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Evaluation of Cavity Collapse and Surface Crater Formation for Selected Lawrence Livermore National Laboratory Underground Nuclear Tests - 2006

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This report describes evaluation of collapse evolution for selected LLNL underground nuclear tests at the Nevada Test Site (NTS). The work is being done at the request of Bechtel Nevada and supports the Department of Energy National Nuclear Security Association Nevada Site Office Borehole Management Program (BMP). The primary objective of this program is to close (plug) weapons program legacy boreholes that are deemed no longer useful. Safety decisions must be made before a crater area, or potential crater area, can be reentered for any work. Our statements on cavity collapse and crater formation are input into their safety decisions.

The BMP is an on-going program to address hundreds of boreholes at the NTS. Each year Bechtel Nevada establishes a list of holes to be addressed. They request the assistance of the Lawrence Livermore National Laboratory and Los Alamos National Laboratory Containment Programs to provide information related to the evolution of collapse history and make statements on completeness of collapse as relates to surface crater stability. These statements do not include the effects of erosion that may modify the collapse craters over time. They also do not address possible radiation dangers that may be present.

Subject matter experts from the LLNL Containment Program and the Chemistry Biology and Nuclear Sciences Division who had been active in weapons testing activities performed these evaluations. Information used included drilling and hole construction, emplacement and stemming, timing and sequence of the selected test and nearby tests, geology, yield, depth of burial, collapse times, surface crater sizes, cavity and crater volume estimations, and ground motion. Both classified and unclassified data were reviewed. Various amounts of information are available for these tests, depending on their age and other associated activities. Lack of data can hamper evaluations and introduce uncertainty. We make no attempt to quantify this uncertainty.

The following unclassified summary statements describe collapse evolution and crater stability in response to the 2006 request to review 12 LLNL test locations in areas 2, 9, and 10 of Yucca Flat. Included are: Bunker in U9bb, Carmel in U2h, Chenille in U9bg, Club in U2aa, Dub in U10a, Handicap in U9ba, Mustang in U9at, Narraguagus in U2f, Par in U2p, Satsop in U2g, Stillwater in U9c, and Tornillo in U9aq.

Bunker U9bb

The LLNL-sponsored Bunker test was detonated in cased hole U9bb on 13-February-1964. Bunker, with an announced yield of <20 kt (DOE/NV209—REV 15¹), was detonated in tuff at a working point of 226 m below the surface. U9bb is located in central Area 9 between the Yucca Fault to the west and the Area 9 Fault to the east. The hole is located within the Area 9 ITS area, which was identified after this test was executed. Nearby tests include: Handicap in U9ba on 12-Mar-1964; Hook in U9bc on 14-Apr-1964; Hod-Red in U9 ITS X-20 on 1-May-1970; Scree-Alhambra in U9 ITS Z-21 on 13-Oct-1970; Avens-Asmalte in U9 ITS W-21 on 16-Dec-1970; Haplopappus in U9 ITS W-22 on 28-Jun-1972; and Niza in U9cr on 10-Jul-1981. Stockpiled inventory emplacement hole U9cu is located nearby, as is Area 9 exploratory hole #4.

Bunker collapsed to the surface in 24 minutes. A collapse crater 128 m diameter by 13 m depth was formed. Numerous tests have taken place in Yucca Flat since this test (28 years of subsequent underground testing, and 42 years total since detonation), causing ground motion at the U9bb site, and the surface has not changed over time.

Drill holes associated with Bunker include the emplacement hole, a satellite hole, and two post-test holes. The post-test holes are vertical holes drilled very near the emplacement hole. Drilling of the post-test holes started about two hours after collapse. The post-test holes and the satellite hole are within the collapse crater.

Bunker had an accidental release of radioactivity detected onsite only.

We have reviewed geology and test-related data, including information on the cavity and crater, and believe that complete collapse occurred quickly after detonation. The number of subsequent tests on Yucca Flat, and the entire NTS, gives us comfort that cavity collapse and crater formation should be complete. The ground surface above the U9bb site has not changed over time, so it seems reasonable to conclude that the current configuration is stable. We have evaluated crater stability produced from cavity collapse, and have not considered later erosional effects. We rely on Bechtel Nevada and DOE/NNSA/NSO to make decisions concerning safety issues related to reentering the crater area.

¹DOE (U.S. Department of Energy), 2000, United States Nuclear Tests July 1945 through September 1992, U.S. Department of Energy, Nevada Operations Office, Las Vegas, NV, DOE/NV-209, Rev 15.

Carmel U2h

The LLNL-sponsored Carmel test was detonated in cased hole U2h on 21-Feb-1963. Carmel, with an announced “low” yield (DOE/NV209—REV 15), was detonated in alluvium at a working point of 164 m below the surface. U2h is located in northeastern Area 2 between the Carpetbag Fault to the west and the Yucca Fault to the east. Nearby tests include: Satsop in U2g on 15-Aug-1963; Ace in U2n on 11-Jun-1964; Par in U2p on 9-Oct-1964; Throw in U2bg on 10-Apr-1968; Noor in U2be on 10-Apr-1968; Portulaca in U2bv on 28-Jun-1973; Portmanteau in U2ax on 30-Aug-1974; Liptauer in U2eh on 3-Apr-1980; and Danablu in U2eu on 9-Jun-1983. All of these tests, with the exception of Danablu, are located within the radial surface effects caused by Portmanteau.

Few records make it hard to interpret the collapse history at this site. It appears that an initial subsurface collapse occurred about 8 minutes after detonation. Vertical post-test hole PS1, located very near the emplacement hole, encountered void space from 12-30 m. Subsurface collapse was assumed to have occurred to 12 m depth, terminating at a caliche bed in the alluvium. About 5 years after detonation a surface collapse crater was formed, 46 m in diameter and 12 m deep. This subsequent collapse may have occurred upon the detonation of Throw and Noor, simultaneous tests in separate holes on opposite sides of U2h. However, without better records it is hard to pinpoint the exact date surface collapse date for Carmel. Numerous tests have taken place in Yucca Flat since this test (29 years of subsequent underground testing, and 43 years total since detonation), causing ground motion at the U2h site, and the surface has not changed since surface collapse.

Holes associated with the Carmel test include the emplacement hole and five post-test holes. Vertical hole PS1 is located at the emplacement hole. The other four holes are angled holes: PS4 is located to the northeast, PS2 to the east, PS5 to the southeast, and PS3 farther away to the southeast. [It would be valuable to check original records for the east coordinate of PS3. This hole is over 300 m from the emplacement site, while all other post-test holes are within 70 m.] PS1 is within the collapse crater, but the others are outside of it.

We have reviewed geology and test-related data, including information on the cavity and crater, and believe that collapse is complete. This test collapsed almost to the surface soon after detonation, and then a crater formed at the surface five years later. The number of subsequent tests on Yucca Flat, and the entire NTS, gives us comfort that cavity collapse and crater formation should be complete. The ground surface above the U2h site has not changed since collapse to the surface, so it seems reasonable to conclude that the current configuration is stable. We have evaluated crater stability produced from cavity collapse, and have not considered later erosional effects. We rely on Bechtel Nevada and DOE/NNSA/NSO to make decisions concerning safety issues related to reentering the crater area.

Chenille
U9bg

The LLNL-sponsored Chenille test was detonated in cased hole U9bg on 22-Apr-1965. Chenille, with an announced yield of <20 kt (DOE/NV209—REV 15), was detonated in alluvium at a working point of 141 m below the surface. U9bg is located in south-central Area 9, almost on the Area 7-Area 9 border, between the Yucca Fault to the west and the Area 7 Fault to the east. Nearby tests include: Fade in U9be on 25-Jun-1964; Links in U9bf on 23-Jul-1964; Spoon in U9bd on 11-Sep-1964; Ticking in U9bj on 21-Aug-1965; Elkhart in U9bs on 17-Sep-1965; Templar in U9bt on 24-Mar-1966; Obar in U7ag on 30-Apr-1975; Dauphin in U9cq on 14-Nov-1980; and Armada in U9cs on 22-Apr-1983.

Chenille collapsed to the surface in 6 minutes. A collapse crater 95 m diameter by 15 m depth was formed. Numerous tests have taken place in Yucca Flat since this test (27 years of subsequent underground testing, and 41 years total since detonation), causing ground motion at the U9bg site, and the surface has not changed over time.

Drill holes associated with Chenille include the emplacement hole, a satellite hole, and a post-test hole (PS1A) with a kickoff hole (PS1AS). One report mentioned a pre-post-test hole, 58 m from site ground zero, casing set at 31 m depth, grouted in, filled with water and the abandonment valve installed and closed, and a second post-test hole, but these holes were not found in Bechtel Nevada drilling records and other than this report nothing else was found to document them. The satellite hole is within the collapse crater, but PS1A is outside of it.

Chenille had an accidental release of radioactivity detected onsite only.

We have reviewed geology and test-related data, including information on the cavity and crater, and believe that complete collapse occurred quickly after detonation. The number of subsequent tests on Yucca Flat, and the entire NTS, gives us comfort that cavity collapse and crater formation should be complete. The ground surface above the U9bg site has not changed over time, so it seems reasonable to conclude that the current configuration is stable. We have evaluated crater stability produced from cavity collapse, and have not considered later erosional effects. We rely on Bechtel Nevada and DOE/NNSA/NSO to make decisions concerning safety issues related to reentering the crater area.

Club
U2aa

The LLNL-sponsored Club test was detonated in cased hole U2aa on 30-Jan-1964. Club, with an announced yield of <20 kt (DOE/NV209—REV 15), was detonated in alluvium at a working point of 180 m below the surface. U2aa is located in a heavily used area of east central Area 2 between the Carpetbag Fault to the west and the Yucca Fault to the east. Nearby tests include: Drill (Source-Lower) and Drill (Target-Upper), simultaneous detonations in U2ai on 5-Dec-1964; Tee in U2ab on 7-May-1965; Centaur in U2ak on 27-Aug-1965; Emerson in U2al on 16-Dec-1965; Tapestry in U2an on 12-May-1966; Effendi in U2ap on 27-Apr-1967; Calabash in U2av on 29-Oct-1969; Carpetbag in U2dj on 17-Dec-1970; Harebell in U2br on 24-Jun-1971; Portmanteau in U2ax on 30-Aug-1974; Stanyan in U2aw on 26-Sep-1974; Rivoli in U2eg on 20-May-1976; Azul in U2em on 14-Dec-1979; Romano in U2ex on 16-Dec-1983; and Cornucopia in U2gaS on 24-Jul-1986. Several of these tests were of large yield and left significant surface effects, including Carpetbag (220 kt), Portmanteau (20-200 kt), Harebell (20-200 kt), Calabash (110 kt), and Stanyan (20-200 kt). Stockpiled inventory emplacement hole U2gj is located northwest of U2aa.

A subsurface collapse occurred about 8 minutes after detonation. Vertical post-test holes PS1 and PS2, located very near the emplacement hole, both encountered void space from 43-55 m. Subsurface collapse was assumed to have occurred to 44 m depth. About three years later surface collapse occurred, forming a collapse crater 39 m in diameter and 8 m deep. This subsequent collapse may have occurred upon the detonation of Effendi, but without better records it is hard to pinpoint the exact date surface collapse occurred for Club. Numerous tests have taken place in Yucca Flat since this test (28 years of subsequent underground testing, and 42 years total since detonation), causing ground motion at the U2aa site, and the surface has not changed since surface collapse.

Holes associated with the Club test include the emplacement hole U2aa, an abandoned emplacement hole U2aa (abandoned), a satellite hole U2aa #1, and four post-test holes. PS1 and PS2 are vertical holes very near the emplacement hole, while PS3 and PS4 are slant holes over 60 m from the emplacement hole. U2aa (abandoned), U2aa #1, PS1 and PS2 are within the collapse crater. [Exploratory hole UE2aa, though labeled similarly to these holes, is quite distant from this site.]

Club had an accidental release of radioactivity detected onsite only.

We have reviewed geology and test-related data, including information on the cavity and crater, and believe that collapse is complete. This test collapsed almost to the surface soon after detonation, and then a crater formed at the surface three years later. The number of subsequent tests on Yucca Flat, and the entire NTS, gives us comfort that cavity collapse and crater formation should be complete. The ground surface above the U2aa site has not changed since collapse to the surface, so it seems reasonable to conclude that the current configuration is stable. We have evaluated crater stability produced from cavity collapse, and have not considered later erosional effects. We rely

on Bechtel Nevada and DOE/NNSA/NSO to make decisions concerning safety issues related to reentering the crater area.

Dub U10a

The LLNL-sponsored Dub test was detonated in cased hole U10a on 30-Jun-1964. Dub, a Plowshare device development test with an announced yield of 11.7 kt (DOE/NV209—REV 15), was detonated in alluvium at a working point of 259 m below the surface. U10a is located in northern Area 10, just east of the Yucca Fault and west of the Sedan test. Nearby tests include: Sedan in U10h on 6-Jul-1962; Handcar in U10b on 5-Nov-1964; Mudpack in U10n on 16-Dec-1964; Kankakee in U10p on 15-Jun-1966; Lagoon in U10ar on 14-Oct-1971; Natoma in U10aw on 5-Apr-1973; Pinedrops-Bayou, -Sloat and –Tawny, simultaneous detonations in U10as on 10-Jan-1974; Portola and Portola-Larkin, simultaneous detonations in U10bb on 6-Feb-1975; Chevre in U10ay on 23-Nov-1976; and Dofino and Dofino-Lawton, simultaneous detonations in U10ba on 8-Mar-1977.

Dub collapsed to the surface in about 51 minutes. A collapse crater 106 m diameter by 27 m depth was formed. The crater had extremely steep sides and no entry was possible until earth moving equipment made a slope on the sides. Numerous tests have taken place in Yucca Flat since this test (28 years of subsequent underground testing, and 42 years total since detonation), causing ground motion at the U10a site, and the surface has not changed over time.

Drill holes associated with Dub include the emplacement hole, two post-test holes (PS1A and PS2A) each with their own kickoff (PS1AS and PS2AS), and five post-test vent holes. The vent holes are within the collapse crater, but the post-test holes are not.

Dub had an accidental release of radioactivity detected onsite only.

We have reviewed geology and test-related data, including information on the cavity and crater, and believe that complete collapse occurred quickly after detonation. The number of subsequent tests on Yucca Flat, and the entire NTS, gives us comfort that cavity collapse and crater formation should be complete. The ground surface above the U10a site has not changed over time, so it seems reasonable to conclude that the current configuration is stable. We have evaluated crater stability produced from cavity collapse, and have not considered later erosional effects. We rely on Bechtel Nevada and DOE/NNSA/NSO to make decisions concerning safety issues related to reentering the crater area.

Handicap U9ba

The LLNL-sponsored Handicap test was detonated in cased hole U9ba on 12-Mar-1964. Handicap, with an announced yield of <20 kt (DOE/NV209—REV 15), was detonated in alluvium at a working point of 143 m below the surface. U9ba is located in central Area 9 between the Yucca Fault to the west and the Area 9 Fault to the east. The hole is located at the south-central border of the Area 9 ITS area, which was identified after this test was executed. Nearby tests include: Codsaw in U9g on 19-Feb-1962; Tioga in U9f on 18-Oct-1962; Oconto in U9ay on 23-Jan-1964; Bunker in U9bb on 13-Feb-1964; Hod-Red in U9 ITS X-20 on 1-May-1970; Avens-Asmalte in U9 ITS W-21 on 16-Dec-1970. Stockpiled inventory emplacement hole U9cu is located nearby, as is Area 9 exploratory hole #4.

Handicap collapsed to the surface in about 3 minutes. A collapse crater 46 m diameter by 2 m depth was formed. Numerous tests have taken place in Yucca Flat since this test (28 years of subsequent underground testing, and 42 years total since detonation), causing ground motion at the U9bb site, and the surface has not changed over time.

Drill holes associated with Handicap include the emplacement hole, two post-test holes, a pre-post-test hole (PPS3, 26 m deep), and an abandoned pre-post-test hole (PPS4, 27 m deep). PS1 and PS2 are vertical holes drilled very near the emplacement hole. The vertical post-test holes are within the collapse crater, but the pre-post-test holes are outside it.

Handicap had an accidental release of radioactivity detected onsite only.

We have reviewed geology and test-related data, including information on the cavity and crater, and believe that complete collapse occurred quickly after detonation. The number of subsequent tests on Yucca Flat, and the entire NTS, gives us comfort that cavity collapse and crater formation should be complete. The ground surface above the U9ba site has not changed over time, so it seems reasonable to conclude that the current configuration is stable. We have evaluated crater stability produced from cavity collapse, and have not considered later erosional effects. We rely on Bechtel Nevada and DOE/NNSA/NSO to make decisions concerning safety issues related to reentering the crater area.

Mustang
U9at

The LLNL-sponsored Mustang test was detonated in cased hole U9at on 15-Nov-1963. Mustang, with an announced “low” yield (DOE/NV209—REV 15), was detonated in alluvium at a working point of 165 m below the surface. U9at is located in west-central Area 9 between the Yucca Fault to the west and the Area 9 Fault to the east. The hole is located just west of the western border of the Area 9 ITS area, which was identified after this test was executed. Nearby tests include: Cimarron in U9h on 23-Feb-1962; Arikaree in U9r on 10-May-1962; Raritan in U9u on 6-Sep-1962; Tauton in U9aa on 4-Dec-1962; Eagle in U9av on 12-Dec-1963; Ajax in U9al on 11-Nov-1966; Noggin in U9bx on 6-Sep-1968; and Vat in U9cf on 10-Oct-1968.

Mustang collapsed to the surface in 9 minutes. A collapse crater 53 m diameter by 4 m depth was formed. Numerous tests have taken place in Yucca Flat since this test (29 years of subsequent underground testing, and 43 years total since detonation), causing ground motion at the U9at site, and the surface has not changed over time.

Drill holes associated with Mustang include the emplacement hole and two vertical post-test holes drilled very near the emplacement hole. The post-test holes are within the collapse crater.

We have reviewed geology and test-related data, including information on the cavity and crater, and believe that complete collapse occurred quickly after detonation. The number of subsequent tests on Yucca Flat, and the entire NTS, gives us comfort that cavity collapse and crater formation should be complete. The ground surface above the U9at site has not changed over time, so it seems reasonable to conclude that the current configuration is stable. We have evaluated crater stability produced from cavity collapse, and have not considered later erosional effects. We rely on Bechtel Nevada and DOE/NNSA/NSO to make decisions concerning safety issues related to reentering the crater area.

Narraguagus U2f

The LLNL-sponsored Narraguagus test was detonated in cased hole U2f on 27-Sep-1963. Narraguagus, with an announced “low” yield (DOE/NV209—REV 15), was detonated in alluvium at a working point of 150 m below the surface. U2f is located in northeastern Area 2 between the Carpetbag Fault to the west and the Yucca Fault to the east. Nearby tests include: Carmel in U2h on 21-Feb-1963; Cumberland in U2e on 11-Apr-1963; Satsop in U2g on 15-Aug-1963; Par in U2p on 9-Oct-1964; Vulcan in U2bd on 25-Jun-1966; Throw in U2bg on 10-Apr-1968; Noor in U2be on 10-Apr-1968; Waller in U2bz on 2-Oct-1973; Seafoam in U2ea on 13-Dec-1973; and Portmanteau in U2ax on 30-Aug-1974. U2f is located just outside the radial surface effects caused by Portmanteau. Stockpiled inventory emplacement hole U2gc is located northwest of U2f.

Drill holes associated with Narraguagus include the emplacement hole and four post-test holes. Records are confusing on these post-test holes. It appears that two are vertical holes near the emplacement hole and two are slant holes farther from SGZ. Limited records for Narraguagus are inconsistent with Bechtel Nevada drilling records.

We have reviewed geology and test-related data for Narraguagus, including information on the cavity. We know that:

- Narraguagus did not collapse to the surface. If we assumed a maximum yield of 20 kt for the announced “low” yield, collapse to the surface would have occurred based on scaled depth of burial (SDOB) guidelines used today. At that maximum yield the SDOB would be about $55 \text{ m/kt}^{1/3}$. Generally speaking, tests with smaller SDOBs are more likely to collapse to the surface after detonation.
- We could find no information on subsurface collapse time or height.
- With the working point in alluvium and a small SDOB, it is hard to predict where subsurface collapse might terminate.
- Narraguagus in U2f is located in a well-used testing area and surrounded by many tests, some of them relatively large. The ground surface at the U2f site has not changed over the 29 years of subsequent underground testing and 43 years total since detonation.

We have reviewed geology and test-related data, including information on the cavity and subsequent subsurface collapse. We don’t know if the subsurface collapse has changed over time, nor can we preclude that small, additional collapses have or have not occurred. Ground motion from many subsequent tests gives credibility that collapse is complete and permits us to conclude that the current configuration may be stable. However, LLNL has less confidence than normal in making this statement. We rely on Bechtel Nevada and DOE/NNSA/NSO to make decisions concerning safety issues related to reentering potential crater areas.

Par
U2p

The LLNL-sponsored Par test was detonated in cased hole U2p on 9-Oct-1964. Par, a Plowshare test with an announced yield of 38 kt (DOE/NV209—REV 15), was detonated in alluvium at a working point of 404 m below the surface. U2p is located in northeastern Area 2 between the Carpetbag Fault to the west and the Yucca Fault to the east. Nearby tests include: Carmel in U2h on 21-Feb-1963; Satsop in U2g on 15-Aug-1963; Narraguagus in U2f on 27-Sep-1963; Throw in U2bg on 10-Apr-1968; Noor in U2be on 10-Apr-1968; Portulaca in U2bv on 28-Jun-1973; Portmanteau in U2ax on 30-Aug-1974; Liptauer in U2eh on 3-Apr-1980; Danablu in U2eu on 9-Jun-1983; and Agrini in U2ev on 31-Mar-1984. All of these tests, with the exception of Danablu, are located within the radial surface effects caused by Portmanteau. Stockpiled inventory emplacement hole U2gc is located northwest of U2p.

Par collapsed to the surface in 3 hours and 54 minutes. A collapse crater 145 m diameter by 22 m depth was formed. Numerous tests have taken place in Yucca Flat since this test (28 years of subsequent underground testing, and 42 years total since detonation), causing ground motion at the U2p site, and the surface has not changed over time.

Drill holes associated with Par include the emplacement hole, a satellite hole, two slant post-test holes, an abandoned pre-post-test hole, and a vent hole. The satellite and vent holes are within the collapse crater, but the post-test holes are outside of it. No coordinates were found for the plugged pre-post-test hole.

We have reviewed geology and test-related data, including information on the cavity and crater, and believe that complete collapse occurred quickly after detonation. The number of subsequent tests on Yucca Flat, and the entire NTS, gives us comfort that cavity collapse and crater formation should be complete. The ground surface above the U2p site has not changed over time, so it seems reasonable to conclude that the current configuration is stable. We have evaluated crater stability produced from cavity collapse, and have not considered later erosional effects. We rely on Bechtel Nevada and DOE/NNSA/NSO to make decisions concerning safety issues related to reentering the crater area.

Satsop
U2g

The LLNL-sponsored Satsop test was detonated in cased hole U2g on 15-Aug-1963. Satsop, with an announced “low” yield (DOE/NV209—REV 15), was detonated in alluvium at a working point of 225 m below the surface. U2g is located in northeastern Area 2 between the Carpetbag Fault to the west and the Yucca Fault to the east. Nearby tests include: Carmel in U2h on 21-Feb-1963; Narraguagus in U2f on 27-Sep-1963; Par in U2p on 9-Oct-1964; Throw in U2bg on 10-Apr-1968; Noor in U2be on 10-Apr-1968; Portulaca in U2bv on 28-Jun-1973; Portmanteau in U2ax on 30-Aug-1974; Liptauer in U2eh on 3-Apr-1980; Danablu in U2eu on 9-Jun-1983; and Agrini in U2ev on 31-Mar-1984. All of these tests, with the exception of Danablu, are located within the radial surface effects caused by Portmanteau. Stockpiled inventory emplacement hole U2gc is located northwest of Satsop.

Satsop collapsed to the surface in 16 minutes. A collapse crater 91 m diameter by 12 m depth was formed. Numerous tests have taken place in Yucca Flat since this test (29 years of subsequent underground testing, and 43 years total since detonation), causing ground motion at the U2g site, and the surface has not changed over time.

Drill holes associated with Satsop include the emplacement hole and six (vertical?) post-test holes. All six post-test holes are within the collapse crater.

We have reviewed geology and test-related data, including information on the cavity and crater, and believe that complete collapse occurred quickly after detonation. The number of subsequent tests on Yucca Flat, and the entire NTS, gives us comfort that cavity collapse and crater formation should be complete. The ground surface above the U2g site has not changed over time, so it seems reasonable to conclude that the current configuration is stable. We have evaluated crater stability produced from cavity collapse, and have not considered later erosional effects. We rely on Bechtel Nevada and DOE/NNSA/NSO to make decisions concerning safety issues related to reentering the crater area.

Tornillo U9aq

The LLNL-sponsored Tornillo test was detonated in cased hole U9aq on 11-Oct-1963. Tornillo, a Plowshare test with an announced yield of 380 tons (DOE/NV209—REV 15), was detonated in alluvium at a working point of 149 m below the surface. U9aq is located in south-central Area 9 between the Yucca Fault to the west and the Area 7 Fault to the east. Nearby tests include: Dead in U9k on 21-Apr-1962; York in U9z on 24-Aug-1962; Black in U9p on 27-Apr-1962; Allegheny in U9x on 29-Sep-1962; Bogey in U9au on 17-Apr-1964; Kootani in U9w on 24-Apr-1963; Paisano in U9w-1 on 24-Apr-1963; Garden in U9aj on 23-Oct-1964; Seersucker in U9bm on 19-Feb-1965; Terrine-White in U9bi-1 on 18-Dec-1969; and Arsenate in U9ci on 9-Nov-1972. The (apparently abandoned) U9ag site is located about 90 m north of U9aq. It includes an emplacement hole (with limited use), a satellite hole, and two abandoned pre-post-test holes.

Tornillo collapsed to the surface in 3.5 minutes. A collapse crater 122 m diameter by 1 m depth was formed. This shallow crater might have been formed by the traditional cavity collapse and chimney formation reaching the surface, or it might be a feature caused by the rise and subsequent fall of material due to ground motion originating from the detonation. Numerous tests have taken place in Yucca Flat since this test (29 years of subsequent underground testing, and 43 years total since detonation), causing ground motion at the U9aq site, and the surface has not changed over time.

Drill holes associated with Tornillo include the emplacement hole and two post-test holes. PS1 and PS2 are vertical hole drilled very near the emplacement hole. Both holes are within the collapse crater.

We have reviewed geology and test-related data, including information on the cavity and crater, and believe that complete collapse occurred quickly after detonation. The number of subsequent tests on Yucca Flat, and the entire NTS, gives us comfort that cavity collapse and crater formation should be complete. The ground surface above the U9aq site has not changed over time, so it seems reasonable to conclude that the current configuration is stable. We have evaluated crater stability produced from cavity collapse, and have not considered later erosional effects. We rely on Bechtel Nevada and DOE/NNSA/NSO to make decisions concerning safety issues related to reentering the crater area.