) extending southwest through HT-1 and HT-2 best shows the structural relations across the dome. Figure 3.5.1 shows the location of all other available cross sections through Tatum Dome.

TABLE 3.4.1

PHYSICAL PROPERTIES: Tatum Salt Dome
Section Over Dome

	Rock Unit	Compressional Velocities (ft/sec)			Natural Bulk Density (g/cc)		
		min.	max.	mean	min.	max.	mean
Caprock Sediments	Coastal Terrace Deposits	--	--	1,200 ^d	1.9 ^j	2.05 ^j	1.98
	Pascagoula & Hattiesburg	5,750 ^a	6,150 ^a	5,935	1.60 ^e	2.21 ^e	1.93 ^e
	Catahoula Sandstone	6,250 ^a	7,820 ^a	7,030	1.88 ^e	2.56 ^e	2.05 ^e
	Limestone	7,800 ^a	15,500 ^a	10,830	2.24 ^f	2.71 ^f	2.47 ^f
	Gypsum	8,330 ^b	8,700 ^b	8,515	2.2 ^j	2.4 ^j	2.3
	Anhydrite	18,200 ^a	19,230 ^a	18,700	2.85 ^f	2.92 ^f	2.90 ^f
	Salt*	14,300 ^a	14,930 ^a	14,700 ^{a,g}	2.13 ^d	2.215 ^d	2.181 ^j

*Salt: Porosity and Elastic Properties

	min.	max.	mean
Porosity %	1.53 ^h	8.59 ^h	3.61 ^h
Poisson's Ratio	0.215 ^g	0.267 ^g	0.239 ^g
Shear Modulus ($\times 10^{11}$ dynes/cm ²)	1.33 ^g	1.49 ^g	1.42 ^g
Young's Modulus ($\times 10^{11}$ dynes/cm ²)	3.25 ^g	3.71 ^g	3.48 ^g
Bulk Modulus ($\times 10^{11}$ dynes/cm ²)	2.24 ^g	2.44 ^g	2.30 ^g
Tensile Strength (psi)	85 ^h	147 ^h	120
Compressive Strength (psi)			
Standard	3050 ^h	3700 ^h	3330
*L/D = 1/1	4140 ^h	4450 ^h	4250
L/D = 3/1	3240 ^h	3450 ^h	3393

*L/D = Length-Diameter Ratio

TABLE 3.4.2

PHYSICAL PROPERTIES: Tatum Salt Dome
Section Beside Dome

Rock Unit	Compressional Velocity (ft/sec)			Natural State Bulk Density (g/cc)
	min.	max.	mean	
Coastal Terrace deposits	--	--	1,200 ^d	1.98 ^j
Pascagoula & Hattiesburg fms.	6,300 ^c	6,410 ^c	6,370	1.93 ^e
Catahoula Sandstone	7,500 ^c	8,200 ^c	7,850	2.05 ^e
Paynes Hammock & Chickasaway	6,900 ^c	7,100 ^c	7,000	2.5 ^k
Upper Vicksburg	6,750 ^c	7,600 ^c	7,015	2.2 ^j
Lower Vicksburg	10,200 ^c	11,800 ^c	11,000	2.5 ^k
Red Bluff Clay	8,700 ^c	9,500 ^c	9,100	2.2 ^j
Yazoo Clay	6,900 ^c	7,400 ^c	7,040	2.2 ^j
Moody's Branch fm.	8,700 ^c	10,700 ^c	9,930	2.5 ^k
Cockfield fm.	6,500 ^c	7,350 ^c	7,000	2.2 ^j
Cook Mountain fm.	9,700 ^c	10,750 ^c	10,315	2.1 ^j

- References:
- a. In hole Velocity logs on dome (see Tables 1 and 2)
 - b. In hole Velocity log WP-1, tabulated, in DR-19
 - c. In hole Velocity logs off dome (HT-1, HT-2, Humble Hibernia #1)
 - d. Up hole Velocity Survey, RFB 4094
 - e. Gamma gamma density log, HT-3
 - f. Gamma gamma density log, E-15
 - g. Memo: D. M. Christensen, LRL-N May 14, 1963
Statistical Summary of Calculations from in hole Velocity logs:
E-14, E-15, WP-1
 - h. RFB 4085, Petrographic Examination and Physical Tests of Cores,
Tatum Salt Dome, Mississippi, Table 6, WES, Jan. 1963
 - j. Birch, Francis, 1942 Handbook of Physical Constants, GSA sp. paper 36
 - k. Heiland, C. A., 1946, Geophysical Exploration, Prentice-Hall
- Unmarked means are by compiler.

TABLE 3.5.1

Physical Properties Applied to Calculation
of the Compound Transmission Coefficient
at HT-3, Tatum Salt Dome

	<u>Rock</u> <u>Unit</u>	<u>Depth</u> <u>feet</u>	<u>Thickness</u> <u>feet</u>	<u>Description</u>	<u>Velocity</u> <u>ft/sec</u>	<u>Density</u> <u>gm/cc</u>
Pascagula & Hattiesburg fms., undifferentiated	{ 15	0-105	105	Clay	4875 ⁽¹⁾	1.94 ⁽²⁾
	{ 14	105-180	75	Sand & Clay	5140 ⁽¹⁾	1.90 ⁽²⁾
	{ 13	180-375	195	Sand & Clay	5650 ⁽¹⁾	1.96 ⁽²⁾
	{ 12	375-475	100	Sand, Aquifer 1	5870 ⁽¹⁾	1.70 ⁽²⁾
	{ 11	475-588	113	Clay	6360 ⁽¹⁾	2.00 ⁽²⁾
	{ 10	588-672	84	Sand, Aquifer 2A	6200 ⁽¹⁾	1.96 ⁽²⁾
	{ 9	672-750	78	Clay	6450 ⁽¹⁾	2.02 ⁽²⁾
	{ 8	750-790	40	Sand, Aquifer 2B	6250 ⁽¹⁾	1.96 ⁽²⁾
	{ 7	790-830	40	Clay	6420 ⁽¹⁾	2.00 ⁽²⁾
	{ 6	830-870	40	Sand, Aquifer 3A	6580 ⁽¹⁾	1.94 ⁽²⁾
Catahoula Sandstone	{ 5	870-900	30	Clay	7150 ⁽¹⁾	2.12 ⁽²⁾
	{ 4	900-940(?)	40(?)	False caprock, sandstone	7000 ⁽³⁾	2.18 ⁽²⁾
	{ 3	940(?) - 1060(?)	120(?)	Limestone caprock	12500 ⁽³⁾	2.47 ⁽⁴⁾
Caprock	{ 2	1060(?) - 1495	435(?)	Anhydrite	19000 ⁽³⁾	2.90 ⁽⁴⁾
	{ 1	1495-		Salt	14900 ⁽³⁾	2.17 ⁽⁴⁾

(1) From Sonic Log HT-3

(2) From Gamma-Gamma Density Log HT-3

(3) Generalized from sonic logs in various holes in dome

(4) From Gamma-Gamma Density Log E-15

Map Showing Location of Cross-Sections

References:

- (1) DRIBBLE-29.
- (2) DRIBBLE-1, includes sections A-A' through F-F'.
- (3) RFB 4094 - (Project DRIBBLE, Seismic Profiling of the Southeast Flank of the Tatum Salt Dome. UED, Inc., Dec. 1962).
- (4) Beers, Inc. files, compiled from DRIBBLE-1 and DRIBBLE-10.

Faulting of the caprock is indicated in the vicinity of E-7, 2000 feet southeast of SAND shot point (See Figure 3.3.1). There a 136-foot section of brecciated sandstone, calcite conglomerate and black chert gravel was found where the anhydrite would normally be. Numerous fractures are present in the anhydrite -- as mentioned previously.

Although little mention of jointing is made specifically in the literature, it seems reasonable to expect its moderate development in the more brittle lithologic types including sandstones, limestones, anhydrites and gypsum. The salt, within the dome, is essentially free from jointing and fracturing.

3.6 Hydrology

A complete and up-to-date review of the hydrology of the dome area is contained in USGS Technical Letter: DRIBBLE-34. There are five aquifers of importance in the Tatum Dome area (shown on Figure 3.3.1); all of which are under artesian pressure except the "Local Aquifer" which holds perched water. Aquifer 5 in the Cook Mountain limestone is the shallowest of the saline aquifers in the area and is about 2600 feet deep near the dome. It is separated from the deepest fresh water aquifer (#4) by several hundred feet of impervious clays. Both of these aquifers are discontinuous over

the dome. Aquifer 4 has a very small yield and is not presently a water supply source.

Aquifers 1, 2, and 3 are Miocene sandstone units which are continuous over the dome. Locally they are the principal sources of fresh water. Aquifer 2a in the Pascagoula and Hattiesburg Formations has the highest permeability.

The calcitic portion of the caprock is another major water-bearing unit. The following is quoted from Reference 3:

The calcite caprock contains numerous open fractures filled with water that probably have been enlarged by solution. In nearly all test holes drilled through the calcite caprock, lost circulation has been a major problem in drilling. When drilling fluid is lost from a hole being drilled through the caprock, the loss is reflected almost immediately as a rise in water levels in an observation well along the east margin of the calcite caprock. These conditions suggest that the calcite caprock has a high permeability.

The aquifer in the caprock may be in hydraulic continuity with aquifer 4 along the flank of the dome.

Possible aquifer contamination is summarized in the same reference:

On the remote chance that radioactivity might escape from the salt stock in which the nuclear devices are proposed to be detonated, the activity would most likely enter the caprock, the overlying sands of aquifer 3, or aquifers 4 and 5 on the flank. Computed values of the rate of

movement of water in aquifers 3, 4, and 5 indicate the movement will be less than 10 feet per year. This slow rate of movement coupled with the high [ion] exchange capacity of the material comprising the aquifers lead to the conclusions that the off site contamination potential is small to nil. The highest rate of movement, about 160 feet per year, was computed for aquifer 2a. It is unlikely that radioactivity would be released into this aquifer, several hundred feet above the caprock.

4.0 PHENOMENOLOGY AND CONTAINMENT

4.1 Radius of Cavity

The prediction of cavity radius for the SALMON Event is based upon the cavity realized from the GNOME Event, a 3.1 KT detonation in a similar medium (revised from 3.5 KT on the basis of information in Reference 6). The GNOME cavity was not spherical but resembled an oblate spheroid with the vertical dimension from the W.P. to the bottom of the cavity being about 53 feet and the average horizontal radius being on the order of 83 feet. The SALMON cavity is anticipated to more nearly approach a spherical shape since the bedding plane effects existent at GNOME will not be present, and prediction of the cavity radius is accomplished by applying cube root scaling to the GNOME radii. The results are stated in terms of a "most probable" radius and a "maximum probable" radius to account for possible variations due to stratigraphy.

$$\left(\frac{5.0}{3.1}\right)^{\frac{1}{3}} \times 53 = 62 \text{ feet} - \text{Most probable radius}$$
$$\left(\frac{5.0}{3.1}\right)^{\frac{1}{3}} \times 83 = 97 \text{ feet} - \text{Maximum probable radius}$$

For comparative purposes, both of these figures are utilized where applicable to subsequent calculations.

4.2 Cracking Radius

The fracturing of the medium surrounding the post-shot cavity may be divided into several zones for the purposes of analysis. In the region immediately surrounding the cavity, displacement associated with cavity expansion occurs by plastic deformation such that the condition of post-shot rock closely resembles that of the original in situ condition. Farther out, larger block-type shear failures occur which would mask any fractures developed from tension. The outer limit of fracturing has a radial orientation and is tensional. This is of particular interest from the possibility that these fractures present channels for radioactive transfer.

The creation of these fractures can be attributed to the passage of the shock wave and the subsequent expansion of the cavity wall, these actions causing radial displacements and strains to occur throughout the medium. An investigation was made of these possible mechanisms in relation to the fracturing which occurred at GNOME. Here, the outer limit of cracking, other than bed separation, was estimated to be 250 feet, with the major lateral shock-induced effects being confined to a radius of 140 feet.

Figure 4.2.1 shows the predicted and observed horizontal radial displacements for the GNOME Event. Predictions were obtained by use of the method outlined in Appendix A. The permanent displacement at the outer limit of cracking is found to be 3.1 feet. The creation of fractures is more logically associated with strains rather than gross displacements, and therefore, the radial strain was computed and found to be .021 ft/ft or 2.1%. The allowable compressive strain for salt was obtained from the Waterways Experiment Station test of the DRIBBLE cores (Reference 7) by uniaxial compression. The strain at ultimate strength for 12 tests averaged 2.07% which compares remarkably well with that computed above on the basis of displacements. Predictions of the anticipated permanent displacements and strains for the SALMON Event were made, based on the most probable cavity radius of 62 feet and the maximum probable cavity radius of 97 feet. These are shown in Figure 4.2.2. Utilizing a radial strain of 2.1%, the outer limits of cracking associated with these radii for the SALMON Event are 190 and 300 feet, respectively.

FIGURE 4.2.2
PREDICTED
RADIAL DISPLACEMENT AND STRAIN
Versus
RADIAL DISTANCE
SALMON EVENT
Roland F. Beers, Inc.
Alexandria, Virginia
April 1, 1964

4.3 Radius of Radiation Injection into Cracks by Particulates and Condensates

At the GNOME Event, injection of intrusive breccia into post-shot fissures occurred to a distance of at least 110 feet, and fracturing to 250 feet (Reference 8). Other estimates have placed the limit of radioactivity at distances as large as 200 feet. Accepting the greater distance and assuming that the ratio of the radius of radioactivity to the radius of cracking will be similar for GNOME and SALMON Events, the outer limit for SALMON will be:

$$\frac{200}{250} \times 190 = 152 \text{ feet} - \text{Most probable}$$

$$\frac{200}{250} \times 300 = 240 \text{ feet} - \text{Maximum probable.}$$

The cracking limits of 190 and 300 feet were derived in Section 4.2.

A similar computation may be performed using data from RAINIER where fracturing extended 280 feet (Reference 9) and radioactivity 190 feet (Reference 10). For SALMON, the radioactive radius would then be:

$$\frac{190}{280} \times 190 = 129 \text{ feet} - \text{Most probable}$$

$$\frac{190}{280} \times 300 = 204 \text{ feet} - \text{Maximum probable.}$$

These agree fairly well with the values obtained above; therefore, 152 and 240 feet are predicted as being, respectively, the most probable and maximum probable limits of radiation injection into fractures.

4.4 Height of Chimney

For other events, an estimate of chimney height has been made on the basis of

$$H = \frac{2R/3 (1 + n)}{n - 1}$$

where (H) is the height above the working point, (R) is the radius of both the cavity and chimney, and (n) equals the swell factor, or ratio of volume of chimney rubble to the volume occupied in situ, see Appendix A.

An appropriate salt swell factor has not been determined on the basis of past experience. GNOME did not lend itself to this purpose since the formation of a chimney was incomplete. Thus, in order to predict a possible maximum chimney height for the SALMON Event, the swell factor was assumed to be 1.35. This was the value determined for the massive granodiorite at HARDHAT. An assessment of the range of swell factors associated with the excavation of hard materials indicates that this factor is reasonable for the intended

purpose. Thus, with most probable and maximum probable cavity radii values of 62 and 97 feet, respectively, and a swell factor of 1.35, a most probable chimney height would be calculated as 279 feet while a maximum probable height would be calculated as 435 feet. Based upon SALMON stratigraphy and GNOME experience wherein a chimney did not form in the halite (though cavity collapse did occur to a height of about 91 feet above the Zero Point), it is considered unlikely that a similar chimney will develop for the SALMON Event. Therefore, it is emphasized that the foregoing values of chimney height represent only those based upon the assumption that a chimney will develop as at HARDHAT. By reason of the experience at GNOME, it is unlikely that the chimney height will attain a value as large as these figures.

4.5 Depth of Spalling

The possibility of spalling at ground zero owing to the detonation of a 5 KT device at a depth of 2,700 feet was investigated by means of a graphical analysis. The geologic setting, densities and velocities of the various beds and transmission coefficients used are shown in Tables 4.5.1 and 4.5.2.

TABLE 4.5.1

Approximate Physical Properties of the Stratigraphic SectionTatum Salt Dome

<u>Rock Unit</u>	<u>Depth feet</u>	<u>Thickness feet</u>	<u>Description</u>	<u>Velocity, V ft/sec</u>	<u>Density, P gr/cm³</u>
11	0-35	35	Soil, silt	4,000 ⁽¹⁾	1.70 ⁽¹⁾
10	35-206	171	Clay, silt, sand	5,000 ⁽¹⁾	1.85 ⁽¹⁾
9	206-340	134	Clayey silt	6,250 ⁽²⁾	1.95 ⁽¹⁾
8	340-440	100	Sand	5,250 ⁽²⁾	1.92 ⁽¹⁾
7	440-500	60	Silt, clay	6,000 ⁽²⁾	1.97 ⁽¹⁾
6	500-600	100	Sand w/silt, clay	5,600 ⁽²⁾	1.94 ⁽¹⁾
5	600-670	70	Sand	5,400 ⁽²⁾	1.93 ⁽¹⁾
4	670-930	260	Clay, sand, silt	6,500 ⁽²⁾	1.97 ⁽¹⁾
3	930-1050	120	Vuggy limestone	8,700 ⁽²⁾	2.63 ⁽³⁾
2	1050-1510	460	Anhydrite	19,230 ⁽²⁾	3.06 ⁽³⁾
1	1510-2700	1190	Salt, massive	14,700 ⁽²⁾	2.254 ⁽³⁾

(1) Estimated

(2) TL-DRIBBLE-15, Table V

(3) "Project DRIBBLE, Petrographic Examination and Physical Tests of Cores, Tatum Salt Dome, Mississippi", Technical Report 6-614, U. S. Army Waterways Experiment Station, Corps of Engineers, Vicksburg, Mississippi.

TABLE 4.5.2

Development of Compound Transmission Coefficients
Project DRIBBLE

<u>Rock</u> <u>Unit</u>	<u>V_{xp}</u>	<u>2V_p</u>	<u>V_{p1} +</u> <u>V_{p2}</u>	<u>Transmission</u> <u>Coefficient, UP</u> $\frac{2V_{p1}}{V_{p1}+V_{p2}}$	<u>Compound</u> <u>Transmission</u> <u>Coefficient, UP</u>	<u>Transmission</u> <u>Coefficient,</u> <u>DOWN</u>	<u>Compound</u> <u>Transmission</u> <u>Coefficient,</u> <u>DOWN</u>
Air	-	-			3.525		
11	6,800	13,600	6,800	2	1.762	2	1.762
10	9,250	18,500	16,050	1.153	1.529	.847	1.493
9	12,187	24,374	21,437	1.137	1.345	.863	1.289
8	10,080	20,160	22,267	.905	1.485	1.095	1.411
7	11,820	23,640	21,900	1.080	1.376	.921	1.299
6	10,864	21,728	22,684	.958	1.437	1.042	1.353
5	10,422	20,844	21,286	.979	1.467	1.021	1.381
4	12,805	25,610	23,227	1.103	1.330	.897	1.240
3	22,881	45,762	35,686	1.282	1.038	.718	.890
2	58,844	117,688	81,725	1.440	.720	.560	.498
1	33,134	66,268	91,978	.720	1.000	1.280	.637

The analysis presented in Figure 4.5.1 was constructed from the physical and computed data by a procedure similar to that outlined in Appendix A. The use of this method requires a prediction of the anticipated pressure versus distance. As has been stated previously (pages 2 and 3), the prediction procedure for obtaining pressure is being re-examined, but the current method is felt to be of sufficient accuracy to permit an estimate of the order of magnitude of spalling effects. In this analysis, the conservative single spall method is employed. An assumption of multiple spalls would have permitted energy to be trapped in the initial spalls, thereby decreasing the depth of spalling predicted. No tensile strength was assumed for the medium.

Results predicted on this basis indicate that spalling should occur to a maximum depth of about 131 feet (40 meters). The driving force, or difference between net tension and overburden pressure, to produce spalling in this region is, however, very low — less than 1 bar (14.5 psi). This means that if the atmospheric pressure of approximately 1 bar is added to the overburden, spalling would be predicted to only about 10 meters. Any tensile strength of the medium will also add restraint. The conclusion, therefore, is that the

FIGURE 4.5.1

PREDICTED
 PRESSURE VERSUS DEPTH
 SALMON EVENT

Roland F. Beers, Inc.
 Alexandria, Virginia
 April 1, 1964

probability of major spalling at surface ground zero is rather low, but that some projection of unconsolidated surface material may take place.

Predicted displacement at the surface of any possible spall was computed using the predicted free-field particle velocity obtained from machine calculations and multiplying this by the compound transmission coefficient as follows:

$$d = \frac{V^2}{2g} = \frac{(47 \times 3.52)^2}{2 (981)} = 14 \text{ cm (5.5 inches)}.$$

The vertical displacement of any dislodged material will thus be of small magnitude.

4.6 Radius of Spalling

The demarcation line between the region where spalling occurs and that where surface motion is solely due to seismic waves is essentially non-existent. Rather, a transition occurs from the maximum vertical displacement, which occurs at surface zero due to spalling, to a region where displacements by this mechanism are infinitesimal. Since the probability of a major spall at surface zero is low (see Section 4.5) and the magnitude of the anticipated displacement is only 5.5 inches, the lateral extent of spalling should not be very

great. From an examination of surface displacements versus horizontal distance (Figure 4.6.1) for several events, it can be seen that displacements due to spalling drop off rapidly with increasing range. Considering the anticipated SALMON displacement in relation to those of the previous events shown, it is seen to be much less. The lateral extent of spalling should also be less, something less than 1,000 feet.

4.7 Elastic Radius

From an analysis of the GNOME data on measured particle velocity (Reference 11) a distinct change in the attenuation rate occurs at 328 feet. This corresponds to a particle velocity of about 12 meters/sec. In terms of pressure, a value of 1.1 K bars may be taken as the limit on the elastic precursor for salt (Reference 12).

Scaling the 328 feet distance to the SALMON yield gives:

$$\left(\frac{5}{3.1}\right)^{\frac{1}{3}} \times 328 = 387 \text{ feet.}$$

4.8 Stemming Predictions

Basis of Evaluation - The evaluation presented herein correlates stemming data from previous events at NTS and Project GNOME with the stemming plan for the SALMON Event.

SURFACE DISPLACEMENT (INCHES)

1000

100

10

1

.1

Observed GNOME

Observed HARDHAT

Observed RAINIER

Estimated SALMON

FIGURE 4.6.1

SURFACE DISPLACEMENT
Versus
HORIZONTAL DISTANCE
Roland F. Beers, Inc.
Alexandria, Virginia
April 1, 1964

HORIZONTAL DISTANCE (FEET)

100

1000

The details of this plan are shown on LRL Drawing L6-17434A, dated April 17, 1964, and provide for the detonation of a 5 KT device at 2,700 feet in a salt medium. Twenty-inch OD casing is to be terminated in the salt at an approximate depth of 2,200 feet. Below this level to the bottom of the hole, the minimum drilled diameter is to be $17\frac{1}{2}$ inches (Reference 23). Centered within essentially the full hole depth there is to be a slotted, $5\frac{1}{2}$ -inch OD, J-55 T&C casing which is to be used for grouting.

Emplacement Holes - Stations 1 and 1A - The satisfactory containment of drill hole events in alluvium or granite by complete stemming with sand, and more recently with pea-sized gravel, has been generally demonstrated at the Nevada Test Site. For the SALMON Event, the emplacement hole was originally designated as Station 1; however, considerable difficulties were encountered in the drilling, casing, and grouting of this hole. These resulted in the decision to abandon this location (N537,328.14, E269,540.96) and to drill a new hole 30 feet north to be designated as Station 1A (N537,358.14, E269,540.96). The Station 1 hole was bottomed at 1,524 feet, and it is understood that this will be used both as a pre- and post-shot hole. The

difficulties referred to are enumerated in the Fenix and Scisson, Inc. report dated January, 1964 (Reference 22). This report and the Fenix and Scisson, Inc. revised specifications for Station 1A (Reference 19) have been reviewed to ascertain those factors pertinent to an evaluation of operational safety.

In regard to Station 1, Fenix and Scisson, Inc. data (Reference 22) show this hole to be presently grouted to the surface with 50-50 pozmix, salt-saturated cement, 6% gel. Certain attachments to recent NVOO correspondence (Reference 24) indicate this hole to be so grouted, except that the grout terminates some 250 feet below the surface, and the material left in the hole from surface to 250 feet is apparently mud-contaminated cement. Further, it is indicated in these attachments that Lawrence Radiation Laboratory has requested that the following action be taken to enable this hole to be used for pre- and post-shot activities:

1. Place a 30 to 40 foot plug of salt-saturated cement in the bottom of subject hole;
2. Backfill hole to surface with a graded river run sand;
3. Bolt a steel flange on top of either the 26" conductor pipe or the 20" casing after completion of the blow-out preventer collar.

It is concluded that either of the above arrangements constitute adequate stemming of the Station 1 hole from the viewpoint of containment inasmuch as this hole penetrates only to a depth of 1,524 feet.

In regard to Station 1A, LRL Drawing L6-17434A shows that cement grout will be placed both inside of the hole and the 5½-inch diameter casing to a level approximately 600 feet above the center of the device. This will place the top of the grout some 100 feet into the bottom of the 20-inch diameter casing. Above this level, pea-sized gravel is to be placed in both casings throughout the remaining hole to the surface. Of the phenomena stated in Section 2.1 - ABSTRACT OF PREDICTIONS, that of chimney development appears most critical in respect to affecting the integrity of the stemming in relation to containment. It has been previously stated in Section 4.4 that the calculated possible maximum chimney height is 435 feet. Should the full height develop, there would still remain some 165 feet of grout plug which would be effective as stemming and in preventing the loss of gravel by flow into the cavity. However, based upon experience at GNOME and a comparison of media, it is considered

likely that little, if any, chimney will develop for the SALMON Event.

On the basis of the foregoing, it is concluded that the stemming proposed for Station 1A is considered to be adequate for preventing immediate release of radioactive products through the emplacement hole.

Instrument Holes -

E-15 (N537,415.13, E269,491.64) and
E-16 (N537,414.35, E269,591.63):

These holes are located about 76 feet laterally from Station 1A; however, E-16 is planned for a depth of only 975 feet while E-15 is to penetrate to a depth of 2,700 feet. Accordingly, the lower portion of E-15 will be within the predicted cavity radius of 97 feet while the bottom of E-16 will be well beyond the predicted cracking radius of 300 feet. Reference 13 indicates that both these holes are to be grouted to the surface, and this manner of stemming is considered adequate.

E-4 (N537,915.26, E270,425.47), E-6 (N538,050.45,
E268,734.48), and WP-4 (N536,303.98, E269,172.86):

Reference 14 states that the shortest conceivable venting

path is through the brine-filled holes above the grout in E-4 and WP-4. It is also stated that these two holes will be grouted to a radial distance of at least 1150 feet from the device. The same treatment will apply to E-6 which will also be brine-filled to the surface. This distance of 1150 feet will provide a factor of safety against any unknown geologic effects. Thus, the stemming for these three holes is considered adequate.

E-14 Complex: E-14 (N537,199.25, E269,006.28)
E-14T (N537,199.25), E268,986.28), and
E-14B (N537,121.75, E269,026.12):

Initially, only hole E-14 was planned, and this was to have been grouted to the surface; however, grouting of full depth was not achieved due to failure of grout hoses. Reference 21 provides a historical summary of the events connected with the drilling, casing, and grouting of this hole and the subsequent attempts to achieve a satisfactory installation of instrumentation by means of grouting through two additional holes, E-14T and E-14B. These were drilled and whipstocked to connect with E-14 at approximate depths of 1900 and 4000 feet, respectively. Attempts were then made to circulate grout from E-14B into E-14 and out of E-14T. Circulation was achieved; however, grouting was only partially successful in that just the canister at a depth of 2000 feet was

grouted. After study, it was concluded that grout was cutting across the holes somewhere around a depth of 2000 feet.

Laterally, these holes are 560 to 580 feet from Station 1A. This places them some 260 feet beyond the predicted cracking radius of 300 feet. Vertically, the device and presumed channel are separated by some 700 feet, thus placing the channel approximately 400 feet beyond the predicted cracking radius. Thus, it is considered unlikely that communication will be established either laterally or vertically.

The conclusions which are summarized below are based upon study of Reference 21 and upon knowledge gained from March 13, 1964, DRIBBLE Review Panel meeting at NVOO. The data from these sources constitute the latest official information available to Beers, Inc. regarding E-14 complex. Conclusions, and reasons therefor, regarding operational safety predictions and securing E-14 complex are as follow:

1. In regard to all 3 holes of E-14 complex, Beers, Inc. assumes casing to be satisfactorily grouted to medium as there is no information to the contrary. Subject

- F&S report matter-of-factly reports sequence of installations and makes no reference to any difficulties or imperfections in grouting casing in place;
2. E-14T is considered to be adequately stemmed and no additional treatment is required. F&S report indicates this hole became fully plugged with grout in process of attempting to grout E-14. For the lack of information to the contrary, the grout within this hole is assumed to be of satisfactory consistency;
 3. It was learned at the NVOO meeting of March 13 that E-14B will be utilized as an instrument hole. It is assumed by Beers, Inc. that the installation would normally include grouting to the surface in this hole. On this and the further assumption that this grouting will be accomplished without difficulty, this hole would be considered to be adequately stemmed, and no further treatment would be required. Should difficulties be encountered during grouting, a re-evaluation would be required on basis of particular circumstances;
 4. E-14 now has a grout plug which is presumed to be approximately 2000 feet in length. Though F&S report indicates that this plug is not consistent as fluid

bled from hole for several weeks following cessation of grouting operations, it is still considered to be adequate stemming for this hole. This statement is based on the opinion that the possibility of communication being established between E-14 and Station 1A is remote. There is less assurance of safety with the condition of inconsistent grout than with a hole which is tightly grouted; however, it is emphasized that the possibility of communication is considered remote. From March 13 meeting at NVOO, it was understood that LRL is either designing, or can design, a pressure seal device for E-14 hole which will provide for cable installation, as it is desired to maintain instrumentation capability in this hole. Beers, Inc. certainly concurs with the principle of use of such device from standpoint of increasing degree of safety in regard to uncertainty of grout condition; however, Beers, Inc. does not lay on requirement for use due to opinion of remote possibility of communication being established.

F&S report indicates that present plug in E-14 hole extends from approximately 2000 feet to surface.

This is indicated to Beers, Inc. on basis of F&S statement that grout was observed coming out of hole after pumping in 45 cubic yards. Considering approximate volume of cables and hoses, this volume of grout is calculated to fill eleven-inch inside diameter casing to approximate depth of 1895 feet, thus indicating that plug is essentially continuous to surface from depth of approximately 2000 feet.

The foregoing conclusion regarding E-14 appears to be inconsistent with previous Beers, Inc. telegram of Sept. 9, 1963 to NVOO; however, such is not the case. At 13 March DRIBBLE meeting at NVOO, Beers, Inc. representative attempted to make this clear by amplification of wording of subject telegram, quoted in part as follows: "...provided grout is sound down to a depth of 2000 feet both inside and outside of casing." This telegram resulted from request in OSA:RLK-1501, dated Aug. 30, 1963 for final evaluation of E-14 grouting problems on basis of two assumptions as follow: (a) All holes would be cased into salt section and grout-filled from surface to depth of casing, or to total depth, and (b) Medium in hole under grouted section would

consist of liquid or semi-fluid such as drilling mud, salt brine or incoherent grout. It was also requested to consider effects resulting from holes only partially filled with solid fluids, leaving a minor portion of hole air-filled beneath grout. In this latter respect, it was replied that no adverse effects on safety are anticipated.

It was explained at this meeting that depth of 2000 feet was not a Beers, Inc. requirement but was used in the 9 Sept. telegram because Beers, Inc. had understood from previous information that grout had, in fact, already been placed to this depth rather than just to bottom of casing as would be implied from assumption number one of OSA:RLK-1501 in the case of E-14 hole. This information consisted of copy of F&S letter to D'Agostino, dated 27 Aug. 1963 which stated in part that there was not a good cement plug from approximately 2000 feet to the surface of E-14. It was further emphasized at this meeting that the presumed length of plug within the casing is considered sufficient, though not consistent, to provide adequate stemming on the basis of the remote possibility of communication. In reply to query from Mr. Thalgott as to what length of stemming would be

necessary for an hypothetically open hole at the E-14 location, Beers, Inc. representative stated that a plug approximately 400 feet in length would be considered adequate.

The study and evaluation of E-14 complex have been made on basis of all data made available to Beers, Inc. to date. It was previously understood that a committee was to have been formed to investigate construction methods and problems at site. Results of this action are not known. If data were obtained which would have added bearing on Beers, Inc. evaluation of E-14 complex, these are required for any further appraisal.

4.9 Possibility of Secondary Explosions

The halite at a depth of 2700 feet has no significant water content (Reference 7, Table 6). The planned procedure for emplacement of the device requires grouting around the device and inside the casing to an elevation 600 feet above the working point. Therefore, there is a high degree of assurance that there will be no substantial quantities of water present in the vicinity of the shot point. Also, the volume of air will be extremely small. Accordingly, following the explosion, when the condensation

of all gaseous halite, grout and metal has occurred and the temperature has dropped to the melting point of halite, about 1450°F, the cavity should have a very low absolute pressure. Theoretically, if there were no steam and no air present, the absolute pressure would be zero.

Should water flow into the cavity following the explosion, the steam pressure could build up in the cavity. However, assuming that there is no very large opening through which the water can flow, the pressure buildup would be self-limiting. The head, assuming the water table at the surface, would be 2700 feet, and the corresponding pressure would be 1170 psi. Accordingly, a build up of pressure to 1170 psi would prevent further inflow of water and further increase in pressure. The lithostatic pressure would be on the order of 2800 psi, over twice the maximum probable pressure that would develop from leakage of water into the cavity and its conversion to steam.

In view of the above considerations, no hazard from secondary explosions is predicted.

4.10 Estimate of Prompt Venting

It is estimated that the likelihood of prompt venting to the surface through existing and shot induced fractures is remote. The possibility of venting by means involving man-made openings is discussed in Section 4.8.

Examination of the geologic settings for the SALMON Event does not indicate any potential fissures or faults which would permit the prompt transfer of radioactive products. The shot induced fractures are anticipated to extend to only 300 feet and collapse of the chimney, if occurring, is predicted to be less than 435 feet. Considering these distances in relation to the maximum spalling depth of 131 feet, it can be seen that

$$2,700 - (435 + 131) = 2,134 \text{ feet}$$

of relatively undisturbed material will remain as a barrier to prompt release. This thickness is sufficient to prohibit any prompt venting by this means.

4.11 Damage to Grout Seals and Aquifer Contamination

Concern has been expressed that, as a result of the explosion, there may be relative movement of the casing and surrounding media, particularly at the depth of aquifers 1, 2 and 3. Such

relative motion might cause damage to the seal established by grouting the space between the casing and the hole, particularly where grouting is not sound.

An important consideration is that the casing (20" OD, 133 lb./ft., J-55, ST&C, 8rd) extends into the top of the halite to a total depth of approximately 2,200 feet. This places the bottom approximately 500 feet above the W.P. This is a distinctly different situation from that in other events where the explosion occurred at the bottom of the casing, causing it to be pushed upward. While precise calculations have not been feasible, an approximate evaluation indicates that the relative motion of the casing and surrounding media would be unlikely to damage the seal if properly placed.

Should there be damage, two possibilities exist: (a) Flow of water between aquifers, and (b) Escape of radioactive gases if communication should develop between the cavity and bottom of casing. In either case it is difficult to find any reason for alarm. All aquifers penetrated by the Station 1A hole contain fresh water, and the head on each is such that flow through any channel along the casing

would be small. Radioactive contamination outside the casing at this distance from the explosion is not believed to be a consideration. However, this is a question beyond the scope of Beers, Inc. contract.

The second possibility is felt to be very remote as communication is not likely on the basis of the circumstances predicted. These are described elsewhere in this report. An evaluation of the degree of damage to the grout seal is not possible since the effectiveness of grouting is indeterminate. However, on the basis of previous remarks, the escape of hazardous quantities of radioactive gases cannot be visualized, even if communication is established between the cavity and the bottom of the casing.

4.12 Containment Predictions

On the basis of the results of the foregoing evaluations and the assumption that construction and emplacement will be accomplished in accordance with the proposed construction and emplacement plans, it is predicted that the SALMON detonation at a yield of 5 KT will be essentially contained.

5.0 HAZARDS TO EXISTING FACILITIES

5.1 Possibility of Damage to Wells and Pipelines

The structures to be evaluated for possible damage include all oil and gas wells and pipe lines in the vicinity of the SALMON Event, Tatum Dome. The characteristics of these structures are described in detail in Reference 15. Briefly, the nearest pipe line (United Gas Pipe Line) is a 16-inch line, passing at a distance of 2.8 miles from the shot point, and operates at a pressure of 1,000 psi. It is buried in two to three feet of clay and soil.

For gas wells, the State of Mississippi requires a minimum of 500 feet of surface casing cemented to the surface, and the producing string shall be cemented at least 1,700 feet above the base of the casing. Surface casing is 10 $\frac{3}{4}$ ".

The casing requirements for oil wells vary. All of the wells possibly affected have surface casing at least to a depth of 850 feet and are generally tested for 2,100 psi.

Possibility of Damage to United Gas Pipe Line and Wells

Near Baxterville - The essential data obtained from section 2.3 are contained in Table 5.1.1 as follows:

TABLE 5.1.1

Maximum Predicted Surface Motions
On Oil and Gas Structures

<u>Structure</u>	<u>Horizontal</u> <u>Range</u> (miles)	<u>Maximum</u> <u>Predicted</u> <u>Acceleration</u> (g's)	<u>Maximum</u> <u>Predicted</u> <u>Velocity</u> (cm/sec)	<u>Energy</u> <u>Ratio</u>
United Gas Pipe Line	2.8	.31	7.9	2.6
Nearest Oil Well	4.8	.09	3.3	.48
Nearest Gas Well	4.8	.09	3.3	.48
Baxterville Dehydration Plant	6.0	.05	2.3	.23

During the 1952 California earthquake, buried steel pipes at the Paloma Cycling Plant received damage only where they were placed in very poor soil (Reference 16).

Also, in nuclear tests, pipe lines exposed to ground shock have shown a high resistance to damage. In general, based on results of bombing in Japan, damage occurred only to subsurface pipes where they passed from a relatively rigid soil into fill. Considering the above general factors and

the high pressure carried which would require rugged construction, it is believed that the pipe line would not be damaged by the indicated ground motions.

The oil and gas wells are considered safe and support is given for this conclusion by data shown in Table 5.1.2 below:

Table 5.1.2

Surface Motions On Oil Wells
Near GNOME Event Which Were Undamaged

<u>Well</u>	<u>Horizontal</u> <u>Range</u> <u>(Miles)</u>	<u>Peak</u> <u>Particle</u> <u>Acceleration</u> <u>(g)</u>	<u>Peak</u> <u>Particle</u> <u>Velocity</u> <u>(cm/sec)</u>
Texaco #1 Remrida Basin Unit	4.4 ^(a)	about .1 ^(b)	(?)
Shell James Ranch #1	6.1	.094 ^(c)	2.17 ^(c) 2.93

(a) PNE-127F.

(b) PNE-150F, Figure 3.

(c) Beers, Inc. Memo to O. H. Roehlk, December 20, 1962.

5.2 Possible Damage to Stations 2 and 3

As of the currency date for this report, the status of Stations 2 and 3 at the time of the SALMON Event is uncertain.

Reference OSA:RAJ-2652, dated March 31, 1964, indicates that plans are forthcoming. Evaluation and comment will be made following receipt of the plans.

5.3 Securing of Station 3 Holes

NVOO letter, Reference OSA:RLK-1899, dated November 22, 1963, Subject: Station #3 DRIBBLE-Asbuilt Drawing for Vent Shaft and Proposal for Access Shaft, transmitted the Fenix and Scisson, Inc. proposal for providing a new Station 3A Access Shaft. This information was transmitted for the purpose of providing basic data on which to base predictions of damage to these shafts at Station 3 as a result of the SALMON Event. This Section pertains solely to means for securing Station 3 holes.

The vent and access holes are located approximately 2,000 feet from Station 1A Emplacement Hole. Insofar as containment is concerned, the possibility of any communication between Station 3 holes and Station 1A is considered to be extremely remote.

Vent Hole - According to Reference 21 and the preliminary asbuilt drawing, this hole was drilled to a total depth of 2087 feet, and the 30-inch casing was bottomed at 1643 feet. Difficulty was encountered in grouting, and a leak developed. Subsequent attempts to seal were unsuccessful, and shortly after drill rig demobilization, the water level was found to be 310 feet below the surface. Due to the aforementioned opinion regarding possibility of venting at this range, it is deemed satisfactory to stem this hole by filling approximately to the surface with water and, as an added safeguard, seal top of casing either with grout plug or welded cap.

Access Shaft - According to Reference 21, numerous difficulties were encountered in setting and grouting the 70-inch casing which was ultimately bottomed at design depth of approximately 950 feet. Several breaks in casing occurred, water was found to be entering after bailing to a depth of 390 feet, and grout invaded the casing. Corrective measures were attempted, and efforts to continue drilling were made. However, obstructions were encountered, and it was not possible to penetrate beyond 672 feet with a 64-inch bit. Drill rig has remained secured since this time.

At one time, water was known to be at a depth of 373 feet; however, it is not known if this is the current condition. Due to the aforementioned opinion regarding possibility of venting at this range, it is deemed satisfactory to also stem this hole by filling approximately to surface with water and, as an added safeguard, to seal the top of the casing either with grout plug or welded cap.

6.0 BASES OF GROUND MOTION PREDICTIONS

6.1 Effects of Transmission Model

The Tatum Dome, site of Project DRIBBLE, has a configuration and geologic environment typical of most salt domes in the gulf coast section of the United States. The dome is shaped roughly like a vertical cylinder, about one mile in diameter, and has been pushed up through relatively soft sedimentary deposits. The top of the salt is approximately 1500 feet below the surface. Directly overlying the salt is a caprock of anhydrite roughly 500 feet thick. This is overlain by 100-200 feet of limestone caprock. The areal extent of the anhydrite and limestone is approximately equivalent to that of the salt. Overlying the limestone are about 750-800 feet of sediments (clays, shale, sandstone, etc.). The physical properties of each of these layers overlying the salt will have an effect on the ground motion amplitude and must be considered when predictions are computed.

Since the SALMON and TAR events are to be in salt, the ground motion measurements recorded for the GNOME event (3.1 KT in salt) provide a basis for making DRIBBLE predictions. Because of the many differences in geologic

environment, GNOME surface measurements are not considered reliable indicators of motions to be expected at DRIBBLE, and that the subsurface measurements in salt at GNOME are applicable to surface predictions of DRIBBLE events as long as the DRIBBLE geology is taken into account.

Prior to the DRIBBLE HE tests, it was believed that the structural configuration of the dome might cause a variable rate of amplitude decay with distance; and therefore, possible shadow zones as well as azimuthal variations were anticipated. However, the DRIBBLE HE tests and a review of data observed from HE shots in a dome in Louisiana (Project COWBOY) indicate that while a slight amount of azimuthal variation may be expected, the decay of surface amplitudes with distance will follow a relatively uniform exponential rate.

The presence of a fairly thick section of soft, poorly consolidated sediments near the surface suggests the possibility of the generation of large amplitude surface waves. The empirical data furnished by the DRIBBLE HE tests indicate that it is possible to generate surface waves in this area by detonating shots in the near-surface sediments. However, for the three 1000-pound shots in salt no evidence of surface waves was observed. While these data seem to indicate

that surface waves will not be a hazard for shots in salt, it should be realized that considerable uncertainty accompanies the scaling of effects of 1000 pounds to 5 KT (yield ratio of 10,000 to 1) or even to .1 KT (ratio of 200 to 1).

6.2 Acceleration

Predictions of peak surface particle acceleration are based on the observed radial accelerations measured in salt at GNOME (References 11 and 20) and illustrated in Figure 2.2.1 in scaled form, i.e., scaled acceleration versus scaled distance. Surface accelerations for SALMON are determined from this graph in the following manner. Given the yield and distance, the scaled distance is computed by dividing distance by the cube root of the yield, and the corresponding scaled acceleration is read from the graph. The scaled acceleration is converted to real acceleration by dividing by the cube root of the yield. At or near surface zero the value of acceleration is then multiplied by a factor of 3.52, called the compound transmission coefficient, which compensates for alterations of amplitude due to the free surface and the various stratigraphic units which will be traversed by the seismic waves which reach the surface. The compound transmission coefficient is the product of transmission coefficients computed at each interface encountered.

Each transmission coefficient, T, at an individual interface is computed using

$$T = \frac{2\rho_1 c_1}{\rho_2 c_2 + \rho_1 c_1} \quad (6.2.1)$$

where ρ is density, c is sonic velocity and subscripts 1 and 2 refer to the incident and transmitting media respectively. This equation is valid only at normal incidence. Computation of the coefficient at other angles of incidence is quite complex and requires accurate ray tracing which in the case of the Tatum Dome is very questionable. Therefore, the values computed from equation (6.2.1) are used near surface zero only. At all other locations, a factor of 2.0 has been used.

6.3 Velocity

At GNOME, subsurface measurements of radial particle velocity in salt were made by Sandia Corporation (Reference 11) and Stanford Research Institute (Reference 20). A least squares regression line through these data yield the following relationships between velocity and distance:

$$u = 3.04 \times 10^6 R^{-1.64} \quad (6.3.1)$$

where particle velocity, u , is in cm/sec and distance, R , is in meters. Utilizing point source cube root scaling

theory where

$$u = K \left(\frac{R}{W^{1/3}} \right)^n \quad (6.3.2)$$

equation (6.3.1) can be written

$$u = 1.63 \times 10^6 W^{.55} R^{-1.64} \quad (6.3.3)$$

where the yield, W, for GNOME is assumed to be 3.1 KT.

Multiplying equation (6.3.3) by the compound transmission coefficient (3.52) we obtain

$$u = 5.74 \times 10^6 W^{.55} R^{-1.64} \quad (6.3.4)$$

which is the equation used to obtain both SALMON and TAR surface predictions at surface zero. For other locations equation (6.3.3) was multiplied by 2.0 yielding

$$u = 3.26 \times 10^6 W^{.55} R^{-1.64} \quad (6.3.5)$$

6.4 Energy Ratio

The energy ratio, ER, is defined as

$$ER = \frac{a^2}{f^2} \quad (6.4.1)$$

where a is acceleration in ft/sec/sec and f is frequency in cycles/sec. Using the simple harmonic motion relationship

$$a = 2\pi f u \quad (6.4.2)$$

where u is particle velocity in ft/sec (since a is in

ft/sec/sec), the energy ratio may be expressed

$$ER = 4\pi^2 u^2 \quad (6.4.3)$$

for particle velocity, u , in ft/sec. If particle velocity is in cm/sec the energy ratio is

$$ER = \frac{4\pi^2 u^2}{(30.48)^2} \quad (6.4.4)$$

6.5 Displacement

Recorded displacement data at GNOME is not considered to be of equal reliability to the acceleration and velocity data. Consequently, simple harmonic motion has been assumed; and displacements computed using the relationship

$$d = \frac{u^2}{980a} \quad (6.5.1)$$

where d = displacement in centimeters

u = particle velocity in cm/sec at the same distance at which displacement is required

a = particle acceleration in units of gravity (g) at the same distance at which displacement is required.

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APPENDIX A

ANALYSIS OF SPALLING MECHANISM

Spalling is herein defined as the fracturing of a solid by tensional stresses produced when a seismic pulse is reflected from a free face. The conversion of a compressional pulse to a tensional one is considered to be perfectly elastic with no loss of energy into the atmosphere at the solid-air interface.

The problem is to analyze the stress situation at continuous distances back from the free face to determine if sufficient tension exists to fracture the solid. The tensional stress arises only from the reflected pulse, whereas those forces resisting fracturing are that portion of the compressional pulse waveform which has not yet arrived at the interface, the tensile strength of the medium, and any overburden pressure which becomes significant when horizontal surfaces and long wave lengths are considered.

If the problem is restricted to one involving compressional pulses arising from subsurface nuclear detonations and a rock medium, generalized equations may be used to determine the stress condition at continuous depths below the surface. The equations are based on hydrodynamic considerations and machine computations; in the form shown they are applicable at ranges of a few hundred meters. The pulse shape assumed is one with an exponential decay thus producing a maximum pressure the instant the peak reaches a point of interest. The stress condition at any point below the surface may then be given by:

$$P_{net} = P_{ovb} + P_{ts} + P_{pwf} - P_{ref.}$$

where P_{net} = net stress at the section of interest

P_{ts} = constant - tensile strength of the medium

P_{ovb} = K (depth) - overburden stress

$P_{pwf} = P_p \left(\frac{r}{R}\right)^2$ - pressure wave form or that portion of the pulse which has not arrived at the free surface

$P_{ref.} = CR^{-1.5}$ - reflected peak pressure

where R = depth of burial plus the depth of interest

r = depth of burial minus the depth of interest.

The value of each of these quantities may then be computed as functions of depth to determine if P_{net} becomes $\geq$ zero, in which case a spall is predicted to occur. When a spall occurs, the overburden pressure must be reduced to zero since the overlying strata are detached, and recomputed for further depths of interests on the basis of the newly created free surface. Additionally, the peak reflected pressure ($P_{ref.}$) must be reduced to the value of the pressure wave form (P_{pwf}) at the new free face since the energy in the descending pulse is trapped in the spalled section. On the basis of these new values further depths of interest may be investigated to determine if additional spalls will occur.

Since actual test conditions are not similar to free field predictions for a homogeneous medium, corrections for the variation in the stratigraphic section are introduced. The transmission coefficient, or change of pressure across an interface, is given by:

$$\frac{P_2}{P_1} = \frac{2\rho_1 C_1}{\rho_1 C_1 + \rho_2 C_2}$$

where $\rho_1 C_1$ are the density and compressional wave propagation velocity of the original medium and $\rho_2 C_2$ are those of the medium across the interface. Corrections for transmission coefficients must be introduced at all depths where they are applicable, to both the ascending and descending pulses.

The analysis as outlined above is confined to the case of normal incidence only and three methods are presently available for the solution of the calculations; these are by graphical procedures, analog computer and digital computer.

POST-SHOT CHIMNEY CALCULATIONS

Calculations to determine the height to which post-shot chimney formation will occur are based on the assumption that:

- 1) The post-shot cavity is spherically symmetrical,
- 2) The chimney is cylindrical with a radius equal to that of the cavity, and
- 3) An increase in volume will occur upon breaking of solid material.

The volume of the cavity, or void, is

$$V_{cav.} = 4/3 \pi R^3$$

The volume of the chimney (V_{ch}) is then given by $V_{ch} = \pi R^2 h$ where (h) is the height above the shot point.

Since the chimney volume includes one half of the cavity void, the volume of solids is seen to be:

$$V_{sol} = V_{ch} - \frac{1}{2} V_{cav.}$$

The original volume of solid material must then swell upon breaking to include both its original volume and the volume of the existing void

$$(n) V_{sol} = V_{cav.} + V_{sol}$$

where (n) is the swell factor for the medium being considered.

$$\begin{aligned} \text{Then } n \left[\pi R^2 h - \frac{2}{3} \pi R^3 \right] &= \frac{4}{3} \pi R^3 + \pi R^2 h - \frac{2}{3} \pi R^3 \\ \text{and } n \left(h - \frac{2}{3} R \right) &= \frac{2}{3} R + h \\ \text{yielding } n &= \frac{h + \frac{2}{3} R}{h - \frac{2}{3} R} \quad \text{and } h = \frac{\frac{2}{3} R (1+n)}{n-1} \end{aligned}$$

The value of (n) may then be determined for mediums in which experience is available and subsequently be used to determine the chimney height for future events, in the same medium, based on the predicted cavity radius.

PERMANENT DISPLACEMENT AND STRAIN CALCULATIONS

With the detonation of an underground nuclear explosion a post-shot cavity results which is larger than the original shot chamber. The expansion of this cavity to its final size entails the vaporization, melting and deformation of the material surrounding the original chamber. The major portion of the material is displaced radially from the source. The difference in position between an original point in the medium and its final location, as measured upon re-entry, is termed the permanent radial displacement of the point.

EQUATION DERIVATION

Given the initial chamber radius and final cavity size, the assumption can be made that the medium has behaved as an incompressible material and no loss of volume of material has occurred through vaporization or melting. The volume of material which originally occupied the post-shot cavity must therefore be distributed throughout the medium. Assuming spherical symmetry the following equation may be derived:

Given: R_1 = radius of original shot chamber

R_1' = radius of post-shot cavity.

R_2 = original radius to point of interest

R_2' = final radius to point of interest

If the original and final volumes are equal, then

$$\frac{4}{3} \pi \left[(R_2)^3 - (R_1)^3 \right] = \frac{4}{3} \pi \left[(R_2')^3 - (R_1')^3 \right]$$

and $(R_2')^3 = (R_2)^3 - (R_1)^3 + (R_1')^3$ yielding $\Delta R_2 = R_2' - R_2$

which is the permanent radial displacement of a point whose initial position was R_2 .

Given the predicted radial permanent displacements, the tangential strains may be computed by considering the change in circumference at any radius of interest.

The compressive strain due to a radial displacement is obtained by plotting the displacement versus distance, and fitting an equation to that segment of interest. At distances relevant to radial fracturing, this portion of the curve may be approximated by the equation $D = CR^{-1.9}$ ft. The radial strain is then $\frac{dD}{dR} = -1.9 CR^{-2.9}$ ft/ft.