AZUL Containment Data Report

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AZUL Instrumentation Summary

Instrumentation	Fielded on this Event	Data Return	Present in this Report
<u>Plug Emplacement</u>	yes	yes	yes(a)
<u>Radiation</u>	yes	yes	yes
<u>Pressure</u>			
Stemming	yes	yes	yes
Challenge	no	-	-
Cavity	no	-	-
Atmospheric	no	-	-
<u>Motion</u>			
Free Field	no	-	-
Surface	yes	yes	yes
Plug	yes	yes	yes
Stemming	yes	yes	yes
Surface Casing	no	-	-
Emplacement Pipe	no	-	-
<u>Hydroyield (b)</u>	yes	yes	no
<u>Collapse (c)</u>	yes	yes	yes
<u>Stress</u>	no	-	-
<u>Strain(d)</u>	yes	yes	no
<u>Other Measurements(e)</u>	yes	yes	yes

(a) Description only.

(b) CORTEX and/or SLIFER in emplacement hole.

(c) EXCOR or CLIPER in emplacement hole.

(d) Strain load on emplacement pipe.

(e) Pressure, temperature and stress on the device canister.

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1. Event Description

1.1 Site

The AZUL event was detonated in hole U2em of the Nevada Test Site as indicated in figure 1.1. The AZUL device had a depth-of-burial (DOB) of 204 m in the alluvium of area 2, about 570 m above the Paleozoic formation and 330 m above the standing water level, as shown in figure 1.2⁽¹⁾. Included in figure 1.2 is a plan map of the immediate vicinity of hole U2ec showing the drill holes used in the construction of the cross section plot. Hole U2em is not shown but is 11.6 m horizontally separated from hole U2ec and is considered to be geologically similar to it. Stemming of the 2.44 m diameter emplacement hole followed the plan shown in figure 1.3. A log of the stemming operations was maintained by Holmes & Narver⁽²⁾.

Detonation time was 10:00 PST on December 14, 1979, and subsurface collapse progressed to a depth of around 90 m about 5.5 minutes after detonation. This was followed by a series of discrete subsurface collapses or stemming falls.

No radiation arrivals were detected above ground and the AZUL containment was considered successful.

1.2 Instrumentation

Figure 1.4 is a schematic layout of the instrumentation designed to monitor the emplacement procedures and stemming performance of the AZUL event.

Pressure and radiation were monitored at ten places in the stemming material, as shown in figure 1.5. Six of the stations were in the stemming below the deepest rigid plug with two of these six being of an experimental design.

Vertical motion was monitored in the stemming at four locations below the bottom plug as well as in each of the three rigid plugs and the ground surface, 15.42 m from SGZ. Tri-axial motion of the recording trailer was also recorded.

The diagnostics canister was monitored for motion at a location about 5.3 m below its top. Additionally, pressure, temperature and stress were monitored internally to the canister. A total of three "flat-pack" carbon foil stress transducers were fielded, two of which were internal to the canister with one in the stemming about 2.5 m above it.

Data from each of the above instruments were transmitted to the recording trailer by an analog system and recorded on magnetic tape.

D-cable information was used for quality assurance during the stemming operations. One CLIPER sensor was mounted in the emplacement hole on the containment gauge pendant along with the D-cable to monitor the progression of cavity collapse.

A set of four SLIFER cables were placed on and near the diagnostics canister to monitor the progression of the shock wave and for a measure of the device yield⁽³⁾.

A history of the fielding operations of the instrumentation is outlined in reference 4. Details of the instrumentation are given in reference 5.

1.3. Emplacement

The three stemming plugs above the AZUL event consisted of "LAE 59" rigid coal-tar epoxy (CTE) layers each about 5.5 m thick and the top plug was capped with about 3.3 m of soft coal tar and aggregate mixture (CTA) to act as a gas sealant. This plug was designed to be completely contained within the bottom portion of the surface casing, beginning about 2 m above the bottom of the casing. The emplacement pipe was coated with hydroseal in the region of the top plug, allowing nearly free motion of the pipe in the plug. Dual drag rings were mounted rigidly to the pipe at the location of the deepest CTE plug and a single drag ring was attached to the pipe at the elevation of the intermediate CTE plug. These structures were designed to couple the emplacement pipe to the geologic formation at those elevations.

Stemming between the plugs consisted of layers of fines and coarse gravel. The top of the hole (above the top plug) was filled with coarse gravel and the inside of the emplacement pipe was grouted for its full length. See figure 1.3.

Figure 1.1 Map of the Nevada Test Site indicating the location of hole U2em.

Figure 1.2 East-West geologic cross section through hole U2ec including a plan map of the vicinity. U2em is 11.6 m horizontally separated from U2ec.

Figure 1.3 As-built stemming plan for the event AZUL in Hole U2em.

Figure 1.4 As-built containment instrumentation plan for the emplacement hole (U2em) on the AZUL event.

2. Stemming Performance

2.1 Pressure and Radiation

Pressure and radiation were monitored on the AZUL event at ten stations in the stemming of the emplacement hole and the wave forms of these measurements are shown in figures 2.1–2.10. Two of these stations (31A and 34A) were a test of an experimental digital data system.

A first radiation arrival is suggested at station 31 (figure 2.1) to be about 12 s with a later arrival at about 33 s. The shock arrival causes a pressure offset of about 3 psi. Pressure then begins to build between the two radiation arrival times and reaches its maximum of 25 psia about 1 minute before the time of signal loss at around 330 s. The pressure wave forms from stations 31, 32, 33, and 34 (all below the deepest rigid plug) suggest a pulse of gas pressure diffusing upward. These four are shown as a composite in figure 2.11 along with the corresponding radiation wave forms. Differences in the radiation wave forms may be due to a difference in the shielding characteristics of the coarse and fines stemming around the corresponding stations, but these data show that the entire region below the bottom rigid plug was bathed in nearly the same radiation source. This suggests that the alternating coarse and fines layers had little effect on the radiation transport below the deepest rigid plug.

Figures 2.7 - 2.10 all indicate that, prior to subsurface collapse, the radiation did not reach elevations above the deepest rigid plug. All of the pressure wave forms above that plug can be explained by motion in the stemming during collapse at around 330 s.

The radiation data are consistent with satisfactory containment.

2.2 Motion

Explosion-induced histories of the motion measured on the AZUL event are shown in figures 2.12–2.23. Characteristics of the associated motion and transducers are given in tables 2.1–2.3.

Figure 2.12 contains only the three components of the tri-axial acceleration obtained at station 2, in the diagnostics canister at a range of 23.3 m from the device. The signal went beyond the system limits in all three axes and only the arrival time and the first peak of the horizontal-transverse acceleration was recorded.

An early arrival at station 24 (figure 2.16) was likely due to transverse motion of the emplacement pipe, while the first acceleration signals at station 25 and 26 (figures 2.17 and 2.18) show considerable drag ring interaction between the emplacement pipe and the ground motion. The explosion-induced motion at other stations was unremarkable.

Figure 2.1 Pressure and radiation measured at the deepest station in the fines stemming below the bottom plug (station 31 at a depth of 144.0 m).

Figure 2.2 Pressure and radiation measured in the coarse stemming in the fines stemming below the bottom plug (station 31A at a depth of 143.4 m). This was an experimental digital station to be compared with station 31. See figure 4.2.

Figure 2.3 Pressure and radiation measured in the coarse stemming below the bottom plug (station 32 at a depth of 120.1 m).

Figure 2.4 Pressure and radiation measured in the fines stemming below the bottom plug (station 33 at a depth of 106.1 m).

Figure 2.5 Pressure and radiation measured in the fines stemming below the bottom plug (station 34A at a depth of 94.5 m). This was an experimental digital station to be compared with station 34. See figure 4.3.

Figure 2.6 Pressure and radiation measured in the fines stemming below the bottom plug (station 34 at a depth of 94.2 m).

Figure 2.7 Pressure and radiation measured in the fines stemming above the deepest plug (station 35 at a depth of 82.0 m).

Figure 2.8 Pressure and radiation measured in the fines stemming below the second plug (station 36 at a depth of 61.9 m).

Figure 2.9 Pressure and radiation measured in the fines stemming above the second plug (station 37 at a depth of 46.9 m).

Figure 2.10 Pressure and radiation measured in the fines stemming below the top plug (station 38 at a depth of 36.0 m).

Figure 2.11 Composite of pressure and radiation measured at stations 31 - 34, beneath the deepest rigid plug.

Figure 2.12 Explosion-induced tri-axial acceleration of the diagnostics canister (station 2 at a depth of 181.3 m). This station was driven beyond its system limits in all three axes shortly after signal arrival.

Figure 2.13 Explosion-induced vertical motion of the stemming (station 21 at a depth of 164.9 m). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter.

Figure 2.14 Explosion-induced vertical motion of the stemming (station 22 at a depth of 154.9 m). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter.

Figure 2.15 Explosion-induced vertical motion of the stemming (station 23 at a depth of 144.9 m). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter. This is close to the elevation of the deepest pair of pressure and radiation monitors (stations 31 and 31A).

Figure 2.16 Explosion-induced vertical motion of the stemming (station 24 at a depth of 134.7 m). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter.

Figure 2.17 Explosion-induced vertical motion of the deepest rigid plug (station 25 at a depth of 88.4 m). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter. This plug contained dual drag rings.

Figure 2.18 Explosion-induced vertical motion of the intermediate rigid plug (station 26 at a depth of 53.5 m). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter. This plug contained a single drag ring.

Figure 2.19 Explosion-induced vertical motion of the top plug (station 27 at a depth of 31.7 m) When there is more than one trace in a plot, the heavier is derived from the associated velocimeter. This plug was contained within the surface casing.

Figure 2.20 Explosion-induced vertical motion of the ground surface, 15.24 from SGZ (station 61 at a depth of 0.9 m). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter.

Figure 2.21 Explosion-induced vertical motion of the recording trailer (station 71 approximately 230 m from SGZ). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter.

Figure 2.22 Explosion-induced horizontal-radial motion of the recording trailer (station 71 approximately 230 m from SGZ). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter.

Figure 2.23 Explosion-induced horizontal-transverse motion of the recording trailer (station 71 approximately 230 m from SGZ). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter.

Table 2.1 Summary of Containment-Related Motion

Gauge	Slant Range (m)	Arrival Time (ms)	Acceleration Peak (g)	Velocity Peak (m/s)	Displacement Peak (cm)	Displacement Residual (cm)
2av(a)		5	-	-	-	-
2ar(a)	23.3	5	-	-	-	-
2at(a)		5	-	-	-	-
21av	40	22	548	26.5	275	250
21uv(b)		-	-	-	-	-
22av	50	30	73	10.9	100	93
22uv		34	-	9.6	89	78
23av	60	37	39.5	5.6	37	28
23uv		37	-	5.1	36	29
24av	70	24(c)	5.3	2.1	15.6	7.2
24uv		36	-	2.0	15.0	6.5
25av	116	30(c)	(d)	0.68(e)	6.3	1.0
25uv		35(c)	-	0.62	5.6	-2.0
26av	152	40(f)	11	0.54	5.1	-5.0
26uv		52(f)	-	0.53	4.9	-4.7
27av(g)	173	116	1.7	0.61(g)	6.2(g)	-7(g)
27uv		115	-	0.51	4.9	-5.8
61av	205	152	1.7, 22.8(h)	0.77	8.3	-14(e)
61uv		156	-	0.80	8.5	-10.5
71av	(k)	172	1.3	0.87	9.6	-12
71uv	(k)	178	-	0.77	8.4	-10
71ar	(k)	165	0.38	0.28	9.0	7.5
71ur	(k)	175	-	0.33	10.5	9.5
71at	(k)	167	0.2	0.11	2.8	0.5
71ut	(k)	175	-	0.14	4.0	2.8

(a) Wrong gauge class installed: system range < 20 g's.

(b) Gauge destroyed by ZIP.

(c) Arrival from emplacement pipe.

(d) Can not determine.

(e) Approximate.

(f) Early arrivals obscured by pipe ringing.

(g) Wave form altered by noise from grounding system.

(h) Slap-down.

(k) In recording trailer, range approximately 229 m.

Table 2.2 Containment-Related Accelerometer Characteristics

Gauge	Natural Frequency (Hz)	Damping Ratio	System Range (g's)
2av	180	0.65	10
2ar	210	0.70	10
2at	180	0.75	10
21av	1600	0.65	1000
22av	1500	0.65	500
23av	1500	0.65	500
24av	900	0.65	200
25av	640	0.65	50
26av	680	0.65	50
27av	390	0.70	20
61av	435	0.65	20
71av	230	0.75	10
71ar	255	0.65	10
71at	250	0.65	10

Table 2.3 Containment-Related Velocimeter Characteristics

Gauge	Natural Frequency (Hz)	Time to 0.5 Amplitude (s)	Calibration Temperature (°F)	Operate Temperature (°F)	System Range (m/s)
21uv	3.77	29.1	74.2	64.4	80
22uv	3.90	20.9	73.9	64.1	36
23uv	3.82	18.6	73.4	70.0	20
24uv	3.50	12.7	72.6	66.7	10
25uv	3.57	7.35	74.3	123.0	6
26uv	3.52	7.50	74.0	124.0	5
27uv	3.65	8.70	73.8	131.2	6
61uv	3.60	7.35	74.0	52.7	10
71uv	3.75	13.09	74.3	59.6	1.8
71ur	3.00	10.0	76.2	59.6	1.8
71ut	3.00	8.7	74.1	59.6	1.8

3 Collapse phenomena

All stations in the emplacement hole below the top plug registered the effects of a subsurface collapse occurring between 330 and 340 s after detonation. Slight motion was also observed at that time in the recording trailer although none was detected on the ground surface 15 m from SGZ. When the instrumentation trailer was re-occupied all pressure and radiation instrumentation was found to be inoperative although motion stations 22 and 27 were still functioning⁽⁴⁾.

3.1 Pressure and radiation

Pressure and radiation wave forms obtained from the eight standard stations during a 12 second period encompassing the first major collapse episode spanning 335 s are shown in figures 3.1 - 3.8. Pressure histories from these eight stations are also shown in figure 3.11 along with the output from the CLIPER cable (station 92). All pressure wave forms from surviving stations at collapse show a rapid, transient decrease followed by a slow recovery. This is suggestive of a collapse and/or stemming loss progressing smoothly up the column with all signals from station 34 and above lasting for an extended period beyond the initial collapse episode.

Signals from Station 34 were lost at about 420 s (figure 2.6), an additional 80 s after the end of the data displayed in figure 3.9. The CLIPER registered one additional cable break to 70.5 m depth at 438 s after detonation. This corresponds to the loss of signal at station 35 seen in figure 2.7. Signals from station 36 were lost at about 480 s (figure 2.8) and station 37 was lost at around 560 s (figure 2.9). Loss of signal from the pressure and radiation channels of station 38 occurred at different times (figure 2.10): the radiation signal was lost at about 1140 s while the pressure signal was lost almost 90 s later.

As noted in section 2, no radiation was detected above the bottom rigid plug prior to collapse. Closely following collapse, there was a slight radiation increase over background in those stations at locations above the bottom rigid plug (stations 35 and greater). See figures 2.7 - 2.10. The low level, brief, almost simultaneous pulse in radiation at stations 35- 38 at about 335.7 s (figures 3.5 - 3.8) suggests an open channel for radiation to just below the top plug.

3.2 Motion

The collapse-induced motion detected on AZUL is shown in figures 3.10-3.19. The deepest motion station (21) recorded only an arrival (figure 3.10).

Stations 22, 23, and 24 (figures 3.11 - 3.13), in or below the deepest fines layer in the stemming below the deepest rigid plug, all were lost shortly after falling greater than 2 m during.

The stations in the rigid plugs (figures 3.14 - 3.16) all survived the collapse but none dropped more than 0.5 m. In fact, the motion in the top plug was within the noise level of the signal and is shown only for completeness. Stations 25 and 26 were lost, presumably due to cable breakage at locations at a distance from the stations and did not record motion when their cables broke.

Motion of the recording trailer during collapse is shown in figures 3.19 -3.21

Figure 3.1 Collapse epoch pressure and radiation measured at the deepest station in the fines stemming below the bottom plug (station 31 at a depth of 144.0 m).

Figure 3.2 Collapse epoch pressure and radiation measured in the coarse stemming below the bottom plug (station 32 at a depth of 120.1 m).

Figure 3.3 Collapse epoch pressure and radiation measured in the fines stemming below the bottom plug (station 33 at a depth of 106.1 m).

Figure 3.4 Collapse epoch pressure and radiation measured in the fines stemming below the bottom plug (station 34 at a depth of 94.2 m).

Figure 3.5 Collapse epoch pressure and radiation measured in the fines stemming above the deepest plug (station 35 at a depth of 82.0 m).

Figure 3.6 Collapse epoch pressure and radiation measured in the fines stemming below the second plug (station 36 at a depth of 61.9 m).

Figure 3.7 Collapse epoch pressure and radiation measured in the fines stemming above the second plug (station 37 at a depth of 46.9 m).

Figure 3.8 Collapse epoch pressure and radiation measured in the fines stemming below the top plug (station 38 at a depth of 36.0 m).

Figure 3.9 Progression of the collapse as indicated by the CLIPER record (station 92) and the pressure histories as measured in the stemming. One additional collapse episode to a depth of 71 m was seen on the CLIPER at 438 s.

Figure 3.10 Collapse-induced vertical motion of the stemming (station 21 at a depth of 164.9 m).

Figure 3.11 Collapse-induced vertical motion of the stemming (station 22 at a depth of 154.9 m). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter.

Figure 3.12 Collapse-induced vertical motion of the stemming (station 23 at a depth of 144.9 m). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter. This station was near the elevation of the deepest pair of pressure and radiation monitors (stations 31 and 31A).

Figure 3.13 Collapse-induced vertical motion of the stemming (station 24 at a depth of 134.7 m). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter.

Figure 3.14 Collapse-induced vertical motion of the deepest rigid plug (station 25 at a depth of 88.4 m). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter. This plug contained dual drag rings.

Figure 3.15 Collapse-induced vertical motion of the intermediate rigid plug (station 26 at a depth of 53.5 m). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter. This plug contained a single drag ring.

Figure 3.16 Collapse-induced vertical motion of the top plug (station 27 at a depth of 31.7 m)
 When there is more than one trace in a plot, the heavier is derived from the associated velocimeter. This plug was contained within the surface casing.

Figure 3.17 Collapse-induced vertical motion of the recording trailer (station 71). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter.

Figure 3.18 Collapse-induced horizontal-radial motion of the recording trailer (station 71). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter.

Figure 3.19 Collapse-induced horizontal-transverse motion of the recording trailer (station 71). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter.

4. Other measurements

The inside of the diagnostics canister was monitored for temperature and gas pressure at station 1. Data were quite noisy and were likely lost before 5 ms after detonation. Wave forms of these data for the first 25 ms are presented in figure 4.1 for completeness.

A new down-hole digital data transmission system, consisting of two pressure and radiation stations, was field tested for the first time on AZUL. Data recorded from these two stations are compared with the output from standard instruments used as controls (stations 31 and 34) in figures 4.2 and 4.3. Station 31A was fielded about 0.6 m above the corresponding standard station 31 while 34A was 0.3 m below its reference station 34. Stations 31A and 34A were not wired as planned and it was thought that a change in designation would suffice to correct the problem. This may not have been true as evidenced by the wave forms of the radiation from the two stations. Note that the radiation arrival at station 31A is much later than that at station 31 (its control), in fact the arrival time and wave form is almost identical to that of station 34A. The radiation wave form of station 34A closely matches its control (station 34) except for magnitude. There seems to be no major differences between the test and control pressure wave forms during the time both survived. Both radiation and pressure signals survived collapse at station 34 while neither did at station 34A suggesting a more rugged construction was afforded in the standard package.

Three "flat-pack" carbon foil transducers were fielded: two within the diagnostics canister and one in the stemming, 2.5 m above the top of the canister. The results of these measurements are shown in figure 4.4. The arrival times were confirmed by the SLIFER data⁽³⁾ and the peak stress appears to attenuate approximately as the square of the range as shown in figure 4.5. Note that the signal from station 6 had the approximately correct arrival time but went negative. We assumed that the gauge output was inverted and made that adjustment for presentation and calibrated the transducer as if this assumption were correct.

Figure 4.1 Pressure and temperature measured in the diagnostics canister at a range of 21.5 m from the device.

Figure 4.2 Comparison of pressure and radiation wave forms obtained at stations 31 and 31A. The heavier of the two data traces was obtained from the experimental station (31A). The radiation channel of 31A was incorrectly labeled prior to the experiment and may not be reported properly. Its data should probably not be accepted.

Figure 4.3 Comparison of pressure and radiation wave forms obtained at stations 34 and 34A. The heavier of the two data traces was obtained from the experimental station (34A). Note the strong similarity of the radiation wave form of station 34A to that of station 31A (figure 4.2).

Figure 4.4 Output of the three carbon foil stress transducers. The data shown for station 6 has been inverted from the as-recorded signal. Note the different time scales on all three plots.

Figure 4.5 Range dependence of the peak stress at stations 4, 5, and 6.

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