LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

LLNL-TR-471719

Evaluation of Cavity Collapse and Surface Crater Formation for Selected Lawrence Livermore National Laboratory Underground Nuclear Tests - 2011

Gayle A. Pawloski

March 2, 2011

Disclaimer

Auspices Statement

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Evaluation of Cavity Collapse and Surface Crater Formation for Selected Lawrence Livermore National Laboratory Underground Nuclear Tests – 2011

Gayle A. Pawloski
Atmospheric, Earth and Energy Division
Physical and Life Sciences Directorate

March 2, 2011

Lawrence Livermore National Laboratory

Livermore, CA 94551

Evaluation of Cavity Collapse and Surface Crater Formation for Selected Lawrence Livermore National Laboratory Underground Nuclear Tests – 2010

This report evaluates collapse evolution for selected Lawrence Livermore National Laboratory (LLNL) underground nuclear tests at the Nevada National Security Site (NNSS, formerly called the Nevada Test Site). The work is being done at the request of National Security Technologies, LLC (NSTec) and supports the Department of Energy, National Nuclear Security Administration for the 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 NSTec 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 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, ground motion, and radiological release information. 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 a recent request to review 3 LLNL test locations in areas 2 and 12: Kennebec in U2af, Cumberland in U2e, and Yuba in U12b.10.

Kennebec
U2af

The LLNL sponsored Kennebec test was detonated in cased hole U2af on June 25, 1963. Kennebec had an announced yield of low (less than 20 kt) (DOE/NV-209, Rev 15[1]). It was detonated in alluvium at a working point of 226 m below the surface. U2af is located in east central Area 2 between the Carpetbag Fault to the west and the Yucca Fault to the east. Nearby tests are shown in Figure 1 and include: Mullet in U2ag on October 17, 1963; Drill in U2ai on December 5, 1964; Pongee in U2ah on July 22, 1965; Tapestry in U2an on May 12, 1966; Commodore in U2am on May 20, 1967; and Stanyan in U2aw on September 26, 1974.

There were two instrument holes associated with the Kennebec test: a radiochemistry hole and a hydro-yield hole.

- U2af #1 Rad Chem, was an early-time radiochemistry hole with shallowly buried sampling equipment at the surface. This vertical hole, near the emplacement hole, had 10.75" pipe from near the working point to the sampling equipment. Records show that this hole, within the collapse crater, is currently plugged with cement from about 30-3 m depth.
- U2af #2, was instrumented for hydro-yield and grouted before detonation. This vertical hole is located close to the emplacement hole, within the collapse crater.

Kennebec collapsed to the surface about 10 minutes after detonation. It formed a crater about 12 m deep and about 110 m in diameter.

There were 3 post-test holes associated with Kennebec that were drilled soon after detonation:

- U2af PS #1 is a slant hole drilled to 283 m depth. It was surveyed and sampled and plugged with cement from 46 m to the surface. The plugging may have occurred in 1974, well after the post-test drilling.
- U2af PS #2 is a vertical hole near the emplacement hole. It was drilled to 263 m depth, surveyed and sampled.
- U2af PS #3 is a vertical hole near the emplacement hole. It was drilled to 256 m depth, surveyed and sampled.

Kennebec had an accidental release of radioactivity detected onsite only (DOE/NV-209 Rev 15). More specifically, a release from the rad chem line occurred 10 seconds after detonation and lasted for 1 minute; a drillback release from a post-test hole occurred June 26, 1963 and lasted for 1.7 hours (DOE/NV-317 Rev 1[2]).

[1] DOE (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.

[2] DOE (U.S. Department of Energy), 1996, Radiological Effluents Released from U.S. Continental Tests 1961 through 1992, U.S. Department of Energy, Nevada Operations Office, Las Vegas, NV, DOE/NV-317, Rev 1.

Surface collapse from the Stanyan test, detonated in nearby U2aw 11 years after Kennebec, created a large crater (183 m diameter and 21 m depth) that now encompasses other drill holes (Figure 2). This include four of the five holes associated with Kennebec - U2af, U2af #1 Rad Chem, U2af #2, U2af PS #2 and U2af PS #3.

Nearby Mullet in U2ag also had an early-time radiochemistry sampling system with accompanying surface equipment. This site is associated with CAU 547 CAS 02-37-02.

We have reviewed geology and test-related data for a number of tests in the locality of U2af. We believe that the Kennebec test displayed complete collapse soon after detonation. Commodore, east-southeast of U2af, was detonated about 4 years after Kennebec, and at a yield of 250 kt (DOE/NV-209 Rev 15), produced enough ground motion to significantly shake this locality. Stanyan to the north also provided ground motion, and we know that its surface collapse crater consumed the U2af site. There have been a number of other subsequent tests on Yucca Flat, and the entire NNSS, providing additional ground motion, and this gives us comfort that cavity collapse and crater formation for the Kennebec, and Stanyan, tests should be complete. The ground surface above the U2af 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 erosion effects. We rely on NSTec and DOE/NNSA/NSO to make decisions concerning safety issues related to reentering the crater area.

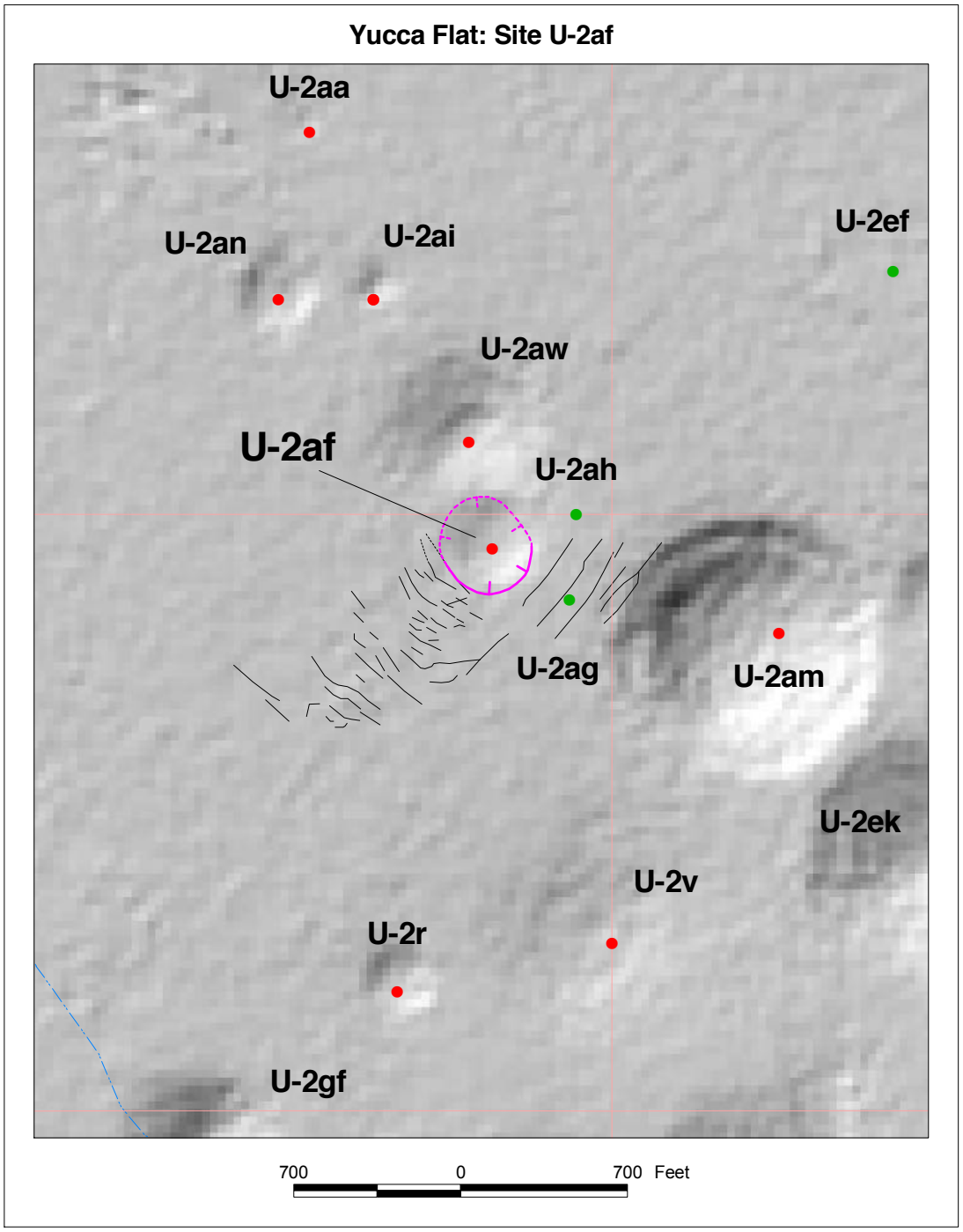

Figure 1: Surface effects map of Kennebec at U2af (Grasso, 2003).

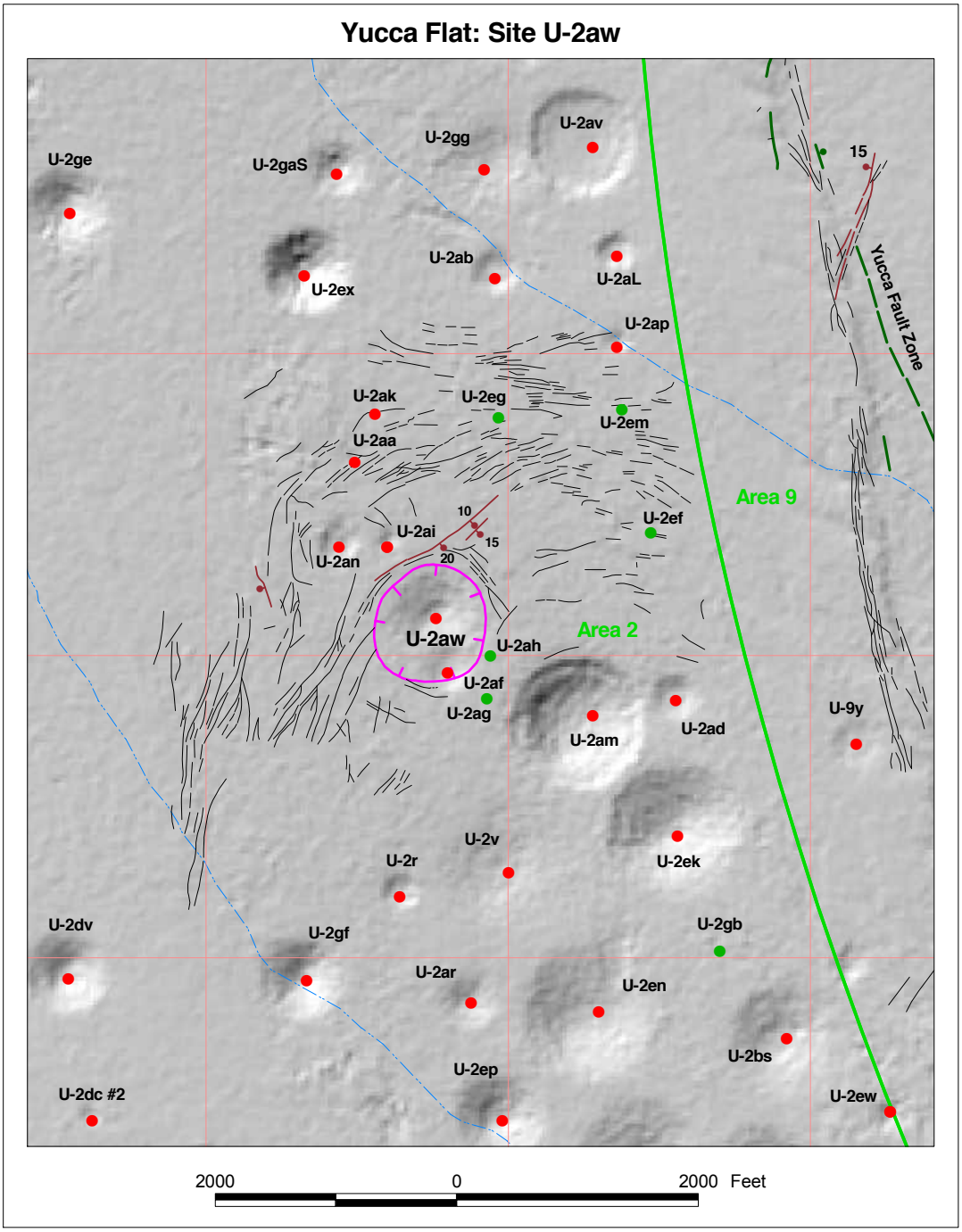

Figure 2: Surface effects map of Stanyan in U2aw (Grasso, 2003).

Cumberland
U2e

The LLNL sponsored Cumberland test was detonated in cased hole U2e on April 11, 1963. Cumberland had an announced yield of low (less than 20 kt) (DOE/NV-209, Rev 15). It was detonated in alluvium at a working point of 227 m below the surface. U2e is located in northeastern Area 2 near a number of tests that were detonated in a circular pattern. Selected nearby tests are shown in Figure 3 and include: Satsop in U2g on August 15, 1963; Narraguagus in U2f on September 27, 1963; Vulcan in U2bd on June 25, 1966; Kyack-A in U2bq #1 and Kyack-B in U2bq #2 on September 26, 1969; Parnassia in U2bc on November 30, 1971; Polygonum in U2by on October 2, 1973; and Waller in U2bz on October 2, 1973.

Cumberland collapsed to the surface about 22 minutes after detonation. It formed a crater about 19 m deep and about 140 m in diameter.

There were 4 vertical post-test holes associated with Cumberland. All were drilled near the emplacement hole in the collapse crater soon after detonation.

- U2e PS #1 was drilled to 261 m depth, surveyed and sampled.
- U2e PS #2 was drilled to 215 m when drilling issues were encountered and the hole was abandoned.
- U2e PS #3 was drilled to 261 m and collapsed when pipe was being removed, causing it to be abandoned.
- U2e PS #4 was drilled to 262 m depth, surveyed and sampled.

A drillback release occurred from a post-test drill hole on April 12, 1963 and lasted for seven hours (DOE/NV-317 Rev 1).

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 nearby and on Yucca Flat, including the entire NNSS, gives us comfort that cavity collapse and crater formation should be complete. The ground surface above the U2e 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 erosion effects. We rely on NSTec and DOE/NNSA/NSO to make decisions concerning safety issues related to reentering the crater area.

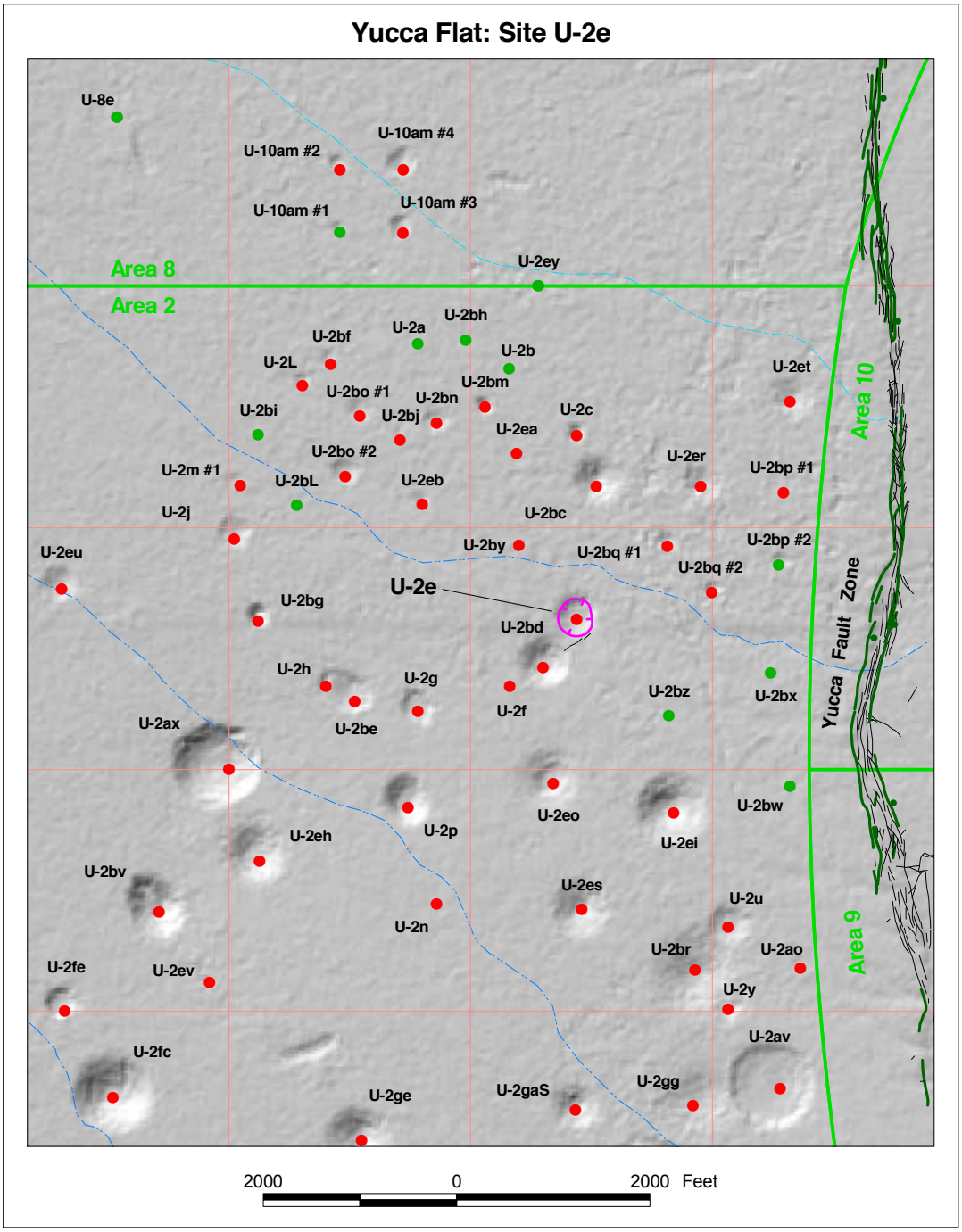

Figure 3: Surface effects map of Cumberland in U2e (Grasso, 2003).

Yuba
U12b.10

The LLNL-sponsored Yuba test was detonated in tunnel U12b.10 at Rainier Mesa on June 5, 1963 (Figure 4). Yuba has an announced yield of 3.1 kt (DOE/NV-209 Rev 15) and was detonated in the vitric pre-Rainier-post Grouse Canyon section (previously this assemblage has been identified as the Paintbrush Tuff) at a working point of about 242 m below the surface. U12b.10 is located in southwestern Area 12, and was one of six tests in B tunnel (Figure 5). Other B tunnel tests included: Rainier in U12b on September 19, 1957; Tamalpais in U12b.02 on October 8, 1958; Evans in U12b.04 on October 29, 1958; Chena in U12b.09 on October 10, 1961; and Feather in U12b.08 on December 22, 1961. Misty Echo in U12n.23 on December 10, 1988 was also a nearby test, but located in the N tunnel complex to the north of the B tunnel complex, as shown in Figure 6.

With the exception of Rainier (the first detonation contained underground), each of the B tunnel tests had some type of prompt radiochemistry sampling system. Yuba had a horizontal radiochemistry experiment from the working point to alcoves with instrumentation and a vertical radiochemistry experiment that had sampling equipment at the mesa surface. The vertical system had a 242 m long, 12" diameter pipe to the surface and various equipment at the surface.

Yuba had a subsurface collapse at about 12 minutes after detonation. Chimney height is estimated to be at about 87 m depth.

Few tunnel tests showed collapse to the surface, and, as generalized statement, surface effects were rather minor when compared to other testing areas at the NTS. Rainier was the only test in B tunnel to have recorded surface effects.

Two vertical post-test holes are associated with Yuba.

- U12b.10 PS #4 was drilled to 122 m before the test, and deepened to 277 m after the test. It was surveyed and sampled.
- U12b.10 PS #5 was drilled to 282 m after the test and surveyed and sampled.

Yuba had an accidental release of radioactivity detected onsite only, and an operational release of radioactivity detected offsite (NV/DOE-209 Rev 15). More specifically, a release occurred from the rad-chem pipe, and a drillback release from a post-test hole that occurred June 7, 1963 and lasted for 100 hours (DOE/NV-317 Rev 1).

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

- Yuba did not collapse to the surface. Subsurface collapse appears to have stopped at the base of the welded Rainier Mesa Tuff, at a depth of about 87 m. The welded Rainier Mesa Tuff is a couple hundred meters thick at this location and it would not be surprising that this strong, continuous layer could inhibit upward collapse.

- Yuba was the last test conducted in B tunnel. However, subsequent tests were detonated in N tunnel to the north and E tunnel to the south. The ground surface at the U12b.10 site has not changed over the 29 years of subsequent ground motion caused by underground testing.

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. Due to lack of complete collapse to the surface, however, LLNL has less confidence than normal in making this statement. We rely on DOE/NNSA/NSO to make decisions concerning safety issues related to reentering potential crater areas.

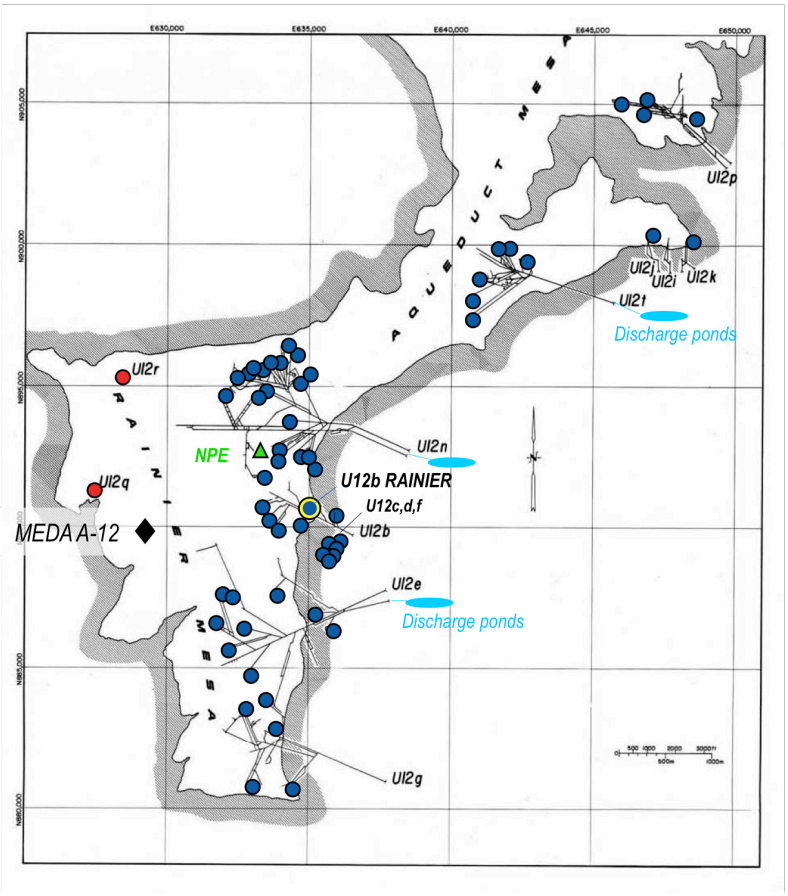

Figure 4: Location of tunnel tests at Rainier and Aqueduct mesas.

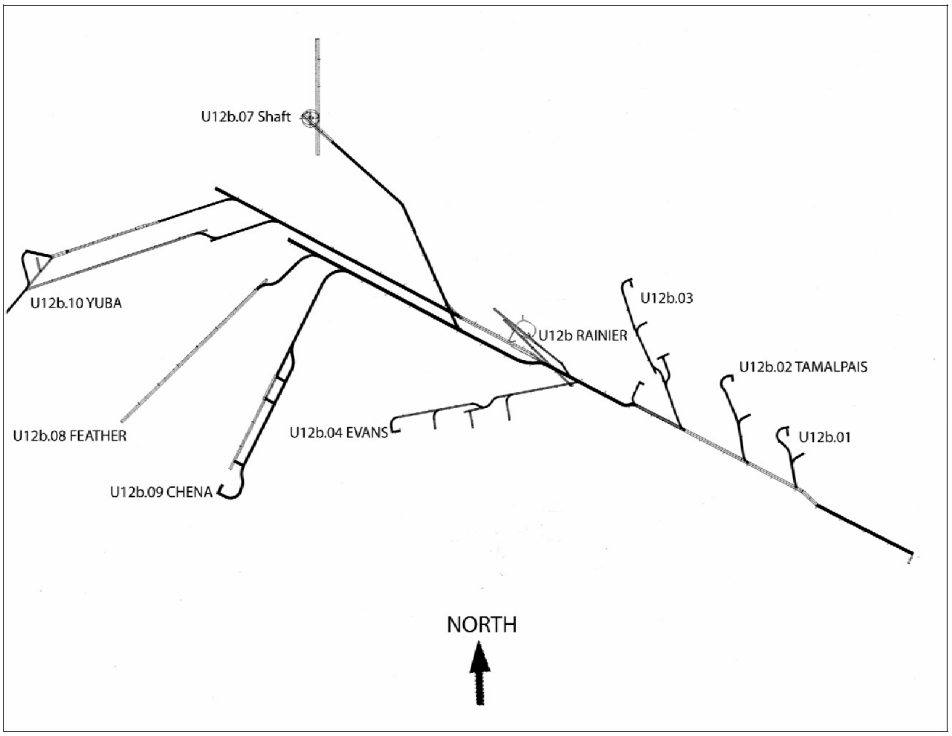

Figure 5: Location of Yuba in U12b.10 in the B tunnel complex.

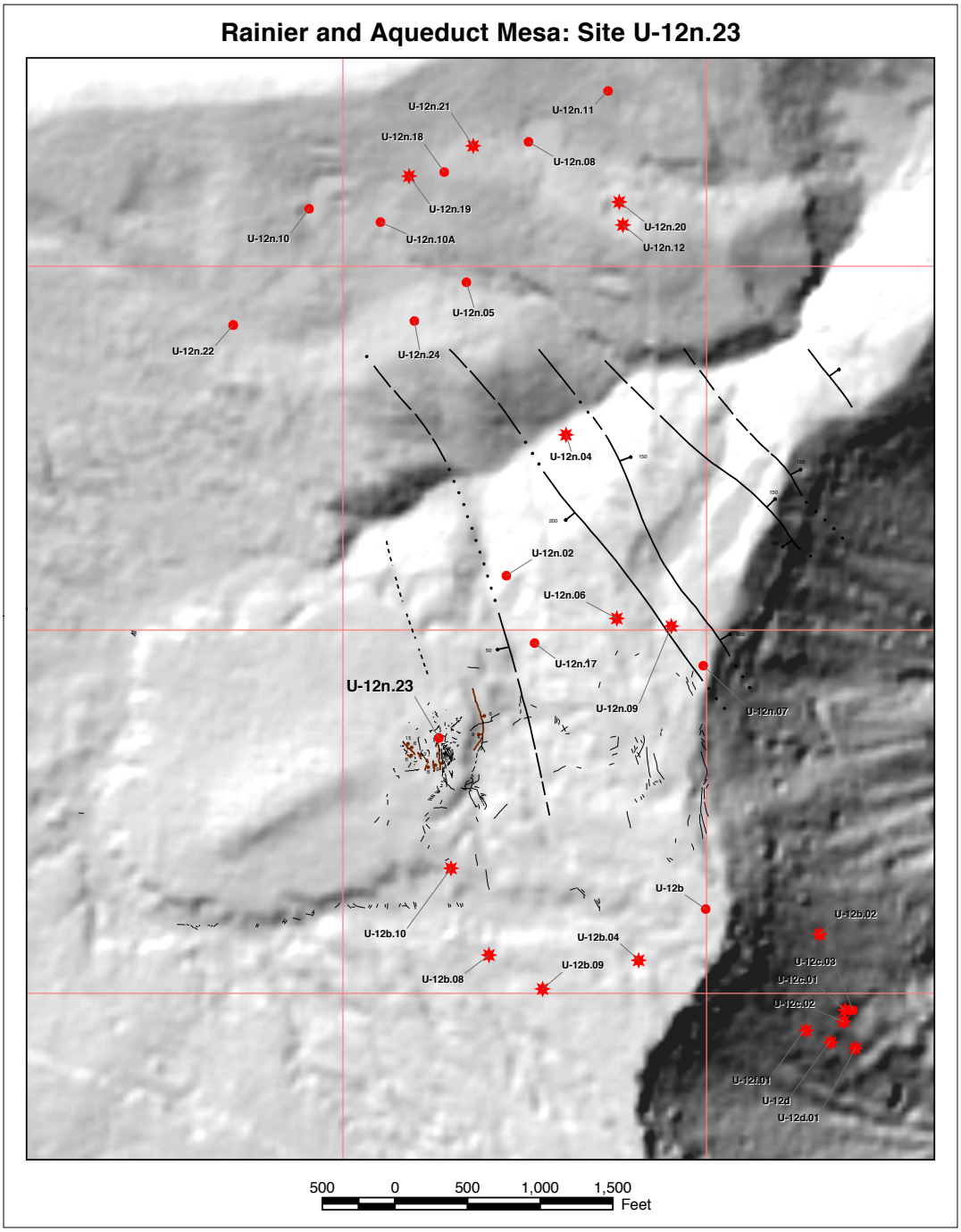

Figure 6: Surface effects map of Misty Echo in U12n.23, with Yuba located to the south (Grasso, 2003).