UCRL--53437

DE84 005750

Riola Release Report

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Manuscript date: August 4, 1983

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Contents

Summary	1
Safety	1
Radiation	1
Subsidence	2
Investigations	7
Surface Ground Zero	7
Downhole Photography	7
Reviews	18
Emplacement and Stemming	18
Studies	27
Radiation Release	27
Study 1	27
Study 2	27
Study 3	28
Study 4	28
Study 5	30
Plug-Hole Interaction	30
Erosion	32
Geophone Signals	32
Emplaced Plug Properties	34
Conclusions	36
References	37

Riola Release Report

Summary

Eleven hours after execution of the Riola Event (at 0826 PDT on 25 September 1980) in hole U2eq of the Nevada Test Site (NTS), a release of radioactivity began. When the seepage stopped at about noon the following day, up to some 3200 Ci of activity had been dispersed by light variable winds. Table 1 is a chronology of events.

On 26 September, examination of the geophone records showed six hours of low-level, but fairly continuous, activity before the release. Electrical measurements indicated that most cables were still intact to a depth below the stemming platform. A survey of the ground zero area showed that the seepage came through cracks between the surface conductor and the pad, through cracks in the pad, and through a crack adjacent to the pad around the mousehole (a small hole adjacent to the emplacement hole).

To preclude undue radiation exposure or injury from a surprise subsidence, safety measures were instituted. Tritium seepage was sufficient to postpone site activities until a box and pipeline were emplaced to contain and remove the gas.

A thorough engineering review showed that the emplacement and stemming had been done according to the approved plan and established procedures.

Downhole photography revealed the emplacement hole to be significantly enlarged for 150 ft of depth encompassing the zone of the stemming platform. It also showed that only the core portion of the platform supported by the plug support ring at 699 ft remained and that the emplacement pipe had undergone column failure well below the stemming platform at a depth of 856 ft.

Radiation release modeling and calculations were generally consistent with observations. Plug-hole interaction calculations showed that the alluvium near the bottom of the plug may have been overstressed and that improvements in the design of the plug-medium interface can be made. Experimental studies verified that the surface appearance of the plug core was caused by erosion, but, assuming a normal strength for the plug material, that erosion alone could not account for the disappearance of such a large portion of the stemming platform. Samples from downhole plug experiments show that the plug may have been considerably weaker than had been indicated by quality assurance (QA) samples.

Safety

Radiation

To prevent undue exposure, extensive radiation monitoring was done in the area of hole U2eq. By 1200 h Friday, 26 September 1980, the release of radioactive fission products driven by cavity gas pressure ceased. Subsequent occasional detection of these releases resulted from atmospheric pressure lows that caused the cavity gas to "breathe."

The release of tritium contained in HT (hydrogen-tritium) gas and HTO (hydrogen-tritium-oxygen) vapor followed a different pattern. Sample concentrations increased from about 2 $\mu\text{Ci}/\text{cm}^3$ on September 26 to about 3 mCi/cm^3

on October 10. Because this concentration was in excess of the maximum permissible concentration for a 40-h work week, operations around hole U2eq were postponed and additional samples were taken around surface ground zero (SGZ). Figure 1 illustrates the tritium concentrations near Riola in mid-October 1980.

A box that was 20 ft square by 6 ft high was built and emplaced over surface ground zero, and a pipeline and pumping equipment were installed to remove contaminated air from the box and inject it into the Nessel (U2ep) chimney through the postshot hole (U2ep-PS1A). Figure 2 is a schematic of the gas-disposal system, and Fig. 3 shows the box and pipe leading from it. Facilities and

Table 1. Chronology of events and available information subsequent to and until termination of the Riola release.

September 25	
Time	
0826	Zero time. Geophones register greater than 10 V full scale for 12 s, greater than 5 V full scale for 21 s, and decrease to background at about 90 s.
0906	Bonarda (U3gv) collapse. Riola geophones register 1 V full scale, then decrease to background in about 30 s.
0951	First prompt gas sample taken. End of hose at 1227 ft.
1200	Geophones register occasional signals of up to 0.3 V.
1350	Geophones begin to register very frequent small signals with occasional signals of about 1 V.
1506	Prompt gas sampling completed for the day. Cables still intact to about 1280 ft, as measured on Cliper and D-cable. Slifer oscillator indicates uncrushed Slifer cable to 1230 ft.
1922	Surface ground zero (SGZ) RAMS detects initial seepage of radioactivity to the atmosphere.
1925	Perimeter RAMS No. 6 (2 ft southwest of GZ) reads 13 mR/h.
1950	SGZ RAMS reads 500 mR/h, the highest reading recorded. Geophone signals become infrequent.
2130	SGZ RAMS reads 166 mR/h. Perimeter RAMS reads 20 mR/h, and U3gv portable units read 0.4 mR/h.
September 26	
1030	SGZ RAMS reads 15 mR/h.
1100	Measurements show D-cable broken at 99 ft, Cliper cable broken at 843 ft, and gas-sampling hose pulled 65 ft downhole. Readings between 30 and 1500 mR/h obtained on, in, and around concrete pad at SGZ.
1200	SGZ RAMS reads background.
1630	Measurement of diagnostics cables shows them broken at cable fanout at about 865 ft.

equipment supporting a downhole camera appear in the background. The holding capacity of alluvium for gases injected at some depth is discussed in "Waste Gas Dispose? . Alluvium."¹

Lawrence Livermore National Laboratory's Health and Safety Department at NTS (LLNL-N), assisted by Reynolds Electric Company's (REECO's) Rad Safe, continued to monitor the working environment throughout all on-site activities. To ascertain the quantities and proportions of the constituent gases and to evaluate any explosive hazard, LLNL's Nuclear Chemistry Department took both surface and downhole samples.² Tracer gas measurements show that some 50 million litres of noncondensable gases were produced in the Riola cavity.

Subsidence

To guard against the hazard of a surprise subsidence or collapse to the surface, an important

safety consideration, geophone signals were monitored continuously. Table 2 summarizes the signals of interest, and Figs. 4 through 6 illustrate some of the signals summarized in the table. More geophone signals are contained in "Riola Information for CEP."³

The lengths of the downhole signal cables were monitored periodically, particularly before each new activity near hole U2eq was undertaken. About three-fourths of the prompt diagnostic cables remained intact to depths below the stemming platform. No significant changes from the conditions found on September 26 occurred.

After the initial downhole photography had revealed no evidence of a large-scale subsurface collapse and a study of collapse experience showed that collapse to the surface at the Riola scaled depth of burial had never taken place, operations requiring heavy equipment near SGZ were permitted and the investigation was completed without incident.

Location	Activity ($\mu\text{Ci}/\text{cm}^3$)	Location	Activity ($\mu\text{Ci}/\text{cm}^3$)
SGZ	8.0×10^{-4} HT 2.2×10^{-6} HTO	200 ft S of SGZ	4.0×10^{-5} HT 7.0×10^{-6} HTO
100 ft N of SGZ	3.9×10^{-6} HT 1.2×10^{-9} HTO	100 ft W of SGZ	5.0×10^{-5} HT 3.2×10^{-8} HTO
200 ft N of SGZ	1.0×10^{-4} HT 1.0×10^{-8} HTO	200 ft W of SGZ	4.0×10^{-5} HT 6.5×10^{-8} HTO
100 ft E of SGZ	1.1×10^{-4} HT 1.5×10^{-8} HTO	Near U2az-2	4.0×10^{-5} HT 3.4×10^{-7} HTO
200 ft E of SGZ	3.0×10^{-5} HT 2.0×10^{-7} HTO	Maximum permissible concentration for 40 h	2.0×10^{-3} HT 5.0×10^{-6} HT
100 ft S of SGZ	9.0×10^{-5} HT 3.1×10^{-9} HTO		

Figure 1. Tritium activity at the Nevada Test Site (NTS), mid-October 1980.

Figure 2. Gas-disposal system.

Figure 3. Box built over SGZ and pipeline leading from it.

Figure 4. Geophone activity (a) from 1300 to 1730 h and (b) from 1730 to 2200 h.

Figure 5. North geophone record of (a) earthquake and (b) later activity.

Figure 6. North geophone record at U2eq following shot U9cq (Dauphine).

Table 2. Riola geophone records.

Time		Signal size full swing (mV)	Remarks
Day	Hour		
9/25/80	0826	>10,000 >5,000	Saturated 12 s Saturated 21 s Ringing to 120 s
	0907	Decrease to background 900	~10 s following Bonarda collapse
	1329 to	200 to	Mostly ~200 mV, 500 mV
	1556	1,000	about once in 10 min, 1,000 mV about once per hour
	1700	1,500	Brief
	1740 to	200 to	Mostly ~200 mV, 500 mV
	1947	1,000	about once in 10 min, 1,000 mV about once per hour
11/8/80	0250	4	Earthquake off Eureka, California
11/11/80	0225	12	Riola activity
11/14/80	0850	>50	Dauphine (U9cq)

Investigations

Surface Ground Zero

On 26 September 1980, a radiation survey team carefully monitored the area near ground zero. They found that the largest sources of radiation were the ladder support holes. Radiation was also detected between the surface conductor and the pad, along some cracks in the pad, and along a crack south of the pad, encircling the mousehole. Figure 7(a) shows the results of a survey at 1230 h, and Fig. 7(b) shows the results of a partial survey at 1500 h. The north side of the pad area, viewed from the west, is shown in Fig. 8(a). Figure 8(b) shows the two ladder holes having the highest radiation readings: 1.5 mR/h for the hole in the center of the figure, and 0.5 R/h for the hole at right. Figure 8(c), from the south, shows a crack that had a reading of 150 mR/h. Readings within the surface conductor were 30 mR/h, which was background for this location at the time.

In January 1982, the pad was sawed into pieces and removed, visual and documentary photography were performed, and soil samples were taken. The results are contained in "Riola Soil Sample Results"⁴ and in "Riola Graphical Soil Sample Results."⁵ Visually, no new information was acquired. The soil samples showed a fairly uniform permeation of tritium throughout the material near ground zero.

Downhole Photography

For downhole photography, three postshot holes were drilled to intersect the emplacement hole. The first and second holes were, respectively, below and above the stemming platform location, while the third was higher in the hole but necessarily below the bottom of the surface conductor. Table 3 lists the spudding (start of hole) distances and directions from SGZ and the estimated intersection depths for the three holes. Figure 9 illustrates the site geometry. "U2eq Post-Shot Hole Drilling Summary"⁶ provides a brief history of these holes.

Six downhole photography runs have provided pictures of the interior of the emplacement hole, the emplacement hardware, the cables, and what remains of the stemming platform. Photographs and videotape records encompass the hole between depths of 300 and 1170 ft. The camera, a product of V. Brugman and his Photo Applications Group at LLNL-N, contains both photographic and video cameras and has pan, tilt, and zoom capabilities (Fig. 10).

Uppermost entry into the emplacement hole was made at a depth of 301 ft. Except for the smaller number of cables, both the hole and emplaced hardware are similar in appearance to their prestemmed condition. The upper

Figure 7. Results of surveys at (a) 1230 and (b) 1500 h, 26 September 1980.

Figure 8. (a) North side of pad area, viewed from the west; (b) ladder support holes having highest radiation readings; (c) view of pad from south, showing crack with radiation reading of 150 mR.

vacuum-demand valve of the prompt-gas sampling system is shown in Fig. 11. It is located at a depth of 434 ft, some 66 ft deeper than when it was emplaced. This displacement agrees well with the estimated 65 ft of surface-gas sampling hose that disappeared downhole subsequent to Riola D-day sampling activities, but prior to reentry on D+1. The hose now ends at 490 ft. Down to a depth of 655 ft, the hole appears to be unaltered from its preshot condition. At this depth the hole becomes enlarged and remains enlarged to a depth of 805 ft [Figs. 12(a) and (b)]. This enlargement, which amounts to an increase in radius of 2 to 4 ft, is uniform at some depths and not at others [Figs. 13(a) and (b)].

The top of the plug (Fig. 14) was at a depth of 685 ft, the as-built depth. Figures 15(a) through (d) show what remains of the stemming platform and the plug support ring located at 699 ft.

Figure 16 is a mosaic of seven photographs showing, from the opposite side, what remains of the lower portions of the stemming platform. The large cable snarl near 780 ft, seen in Fig. 17, is the result of cable breakage and stemming fall. Figures 18(a) and (b) show the bend above and the broken end of the emplacement pipe at 856 ft.

The broken end of the fallen lower portion of the emplacement pipe at 1059 ft and the bend below are shown in Figs. 18(c) and 18(d).

At about 1135 ft, the lower gage portion of the hole ends and the top of the chimney is encountered (Fig. 19). The fallen emplacement pipe disappears in the rubble at 1170 ft (Fig. 20). A mosaic of 11 photographs of the chimney, looking down at 45 deg from vertical, is shown in Fig. 21. We estimate that the rubble meets the chimney wall at about a distance of 50 ft. Figure 22, a view looking up from 310 ft, shows both a gage emplacement hole and the cable that supports the camera as it enters the emplacement hole through one of the post-shot holes.

In summary, 150 ft of the emplacement hole was enlarged significantly, well above and below the stemming platform location. We also saw the remains of the stemming platform, which resemble the frustum of a cone, and its upper portion, which remains bonded to the cables but not to the emplacement pipe; an intact plug support ring (42 in. diam); and the emplacement pipe, showing column failure at a depth of 856 ft—some 535 ft above the working point.

Table 3. Riola photography postshot holes.

Hole	Distance from SGZ (ft)	Direction from SGZ	Intersection depth (ft)	Remarks
U2eq PS-3AA	260.1	S 63°46' E	695	Entered enlarged emplacement hole some 9 ft off axis of U2eq
U2eq PS-4A	239.8	N 63°57' W	671	Broke through to emplacement hole from 671 to 673 ft
U2eq PS-1DA	15.8	S 59°29' E	301	Close to vertical

Figure 9. Photographic postshot holes.

Figure 10. Camera for downhole photography.

Figure 11. Upper vacuum demand valve.

Figure 12. (a) Top of emplacement hole enlargement at 655 ft, and (b) cable snarl and bottom of hole enlargement at 805 ft.

Figure 13. Enlarged hole (a) below and (b) above stemming platform.

Figure 14. Top of plug at as-built depth (685 ft).

Figure 15. (a) Remains of stemming platform from above, (b) upper portion of stemming platform core supported by cables, (c) remains of stemming platform around 695 ft, and (d) plug support ring and stemming platform core at 699 ft.

Figure 16. Mosaic of seven photographs (opposite side) showing remains of lower portions of stemming platform.

Figure 17. Large cable snarl near 780 ft resulting from cable breakage and stemming fall.

Figure 18. (a) Bend above and (b) broken end of emplacement pipe at 856 ft. (c) Broken end of lower portion of emplacement pipe at 1059 ft and (d) bend below.

Figure 19. Top of chimney at about 1135 ft.

Figure 20. Fallen emplacement pipe disappearing into rubble at 1170 ft.

Figure 21. Mosaic of 11 photographs of chimney, looking down at 45 deg from vertical.

Figure 22. View looking up from 310 ft, showing gage emplacement hole and cable that supports camera.

Reviews

Emplacement and Stemming

The Riola Event was emplaced and stemmed according to the plan presented to the Containment Evaluation Panel. The only modification was use of an increased thickness of fines layers to ensure the covering of fanouts. Coal-tar epoxy (CTE) for the stemming platform plug was pumped through a tremie pipe (a pipe for pumping fluids, grout, CTE, etc.) to the plug elevation, while gravel was poured into the hole. This was standard procedure for emplacing plugs at depths of more than 500 ft. A diagram of the stemming and emplacement is shown in Fig. 23. Plug and gas-block locations are shown in Fig. 24. Figure 25 shows the downhole gas-sampling installation. Table 4 is a summary of the stemming, and Table 5 shows stemming balance information. The results of the QA samples for the Riola stemming platform are contained in Table 6, and Fig. 26 shows the temperature profile provided by a thermistor at a depth of 695 ft (well within the plug) and about 3 in. from the emplacement pipe, where it also detected thermal effects from the emplacement pipe grouting. "Emplacement and

Containment Report for U2eq"⁷ contains more detail and documentation on the emplacement and stemming.

Shortly after the event, H. E. Watling, then group leader for containment in the Mechanical Engineering Department, reviewed Riola design and construction. He states⁸:

"I have reviewed the engineering design and execution of the Riola emplacement and stemming and can find nothing that explains clearly the post-event phenomena which were observed. The areas which I have reviewed include the design, emplacement, and operation of the gas sampling system, the special measurements, the emplacement hardware, the cables and gas blocks, and the stemming and plastic plugs. I have also reviewed the QA documentation and deviations which occurred. While there were changes and deviations in the field, they were minor in nature and were not, in my opinion, connected to any post-event phenomena. The entire operation appears to have been conducted in a

Figure 23. Riola stemming and emplacement for U2eq.

proper manner using good design practices and sound engineering judgment."

An independent review was subsequently made by Alan B. Casamajor. His conclusions and recommendations are quoted below⁹:

"Based upon my examination of the records of the Riola Event, I can find no discrepancies between the specifications, procedures, and normal practices for a containment system and what was actually done in the field. All of the people involved with this program appear competent and conscientious. Where I was

able to make an independent check of their work, I found that everything was in order.

"Specifications that have been formalized are clear, performable, and appear sufficient for their specific tasks. There is a need to do some additional work in the area of defining the acceptance criteria for an emplaced plug. This includes both documenting existing data, and obtaining and documenting additional data in several areas."

Cables

Top of hole

Field gas block	15
Factory gas block	48
No gas block	2
Total	65

Top plug

Field gas block	15
Factory gas block	48
Total	63

Bottom plug

Field gas block	12
Factory gas block	43
Total	55

Figure 24. Riola plugs and gas blocks.

Figure 25. Downhole gas sampling.

Table 4. Riola material balance.

Title Material balance U2eq

By RGH Date 9-22-80

DH elev	Plan			Material	As-built				Remarks
	Lin ft	Yd ³	Tons		Elev	Lin ft	Tons	Density lb/ft ³	
1411									
1406	5	9.8	23.0	Magnetite					
				Adjustment			(9 K on SG)		
				Total Magnetite	1406	5	23.0	175.0	Calc
1360	46	34.0	41.3	Ulexite					
		-0.8	-0.9	Adjustment - 1 ft					
		33.2	40.4	Total ulexite	1361	45	47.9	106.6	SS 1364 42.7T
1297	63	104.3	140.8	Overton sand					SS 1364 44.6T
		-3.7	-5.0	Adjustment - 1 ft					
		100.6	135.8	Total Overton sand	1299	62	138.1	101.7	(2) SS1299
1252	45	85.3	103.7	LLNL coarse					
		+4.5	+5.4	Adjustment + 2 ft					
		89.8	109.1	Total LLNL coarse	1252	47	102.0	84.1	"D" 1252
1216	36	66.9	86.7	Quartzite					
		-1.9	-2.4	Adjustment - 1 ft					
		65.0	84.3	Total Quartzite	1217	35	85.5	97.3	"D" 1217
1060	56	295.6	359.2	LLNL coarse					
				Adjustment 0 ft					
				Total LLNL coarse	1061	56	346.0	86.7	"D" 1061
1015	45	85.1	108.0	LLNL mix					
				Adjustment 0 ft					
				Total LLNL mix	1016	45	109.3	95.1	"D" 1016
883	132	255.5	310.4	LLNL coarse					
		+1.9	+2.3	Adjustment + 1 ft					
		257.4	312.7	Total LLNL coarse	883	133	307.7	88.6	"D" 883
828	55	105.29	133.6	LLNL mix					
				Adjustment 0 ft					
				Total LLNL mix	828	55	132.8	93.4	"D" 828
720	108	209.0	253.8	LLNL coarse					
		+1.9	+2.3	Adjustment + 1 ft					
		210.9	256.1	Total LLNL coarse	719	109	256.1	90.0	(2) SS 720 "D" 720
701	19	36.7	46.6	LLNL mix					
		-1.9	-2.4	Adjustment - 1 ft					
		34.8	44.2	Total LLNL mix	701	18	49.5	105.2	Tag 701
689	12			LAE 59Z plug					
				Adjustment 4 ft					
				Total LAE 59Z plug	685	16			Tag 685
673	16	30.4	38.5	LLNL mix					
		-7.6	-9.6	Adjustment - 4 ft					
		22.8	28.9	Total LLNL mix	673	12	29.3	95.3	"D" 673
548	125	237.6	288.7	LLNL coarse					
				Adjustment 0 ft					
				Total LLNL coarse	548	125	296.0	92.3	"D" 548
513	35	66.4	84.3	LLNL mix					
				Adjustment 0 ft					
				Total LLNL mix	513	35	91.8	102.4	"D" 513

Table 4. (Continued)

Title Material balance U2eq

By RGH

Date 9-22-80

Plan					As-built				
DH elev	Lin ft	Yd ³	Tons	Material	Elev	Lin ft	Tons	Density lb/ft ³	Remarks
377	136	259.4	315.0	LLNL coarse					
		- 3.8	- 4.6	Adjustment - 2 ft					
		255.6	310.4	Total LLNL coarse	379	135	318.9	92.4	"D" 378
328	49	94.2	119.5	LLNL mix					Tag 379
		+ 3.9	+ 4.8	Adjustment + 2 ft					
		98.0	124.3	Total LLNL mix	328	51	117.4	88.7	"D" 328
28	100	194.9	236.8	LLNL coarse					
				Adjustment 0 ft					
				Total LLNL coarse	228	100	243.6	92.6	"D" 228
193	35	69.5	86.2	LLNL mix					
				Adjustment 0 ft					
				Total LLNL mix	193	35	84.7	90.3	"L" 193
68	125	247.6	300.8	LLNL coarse					
		- 7.6	- 9.3	Adjustment - 4 ft					
		240.0	291.5	Total LLNL coarse	72	121	266.6	82.3	"D" 72
34	34	64.9	82.4	LLNL mix					
				Adjustment 0 ft					
				Total LLNL mix	34	38	86.8	99.0	Tag 34
22	12			LAE 59 plug					
				Adjustment + 1 ft					
				Total plug	21	13			Tag 21
DH elev	Lin ft	Ft ³	Tons	Material	Elev	Lin ft	Tons	Density lb/ft ³	Remarks
16	6	-	-	LAE-59MY plug					
				Adjustment					
				Total plug	13.3	7.7	-	-	Tag 13.3
15	1	1.9	2.6	Overton sand					
				Adjustment + 1.3 ft					
				Total Overton sand	11	2.3	-	-	Tag 11

Table 5. Stemming material U2eq.

Material	Plan	As-built	Tons ±	%
Magnetite	23.0	23.0	0	0
Ulexite	40.4	47.9	+7.5	+18.5
Overton sand	135.8	138.1	+2.3	+1.7
Quartzite	84.3	85.5	+1.2	+1.4
LLNL coarse	2164.5	2136.9	-27.6	-1.3
LLNL mix	693.9	701.6	+7.7	+1.1
Total	3141.9	3133.0	-8.9	-0.3
6.2% Flyash replaced with LLNL mix.				
LLNL mix to LLNL coarse 33%.				

Table 6. Assurance tests.

Assurance tests		Technology & Construction On-Continent Test Division		Page 1 of 3		
Event/location: <u>Riola U-2eq</u>		Specimens made by: <u>V. Hunter</u> <u>V. Hunter</u>				
Plug/batch number: <u>1.1</u>		Specimens tested by: <u>J. Herron</u>				
Formulation: <u>LAE-59Z</u>						
Test results from quality assurance tests per NS 76-5-3 and NS 76-5-4						
Flexure test						
Specimen identity	Dimensions of break area	Total force to break (lb)	Effective area (in. ²)	Results (psi)	Remarks	
1.1A	3- × 1-3/4	844.3	5.3	160.8		
1.1B	3- × 1-3/4	687.2	5.3	130.9		
1.1C	3-3/16 × 1-3/4	903.2	5.6	161.9		
Samples cured at: <u>140°F for 5 h</u> <u>102°F for 15 h</u> Average psi 151.2 Tested at <u>102°F</u>						
Adhesion test						
Specimen identity	Specimen height	Specimen diameter	Total force to break (lb)	Shear area (in. ²)	Results (psi)	Remarks
1.1A	2--	1.312	2179.5	8.2	264.3	
1.1B	2--	1.312	2061.7	8.2	250.0	
1.1C	2--	1.312	2061.7	8.2	250.0	
Samples cured at: <u>140°F for 5 h</u> <u>102°F for 15 h</u> Average psi 254.8 Tested at <u>102°F</u>						
Wall shear test						
Specimen identity	Specimen height	Specimen diameter	Total force to break (lb)	Shear area (in. ²)	Results (psi)	Remarks
1.1A	2--	4.00	7716.6	25.1	307.0	
1.1B	2--	4.00	7461.3	25.1	296.9	
1.1C	2--	4.00	7550.5	25.1	300.8	
Samples cured at: <u>140°F for 5 h</u> <u>102°F for 15 h</u> Average psi 301.6 Tested at <u>102°F</u>						

Table 6. (Continued)

Assurance tests		Technology & Construction On-Continent Test Division		Page 2 of 3		
Event/location: Riola U-2eq			Specimens made by: V. Hunter			
Plug/batch number: 1.2			V. Hunter			
Formulation: LAE-59Z			Specimens tested by: J. Herron			
Test results from quality assurance tests per NS 76-5-3 and NS 76-5-4						
Flexure test						
Specimen identity	Dimensions of break area	Total force to break (lb)	Effective area (in. ²)	Results (psi)	Remarks	
1.2A	3-3/16 × 1-5/8	944.5	5.2	182.0		
1.2B	3-1/8 × 1-3/4	785.4	5.5	143.6		
1.2C	3-3/16 × 1-3/4	962.1	5.6	172.5		
Samples cured at: 140°F for 5 h 102°F for 15 h Average psi 166.0						
Tested at 102°F						
Adhesion test						
Specimen identity	Specimen height	Specimen diameter	Total force to break (lb)	Shear area (in. ²)	Results (psi)	Remarks
1.2A	2-1/16	1.312	2120.6	8.5	249.4	
1.2B	2-	1.312	2159.9	8.2	261.9	
1.2C	2-1/8	1.312	2061.7	8.8	235.3	
Samples cured at: 140°F for 5 h 102°F for 15 h Average psi 248.9						
Tested at 102°F						
Wall shear test						
Specimen identity	Specimen height	Specimen diameter	Total force to break (lb)	Shear area (in. ²)	Results (psi)	Remarks
1.2A	2-1/16	4.00	6891.9	25.9	265.9	
1.2B	2-	4.00	8619.8	25.1	343.0	
1.2C	2-1/8	4.00	7009.7	26.7	262.5	
Samples cured at: 140°F for 5 h 102°F for 15 h Average psi 290.5						
Tested at 102°F						

Table 6. (Continued)

Assurance tests		Technology & Construction On-Continent Test Division		Page 3 of 3	
Event/location: <u>Riola U-2eq</u>			Specimens made by: <u>V. Hunter</u>		
Plug/batch number: <u>1.3</u>			V. Hunter		
Formulation: <u>LAE-59Z</u>			Specimens tested by: <u>J. Herron</u>		
Test results from quality assurance tests per NS 76-5-3 and NS 76-5-4					
Flexure test					
Specimen identity	Dimensions of break area	Total force to break (lb)	Effective area (in. ²)	Results (psi)	Remarks
1.3A	3-1/16 × 1-3/4	785.4	5.4	146.5	
1.3B	3-3/16 × 1-3/4	942.5	5.6	169.0	
1.3C	3- × 1-3/4	1021.0	5.3	194.5	
Samples cured at: 140°F for 5 h 102°F for 15 h Average psi 170.0					
Tested at 102°F					
Adhesion test					
Specimen identity	Specimen height	Specimen diameter	Total force to break (lb)	Shear area (in. ²)	Results (psi) Remarks
1.3A	2-1/16	1.312	2140.2	8.5	251.7
1.3B	2-1/8	1.312	2277.7	8.8	259.9
1.3C	2-1/8	1.312	2218.8	8.8	253.2
Samples cured at: 140°F for 5 h 102°F for 15 h Average psi 254.9					
Tested at 102°F					
Wall shear test					
Specimen identity	Specimen height	Specimen diameter	Total force to break (lb)	Shear area (in. ²)	Results (psi) Remarks
1.3A	2-1/16	4.00	8148.5	25.9	314.4
1.3A	2-1/8	4.00	8403.8	26.7	314.7
1.3A	2-1/8	4.00	7971.8	26.7	299.5
Samples cured at: 140°F for 5 h 102°F for 15 h Average psi 309.2					
Tested at 102°F

Figure 26. Temperature history of stemming platform.

Studies

Radiation Release

Study 1

The official value for the release of radioactive fission products from Riola is 3123.5 Ci. Because of wind-velocity effects and remote air-monitoring system (RAMS) data recording and interpolation, this value is considered to represent an upper limit to the amount of material released, and a value of 1624 Ci is thought to be more cor-

rect. In addition a seepage of tritium estimated at 2775 Ci occurred in the five months following the event. Further details are contained in "The Riola Incident—Prompt Release Results."¹⁰

Study 2

Release dispersion data were collected by the Environmental Protection Agency's (EPA's) Environmental Monitoring Systems Laboratory in Las Vegas (EMSL-Las Vegas). Radioxenon was reported offsite at Lathrop Wells, Nevada, while

onsite radionuclides were detected at BJY, at Areas 12, 15, and 51, and by aircraft over SGZ. No radionuclides were reported at Mercury or Area 400, however, both of which are on the path between the release and Lathrop Wells. Results of the compressed air samples are shown in Table 7. The interim report by the EMSL-Las Vegas contains further detail.¹¹

Study 3

REECo monitors radioactivity in the general onsite environment for the Department of Energy (DOE). Air-sampling stations are located at sites throughout the NTS. Gross beta analysis has provided the most information on the majority of test site samples, permits rapid determination of trends in gross radioactivity, and has a low detection limit.

An examination of the data for 1980 showed that a number of air-sampling stations collected a significantly larger amount of gross beta radioactivity than background for the week in which the Riola release occurred. These stations are in Areas 3, 5, and 6; Fig. 27 shows their locations. The "Environmental Surveillance Report for the Nevada Test Site" contains detailed information.¹²

Study 4

Release dispersion calculations were performed by Paul Gudiksen and George Greenly¹³ of the Atmospheric and Geophysical Sciences Division of LLNL. To do these calculations, they employed two three-dimensional atmospheric transport and dispersion codes, using source data supplied by K. Oswald and meteorological data provided by the Weather Service Nuclear Support Office at the NTS. Their calculations showed, because of the topography surrounding the Riola event site, that downslope surface flows during the night of 25 September provided a generally southward advection of air carrying the ¹³⁵Xe. After sunrise, these flows were destroyed because of heating of the sloped surfaces, causing a reversal to northward upslope flows.

During the first six hours, the xenon gas was transported directly southward, toward Yucca Flat (UCC), where the Skull and Half Pint mountain ranges directed the radioactivity toward the Jackass Flats (JAC) area (where no activity was detected). The activity continued in a southwesterly direction, reaching an area immediately north of the Lathrop Wells (LAW) sampler location by about 0800 h PDT on 26 September [Fig. 28(a)]. By

Table 7. Compressed air samples.

Location	Date collected	Sampling Period		Concentration ^{a,b} (pCi/m ³)	
		Date/Time to	Date/Time	¹³⁵ Xe	¹³⁵ Xe
Beatty, NV	09/26/80	24/1435	26/1405	ND	ND
Indian Springs, NV	09/26/80	23/0945	26/1115	ND	ND
Lathrop Wells, NV	09/26/80	24/1150	26/1400	34	360
Tonopah, NV	09/29/80	24/1500	29/1305	ND	ND
Rachael, NV	09/29/80	25/0920	29/1605	ND	ND
Hiko, NV	09/29/80	25/1030	29/1715	ND	ND
Area 15, NTS	09/26/80	23/1350	26/1335	7.7	64
Area 400, NTS	09/26/80	24/1400	26/1230	ND	ND
Mercury, NTS	09/26/80	23/1040	26/1150	ND	ND
Area 51, NTS	09/26/80	23/1435	26/1415	ND	12
BJY, NTS	09/26/80	23/1135	26/1215	2,100	30,000
Area 12, NTS	09/26/80	23/1205	26/1300	34	280
Aircraft sample No. 1 collected over SGZ	09/26/80	26/1132	26/1143	150	1,300
Aircraft sample No. 2 collected along Hwy 95 from Mercury to NECO	09/26/80	24/1421	26/1433	ND	ND

^a All results are extrapolated to the midpoint of the estimated exposure period.

^b ND = not detected.

Figure 27. NTS air-sampling stations for environmental surveillance.

Figure 28. Radiation dispersion calculation (a) morning and (b) afternoon 26 September 1980.

noon, the effects of the daytime upslope resulted in the apparent northerly transport of activity toward the northeast corner of the test site [Fig. 28(b)].

Study 5

"Wind Flow Study—Riola, U2eq"¹⁴ describes a release transport study performed by J. R. Smith, using surface wind data from the appropriate onsite meteorological data acquisition air-sampling stations. Employing a simple vector solution, he developed the path of a marker particle. Two possible paths exist for the near-surface activity to move from Yucca Flat to Frenchman Flat. The wind velocity history indicates that the drainage winds dispersed after 0200 h on 26 September (Fig. 29).

Plug-Hole Interaction

"Ground Shock Evaluation of the CTE Plug for the U2eq Riola Event"¹⁵ describes a dynamic finite element analysis program in which appropriate soil mechanics equations and criteria were applied for stress analysis of an axisymmetric model. The soil, plug, and stemming material properties used are shown in Table 8. Figure 30

shows the vertical stress-time history, and Fig. 31 shows the axisymmetric finite element model.

The calculations show the element in the alluvium, along the plug-alluvium interface near the bottom of the plug, to be critically stressed (25% greater than a conservative failure criterion). Calculations were also done on a keyway (purposely enlarged zone of the emplacement hole) plug configuration.

The conclusions that resulted from this analytical investigation of Riola plug behavior during ground shock are:

"1. Based on (the) conservative failure criterion for alluvium at the plug depth, it is possible that failure of the Riola plug could have been caused by ground shock.

"2. Even if a material failure due to ground shock did not occur, the alluvium near the plug-soil interface was in a relatively high state of stress due to ground shock plus overburden loadings and reliance on bond and friction at the interface under these conditions is not a strongly desirable design approach.

"3. A small keyway protruding into the soil around the plug can provide a more reliable approach for assuring integral movement of the plug and soil. For

Figure 29. Surface wind-flow study for Riola 9/25-9/26/1980.

this design, the highly stressed alluvium is confined by the plug material in a manner such that soil failure due to ground shock is very unlikely.

"4. A keyway which is at least two feet in length and six inches deep is adequate to achieve integral movement of the plug with the surrounding soil even if there is no shear capacity of the plug-

soil interface. Note that such a key should be located in the upper half of the plug as the highest stressed alluvium is at the bottom face of the key. To provide adequate confinement to this alluvium, it is recommended that the keyway be at least three feet from the bottom face of the plug."

Table 8. Material properties for calculations.

Material	Compressory wave velocity C_p (fps)	Young's modulus E (psi)	Poisson's ratio ν	Weight density γ (pcf)
Alluvium	4,500	390,000	0.3	120
CTE	5,000	500,000	0.28	117
Stemming	750	10,000	0.22	94
Grout-filled pipe (composite)	12,800	5,200,000	0.25	175

Figure 30. Time history of ground-shock longitudinal compressive stress through emplacement casing and alluvium at CTE plug.

Erosion

The surface of the remaining portion of the Riola stemming platform appears eroded rather than fractured. In part it has the appearance of a fluted column, with CTE-gravel between the cables being eroded away to form the fluting. Some 1500 tons of stemming passed by the Riola plug location. To gain improved insight into erosional effects, two somewhat qualitative tests were done.

In the first test¹⁶ gravel was dropped from a height of 16.5 ft onto the end of a cylinder of CTE plug material that was 12 in. in diameter and 13-3/4 in. tall. The rate of erosion was about 1 lb of plug material for 44 tons of gravel. Even if we assume terminal velocity for the stemming material and a hundredfold increase in erosion rate, we can only account for about 3% of the plug material removed.

The second test¹⁷ consisted of sandblasting some typical materials exposed to erosion by stemming. It showed that plug material is more resistant than tuff and that cable jacket material is more resistant than either. The results of this test and the fluted appearance of the Riola plug core are consistent.

Geophone Signals

The geophone signal history [Figs. 4(a) and 4(b)] suggests several things. First, it suggests a loss of stemming below the stemming platform, starting slowly at about 1210 h and continuing until about 1600 h. It also suggests a relative lack of activity in the hole until 1658 h and a subsequent loss of stemming in the upper part of the hole until 1923 h, when the SGZ RAMS began to detect the release of radioactivity. Finally, it suggests some additional fall of material until 1947 h, with only occasional rock falls thereafter.

To better understand the relationship of geophone signals to downhole activity, Los Alamos and LLNL took two types of measurements. First, Los Alamos at the Dutchess site (U7bm) and LLNL at the Dauphin site (U9cq) monitored geophone signals during a portion of the stemming operation at each site. In both cases they found that any geophone signals caused by the emplacement of stemming were below the detection threshold of geophones located at the distance of the recording trailer park.

Second, LLNL performed an experiment at hole U10bg. In this experiment rocks, weighing 1,

Figure 31. Axisymmetric finite element model.

10, and 100 lb (within a factor of 2), were dropped downhole singly and in groups and the geophone signals were recorded. Signals from trailer park geophones located about 170 ft from SGZ were recorded in CP-9, and those from the geophone array (300, 600, and 900 distant from SGZ) were recorded in Trailer 973. The depth of hole U10bf was approximately the same as the distance between the Riola stemming platform and working point. No 1-lb rock was detected; however, 70% of the singly dropped 10-lb rocks and 100% of all larger weight drops were detected. Figure 32 shows the results of this experiment. In this range, the relationship of weight dropped to recorded signal appears to be exponential.

Emplaced Plug Properties

Several successful efforts have been made to emplace and recover downhole plug material. The purpose of these efforts was to ascertain the quality of emplaced plugs and to compare their emplaced properties with the properties of quality control samples.

Los Alamos performed two retrievable plug pours, both of which were recovered and broken up. The material in both plugs appeared to be poorly mixed and friable.

LLNL performed a retrievable plug pour in hole U4ac, at a depth of 800 ft.¹⁸ The plug ap-

peared to be well mixed, and there was no evidence of major intrusions by native material. However, there was evidence that it had not cured completely and that its mechanical strength was significantly less than had been expected. Table 9 shows a comparison of downhole and QA sample strengths. While LLNL plug material QA samples undergo an isothermal (140°F) cure for a fixed period, Los Alamos samples are cured at ambient temperature from the time of plug pour until within a few hours of the D-1 containment briefing.

LLNL also retrieved samples of two pumped and one poured plug from U9ITS-U29 during the containment downhole system test. The pumped-plug sample [DIPS (dowhole inverted pyramid sampler) plug 2] contained large-scale inhomogeneities (regions containing only CTE and only gravel), and no mechanical testing was done on this sample. It also contained a considerable amount of water, and infrared spectroscopy indicated the sample was not cured. The poured-plug sample (DIPS plug 3) showed good mixing, but infrared spectroscopy indicated the sample was not cured. Its shear strength was 89 psi, and it had a flexure strength of 262 psi. Testing of laboratory, field QA, and dowhole samples was performed by A. Kusubov, A. E. Abey, and S. R. Trettenero,¹⁹ and the results are shown in Table 10.

Table 9. Summary of U4ac strength tests.

<u>Beam flexure</u>		
Sample source	Flexure strength MC/I (psi)	Standard deviation (psi)
U4ac QA	857	56
U4ac downhole	284	95
Los Alamos history (12/76-5/78)	720	297
LLNL history (~ last 5 years)	630	98
<u>Direct shear</u>		
Sample source	Shear strength (psi)	Standard deviation (psi)
U4ac downhole	103	19.6
Lab cured and prepared	577	33.6

Figure 32. Weight of rock dropped vs geophone signal.

Table 10. Strength of CTE plug materials.

CTE material	1-bar confining pressure		1000-bar confining pressure	
	Strain 0.01 (bars)	Strain 0.10 (bars)	Strain 0.01 (bars)	Strain 0.10 (bars)
Laboratory LAE 59	50	70	300	500
Quality Assurance LAE 59	50	70	280	500
Extracted downhole LAE 59				
Hole U4ac	2	10	50	110
"DIPS" plug No. 3	4	8	65	155

Conclusions

If the likelihood of a radiation release from an uncollapsed event is to be minimized, some portion of the stemming column beneath the surface conductor must remain in place. After the stemming had fallen in hole U2eq, gas penetrated cracks between the surface conductor and surrounding grout, cracks in the grout, and around the mousehole and reached the surface.

To maintain the portion of stemming column above the stemming platform, the integrity of both the platform and the hole surrounding the platform must be maintained after the event. In the case of Riola 150 ft of the hole in the region of the stemming platform became enlarged up to twice its original diameter, and only the core of the stemming platform supported by the plug support ring remains.

Evidence is insufficient to ascertain whether the hole or the plug failed first. The failures may have been simultaneous. However, the disappearance of 80% of the stemming platform cannot be explained by erosion alone, assuming a normal strength for the plug material. Moreover, the retrieved plug experiments provide strong evidence that the Riola stemming platform material was weak.

The use of stronger plug material, together with an appropriately located and shaped keyway, should considerably enhance the maintenance of stemming in the upper portion of the emplacement hole, thereby preventing recurrence of a Riola-mode release.

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