# APPENDIX B

# EPA ANNUAL WATER QUALITY REPORT FOR 2004
# AND HISTORIC DATA

United States Environmental Protection Agency
Office of Radiation and Indoor Air
Washington, DC 20460
EPA-402-R-04-006
November 2004

# Annual Water Sampling and Analysis, Calendar Year 2004:

## SHOAL Test Site Area
## FAULTLESS Test Site Area
## RULISON Test Site Area
## RIO BLANCO Test Site Area
## GASBUGGY Test Site Area
## GNOME Test Site Area

EPA

# Annual Water Sampling and Analysis, Calendar Year 2004

## SHOAL Test Site Area
## FAULTLESS Test Site Area
## RULISON Test Site Area
## RIO BLANCO Test Site Area
## GASBUGGY Test Site Area
## GNOME Test Site Area


by

Max G. Davis
Rose (Kitty) Houston



Prepared for the U.S. Department of Energy
under Interagency Agreement
DE-AI08-96NV11969



RADIATION AND INDOOR ENVIRONMENTS NATIONAL LABORATORY
OFFICE OF RADIATION AND INDOOR AIR
U.S. ENVIRONMENTAL PROTECTION AGENCY
P.O. BOX 98517
LAS VEGAS, NV 89193-8517

# NOTICE

The information in this document has been funded wholly or in part by the United States Environmental Protection Agency (EPA) through Interagency Agreement (IAG) DE-AI08-96 NV 11969 from the United States Department of Energy (DOE). This document has been subjected to the Agency's peer and administrative reviews, and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

# ABSTRACT

The U. S. Environmental Protection Agency, Radiation and Indoor Environments National Laboratory in Las Vegas, Nevada (R&IE), operates the radiological surveillance program and monitors former nuclear test areas in Alaska, Colorado, Mississippi, Nevada, and New Mexico, each year under the Long Term Hydrological Monitoring Program (LTHMP). The LTHMP is designed to detect residual man-made radionuclides in surface and ground water resulting from underground nuclear test activities. This report describes the sampling and analysis of water samples collected from six former nuclear test sites in three western states during 2004: Projects Shoal and Faultless in Nevada; Projects Rulison and Rio Blanco in Colorado; and Projects Gasbuggy and Gnome in New Mexico. Monitoring results for Alaska and Mississippi are reported separately.

Radiological results for 2004 are consistent with results from previous years. No increase was seen in either tritium concentrations or gamma-ray emitting radionuclides at any site. Tritium levels at the sites are generally decreasing or stable and are well below the 20,000 pCi/L guideline specified in the National Primary Drinking Water Regulations; Radionuclides; Final Rule (40CFR9/141/142), with the exception of samples from several deep wells adjacent to the nuclear cavity at the Gnome site. As in previous years, the highest tritium value recorded for any sample, $3.0 \times 10^7$ pCi/L, was from, Well DD-1 (Project Gnome).

This page left blank intentionally.

# CONTENTS

# FIGURES



# TABLES

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AEC | U.S. Atomic Energy Commission |
| Bq/L | Becquerel per liter |
| DOE | U.S. Department of Energy |
| DCG | Derived Concentration Guide (20,000 pCi/L for Tritium in Drinking Water) |
| EPA | U.S. Environmental Protection Agency |
| g | gram |
| $^3H+$ | enriched tritium |
| $^3H$ | tritium |
| HpGe | high purity germanium gamma detector |
| IAG | Interagency Agreement |
| ITC | International Technology Corporation |
| $^{131}I$ | Iodine 131 |
| keV | kilo electron volts (one thousand electron volts) |
| kg | kilogram, 1000 grams |
| KT | kiloton (one thousand tons TNT equivalent) |
| L | liter |
| LTHMP | Long-Term Hydrological Monitoring Program |
| m | meter |
| MCL | maximum contaminant level |
| MDA | minimum detectable activity |
| MDC | minimum detectable concentration |
| MeV | one million electron volts |
| min | minute |
| mL | milliliter (one thousandth of a liter) |
| MT | megaton (one million tons TNT equivalent) |
| ORIA | Office of Radiation and Indoor Air |
| pCi/L | picocuries per liter = $10^{-12}$ curies per liter = 1/1,000,000,000,000 curies per liter |
| PHS | U.S. Public Health Service |
| REECo | Reynolds Electrical & Engineering Company |
| R&IE | Radiation and Indoor Environments National Laboratory, Las Vegas, NV |
| $^{90}Sr$ | Stronium 90 |
| SGZ | surface ground zero |
| USGS | U.S. Geological Survey |
| $^{131}Xe$ | Xenon 131 |
| $^{133}Xe$ | Xenon 133 |

**ACKNOWLEDGMENTS**

The external peer review was provided by Vernon Hodge, Ph.D., Chemistry, University of Nevada, Las Vegas. In addition, the authors would like to acknowledge David R. Musick, Ph.D., Director of CRQA, Richard Flotard, Ph.D., and George Dilbeck, Ph.D., as internal reviewers.

# 1.0 INTRODUCTION

Under an Interagency Agreement with the Department of Energy (DOE), the Radiation & Indoor Environments National Laboratory (R&IE), Office of Radiation and Indoor Air (ORIA), EPA, located in Las Vegas, NV, conducts a Long-Term Hydrological Monitoring Program (LTHMP) to measure radioactivity concentrations in water sources near the sites of former underground nuclear explosions. The results of the LTHMP provide assurance that radioactive materials from the tests have not migrated into drinking water supplies. This report presents the results for the samples collected in February, March, May, and June of 2004, around the following test site areas:

- Project SHOAL Test Site, Churchill County, Nevada
- Project FAULTLESS Test Site, Nye County, Nevada
- Project RULISON Test Site, Garfield County, Colorado
- Project RIO BLANCO Test Site, Rio Blanco County, Colorado
- Project GASBUGGY Test Site, Rio Arriba County, New Mexico
- Project GNOME Test Site, Eddy County, New Mexico

# 2.0 Sample Analysis

Radiochemical laboratory procedures used to analyze the samples collected for this report are summarized in R&IE's SOPs (see Appendix A and B). These include standard methods to identify natural and man-made gamma-emitting radionuclides, tritium, plutonium, strontium, and uranium in water samples. Two types of tritium analyses were performed; conventional and electrolytic enrichment. The enrichment method lowers the minimum detectable concentration (MDC) from approximately 300 pCi/L to 5 pCi/L. An upper limit of activity of 700 - 800 pCi/L has been established for the tritium enrichment method because sample cross contamination becomes a problem at higher levels.

It has been decided by EPA, that a maximum of 25 percent of all samples collected would be analyzed by the low-level enrichment method. This decision was based on the time required for analysis and an assessment of past results. Under the current sampling and analysis protocol for the site, all samples are initially screened for tritium activity by the conventional method, and selected samples are enriched. At this time, only sampling locations that are in a position to show migration are selected for enrichment.

Sufficient sample is collected from new sampling locations to perform all routine analyses, and a full-suite of other radiochemical determinations including assays for strontium, plutonium, and uranium.

**Summary of Analytical Procedures**

| Type of Analysis | Analytical Equipment | Counting Period (Min) | Analytical Procedures | Size of Sample | Approximate Detection Limit[a] |
|---|---|---|---|---|---|
| HpGe Gamma[b] | HpGe detector calibrated at 0.5 keV/ channel (0.04 to 2 MeV range) individual detector. Efficiencies ranging from 15 to 35%. | ~150 | Radionuclide concentration quantified from gamma spectral data by online computer program. | 3.5 L | Varies with radionuclides and detector used, if counted to a MDC of approx. 5 pCi/L for $^{137}Cs$. |
| $^{3}H$ | Automatic liquid scintillation counter | 300 | Sample prepared by distillation. | 30 - 40 mL | 300 to 700 pCi/L |
| $^{3}H$+ Enrichment | Automatic liquid scintillation counter | 300 | Sample concentrated by electrolysis following distillation. | 250 mL[C] | 5 pCi/L |

[a] The detection limit is defined as the smallest amount of radioactivity that can be reliably detected, i.e., probability of Type I and Type II error at 5 percent each (DOE 1981).

[b] Gamma spectrometry using a high purity intrinsic germanium (HpGe) detector.

[C] Sample distilled, then concentrated to ~5 mL by electrolysis.

## 2.1 Sampling at Project SHOAL, Nevada

### History

Project SHOAL, a 12-KT nuclear test emplaced at 365 m (1,204 ft), was conducted on October 26, 1963, in a sparsely populated area near Frenchman Station, Nevada, 28 miles southeast of Fallon, Nevada. The test, a part of the Vela Uniform Program, was designed to investigate detection of a nuclear detonation in an active earthquake zone. The working point was in granite and no surface crater was created. The effluent released during drillback was detected onsite only and consisted of 110 curies of $^{131}Xe$ and $^{133}Xe$, and less than 1.0 curie of $^{131}I$.

### 2.1.1 Sample Collection

Samples were collected on February 24-26, 2004. The sampling locations are shown in Figure 1. All of the locations were sampled with the exception of Well H-3. The pump was inoperable. The routine sampling locations included one spring, two windmills, and eleven wells of varying depths. At least one location, Well HS-1, should intercept radioactivity migrating from the test cavity, if it should occur (Chapman and Hokett 1991).

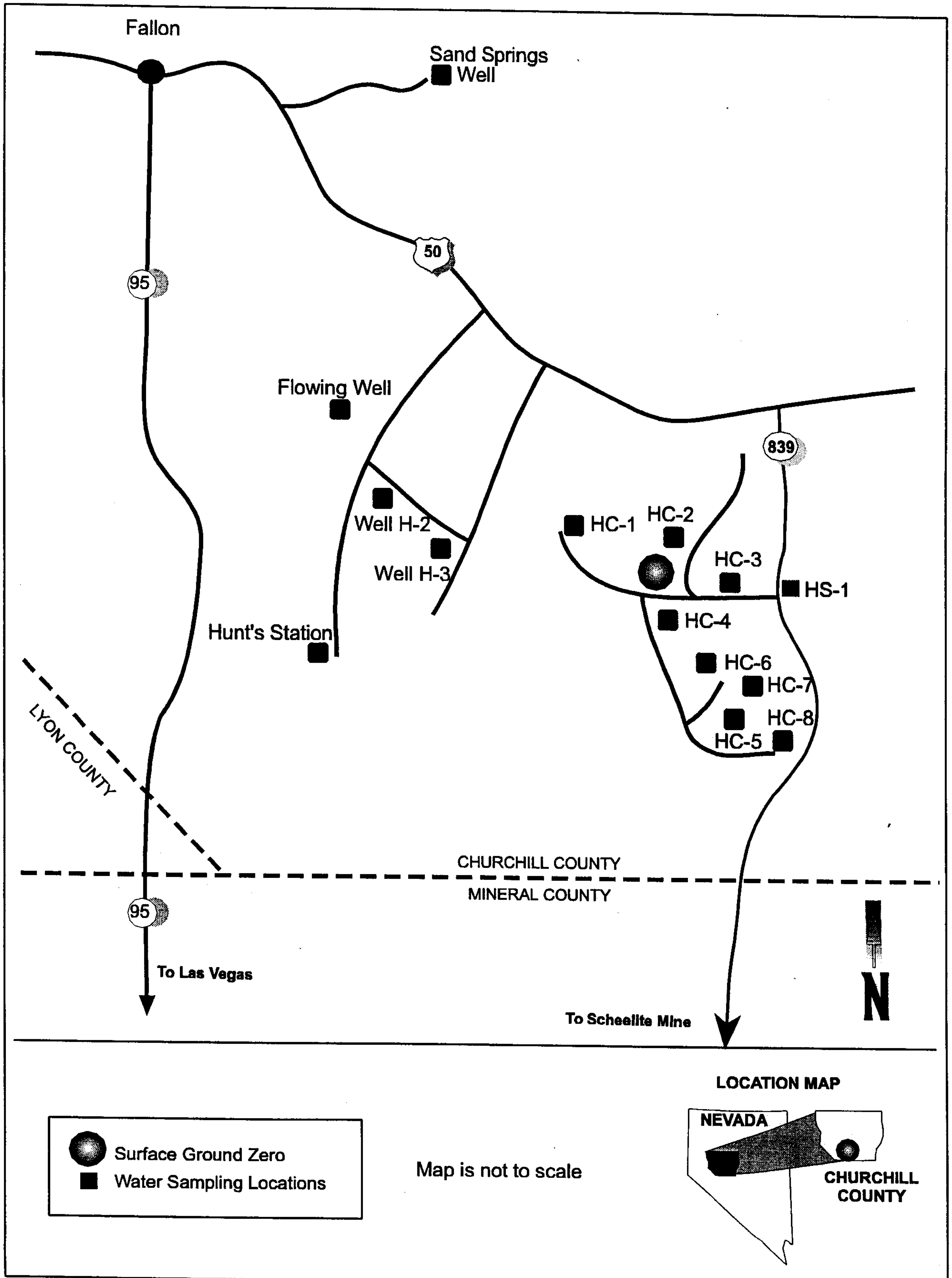



Figure 1. Project SHOAL sampling locations for February 2004.

## 2.1.2 Water Analysis Results

Gamma-ray spectral analysis results indicated that no man-made gamma-ray emitting radionuclides were present in any samples above the MDC. Tritium concentrations at all locations except for one were below the MDC. The only sampling location that had a tritium concentration above the MDC was Well HC-4 of 368 ± 151 pCi/L (see Table 1, below).

±

## 2.1.3 Conclusions

No radioactive materials attributable to the SHOAL nuclear test were detected in samples collected in the onsite and offsite areas during 2004.

**Analysis Results for Water Samples Collected at the SHOAL Site - February 2004**

**TABLE 1**

| Sample Location | Collection Date | Enriched Tritium pCi/L ± 2 SD | (MDC) | Tritium[a] pCi/L ± 2 SD | (MDC) | Gamma Spectrometry[b] pCi/L | (MDC) |
|---|---|---|---|---|---|---|---|
| Hunts Station | 2/24/04 | ND | (9.0) | | | ND | (4.8) |
| Flowing Spring | 2/24/04 | | | 7.2 ± 144[a] | (235) | ND | (5.0) |
| Spring Windmill | 2/26/04 | | | 118 ± 145[a] | (235) | ND | (4.9) |
| Well H-3 | 2/24/04 | | | | | Pump inoperable | |
| Well HS-1 | 2/25/04 | | | 15.3 ± 143[a] | (235) | ND | (1.8) |
| Well HC-1 | 2/24/04 | | | 97.0 ± 145[a] | (235) | ND | (4.9) |
| Well HC-2 | 2/24/04 | ND | (8.7) | | | ND | (4.8) |
| Well HC-3 | 2/25/04 | | | 56.0 ± 144[a] | (235) | ND | (4.7) |
| Well HC-4 | 2/26/04 | | | 368 ± 151 | (235) | ND | (5.0) |
| Well HC-5 | 2/26/04 | ND | (9.0) | | | ND | (4.9) |
| Well HC-6 | 2/26/04 | | | 7.0 ± 144[a] | (235) | ND | (4.8) |
| Well HC-7 | 2/26/04 | ND | (4.0) | | | ND | (4.9) |
| Well HC-8 | 2/24/04 | ND | (7.7) | | | ND | (4.8) |
| HC-3 Filter | 2/25/04 | | | | | Cs-137 | (3.0) |

(a) Indicate results are less than MDC (enriched or conventional method).
(b) Value in parenthesis represents $^{137}Cs$ MDC (pCi/L).
ND Non-detected.
MDC Minimum detectable concentration..

## 2.2 Sampling at Project FAULTLESS, Nevada

**History**

Project FAULTLESS was a "calibration test" conducted on January 19, 1968, in a sparsely populated area near Blue Jay Maintenance Station, Nevada. The test had a yield of less than 1 MT and was designed to test the behavior of seismic waves and to determine the usefulness of the site for high-yield tests. The emplacement depth was 975 m (3,200 ft). A surface crater was formed, but as an irregular block along local faults rather than as a saucer-shaped depression. The area is characterized by basin and range topography, with alluvium overlying tuffaceous sediments. The working point of the test was in tuff. The groundwater flow is generally from the highlands to the valley and through the valley to Twin Springs Ranch and Railroad Valley (Chapman and Hokett, 1991).

### 2.2.1 Sample Collection

Sampling was conducted on March 22-25, 2004. Sampling locations are shown in Figure 2. They include two springs and seven wells of varying depths. All sampling locations were collected with the exception of HTH-2. The pump is inoperable and will be replaced prior to the next sampling in 2005 according to DOE. The Jim Bias Well has been deleted from the program in 2003.

At least two wells (HTH-1 and HTH-2) are positioned to intercept migration from the test cavity, should it occur (Chapman and Hokett, 1991). All samples yielded negligible gamma activity. These results were all consistent with results obtained in previous years. The consistently below-MDC results for tritium indicate that, to date, migration into the sampled wells has not taken place and no event-related radioactivity has entered area drinking water supplies.

### 2.2.2 Water Analysis Results

All gamma-ray spectral analysis results indicated that no man-made gamma-ray emitting radionuclides were present above MDC. Tritium concentrations at all the locations were below the MDC, with the exception of HTH-1, results were $44 \pm 3.7$ which is well below 20,000pCi/L safe drinking water standard.

### 2.2.3 Conclusions

Tritium concentrations in water samples collected onsite and offsite are consistent with those of past studies at the FAULTLESS site. No radioactive materials attributable to the FAULTLESS test were detected in samples collected in the offsite areas. All samples were analyzed for the presence of gamma-ray emitting radionuclides.

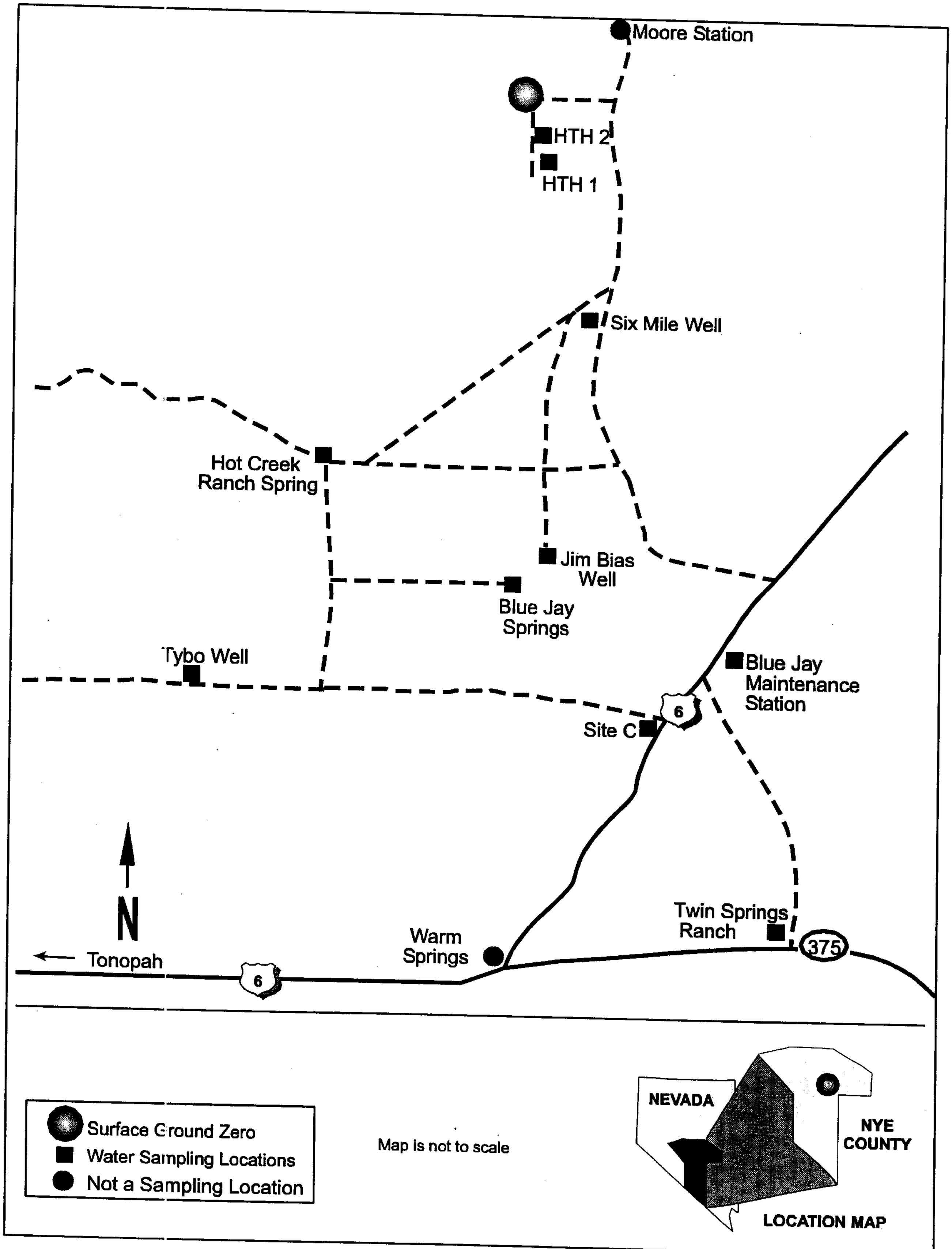



**Figure 2** Project FAULTLESS sampling locations for March 2004.

**Analysis Results for Water Samples Collected at the FAULTLESS Site - March 2004.**

| TABLE 2 | | | | |
|---|---|---|---|---|
| Sample Location | Collection Date | Enriched Tritium[a] pCi/L ± 2 SD (MDC) | Tritium[a] pCi/L ± 2 SD (MDC) | Gamma Spectrometry[b] pCi/L (MDC) |
| Hot Creek Ranch | 3/24/04 | | ND (257) | ND (4.8) |
| Blue Jay Springs | 3/24/04 | | 43 ± 157[a] (257) | ND (4.9) |
| Blue Jay Maint Station | 3/23/04 | | ND (257) | ND (4.8) |
| Well HTH-1 | 3/23/04 | 44 ± 3.7 (6.2) | | ND (4.9) |
| Well HTH-2 | 3/26/04 | | | Pump inoperable |
| Site C Base Camp | 3/25/04 | .96 ± 4.0[a] (6.5) | | ND (4.9) |
| Six Mile Well | 3/23/04 | | ND (257) | ND (4.8) |
| Tybo Well | 3/24/04 | | 16.0 ± 157[a] (257) | ND (4.8) |
| Twin Springs Ranch | 3/22/04 | ND (6.3) | | ND (5.0) |

(a) Indicate results are less than MDC (enriched or conventional method).
(b) Value in parenthesis represents $^{137}Cs$ MDC (pCi/L).
ND Non-detected.
MDC Minimum detectable concentration.

## 2.3 Sampling at Project RULISON, Colorado

**History**

Co-sponsored by the U.S. Atomic Energy Commission (AEC) and Austral Oil Company under the Plowshare Program, Project RULISON was designed to stimulate natural gas recovery in the Mesa Verde formation. The test, conducted near Grand Valley, Colorado, on September 10, 1969, consisted of a 40-KT nuclear explosive emplaced at a depth of 2,568 m (8,425 ft). Production testing began in 1970 and was completed in April 1971. Cleanup was initiated in 1972, and the wells were plugged in 1976. Some surface contamination resulted from decontamination of drilling equipment and fallout from gas flaring. Contaminated soil was removed during the cleanup operations.

### 2.3.1 Sample Collection

Sampling was conducted on May 12, 2004, from all sampling locations at Grand Valley and Rulison, Colorado. Routine sampling locations are shown in Figure 3. Sampling included the Grand Valley municipal drinking water supply springs, water supply wells for six local ranches, and two sites in the vicinity of surface ground zero (SGZ), including one test well and two surface-discharge springs.

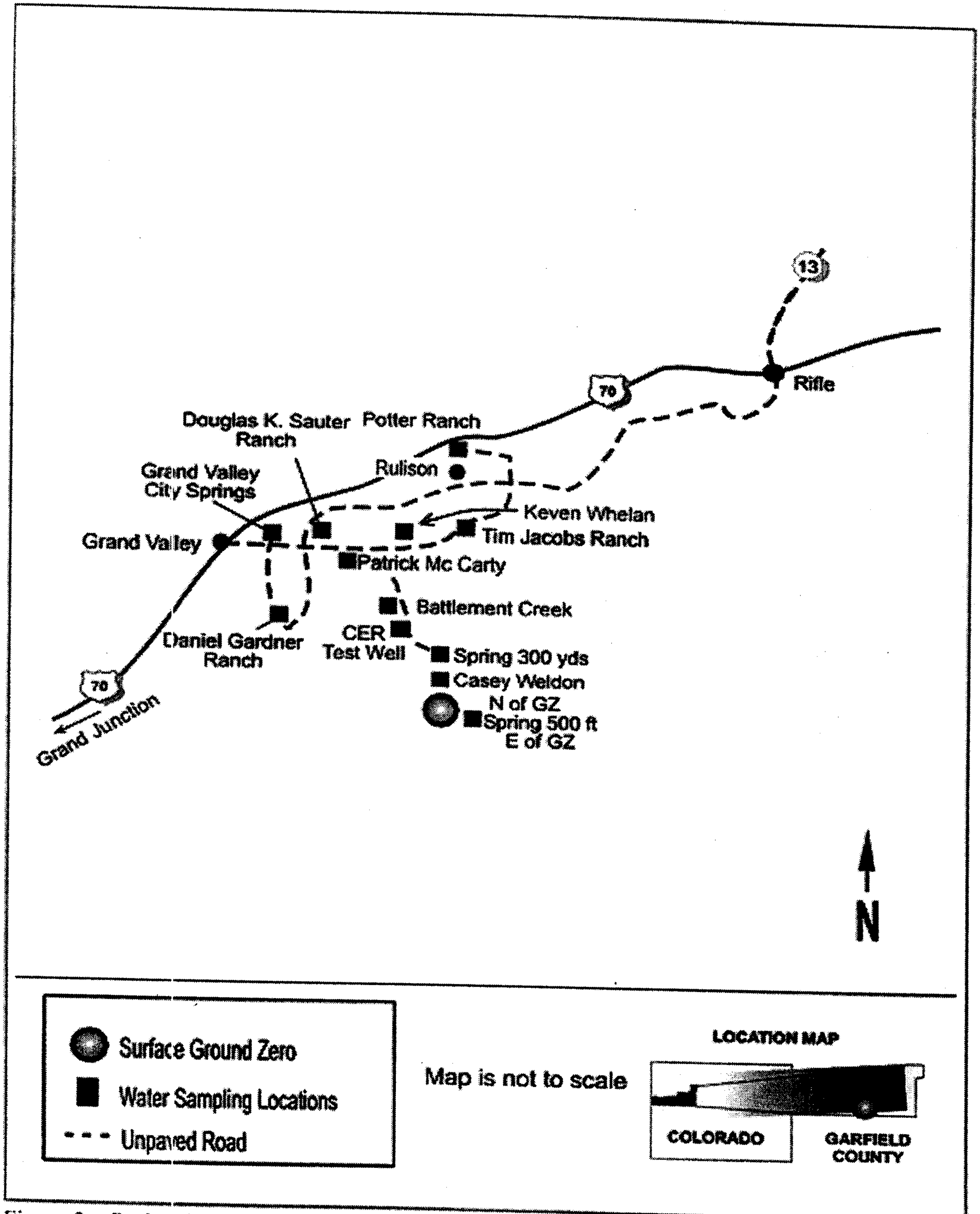



Figure 3. Project RULISON sampling locations for May 2004.

### 2.3.2 Water Analysis Results

Tritium has never been observed in measurable concentrations in the Grand Valley City Springs. All of the remaining sampling sites show detectable levels of tritium, which have generally exhibited a stable or decreasing trend over the last two decades. The range of tritium activity in 2004, was from 28 ± 4.8 pCi/L at Casey Weldon to 39.5 ± 5.0 pCi/L at CER Test Well (see Table 3). All enriched values were less than 0.25 percent of the DCG (20,000 pCi/L). The detectable tritium activities are consistent with values found in current precipitation and, perhaps, a small residual component remaining from clean-up activities at the site. This is supported by Desert Research Institute analysis, which indicates that most of the sampling locations at the RULISON site are shallow, drawing water from the surficial aquifer, and therefore, unlikely to become contaminated by radionuclide migration from the Project RULISON cavity (Chapman and Hokett 1991).

**Analysis Results for Water Samples Collected at the RULISON Site - May 2004**

**TABLE 3**

| Sample Location | Collection Date | Enriched Tritium pCi/L ± 2 SD (MDC) | Tritium[a] pCi/L ± 2 SD (MDC) | Gamma Spectrometry[b] pCi/L | (MDC) |
|---|---|---|---|---|---|
| Battlement Creek | 5/12/04 | 3.1 ± 4.7[a] (6.9) | | ND | (4.8) |
| City Springs | 5/12/04 | | 96 ± 160[a] (261) | ND | (5.0) |
| Daniel Gardner | 5/12/04 | 33 ± 4.7 (6.7) | | ND | (4.5) |
| CER Test Well | 5/12/04 | 39 ± 5.0 (7.0) | | ND | (4.8) |
| CER Test Well R | 5/12/04 | | 21 ± 159[a] (261) | | |
| Patrick McCarty | 5/12/04 | | ND (261) | ND | (4.9) |
| Potter Ranch | 5/12/04 | | 42 ± 159[a] (261) | ND | (4.8) |
| Douglas Sauter | 5/12/04 | | 256 ± 163[a] (261) | ND | (4.9) |
| Tim Jacobs | 5/12/04 | | 143 ± 161[a] (261) | ND | (1.5) |
| Kevin Whelan | 5/12/04 | 33 ± 4.7 (6.7) | | ND | (1.7) |
| Casey Weldon | 5/12/04 | 28 ± 4.8 (7.1) | | ND | (1.8) |
| Spring 300 yds N. of GZ | 5/12/04 | | 126 ± 161[a] (261) | ND | (5.0) |
| Spring 500 ft E. of GZ | 5/12/04 | | 59 ± 160[a] (261) | ND | (4.5) |

(a) Indicate results are less than MDC (enriched or conventional method).
(b) Value in parenthesis represents $^{137}Cs$ MDC (pCi/L).
ND Non-detected.
MDC Minimum detectable concentration.
R Rinse sample

### 2.3.3 Conclusions

Tritium concentrations in water samples collected onsite and offsite are consistent with those of past studies at the RULISON Test Site. In general, the current level of tritium in shallow wells at the RULISON site cannot be distinguished from the rain-out of naturally produced tritium augmented by, perhaps, a small amount of residual global "fallout tritium" remaining from nuclear testing in the 1950s and 1960s. All routine samples were analyzed for presence of gamma-ray emitting radionuclides.

## 2.4 Sampling at Project RIO BLANCO, Colorado

**History**

Project RIO BLANCO, a joint government-industry test designed to stimulate natural gas flow, was conducted under the Plowshare Program. The test was conducted on May 17, 1973, at a location between Rifle and Meeker, Colorado. Three explosives with a total yield of 99 KT were emplaced at 1,780, 1,920, and 2,040 m (5,840, 6,299, and 6,693 ft) depths in the Ft. Union and Mesa Verde formations. Production testing continued until 1976 when cleanup and restoration activities were completed. Tritiated water produced during testing was injected to 1,710 m (5,610 ft) in a nearby gas well.

### 2.4.1 Sample Collection

Sampling was conducted on May 13-14, 2004, and locations are shown in Figure 4. The routine sampling locations included four springs, four surface, and five wells, three of which are located near the cavity. At least two of the wells (Wells RB-D-01 and RB-D-03) are suitable for monitoring because they were down gradient and would indicate possible migration of radioactivity from the cavity.

### 2.4.2 Water Analysis Results

Gamma-ray spectral analysis results indicated that no man-made gamma-ray emitting radionuclides were present in any offsite samples. Three of the 15 samples collected were above the MDC for enriched tritium and none were above the MDC using the conventional method (see Table 4, page 12).

### 2.4.3 Conclusions

Tritium concentrations in water samples collected onsite and offsite are consistent with those of past studies at the RIO BLANCO Site. No radioactive materials attributable to the RIO BLANCO test were detected in samples collected in the offsite areas during May 2004. All samples were analyzed for presence of gamma-ray emitting radionuclides.

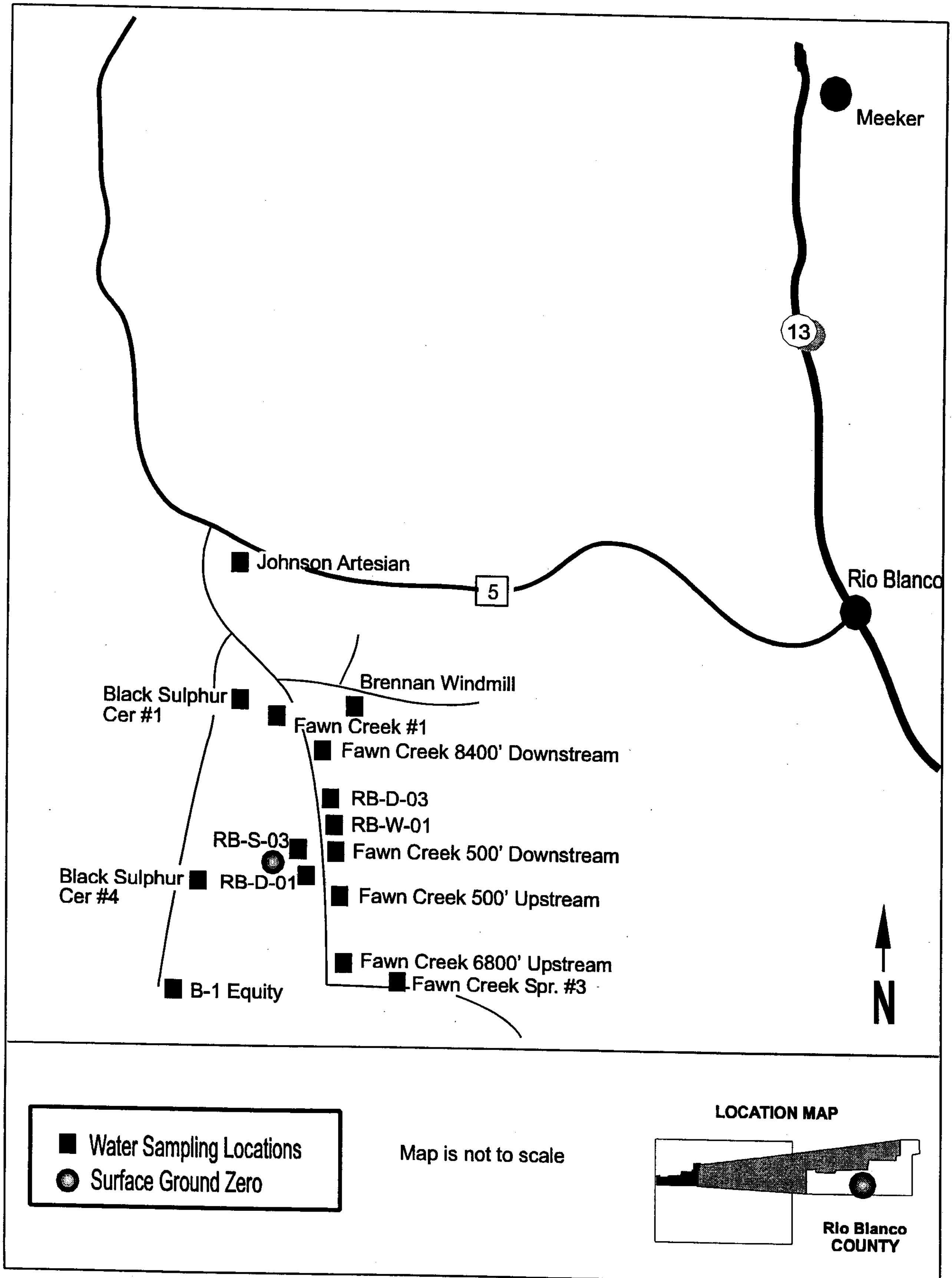



Figure 4. Project RIO BLANCO sampling locations for May 2004.

## Analysis Results for Water Samples Collected at the RIO BLANCO Site - May 2004

**TABLE 4**

| Sample Location | Collection Date | Enriched Tritium pCi/L ± 2 SD (MDC) | Tritium[(a)] pCi/L ± 2 SD (MDC) | Gamma Spectrometry[(b)] pCi/L (MDC) |
|---|---|---|---|---|
| B-1 Equity Camp | 5/14/04 | | ND (248) | ND (5.0) |
| Brennan Windmill | 5/13/04 | | 109 ± 153[(a)] (248) | ND (4.6) |
| CER #1 Black Sulphur | 5/14/04 | | ND (248) | ND (4.7) |
| CER #4 Black Sulphur | 5/14/04 | | ND (248) | ND (4.8) |
| Fawn Creek #1 | 5/13/04 | 15 ± 4.7 (7.2) | | ND (5.0) |
| Fawn Creek #3 | 5/13/04 | | 47 ± 152[(a)] (248) | ND (4.7) |
| Fawn Creek 500' Upstream | 5/13/04 | | 150 ± 154[(a)] (248) | ND (4.5) |
| Fawn Creek 6800' Upstream | 5/13/04 | | 114 ± 153[(a)] (248) | ND (4.8) |
| Fawn Creek 500' Downstream | 5/13/04 | 15 ± 4.9 (7.7) | | ND (4.5) |
| Fawn Creek 8400' Downstream | 5/13/04 | | 72 ± 152[(a)] (248) | ND (4.3) |
| Johnson Artesian Well | 5/13/04 | | ND (248) | ND (4.6) |
| Well RB-D-01 | 5/13/04 | 4.1 ± 5.6[(a)] (9.1) | | ND (4.8) |
| Well RB-D-03 | 5/13/04 | 21 ± 5.6 (8.5) | | ND (4.6) |
| Well RB-S-03 | 5/13/04 | | ND (248) | ND (4.9) |
| Well RB-W-01 | 5/13/04 | | ND (248) | ND (4.7) |
| Well RB-D-01 R | 5/13/04 | | ND (248) | |
| Well RB-S-03 R | 5/13/04 | | ND (248) | |
| Well RB-D-03 R | 5/13/04 | | ND (248) | |
| Well RB-W-01 R | 5/13/04 | | ND (248) | |

(a) Indicate results are less than MDC (enriched or conventional method).
(b) Value in parenthesis represents $^{137}Cs$ MDC (pCi/L).
ND Non-detected.
MDC Minimum detectable concentration
R Rinse sample.

# 2.5 Sampling at Project GASBUGGY, New Mexico

### History

Project GASBUGGY was a Plowshare Program test co-sponsored by the U.S. AEC and El Paso Natural Gas Co., conducted near Gobernador, New Mexico, on December 10, 1967. A nuclear explosive with a 29-KT yield was detonated at a depth of 1,290 m (4,240 ft) to stimulate a low productivity natural gas reservoir. Production testing was completed in 1976 and restoration activities were completed in July 1978.

The principal aquifers near the test site are the Ojo Alamo Sandstone, an aquifer containing non-potable water located above the test cavity, and the San Jose formation and Nacimiento formation.

Both surficial aquifers contain potable water. The flow regime of the San Juan Basin is not well known, although it is likely that the Ojo Alamo Sandstone discharges to the San Juan River 50 miles northwest of the Gasbuggy site. Hydrologic gradients in the vicinity are downward, but upward gas migration is possible (Chapman and Hokett, 1991).

## 2.5.1 Sample Collection

Annual sampling at Project GASBUGGY was completed during June 15-18, 2004. All of the routine sampling locations were collected except for Bubbling Spring which was dry (see Figure 5) and EPNG-10-36 which was plugged in 2003.

## 2.5.2 Water Analysis Results

Tritium concentrations of water samples collected onsite and offsite are consistent with those of past studies at the GASBUGGY Site.

Well EPNG 10-36 has yielded tritium activities between 100 pCi/L in 2000 to $0.05 \pm 4$ in 2003. In 2003 Well EPNG 10-36 was plugged due to the severe deterioration of the well casing. DOE will drill several wells in the near future, placed in strategic location designed to intercept migration of radionuclides if they should occur. The migration mechanism and route are not currently known, although an analysis by Desert Research Institute indicated two feasible routes, one through the Printed Cliffs sandstones, and the other one through the Ojo Alamo sandstone, one of the principal aquifers in the region (Chapman and Hokett, 1991).

Gamma-ray spectral analysis results indicated that no man-made gamma-ray emitting radionuclides were present in any onsite and offsite samples above the MDC. Tritium concentrations at all locations except for one were below the MDC. The only sampling locations that had a tritium concentration above the MDC was Cave Springs of $12 \pm 6$ pCi/L. (see Table 5, page 14).

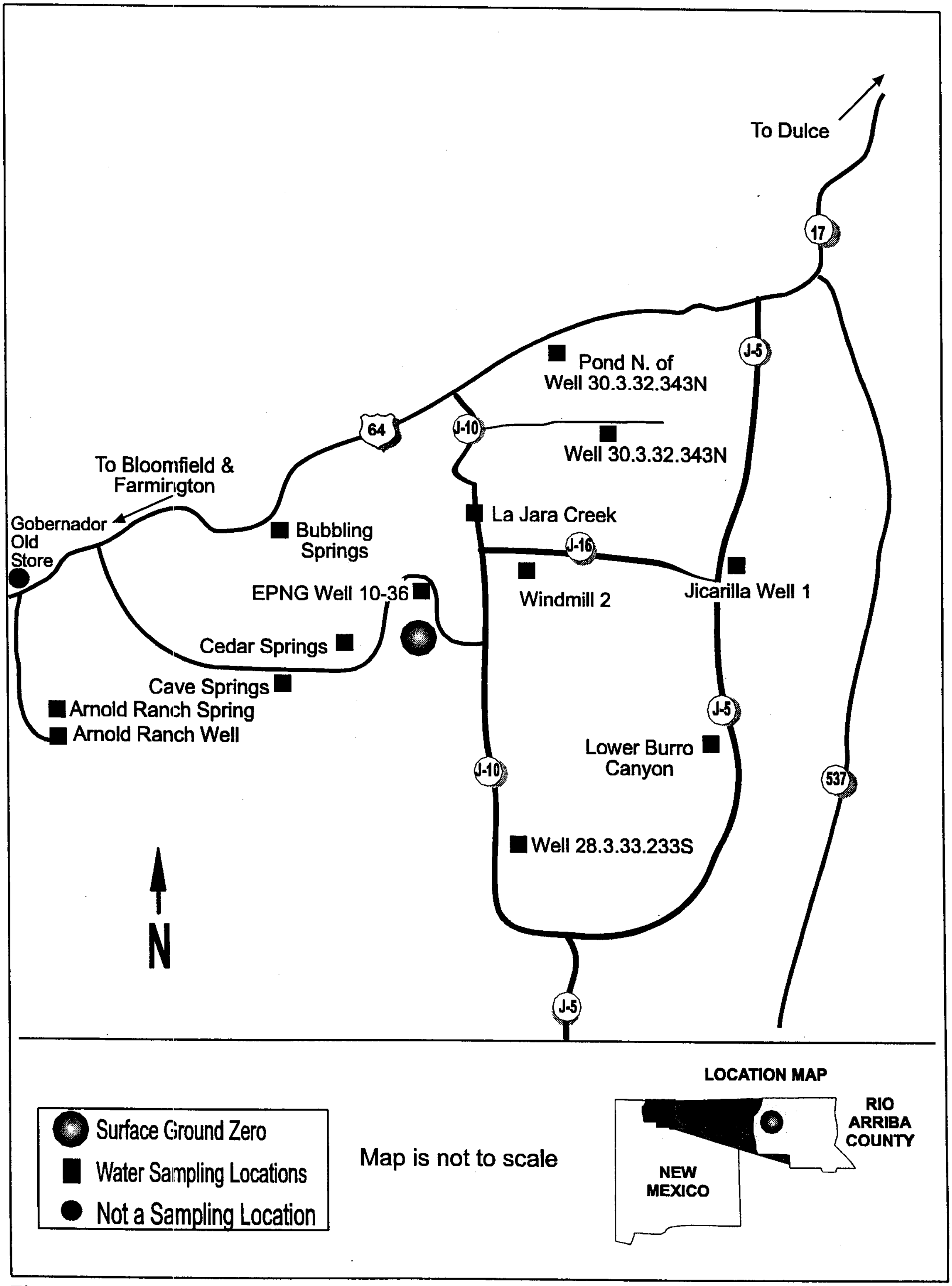


Figure 5. Project GASBUGGY sampling locations for June 2004.

## 2.5.3 Conclusions

Tritium concentrations of water samples collected onsite and offsite are consistent with those of past studies at the GASBUGGY Site.

**Analysis Results for Water Samples Collected at the GASBUGGY Site - June 2004**

**TABLE 5**

| Sample Location | Collection Date | Enriched Tritium pCi/L ± 2 SD ( MDC) | Tritium[a] pCi/L ± 2 SD (MDC) | Gamma Spectrometry[b] pCi/L (MDC) |
|---|---|---|---|---|
| Arnold Ranch Spring | 6/18/04 | 3.8 ± 4.4[a] (7.0) | | ND (4.9) |
| Bubbling Springs | 6/15/04 | | | No sample, spring dry |
| Cave Springs | 6/16/04 | 12 ± 6 (9.6) | | ND (4.9) |
| Cedar Springs | 6/16/04 | | ND (264) | ND (4.8) |
| La Jara Creek | 6/16/04 | | ND (264) | ND (4.7) |
| Lower Burro Canyon | 6/17/04 | | ND (264) | ND (4.5) |
| Pond N. of Well 30.3.32.343 | 6/17/04 | | 73 ± 162[a] (264) | ND (4.9) |
| Well EPNG-10-36 | 6/16/04 | | | No Sample Well Plugged |
| Jicarilla Well 1 | 6/17/04 | | ND (264) | ND (4.9) |
| Well 28.3.33.233 (South) | 6/16/04 | | ND (264) | ND (4.9) |
| Well 30.3.32.343 (North) | 6/17/04 | | ND (264) | ND (4.2) |
| Windmill #2 | 6/16/04 | 5.6 ± 4.9[a] (8.0) | | ND (5.0) |
| Arnold Ranch Well | 6/18/04 | | 56 ± 161[a] (264) | ND (4.8) |

(a) Indicate results are less than MDC (enriched or conventional method).
(b) Value in parenthesis represents $^{137}Cs$ MDC (pCi/L).
ND Non-detected.
MDC Minimum detectable concentration.

## 2.6 Sampling at Project GNOME, New Mexico

### History

Project GNOME, conducted on December 10, 1961, near Carlsbad, New Mexico, was a multipurpose test emplaced at a depth of 370m (1,216 ft) in the Salado salt formation. The explosive yield was slightly-more-than 3-KT. Oil and gas are produced from the geologic units below the working point. The overlying Rustler formation contains three water-bearing zones: brine located at the boundary of the Rustler and Salado formations, the Culebra Dolomite which is used for domestic and stock supplies, and the Magenta Dolomite which is above the zone of saturation (Chapman and Hokett, 1991). The ground water flow is generally to the west and southwest.

Radioactive gases were accidentally vented following the test. In 1963, USGS conducted a tracer study involving injection of 20 Ci tritium, 10 Ci $^{137}$Cs, 10 Ci $^{90}$Sr, and 4 Ci $^{131}$I in the Culebra Dolomite zone; using Wells USGS 4 and 8. During remediation activities in 1968-69, contaminated material was placed in the test cavity and the shaft up to within 7 ft of the surface. More material was slurried into the cavity and drifts in 1979. A potential exists for discharge of this slurry to the Culebra Dolomite and to Rustler-Salado brine. Potentially this may increase as the salt around the cavity compresses, forcing contamination upward and distorting and cracking the concrete stem and grout.

### 2.6.1 Sample Collection

Annual sampling at Project GNOME was completed during June 22-24, 2004. The routine sampling sites, depicted in Figure 6, includes ten monitoring wells in the vicinity of surface GZ; the municipal supplies at Loving and Carlsbad, New Mexico.

### 2.6.2 Water Analysis Results

No tritium activity was detected in the Carlsbad municipal supply or the Loving Station well. An analysis by Desert Research Institute (Chapman and Hokett, 1991) indicates that these sampling locations, which are on the opposite side of the Pecos River from the Project GNOME site, are not connected hydrologically to the site and, therefore, cannot become contaminated by Project GNOME radionuclides.

Tritium results greater than the MDC were detected in water samples from four of the 12 sampling locations in the immediate vicinity of GZ. Tritium activities in wells DD-1, LRL-7, USGS-4, and USGS-8 ranged from $1.12 \pm 0.16 \times 10^3$ (LRL-7) to $3.04 \times 10^7$ (DD-1) pCi/L. Well DD-1 collects water from the test cavity; Well LRL-7 collects water from a side drift; and Wells USGS-4 and USGS-8 were used in the radionuclide tracer study conducted by the USGS. None of these wells are sources of potable water.

In addition to tritium, $^{137}$Cs and $^{90}$Sr concentrations were observed in samples from Wells DD-1, LRL-7, and USGS-8, while $^{90}$Sr activity was detected in Well USGS-4 as in previous years (see Table 6). No tritium was detected in the remaining sampling locations, including Well USGS-1, which the DRI analysis (Chapman and Hokett, 1991) indicated is positioned to detect any migration of radioactivity from the cavity. All other tritium results were below the MDC.

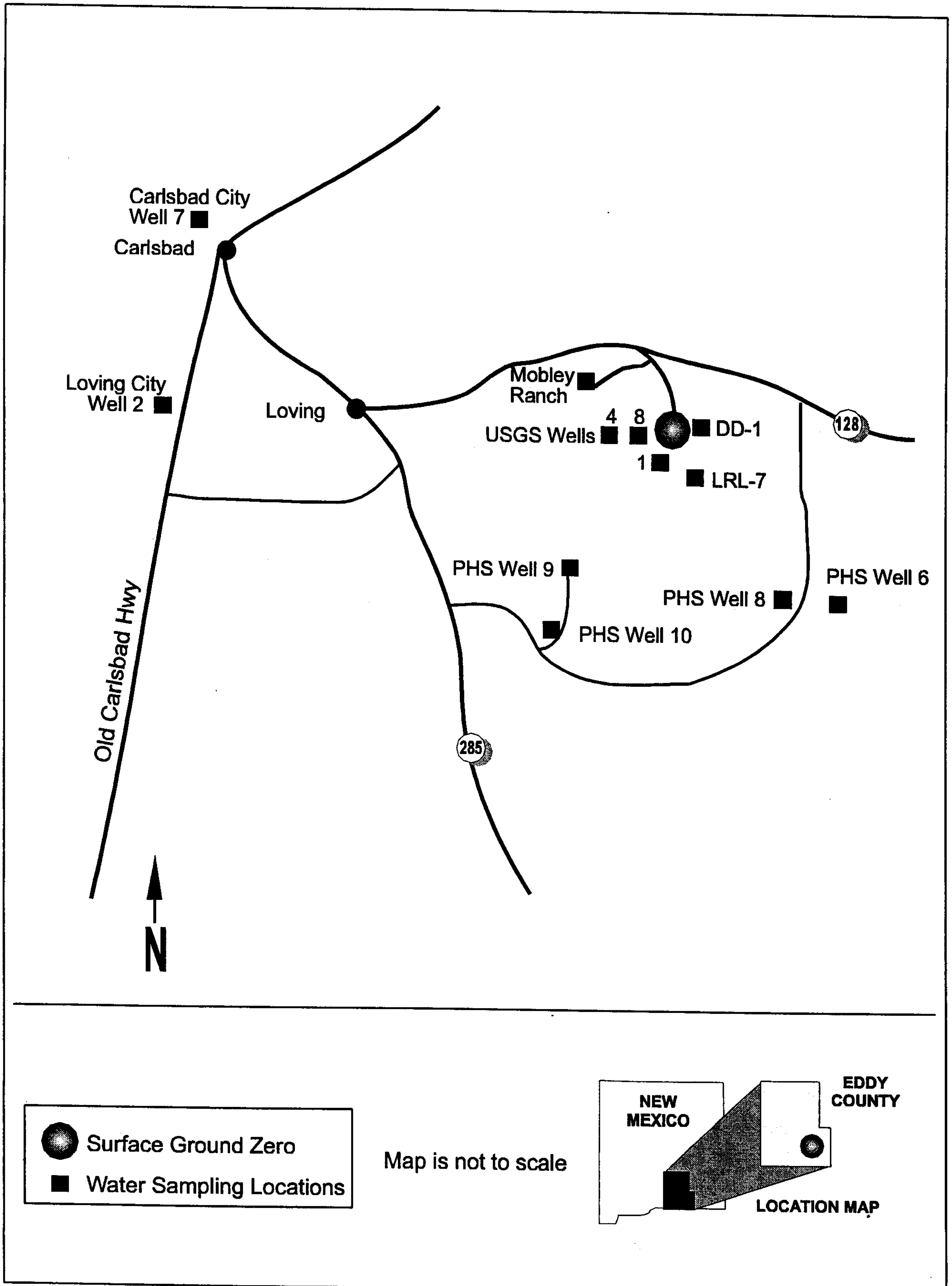



Figure 6. Program GNOME sampling locations for June 2004.

## 2.6.3 Conclusion

No radioactive materials attributable to the GNOME Test were detected in samples collected in the offsite areas during June of 2004.

**Analysis Results for Water Samples Collected at the GNOME Site - June 2004**

**TABLE 6**

| Sample Location | Collection Date | Enriched Tritium pCi/L ± 2 SD (MDC) | Tritium pCi/L ± 2 SD (MDC) | Gamma Spectrometry[(b)] pCi/L (MDC) |
|---|---|---|---|---|
| Well 7 City | 6/22/04 | 1.2 ± 4.5[(a)] (7.5) | | ND (4.7) |
| Well 2 City | 6/22/04 | ND (7.1) | | ND (4.9) |
| Well PHS 6 | 6/22/04 | | ND (244) | ND (5.0) |
| Well PHS 8 | 6/22/04 | | ND (244) | ND (4.9) |
| Well PHS 9 | 6/22/04 | ND (8.1) | | ND (4.9) |
| Well PHS 10 | 6/22/04 | | ND (244) | ND (5.0) |
| Well USGS 1 | 6/22/04 | 4.9 ± 5.7[(a)] (9.2) | | ND (4.6) |
| Well USGS 4 | 6/23/04 | | $2.75 \pm .04 \times 10^4$ (235) | ND (1.8) |
| Well USGS 8 | 6/23/04 | | $4.38 \pm .05 \times 10^4$ (235) | Cs-137 65 ± 10.4 (184) |
| J. Mobley Ranch | 6/22/04 | | 10 ± 148[(a)] (244) | ND (5.0) |
| Well DD-1 | 6/24/04 | | $3.04 \pm 722 \times 10^7$ (244) | Cs-137 $6.35 \pm 1.11 \times 10^5$ |
| Well LRL-7 | 6/23/04 | | $1.12 \pm .16 \times 10^3$ (235) | Cs-137 21.1 ± 3.8 (1.7) |
| Well DD-1 R | 6/24/04 | | ND (244) | |
| Well USGS 4 R | 6/23/04 | | ND (244) | |
| Well USGS 8 R | 6/23/04 | | ND (244) | |
| Well LRL-7 R | 6/23/04 | | ND (244) | |

(a) Indicate results are less than MDC (enriched or conventional method).
(b) Value in parenthesis represents $^{137}$Cs MDC (pCi/L).
ND Non-detected.
MDC Minimum detectable concentration.
R Rinse sample.

## REFERENCES

Chapman & Hockett, 1991. *Evaluation of Groundwater Monitoring at Offsite Nuclear Test Areas*, Las Vegas, NV, Desert Research Institute, University of Nevada System, Report DOE/NV/10845-07.

Final rule on Dec. 7, 2000. Code of Federal Regulations, Vol. 65, Title 40, Parts 9, 141, and 142, December 7, 2000, *National Primary Drinking Water Regulations*; Radionuclides; Final Rule; (40CFR9/141/142).

*A Guide for Environmental Radiological Surveillance at U.S. Dept. of Energy Installations, July 1981,* Office of Operational Safety Report. Las Vegas, NV: U.S. Department of Energy; DOE/EP-0023.

Johns, F., et al. 1979. *Radiochemical and Analytical Procedures for Analysis of Environmental Samples*. Las Vegas, NV: U.S. Environmental Protection Agency; EMSL-LV-0539-17-1979.

*Offsite Environmental Monitoring Report Radiation Monitoring Around Nuclear Test Areas, Calendar Year 1992.* EPA 600/R-94/209.

# GLOSSARY OF TERMS

**Background Radiation**

The radiation in man's environment, including cosmic rays and radiation from naturally-occurring and man-made radioactive elements, both outside and inside the bodies of humans and animals. The usually quoted average individual exposure from background radiation is 125 millirem per year in mid-latitudes at sea level.

**Curie (Ci)**

The basic unit used to describe the rate of radioactive disintegration. The curie is equal to 37 billion disintegrations per second, which is the equivalent of 1 gram of radium. Named for Marie and Pierre Curie who discovered radium in 1898. One microcurie (μCi) is 0.000001 Ci.

**Isotope**

Atoms of the same element with different numbers of neutrons in the nuclei. Thus $^{12}C$, $^{13}C$, and $^{14}C$ are isotopes of the element carbon, the numbers denoting the approximate atomic weights. Isotopes have very nearly the same chemical properties, but have different physical properties (for example $^{12}C$ and $^{13}C$ are stable, $^{14}C$ is radioactive).

**Enrichment Method**

A method of electrolytic concentration that increases the sensitivity of the analysis of tritium in water. This method is used for selected samples if the tritium concentration is less than 700 pCi/L.

**Minimum Detectable Concentration (MDC)**

The smallest amount of radioactivity that can be reliably detected with a probability of Type I and Type II errors at 5 percent each (DOE 1981).

**Offsite**

Areas exclusive of the immediate Test Site Area.

**Type I Error**

The statistical error of accepting the presence of radioactivity when none is present. Sometimes called alpha error.

**Type II Error**

The statistical error of failing to recognize the presence of radioactivity when it is present. Sometimes called beta error.

# Appendix A

Typical MDC Values for Gamma Spectroscopy
(100 minute count time)

| | | | |
|---|---|---|---|
| Geometry* | Marinelli | Model | 430G |
| Matrix | Water | Density | 1.0 g/ml |
| Volume | 3.5 liter | Units | pCi/L |

| Isotope | MDC | Isotope | MDC |
|---|---|---|---|
| | | Ru-106 | 4.76E+01 |
| Be-7 | 4.56E+01 | Sn-113 | 8.32E+00 |
| K-40 | 4.92E+01 | Sb-125 | 1.65E+01 |
| Cr-51 | 5.88E+01 | I-131 | 8.28E+00 |
| Mn-54 | 4.55E+01 | Ba-133 | 9.16E+00 |
| Co-57 | 9.65E+00 | Cs-134 | 6.12E+00 |
| Co-58 | 4.71E+00 | Cs-137 | 6.43E+00 |
| Fe-59 | 1.07E+01 | Ce-144 | 7.59E+01 |
| Co-60 | 5.38E+00 | Eu-152 | 2.86E+01 |
| Zn-65 | 1.24E+01 | Ra-226 | 1.58E+01 |
| Nb-95 | 5.64E+00 | U-235 | 1.01E+02 |
| Zr-95 | 9.06E+00 | Am-241 | 6.60E+01 |

**Disclaimer**
The MDA's provided are for background matrix samples presumed to contain no known analytes and no decay time. All MDA's provided here are for one specific *Germanium detector and the geometry of interest. The MDA's in no way should be used as a source of reference for determing MDA's for any other type of detector. All gamma spectroscopy MDA's will vary with different types of shielding, geometries, counting times and decay time of sample.

# Appendix B

**Standard Operating Procedures for the Center for Radioanalysis & Quality Assurance**

| | |
|---|---|
| RQA-302 | Standard Operating Procedures of Gamma-Ray Detector Systems |
| RQA-602 | Tritium Enrichment Procedure |
| RQA-603 | Standard Operating Procedure for $^{89}Sr$ and $^{90}Sr$ in Water, Air Filters and Milk |
| RQA-604 | Standard Operating Procedure of Convention Tritium in Water |
| RQA-606 | Analysis of Plutonium, Uranium and Thorium in Environmental Samples by Alpha Spectroscopy |

**Standard Operating Procedures for the Center for Environmental Restoration, Monitoring & Emergency Response**

| | |
|---|---|
| CER-203 | Standard Operating Procedure for the Long-Term Hydrological Monitoring Program |

ITLV/10972--177
UC-700

# Preliminary Site Characterization Report Rulison Site, Colorado

August 1996

Approved for public release; further dissemination unlimited.

ITLV/10972--177
UC-700

# PRELIMINARY SITE CHARACTERIZATION REPORT RULISON SITE, COLORADO

IT CORPORATION
2621 Losee Road, Building B-1, Suite 3050-01
North Las Vegas, Nevada 89030

August 1996



This work performed for the U.S. Department of Energy by IT Corporation under
Contract No.: DE-AC08-96NV10972

# *Abstract*

This report is a summary of environmental information gathered during a review of the documents pertaining to Project Rulison and interviews with personnel who worked on the project. Project Rulison was part of Operation Plowshare (a program designed to explore peaceful uses for nuclear devices). The project consisted of detonating a 43-kiloton nuclear device on September 10, 1969, in western Colorado to stimulate natural gas production. Following the detonation, a reentry well was drilled and several gas production tests were conducted. The reentry well was shut-in after the last gas production test and was held in standby condition until the general cleanup was undertaken in 1972. A final cleanup was conducted after the emplacement and testing wells were plugged in 1976. However, some surface radiologic contamination resulted from decontamination of the drilling equipment and fallout from the gas flaring during drilling operations. With the exception of the drilling effluent pond, all surface contamination at the Rulison Site was removed during the cleanup operations. All mudpits and other excavations were backfilled, and both upper and lower drilling pads were leveled and dressed.

This report provides information regarding known or suspected areas of contamination, previous cleanup activities, analytical results, a review of the regulatory status, the site's physical environment, and future recommendations for Project Rulison. Based on this research, several potential areas of contamination have been identified. These include the drilling effluent pond and mudpits used during drilling operations. In addition, contamination could migrate in the gas horizon.

The drilling effluent pond at the Rulison Site was used to store nonradioactive drilling mud during the drilling of the emplacement hole for the nuclear device. In 1994 and 1995, three pond-sediment sampling events were conducted to evaluate the nature of this residual drilling fluid. The sampling indicated the presence of up to seven percent, by weight, of diesel fuel and the presence of chromium. The diesel fuel contained total petroleum hydrocarbon compounds in addition to benzene, toluene, ethylbenzene, and xylene. Prior to the detonation of the nuclear device, the sumps remaining from drilling the emplacement hole (with the exception of the drilling effluent pond previously mentioned) were cleaned and filled with earth.

Two natural gas production wells are located within 5 kilometers (3 miles) of the Rulison Site. Both wells are currently shut-in because current (1995) low gas prices make production uneconomical. If contamination enters the gas horizons, it should appear in the water or gas from

one or both of these wells. Tritium is the most likely contaminant to be found in the natural gas or groundwater from the production wells because it is the most mobile of the radionuclides produced by detonation of the nuclear device.

Based on information provided in this report, the following tasks should be completed to close the remaining information gaps for Project Rulison:

- Complete the human health baseline risk assessment
- Collect gas/water samples from the gas wells closest to the shot cavity
- Characterize the mudpit located by the reentry (RE-X) well
- Continue the Long-Term Hydrologic Monitoring Program
- Develop action plan in the event contamination is found.

## *Table of Contents*

## ***Table of Contents*** *(Continued)*

## *Table of Contents* *(Continued)*

## List of Figures

## *List of Figures (Continued)*

| Number | Title | Page |
|---|---|---|

## *List of Figures* *(Continued)*

| Number | Title | Page |
|---|---|---|

## *List of Tables*

## List of Tables *(Continued)*

## List of Acronyms and Abbreviations

| | |
|---|---|
| AEC | U.S. Atomic Energy Commission |
| amsl | Above mean sea level |
| BLM | U.S. Bureau of Land Management |
| BMI | Battelle Memorial Institute |
| °C | Degree(s) Celsius |
| CDNR | State of Colorado Department of National Resources |
| CERCLA | Comprehensive Environmental Response, Compensation, and Liability Act |
| CFR | Code of Federal Regulations |
| CG | Contaminant guideline |
| Ci | Curie(s) |
| cm | Centimeter(s) |
| $cm^2$ | Square centimeter(s) |
| $cm^3$ | Cubic centimeter(s) |
| DOE | U.S. Department of Energy |
| DOE/NV | DOE/Nevada Operations Office |
| dpm | Disintegration(s) per minute |
| DRI | Desert Research Institute |
| ERDA | U.S. Energy Research and Development Administration |
| EPA | Environmental Protection Agency |
| °F | Degree(s) Fahrenheit |
| FEMA | Federal Emergency Management Agency |
| FIRM | Flood Insurance Rate Map |
| ft | Foot (feet) |
| gpd | Gallon(s) per day |
| HRS | Hazard Ranking System |
| in. | Inch(es) |
| IT | IT Corporation |
| $K_d$ | Distribution coefficient |
| km | Kilometer(s) |
| LTHMP | Long-Term Hydrologic Monitoring Program |
| $\mu$d | Microdarcy(ies) |
| m | Meter(s) |
| $m^2$ | Square meter(s) |

| | |
|---|---|
| $m^3$ | Cubic meter(s) |
| $\mu$Ci/mL | MicroCurie(s) per milliliter |
| MCF | Million cubic feet |
| mi | Mile(s) |
| mg | Milligram(s) |
| mL | Milliliter(s) |
| mrad | Millirad(s) |
| NEPA | National Environmental Policy Act |
| pCi/mL | PicoCurie(s) per milliliter |
| pCi/g | PicoCurie(s) per gram |
| pCi/L | PicoCurie(s) per liter |
| $\mu$R/h | Microroentgen(s) per hour |
| R-E | Emplacement well |
| R-EX | Reentry well |
| SGZ | Surface ground zero |
| SCS | Soil Conservation Service |
| USDA | U.S. Department of Agriculture |
| USGS | U.S. Geological Survey |
| USPHS | U.S. Public Health Service |

# 1.0 Introduction

## 1.1 Site Location

The Rulison Site is located in Section 25, Township 7 South, Range 95 West (6th Principal Meridian), Garfield County, Colorado, approximately 19 kilometers (km) (12 miles [mi]) southwest of Rifle, Colorado, and approximately 65 km (40 mi) northeast of Grand Junction, Colorado (Figure 1-1). The site can be accessed by traveling west on I-70 from Rifle, 22 km (14 mi) to the town of Parachute. Then proceeding south from Parachute, up the Battlement Creek Valley, approximately 13 km (8 mi) to surface ground zero (SGZ).

## 1.2 Objective

The objective of this preliminary site characterization report is to summarize the information gathered during the recent literature search and interview process. The documents that have been reviewed were gathered from the U.S. Department of Energy (DOE) resource centers and Central Files and ranged from field personnel daily logs to issued reports dated from the projects' origination to current data from field activities. The personnel who were interviewed included local residents and retired or current DOE and contractor employees who were present during the testing. Information gathered from these sources has been evaluated to provide a clear picture of the site, including physical characteristics, testing, cleanups, and potential contaminated areas. This preliminary site characterization report will be used to identify potential DOE liabilities, formulate baseline risk assessments, and develop field work plans which will be implemented during the Phase II-Field Site Characterization process.

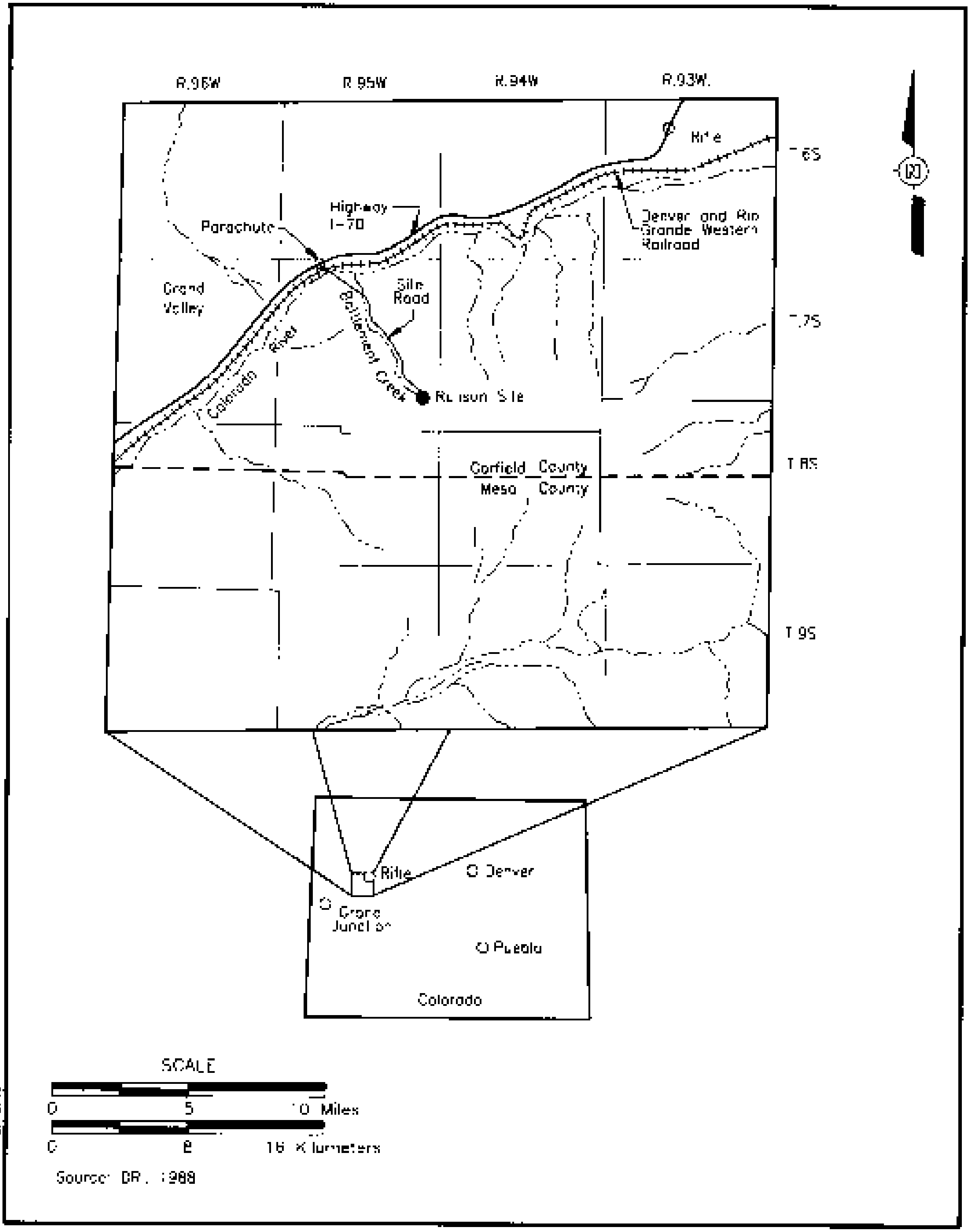



**Figure 1-1**
**Rulison Site Location Map, Garfield County, Colorado**

# 2.0 Rulison Site History

## 2.1 Overview

The Rulison Project was the second of three joint government/industry, gas-production stimulation experiments conducted under the Plowshare Program, a project designed to develop peaceful uses of nuclear explosions. Project Rulison was a joint project between the U.S. Atomic Energy Commission (AEC) (currently known as the U.S. Department of Energy) and the Austral Oil Company. Under this program, the feasibility of stimulating natural gas production in low-permeability, gas-producing geologic formations with underground nuclear explosions was studied. On September 10, 1969, a 43-kiloton nuclear device was detonated at a depth of 2,568 meters (m) (8,426 feet [ft]) below the ground surface. Redrilling of the former pre-shot exploratory hole which was then converted into the reentry well (R-EX), designed for conducting production testing of the stimulated zone, was located 300 ft southeast of the emplacement well (R-E) and was completed in October 1970.

Production testing and data evaluation took place over a seven month period between October 1970 and April 1971, and included four separate flow periods. Approximately 12.0 million stock cubic m (455 million stock cubic ft) of natural gas were produced. The well was shut-in after the last test and left in a standby condition until a general cleanup was undertaken in 1972. Cleanup activities were conducted at the site from July 10 through July 25, 1972, to remove all extraneous materials and equipment not required for gas production. A final cleanup was conducted after the emplacement and testing wells were plugged in 1976. Neither the Austral Oil Company nor the U.S. Energy Research and Development Administration (ERDA) developed any plans to commercially produce the available natural gas. Accordingly, during the period of September 1, 1976, through October 12, 1976, the R-E and R-EX wells were plugged and abandoned, and the equipment that remained after the 1972 general cleanup was decontaminated as necessary and removed from the site (Eberline, 1977, p. 2). Some surface radiologic contamination resulted from decontamination of drilling equipment and fallout from the gas flaring (DRI, 1988, p. 3.6.18); however, except for the drilling effluent pond, all surface contamination was removed during site clean-up operations.

## 2.2 Facility Description

### 2.2.1 Known or Suspected Areas of Contamination

Based on the review of available documentation and field sampling activities, several known or suspected areas of subsurface contamination are present. These include the drilling effluent pond and the mudpits used during drilling operations. In addition, contamination may be present in natural gas or water produced from nearby gas wells. Each of these locations is discussed below.

#### 2.2.1.1 Drilling Effluent Pond

The effluent pond at the Rulison Site was used to store nonradioactive drilling mud during the boring of the emplacement hole for the nuclear device (Well R-E). The drilling fluids consisted of a bentonitic drilling mud with additives (such as diesel fuel and chrome lignosulfonate) to improve drilling characteristics. Most of the drilling mud was removed from the pond when the site was cleaned up and decommissioned in 1972; however, some residual fluid was left in the pond. In 1994 and 1995, three pond-sediment sampling events were conducted to evaluate the nature of this residual drilling fluid. The sampling indicated the presence of up to 7 percent, by weight, of diesel fuel as well as the presence of chromium. The diesel fuel contains total petroleum hydrocarbon compounds in addition to benzene, toluene, ethylbenzene, and xylene.

The DOE/Nevada Operations Office (DOE/NV) Nevada Environmental Restoration Project has undertaken a voluntary removal action to clean up the contaminated pond sediments, following which the pond will be restored to support an aquatic ecosystem. It is expected that pond restoration will be completed during the summer of 1996.

#### 2.2.1.2 Mudpits

A pre-shot bioenvironmental survey of the area around the Rulison Site was made early in 1969 by Battelle Memorial Institute (BMI) (AEC, 1973b, p. 50). The objectives were to characterize the ecological setting of the project site and to identify any potential adverse consequences, as a result of prior project activities, which might require preventive or remedial action.

The only significant bioenvironmental hazard identified during the pre-shot survey was the possible danger of pollution of Battlement Creek by drilling wastes or other contaminants resulting from drilling operations. Sump ponds used in drilling the R-EX and the R-E wells were located very close to the channel of the East Fork of Battlement Creek (Figure 2-1).

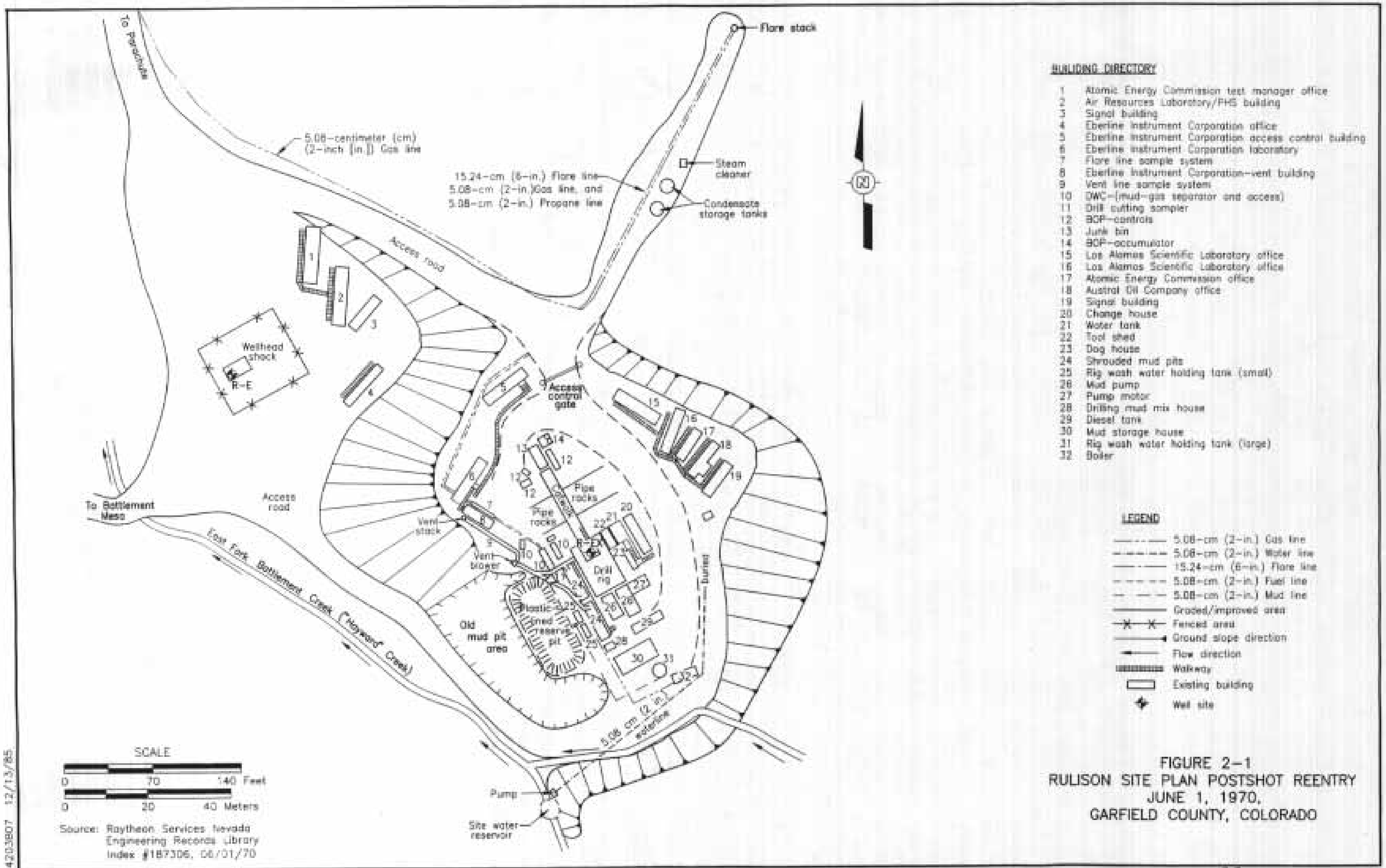



FIGURE 2–1
RULISON SITE PLAN POSTSHOT REENTRY
JUNE 1, 1970,
GARFIELD COUNTY, COLORADO

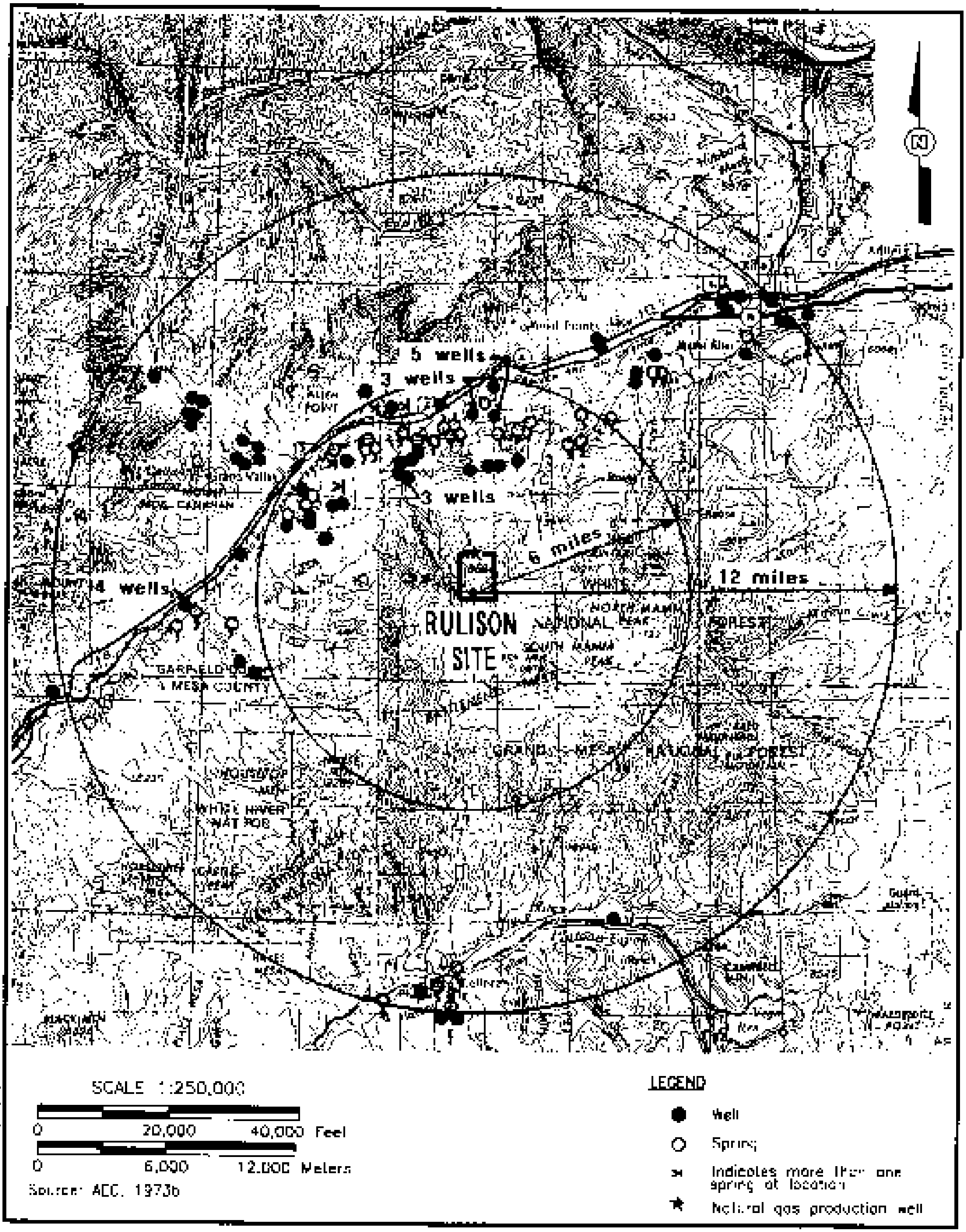
A sump failure occurred during the drilling of the pre-shot exploratory hole (Well R-EX) in December 1967, which killed fish in the stream below the site and temporarily contaminated the domestic and stock water supplies of some of the Morrisania Mesa residents. The pre-shot bioenvironmental survey report recommended that adequate precautions be taken to prevent any further pollution of the Battlement Creek watershed during the final site preparation and detonation phase. A water sampling plan for evaluating the effectiveness of these precautionary measures was also outlined. Results of a pre- and postshot stream water sampling program carried out by the Colorado Department of Health (Appendices B, C, and D) indicated these precautions were successful. In addition, springs and wells in the vicinity of the Rulison Site were sampled by the U.S. Geological Survey (USGS) (Figure 2-2) both before and after the detonation. While an increase in flow from springs and flow in Battlement Creek was observed immediately following the shot, the flow in all cases returned to pre-shot levels within a short time.

During a visit to the site between June 15 and 17, 1970, BMI and AEC personnel reported that oil and water had been running into Battlement Creek from one of the old mud sumps located next to the creek (Mason, 1970). Close examination of this area showed that most of the water was from snow buried at the time the mudpit was constructed. Two samples of water coming from the old sump were taken and submitted to the U.S. Public Health Service (USPHS) for analysis, and both samples contained elevated levels of hydrocarbons. Although the levels of hydrocarbons were an order of magnitude higher than the USPHS Drinking Water Standards, this was not considered a problem at the time because of the dilution factor when the stream flowed into Battlement Creek.

Prior to the detonation, the sumps remaining from drilling of the emplacement hole, with the exception of the drilling effluent pond previously mentioned, were cleaned and filled with earth (AEC, 1973b, p. 50). During site decommissioning in 1976, all mudpits and other excavations were backfilled and both the upper and lower drilling pads were leveled and dressed (ERDA, 1977, p. 5).

#### *2.2.1.3 Natural Gas Wells*

Two natural gas production wells are located near the Rulison Site (Section 5.5.4). These wells are the Federal 28-95, located 4.3 km (2.7 mi) west and the Federal 14-95 located 4.3 km (2.7 mi) to the northwest of SGZ (Figure 2-2). These wells have changed possession several




4201A01 08/21/96

**Figure 2-2**
**Water Wells and Springs in the Vicinity of Project Rulison, Garfield and Mesa Counties, Colorado**

times since they were initially completed and have produced gas and minor amounts of water on an intermittent basis.  Both wells are currently shut-in because of low gas prices.

If any contamination enters the gas horizons, it would be expected to appear in the water or gas from these wells.  Since natural gas production from the Mesaverde Group is primarily from fractures, and the dominant fracture strike in the Rulison area is northwest-southeast, then contaminated natural gas or groundwater may be drawn by well production activity or by natural gradients toward these production wells, principally the Federal 14-95.  The highly anisotropic nature of the fracturing in the Mesaverde limits the potential for contaminated gas or groundwater production from wells that are or may be located in other directions from the Rulison Site.

Tritium is the contaminant most likely to be found in the natural gas or groundwater from the production wells because it is the most mobile of the radionuclides produced by the nuclear device.  The amount of tritium and other radionuclides produced by the explosion of the nuclear device is still classified information.

### *2.2.2 Previous Cleanup*

The decontamination effort at the Rulison Site was divided into two operations:  the general (initial) cleanup in 1972 and the final cleanup in 1976 (Eberline, 1977).  The total amount of tritium shipped from the Rulison Site as a result of both cleanup operations was estimated to be 0.781 curies (Ci).  No other radionuclides were reported in either cleanup, and no burial of radioactive solids occurred at the Rulison Site.  All on-site equipment was removed during the final cleanup with the exceptions of the R-E wellhead, a power pole with a fuse box, a telephone line, a concrete slab, and a small monument over the emplacement well stating drilling restrictions at the site (DRI, 1988, p. 3.6.5).

#### *2.2.2.1 Initial Cleanup Effort (July 10 through 25, 1972)*

Prior to the initial cleanup, the site was in standby condition with all surface equipment intact (Figure 2-3).  During this cleanup, all items of equipment and material that were not required for production testing were removed from the site.  Following the cleanup, soil, water, and vegetation sampling was conducted which is further discussed in Section 2.2.2.4.2.  A release log was maintained to describe each item and to record its radiological condition if it were to be released for unrestricted use.  There were 504 uncontaminated and decontaminated items logged and released, and those items that could not be economically decontaminated were included in

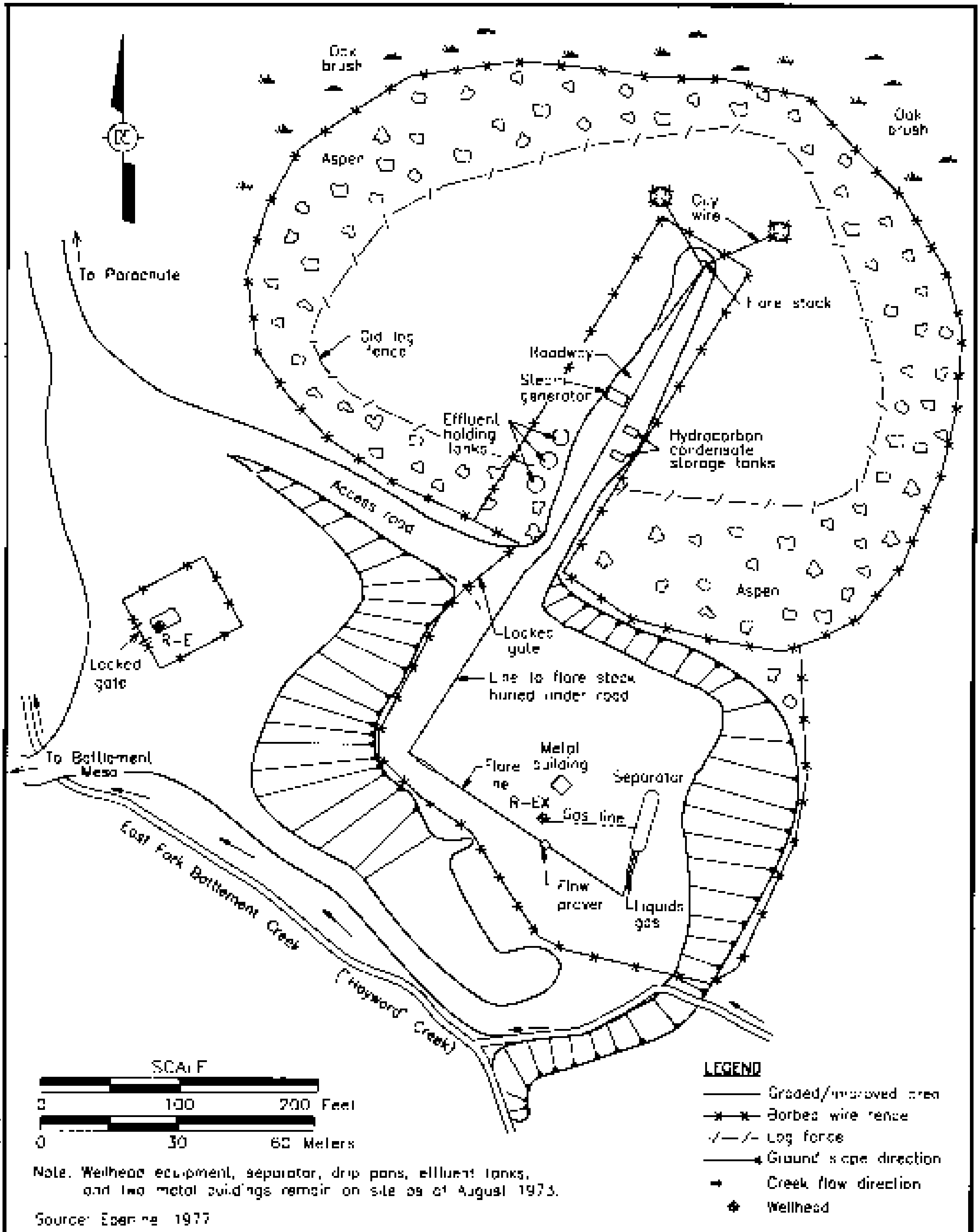



**Figure 2-3**
**Rulison Site at Completion of Flare Testing, April 1971, Garfield County, Colorado**

the material shipped to Beatty, Nevada, for burial at the Nuclear Engineering Company facility, now known as U.S. Ecology. Decontamination operations were conducted in a large, sheet-metal pan using saturated steam and Steamzall®. The guideline limits for release of material were 1,000 counts per minute beta-gamma removable from any 100 square centimeters ($cm^2$), and a total of 0.4 millirad (mrad)/hour at 1 centimeter (cm) from the surface, through not more than a 7 milligram (mg)/$cm^2$ absorber. In practice, the actual removable contamination for released items in each case was not above background (0.02 mrad/hour) of the site area. Items of equipment and materials found to be clean, or that had been decontaminated, were removed to the Austral storage yard at Rifle, Colorado. Items in this category included the flare stack and the sections of 2-inch (in.) and 6-in. pipe that ran between the north gate and the separator.

On July 20, 1972, 11.36 cubic meters ($m^3$) (3,000 gallons) of decontamination fluid containing 0.69 Ci of tritium were shipped by tank truck to the waste facility at Beatty, Nevada. On July 22, 1972, thirty-two packages of contaminated solid waste and six 55-gallon steel drums of solidified liquid waste, both containing an estimated 0.073 Ci of tritium, were also shipped.

Upon completion of the 1972 cleanup, the following equipment was left on site (Figure 2-4):

- The high-pressure wellhead and pressure measuring equipment and instruments at the R-E well remained. The wellhead was protected by a metal shed surrounded by a 6-ft high cyclone and barbed wire fence with a locked gate.

- The wellhead valves (Christmas tree), separator, and connecting piping at the R-EX well were left configured for future gas production. One drip pan was in place around the wellhead, and another was under the separator.

- A tool and instrument shed in the vicinity of the R-EX well was left.

- A large decontamination pan (old pipe rack pan) was left.

- Three 210-barrel water holding tanks and two 500-gallon hydrocarbon distillate tanks, all internally contaminated stayed. The water tanks contained a few inches of contaminated sludge solidified with bentonite. The hydrocarbon tanks were drained completely dry.

- Telephone facilities and electric power on boards and poles remained.

- The area was fenced with barbed wire and posted.

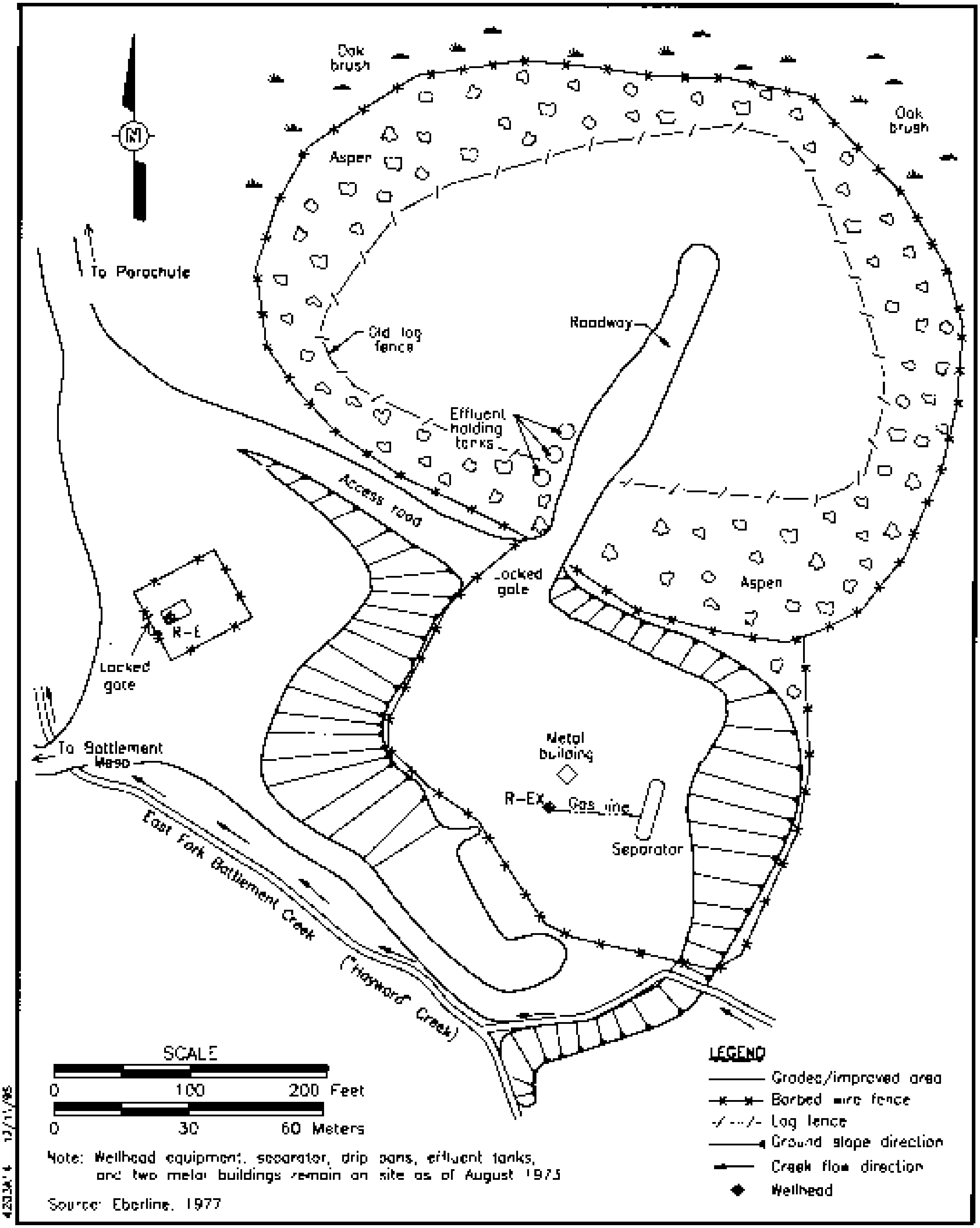



**Figure 2-4**
**Rulison Site at Completion of the General Site Cleanup Effort, July 1972, Garfield County, Colorado**

Some of the above items were, or were presumed to be, contaminated internally. Items contaminated internally with tritium were appropriately labeled. None of these items was externally contaminated.

#### *2.2.2.2 Final Cleanup Effort (September 1 through October 12, 1976)*

The R-E and R-EX wells were plugged and abandoned during the final cleanup. Concurrently, the surface equipment (itemized in the general cleanup) was dismantled, decontaminated, documented in the release log, and removed from the site. The primary method of decontamination was by cleaning in a large, sheet-metal pan using saturated steam and Steamzall® or detergent. The only contaminant of concern was tritium. The guideline limit for release to unrestricted use was 5,000 disintegrations per minute (dpm)/100 $cm^2$ total activity and 1,000 dpm/100 $cm^2$ removable activity (ERDA, 1976). The release log listed 126 items for unrestricted use. No item was above the ambient area background when surveyed at approximately 1 cm with an HP-210 beta-gamma probe having less than a 7 mg/$cm^2$ absorber. Removable contamination as determined by swipe sampling was in no case more than a small fraction of the guideline (ERDA, 1977, p. 3).

On October 4, 1976, 0.166 Ci of tritium in waste water and drilling mud were pumped into the Mesaverde formation of the R-E well at a depth of approximately 1,615 to 1,768 m (5,300 to 5,800 ft) for disposal. The potable aquifers above this depth were cemented off during well drilling and casing installation.

Items having inaccessible surfaces (i.e., pipes) were initially flushed with steam and cleaning solutions until flush liquids were below detection sensitivity for tritium. Following a drying period, an appropriate amount (not to exceed 1 liter) of distilled water was placed in contact with the portion of the surface to be tested. A one cubic centimeter ($cm^3$) aliquot of this water was collected and analyzed for tritium. If the concentration exceeded 5,000 dpm/milliliter (mL), the item was considered unfit for unconditional release. None of the decontaminated items exceeded this limit. The R-E wellhead equipment and metal shed were not contaminated and were released after the survey.

The R-EX wellhead, separator, and connecting pipeline were internally contaminated. The wellhead was disassembled so that the internal surfaces were accessible for steam cleaning. The pipeline was cut into manageable lengths which were cleaned internally with a steam lance. The separator was moved onto the decontamination pan where its pressure tanks were cut open with an acetylene torch so that internal surfaces were accessible for steam cleaning. The wellhead drip pan, the separator drip pan, and the tool shed were not contaminated.

The three water holding tanks were moved onto the decontamination pan. The heater of each was removed for decontamination and to obtain a large access port to the tank. Thirty 55-gallon steel drums of solidified sludge were mucked from the bottom of these tanks through the heater openings. The heaters and internal surfaces of the tanks were decontaminated with de-tar solvent, saturated steam, Steamzall®, and detergent. The two hydrocarbon tanks had been transferred to Project Rio Blanco, and they were not included in the Rulison cleanup.

On October 8, 1976, as a result of the final cleanup, sixty-eight 55-gallon steel drums of contaminated soil and other solid waste containing a total of 0.018 Ci of tritium were shipped to Beatty, Nevada, for burial at the Nuclear Engineering Company facility. This waste originated from mucking the tanks, soil removal of known spill areas, and from decontamination activities associated with drillback and flaring operations. The total amount of tritium shipped for burial from the Rulison Site as a result of both the general and final cleanup operations was estimated to be 0.781 Ci. No other radionuclide was involved in either cleanup.

#### *2.2.2.3 Plugging and Abandonment Operations*

The R-E and R-EX wells were plugged concurrently with the final cleanup work. The R-EX well was plugged first and the R-E well second. Both procedures required the use of a work-over drilling rig with routine support activities. Radiological monitoring support was provided to assure safety of personnel and containment of any radioactive material coming from downhole.

##### *2.2.2.3.1 R-EX Well*

This well was originally the pre-shot exploratory hole used to perform pre-shot gas-production tests, conducting geological and hydrological studies, and other studies for technical and safety confirmation. This well was also used for reentry and production testing (ERDA, 1976, p. 5). It was plugged pursuant to the plan (ERDA, 1976) (Figure 2-5). An unexpected return to the surface of 300 barrels of drilling mud and water contaminated with low levels of tritium was a potential source of contamination. However, this return was totally contained in tanks and was later disposed of, along with other liquids, as previously noted.

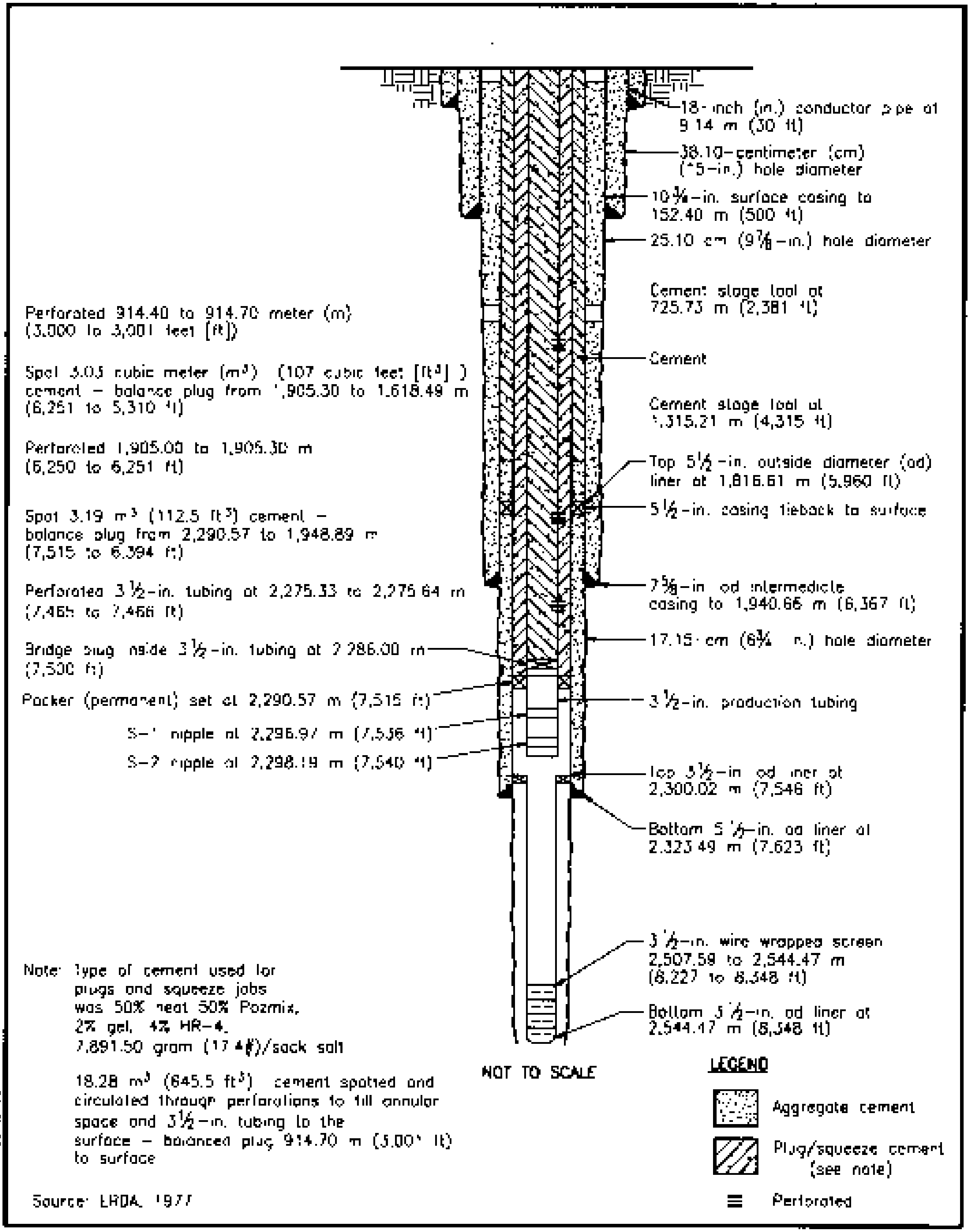



**Figure 2-5**

**Project Rulison Exploratory - Reentry Well (R-EX) "As Built" Plugging Condition, July 1972, Garfield County, Colorado**

### *2.2.2.3.2 R-E Well*

The R-E Well contained stemming gravel and the nuclear device emplacement and detonation cable. There were several physical problems related to the washing out of stemming material and the removal of the cable (Figure 2-6). The original plan (ERDA, 1976) was modified by both regulatory decisions and practical demands. During the destemming operation, the return line of the wash-down fluid recirculating system was continuously monitored for gamma radiation with a 2-in. x 2-in. sodium iodide detector equipped with an alarm and recorder. A sample of the return fluid was collected at least every 36.58 m (120 ft) of depth and analyzed for tritium by liquid scintillation. Several samples of returned stemming material were analyzed for radioactive particulate contamination using pulse-height analysis. No radioactive contaminant above natural background was detected, and the well was satisfactorily plugged without a radiological incident.

### *2.2.2.4 Environmental Sampling and Survey Programs*

Three environmental sampling programs were conducted. The first program was conducted after completion of production testing in 1971 and consisted of collecting soil samples from around the flare stack in a radial pattern. The second program was conducted in conjunction with the 1972 general cleanup. It included soil, vegetation, and water on and around the R-EX area, including more samples around the flare stack. The third program was part of the final cleanup in 1976 which was involved with well plugging and abandonment. It included extensive soil sampling in areas of known or potential contamination based on the results of prior sampling and operating experience. This program also included sampling the creek above and below the site as well as spring water at the site.

The three sampling programs adequately delineated the extent of soil and water contamination in the site area after completion of plugging procedures on the R-E and R-EX wells. The only radioactive nuclide in the environment of the site, other than those naturally occurring or resulting from worldwide fallout, was tritium. The final survey of tritium concentration did not exceed the guideline limit of $3 \times 10^{-2}$ microCuries per milliliter (µCi/mL) ($3 \times 10^{4}$ picoCuries per milliliter [pCi/mL]) of soil moisture (ERDA, 1976).

After the final cleanup was completed, a survey of the site was made at 1-cm distance on a 15.24-m (50-ft grid) by 3.05-m ([10-ft] grid over areas of known spills) using an HP-210 beta-gamma probe having less than a 7 mg/cm$^2$ absorber. No reading was obtained greater than the ambient background (0.02 mrad/hour) of the area.

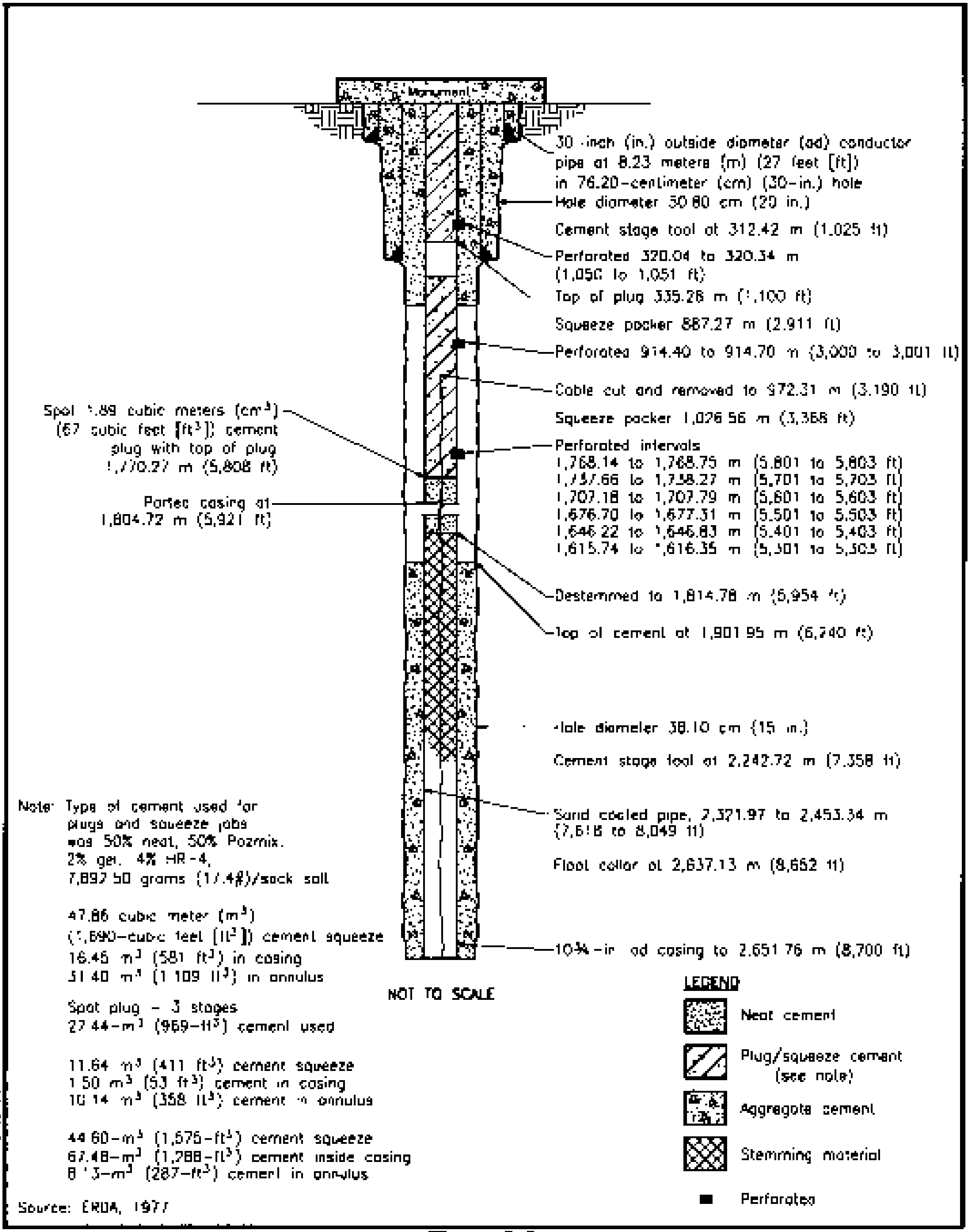



**Figure 2-6**

**Project Rulison, Emplacement Hole (R-E) "As Built" Plugging Condition, July 1972, Garfield County, Colorado**

#### *2.2.2.4.1 First Sampling Program*

This first sampling program was conducted in April 1971 when the site was placed on standby after completion of production tests. A total of 133 soil samples was taken at 70 sampling points around the flare stack. All samples were well below the guidelines for tritium in soil moisture. Figures 2-7 and 2-8 show the locations of each sampling point by azimuth and distance from the flare stack and the tritium concentration in soil moisture per milliliter and per gram at the indicated sample depths. Table 2-1 provides the same information in tabular form.

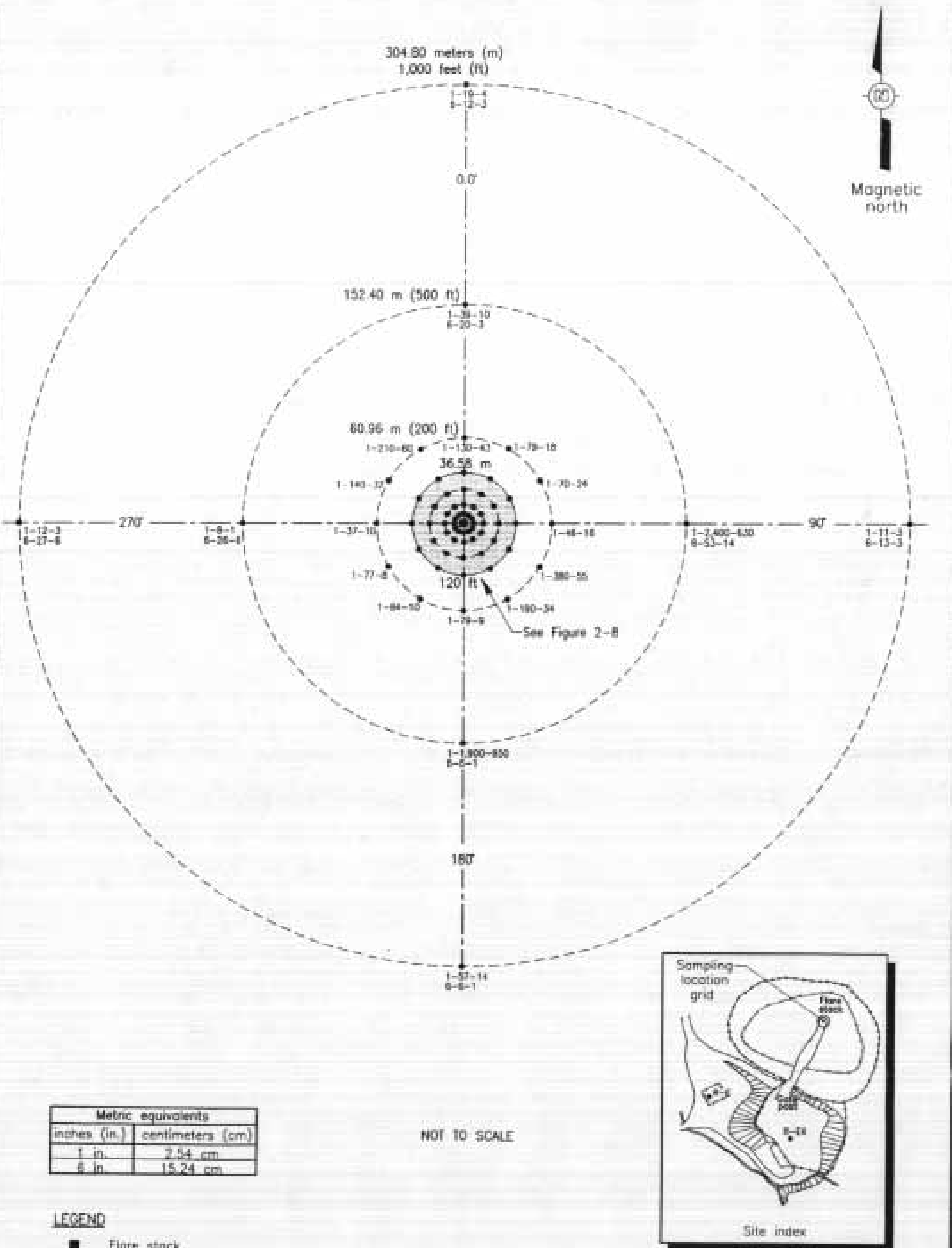
#### *2.2.2.4.2 Second Sampling Program*

This program was part of the general cleanup conducted in July 1972. It included the sampling of soil, vegetation and water.

***Soil Sampling***

A square grid of soil sampling points was laid out on magnetic cardinal headings using the site entrance gate post as the zero and primary reference point. Ten- and twenty-foot squares were used, depending on the area use history and on the probability of soil contamination. Squares were sometimes distorted to sample points of special interest such as storage tanks, pipeline runs, the separator, and drip pan areas or to avoid obstructions such as cement pads. While the flare stack was located on the square grid system, the area around it was sampled on a radial grid referenced to the stack. This radial grid was used because contaminated fallout originated from the stack as a center and because a radial sampling grid was used previously during postflare operations, making a comparison more meaningful. A total of 192 sampling points was located (see Figures 2-9 and 2-10). Most of these points were sampled at 2.54-cm and 30.48-cm (1- and 12-in.) depths. Fourteen points were sampled at 2.54-cm, 30.48-cm, 60.96-cm, and 121.92-cm (1-, 12-, 24-, and 48-in.) depths. Two points were sampled at multiple depths to 2.44 m and 3.35 m (96 and 132 in.), respectively, and a few were sampled at other selected depths. A total of 426 soil samples was collected for tritium analysis.

The depth increment for soil samples taken was 2.54 cm (1 in.) (i.e., the 2.54-cm sample was from the surface to 2.54 cm, and the 30.48-cm [12-in.] sample was from 27.94 to 30.48 cm [11 to 12 in.], etc.). Soil samples were collected in standard 454-gram (16-ounce) cottage cheese containers that held 61 to 68.6 $cm^3$ (24 to 27 cubic in.) of sample. At undisturbed and uncompacted sampling locations, an earth auger was used to bore holes up to 1.22-m (4-ft) deep. For sampling at greater depths, and at disturbed and compacted locations, a powered backhoe was used to dig required holes. After these holes were cleaned out, samples were taken from




| Metric equivalents | |
|---|---|
| inches (in.) | centimeters (cm) |
| 1 in. | 2.54 cm |
| 6 in. | 15.24 cm |

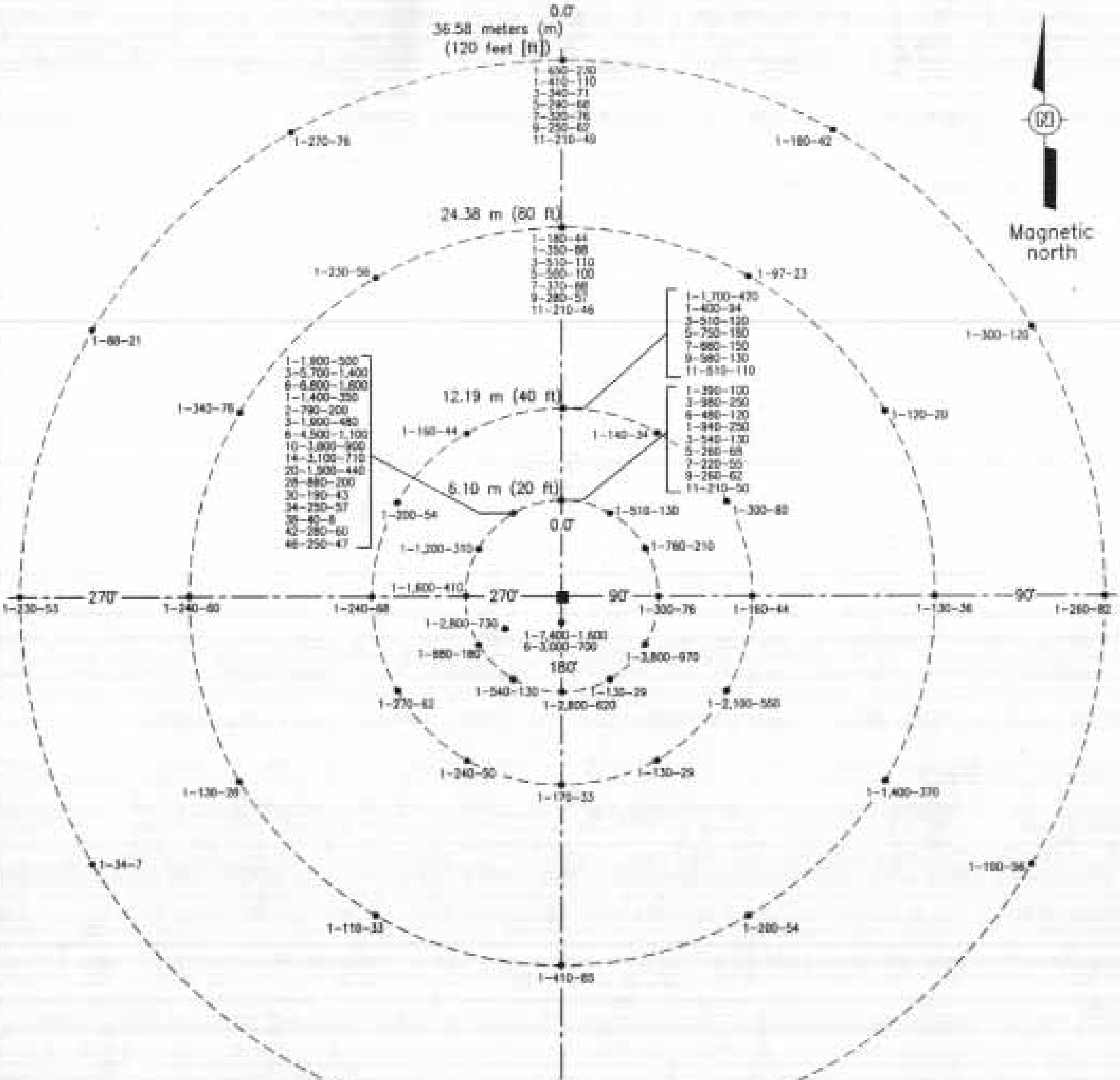
LEGEND

- ■ Flare stack
- ND Nondetectable
- $^3H$ Tritium
- • Sample location

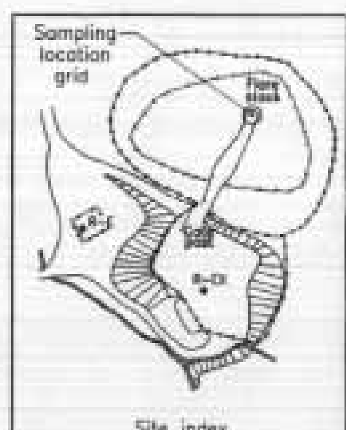
1-11-48
- Picocurie/gram $^3H$
- Picocurie/milliliter $^3H$ in soil moisture
- Depth in inches

Source: Rulison Radiation Contamination Clearance Report, 1977

FIGURE 2-7
PROJECT RULISON SOIL SAMPLE LOCATIONS TAKEN AFTER COMPLETION OF PRODUCTION TESTING, APRIL 1971, GARFIELD COUNTY, COLORADO




| Metric equivalents | |
|---|---|
| inches (in.) | centimeters (cm) |
| 1 in. | 2.54 cm |
| 2 in. | 5.08 cm |
| 3 in. | 7.62 cm |
| 5 in. | 12.70 cm |
| 6 in. | 15.24 cm |
| 7 in. | 17.78 cm |
| 9 in. | 22.86 cm |
| 10 in. | 25.40 cm |
| 11 in. | 27.94 cm |
| 14 in. | 35.56 cm |
| 20 in. | 50.80 cm |
| 28 in. | 71.12 cm |
| 30 in. | 76.20 cm |
| 34 in. | 86.36 cm |
| 38 in. | 96.52 cm |
| 42 in. | 106.68 cm |
| 46 in. | 116.84 cm |




LEGEND

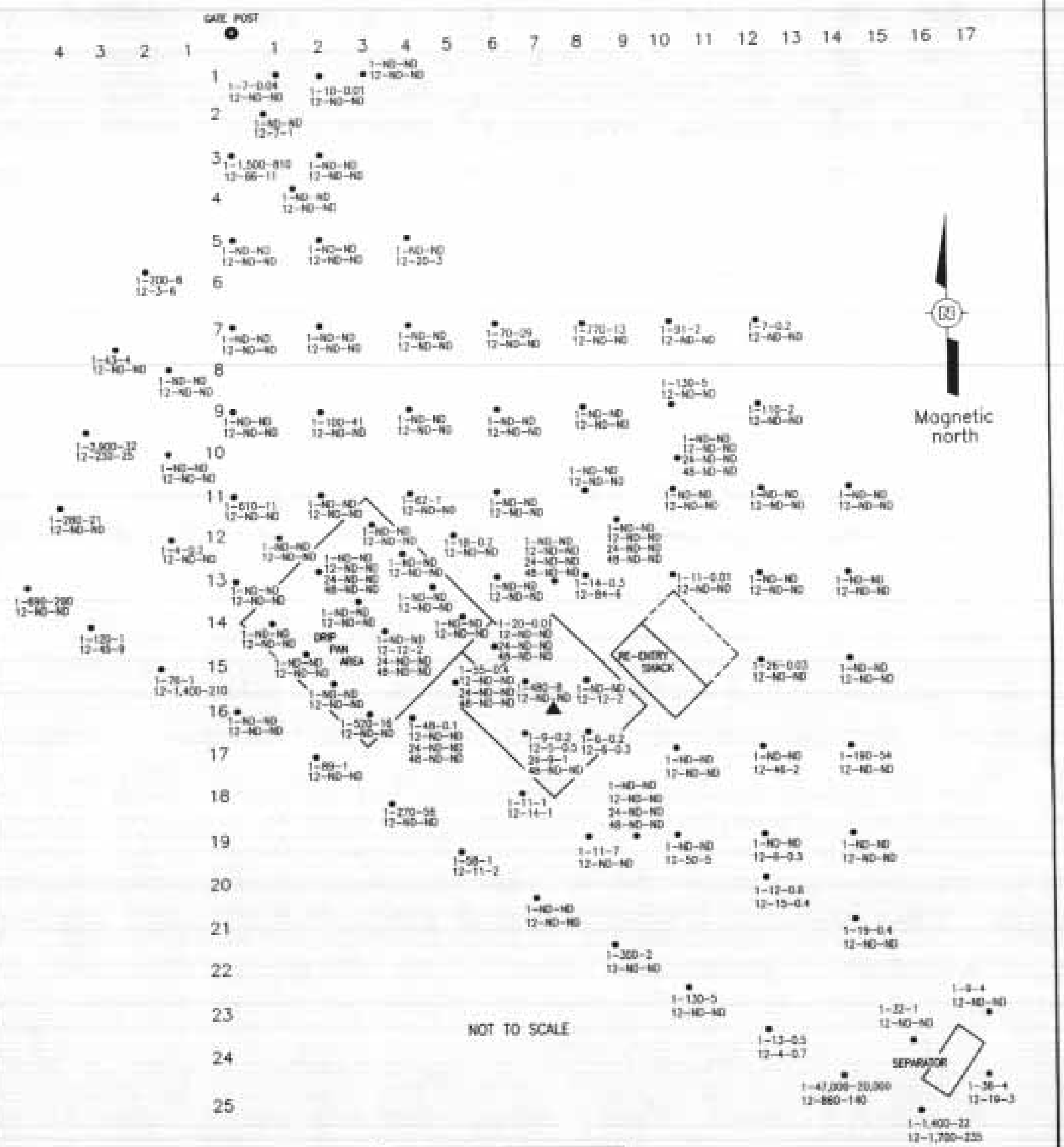
- ■ Flare stack
- ND Nondetectable
- $^3H$ Tritium
- • Sample location

1-11-48
- └ Picocurie/gram $^3H$
- └ Picocurie/milliliter $^3H$ in soil moisture
- └ Depth in inches

FIGURE 2-8
PROJECT RULISON SOIL SAMPLE LOCATIONS TAKEN AFTER COMPLETION OF PRODUCTION TESTING, APRIL 1971, GARFIELD COUNTY, COLORADO

Source: Rulison Radiation Contamination Clearance Report, 1977

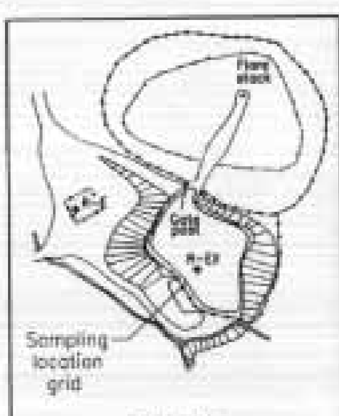
4203B04 10/13/95




**WELLHEAD LOCATION**

107° 56' 53" W longitude
39° 24' 21" N latitude

| Metric equivalents | |
|---|---|
| inches (in.) | centimeters (cm) |
| 1 in. | 2.54 cm |
| 12 in. | 30.48 cm |
| 24 in. | 60.96 cm |
| 48 in. | 121.92 cm |



Site index

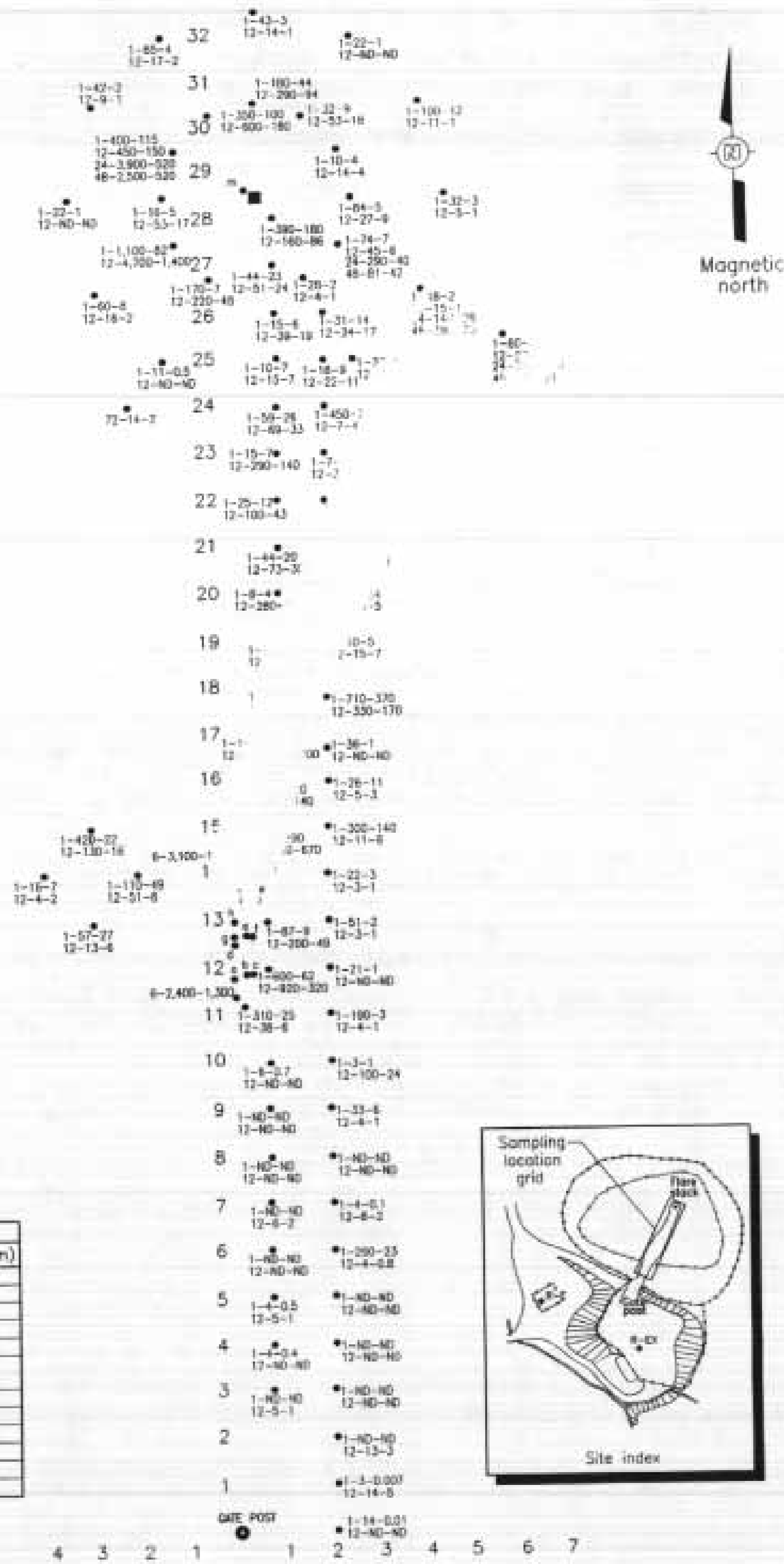
**LEGEND**

— Building
▲ Re-entry wellhead
ND Nondetectable
$^3H$ Tritium
• Sample location

1-11-48
└ Picocurie/gram $^3H$
└ Picocurie/milliliter $^3H$ in soil moisture
└ Depth in inches

Note: Grid represents 3.05-meter (10-foot) intervals
Source: Rulison Radiation Contamination Clearance Report, 1977

FIGURE 2-9
PROJECT RULISON SOIL SAMPLE LOCATIONS TAKEN AT TIME OF SITE CLEANUP, JULY 1972, GARFIELD COUNTY, COLORADO




a 24-850-510
60-7,800-4,400

b 1-11-2
12-33-7

c 1-110-24
12-93-22

d 1-300-34
12-12-15

e 1-44-10
12-ND-ND

f 1-21-8
12-11-5

g 6-150-81

h 12-73-41
60-51-24

i 1-10,000-1,400
12-20,000-5,600
24-21,000-5,800

j 1-2,700-14
12-5,100-1,600
24-4,700-1,600

k 1-4,700-1,400
12-3,300-1,800

l 1-8,600-1,500
12-29,000-6,500
24-35,000-11,000
36-34,000-19,000
48-27,000-7,300
60-28,000-14,000
72-18,000-9,600
96-8,000-9,800
108-9,700-2,300
120-5,600-1,400
132-3,300-600

m 1-230-100
12-780-400
24-3,300-1,900
36-3,800-820
48-5,700-1,300
60-6,400-3,200
72-4,400-2,500
84-2,900-1,400
96-2,700-1,300

| Metric equivalents | |
|---|---|
| inches (in.) | centimeters (cm) |
| 1 in. | 2.54 cm |
| 6 in. | 15.24 cm |
| 12 in. | 30.48 cm |
| 24 in. | 60.96 cm |
| 36 in. | 91.44 cm |
| 48 in. | 121.92 cm |
| 60 in. | 152.40 cm |
| 72 in. | 182.88 cm |
| 84 in. | 213.36 cm |
| 96 in. | 243.84 cm |
| 108 in. | 274.32 cm |
| 120 in. | 304.80 cm |
| 132 in. | 335.28 cm |

LEGEND

- ■ Flare Stack
- ND Nondetectable
- $^3H$ Tritium
- • Sample location

1-11-48
└ Picocurie/gram $^3H$
└ Picocurie/milliliter $^3H$ in soil moisture
└ Depth in inches

Note: Grid represents 3.05-meter (10-foot) intervals

Source: Rulison Radiation Contamination Clearance Report, 1977

FIGURE 2-10
PROJECT RULISON SOIL SAMPLE LOCATIONS TAKEN AT TIME OF SITE CLEANUP, JULY 1972, GARFIELD COUNTY, COLORADO

## Table 2-1
## Tritium in Rulison Soil Moisture Postproduction Test - April 23, 1971
(Page 1 of 4)

| Grid Coordinates[a] degrees, meters (feet) | Sampling Depth[b] centimeters (inches) | pCi/ml[c] | pCi/g[d] (soil) |
|---|---|---|---|
| 000°, 6.10 (20) | 2.54 (1) | 390 | 100 |
| 000°, 6.10 (20) | 7.62 (3) | 980 | 250 |
| 000°, 6.10 (20) | 15.24 (6) | 480 | 120 |
| 000°, 6.10 (20) | 0 to 5.08 (0 to 2) | 940 | 250 |
| 000°, 6.10 (20) | 5.08 to 10.16 (2 to 4) | 540 | 130 |
| 000°, 6.10 (20) | 10.16 to 15.24 (4 to 6) | 260 | 68 |
| 000°, 6.10 (20) | 15.24 to 20.32 (6 to 8) | 220 | 55 |
| 000°, 6.10 (20) | 20.32 to 25.40 (8 to 10) | 260 | 62 |
| 000°, 6.10 (20) | 25.40 to 30.48 (10 to 12) | 210 | 50 |
| 000°, 12.19 (40) | 2.54 (1) | 1,700 | 420 |
| 000°, 12.19 (40) | 0 to 5.08 (0 to 2) | 400 | 94 |
| 000°, 12.19 (40) | 5.08 to 10.16 (2 to 4) | 510 | 120 |
| 000°, 12.19 (40) | 10.16 to 15.24 (4 to 6) | 750 | 180 |
| 000°, 12.19 (40) | 15.24 to 20.32 (6 to 8) | 660 | 150 |
| 000°, 12.19 (40) | 20.32 to 25.40 (8 to 10) | 580 | 130 |
| 000°, 12.19 (40) | 25.40 to 30.48 (10 to 12) | 510 | 110 |
| 000°, 24.38 (80) | 2.54 (1) | 180 | 44 |
| 000°, 24.38 (80) | 0 to 5.08 (0 to 2) | 350 | 88 |
| 000°, 24.38 (80) | 5.08 to 10.16 (2 to 4) | 510 | 110 |
| 000°, 24.38 (80) | 10.16 to 15.24 (4 to 6) | 500 | 100 |
| 000°, 24.38 (80) | 15.24 to 20.32 (6 to 8) | 370 | 88 |
| 000°, 24.38 (80) | 20.32 to 25.40 (8 to 10) | 280 | 57 |
| 000°, 24.38 (80) | 25.40 to 30.48 (10 to 12) | 210 | 46 |
| 000°, 36.58 (120) | 2.54 (1) | 650 | 230 |
| 000°, 36.58 (120) | 0 to 5.08 (0 to 2) | 410 | 110 |
| 000°, 36.58 (120) | 5.08 to 10.16 (2 to 4) | 340 | 71 |
| 000°, 36.58 (120) | 10.16 to 15.24 (4 to 6) | 290 | 68 |
| 000°, 36.58 (120) | 15.24 to 20.32 (6 to 8) | 320 | 76 |
| 000°, 36.58 (120) | 20.32 to 25.40 (8 to 10) | 250 | 62 |
| 000°, 36.58 (120) | 25.40 to 30.48 (10 to 12) | 210 | 49 |
| 000°, 60.96 (200) | 2.54 (1) | 130 | 43 |
| 000°, 152.40 (500) | 2.54 (1) | 39 | 9.8 |
| 000°, 152.40 (500) | 15.24 (6) | 20 | 3.4 |
| 000°, 304.80 (1,000) | 2.54 (1) | 19 | 4.1 |
| 000°, 304.80 (1,000) | 15.24 (6) | 12 | 2.7 |
| 030°, 6.10 (20) | 2.54 (1) | 510 | 130 |
| 030°, 12.19 (40) | 2.54 (1) | 140 | 34 |
| 030°, 60.96 (200) | 2.54 (1) | 79 | 18 |
| 030°, 24.38 (80) | 2.54 (1) | 97 | 23 |

Refer to footnotes at end of table.

**Table 2-1**
**Tritium in Rulison Soil Moisture Postproduction Test - April 23, 1971**
(Page 2 of 4)

| Grid Coordinates[a] degrees, meters (feet) | Sampling Depth[b] centimeters (inches) | pCi/ml[c] | pCi/g[d] (soil) |
|---|---|---|---|
| 030°, 36.58 (120) | 2.54 (1) | 180 | 42 |
| 060°, 6.10 (20) | 2.54 (1) | 760 | 210 |
| 060°, 24.38 (80) | 2.54 (1) | 120 | 20 |
| 060°, 36.58 (120) | 2.54 (1) | 300 | 120 |
| 060°, 60.96 (200) | 2.54 (1) | 70 | 24 |
| 090°, 6.10 (20) | 2.54 (1) | 300 | 76 |
| 090°, 12.19 (40) | 2.54 (1) | 160 | 44 |
| 090°, 24.38 (80) | 2.54 (1) | 130 | 36 |
| 090°, 36.58 (120) | 2.54 (1) | 260 | 82 |
| 090°, 60.96 (200) | 2.54 (1) | 46 | 16 |
| 090°, 152.40 (500) | 2.54 (1) | 2,400 | 630 |
| 090°, 152.40 (500) | 15.24 (6) | 53 | 14 |
| 090°, 304.80 (1,000) | 2.54 (1) | 11 | 3.2 |
| 090°, 304.80 (1,000) | 15.24 (6) | 13 | 3.3 |
| 120°, 6.10 (20) | 2.54 (1) | 3,800 | 970 |
| 120°, 12.19 (40) | 2.54 (1) | 2,100 | 550 |
| 120°, 24.38 (80) | 2.54 (1) | 1,400 | 370 |
| 120°, 36.58 (120) | 2.54 (1) | 190 | 56 |
| 120°, 60.96 (200) | 2.54 (1) | 380 | 55 |
| 150°, 6.10 (20) | 2.54 (1) | 130 | 29 |
| 150°, 12.19 (40) | 2.54 (1) | 710 | 160 |
| 150°, 24.38 (80) | 2.54 (1) | 200 | 54 |
| 150°, 36.58 (120) | 0 to 2.54 (0 to 1) | 210 | 65 |
| 150°, 36.58 (120) | 2.54 to 5.08 (1 to 2) | 180 | 53 |
| 150°, 36.58 (120) | 5.08 to 10.16 (2 to 4) | 220 | 62 |
| 150°, 36.58 (120) | 10.16 to 20.32 (4 to 8) | 290 | 87 |
| 150°, 36.58 (120) | 20.32 to 30.48 (8 to 12) | 420 | 110 |
| 150°, 36.58 (120) | 30.48 to 40.64 (12 to 16) | 340 | 84 |
| 150°, 36.58 (120) | 40.64 to 50.80 (16 to 20) | 130 | 25 |
| 150°, 36.58 (120) | 50.80 to 60.96 (20 to 24) | 79 | 16 |
| 150°, 36.58 (120) | 60.96 to 71.12 (24 to 28) | 75 | 15 |
| 150°, 36.58 (120) | 71.12 to 81.28 (28 to 32) | 110 | 19 |
| 150°, 36.58 (120) | 81.28 to 91.44 (32 to 36) | 110 | 22 |
| 150°, 36.58 (120) | 91.44 to 101.60 (36 to 40) | 87 | 19 |
| 150°,36.58 (120) | 101.60 to 111.76 (40 to 44) | 62 | 14 |
| 150°, 36.58 (120) | 111.76 to 121.92 (44 to 48) | 59 | 13 |
| 150°, 60.96 (200) | 2.54 (1) | 190 | 34 |
| 180°, 1.52 (5) | 2.54 (1) | 7,400 | 1600 |
| 180°, 1.52 (5) | 15.24 (6) | 3,000 | 700 |

Refer to footnotes at end of table.

## Table 2-1
## Tritium in Rulison Soil Moisture Postproduction Test - April 23, 1971
(Page 3 of 4)

| Grid Coordinates[a] degrees, meters (feet) | Sampling Depth[b] centimeters (inches) | pCi/ml[c] | pCi/g[d] (soil) |
|---|---|---|---|
| 180°, 6.10 (20) | 2.54 (1) | 2,800 | 620 |
| 180°, 12.19 (40) | 2.54 (1) | 170 | 33 |
| 180°, 24.38 (80) | 2.54 (1) | 410 | 85 |
| 180°, 36.58 (120) | 2.54 (1) | 1,500 | 300 |
| 180°, 60.96 (200) | 2.54 (1) | 79 | 8.7 |
| 180°, 152.40 (500) | 2.54 (1) | 1,900 | 650 |
| 180°, 152.40 (500) | 15.24 (6) | 6 | 1.1 |
| 180°, 304.80 (1,000) | 2.54 (1) | 57 | 14 |
| 180°, 304.80 (1,000) | 15.24 (6) | 6 | 1.2 |
| 240°, 4.27 (14) | 2.54 (1) | 2,800 | 730 |
| 240°, 6.10 (20) | 2.54 (1) | 680 | 180 |
| 240°, 12.19 (40) | 2.54 (1) | 270 | 62 |
| 240°, 24.38 (80) | 2.54 (1) | 130 | 28 |
| 240°, 36.58 (120) | 2.54 (1) | 34 | 7 |
| 240°, 60.96 (200) | 2.54 (1) | 77 | 8.1 |
| 270°, 6.10 (20) | 2.54 (1) | 1,600 | 410 |
| 270°, 12.19 (40) | 2.54 (1) | 240 | 68 |
| 270°, 24.38 (80) | 2.54 (1) | 240 | 60 |
| 270°, 36.58 (120) | 2.54 (1) | 230 | 53 |
| 270°, 60.96 (200) | 2.54 (1) | 37 | 10 |
| 270°, 152.40 (500) | 2.54 (1) | 8 | 1.2 |
| 270°, 152.40 (500) | 15.24 (6) | 26 | 5.8 |
| 270°, 304.80 (1,000) | 2.54 (1) | 12 | 2.6 |
| 270°, 304.80 (1,000) | 15.24 (6) | 27 | 5.6 |
| 300°, 6.10 (20) | 2.54 (1) | 1,200 | 310 |
| 300°, 12.19 (40) | 2.54 (1) | 200 | 54 |
| 300°, 24.38 (80) | 2.54 (1) | 340 | 76 |
| 300°, 36.58 (120) | 2.54 (1) | 88 | 21 |
| 300°, 60.96 (200) | 2.54 (1) | 140 | 32 |
| 330°, 6.10 (20) | 2.54 (1) | 1,900 | 500 |
| 330°, 6.10 (20) | 7.62 (3) | 5,700 | 1400 |
| 330°, 6.10 (20) | 15.24 (6) | 6,800 | 1600 |
| 330°, 6.10 (20) | 2.54 (1) | 1,400 | 350 |
| 330°, 6.10 (20) | 5.08 (2) | 790 | 200 |
| 330°, 6.10 (20) | 5.08 to 10.16 (2 to 4) | 1,900 | 480 |
| 330°, 6.10 (20) | 10.16 to 20.32 (4 to 8) | 4,500 | 1100 |
| 330°, 6.10 (20) | 20.32 to 30.48 (8 to 12) | 3,800 | 900 |
| 330°, 6.10 (20) | 30.48 to 40.64 (12 to 16) | 3,100 | 710 |
| 330°, 6.10 (20) | 40.64 to 60.96 (16 to 24) | 1,900 | 440 |

Refer to footnotes at end of table.

**Table 2-1**
**Tritium in Rulison Soil Moisture Postproduction Test - April 23, 1971**
(Page 4 of 4)

| Grid Coordinates[a] degrees, meters (feet) | Sampling Depth[b] centimeters (inches) | pCi/ml[c] | pCi/g[d] (soil) |
|---|---|---|---|
| 330°, 6.10 (20) | 60.96 to 71.12 (24 to 28) | 860 | 200 |
| 330°, 6.10 (20) | 71.12 to 81.28 (28 to 32) | 190 | 43 |
| 330°, 6.10 (20) | 81.28 to 91.44 (32 to 36) | 250 | 57 |
| 330°, 6.10 (20) | 91.44 to 101.60 (36 to 40) | 40 | 8.1 |
| 330°, 6.10 (20) | 101.60 to 111.76 (40 to 44) | 280 | 60 |
| 330°, 6.10 (20) | 111.76 to 121.92 (44 to 48) | 250 | 47 |
| 330°, 12.19 (40) | 2.54 (1) | 160 | 44 |
| 330°, 24.38 (80) | 2.54 (1) | 230 | 56 |

Source: Eberline, 1977

[a]Radial coordinates are in degrees and meters (feet) referenced to flare stack.

[b]Sampling depth increments, when not otherwise indicated, are 2.54 cm (i.e., 2.54 cm is from 0 to 2.54 cm, 15.24 cm is from 12.70 to 15.24 cm, etc.) (1" [i.e., 1" is from 0 to 1", 6" is from 5" to 6", etc.]).

[c]Picocurie per milliliter

[d]Picocurie per gram

their side walls at measured depths. Access to sampling points under waste water storage tanks was attained by drilling horizontally under each tank from a trench at its perimeter. Access to sampling points under drip pans was attained by cutting through the pan or by moving it to one side.

Each sample was weighed wet, as collected, and was then dried in an electric oven for 15 hours at 180 degrees centigrade. After drying, the sample was again weighed. Wet and dry weights were recorded for each sample, and the percentages of moisture were calculated. Where possible, a 5-mL aliquot of soil moisture was distilled from each sample. The aliquots were analyzed by liquid scintillation for tritium concentration in pCi/mL. From this, the concentration in picoCuries per gram (pCi/g) was calculated. Results of these analyses are shown in Table 2-2.

Since no soil samples contained tritium above the concentration criterion of $3 \times 10^4$ pCi/g, no soil was removed from the area.

Eight randomly located soil samples were collected for pulse height analysis by gamma spectrometry. No radioisotopes other than those naturally occurring were detected.

***Vegetation Sampling***

A vegetation sample was taken at each cardinal point on a 152-m, a 305-m (500-ft, and a 1,000-ft) arc around the flare stack. Additional vegetation samples were collected at site grid point N-14, W-2, and stack grid points 030º, 5' and 120º, 40'. These samples were collected because of a leak from a water tank and a close proximity to the flare stack. This was the area of highest concentration as indicated by the post-flare sampling.

Vegetation samples were analyzed at Eberline Instrument Corporation's facilities in Albuquerque after the cleanup operation. Each sample was weighed wet and dry, and an aliquot of moisture was distilled from the sample. An aliquot of dry sample was oxidized and condensed to obtain the bound tritium. The results of these analyses are shown in Table 2-3.

***Water Sampling***

Prior to completion of the cleanup, water samples were taken from each of two local springs at the site. One was located just off the southeast corner of the R-EX well pad, the other was on the upper side of the road about 274 m (300 yards) downhill from the pad. Both samples were analyzed by liquid scintillation, and no tritium was detected.

## Table 2-2
## Tritium in Rulison Soil Moisture - July 1972
(Page 1 of 9)

| Grid Coordinates[a] | Sampling Depth[b] centimeters (inches) | pCi/ml[c] | pCi/g[d] (soil) |
|---|---|---|---|
| N-0, E-2 | 2.54 (1) | 14 | 0.01 |
| N-0, E-2 | 30.48 (12) | (5) ND | ND |
| N-1, E-2 | 2.54 (1) | 3.2 | 0.007 |
| N-1, E-2 | 30.48 (12) | 14 | 5.2 |
| N-2, E-2 | 2.54 (1) | ND | ND |
| N-2, E-2 | 30.48 (12) | 13 | 2.9 |
| N-3, E-.7 | 2.54 (1) | ND | ND |
| N-3, E-.7 | 30.48 (12) | 5.2 | 1.1 |
| N-3, E-2 | 2.54 (1) | ND | ND |
| N-3, E-2 | 30.48 (12) | ND | ND |
| N-4, E-.7 | 2.54 (1) | 3.8 | 0.4 |
| N-4, E-.27 | 30.48 (12) | ND | ND |
| N-4, E-2 | 2.54 (1) | ND | ND |
| N-4, E-2 | 30.48 (12) | ND | ND |
| N-5, E-.7 | 2.54 (1) | 4.3 | 0.5 |
| N-5, E-.7 | 30.48 (12) | 4.9 | 0.95 |
| N-5, E-2 | 2.54 (1) | ND | ND |
| N-5, E-2 | 30.48 (12) | ND | ND |
| N-6, E-.7 | 2.54 (1) | ND | ND |
| N-6, E-2 | 2.54 (1) | 290 | 23 |
| N-6, E-2 | 30.48 (12) | 4 | 0.8 |
| N-7, E-.7 | 2.54 (1) | ND | ND |
| N-7, E-.7 | 30.48 (12) | 5.9 | 2 |
| N-7, E-2 | 2.54 (1) | 3.9 | 0.1 |
| N-7, E-2 | 30.48 (12) | 8.3 | 1.8 |
| N-8, E-.7 | 2.54 (1) | ND | ND |
| N-8, E-.7 | 30.48 (12) | ND | ND |
| N-8, E-2 | 2.54 (1) | ND | ND |
| N-8, E-2 | 30.48 (12) | ND | ND |
| N-9, E-.7 | 2.54 (1) | ND | ND |
| N-9, E-.7 | 30.48 (12) | ND | ND |
| N-9, E-2 | 2.54 (1) | 33 | 5.8 |
| N-9, E-2 | 30.48 (12) | 4.2 | 0.9 |
| N-10, E-.7 | 2.54 (1) | 6.1 | 0.68 |
| N-10, E-.7 | 30.48 (12) | ND | ND |
| N-10, E-2 | 2.54 (1) | 2.8 | 0.08 |
| N-10, E-2 | 30.48 (12) | 100 | 24 |
| N-11, E-2 | 2.54 (1) | 190 | 2.8 |
| N-11, E-2 | 30.48 (12) | 4.1 | 0.9 |
| N-11.2, E-.2 | 2.54 (1) | 310 | 25 |
| N-11.2, E-.2 | 30.48 (12) | 38 | 6 |
| N-11.4, E-0 | 15.24 (6) | 2,400 | 1,300 |
| N-11.8, E-0 | 60.96 (24) | 850 | 510 |
| N-11.8, E-0 | 152.40 (60) | 7,800 | 4,400 |
| N-11.9, E-2.8 | 2.54 (1) | 11 | 2.3 |
| N-11.9, E-2.8 | 30.48 (12) | 33 | 6.9 |
| N-11.9, E-3.3 | 2.54 (1) | 110 | 24 |
| N-11.9, E-3.3 | 30.48 (12) | 93 | 22 |
| N-12, E-.7 | 2.54 (1) | 600 | 62 |
| N-12, E-.7 | 30.48 (12) | 920 | 320 |
| N-12, E-2 | 2.54 (1) | 21 | 1 |

Refer to footnotes at end of table.

## Table 2-2
## Tritium in Rulison Soil Moisture - July 1972
(Page 2 of 9)

| Grid Coordinates[a] | Sampling Depth[b] centimeters (inches) | pCi/ml[c] | pCi/g[d] (soil) |
|---|---|---|---|
| N-12, E-2 | 30.48 (12) | ND | ND |
| N-12.5, E-0 | 2.54 (1) | 300 | 34 |
| N-12.5, E-0 | 30.48 (12) | 120 | 15 |
| N-12.7, E-0 | 15.24 (6) | 150 | 81 |
| N-12.7, E-2.8 | 2.54 (1) | 44 | 10 |
| N-12.7, E-2.8 | 30.48 (12) | ND | ND |
| N-12.7, E-3.3 | 2.54 (1) | 21 | 8.3 |
| N-12.7, E-3.3 | 30.48 (12) | 11 | 4.7 |
| N-13, E-0 | 30.48 (12) | 73 | 41 |
| N-13, E-0 | 152.40 (60) | 51 | 24 |
| N-13, E-.7 | 2.54 (1) | 87 | 9.3 |
| N-13, E-.7 | 30.48 (12) | 200 | 49 |
| N-13, E-2 | 2.54 (1) | 51 | 2.4 |
| N-13, E-2 | 30.48 (12) | 2.9 | 0.6 |
| N-13, W-3 | 2.54 (1) | 57 | 27 |
| N-13, W-3 | 30.48 (12) | 13 | 6.2 |
| N-13.7, E-.1 | 2.54 (1) | 10,000 | 1,400 |
| N-13.7, E-.1 | 30.48 (12) | 20,000 | 5,600 |
| N-13.7, E-.1 | 60.96 (24) | 21,000 | 5,800 |
| N-13.7, E-.6 | 2.54 (1) | 2,700 | 150 |
| N-13.7, E-.6 | 30.48 (12) | 5,100 | 1,600 |
| N-13.7, E-.6 | 60.96 (24) | 4,700 | 1,400 |
| N-14, E-0 | 2.54 (1) | 4,700 | 1,400 |
| N-14, E-0 | 30.48 (12) | 3,300 | 1,800 |
| N-14, E-2 | 2.54 (1) | 22 | 0.3 |
| N-14, E-2 | 30.48 (12) | 3.3 | 0.7 |
| N-14.2, E-.7 | 2.54 (1) | 8,600 | 1,500 |
| N-14.2, E-.7 | 30.48 (12) | 29,000 | 6,500 |
| N-14.2, E-.7 | 60.96 (24) | 35,000 | 11,000 |
| N-14.2, E-.7 | 91.44 (36) | 34,000 | 19,000 |
| N-14.2, E-.7 | 121.92 (48) | 27,000 | 7,300 |
| N-14.2, E-.7 | 152.40 (60) | 26,000 | 14,000 |
| N-14.2, E-.7 | 182.88 (72) | 18,000 | 9,600 |
| N-14.2, E-.7 | 243.84 (96) | 8,000 | 4,500 |
| N-14.2, E-.7 | 274.32 (108) | 9,700 | 2,300 |
| N-14.2, E-.7 | 304.80 (120) | 5,600 | 1,400 |
| N-14.2, E-.7 | 335.28 (132) | 3,300 | 600 |
| N-14, W-2 | 2.54 (1) | 110 | 49 |
| N-14, W-2 | 30.48 (12) | 51 | 7.7 |
| N-14, W-4 | 2.54 (1) | 16 | 7.3 |
| N-14, W-4 | 30.48 (12) | 4.4 | 2.1 |
| N-14.2, E-0 | 15.24 (6) | 3,100 | 1,700 |
| N-15, E-1 | 2.54 (1) | 650 | 290 |
| N-15, E-1 | 30.48 (12) | 1,400 | 670 |
| N-15, E-2 | 2.54 (1) | 300 | 140 |
| N-15, E-2 | 30.48 (12) | 11 | 6 |
| N-15, W-3 | 2.54 (1) | 420 | 22 |
| N-15, W-3 | 30.48 (12) | 130 | 16 |
| N-16, E-1 | 2.54 (1) | 270 | 120 |
| N-16, E-1 | 30.48 (12) | 260 | 140 |
| N-16, E-2 | 2.54 (1) | 26 | 11 |

Refer to footnotes at end of table.

# Table 2-2
# Tritium in Rulison Soil Moisture - July 1972
(Page 3 of 9)

| Grid Coordinates[a] | Sampling Depth[b] centimeters (inches) | pCi/ml[c] | pCi/g[d] (soil) |
|---|---|---|---|
| N-16, E-2 | 30.48 (12) | 5.3 | 2.6 |
| N-17, E-1 | 2.54 (1) | 160 | 75 |
| N-17, E-1 | 30.48 (12) | 17,000 | 6,000 |
| N-16.7, E-2 | 2.54 (1) | 36 | 0.9 |
| N-16.7, E-2 | 30.48 (12) | ND | ND |
| N-17.8, E-2 | 2.54 (1) | 710 | 370 |
| N-17.8, E-2 | 30.48 (12) | 330 | 170 |
| N-18, E-1 | 2.54 (1) | 11 | 5.3 |
| N-18, E-1 | 30.48 (12) | 80 | 41 |
| N-19, E-1 | 2.54 (1) | 25 | 12 |
| N-19, E-1 | 30.48 (12) | 22 | 11 |
| N-19, E-2 | 2.54 (1) | 10 | 4.5 |
| N-19, E-2 | 30.48 (12) | 15 | 7.1 |
| N-20, E-1 | 2.54 (1) | 8.4 | 3.9 |
| N-20, E-1 | 30.48 (12) | 280 | 130 |
| N-20, E-2 | 2.54 (1) | 71 | 34 |
| N-20, E-2 | 30.48 (12) | 10 | 4.6 |
| N-21, E-1 | 2.54 (1) | 44 | 20 |
| N-21, E-1 | 30.48 (12) | 73 | 30 |
| N-21, E-2 | 2.54 (1) | 56 | 25 |
| N-21, E-2 | 30.48 (12) | ND | ND |
| N-22, E-1 | 2.54 (1) | 25 | 12 |
| N-22, E-1 | 30.48 (12) | 100 | 43 |
| N-22, E-2 | 2.54 (1) | 8.4 | 3.9 |
| N-22, E-2 | 30.48 (12) | 23 | 12 |
| N-23, E-1 | 2.54 (1) | 15 | 6.8 |
| N-23, E-1 | 30.48 (12) | 290 | 140 |
| N-23, E-2 | 2.54 (1) | 6.6 | 3.2 |
| N-23, E-2 | 30.48 (12) | 3.4 | 1.7 |
| N-24, E-1 | 2.54 (1) | 59 | 26 |
| N-24, E-1 | 30.48 (12) | 69 | 33 |
| N-24, E-2 | 2.54 (1) | 450 | 220 |
| N-24, E-2 | 30.48 (12) | 6.9 | 3.6 |
| N-24, W-2 | 182.88 (72) | 14 | 2.1 |
| N-25, E-1 | 2.54 (1) | 16 | 7.1 |
| N-25, E-1 | 30.48 (12) | 15 | 7.3 |
| N-25, E-2 | 2.54 (1) | 18 | 8.7 |
| N-25, E-2 | 30.48 (12) | 22 | 11 |
| N-26, E-1 | 2.54 (1) | 15 | 6.4 |
| N-26, E-1 | 30.48 (12) | 39 | 19 |
| N-26, E-2 | 2.54 (1) | 31 | 14 |
| N-26, E-2 | 30.48 (12) | 34 | 17 |
| N-27, E-1 | 2.54 (1) | 44 | 23 |
| N-27, E-1 | 30.48 (12) | 51 | 24 |
| N-28, E-1 | 2.54 (1) | 390 | 180 |
| N-28, E-1 | 30.48 (12) | 160 | 86 |
| | | | |
| 000°, 6.10 (20) | 2.54 (1) | 180 | 44 |
| 000°, 6.10 (20) | 30.48 (12) | 290 | 94 |
| 000°, 12.19 (40) | 2.54 (1) | 43 | 3.2 |

Refer to footnotes at end of table.

## Table 2-2
## Tritium in Rulison Soil Moisture - July 1972
(Page 4 of 9)

| Grid Coordinates[a] | Sampling Depth[b] centimeters (inches) | pCi/ml[c] | pCi/g[d] (soil) |
|---|---|---|---|
| 000°, 12.19 (40) | 30.48 (12) | 14 | 1.1 |
| 030°, 6.10 (20) | 2.54 (1) | 32 | 8.5 |
| 030°, 6.10 (20) | 30.48 (12) | 53 | 18 |
| 030°, 12.19 (40) | 2.54 (1) | 22 | 1.1 |
| 030°, 12.19 (40) | 30.48 (12) | ND | ND |
| 060°, 6.10 (20) | 2.54 (1) | 10 | 3.5 |
| 060°, 6.10 (20) | 30.48 (12) | 14 | 4.3 |
| 060°, 12.19 (40) | 2.54 (1) | 100 | 12 |
| 060°, 12.19 (40) | 30.48 (12) | 11 | 0.75 |
| 090°, 6.10 (20) | 2.54 (1) | 84 | 4.9 |
| 090°, 6.10 (20) | 30.48 (12) | 27 | 8.6 |
| 090°, 12.19 (40) | 2.54 (1) | 32 | 3 |
| 090°, 12.19 (40) | 30.48 (12) | 4.8 | 0.55 |
| 120°, 6.10 (20) | 2.54 (1) | 74 | 7.3 |
| 120°, 6.10 (20) | 30.48 (12) | 45 | 6 |
| 120°, 6.10 (20) | 60.96 (24) | 290 | 40 |
| 120°, 6.10 (20) | 121.92 (48) | 81 | 42 |
| 120°, 12.19 (40) | 2.54 (1) | 18 | 2 |
| 120°, 12.19 (40) | 30.48 (12) | 15 | 1.4 |
| 120°, 12.19 (40) | 60.96 (24) | 140 | 28 |
| 120°, 12.19 (40) | 121.92 (48) | 380 | 73 |
| 120°, 18.29 (60) | 2.54 (1) | 60 | 8.4 |
| 120°, 18.29 (60) | 30.48 (12) | 27 | 3.6 |
| 120°, 18.29 (60) | 60.96 (24) | 290 | 160 |
| 120°, 18.29 (60) | 121.92 (48) | 290 | 61 |
| 150°, 6.10 (20) | 2.54 (1) | 28 | 2.3 |
| 150°, 6.10 (20) | 30.48 (12) | 3.6 | 0.6 |
| 150°, 12.19 (40) | 2.54 (1) | 37 | 5.4 |
| 150°, 12.19 (40) | 30.48 (12) | 21 | 3.1 |
| 210°, 6.10 (20) | 2.54 (1) | 170 | 7.1 |
| 210°, 6.10 (20) | 30.48 (12) | 220 | 48 |
| 210°, 12.19 (40) | 2.54 (1) | 11 | 0.46 |
| 210°, 12.19 (40) | 30.48 (12) | ND | ND |
| 240°, 6.10 (20) | 2.54 (1) | 1,100 | 82 |
| 240°, 6.10 (20) | 30.48 (12) | 4,700 | 1,400 |
| 240°, 12.19 (40) | 2.54 (1) | 60 | 7.6 |
| 240°, 12.19 (40) | 30.48 (12) | 16 | 2 |
| 270°, 6.10 (20) | 2.54 (1) | 16 | 5.3 |
| 270°, 6.10 (20) | 30.48 (12) | 53 | 17 |
| 270°, 12.19 (40) | 2.54 (1) | 22 | 0.93 |
| 270°, 12.19 (40) | 30.48 (12) | ND | ND |
| 300°, 0.91 (3) | 2.54 (1) | 230 | 100 |
| 300°, 0.91 (3) | 30.48 (12) | 780 | 400 |

Refer to footnotes at end of table.

# Table 2-2
## Tritium in Rulison Soil Moisture - July 1972
(Page 5 of 9)

| Grid Coordinates[a] | Sampling Depth[b] centimeters (inches) | pCi/ml[c] | pCi/g[d] (soil) |
|---|---|---|---|
| 300°, 0.91 (3) | 60.96 (24) | 3,300 | 1,900 |
| 300°, 0.91 (3) | 91.44 (36) | 3,800 | 820 |
| 300°, 0.91 (3) | 121.92 (48) | 5,700 | 1,300 |
| 300°, 0.91 (3) | 152.40 (60) | 6,400 | 3,200 |
| 300°, 0.91 (3) | 182.88 (72) | 4,400 | 2,500 |
| 300°, 0.91 (3) | 213.36 (84) | 2,900 | 1,400 |
| 300°, 0.91 (3) | 243.84 (96) | 2,700 | 1,300 |
| 300°, 6.10 (20) | 2.54 (1) | 400 | 115 |
| 300°, 6.10 (20) | 30.48 (12) | 450 | 150 |
| 300°, 6.10 (20) | 60.96 (24) | 3,900 | 520 |
| 300°, 6.10 (20) | 121.92 (48) | 2,500 | 520 |
| 300°, 12.19 (40) | 2.54 (1) | 42 | 2.1 |
| 300°, 12.19 (40) | 30.48 (12) | 8.6 | 1.2 |
| 330°, 6.10 (20) | 2.54 (1) | 350 | 100 |
| 330°, 6.10 (20) | 30.48 (12) | 600 | 180 |
| 330°, 12.19 (40) | 2.54 (1) | 65 | 4.1 |
| 330°, 12.19 (40) | 30.48 (12) | 17 | 1.5 |
| | | | |
| S-1, E-1 | 2.54 (1) | 6.5 | 0.04 |
| S-1, E-1 | 30.48 (12) | ND | ND |
| S-1, E-2 | 2.54 (1) | 10 | 0.006 |
| S-1, E-2 | 30.48 (12) | ND | ND |
| S-1, E-3 | 2.54 (1) | ND | ND |
| S-1, E-3 | 30.48 (12) | ND | ND |
| S-2, W-.7 | 2.54 (1) | ND | ND |
| S-2, W-.7 | 30.48 (12) | 7.3 | 1.2 |
| S-3, E-0 | 2.54 (1) | 1,500 | 810 |
| S-3, E-0 | 30.48 (12) | 66 | 11 |
| S-3, E-2 | 2.54 (1) | ND | ND |
| S-3, E-2 | 30.48 (12) | ND | ND |
| S-3.8, E-1.4 | 2.54 (1) | ND | ND |
| S-3.8, E-1.4 | 30.48 (12) | ND | ND |
| S-5, E-0 | 2.54 (1) | ND | ND |
| S-5, E-0 | 30.48 (12) | ND | ND |
| S-5, E-2 | 2.54 (1) | ND | ND |
| S-5, E-2 | 30.48 (12) | ND | ND |
| S-5, E-4 | 2.54 (1) | ND | ND |
| S-5, E-4 | 30.48 (12) | 20 | 3.4 |
| S-5.7, W-2 | 2.54 (1) | 200 | 7.5 |
| S-5.7, W-2 | 30.48 (12) | 2.9 | 0.56 |
| S-7, E-0 | 2.54 (1) | ND | ND |
| S-7, E-0 | 30.48 (12) | ND | ND |
| S-7, E-2 | 2.54 (1) | ND | ND |
| S-7, E-2 | 30.48 (12) | ND | ND |
| S-7, E-4 | 2.54 (1) | ND | ND |
| S-7, E-4 | 30.48 (12) | ND | ND |
| S-7, E-6 | 2.54 (1) | 70 | 29 |
| S-7, E-6 | 30.48 (12) | ND | ND |

Refer to footnotes at end of table.

## Table 2-2
## Tritium in Rulison Soil Moisture - July 1972
(Page 6 of 9)

| Grid Coordinates[a] | Sampling Depth[b] centimeters (inches) | pCi/ml[c] | pCi/g[d] (soil) |
|---|---|---|---|
| S-7, E-8 | 2.54 (1) | 770 | 13 |
| S-7, E-8 | 30.48 (12) | ND | ND |
| S-7, E-10 | 2.54 (1) | 91 | 2.3 |
| S-7, E-10 | 30.48 (12) | ND | ND |
| S-7, E-12 | 2.54 (1) | 6.7 | 0.17 |
| S-7, E-12 | 30.48 (12) | ND | ND |
| S-7.5, W-2.7 | 2.54 (1) | 43 | 0.37 |
| S-7.5, W-2.7 | 30.48 (12) | ND | ND |
| S-8, W-1.5 | 2.54 (1) | ND | ND |
| S-8, W-1.5 | 30.48 (12) | ND | ND |
| S-9, E-0 | 2.54 (1) | ND | ND |
| S-9, E-0 | 30.48 (12) | ND | ND |
| S-9, E-2 | 2.54 (1) | 100 | 41 |
| S-9, E-2 | 30.48 (12) | ND | ND |
| S-9, E-4 | 2.54 (1) | ND | ND |
| S-9, E-4 | 30.48 (12) | ND | ND |
| S-9, E-6 | 2.54 (1) | ND | ND |
| S-9, E-6 | 30.48 (12) | ND | ND |
| S-9, E-8 | 2.54 (1) | ND | ND |
| S-9, E-8 | 30.48 (12) | ND | ND |
| S-9, E-10 | 2.54 (1) | 130 | 4.5 |
| S-9, E-10 | 30.48 (12) | ND | ND |
| S-9, E-12 | 2.54 (1) | 110 | 2.1 |
| S-9, E-12 | 30.48 (12) | ND | ND |
| S-9.4, W-3.4 | 2.54 (1) | 3,900 | 32 |
| S-9.4, W-3.4 | 30.48 (12) | 230 | 25 |
| S-10, W-1.5 | 2.54 (1) | ND | ND |
| S-10, W-1.5 | 30.48 (12) | ND | ND |
| S-10.3, E-10.1 | 2.54 (1) | ND | ND |
| S-10.3, E-10.1 | 30.48 (12) | ND | ND |
| S-10.3, E-10.1 | 60.96 (24) | ND | ND |
| S-10.3, E-10.1 | 121.92 (48) | ND | ND |
| S-11, E-0 | 2.54 (1) | 610 | 11 |
| S-11, E-0 | 30.48 (12) | ND | ND |
| S-11, E-2 | 2.54 (1) | ND | ND |
| S-11, E-2 | 30.48 (12) | ND | ND |
| S-11, E-4 | 2.54 (1) | 62 | 0.98 |
| S-11, E-4 | 30.48 (12) | ND | ND |
| S-11, E-6 | 2.54 (1) | ND | ND |
| S-11, E-6 | 30.48 (12) | ND | ND |
| S-11, E-8 | 2.54 (1) | ND | ND |
| S-11, E-8 | 30.48 (12) | ND | ND |
| S-11, E-10 | 2.54 (1) | ND | ND |
| S-11, E-10 | 30.48 (12) | ND | ND |
| S-11, E-12 | 2.54 (1) | ND | ND |
| S-11, E-12 | 30.48 (12) | ND | ND |
| S-11, E-14 | 2.54 (1) | ND | ND |
| S-11, E-14 | 30.48 (12) | ND | ND |
| S-11.2, W-4 | 2.54 (1) | 280 | 21 |
| S-11.2, W-4 | 30.48 (12) | ND | ND |
| S-11.7, E-3.1 | 2.54 (1) | ND | ND |

Refer to footnotes at end of table.

## Table 2-2
## Tritium in Rulison Soil Moisture - July 1972
(Page 7 of 9)

| Grid Coordinates[a] | Sampling Depth[b] centimeters (inches) | pCi/ml[c] | pCi/g[d] (soil) |
|---|---|---|---|
| S-11.7, E-3.1 | 30.48 (12) | ND | ND |
| S-11.7, E-8.7 | 2.54 (1) | ND | ND |
| S-11.7, E-8.7 | 30.48 (12) | ND | ND |
| S-11.7, E-8.7 | 60.96 (24) | ND | ND |
| S-11.7, E-8.7 | 121.92 (48) | ND | ND |
| S-12, E-1 | 2.54 (1) | ND | ND |
| S-12, E-1 | 30.48 (12) | ND | ND |
| S-12, E-5 | 2.54 (1) | 18 | 0.2 |
| S-12, E-5 | 30.48 (12) | ND | ND |
| S-12, W-1.5 | 2.54 (1) | 3.8 | 0.2 |
| S-12, W-1.5 | 30.48 (12) | ND | ND |
| S-12.4, E-3.8 | 2.54 (1) | ND | ND |
| S-12.4, E-3.8 | 30.48 (12) | ND | ND |
| S-12.8, E-1.9 | 2.54 (1) | ND | ND |
| S-12.8, E-1.9 | 30.48 (12) | ND | ND |
| S-12.8, E-1.9 | 60.96 (24) | ND | ND |
| S-12.8, E-1.9 | 121.92 (48) | ND | ND |
| S-13, E-0 | 2.54 (1) | ND | ND |
| S-13, E-0 | 30.48 (12) | ND | ND |
| S-13, E-6 | 2.54 (1) | ND | ND |
| S-13, E-6 | 30.48 (12) | ND | ND |
| S-13, E-8 | 2.54 (1) | 14 | 0.32 |
| S-13, E-8 | 30.48 (12) | 84 | 6.3 |
| S-13, E-10 | 2.54 (1) | 1 | 0.01 |
| S-13, E-10 | 30.48 (12) | ND | ND |
| S-13, E-12 | 2.54 (1) | ND | ND |
| S-13, E-12 | 30.48 (12) | ND | ND |
| S-13, E-14 | 2.54 (1) | ND | ND |
| S-13, E-14 | 30.48 (12) | ND | ND |
| S-13.1, E-7.3 | 2.54 (1) | ND | ND |
| S-13.1, E-7.3 | 30.48 (12) | ND | ND |
| S-13.1, E-7.3 | 60.96 (24) | ND | ND |
| S-13.1, E-7.3 | 121.92 (48) | ND | ND |
| S-13.1, W-4.8 | 2.54 (1) | 690 | 290 |
| S-13.1, W-4.8 | 30.48 (12) | ND | ND |
| S-13.2, E-4.5 | 2.54 (1) | ND | ND |
| S-13.2, E-4.5 | 30.48 (12) | ND | ND |
| S-13.5, E-2.8 | 2.54 (1) | ND | ND |
| S-13.5, E-2.8 | 30.48 (12) | ND | ND |
| S-13.9, E-5.2 | 2.54 (1) | ND | ND |
| S-13.9, E-5.2 | 30.48 (12) | ND | ND |
| S-14, E-.8 | 2.54 (1) | ND | ND |
| S-14, E-.8 | 30.48 (12) | ND | ND |
| S-14, W-3.4 | 2.54 (1) | 120 | 1.1 |
| S-14, W-3.4 | 30.48 (12) | 45 | 8.5 |
| S-14.2, E-3.4 | 2.54 (1) | ND | ND |
| S-14.2, E-3.4 | 30.48 (12) | 12 | 1.6 |
| S-14.2, E-3.4 | 60.96 (24) | ND | ND |
| S-14.2, E-3.4 | 121.92 (48) | ND | ND |
| S-14.6, E-5.9 | 2.54 (1) | 20 | 0.1 |
| S-14.6, E-5.9 | 30.48 (12) | ND | ND |

Refer to footnotes at end of table.

## Table 2-2
## Tritium in Rulison Soil Moisture - July 1972
(Page 8 of 9)

| Grid Coordinates[a] | Sampling Depth[b] centimeters (inches) | pCi/ml[c] | pCi/g[d] (soil) |
|---|---|---|---|
| S-14.6, E-5.9 | 60.96 (24) | ND | ND |
| S-14.6, E-5.9 | 121.92 (48) | ND | ND |
| S-14.7, E-1.6 | 2.54 (1) | ND | ND |
| S-14.7, E-1.6 | 30.48 (12) | ND | ND |
| S-15, E-12 | 2.54 (1) | 26 | 0.03 |
| S-15, E-12 | 30.48 (12) | ND | ND |
| S-15, E-14 | 2.54 (1) | ND | ND |
| S-15, E-14 | 30.48 (12) | ND | ND |
| S-15, W-1.8 | 2.54 (1) | 76 | 1.4 |
| S-15, W-1.8 | 30.48 (12) | 1,400 | 210 |
| S-15.4, E-2.2 | 2.54 (1) | ND | ND |
| S-15.4, E-2.2 | 30.48 (12) | ND | ND |
| S-15.4, E-5 | 2.54 (1) | 55 | 0.4 |
| S-15.4, E-5 | 30.48 (12) | ND | ND |
| S-15.4, E-5 | 60.96 (24) | ND | ND |
| S-15.4, E-5 | 121.92 (48) | ND | ND |
| S-15.4, E-6.6 | 2.54 (1) | 480 | 7.6 |
| S-15.4, E-6.6 | 30.48 (12) | ND | ND |
| S-15.4, E-8 | 2.54 (1) | ND | ND |
| S-15.4, E-8 | 30.48 (12) | 12 | 2.1 |
| S-16, E-0 | 2.54 (1) | ND | ND |
| S-16, E-0 | 30.48 (12) | ND | ND |
| S-16.1, E-3 | 2.54 (1) | 520 | 16 |
| S-16.1, E-3 | 30.48 (12) | ND | ND |
| S-16.2, E-4 | 2.54 (1) | 48 | 1.3 |
| S-16.2, E-4 | 30.48 (12) | ND | ND |
| S-16.2, E-4 | 60.96 (24) | ND | ND |
| S-16.2, E-4 | 121.92 (48) | ND | ND |
| S-16.6, E-6.6 | 2.54 (1) | 8.5 | 0.2 |
| S-16.6, E-6.6 | 30.48 (12) | 5.3 | 0.5 |
| S-16.6, E-6.6 | 60.96 (24) | 8.9 | 0.9 |
| S-16.6, E-6.6 | 121.92 (48) | ND | ND |
| S-16.6, E-8 | 2.54 (1) | 5.9 | 0.24 |
| S-16.6, E-8 | 30.48 (12) | 5.7 | 0.3 |
| S-17, E-10 | 2.54 (1) | ND | ND |
| S-17, E-10 | 30.48 (12) | ND | ND |
| S-17, E-12 | 2.54 (1) | ND | ND |
| S-17, E-12 | 30.48 (12) | 46 | 2.4 |
| S-17, E-14 | 2.54 (1) | 190 | 54 |
| S-17, E-14 | 30.48 (12) | ND | ND |
| S-17.1, E-1.8 | 2.54 (1) | 89 | 1.2 |
| S-17.1, E-1.8 | 30.48 (12) | ND | ND |
| S-18, E-6.5 | 2.54 (1) | 11 | 0.1 |
| S-18, E-6.5 | 30.48 (12) | 14 | 1.3 |
| S-18.2, E-3.5 | 2.54 (1) | 270 | 56 |
| S-18.2, E-3.5 | 30.48 (12) | ND | ND |
| S-19, E-8 | 2.54 (1) | 11 | 0.67 |
| S-19, E-8 | 30.48 (12) | ND | ND |
| S-19, E-9 | 2.54 (1) | ND | ND |
| S-19, E-9 | 30.48 (12) | ND | ND |
| S-19, E-9 | 60.96 (24) | ND | ND |

Refer to footnotes at end of table.

# Table 2-2
## Tritium in Rulison Soil Moisture - July 1972
(Page 9 of 9)

| Grid Coordinates[a] | Sampling Depth[b] centimeters (inches) | pCi/ml[c] | pCi/g[d] (soil) |
|---|---|---|---|
| S-19, E-9 | 121.92 (48) | ND | ND |
| S-19, E-10 | 2.54 (1) | ND | ND |
| S-19, E-10 | 30.48 (12) | 50 | 4.9 |
| S-19, E-12 | 2.54 (1) | ND | ND |
| S-19, E-12 | 30.48 (12) | 5.8 | 0.28 |
| S-19, E-14 | 2.54 (1) | ND | ND |
| S-19, E-14 | 30.48 (12) | ND | ND |
| S-19.3, E-5.1 | 2.54 (1) | 58 | 1.4 |
| S-19.3, E-5.1 | 30.48 (12) | 11 | 2.3 |
| S-20, E-12 | 2.54 (1) | 12 | 0.56 |
| S-20, E-12 | 30.48 (12) | 15 | 0.39 |
| S-20.4, E-6.8 | 2.54 (1) | ND | ND |
| S-20.4, E-6.8 | 30.48 (12) | ND | ND |
| S-21, E-14 | 2.54 (1) | 19 | 0.43 |
| S-21, E-14 | 30.48 (12) | ND | ND |
| S-21.5, E-8.5 | 2.54 (1) | 300 | 2.2 |
| S-21.5, E-8.5 | 30.48 (12) | ND | ND |
| S-22.5, E-10.2 | 2.54 (1) | 130 | 0.52 |
| S-22.5, E-10.2 | 30.48 (12) | ND | ND |
| S-23.2, E-17 | 2.54 (1) | 9.4 | 4.1 |
| S-23.2, E-17 | 30.48 (12) | ND | ND |
| S-23.5, E-12 | 2.54 (1) | 13 | 0.54 |
| S-23.5, E-12 | 30.48 (12) | 4.1 | 0.71 |
| S-23.5, E-12 | 2.54 (1) | 32 | 1.2 |
| S-23.8, E-15.3 | 30.48 (12) | ND | ND |
| S-24.6, E-13.7 | 2.54 (1) | 47,000 | 20,000 |
| S-24.6, E-13.7 | 30.48 (12) | 860 | 140 |
| S-24.6, E-17 | 2.54 (1) | 36 | 0.39 |
| S-24.6, E-17 | 30.48 (12) | 19 | 3.2 |
| S-25.4, E-15.4 | 2.54 (1) | 1,400 | 22 |
| S-25.4, E-15.4 | 30.48 (12) | 1,700 | 235 |

Source: Eberline, 1977

[a]Cardinal coordinates referenced to entrance gate post scale; 1 unit equals 3.05 meters (10 feet).
Radial coordinates are in degrees and meters (feet) referenced to flare stack.

[b]Sampling depth increments are 2.54 cm (i.e., 2.54 cm is from 0 to 2.54 cm, 30.48 is from 27.94 to 30.48 cm, etc.) (1" [i.e., 1" is from 0 to 1", 12" is from 11" to 12", etc.]).

[c]Picocurie per milliliter

[d]Picocurie per gram

## Table 2-3
## Tritium in Vegetation - July 1972

| Grid Coordinates[a] degrees, meters (feet) | Dry/Wet Ratio | Unbound[b] | | Bound[c] | | Total |
|---|---|---|---|---|---|---|
| | | pCi/ml[d] (H2O)[e] | pCi/g[f] (wet) | pCi/ml ($H_2O$) (water from oxidation) | pCi/g (wet) | pCi/g (wet) |
| 000°, 152.40 (500) | 0.38 | 7 | 4.3 | <31 | <1.7 | ≈ 4.3 |
| 000°, 304.80 (1,000) | 0.42 | 7.2 | 2.8 | <8.3 | <1.4 | ≈ 2.8 |
| 090°, 152.40 (500) | 0.23 | 4.5 | 3.5 | <32 | <1.5 | ≈ 3.5 |
| 090°, 304.80 (1,000) | 0.30 | 8.1 | 5.7 | <33 | <1.1 | ≈ 5.7 |
| 180°, 152.40 (500) | 0.22 | 75 | 58 | <16 | <0.9 | ≈ 58 |
| 180°, 304.80 (1,000) | 0.25 | 7.1 | 5.3 | <11 | <0.8 | ≈ 5.3 |
| 270°, 152.40 (500) | 0.19 | 5.5 | 4.5 | <28 | <0.8 | ≈ 4.5 |
| 270°, 304.80 (1,000) | 0.25 | 7.5 | 5.6 | <14 | <1.0 | ≈ 5.6 |
| 030°, 1.52 (5) | 0.13 | 170 | 150 | 190 | 5.3 | 160 |
| 120°, 12.19 (40) | 0.27 | 64 | 47 | 97 | 3.6 | 51 |
| *N-14, W-2 | 0.22 | 150 | 120 | 41 | 2.3 | 120 |

Source: Eberline, 1977

*West of tank 3, referenced to entrance gate post.

[a]Coordinates are in degrees and meters (feet) referenced to flare stack.

[b]Unbound; tritium in water that was removable by drying the sample in an electric oven for 16 hours.

[c]Bound; tritium converted to water form by oxidizing the dried sample.

[d]Picocurie per milliliter

[e]Water

[f]Picocurie per gram

A Hydrologic Program Advisory Group reviewed the hydrologic monitoring program proposed for the Rulison Site at a meeting in December 1971. They found the program adequate and recommended its immediate initiation. The U.S. Environmental Protection Agency (EPA), Las Vegas, Nevada, has been conducting the monitoring program since that time (ERDA, 1977, p. 33). Sampling locations are presented on Figure 2-11. Analytical results, to date, are given in Appendix A. Results of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Preliminary Assessment prepared by Desert Research Institute (DRI) for the Rulison Site in 1988 recommended that the hydrologic monitoring program be continued and periodically updated as new monitoring wells and hydrologic data become available (p. 3.6.21).

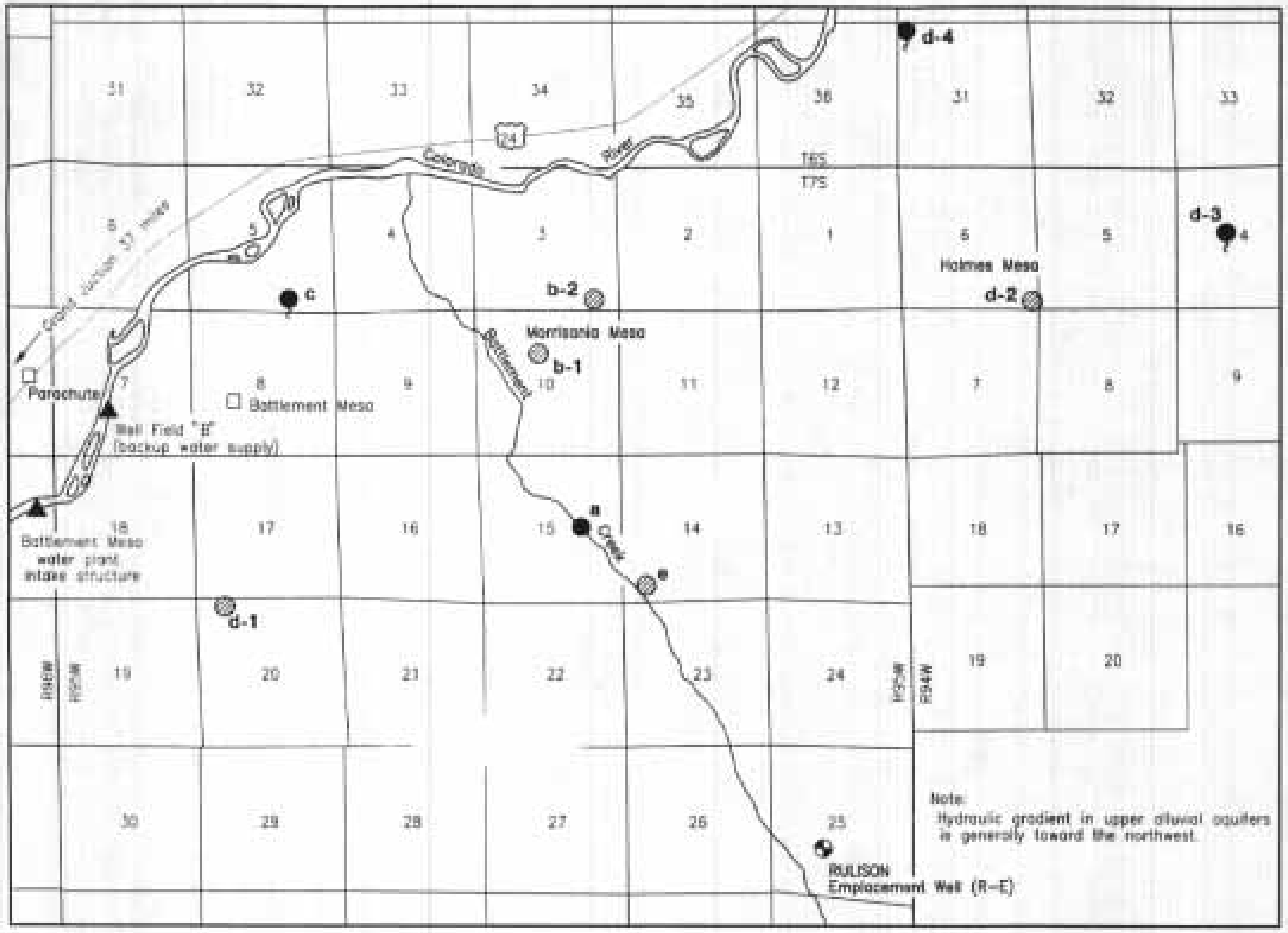
Unless otherwise specified, all samples collected for the hydrologic monitoring program are analyzed for tritium. All samples are also analyzed for gross alpha and gross beta radioactivity and are given a gamma spectral scan. Gross chemistry analyses, comparable to the USGS chemical water quality analyses, will be performed on all samples collected on the initial sample run. Based on the results of those analyses, suspect samples will be analyzed for appropriate, naturally occurring, and man-made isotopes. Splits of each collected sample will be retained by EPA for this purpose until it is demonstrated that the need to retain them does not exist. Each water source is sampled once a year, preferably in the early spring, weather permitting.

#### *2.2.2.4.3 Third Sampling Program*

The third sampling program occurred during September 1 to October 12, 1976, and was associated with the plugging of the emplacement and production wells and abandonment of the Rulison Site. It was designed to consider the history of the site and then to complete all requirements for radiation contamination clearance. It primarily consisted of sampling soil at the following locations:

- At two locations that exceeded the current guideline for tritium in the 1972 cleanup
- At the location of a known spill which occurred during the final cleanup
- In the vicinity of decontamination work
- Around the R-E wellhead location

In addition, the creek was sampled above and below the site, and the same two springs (one on the site, one about 274 m [300 yards] down the road) were sampled.




SAMPLING POINTS

a. Battlement Creek at the nearest down gradient accessible location in T7S, R95W, Sec. 15 SE 1/4 NE 1/4.

b. Two private wells in alluvium on Morrisonia Mesa.

Locations:

(1) T7S, R95W, Sec. 10 NE 1/4 SE 1/4 NW 1/4 (Lee Hayward Ranch).

(2) T7S, R95W, Sec. 3 SW 1/4 SE 1/4 SE 1/4 (Glen Schwab Ranch).

c. Water supply springs for Parachute located at T7S, R95W, Sec. 5 SE 1/4 SW 1/4 SE 1/4.

d. Two springs and two wells located in the vicinity of surface ground zero:

(1) Well: T7S, R95W, Sec. 20 NE 1/4 NW 1/4 NW 1/4 (Albert Gardner Ranch).

(2) Well: T7S, R95W, Sec. 6 NE 1/4 SE 1/4 SE 1/4 (Felix Sefcovic Ranch).

(3) Spring: T7S, R94W, Sec. 4 SW 1/4 SE 1/4 NW 1/4 (Bernklau Ranch).

(4) Spring T6S. R94W, Sec. 31 NW 1/4 NW 1/4 NW 1/4 (Potter Ranch).

e. The Austral Oil Co. well located at T7S, R95W, Sec. 14 SW 1/4 SW 1/4

SCALE

0 5,000 10,000 Feet

0 1,500 3,000 Meters

Source: Project Rulison Well Plugging and Site Abandonment Final Report, 1977.

LEGEND

- Well location sampled
- Spring location sampled
- Creek location sampled
- Town
- Well at surface ground zero
- Municipal water supply intake

FIGURE 2-11
PROJECT RULISON, LONG-TERM HYDROLOGIC MONITORING PROGRAM SAMPLING DATA POINTS, DECEMBER 1971, GARFIELD COUNTY, COLORADO

***Sampling Point N-14.2, E-.7 (Refer to Figure 2-10)***

In July 1972, the samples taken at 61- and 91.4-cm (24- and 36-in.) depths contained concentrations of tritium at 35,000 and 34,000 pCi/mL, respectively, in soil moisture. The guideline was 30,000 pCi/mL (ERDA, 1976). This contamination was the result of a known spill from a valve that froze and broke during the 1971 to 1972 winter. This sampling point and the area adjacent to the spill were sampled thoroughly. Results of analyses showed that intervening time and weather had reduced contamination to negligible levels. The sample locations and results of analyses are shown on Figure 2-12 and in Table 2-4.

***Sampling Point S-24.6, E-13.7 (Refer to Figure 2-9)***

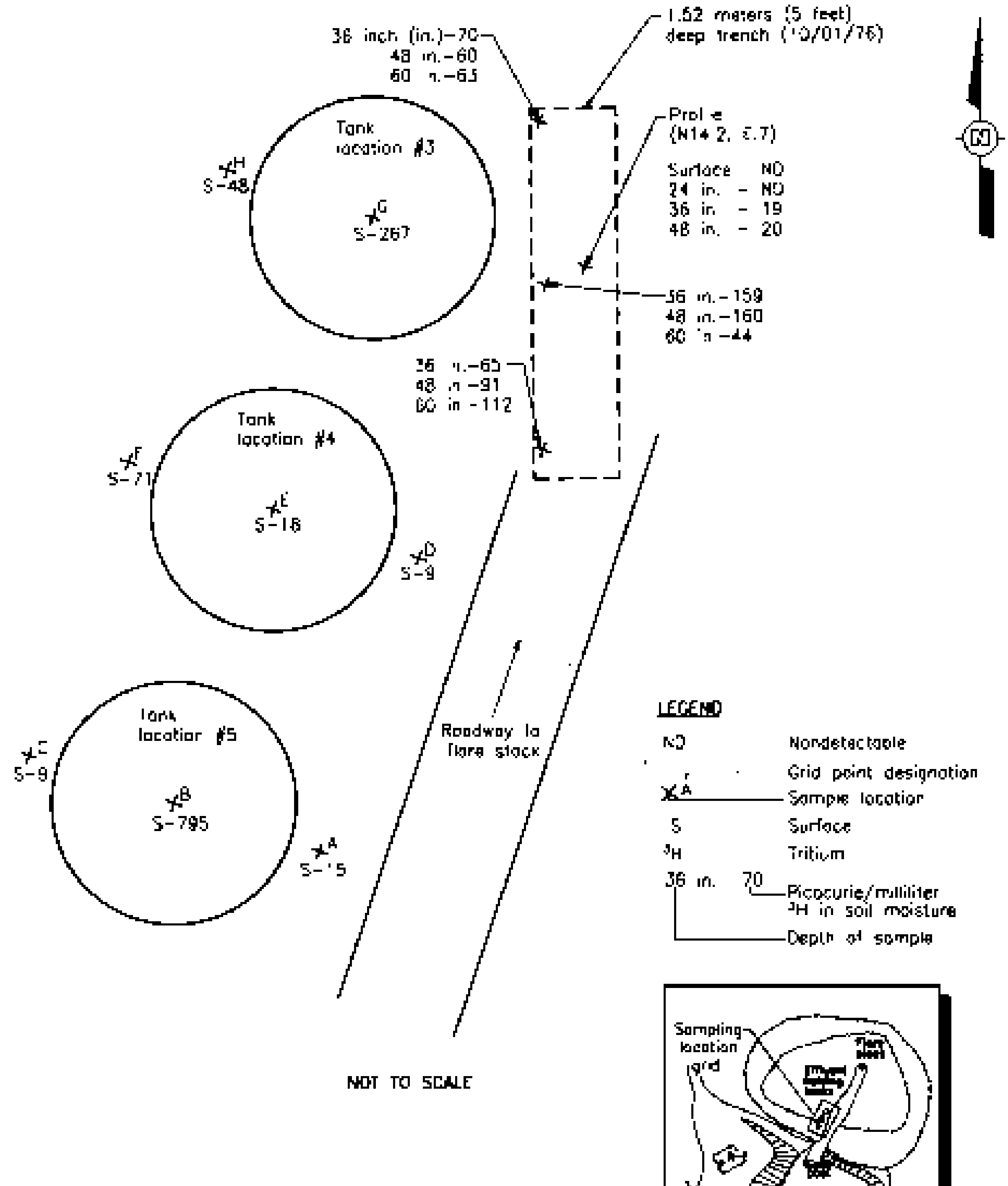
The surface sample taken at this point in July 1972 contained 47,000 pCi/mL tritium in soil moisture. This was the result of a spill that occurred during production test operations. This point and the adjacent area, including the separator location, were sampled. Results of analyses showed that soil contamination at this location is now negligible. The sample locations and results of analyses are shown on Figure 2-13 and in Table 2-5.

***Accidental Spill Area***

On September 1, 1976, the separator was being moved onto the decontamination pan. It was dropped about half onto the pan, and liquid spilled from the separator onto the pan and onto the soil southwest of the pan. An estimated 60 gallons spilled on the soil. The tritium concentration in the separator liquid was about 230,000 pCi/mL. Soil visibly moistened by the liquid was picked up, mixed with diatomaceous earth for additional drying, and was contained in plastic-lined, 55-gallon steel drums. Preliminary samples were taken, and more soil was picked up as indicated. Figure 2-14 shows a sketch of the spill area after 15 drums of soil were removed.

On September 16, 1976, the area was divided into a 1.5-m (5-ft) grid locating 42 sampling points, and a surface sample was taken at each point. Figure 2-15 shows that the contaminated area was delineated and that the decontamination effort had been very effective. All points sampled were less than the guideline; the highest concentration detected was 13,078 pCi/mL tritium in soil moisture.

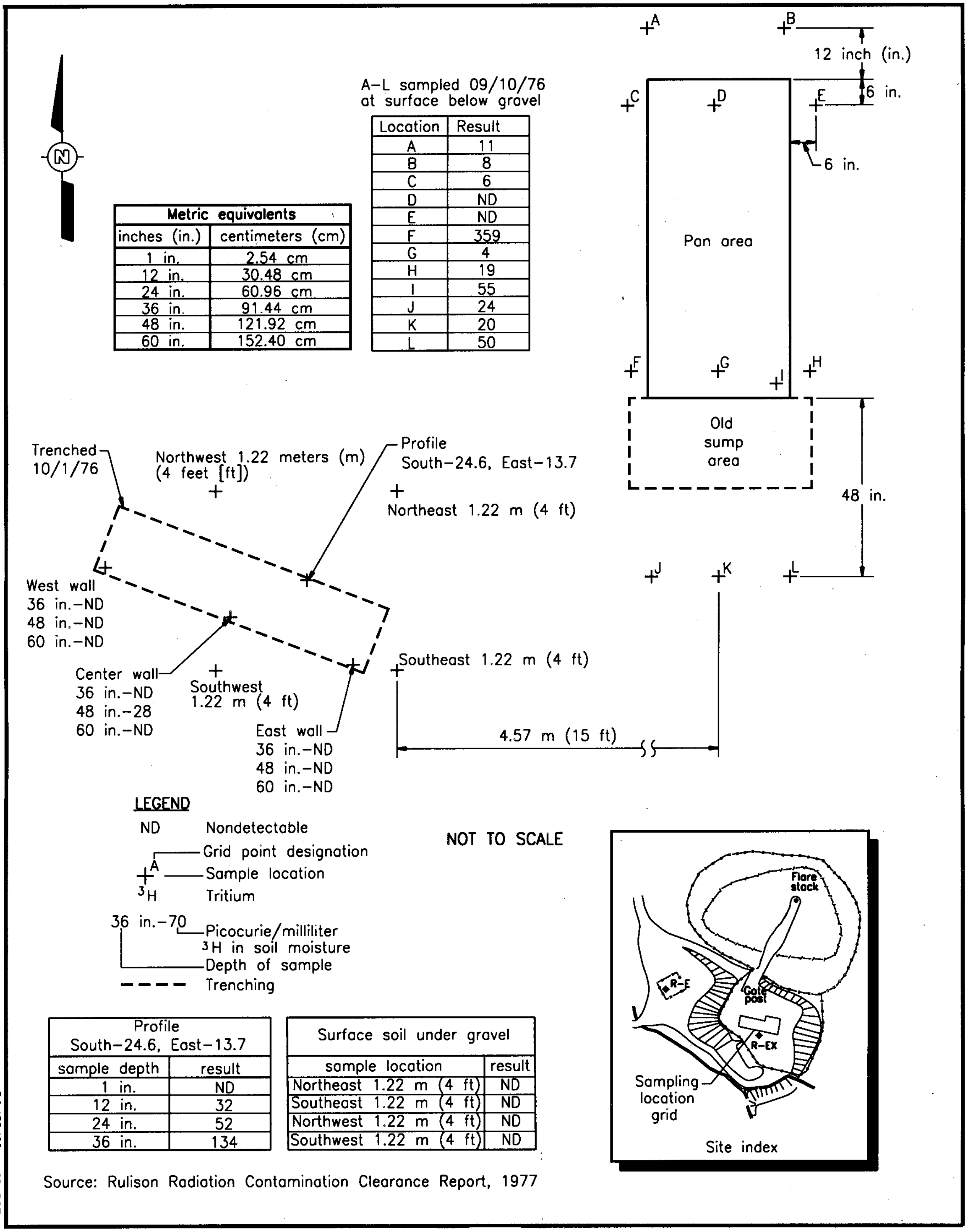
On September 21, 1976, five more drums of soil were removed from the area of highest concentration as indicated by the contour boundary line on Figure 2-16. Samples were taken the length and direction of the removed soil as shown also on Figure 2-16.




| Metric equivalents | |
|---|---|
| inches (in.) | centimeters (cm) |
| 24 in. | 60.96 cm |
| 36 in. | 91.44 cm |
| 48 in. | 121.92 cm |
| 60 in. | 152.40 cm |

Source: Rulison Radiation Contamination Clearance Report, 1977

**Figure 2-12**
**Soil Sampling, Rulison Tank Area, October 1976, Garfield County, Colorado**



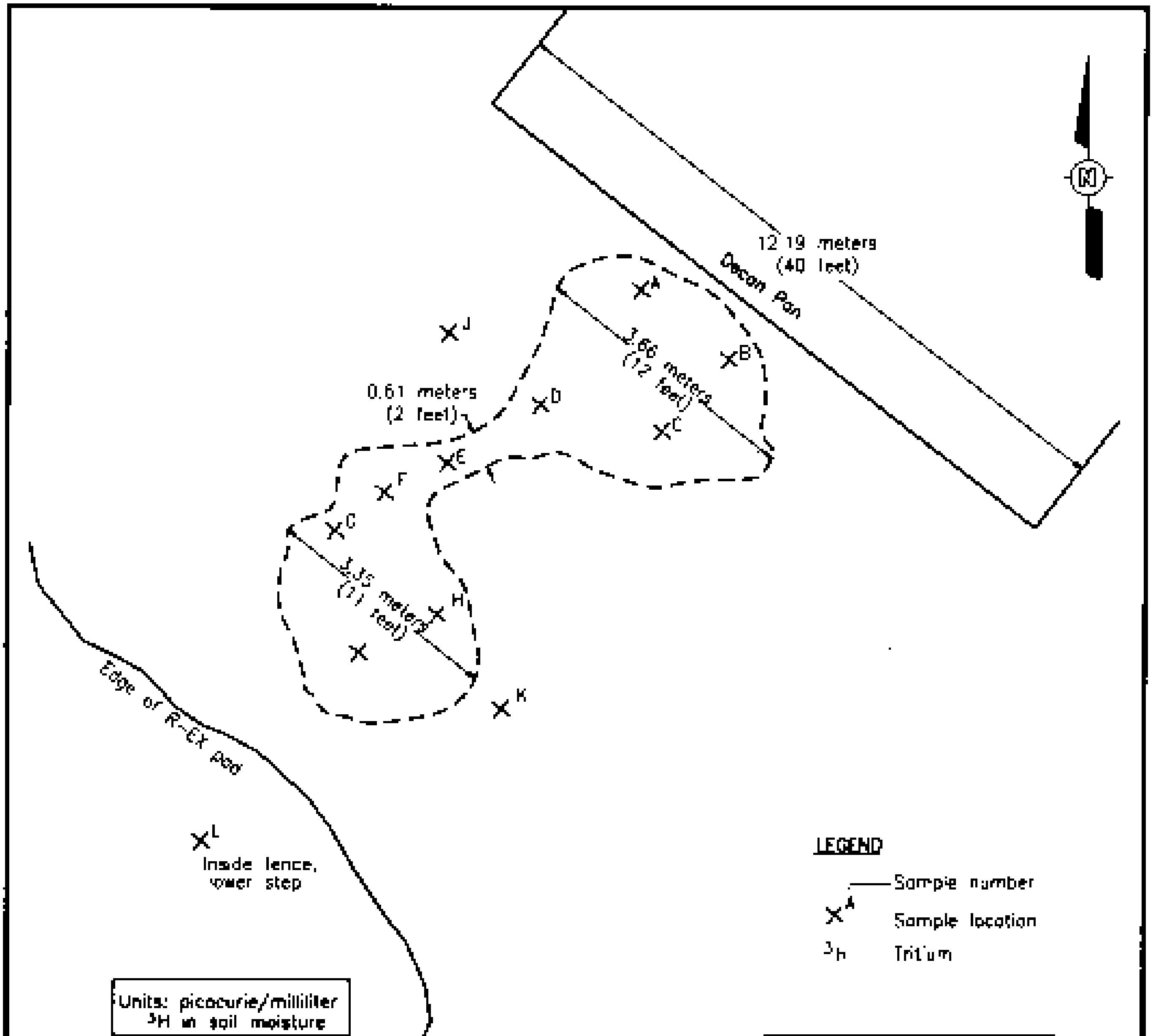

| Metric equivalents | |
|---|---|
| inches (in.) | centimeters (cm) |
| 1 in. | 2.54 cm |
| 12 in. | 30.48 cm |
| 24 in. | 60.96 cm |
| 36 in. | 91.44 cm |
| 48 in. | 121.92 cm |
| 60 in. | 152.40 cm |

| Location | Result |
|---|---|
| A | 11 |
| B | 8 |
| C | 6 |
| D | ND |
| E | ND |
| F | 359 |
| G | 4 |
| H | 19 |
| I | 55 |
| J | 24 |
| K | 20 |
| L | 50 |

| Profile South–24.6, East–13.7 | |
|---|---|
| sample depth | result |
| 1 in. | ND |
| 12 in. | 32 |
| 24 in. | 52 |
| 36 in. | 134 |

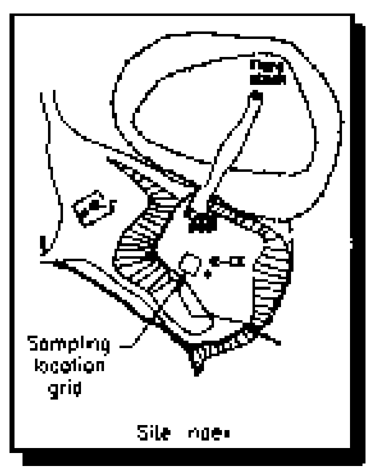
| Surface soil under gravel | |
|---|---|
| sample location | result |
| Northeast 1.22 m (4 ft) | ND |
| Southeast 1.22 m (4 ft) | ND |
| Northwest 1.22 m (4 ft) | ND |
| Southwest 1.22 m (4 ft) | ND |

**Figure 2-13**
**Soil Sampling, Rulison Separator Pan Area (previous pipe spill), September 30, 1976, Garfield County, Colorado**




| Units: picocurie/milliliter $^3H$ in soil moisture | |
|---|---|
| Location | Amount |
| A | 12,830 |
| B | 47,947 |
| C | 50,873 |
| D | 69,210 |
| E | 43,290 |
| F | 5,810 |
| G | 90,000 |
| H | 7,952 |
| I | 14,200 |
| J | BKGD |
| K | BKGD |
| L | 27 |

NOT TO SCALE




Note. Removed 0.30-meter (1-foot) soil at lower end and 10.16 centimeters (4 inches) at upper end (total of fifteen, 55-gallon drums)

Source: Eberline, 1977

4203408 08/20/96

**Figure 2-14**
**Surface Soil Sampling, Rulison Separator Spill, September 1, 1976, Garfield County, Colorado**

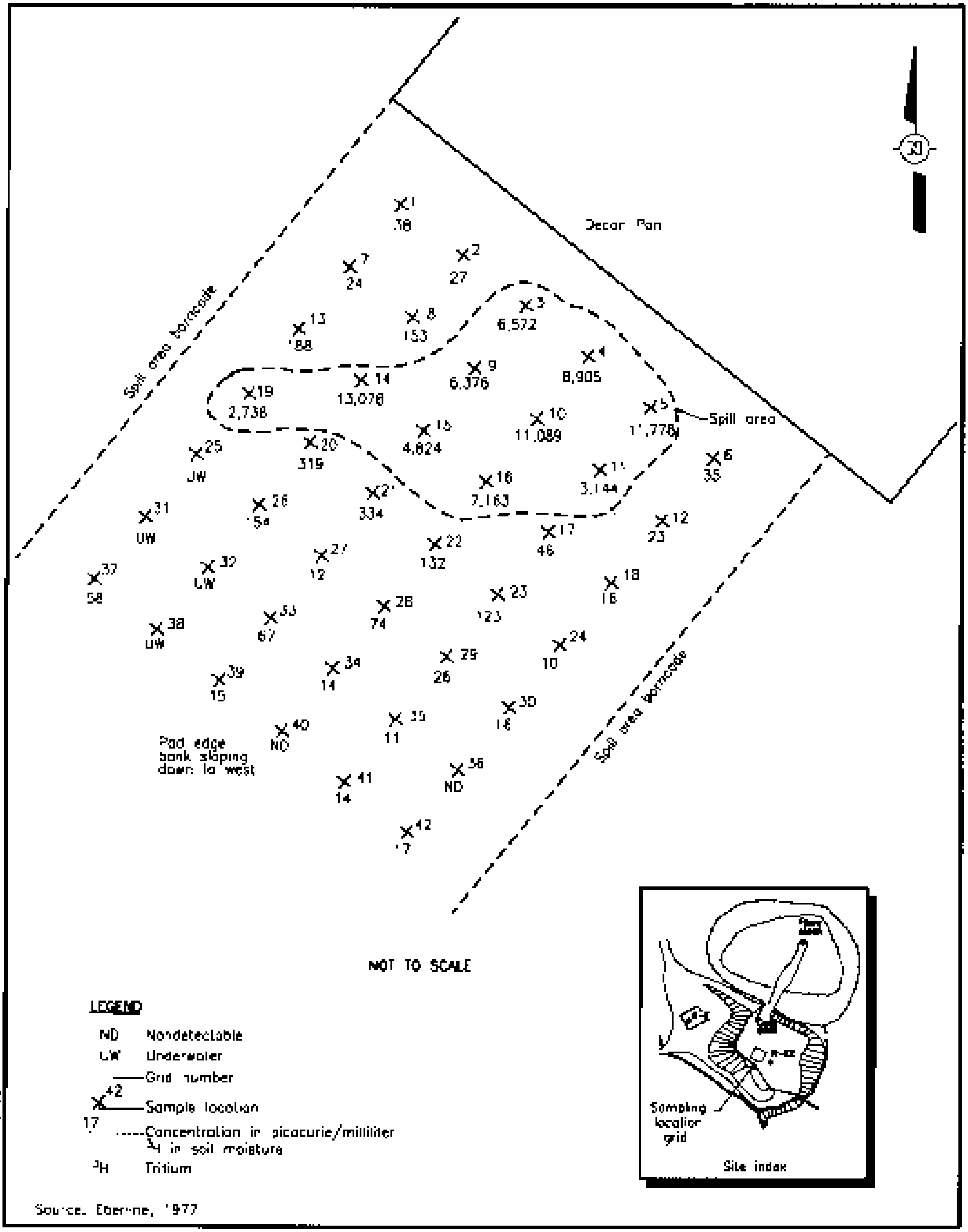
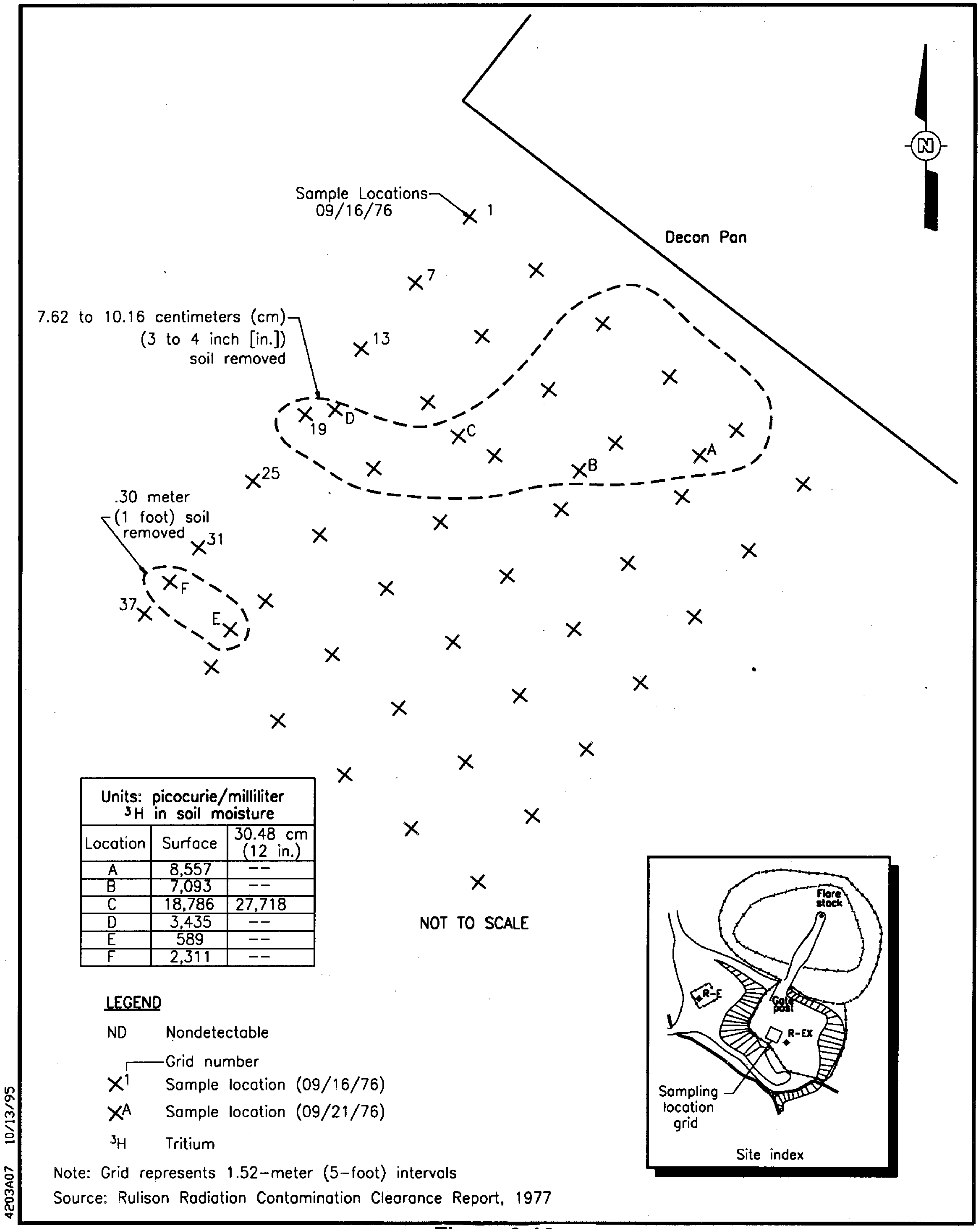



**Figure 2-15**
**Surface Soil Sampling, Rulison Separator Spill Survey after 15 Drum Soil Removal, September 16, 1976, Garfield County, Colorado**




| Units: picocurie/milliliter $^3H$ in soil moisture | | |
|---|---|---|
| Location | Surface | 30.48 cm (12 in.) |
| A | 8,557 | -- |
| B | 7,093 | -- |
| C | 18,786 | 27,718 |
| D | 3,435 | -- |
| E | 589 | -- |
| F | 2,311 | -- |

**Figure 2-16**
**Soil Sampling, Rulison Separator Spill after Removal of Five Additional Drums of Soil, September 21, 1976, Garfield County, Colorado**

## Table 2-4
## Tritium in Soil at Sampling Point N-14.2, E-.7 - October 1976

| Sample Identification | Sampling Depth centimeters (inches) | pCi/ml[a] in Soil Moisture |
|---|---|---|
| Location A | Surface | 15 |
| Location B | Surface | 795 |
| Location C | Surface | 9 |
| Location D | Surface | 9 |
| Location E | Surface | 18 |
| Location F | Surface | 71 |
| Location G | Surface | 267 |
| Location H | Surface | 48 |
| N-14.2, E-.7 | Surface | ND |
| N-14.2, E-.7 | 60.96 (24) | ND |
| N-14.2, E-.7 | 91.44 (36) | 19 |
| N-14.2, E-.7 | 121.92 (48) | 20 |
| Trench, South End | 91.44 (36) | 65 |
| Trench, South End | 121.92 (48) | 91 |
| Trench, South End | 152.40 (60) | 112 |
| Trench, Mid-Point | 91.44 (36) | 159 |
| Trench, Mid-Point | 121.92 (48) | 160 |
| Trench, Mid-Point | 152.40 (60) | 44 |
| Trench, North End | 91.44 (36) | 70 |
| Trench, North End | 121.92 (48) | 60 |
| Trench, North End | 152.40 (60) | 63 |

Source: Eberline, 1977

[a]Picocurie per milliliter

## Table 2-5
## Tritium in Soil at Sampling Point S-24.6, E-13.7 - October 1976

| Sample Identification | Sampling Depth centimeters (inches) | pCi/ml[a] in Soil Moisture |
|---|---|---|
| Location A | Surface | 11 |
| Location B | Surface | 8 |
| Location C | Surface | 6 |
| Location D | Surface | ND |
| Location E | Surface | ND |
| Location F | Surface | 359 |
| Location G | Surface | 4 |
| Location H | Surface | 19 |
| Location I | Surface | 55 |
| Location J | Surface | 24 |
| Location K | Surface | 20 |
| Location L | Surface | 50 |
| S-24.6, E-13.7 | 2.54 (1) | ND |
| S-24.6, E-13.7 | 30.48 (12) | 32 |
| S-24.6, E-13.7 | 60.96 (24) | 52 |
| S-24.6, E-13.7 | 91.44 (36) | 134 |
| S-24.6, E-13.7 (NE 1.22 m [4 ft]) | Surface | ND |
| S-24.6, E-13.7 (SE 1.22 m [4 ft]) | Surface | ND |
| S-24.6, E-13.7 (SW 1.22 m [4 ft]) | Surface | ND |
| S-24.6, E-13.7 (NW 1.22 m [4 ft]) | Surface | ND |
| Trench Wall, East End | 91.44 (36) | ND |
| Trench Wall, East End | 121.92 (48) | ND |
| Trench Wall, East End | 152.40 (60) | ND |
| Trench Wall, Center | 91.44 (36) | ND |
| Trench Wall, Center | 121.92 (48) | 28 |
| Trench Wall, Center | 152.40 (60) | ND |
| Trench Wall, West End | 91.44 (36) | ND |
| Trench Wall, West End | 121.92 (48) | ND |
| Trench Wall, West End | 152.40 (60) | ND |

Source: Eberline, 1977

[a]Picocurie per milliliter

On September 23, 1976, a transect of sampling holes was dug as shown on Figure 2-17 to determine a vertical profile of concentrations across the spill area. Results of these samples are indicated on the figure.

On October 1, 1976, a final comprehensive sampling of the spill area was made. Three ditches were dug with a backhoe across the area of interest to a depth of 152 cm (60 in.). The side walls of each ditch were sampled at four locations at depths of 30, 61, 91, 122, and 152 cm (12, 24, 36, 48 and 60 in.). Figure 2-18 shows the locations and results of these samples. Table 2-6 tabulates the same results. The figure and table indicate that the spill area had been successfully decontaminated.

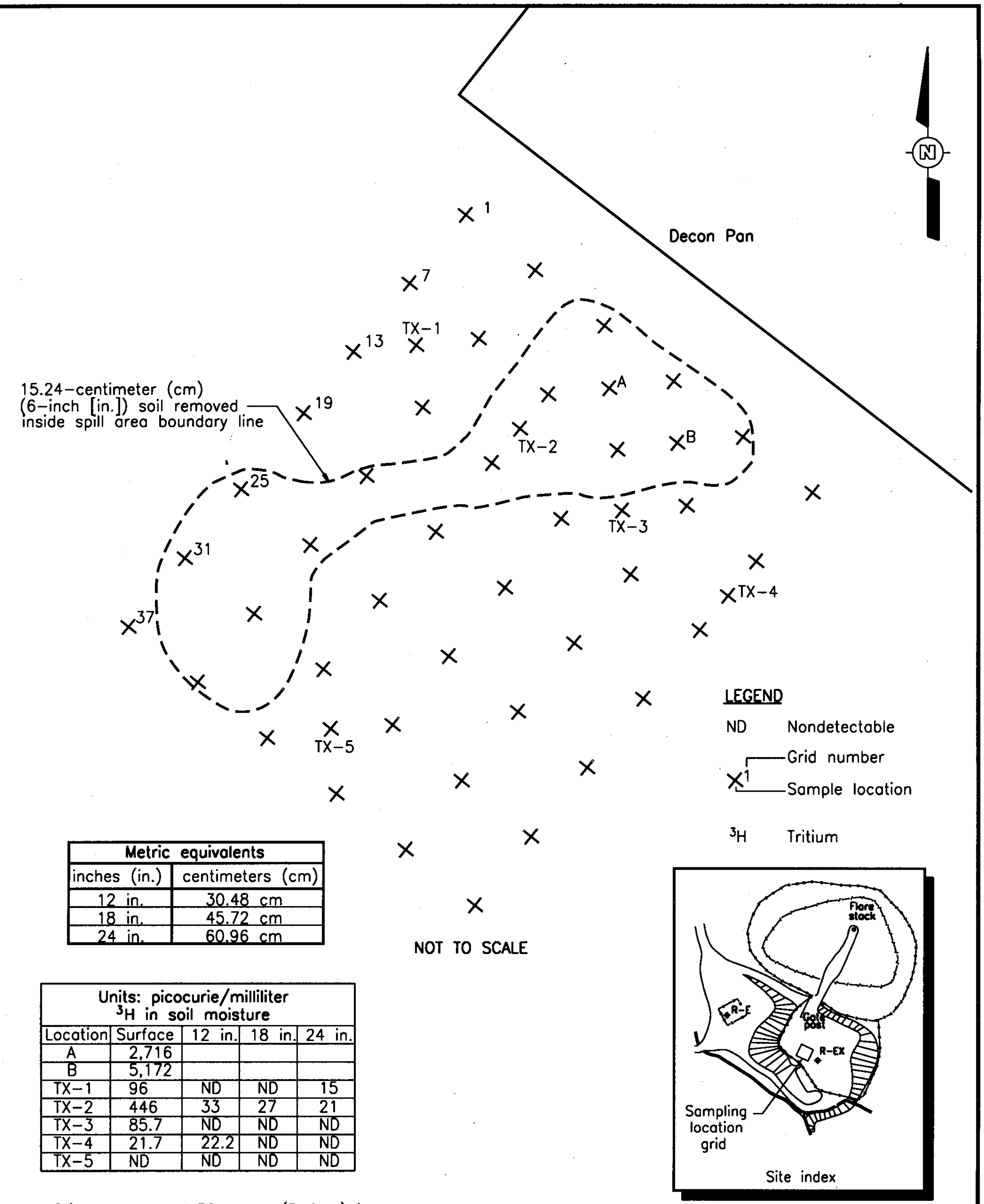
On October 4, 1976, 0.166 Ci of tritium in waste water and drilling mud were pumped into the Mesaverde formation at a depth of approximately 1,615 to 1,768 m (5,300 to 5,800 ft) for disposal. It should be noted that the potable aquifers above this depth were previously cemented off during emplacement drilling.

***Decontamination Work Area***

The decontamination work area included the area around and under the decontamination pan as well as the adjacent area used to convert low-level, tritiated water into steam for disposal. After work in the area was completed, the soil was sampled at 25 points on the surface and at a 30-cm (12-in.) depth, giving a total of 50 samples. Results of sample analyses and the locations are shown on Figure 2-19. The results are also tabulated on Table 2-7. Note that all concentrations of tritium in soil moisture were negligible except for two locations where the highest of four samples was 10,953 pCi/mL, still well below the guideline. This anomaly is explained by the fact that a small hole was punched through the pan at that location. A small amount of the decontaminated liquid leaked to the soil before the hole could be repaired.

***R-E Wellhead Area***

No contamination had ever been detected in the recirculating fluid during the destemming operation, nor were the wellhead or workover rig contaminated, therefore, there was little or no potential for soil contamination around the wellhead. However, since this area had not been previously sampled, soil samples were taken from the surface and from a 30-cm (12-in.) depth at the four corners, 0.3048 m (1 ft) from the cement cellar, giving a total of eight samples. Locations and analytical results are shown on Figure 2-20, and the results are tabulated in Table 2-8. Concentrations of tritium in soil moisture were negligible, as expected.




| Metric equivalents | |
|---|---|
| inches (in.) | centimeters (cm) |
| 12 in. | 30.48 cm |
| 18 in. | 45.72 cm |
| 24 in. | 60.96 cm |

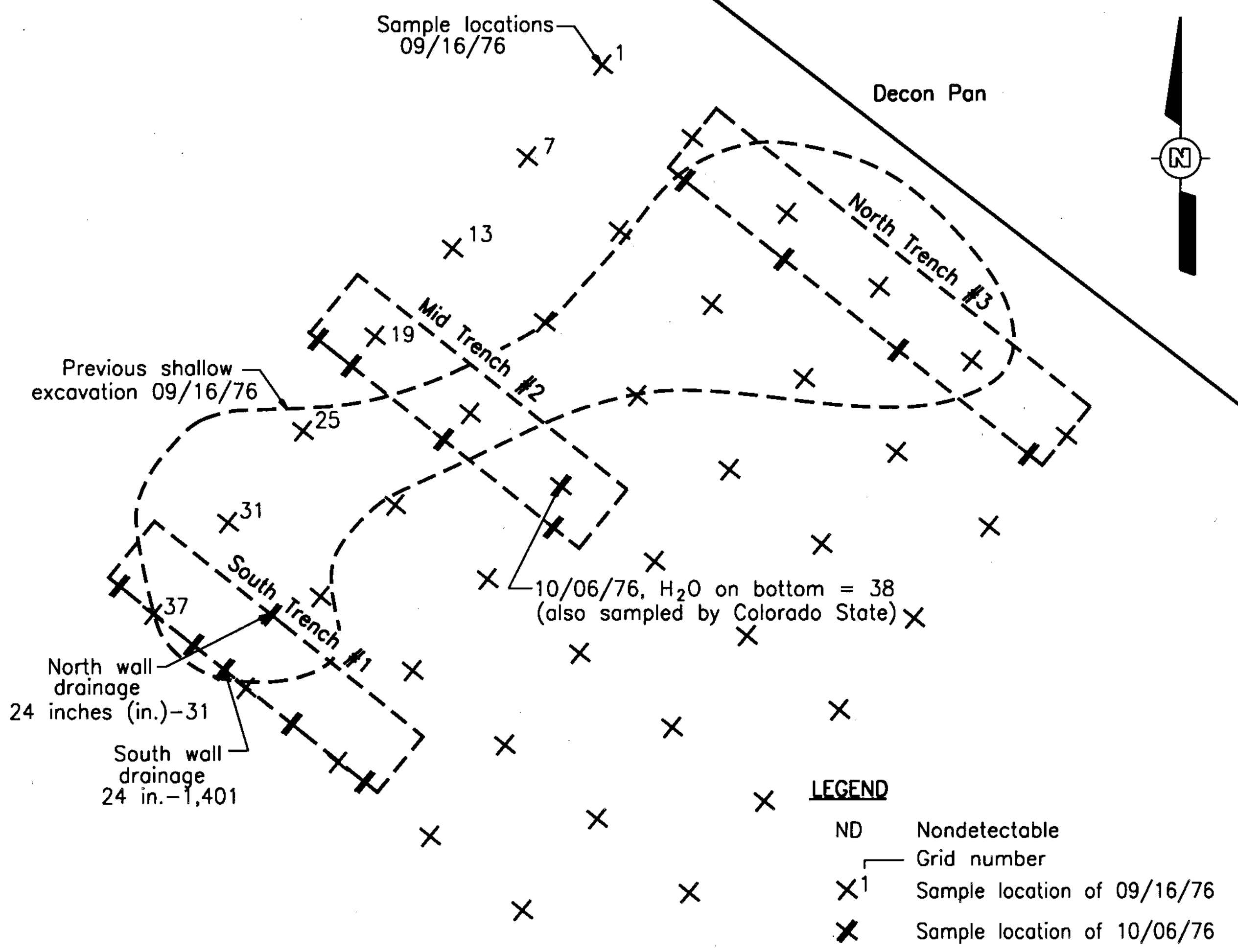
| Units: picocurie/milliliter $^3H$ in soil moisture | | | | |
|---|---|---|---|---|
| Location | Surface | 12 in. | 18 in. | 24 in. |
| A | 2,716 | | | |
| B | 5,172 | | | |
| TX-1 | 96 | ND | ND | 15 |
| TX-2 | 446 | 33 | 27 | 21 |
| TX-3 | 85.7 | ND | ND | ND |
| TX-4 | 21.7 | 22.2 | ND | ND |
| TX-5 | ND | ND | ND | ND |

Note: Grid represents 1.52-meter (5-foot) intervals

Source: Rulison Radiation Contamination Clearance Report, 1977

4203A04 10/13/95

**Figure 2-17**
**Soil Sampling, Rulison Separator Spill, September 23, 1976, Garfield County, Colorado**

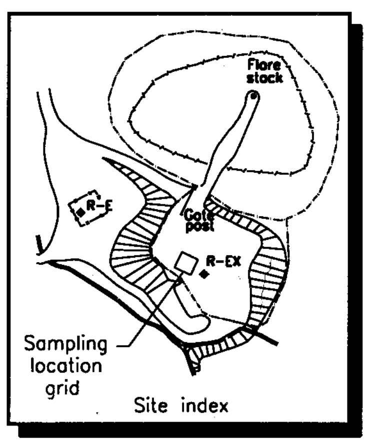



| North Trench #3 Units: picocurie/milliliter $^3H$ in soil moisture | | | | | |
|---|---|---|---|---|---|
| Sample location | 12 in. | 24 in. | 36 in. | 48 in. | 60 in. |
| West wall | 55 | 8 | 10 | ND | ND |
| Southwest wall | 10 | ND | ND | 51 | ND |
| Southeast wall | 11 | 32 | 112 | 50 | 33 |
| East wall | ND | ND | ND | ND | ND |

| Metric equivalents | |
|---|---|
| inches (in.) | centimeters (cm) |
| 12 in. | 30.48 cm |
| 24 in. | 60.96 cm |
| 36 in. | 91.44 cm |
| 48 in. | 121.92 cm |
| 60 in. | 152.40 cm |

| Mid Trench #2 Units: picocurie/milliliter $^3H$ in soil moisture | | | | | | |
|---|---|---|---|---|---|---|
| Sample location | Surface | 12 in. | 24 in. | 36 in. | 48 in. | 60 in. |
| West end | 18 | 298 | 454 | 282 | 325 | -- |
| West wall | -- | 610 | 1,175 | 1,288 | 1,171 | 10 |
| Center | -- | 38 | 21 | 9 | ND | ND |
| East wall | -- | ND | ND | ND | ND | ND |

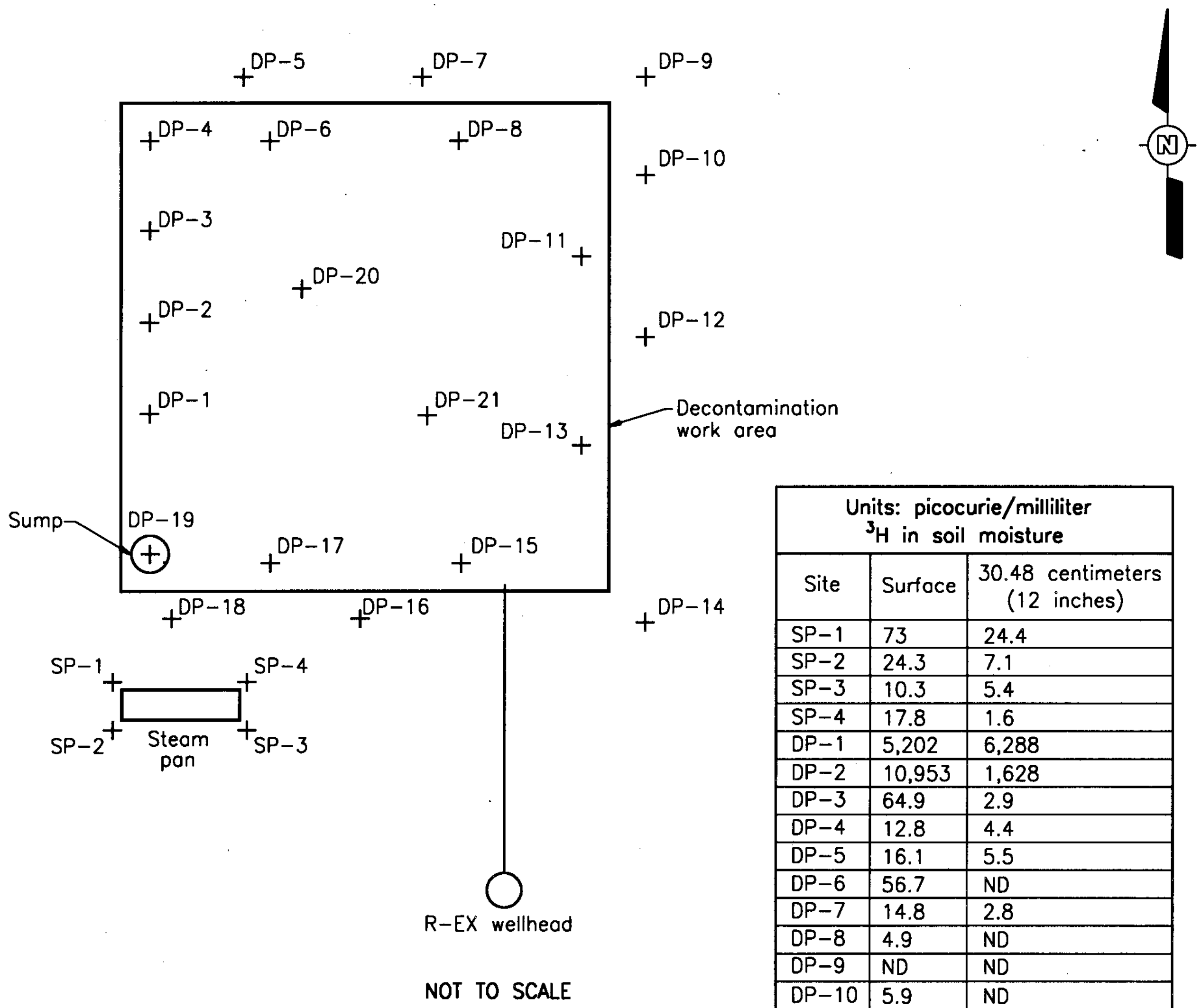
| South Trench #1 Units: picocurie/milliliter $^3H$ in soil moisture | | | | | |
|---|---|---|---|---|---|
| Sample location | 12 in. | 24 in. | 36 in. | 48 in. | 60 in. |
| West wall | 48 | 9 | 24 | 10 | 37 |
| Southwest wall | ND | ND | ND | ND | ND |
| Southeast wall | ND | ND | 116 | 124 | ND |
| East wall | ND | ND | ND | ND | ND |

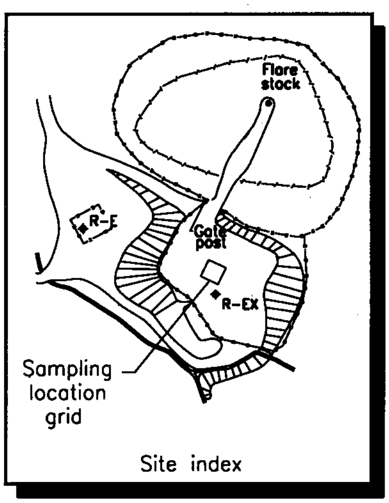



Source: Rulison Radiation Contamination Clearance Report, 1977

4203A05 10/13/95

**Figure 2-18**
**Rulison Separator Spill (Trenches), October 1, 1976, Garfield County, Colorado**




| Units: picocurie/milliliter $^3H$ in soil moisture | | |
|---|---|---|
| Site | Surface | 30.48 centimeters (12 inches) |
| SP-1 | 73 | 24.4 |
| SP-2 | 24.3 | 7.1 |
| SP-3 | 10.3 | 5.4 |
| SP-4 | 17.8 | 1.6 |
| DP-1 | 5,202 | 6,288 |
| DP-2 | 10,953 | 1,628 |
| DP-3 | 64.9 | 2.9 |
| DP-4 | 12.8 | 4.4 |
| DP-5 | 16.1 | 5.5 |
| DP-6 | 56.7 | ND |
| DP-7 | 14.8 | 2.8 |
| DP-8 | 4.9 | ND |
| DP-9 | ND | ND |
| DP-10 | 5.9 | ND |
| DP-11 | 6.0 | 3.7 |
| DP-12 | 10.9 | 3.5 |
| DP-13 | 8.2 | 2.8 |
| DP-14 | ND | ND |
| DP-15 | 4.5 | 5.8 |
| DP-16 | 12.1 | 2.3 |
| DP-17 | 25.4 | 9.5 |
| DP-18 | 35.3 | 93 |
| DP-19 | 35.7 | 31.1 |
| DP-20 | 54 | 4.5 |
| DP-21 | 17.1 | 4.4 |

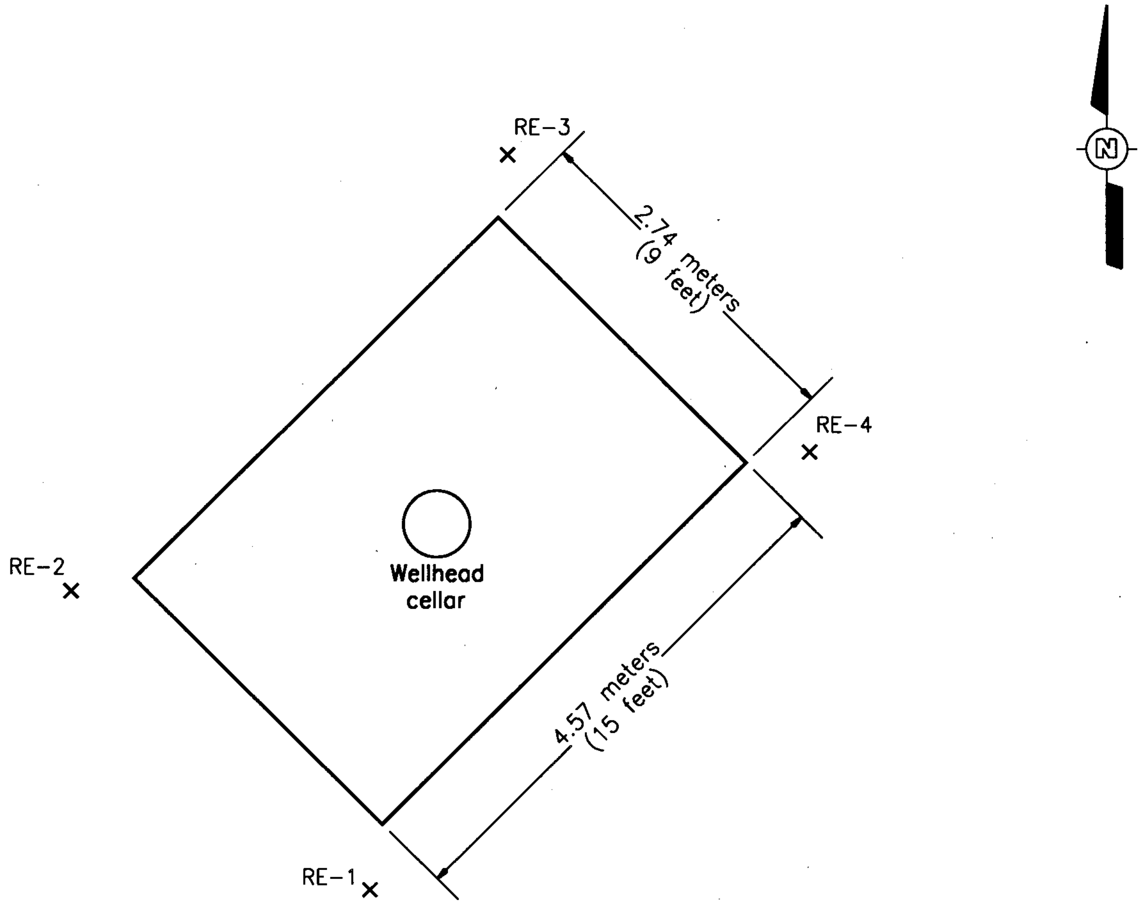
LEGEND

DP-1 Decon Pan
SP-1 Steam Pan
ND Nondetectable
+ Sample location
$^3H$ Tritium

Source: Rulison Radiation Contamination Clearance Report, 1977

4203A09 10/13/95

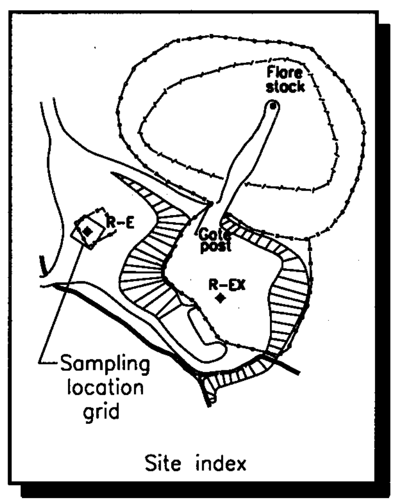
**Figure 2-19**
**Soil Sampling, Rulison R-EX Decon Pan Area, October 7, 1976, Garfield County, Colorado**




**LEGEND**

NOT TO SCALE

| | |
|---|---|
| ND | Nondetectable |
| RE-1 | Sample number |
| + | Sample location |
| $^3H$ | Tritium |




| Units: picocurie/milliliter $^3H$ in soil moisture | | |
|---|---|---|
| Site | Surface | 30.48 centimeters (12 inches) |
| RE-1 | 4.9 | ND |
| RE-2 | 5.7 | ND |
| RE-3 | 6.7 | 4.4 |
| RE-4 | ND | ND |

Source: Rulison Radiation Contamination Clearance Report, 1977

4203A03 10/13/95

**Figure 2-20**
**Soil Sampling, Rulison R-E Wellhead Cellar Area, October 7, 1976, Garfield County, Colorado**

**Table 2-6**
**Tritium in Soil at Spill Area after Decontamination - October 1976**
(Page 1 of 2)

| Sample Identification | Sampling Depth centimeters (inches) | pCi/ml[a] in Soil Moisture |
|---|---|---|
| South Trench #1, East Wall | 30.48 (12) | ND |
| South Trench #1, East Wall | 60.96 (24) | ND |
| South Trench #1, East Wall | 91.44 (36) | ND |
| South Trench #1, East Wall | 121.92 (48) | ND |
| South Trench #1, East Wall | 152.40 (60) | ND |
| South Trench #1, S.E. Wall | 30.48 (12) | ND |
| South Trench #1, S.E. Wall | 60.96 (24) | ND |
| South Trench #1, S.E. Wall | 91.44 (36) | 116 |
| South Trench #1, S.E. Wall | 121.92 (48) | 124 |
| South Trench #1, S.E. Wall | 152.40 (60) | ND |
| South Trench #1, S. Drain Area | 60.96 (24) | 1,401 |
| South Trench #1, S.W. Wall | 30.48 (12) | ND |
| South Trench #1, S.W. Wall | 60.96 (24) | ND |
| South Trench #1, S.W. Wall | 91.44 (36) | ND |
| South Trench #1, S.W. Wall | 121.92 (48) | ND |
| South Trench #1, S.W. Wall | 152.40 (60) | ND |
| South Trench #1, West Wall | 30.48 (12) | 48 |
| South Trench #1, West Wall | 60.96 (24) | 9 |
| South Trench #1, West Wall | 91.44 (36) | 24 |
| South Trench #1, West Wall | 121.92 (48) | 10 |
| South Trench #1, West Wall | 152.40 (60) | 37 |
| Mid Trench #2, East Wall | 30.48 (12) | ND |
| Mid Trench #2, East Wall | 60.96 (24) | ND |
| Mid Trench #2, East Wall | 91.44 (36) | ND |
| Mid Trench #2, East Wall | 121.92 (48) | ND |
| Mid Trench #2, East Wall | 152.40 (60) | ND |
| Mid Trench #2, Center | 30.48 (12) | 38 |
| Mid Trench #2, Center | 60.96 (24) | 21 |
| Mid Trench #2, Center | 91.44 (36) | 9 |
| Mid Trench #2, Center | 121.92 (48) | ND |
| Mid Trench #2, Center | 152.40 (60) | ND |
| Mid Trench #2, West Wall | 30.48 (12) | 610 |
| Mid Trench #2, West Wall | 60.96 (24) | 1,175 |
| Mid Trench #2, West Wall | 91.44 (36) | 1,288 |
| Mid Trench #2, West Wall | 121.92 (48) | 1,171 |
| Mid Trench #2, West Wall | 152.40 (60) | 10 |
| Mid Trench #2, West End | Surface | 18 |
| Mid Trench #2, West End | 30.48 (12) | 298 |
| Mid Trench #2, West End | 60.96 (24) | 454 |
| Mid Trench #2, West End | 91.44 (36) | 282 |
| Mid Trench #2, West End | 121.92 (48) | 352 |

Refer to footnotes at end of table

## Table 2-6
## Tritium in Soil at Spill Area after Decontamination - October 1976
(Page 2 of 2)

| Sample Identification | Sampling Depth centimeters (inches) | pCi/ml[a] in Soil Moisture |
|---|---|---|
| North Trench #3, East Wall | 30.48 (12) | ND |
| North Trench #3, East Wall | 60.96 (24) | ND |
| North Trench #3, East Wall | 91.44 (36) | ND |
| North Trench #3, East Wall | 121.92 (48) | ND |
| North Trench #3, East Wall | 152.40 (60) | ND |
| North Trench #3, S.E. Wall | 30.48 (12) | 11 |
| North Trench #3, S.E. Wall | 60.96 (24) | 23 |
| North Trench #3, S.E. Wall | 91.44 (36) | 112 |
| North Trench #3, S.E. Wall | 121.92 (48) | 50 |
| North Trench #3, S.E. Wall | 152.40 (60) | 33 |
| North Trench #3, S.W. Wall | 30.48 (12) | 10 |
| North Trench #3, S.W. Wall | 60.96 (24) | ND |
| North Trench #3, S.W. Wall | 91.44 (36) | ND |
| North Trench #3, S.W. Wall | 121.92 (48) | 51 |
| North Trench #3, S.W. Wall | 152.40 (60) | ND |
| North Trench #3, West Wall | 30.48 (12) | 55 |
| North Trench #3, West Wall | 60.96 (24) | 8 |
| North Trench #3, West Wall | 91.44 (36) | 10 |
| North Trench #3, West Wall | 121.92 (48) | ND |
| North Trench #3, West Wall | 152.40 (60) | ND |

Source: Eberline, 1977

[a]Picocurie per milliliter

## Table 2-7
## Tritium in Decontamination Work Area Soil
(Page 1 of 2)

| Sample Identification | Sampling Depth centimeters (inches) | pCi/ml[a] in Soil Moisture |
|---|---|---|
| DP-1 | Surface | 5,202 |
| DP-1 | 30.48 (12) | 6,288 |
| DP-2 | Surface | 10,953 |
| DP-2 | 30.48 (12) | 1,628 |
| DP-3 | Surface | 64.9 |
| DP-3 | 30.48 (12) | 2.9 |
| DP-4 | Surface | 12.8 |
| DP-4 | 30.48 (12) | 4.4 |
| DP-5 | Surface | 16.1 |
| DP-5 | 30.48 (12) | 5.5 |
| DP-6 | Surface | 56.7 |
| DP-6 | 30.48 (12) | ND |
| DP-7 | Surface | 14.8 |
| DP-7 | 30.48 (12) | 2.8 |
| DP-8 | Surface | 4.9 |
| DP-8 | 30.48 (12) | ND |
| DP-9 | Surface | ND |
| DP-9 | 30.48 (12) | ND |
| DP-10 | Surface | 5.9 |
| DP-10 | 30.48 (12) | ND |
| DP-11 | Surface | 6 |
| DP-11 | 30.48 (12) | 3.7 |
| DP-12 | Surface | 10.9 |
| DP-12 | 30.48 (12) | 3.5 |
| DP-13 | Surface | 8.2 |
| DP-13 | 30.48 (12) | 2.8 |
| DP-14 | Surface | ND |
| DP-14 | 30.48 (12) | ND |
| DP-15 | Surface | 4.5 |
| DP-15 | 30.48 (12) | 5.8 |
| DP-16 | Surface | 12.1 |
| DP-16 | 30.48 (12) | 2.3 |
| DP-17 | Surface | 25.4 |
| DP-17 | 30.48 (12) | 9.5 |
| DP-18 | Surface | 35.3 |
| DP-18 | 30.48 (12) | 93 |
| DP-19 | Surface | 35.7 |
| DP-19 | 30.48 (12) | 31.1 |
| DP-20 | Surface | 54 |
| DP-20 | 30.48 (12) | 4.5 |
| DP-21 | Surface | 17.1 |

Refer to footnotes at end of table

## Table 2-7
## Tritium in Decontamination Work Area Soil
(Page 2 of 2)

| Sample Identification | Sampling Depth centimeters (inches) | pCi/ml[a] in Soil Moisture |
|---|---|---|
| DP-21 | 30.48 (12) | 4.4 |
| SP-1 | Surface | 73 |
| SP-1 | 30.48 (12) | 24.4 |
| SP-2 | Surface | 24.3 |
| SP-2 | 30.48 (12) | 7.1 |
| SP-3 | Surface | 10.3 |
| SP-3 | 30.48 (12) | 5.4 |
| SP-4 | Surface | 17.8 |
| SP-4 | 30.48 (12) | 1.6 |

Source: Eberline, 1977

[a]Picocurie per milliliter

## Table 2-8
## Tritium in Soil at R-E Wellhead - October 1976

| Sample Identification | Sampling Depth centimeters (inches) | pCi/ml[a] in Soil Moisture |
|---|---|---|
| RE-1 | Surface | 4.9 |
| RE-1 | 30.48 (12) | ND |
| RE-2 | Surface | 5.7 |
| RE-2 | 30.48 (12) | ND |
| RE-3 | Surface | 6.7 |
| RE-3 | 30.48 (12) | 4.4 |
| RE-4 | Surface | ND |
| RE-4 | 30.48 (12) | ND |

Source: Eberline, 1977

[a]Picocurie per milliliter

***Surface Water***

Surface water was sampled at the four locations mentioned: the creek above and below the site, the spring on the site, and the spring down the road from the site. Tritium was not detected at a detection sensitivity of 2 pCi/mL.

### *2.2.2.4.4 Aerial Radiological Survey*

An aerial radiological survey was conducted over the Project Rulison Site, 64 km (40 mi) northeast of Grand Junction, Colorado, from July 6 through July 12, 1993. Parallel lines were flown at intervals of 76 m (250 ft) over a 17-$km^2$ (6.5-$mi^2$) area at a 61-m (200-ft) altitude surrounding Battlement Creek Valley. The gamma energy spectra obtained were reduced to an exposure rate contour map overlaid on a high altitude aerial photograph of the area. The terrestrial exposure rate varied from 3.5 to 12.5 microroentgens per hour ($\mu$R/hr) (excluding cosmic) at 1 m (3 ft) above ground level. No anomalous or man-made isotopes were found (EG&G, 1995, p. ii).

### *2.2.2.5 Sampling Summary*

A review of the history of operations at the Rulison Site, the analytical results of sampling programs, and the results of the detailed radiological survey identified the extent of radioactive contamination on the property. The only nuclide of concern was tritium in surface soil moisture. A reasonable and conscientious effort was made to reduce contamination to an amount as low as practicable. Tritium concentrations, where detected, were in most cases negligible and well below the guideline (ERDA, 1976). There is no reason the Rulison Site should change from unrestricted use, subject to applicable subsurface drilling restrictions as stated in *Project Rulison Well Plugging and Site Abandonment Plan*, NVO-174 (Rev. 1) and *Project Rulison Well Plugging and Site Abandonment Final Report*, NVO-187 (ERDA, 1976, p. 16; ERDA, 1977, p. 20).

# 3.0 Review of Regulatory Status

## 3.1 Federal Regulatory Overview

In May 1976, an environmental impact assessment of the Rulison Site was prepared in accordance with the requirements of Title 10 *Code of Federal Regulations* (CFR), Part 11, dated February 16, 1974, which detailed the procedures to be followed for ERDA implementation of the *National Environmental Policy Act of 1969* (ERDA, 1976). The purpose of this assessment was to present a brief description of proposed activities for the Rulison well plugging and site abandonment cleanup and an evaluation of whether an environmental impact statement needed to be prepared.

It was determined from the assessment that the requested action did not constitute a major federal action which significantly affecting the environment, in the sense of the *National Environmental Policy Act (NEPA), Section 102(2)(c)*. At that time, it was determined that no adverse effects to the environment had occurred (ERDA, 1976, p. 18).

In May 1986, Reynolds Electrical & Engineering Company, Inc., conducted a Hazardous Waste Installation Assessment in which three “operational areas” were sampled, and a report was produced. The descriptive name and actual location of these areas is shown on Figure 3-1. No hazardous materials were detected in any of the samples collected at the Rulison Site (Fauver, 1986, p. 30). The objective of the Hazardous Waste Installation Assessment Project was to identify and evaluate inactive sites at DOE/NV installations where hazardous substances may have been released into the environment. These “Installation Assessments” were the first phase of the DOE/NV effort to satisfy DOE Order 5480/14, which required that federal facilities comply with the CERCLA.

A CERCLA Preliminary Assessment was prepared by the DRI for the Rulison Site in 1988. The *CERCLA/Superfund Amendments and Reauthorization Act* provides that all EPA regulations and criteria pertaining to inactive hazardous waste sites are applicable to U.S. Government facilities. Included among the provisions of these acts are requirements for a preliminary assessment of each facility and an evaluation based on the same Hazard Ranking System (HRS) that is applied to nonfederal facilities.

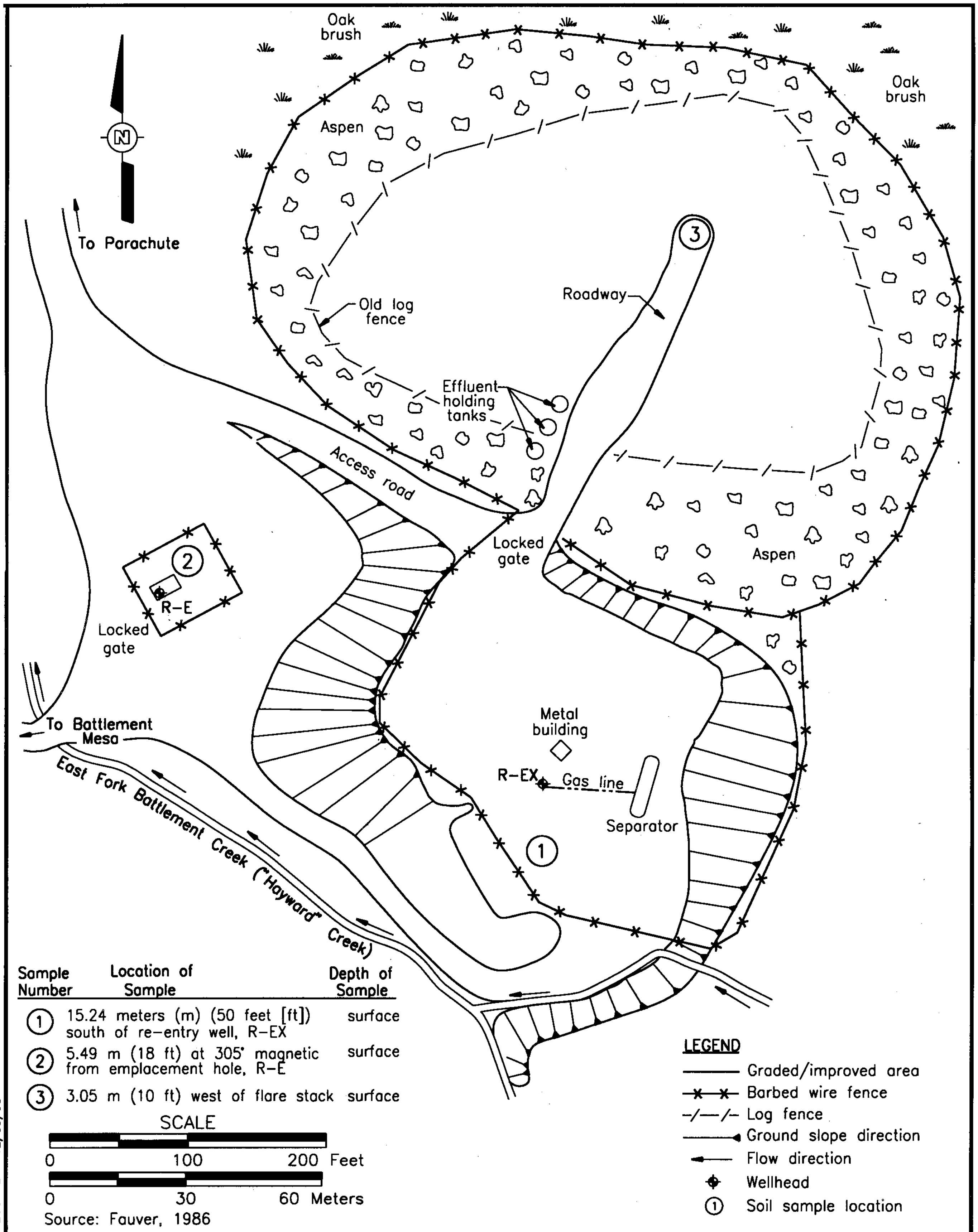



**Figure 3-1**
**Soil Sampling, Potential Hazardous Waste Release Sites at the Rulison Test Site, September 1976, Garfield County, Colorado**

The 1988 preliminary assessment concluded that radiation was released to the environment during Project Rulison production testing. The R-E and R-EX wells were plugged to prevent the escape of radiation, and the explosive device was detonated 2,568 m (8,426 ft) below ground surface in the Mesa Verde formation. Given the extremely low permeability of this formation, radionuclide migration should be very limited; however, surface and subsurface water quality monitoring is still being conducted near the Rulison Site. A preliminary HRS score for Project Rulison was calculated to be 15.12, well below the score of 28.5 which is required for a site to be placed on the National Priorities List. The only contributing score was from the air route due to the release of radioactivity during gas production testing. An extensive on- and off-site radiation surveillance effort failed to detect any radioactivity other than tritium and krypton in the environment. Typically, the concentrations of these isotopes in the air were around one 10-millionth of their concentration in the gas (DOE, 1984). Because the emplacement and re-entry holes have been plugged, it is unlikely that further air releases will occur.

*DOE Order 5440.1E*, implementing NEPA, requires that the presence of environmentally sensitive resources such as cultural resources, sensitive species, wetlands, and floodplains be determined so that the appropriate level of NEPA documentation can be established and adequate mitigation measures implemented. IT Corporation (IT) prepared several reports documenting the surveys conducted for these environmentally sensitive resources (IT, 1993a; IT, 1993b; IT, 1993c).

## *3.2 State Regulatory Overview*

### *3.2.1 Property of Historic, Archaeological, or Architectural Significance*

The Colorado Office of Archaeology and Historic Preservation instituted a file search on December 22, 1992, and IT conducted a Class II Cultural Resources Field Survey on July 1, 1993 (IT, 1993a). The purpose of the investigation was to comply with federal mandates pertaining to the historic preservation of cultural resources, including Section 106 of the *National Historic Preservation Act*, as implemented by the Advisory Council on Historic Preservation, *(Title 36 CFR Part 800; the Archaeological and Historic Preservation Act), Executive Order 11593*, and the *American Indian Religious Freedom Act*. The DOE regulations contained in *Title 10 CFR Part 1021* also require compliance with historic preservation mandates. The Project Rulison survey was conducted on private lands under the auspices of State of Colorado Archaeological Permit No. 93-48, the survey was conducted to evaluate the potential impacts that could occur as a result of performing site characterization or possible remedial activities at the Rulison Site.

The survey resulted in one historic, isolated find consisting of a cast iron stove and one historic monument, the Rulison Site SGZ. The Rulison Site SGZ monument (5GF1656) should be considered eligible for nomination to the National Register of Historic Places along with three other similar sites in Colorado and New Mexico. The monument inscription at SGZ reads:

> *No excavation, drilling, and/or removal of subsurface materials to a depth of 12,450 ft is permitted within Lot 11, NE 1/4 SW 1/4 of Section 25, Township 7 South, Range 95 West, 6th Principal Meridian, Garfield County, Colorado, without U.S. Government permission. U.S. Atomic Energy Commission and the Department of the Interior (AEC, 1973a).*

Based on the field survey results, it was determined that project field activities could proceed. However, if any cultural material were to be uncovered during any field activities, it is recommended that a qualified archaeologist be called in to assess the find. The U.S. Bureau of Land Management (BLM), the Glenwood Springs Resource Area archaeologist, and the Office of Archaeology and Historic Preservation should also be notified under those circumstances.

### *3.2.2 Special Sources of Water*

No water sources within this area are vital to the region. The East Fork of Battlement Creek is used, in part, to irrigate land downstream from the Rulison Site (USGS, 1970, p. 7). Groundwater resources around the Rulison Site occur in surficial deposits such as fan gravel and terraces. These deposits are reportedly “the only sources of usable groundwater near the Rulison Site” (USGS, 1970. p. 9). Available records do not indicate the existence of a sole-source aquifer or a well-head protection area at this site. Refer to Figure 2-1 which shows the wells in the vicinity of the Rulison Site.

# 4.0 Surrounding Land Use

The Rulison Site is located a few miles outside of the White River National Forest and approximately nine miles north of the Grand Mesa National Forest. No areas within the Rulison Site are federal or state property (BLM, 1980 and 1986; USGS, 1987). Surface ground zero is located on the approximately 16-hectare (40-acre) lot owned by Mr. Cary Weldon; however, the U.S. Government retains control of the subsurface rights. The former drilling effluent pond is on land jointly owned by Ms. Cristy Koeneke and Mr. Craig Hayward. The surrounding land is also privately owned. A map showing current ownership is included as Figure 4-1.

The surrounding land is currently used for recreational purposes (e.g., hunting and fishing) and cattle grazing. During the summer months, a residence located approximately 427 m (1,400 ft) from the former drilling effluent pond is occupied. Future use of this land is likely to also include recreational and grazing applications.

The closest population center to the Rulison Site is the town of Parachute, which is located approximately 12 km (8 mi) north of the site and has a recorded population of 660 (Rand McNally, 1993).

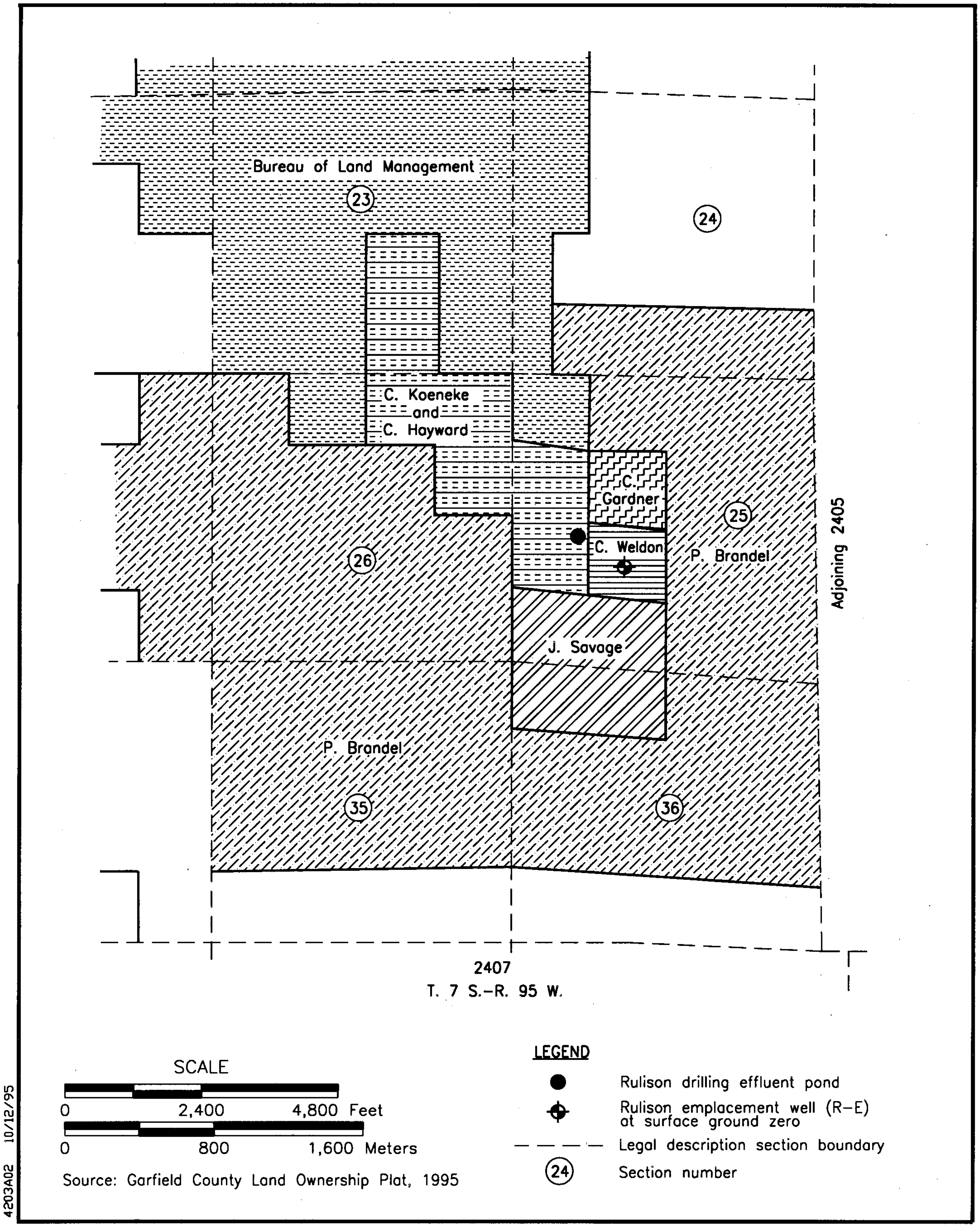



**Figure 4-1**
**Project Rulison, Garfield County, Land Ownership Map**

# 5.0 Physical Environment

## 5.1 Meteorology

West-central Colorado is generally classified as semiarid, with low precipitation and relative humidity, warm summer temperatures, and abundant sunshine (Marlatt, 1973). Winds are generally from the west, but fail to carry much moisture from the Pacific Ocean past mountain barriers. The average annual precipitation for the Rulison Site is 50 cm (20 in.) and the temperature ranges from -10 degrees Fahrenheit (°F) to +98°F (-23 degrees Celsius [°C] to +37°C). Annual precipitation ranges from 25 cm (10 in.) at elevations of 1,524 m (5,000 ft) above mean sea level (amsl) to 64 cm (25 in.) at 2,439 m (8,000 ft) amsl. Winter snowfall may exceed 256 cm (100 in.) on plateau tops (Marlatt, 1973). The length of the growing season at Parachute is 150 days (Brooks et al., 1933). Movement of air away from the Rulison Site is controlled by the valley drainage winds and daily up-slope winds in both the Battlement Creek Valley and the Colorado River Valley. The regional gradient wind generally blows east-northeast, above the topographical features (DOE, 1984, p. 3).

The evaporative demand on the north slope of Battlement Mesa is fairly low compared to that of the area north of the Colorado River (Marlatt, 1973). Moisture has a chance to soak into the volcanic soils; thus, the vegetative community is well developed. This enables the community to support a variety of faunal species.

## 5.2 Biota

### 5.2.1 Sensitive Species Survey

The Rulison Site has the potential for supporting a large number of wildlife species. Uplands, wetlands, and surface water bodies offer numerous resources for the organisms that use the site. Food resources for deer, rodents, birds, and canids are abundant. Acorns from the Gambel oak and seeds from the conifers provide mast for herbivores which, in turn, are prey for the carnivores. The beavers on the site feed primarily on aspen. Cover required for all wildlife species is abundant and varied.

A Level I reconnaissance survey for sensitive species was conducted at the Rulison Site in June 1993 (IT, 1993b). For this survey, sensitive species included both federal- and state-listed threatened and endangered species and candidate species. Tables 5-1 through 5-3 list the various species found on the Rulison Site during this survey.

In addition, suitable habitat and food resources for several endangered and candidate bird species were identified; however, none of these species were observed during the site reconnaissance. The tiger salamander *(Ambystoma tigrinium)*, which is a State listed species, was observed in the drilling effluent pond. However, communication with the Colorado Division of Wildlife indicated that the tiger salamander is not a species of special concern in that area (Nessler, 1995).

### 5.2.2 Vegetation

The habitats present at the Rulison Site are a combination of Rocky Mountain Montane and Subalpine forest (Whitney, 1992). At lower elevations (2,290 to 2,440 m [7,500 to 8,000 ft]), the dominant montane vegetation consists of quaking aspen (*Populus tremuloides*), Colorado blue spruce (*Pecea pungens*), willow (*Salix spp.*), lodgepole pine (*Pinus contorta*), Gambel oak (*Quercus gambelii*), Douglas fir (*Pseudotsuga menziesii*), mountain mahogany (*Cercocarpus montenus*), service berry (*Amelanchier alnifolia*), and mixed mountain shrubs and grasses. The plant species are suitable for grazing of cattle and horses. At elevations greater than 2,440 m (8,000 ft), subalpine species such as sub-alpine fir (*Abies lasiocarpa*) and Engelmann spruce (*Picea engelmannii*) become more prevalent in the vegetation.

## 5.3 Topography

The site is located on the north slope of Battlement Mesa, on the upper reaches of Battlement Creek, at an elevation of approximately 2,500 m (8,200 ft) (Figure 5-1). The valley is open to the north-northwest and is bounded on the remaining three sides by steep mountain slopes, which rise to elevations above 2,927 m (9,600 ft).

**Table 5-1**
**List of Reptile and Amphibian Species Observed during the Sensitive Species Survey of the Rulison Site, Colorado, June 1993**

| Scientific Name | Common Name |
|---|---|
| **Amphibians** | |
| Family: Ambystomatidae<br>*Ambystoma tigrinum* | Tiger Salamander |
| **Reptiles** | |
| Family: Colubridae<br>*Opheodrys vernacis* | Smooth Green Snake |

**Table 5-2**
**List of Bird Species Observed during the Sensitive Species Survey of the Rulison Site, Colorado, June 1993**

| Scientific | Common Name |
|---|---|
| Family: Accipitridae<br>*Aquila chrysaetos* | Golden Eagle |
| Family: Scolopacidae<br>*Calidris minutilla* | Least Sandpiper |
| Family: Columbidae<br>*Zenaida macroura* | Morning Dove |
| Family: Trochilidae<br>*Selasphorus platycercus* | Broad-Tailed Hummingbird |
| Family: Picidae<br>*Sphyrapicus varius*<br>*Colaptes auratus* | Yellow-Bellied Sapsucker<br>Northern Flicker |
| Family: Hirundinidae<br>*Tachycineta bicolor* | Violet-Green Swallow |
| Family: Corvidae<br>*Corvus corax* | Common Raven |
| Family: Paridae<br>*Parus atricapillus* | Black-Capped Chickadee |
| Family: Troglodytidae<br>*Troglodytes aedon* | House Wren |
| Family: Muscicapidae<br>*Regulus calendula*<br>*Catharus guttatus*<br>*Turdus migratorius* | Ruby-Crowned Kinglet<br>Hermit Thrush<br>American Robin |
| Family: Emberizidae<br>Subfamily: Parulinae<br>*Vermivora virginae*<br>*Dendorica petechia*<br>*Dendrocia coronata*<br>*Oporornis tolmiei* | Virginia's Warbler<br>Yellow Warbler<br>Yellow-Rumped Warbler [Audubon's form]<br>MacGillivray's Warbler |
| Subfamily: Emberizinae<br>*Amophila ruficeps*<br>*Pooecetes gramineus* | Rufous-Crowned Sparrow<br>Vesper Sparrow |
| Family: Passeridae<br>*Passer domesticus* | House Sparrow |

**Table 5-3**
**List of Mammal Species Observed during the Sensitive Species Survey of the Rulison Site, Colorado, June 1993**

| Scientific Name | Common Name |
|---|---|
| Family: Leporidae<br>*Sylvilagus nuttalli* | Mountain Cottontail |
| Family: Sciuridae<br>*Eutamias minimus*<br>*Marmota flaviventris*<br>*Citellus lateralis* | Least Chipmunk<br>Yellow-Bellied Marmot<br>Golden-Mantled Ground Squirrel |
| Family: Castoridae<br>*Castor canadensis* | Beaver |
| Family: Procyonidae<br>*Procyon lotor* | Raccoon |
| Family: Canidae<br>*Canis familiaris*<br>*Canis latrans* | Domestic Dog<br>Coyote |
| Family: Cervidae<br>*Odocoileus hemionus* | Mule Deer |

## *5.4 Soils*

The Rifle Area, Colorado, Soil Survey (USDA, 1980) indicates two soil types within the 161,880-square meters ($m^2$) (40-acre) site. These include Bucklon-Inchau association loams and Cochetopa loam (Figure 5-2). The character of these soils was confirmed by field analysis of numerous soil borings during the wetlands and floodplain investigation performed in June 1993 (IT, 1993c, p. 4-4). Neither of these soil types constitutes prime agricultural land (Carlson, 1993, personal communication).

Numerous soil borings were taken and field-analyzed during the wetlands delineation. Hydric soils were identified in areas identified as wetlands. These results correspond with the U.S. Department of Agriculture, Soil Conservation Service soils mapping of the Rifle Area.

Bucklon soils make up approximately 55 percent of the map unit and are found on the more steep, convex parts of the landscape. It is a shallow and well-drained soil. Permeability of the Bucklon soil is slow above bedrock. The available water capacity is very low. Effective rooting depth is about 0.25 to 0.51 m (10 to 20 in.). Surface runoff is medium, and the erosion hazard is severe.

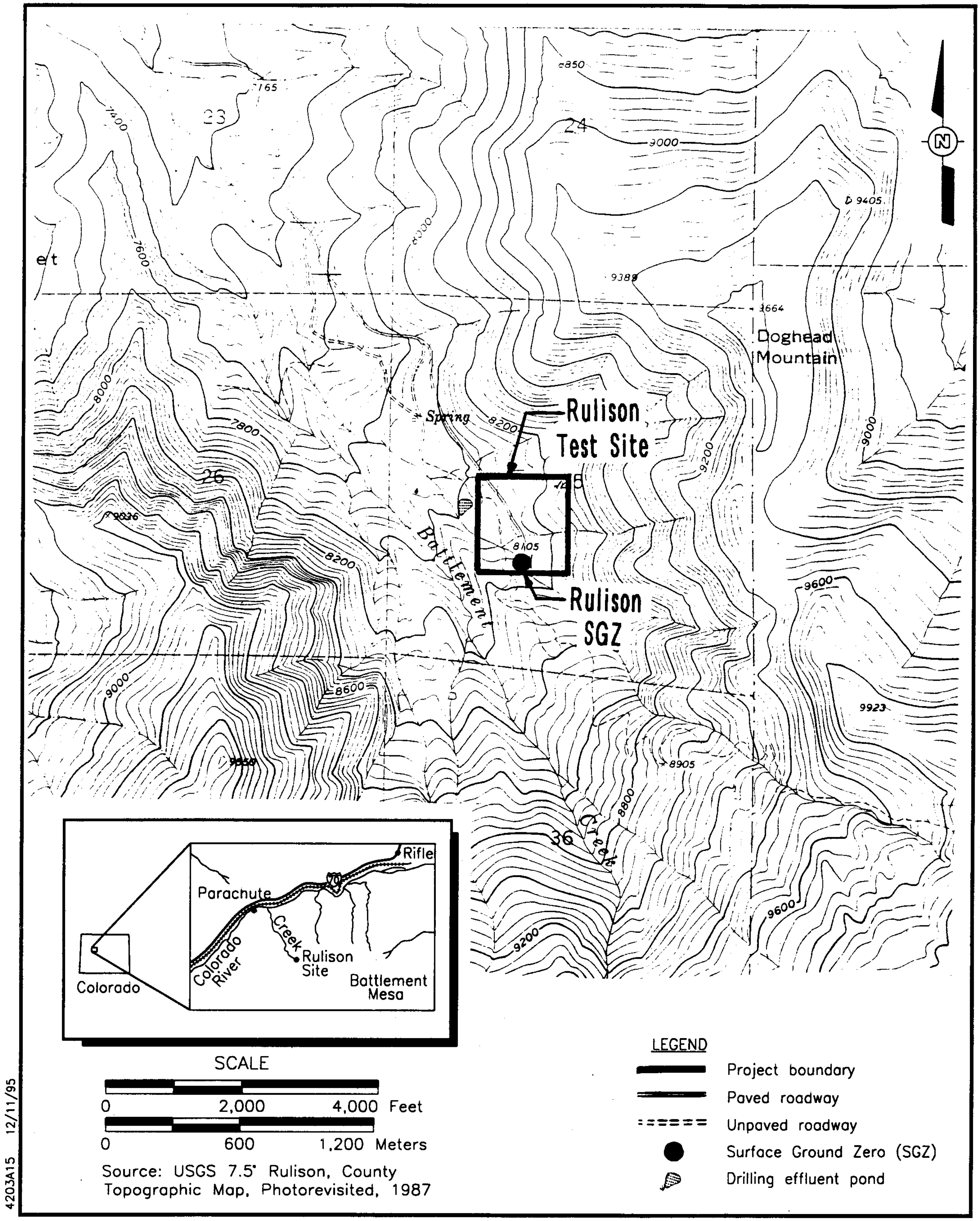



**Figure 5-1**
**Topographic Map of Garfield County, Colorado, Project Rulison**

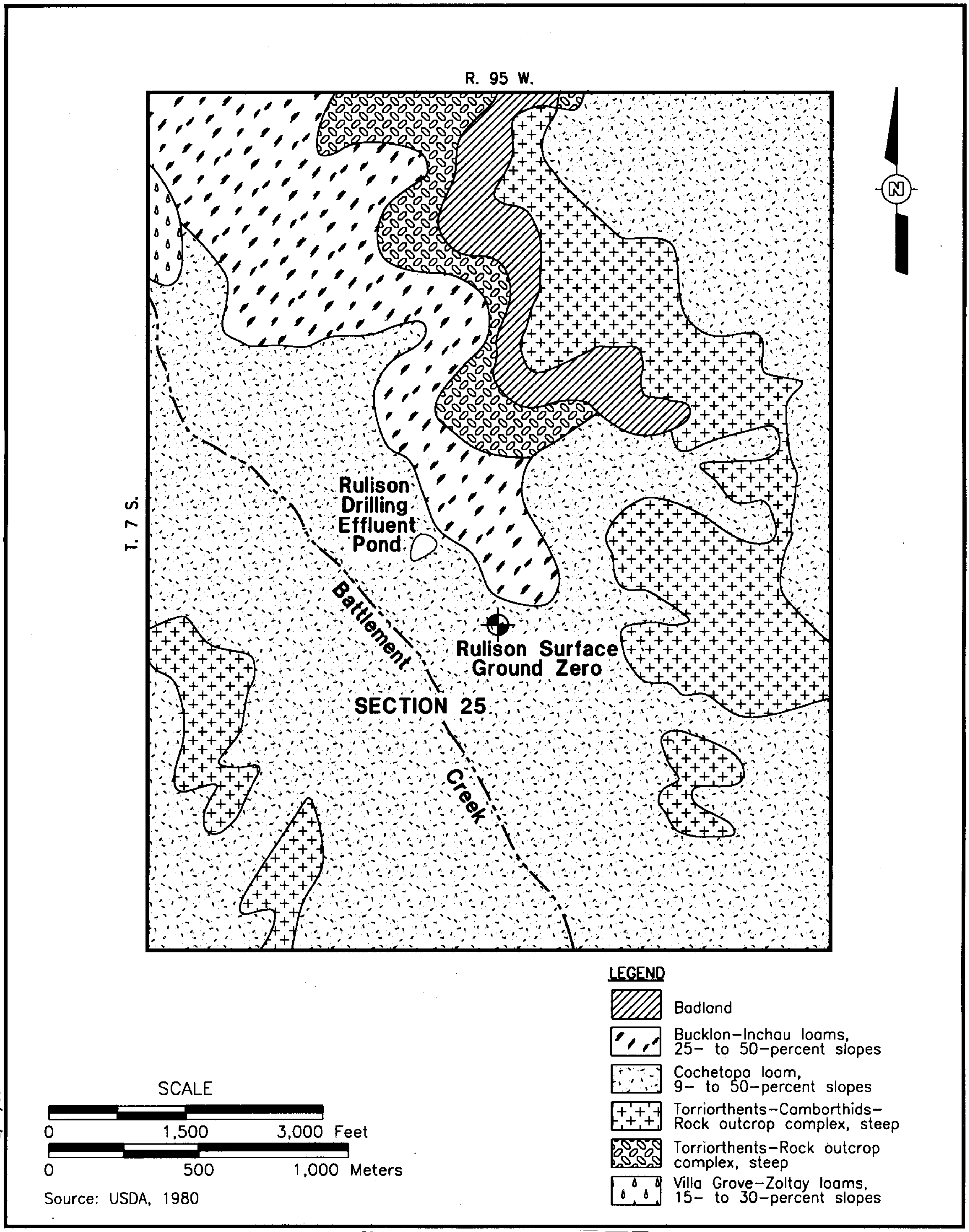



**Figure 5-2**
**U.S. Department of Agriculture Soil Conservation Service Soils Map, Rifle Area, Colorado, Rulison Project**

Inchau soils make up approximately 35 percent of the map unit and occur on the slightly concave parts of the landscape. It is a moderately-deep and well-drained soil. Permeability of Inchau soil is moderate above bedrock, and available water capacity is moderate.

Cochetopa loam is a deep, well-drained soil, and is found on rolling to steep mountainsides and alluvial fans. Elevation ranges from 2,134 to 2,896 m (7,000 to 9,500 ft). This soil is formed in basaltic alluvium. Permeability is slow, and available water capacity is high. Effective rooting depth is 1.5 m (60 in.) or more. Surface runoff is slow, and the erosion hazard is severe. High clay content in the soil causes low soil strength and high potential for soil slumping. The subsoil, below a depth of approximately 0.2 m (24 in.), consists of stony clay with a low permeability. The Rulison SGZ was constructed in the Cochetopa loam.

## *5.5 Geology*

### *5.5.1 General Description*

The Rulison Site is located within the Piceance Creek Basin. This northwest-southeast trending, structurally downwarped basin, is delineated primarily by the distribution of the Mesaverde Formation. The basin was structurally deformed by northeast-directed, Laramide-aged, shortening and reactivated, high angle basement structures (CER, 1989; Dickenson and Snyder, 1978). The present basin axis (a synformal fold axis) is oriented approximately northwest-southeast (Figures 5-3 and 5-4). This present axis is approximately the same as the paleo-depositional axis of the Mesaverde Formation. The Rulison Site is located on the southwest limb of the downwarp where the dip of the Mesaverde is about 2 to 3 degrees to the northeast.

### *5.5.2 Surficial Geology*

The surficial geology at the Rulison Site consists of Quaternary deposits comprised of talus accumulations, mud flows, fan and pediment gravel, and the alluvium of Battlement Creek and the Colorado River. These deposits range from 6 to 12 m (20 to 40 ft) in thickness, but locally may be more than 30-m (100-ft) thick. Groundwater occurs in many of these deposits (Voegeli et al., 1970).

Two soil-mapping units have been identified within the 161,880 $m^2$ (40 acres) surrounding the effluent-pond location. These are the Bucklon-Inchau loams and Cochetopa loam described in Section 5.4 (refer to Figure 5-2). The drilling-effluent pond was constructed in the Cochetopa loam.

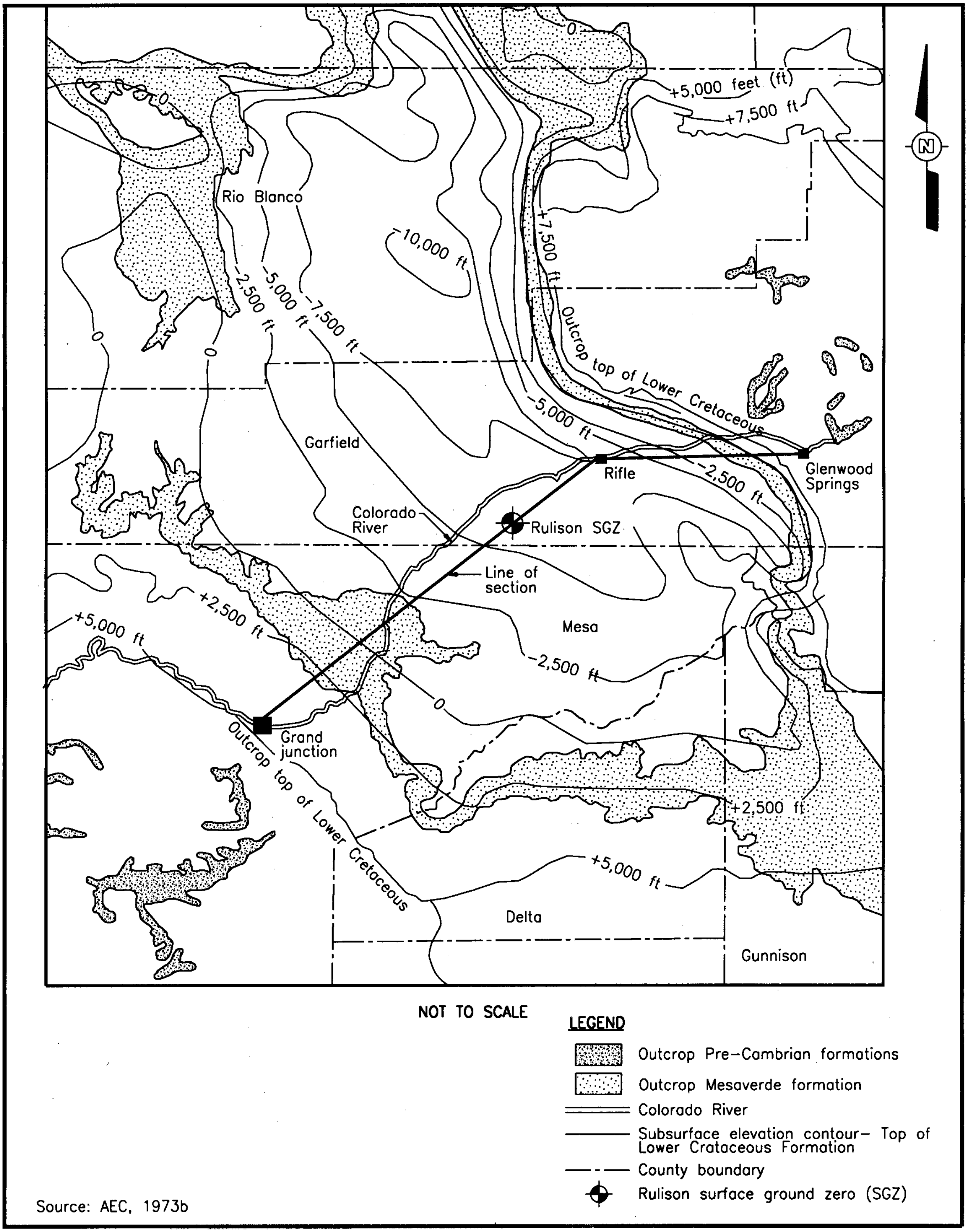



**Figure 5-3**
**Rulison Site, Piceance Creek Basin - Regional Map and Structural Interpretation, Garfield and Mesa Counties, Colorado**

4203A18 12/11/95

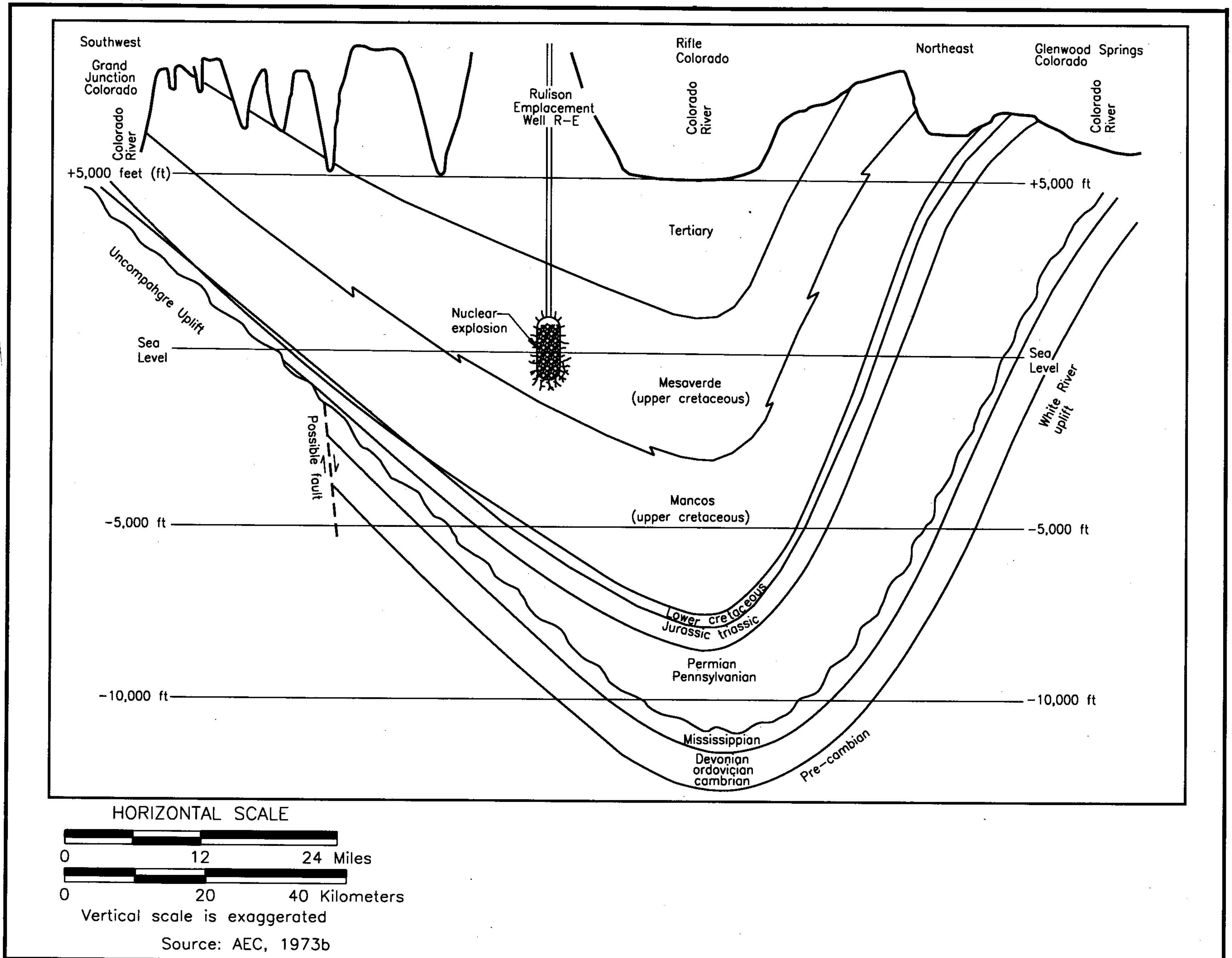



**Figure 5-4**
**Rulison Site Piceance Creek Basin Schematic Cross Section, Garfield and Mesa Counties, Colorado**

### 5.5.3 Subsurface Stratigraphy

The Piceance Basin contains Precambrian through Holocene stratigraphy. However, because the R-E well only encountered rocks as old as the lower Cretaceous (Mancos Shale), this section will only describe the stratigraphy from the Mancos Shale and above (Figures 5-5 and 5-6).

#### 5.5.3.1 Mancos Shale

The lower Cretaceous Mancos Shale is a marine shale with sparse lenses of sand. Towards the upper half of the Mancos Shale, a transition to a regressive sequence begins that intertongues the shales with the upper Cretaceous Iles Formation within the Mesaverde Group. Overlying the Iles Formation (290 m [900 ft]) the regressive transition continues up into the Williams Fork Formation (1,067 m [3,500 ft]) which includes the Tertiary Ohio Creek member (15 m [50 ft]) (Lorenz and Rutledge, 1985). The Tertiary units continue with the Fort Union (152 m [500 ft]), Wasatch (1,188 m [3,900 ft]) and Green River Formations (518 m [2,100 ft]). Quaternary basalt flows, locally found in the Rulison area, and alluvial deposits (Pleistocene and recent) unconformably rest on all units.

#### 5.5.3.2 Mesaverde Group

At Rulison, the Mesaverde Group is divided into two Formations: the Iles and Williams Fork (Figure 5-7). The Mesaverde represents a regressive phase from near-shore, deltaic marine (Isles Formation) to non-marine coastal plain, to paludal and meandering river plain, to fluvial environments (Williams Fork) (Lorenz, 1983; Lorenz, 1985; Johnson et al., 1987).

The Isles Formation is characterized by three sand members: the Cocoran and Cozzette intertongued with the Mancos Shale, and the Rollins, a blanket sand that underlies the Cameo-Fairfield Coal of the Williams Fork Formation. The Isles Formation represents a deltaic, shallow-marine sequence (Lorenz, 1983).

Within the Piceance Basin, the thickest sections of the Williams Fork Formation are coincident with the basin axis. The fluvial sand bodies throughout the Williams Fork are laterally extensive and heterogeneous. This suggests that the basin was subsiding during deposition (CER, 1989). In the vicinity of the Rulison Site, the basin axis is oriented east-southeast from which the fluvial paleocurrent directions in the upper Mesaverde can be inferred. Sand-body shapes in the fluvial sequences appear lenticular in cross-section; they are likely longer than the cross-section in the

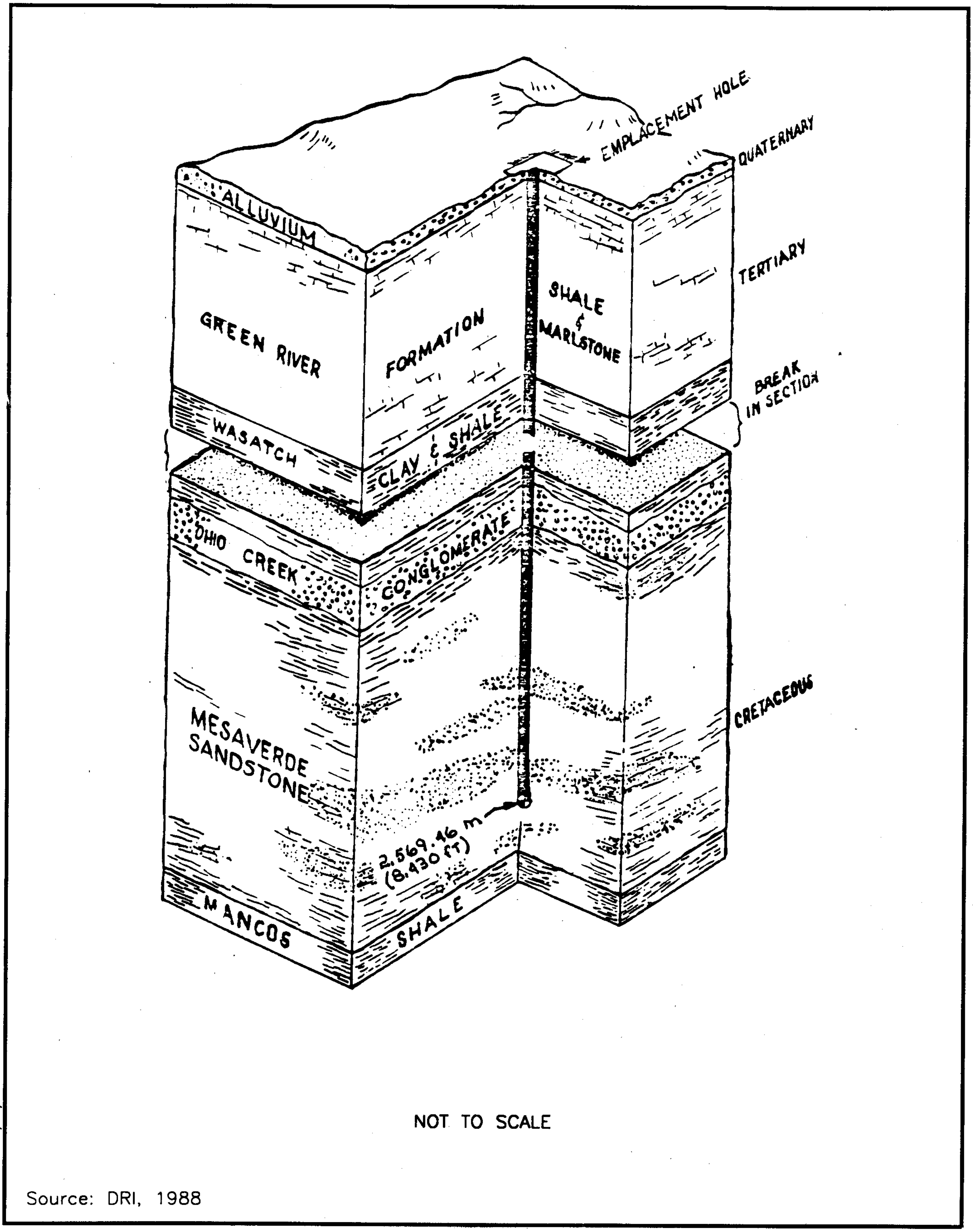



**Figure 5-5**
**Project Rulison Generalized Geologic Cross Section, Garfield County, Colorado**

| SYSTEM AND PERIOD | | | FORMATIONS | STRATIGRAPHIC COLUMN | GENERAL LITHOLOGY | APPROXIMATE THICKNESS meters (m) feet (ft) |
|---|---|---|---|---|---|---|
| Holocene | | | "Recent" | | Low terrace, floodplane, and alluvial deposits | 30.48 m(100 ft) |
| Quaternary | | | "Pleistocene" | | Terrace and fan sand and gravel, pediment gravel, colluvium, mudflow, and solifluction deposits | 60.96 m (200 ft) |
| Tertiary | | | Unnamed | | Basalt flows underlain by variegated claystones and gravel | 304.80 m (1,000 ft) |
| Tertiary | | | Green River | | Oil shales, marlstones, and sandstones (dark color) | 640.08 m (2,100 ft) |
| Tertiary | | | Wasatch | | Bright colored clays and shale with with minor sandstone | 1,188.72 m (3,900 ft) |
| Tertiary | | | Fort Union | | Brown-gray shale and coal | 152.40 m (500 ft) |
| Tertiary | | Mesaverde | Ohio Creek | | Sandstone and conglomerate | 15.24 m (50 ft) |
| Cretaceous | Upper | Mesaverde | Williams Fork | | Shale - sandstone | 1,066.80 m (3,500 ft) |
| Cretaceous | Upper | Mesaverde | Isles | | Shale - sandstone | 274.32 m (900 ft) |
| Cretaceous | Lower | | Mancos | | Gray shale | 518.16 m (1,700 ft) |
| Cretaceous | Lower | | Naturita | | Shale - sandstone | 182.88 m (600 ft) |
| Cretaceous | Lower | | Dakota Cedar Mountain | | Sandstone | 60.96 m (200 ft) |

NOT TO SCALE

Source: AEC, 1973b

4203A19 12/11/95

**Figure 5-6**
**Rulison Site Stratigraphic Column, Garfield County, Colorado**

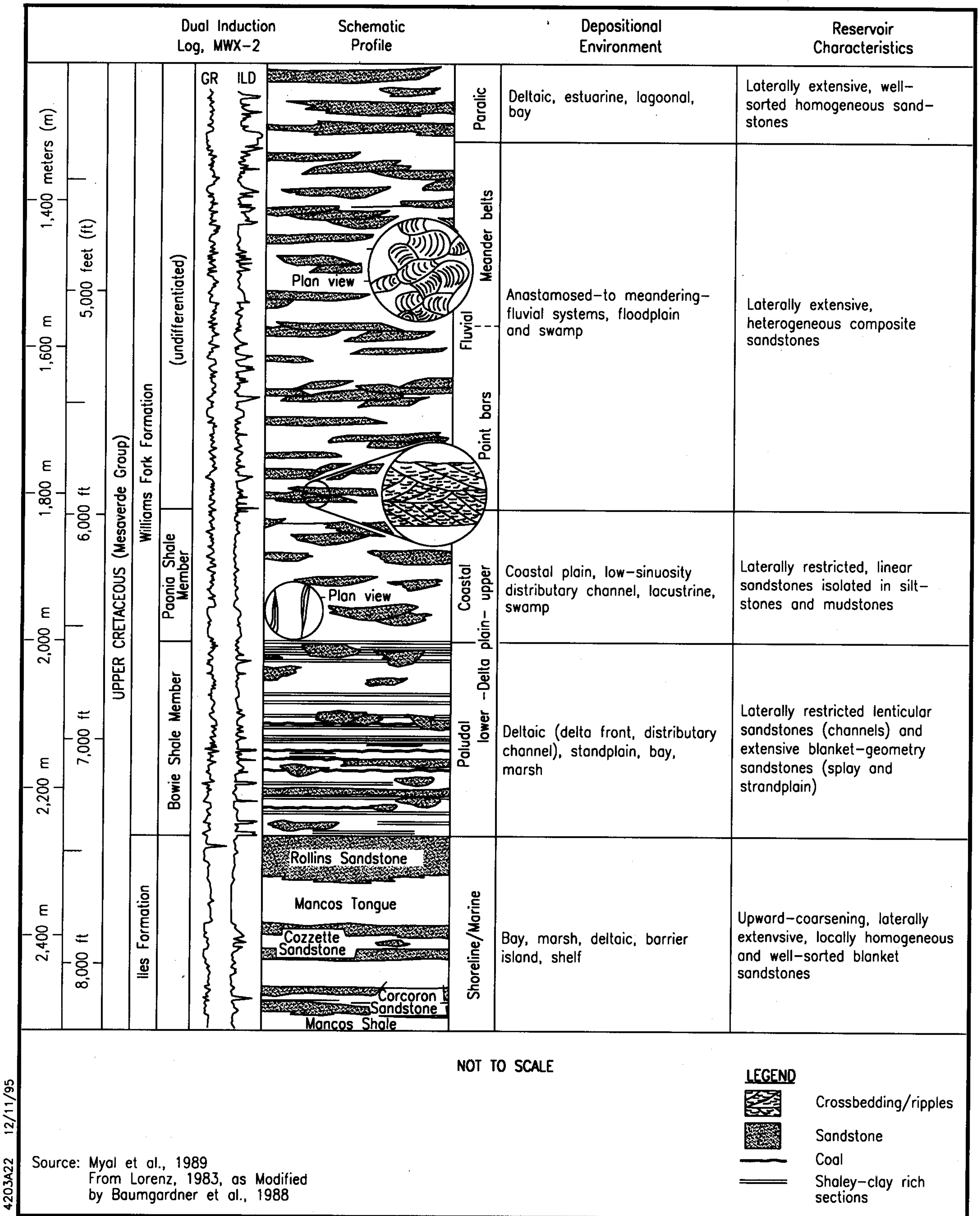



**Figure 5-7**
**Correlation of Paleoenvironmental Depositional Units at the Multi-Well Experiment Site with Regional Stratigraphic Nomenclature, Garfield County, Colorado**

paleocurrent direction parallel to the basin axis. As the basin continued to subside throughout the Tertiary, the axis of the basin became the deepest zone of the burial (Figure 5-8). This resulted in high compaction and reduced porosity and permeability.

#### *5.5.3.3 Tertiary Stratigraphy*

The Tertiary Wasatch and Green River Formations (refer to Figure 5-6) are mostly interbedded shale, marlstone, limestone, and sandstone. Combined, the two formations are over 1,700-m (5,600-ft) thick.

The Wasatch Formation consists of brightly colored clay and shale, but sandstone lenses are common. Locally, minor amounts of conglomerate, pebbly sandstone, limestone, coal, and black cabonaceous shale occur in the formation. The formation is approximately 1,188-m (3,900-ft) thick at the Rulison Site. The Wasatch is not a source of groundwater in the Rulison area.

In and near the Rulison Site, the Green River Formation contains fours members. In ascending order they are: Douglas Creek, Garden Gulch, Parachute Creek, and Evacuation Creek. At the Rulison Site, the Green River Formation is about 518-m (1,700-ft) thick. The most notable unit of the upper Green River, the Parachute Creek member, is an oil shale. This formation is composed of mostly shale and marlstone with minor amounts of sandstone, siltstone, and limestone. Sandy zones in the lower part of the formation may be capable of yielding minor quantities of groundwater at some location in the area (Coffin et al., 1968; Voegeli et al., 1970).

### *5.5.4 Natural Gas Production in the Rulison Area*

In the Southern Piceance Basin, natural gas is found in sandstones of both the Wasatch and Mesaverde Formations and in coals of the Mesaverde. The Rulison Site is on the outskirts of the Rulison and Grand Valley gas fields, centered along the Colorado River, which produces gas from both formations.

The closest commercial production wells to the Rulison Site are the Federal 28-95 located 4.3 km (2.7 mi) west and the Federal 14-95 located 4.34 km (2.7 mi) to the northwest. The wells are currently operated by Riata Energy, Inc. and Bonneville Fuels Corporation and were drilled in 1961 and 1962, respectively. Both wells produce gas from the Mesaverde Formation. Federal 14-95 had produced a total of 2.12 million $m^3$ (75 million cubic feet [MCF]) by 1988, and the Federal 28-95 39.83 million $m^3$ (375 MCF) by 1993. Both wells produced up to 1993 and are now presently shut in because of the declining gas market.

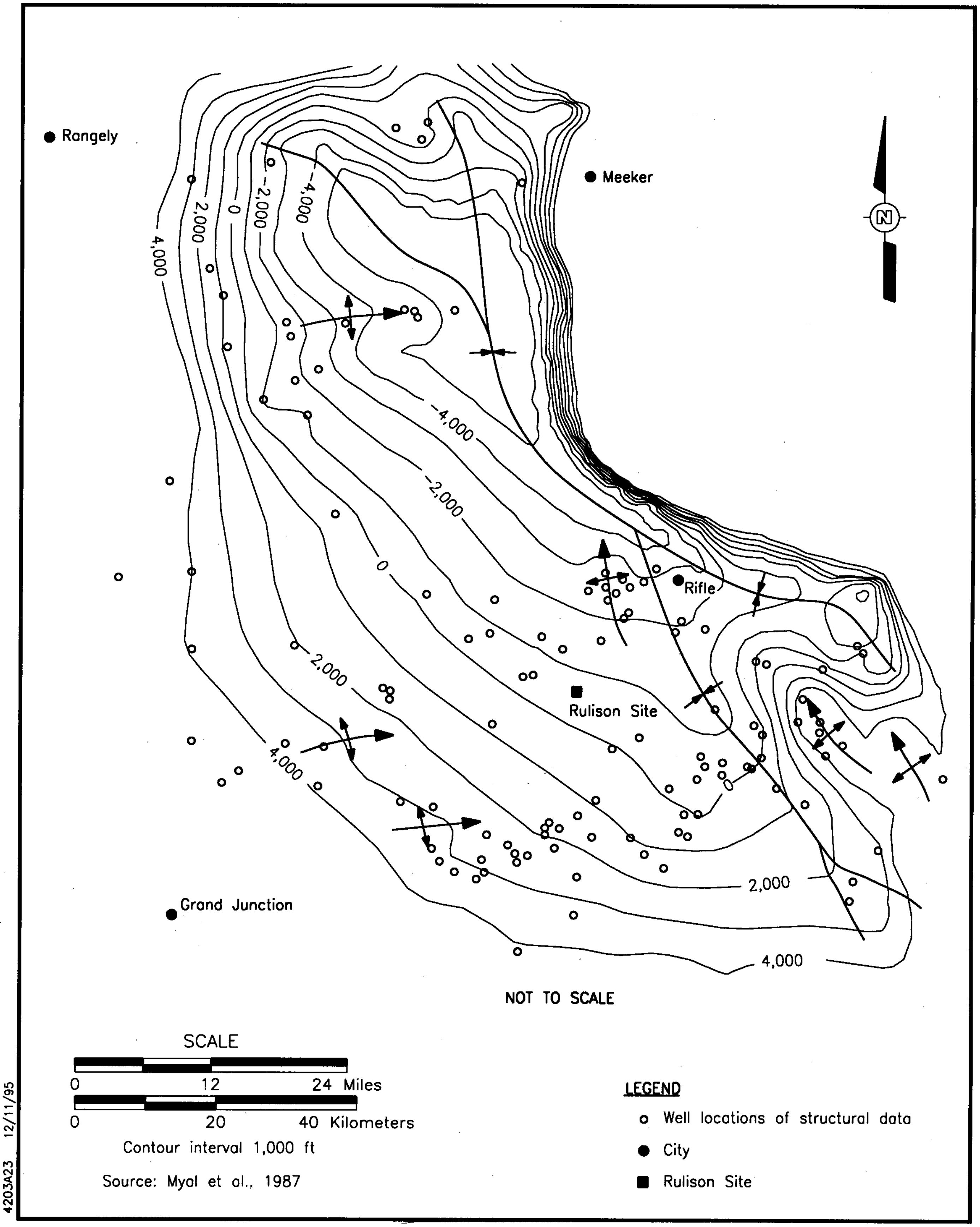



**Figure 5-8**
**Structure Contour Map of the Top of Marine Intervals (Rollins-Trout Creek) of the Piceance Basin, Colorado**

The Mesaverde Formation contains a tremendous gas resource throughout the Piceance Basin. However, because of its very low permeability, commercial development of the resource is often marginally economical. For this reason, the Rulison area has been the center of government- and institution-sponsored research to better understand Mesaverde production characteristics and enhancement potential. The Rulison test in 1969 in the Hayward 25-95 well was the first experiment to attempt to stimulate production of gas by fracturing the formation with a nuclear device.

### *5.5.5 Gas Reservoir Characteristics*

The Mesaverde can be a prolific gas producer; however, it is often found to be "tight", having low porosity (<10%) and low permeability (<0.05 millidarcies) (CER, 1992). The highest production from the Mesaverde is limited to zones where natural, open fractures are encountered. When fractures are not encountered, fractures are artificially induced using hydraulic pressure (Hydrofracs). The enhanced or new fractures are then propped open using sands or other compounds. Artificially stimulated wells do not perform as well as wells that encounter natural open fractures (CER, 1989).

Based upon intensive analysis of the core, high resolution geophysical logging methods, and well interference tests, one dominant fracture set is present within the Mesaverde Group. These open fractures strike northwest-southeast parallel to the local basin axis (Figure 5-9). Wells that intersect these fractures show the highest rates of gas production (CER, 1989). Fracture development by artificial means tends to develop parallel to the dominant fracture set.

Gas produced from the Mesaverde is usually dry. However, water content within the reservoirs is variable, and water can be produced from the formation along with the gas.

## *5.6 Surface Water*

### *5.6.1 Streams, Springs, and Seeps*

There are three major surface water features at the Rulison Site. First, Battlement Creek is a rushing mountain stream that flows through the southwest corner of the site. Battlement Creek is principally fed by snow melt, shallow groundwater, and springs, and its flow is regulated upstream (south) of the site by Battlement Reservoir. Second, a smaller, spring-fed tributary of Battlement Creek flows across the site east of Battlement Creek. Third, an artificially created

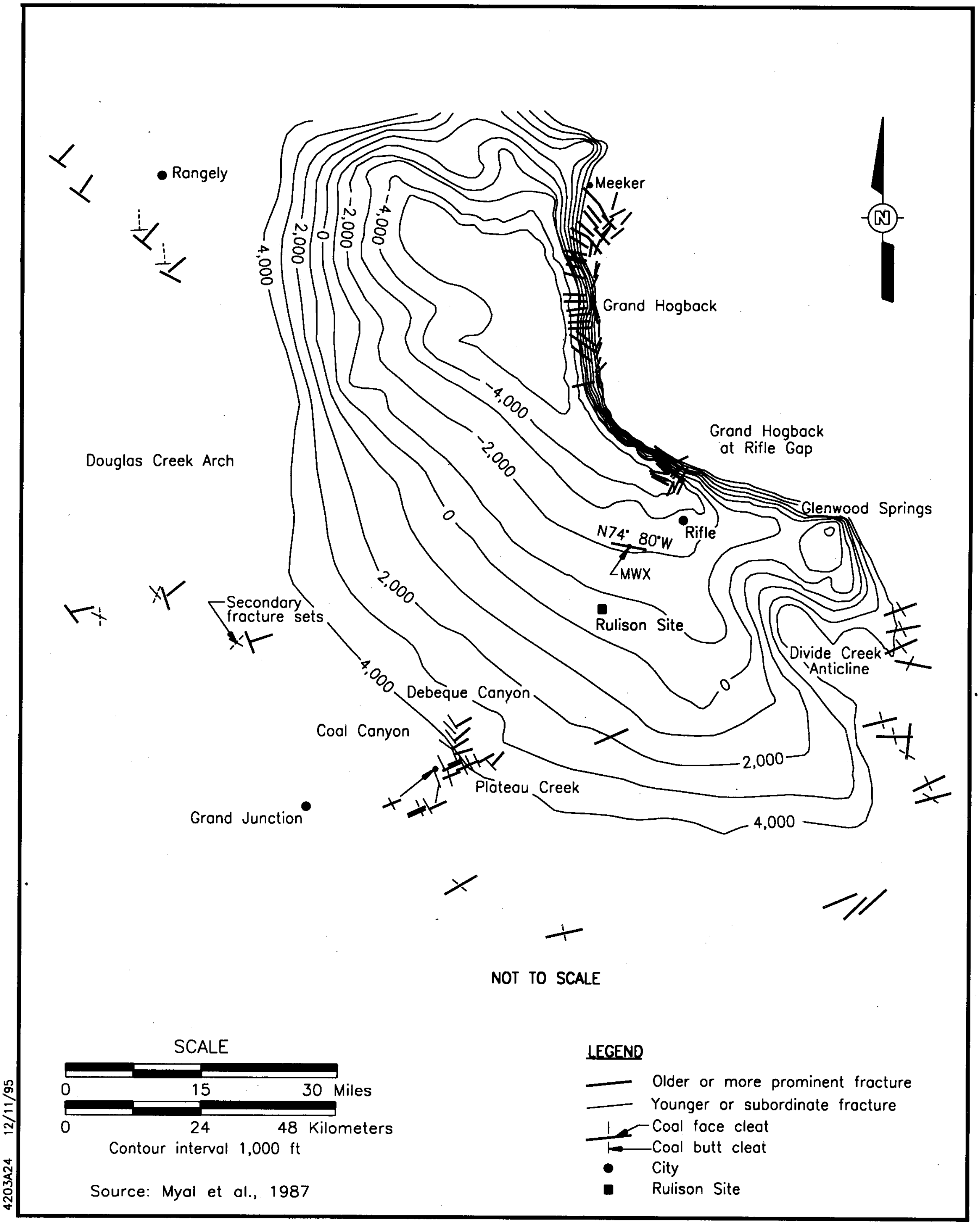



**Figure 5-9**
**Compilation Map of the Fracture Orientation, Piceance Basin, Colorado**

drilling effluent pond is located at the center of the site. This pond was built to store drilling mud as part of emplacement hole drilling for the nuclear device.

Battlement Creek and its tributaries provide the main control over surface waters at the Rulison Site. The creek and the tributaries flow in a generally northwesterly direction toward the Colorado River.

An unnamed tributary (locally known as “Hayward” Creek) transects the Rulison Site and is adjacent to the effluent pond. Approximately 30 m (100 ft) below the effluent pond, this tributary flows into a series of beaver ponds (Figure 5-10). This stream is impounded by the beaver dams, creating a marshy, wetland complex through the middle of the site. Because of the topographic slope of the area, Battlement Creek and its tributaries are generally confined to relatively narrow stream channels except for the beaver pond area where the tributary channel widens because of the slower flow resulting from a more shallow stream gradient.

Additionally, several springs exist near the Rulison Site and the drilling effluent pond. The current source of water for the pond is from snow melt, groundwater, and a spring located approximately 300 m (915 ft) southeast of the pond, which replenishes the pond by surface flow via an inlet in the eastern berm. The pond also has an overflow in the western berm although the water level is seldom high enough for overflow to occur.

The Rulison drilling effluent pond is triangular in shape and covers approximately 1 acre. It is approximately 6-m (20-ft) deep (from top of the berm to pond bottom) and is located approximately 400 m (1,300 ft) north-northwest of SGZ. The pond originally was used for containment of surplus drilling fluids during the emplacement hole drilling operations. The pond is equipped with a spillway on the downslope side, 1.8 m (6 ft) below the crest. The present owner of the property, Lee Hayward, son of Claude V. Hayward, has retained the pond for his own use (AEC, 1973a, p. 5) and has converted the pond to a fresh-water trout pond. The pond is fenced to prevent access by wildlife and livestock. Because the effluent pond is an artificial impoundment that does not have the vegetative characteristics of a natural wetland, it has not been designated as a “wetland” (IT, 1993c, p. 4-1).

### *5.6.2 Wetlands*

A wetlands, vegetation, and floodplains survey was conducted during June 1993 (IT, 1993c). An initial wetlands and floodplains determination for the Rulison Site was made using information

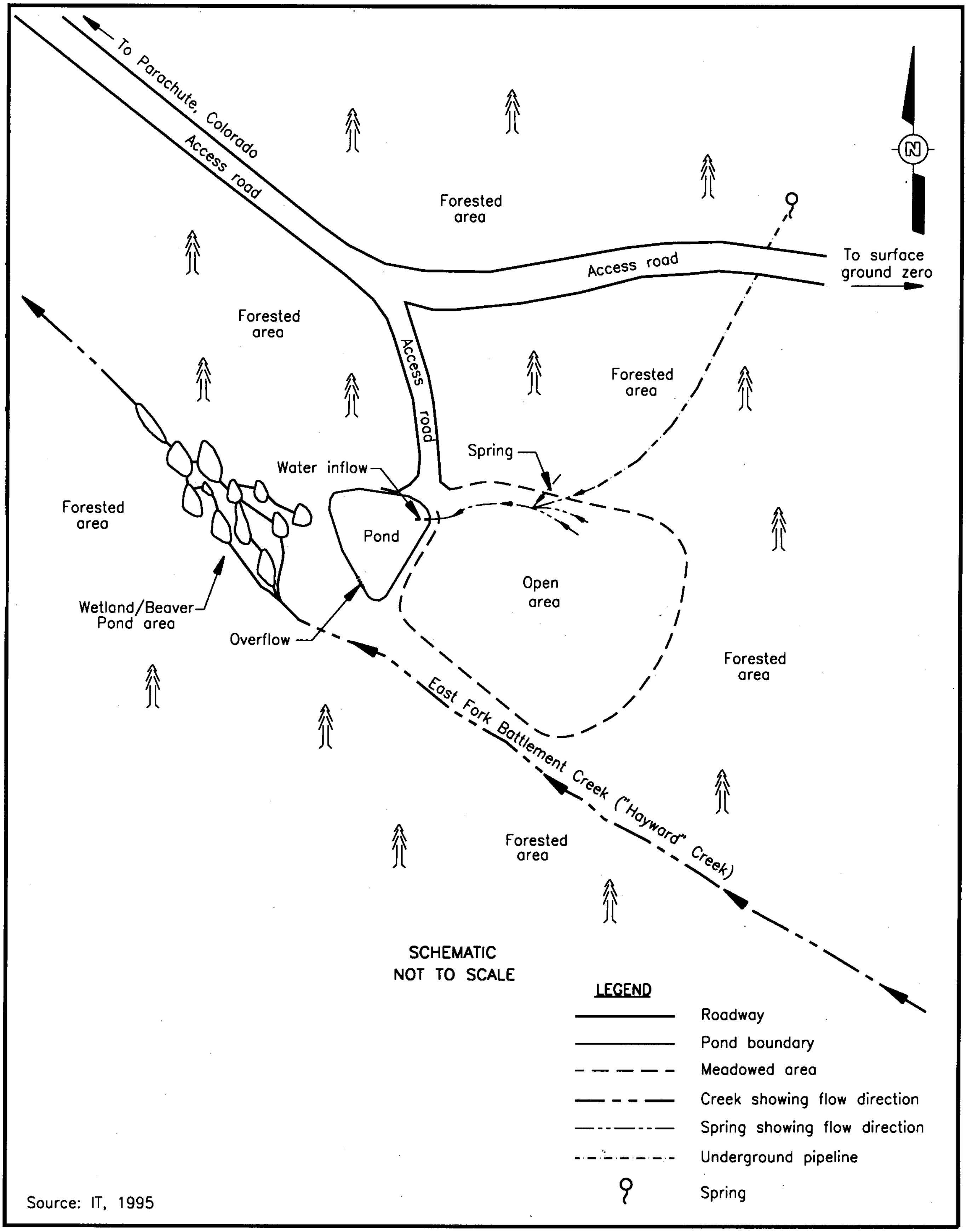



**Figure 5-10**
**General Site Layout Diagram, Rulison Drilling Effluent Pond, January 1995**

from aerial photographs; a USGS topographic map (7.5 minute Rulison quadrangle); a Rifle Area, Colorado, Soil Survey (1980) map; and Flood Insurance Rate Maps (FIRM) for Garfield County, Colorado, in conjunction with field surveys.

Floodplains and wetlands were delineated using the methods outlined in the Corps of Engineers *Wetlands Delineation Manual* (U.S. Army Corps of Engineers, 1987), and the procedures outlined in *Title 10 CFR Part 1022, "Compliance with Floodplains in Wetlands Environmental Review Requirements."*

A list of dominant plant species found in upland and wetland communities at the Rulison Site is presented in Table 5-4.

The wetlands on the site are either associated with Battlement Creek or its tributary which transects the site. Battlement Creek flows within a narrow, well defined path. The high flow rate of Battlement Creek has scoured the channel, leaving a very rocky substrate supporting limited, if any, vegetation within the channel. However, the wooded slopes adjacent to the Creek contain a dense canopy of blue and Englermann spruce intermixed with quaking aspen. The understory contains mountain maple, water birch, and mountain alder.

The tributary to Battlement Creek, which transects the site, has a similar wetland community. These wetlands are due to adjacent springs feeding the tributary and beaver disturbance in the center of the site. The two most common species in this area are the quaking aspen and mountain maple in the canopy, with serviceberry and grasses in the understory and ground cover. Often, the aspen form pure stands. In the center of the site, beaver have removed the canopy layer and formed numerous ponds on several terraces. Associated with the terraces are saplings of quaking aspen with adult spruces intermixed. Sandbar willow is also common, recolonizing the wetter areas with common choke cherry sprouting in the drier areas. Numerous emergent species, such as grasses and sedges, were also observed colonizing the disturbed areas and on the beaver dams.

The center of the site also contains the man-made drilling effluent pond. This drilling effluent pond was created during the original testing activity on the site and is contained within an earthen berm that has little hydrophytic and no aquatic vegetation.

**Table 5-4**
**List of Dominant Plant Species - Rulison Site Wetland Survey**
**June 25 - 30, 1993**

| Scientific Name[b] | Common Name | Indicator Status[a] Regional | National |
|---|---|---|---|
| Osmundaceae<br>*Osmunda cinnamomea* | Cinnamon Fern | NL | FACW |
| Gramineae<br>*Gramineae spp.* | Grasses | NIS | |
| Salicaceae<br>*Salix exigua*<br>*Populus tremuloides* | Sandbar Willow<br>Quaking Aspen | OBL<br>FAC | FACW, OBL<br>FACU, FAC |
| Betulaceae<br>*Betula occidentalis*<br>*Alnus tenuifolia* | Water Birch<br>Mountain Alder | FACW<br>FACW | FAC, FACW<br>FAC, FACW |
| Cyperaceae<br>*Carex spp.* | Sedge | NIS | FACW, OBL |
| Juncaceae<br>*Juncus effusus* | Soft Rush | OBL | FACW, OBL |
| Fagaceae<br>*Quercus gambelii* | Gamble Oak | NL | UPL |
| Rosaceae<br>*Prunus virginiana*<br>*Amelanchier alnifolia*<br>*Cowania mexicana*<br>*Purshia tridentata* | Common Chokecherry<br>Western Serviceberry<br>Cliffrose<br>Antelope Brush | FACU<br>FACU<br>UPL<br>UPL | FACU, FAC<br>UPL, FAC<br>UPL<br>UPL |
| Aceraceae<br>*Acer glabrum* | Rocky Mountain Maple | FAC | FACU, FAC |
| Cornaceae<br>*Cornus stolonifera* | Red-Osier Dogwood | FACW | FAC, FACW |
| Pinaceae<br>*Picea engelmannii*<br>*Picea pungens*<br>*Pinus edulis* | Engelmann Spruce<br>Blue Spruce<br>Colorado Pinyon | FACU<br>FAC<br>UPL | FAC, FACU<br>FAC<br>UPL |
| Typhaceae<br>*Typha latifolia* | Broad-Leaf Cattail | OBL | OBL |
| Balsaminaceae<br>*Impatiens capensis* | Jewelweed | FACW | FACW |
| Urticaceae<br>*Urtica dioica* | Stinging Nettle | FAC | FACU, FACW |

Source: IT, 1993c

[a]Indicator status derived from the U.S. Fish and Wildlife Service's National List of Plant Species that occur in Wetlands: 1988 National Summary (Reed, 1988).
[b]Nomenclature conforms to that of *Grays Manual of Botany* (Fernald, 1950).

OBL = Obligate wetland plants that occur almost always in wetlands (>99%)
FACW = Facultative wetland plants that usually occur in wetlands (67-99%)
FAC = Facultative plants that are equally likely to occur in wetlands or nonwetlands (34-66%)
FACU = Facultative upland plants that usually occur in nonwetlands (1-33%)
UPL = Obligate upland plants that occur almost always in nonwetlands (>99%)
NL = Species not listed
NIS = Not identified to species

Interviews with personnel who were present when the drilling effluent pond was constructed indicated that the pond may have been built on a spring or the pond may have been built below the local water table. Verbal reports by personnel who were present when the site was decommissioned indicate that groundwater entered the pond faster than it could be removed. In addition, the local surface expression of groundwater (springs) proximal to the Rulison Site indicates that the depth to groundwater may be less than expected based on regional information.

Finally, the pond-water level has remained stable after 26 years with only seasonal elevation changes observed, indicating that recharge to the pond and discharge from the pond have reached equilibrium with the local groundwater environment. The water level in the pond ranges from approximately 1 to 3 m (3 to 10 ft) below the pond berm.

Based on this evidence and an inspection of the site hydrology (conducted on April 19 and 20, 1995), groundwater at the effluent pond is expected to be at a relatively shallow depth, following the natural topographic slope. At the south end of the pond, the water surface is anticipated to be equivalent to the groundwater surface. At the north end, the hydraulically down gradient end of the pond, the water surface is anticipated to be above the groundwater surface because of the damming action of the pond berm.

### 5.6.3 Floodplains

No flood plains or flood-prone areas have been identified at the Rulison Site based on review of the FIRM Index Map (FEMA, 1986) for Garfield County, Colorado, although a more detailed map has not been published.

## 5.7 Hydrogeology

### 5.7.1 Occurrence of Groundwater

The groundwater resources in the Rulison area are confined primarily to alluvium and surficial deposits (e.g., floodplain deposits and terrace and fan gravel). Essentially all the wells and most of the springs in the area derive their water from these shallow sources. Water in the alluvium occurs under both water-table and artesian conditions (Coffin et al., 1968, p. 8). Most of the springs are located along the contact of different strata within the surficial deposits. The underlying shale bedrock formations generally have low permeability and yield little or no water (Voegeli et al., 1970, p. 9).

Marine and nonmarine sedimentary rocks, approximately 5,486.40 m (18,000 ft) thick, underlie the Rulison Site. The emplacement (R-E) and exploratory (R-EX) holes, see Figure 5-11 (ERDA, 1977, p. 3), penetrated the following formations, in descending order:

- Quaternary alluvium is as much as 42.67 m (140 ft) thick;
- Green River Formation composed chiefly of shale and marlstone is about 518.16 m (1,700 ft) thick;
- Wasatch Formation consisting principally of clay and shale with sandstone lenses is about 1,188.72 m (3,900 ft) thick;
- An unnamed unit of Paleocene age consisting of sandstone, shale, and a few thin beds of coal is about 152.40 m (500 ft) thick;
- Ohio Creek Conglomerate is about 11.28 m (37 ft) thick;
- Mesaverde Formation consisting mainly of sandstone and interbedded shale is about 762 m (2,500 ft) thick (Nork and Fenske, 1970, p. 5; Voegeli et al., 1970, pp. 5-7).

The Mesaverde Formation is of particular interest because the nuclear device was detonated within this group at a depth of 2,568.24 m (8,426 ft) in hole R-E (Voegeli, 1969, p. 4; Voegeli et al., 1970, p. 5; ERDA, 1977).

A small amount of water was found in an upper Mesaverde sandstone lens during the drilling of hole R-EX. Later tests of this zone and other zones thought to contain water in the Mesaverde yielded no significant groundwater. Several deep drill holes in the Ohio Creek Conglomerate above the Mesaverde Group in the Rulison gas field have produced water; hole R-EX produced no water from the Ohio Creek Conglomerate. The Wasatch Formation contains some sandy zones in the middle and the upper parts of the formation; however, these zones produced no water in hole R-EX. The lower Green River Formation, about 1,524 m (5,000 ft) above the detonation, has some sandy zones that produced water in sufficient quantities (none exceeding 0.73 $m^3$/day [4 gallons per minute]) to make air drilling difficult (Voegeli, 1969, p. 7; Voegeli et al., 1970, p. 15; DOE, 1984, p. 10).

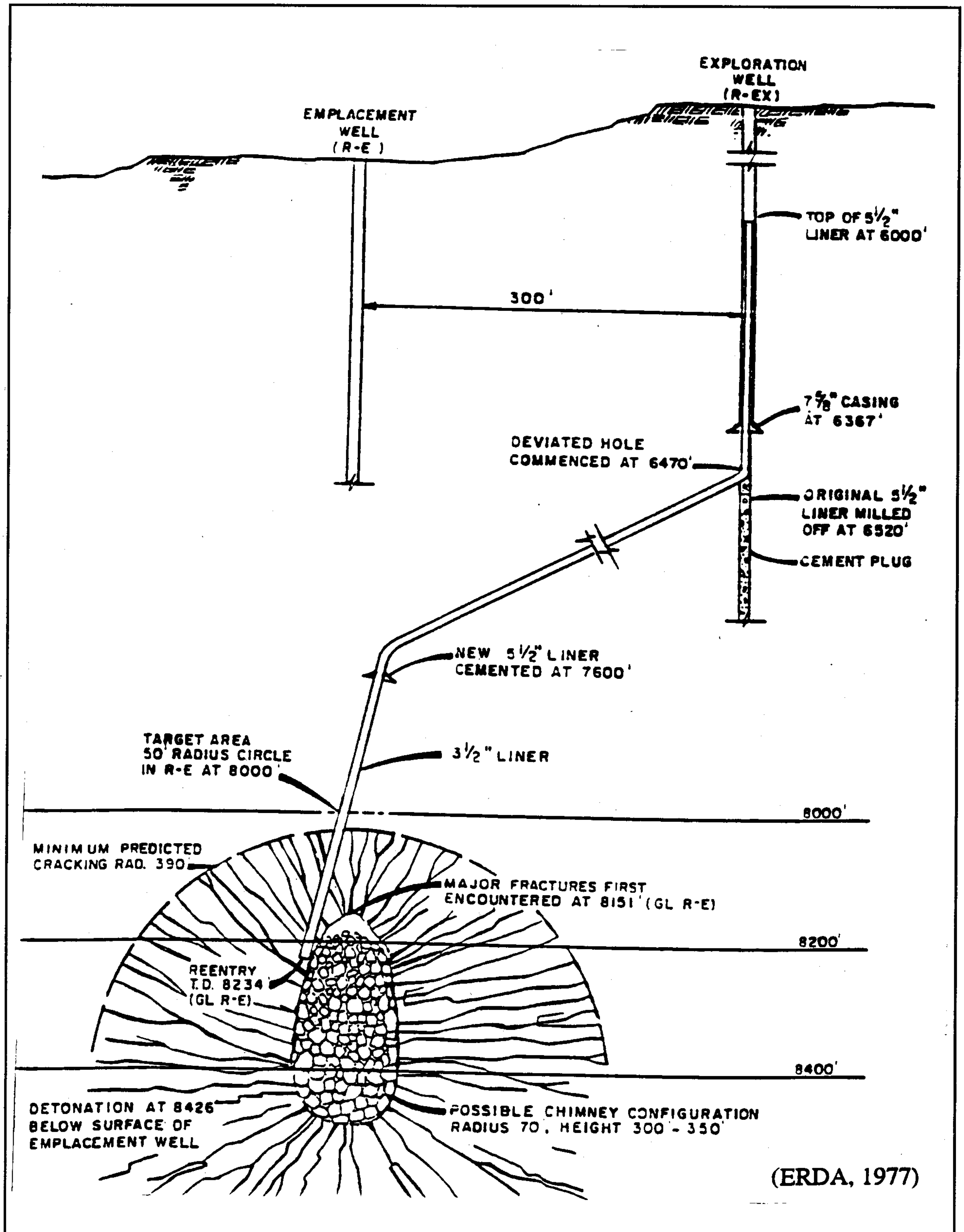



**Figure 5-11**
**Project Rulison Emplacement and Reentry Well Configuration**

The Quaternary alluvial deposits are of particular importance since they provide most of the area's groundwater resources. The deposits include mudflows, talus accumulations, fan and pediment gravel, slump blocks, and the alluvium of Battlement Creek and the Colorado River. The regional water table ranges from 1.83 to 48.77 m (6 to 160 ft) below the land surface (Voegeli et al., 1970, pp. 25-28). The direction of groundwater flow in the alluvial deposits is expected to be northward, consistent with topographic slope. Rocks below the alluvium dip two degrees or less to the north and groundwater flow is expected to be northward also (Nork, 1969, p. 4; Voegeli et al., 1970, pp. 25-28; Nork and Fenske, 1970, p. 7).

#### *5.7.1.1 Hydraulic Characteristics*

Results of hydraulic tests in hole R-EX, shown in Table 5-5 (Voegeli et al., 1970, p. 19), indicate that samples consist primarily of drilling fluid rather than formation water. This suggests that the permeability of the formation is so low that little or no water movement occurs in the zones tested (Voegeli et al., 1970, p. 23). Although no fluid was recovered on any of the swab tests performed during the drill-stem tests, the complete absence of formation water cannot be ruled out as attested to by regular variations in other ions such as carbonate, sulfate, chloride, and sodium. The tritium content of the fluid indicates that it was derived from or contaminated by a surface source rather than from formation water (Voegeli, 1969, p. 14; Voegeli et al., 1970, p. 20).

Hydrologic tests were performed only in the Ohio Creek and Mesaverde rocks encountered in drill hole R-EX. Preshot permeability for the Mesaverde Formation was first estimated at 0.5 microdarcys ($\mu$d) and then at 0.01 $\mu$d, while postshot production data and reservoir simulation studies indicated that actual matrix permeability was approximately 0.001 to 0.04 $\mu$d (Stosur, 1977, p. 709). Additional porosities and permeabilities for deep rocks in the Rulison gas field are presented in DOE's Multi-Well Experiment reports (Sattler, 1984; Hart et al., 1984; CER, 1984; and Hart et al., 1987). Extensive pressure drawdown and build-up data for R-EX are reported by Austral and CER (1969, pp. I-1-IX-3).

Pressures recorded by the USGS during the testing of all water-bearing zones below the unnamed Paleocene unit indicate steep pressure build-up curves as a function of time, but yielded low fluid recoveries. This could indicate fracture dominated permeability. The presence of linear features on the land surface supports this theory. If there is fracture flow, lateral flow rates could be much higher than those previously predicted. The most permeable interval tested was from 2,193.34 to 2,193.95 m (7,196 to 7,198 ft). The shut in pressure for this interval was 2,875

**Table 5-5**
**Summary of Hydraulic Tests, Hole R-EX**
(Voegeli et al., 1970)

| Geologic Formation | Depth of Zone Tested Below Land Surface (feet) | Date Tested | Casing Size (inches) | Perforations | Type of Test Tool | Fluid Entry During Time Tool was Open | Bottomhole Temperature (°F) | Remarks |
|---|---|---|---|---|---|---|---|---|
| Ohio Creek Formation | 6,129 to 6,149 | 1-15-68 | 7⅝ | ⅜ in. to ½ in. 4 per ft | M.F.E.[1] | Pressure charts indicated no fluid entry. | 151 | Recovered about 15 gallons of drilling mud from top of test tool. |
| Mesaverde Group | 7,066 to 7,080 | 4-8-68 | 5½ | ⅜ in. to ½ in. 2 per ft | F.A.S.T.[2] | Pressure charts indicated no fluid entry. | 196 | Swabbed to 7,004 ft below land surface. No fluid recovered. Recovered about 10 gallons of fluid from top of test tool.[3] |
| Mesaverde Group | 7,196 to 7,198 | 4-5&6-68 | 5½ | ⅜ in. to ½ in. 2 per ft | F.A.S.T.[2] | Pressure charts indicated no fluid entry. | 195 | Swabbed to 7,134 ft below land surface. No fluid recovered. Recovered about 240 gallons of fluid from top of test tool.[3] |
| Mesaverde Group | 7,312 to 7,320 | 4-4&5-68 | 5½ | ⅜ in. to ½ in. 2 per ft | F.A.S.T.[2] | Pressure charts indicated no fluid entry. | 196 | Swabbed to 7,250 ft below land surface. No fluid recovered. Recovered about 15 gallons of fluid from top of test tool.[3] |
| Mesaverde Group | 7,598 to 7,604 | 4-3&4-68 | 5½ | ⅜ in. to ½ in. 2 per ft | F.A.S.T.[2] | Pressure charts indicated no fluid entry. | 197 | Swabbed to 7,544 ft below land surface. No fluid recovered. Recovered about 20 gallons of fluid from top of test tool.[3] |
| Mesaverde Group | 8,014 to 8,018 | 3-28-68 | 5½ | ⅜ in. to ½ in. 2 per ft | F.A.S.T.[2] | Pressure charts indicated no fluid entry. | 199 | Swabbed to 7,929 ft below land surface. No fluid recovered. Recovered about 30 gallons of fluid from top of test tool.[3] |

[1] Johnston Testers Multi-Flow Evaluator.
[2] Johnston Testers Fracturing Acidizing Squeezing Tool.
[3] Fluid likely to have entered the tubing after the packer was pulled loose.

pounds per square inch, which is adequate to support a column of water 2,020.82 m (6,630 ft) high or 172.52 m (566 ft) below land surface (Voegeli et al., 1970; Nork and Fenske, 1970, p. 6).

Little information was obtained about the hydraulic properties of the rocks above 1,828.80 m (6,000 ft) (Nork, 1969, p. 4; Nork and Fenske, 1970, p. 5). However, water-bearing characteristics for the same geologic formations in the shallow groundwater aquifer system slightly north (< 48.27 km [< 30 mi]) of the Rulison Site, presented in Table 5-6 (Coffin et al., 1968, p. 3), are assumed to be representative of the water-bearing characteristics for the alluvium and Green River Formation in the Rulison area.

The transmissibility of the alluvial fill differs from place to place. In places where the alluvium is mainly sand and gravel, transmissibility may be as much as 1,242.08 $m^2$/day (100,000 gallons per day [gpd]/ft). In places where the alluvium contains clay beds, the transmissibility may be as low as 248.42 $m^2$/day (20,000 gpd/ft). The average coefficient of storage probably averages about 0.20 (Coffin et al., 1968, p. 17). Thus, well yields depend largely on the lithology of the alluvium at the well, and the location of the well with respect to local hydrologic boundaries.

Specific conductance of the water decreased from about 12,000 to 10,000 microhoms, which may indicate a layering of the water and subsequent mixing when pumped (Coffin et al., 1968, p. 17).

Results of pumping and recovery tests in the Green River Formation indicate a range of transmissibility from 12.42 to 24.84 $m^2$/day (1,000 to 2,000 gpd/ft) (Coffin et al., 1968, pp. 17-18) and a storage coefficient of $1 \times 10^{-5}$ (Coffin et al., 1968, p. 21).

### *5.7.2 Regional Hydrochemistry*

A pre-shot inventory of wells and springs in the Rulison area was conducted by the USGS between March 20 and May 25, 1969, to document the condition of wells and springs and to collect water samples for chemical and radiochemical analysis. All known wells within a 9.65-km (6-mi) radius of the Rulison emplacement hole, as well as selected wells and springs within a 16.09- to 32.18-km (10- to 20-mi) radius, are given in Appendix B (Hurr et al., 1969, pp. 3-9; Voegeli et al., 1970, pp. 25-31). Figure 5-12 shows the location of the water-sampling points in the network (Claassen, 1971, p. 3). Detailed location descriptions of sampling sites are presented in Voegeli et al. (1970, pp. 35-37).

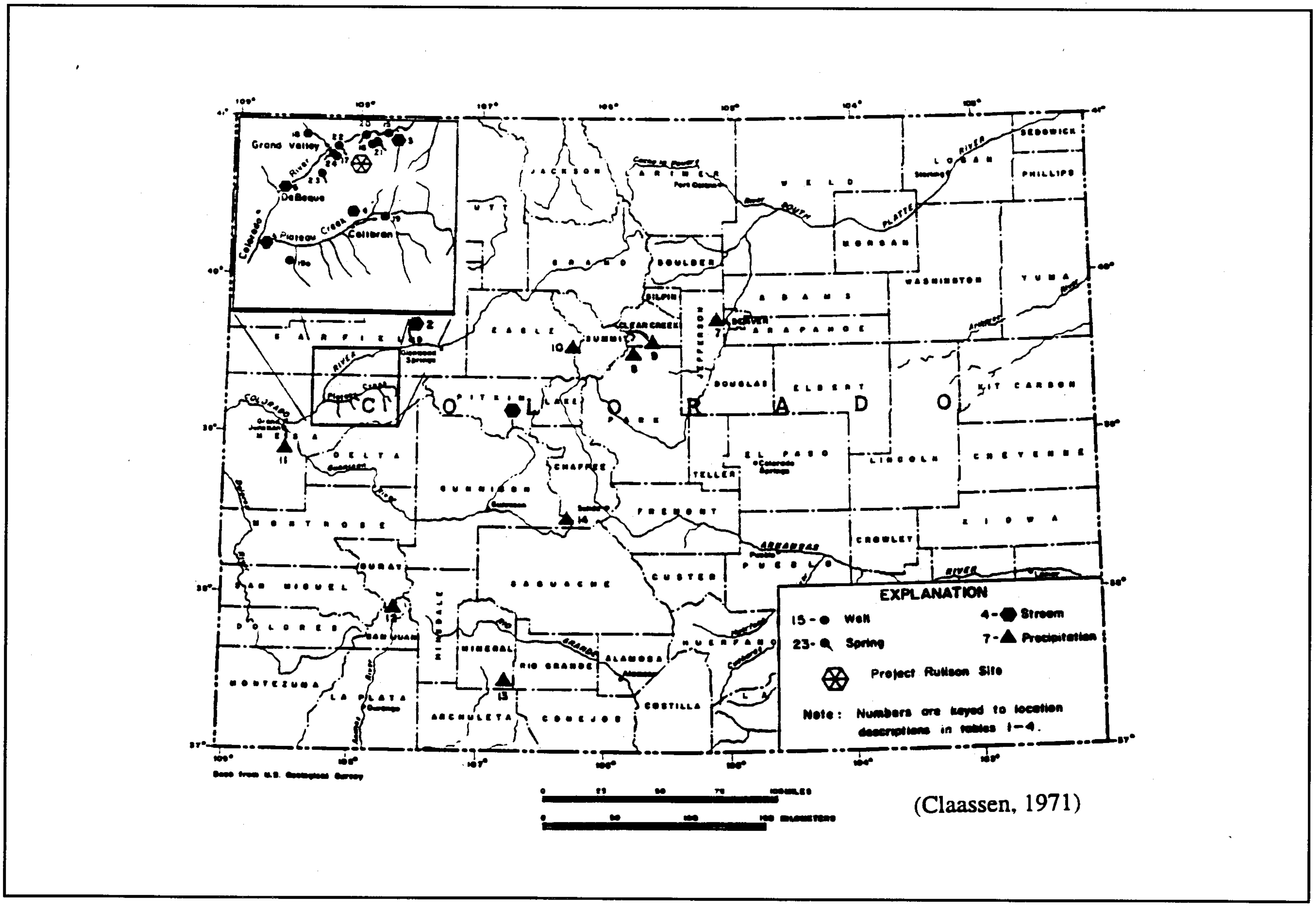



**Figure 5-12**
**Location of the U.S. Geological Survey Water-Sampling Points, Project Rulison**

# Table 5-6
## Summary of the Water-Bearing Characteristics of the Geologic Formation
(Coffin et al., 1968)

| System | Series | Geologic unit | | Thickness (feet) | Physical character | Water quality | Hydrologic character | Water supply |
|---|---|---|---|---|---|---|---|---|
| Quaternary | Recent and Pleistocene | Alluvium | | 0-140 | Sand, gravel, and clay partly fill major valleys as much as 140 feet; generally less than one-half mile wide. Beds of clay may be as thick as 70 feet; generally thickest near the center of valleys. Sand and gravel contain stringers of clay near mouths of small tributaries to major streams. | Near the headwaters of the major streams, dissolved-solids concentrations range from 250 to 700 ppm. The water is generally a calcium magnesium bicarbonate type. In most of the area, dissolved solids range from 700 to as much as 25,000 ppm. Above 3,000 ppm the water is generally a sodium bicarbonate type. | Water is under artesian pressure where sand and gravel are overlain by beds of clay. Well yields will decrease with time because valleys are narrow and the valley walls act as relatively impermeable boundaries. Calculated coefficients of transmissibility range from 20,000 to 150,000 gpd per ft. The coefficient of storage averages 0.20. | Reported yields as much as 1,500 gpm. |
| Tertiary | Eocene | Green River Formation | Evacuation Creek Member | 0-1,250 | Intertonguing and gradational beds of sandstone, siltstone, and marlstone; contains pyroclastic rocks and a few conglomerate lenses. Forms surface rock over most of the area; thins appreciably westward. | Water ranges from 250 to 1,800 ppm dissolved solids. It is a mixed type water with no dominant cation or anion. | Beds of sandstone are predominantly fine grained and are poorly permeable. Water moves primarily through fractures. The part of the member higher than valley floors is mostly drained. | Reported to yield as much as 100 gpm. Member has not been thoroughly tested, and larger yields may be possible. |
| | | | Parachute Creek Member | 500-1,800 | Kerogenaceous dolomitic marlstone (oil shale) and shale; contains thin pyroclastic beds; fractured to depths of at least 1,800 feet. Abundant saline minerals in deeper part of the basin. | Water ranges in dissolved-solids content from 250 to about 63,000 ppm. Below 500 ppm, calcium is dominant cation; above 500 ppm, sodium is generally dominant. Bicarbonate is generally the dominant anion regardless of concentration. Fluoride ranges from 0.0 to 54 ppm. | Oil shale is relatively impermeable. Water moves through the fractures. Calculated coefficients of transmissibility range from 1,000 to 2,000 gpd per ft; storage coefficient is about 0.00001. | Estimated potential yields as much as 500 gpm. |
| | | | Garden Gulch Member | 0-900 | Papery and flaky marlstone and shale; contains some beds of oil shale and, locally, thin beds of sandstone. | One water analysis indicates dissolved-solids concentration of 12,000 ppm. | Relatively impermeable and probably contains few fractures. | Not known to yield water to wells. |
| | | | Douglas Creek Member | 0-800 | Sandstone, shale, and limestone; contains oolites and ostracods. Throughout most of the area the member is deeply buried. Sandstone forms prominent cliffs along the basin margin on the south and west; thins toward the deeper part of the basin where the member seems to grade into a finer grained facies. | The few analyses available indicate that dissolved-solids content ranges from 3,000 to 12,000 ppm. The type is either sodium bicarbonate or sodium chloride. | Relatively low permeability and probably little fractured. | Maximum yield is unknown, but probably less than 50 gpm. |
| | | | Anvil Points Member | 0-1,870 | Shale, sandstone, and marlstone grade within a short distance westward into the Douglas Creek, Garden Gulch, and lower part of the Parachute Creek Members. Beds of sandstone are fine grained. | Water is generally of a magnesium sulfate type and may range in dissolved-solids content from about 1,200 to 1,800 ppm. | Beds of sandstone are poorly permeable. | A few wells tapping beds of sandstone yield less than 10 gpm; maximum potential yield is unknown. Springs yielding less than 100 gpm issue from fractures. |
| | | Wasatch Formation | | 300-5,000 | Clay, shale, lenticular sandstone; locally, beds of conglomerate and limestone. Beds of clay and shale are the main constituents of the formation. Contains gypsum. | Gypsum contributes sulfate to both surface-water and ground-water supplies. | Beds of clay and shale are relatively impermeable. Beds of sandstone are poorly permeable. | Not known to yield water to wells. |

The results of chemical analyses of groundwater (Hurr et al., 1969, pp. 12-13; Larson and Beetem, 1970, pp. 14-15; Voegeli et al., 1970, pp. 32-33) and surface water samples (Larson and Beetem, 1970, p. 8; Voegeli et al., 1970, p. 37) are given in Appendix C. The results of radiochemical analyses of spring and well samples collected during re-entry drilling at the Rulison Site (Voegeli and Claassen, 1971a, pp. 13-14; Voegeli and Claassen, 1971b, pp. 7-8), as well as radiochemical data obtained from stream samples in the Rulison area (Voegeli and Claassen, 1971a, p. 12; Voegeli and Claassen, 1971b, p. 6; Claassen and Voegeli, 1971, p. 4; Claassen, 1971, p. 4), are presented in Appendix D.

Tritium results are given in Appendix A (DOE, 1984, p. 24). Background levels of tritium in surface waters averaged 910 +/- 570 picoCuries per liter (pCi/L), well water samples averaged 640 +/- 450 pCi/L, and spring water samples averaged 770 +/- 770 pCi/L. Water samples collected during flaring ranged from less than 400 to 1,600 pCi/L (Boysen, 1976, p. 31). Numerous analytical results of water samples, as well as environmental and biological samples, collected from the Rulison area are given in Boysen, (1976). Atmospheric levels of radiation, as well as radiation exposures to off-site populations, are reported by the EPA (1974).

Prior to the completion of site cleanup, water samples were collected from two springs at the site, one located just off the southeast corner of the R-EX well pad and the other on the upper side of the road about 274.32 m (300 yards) downhill from the pad. No radioisotopes other than those naturally occurring were detected (AEC, 1973, p. 12; Eberline, 1977, p. 5). Decontamination of drilling equipment and radioactive fallout from gas flaring operations are also possible sources of shallow aquifer contamination. Extensive soil sampling at the site was done to access surface contamination resulting from radioactive fallout during gas flaring. Contaminated soil was removed from the site and transported to a suitable disposal site (Eberline, 1977).

Source term concentrations were estimated by assuming that the radionuclides are completely and uniformly mixed with a quantity of water equivalent to the volume of the cavity void space anticipated to be formed by the detonation. Predictions of cavity dimensions are given in Table 5-7 (AEC, 1969, p. 1; Nork and Fenske, 1970, p. 8). The cavity volume is calculated to be about 56,640 to 141,600 $m^3$ ($2 \times 10^6$ to $5 \times 10^6$ cubic feet). In this water volume, tritium concentration would be about $6 \times 10^{-3}$ microCuries per milliliter ($\mu$Ci/mL) to $2 \times 10^{-1}$ $\mu$Ci/mL (Nork, 1969, p. 5); strontium-90 concentration would be about $4 \times 10^{-2}$ $\mu$Ci/mL to $1 \times 10^{-1}$ $\mu$Ci/mL (Nork and Fenske, 1970, p. 11). From the post-shot drilling data, it was estimated that the rubble-filled chimney was approximately 106.68 m (350 ft) in height. This is greater than the

**Table 5-7**
**Physical Explosion Effects**

| | Maximum | Mean | Minimum | Units |
|---|---|---|---|---|
| Cavity Radius | 108 | 90 | 72 | feet |
| Cracking Radius | 580 | 485 | 390 | feet |
| Chimney Height | 451 | 376 | 301 | feet |
| Cavity Volume (or Chimney Void Space) | $5.28 \times 10^6$ | $3.05 \times 10^6$ | $1.56 \times 10^6$ | cubic feet |
| Chimney Volume | $16.5 \times 10^6$ | $9.57 \times 10^6$ | $4.90 \times 10^6$ | cubic feet |

Source: Nork and Fenske, 1970

minimum 91.74 m (301 ft) that was predicted, but comparable with the associated cavity radii dimensions determined from well test data (Reynolds, 1971, p. 1).

### *5.7.3 Regional Flow System*

The Rulison Site is on the southwest limb of the Piceance Creek basin, a large northwest- trending structural downwarp in northwestern Colorado (Figure 5-13). The northern part of the Piceance Creek basin drains to the White River; the southern part of the basin drains to the Colorado River. The Rulison Site drains northward to the Colorado River (Voegeli, 1969, p. 4; Voegeli et al., 1970, p. 4).

The principal surface hydrologic feature of the Rulison Site is Battlement Creek, a stream that discharges to the Colorado River at Parachute, Colorado. Battlement Creek carries most of the runoff to the river, while some runoff is diverted for irrigation use and some infiltrates the stream alluvium and terrace deposits. The underflow in the alluvium appears as springs in several places downstream from the Rulison Site (Voegeli, 1969, p. 7; Voegeli et al., 1970, p. 7). Ranchers on Morrisania Mesa obtain water for their domestic and livestock usage from shallow wells in alluvium and terrace deposits or from cisterns and ponds which obtain their water from Battlement Creek and other small streams and springs (Voegeli, 1969, p. 10; Voegeli et al., 1970, p. 5). Municipal groundwater resources in the Rulison area are confined primarily to alluvium and surficial deposits (e.g., flood-plain deposits and terrace and fan gravel) (Voegeli, 1969, p.7).

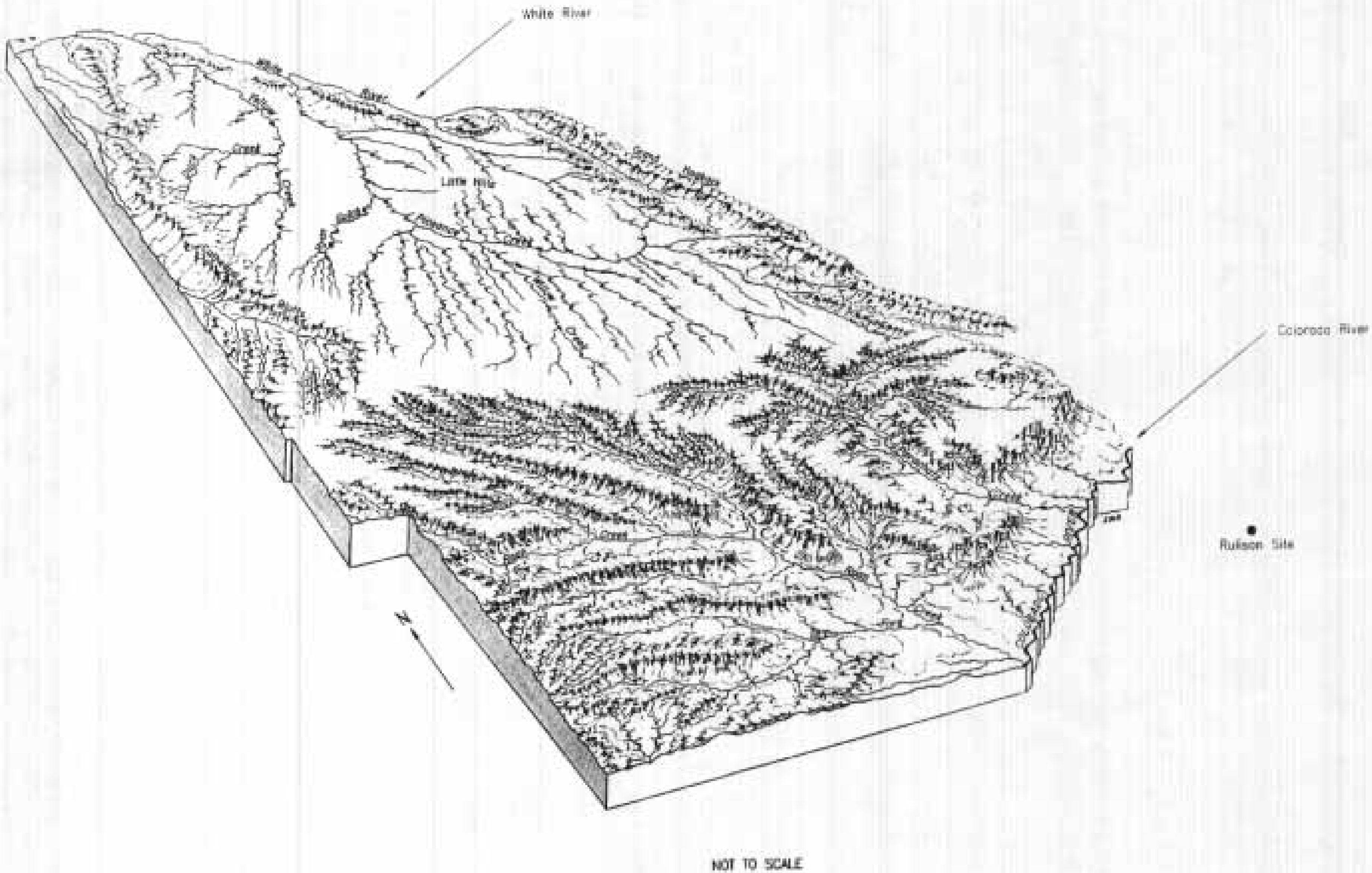



FIGURE 5-13
PICEANCE CREEK BASIN
RIO BLANCO, GARFIELD, AND
MESA COUNTIES, COLORADO

420UBIQ5 12/11/95

### *5.7.4 Impact of Test on Hydrology*

Studies of pre-shot and postshot hydrologic conditions indicate that the detonation had no effect on the physical, chemical, or radiochemical characteristics of wells, springs, streams, shallow aquifers, or reservoirs in or near the Rulison Site (Voegeli et al., 1970, p. 48; AEC, 1973, p. 18). The USGS also sampled springs, rivers, and wells before and after reentry drilling and after each of the three gas production tests with the same negative results (DOE, 1984, pp. 15-16).

The Rulison device was emplaced near the base of the Mesaverde Formation at a depth of 2,568 m (8,426 ft). Essentially all of the explosion-produced radionuclides were contained within the Mesaverde Formation. Any mobile water in the Mesaverde Formation which becomes contaminated with explosion nuclides, and is located below about 2,133.60 m (7,000 ft), is expected to move downward or laterally, but not upward. Above 2,133.60 m (7,000 ft), any contaminated mobile waters are expected to move laterally. Groundwater movement in this formation is estimated to be a maximum of 0.3048 m (1 ft) per day. The most probable rate is essentially negligible (Nork and Fenske, 1970, p. 2).

Six drill stem tests were run in the vicinity of the shot point. The USGS interpreted the chemical character of fluids collected from tubing after each drill stem test in exploration hole R-EX as indicating that "little mobile water occurs in the zones tested" (Voegeli, 1969, P.14). Three of these tests, 2,153.72 to 2,157.98; 2,193.34 to 2,193.95; and 2,228.70 to 2,231.14 m (7,066 to 7,080; 7,196 to 7,198; and 7,312 to 7,320 ft) below land surface resulted in pressure build-up curves that could be extrapolated to infinite time by the Van Everdingen method to estimate the virgin aquifer pressures. Table 5-8 shows the extrapolated shut-in pressures along with the post shot reservoir pressure compared to estimated hydrostatic pressures for the same depths.

The actual distribution of pressures above 7,066 feet are not well known. However, there can be no general upward or downward movement of water in this interval, and lateral flow must predominate. Below 7,066 feet pressures drop off rapidly and downward movement of water is expected to a point within or below the 7,312 to 7,320 foot interval. Since the pressure increases below this interval, a drain exists between 7,312 and about 8,442 feet where lateral flow is likely.

The three drill stem tests analyzed indicate relatively steep pressure build-up curves as a function of time but low fluid recoveries. A possible explanation of this phenomenon is that the predominant permeability belongs to a fracture system. The presence of many linears on the geologic map at the Rulison Site tends to substantiate this hypothesis. If this is the case, lateral

**Table 5-8**
**R-EX Drill Stem Test Formation Pressures**

| **Depth** (feet) | **Estimated Shut-In Pressure** (pounds per inch) | **Estimated Hydrostatic Pressure** (pounds per inch) |
|---|---|---|
| 7,066 - 7,080 | 3,050 | 3,050 |
| 7,196 - 7,198 | 2,900 | 3,096 |
| 7,312 - 7,320 | 2,250 | 3,150 |
| ≈ 8,442 | 2,950 | 3,640 |

flow of water could occur at significant velocities in terms of usual groundwater flow rates. However, since the interfracture blocks in the sandstone beds must also have some permeability, all water would also have to flow through these low permeability blocks. The average water velocity is therefore expected to be extremely low (Nork and Fenske, 1970, pp. 5-6).

If groundwater in the Mesaverde Formation is immobile, all radioactivity will reside essentially in place until artificially removed, and will eventually decay below detection levels. If the groundwater in the Mesaverde Formation is mobile, very likely the velocity of movement will be slow enough and chemical-exchange retardation high enough to prevent the transport of radionuclides in greater-than-contaminant guideline (CG) concentrations for any significant distances. Although distribution coefficient distribution coefficient ($K_d$) values were not determined for the Rulison Site, approximation for retardation of radionuclides may be determined using values from other locations, given in Table 5-9 (Nork, 1969, p. 7; Nork and Fenske, 1970, p. 13). Assuming a 0.31 m/day (1 ft/day) rate of flow, it is predicted that tritium would move less than 1.61 km (1 mi) before decaying to a concentration less than 1 x $10^6$ pCi/L (AEC, 1973, p. 18; DOE, 1984, p. 14). Under the same conditions of movement but with consideration of retardation effects (assuming $K_d$ = 10), strontium-90 would probably move less than 1.62 km (1 mi) before decay to below one CG (Nork, 1969, p. 8; Nork and Fenske, 1970, p. 14).

It is not clear what contaminant release scenario or scenarios were considered in the selection of Long-Term Hydrologic Monitoring Program (LTHMP) sampling sites (refer to Figure 2-11). It appears that rather than drilling a network of monitoring wells based on hydrologic data, the

**Table 5-9**
**Distribution Coefficients of Strontium-85 and Cesium-137 for Various Materials**
(Material suspended in 4 parts saturating solution for 72 hours. Minimum particle diameter is 4,000$\mu$ [Nork, 1969].)

| Material | Saturating Medium | Kd (Ml/g) | |
|---|---|---|---|
| | | Sr | Cs |
| Basalt (Amchitka) | Sea Water | 1.07 | 6.50 |
| Carbonate (Yucca Flat, Nevada Test Site) | Prepared Water* (Well) | 0.19 | 13.5 |
| Salt (Tatum Salt Dome) | Salt Saturated Water | 0.19 | 0.02 |
| Shaley Siltstone (Gasbuggy Site, Northern New Mexico) | GB-2 Well Water | 8.32 | 309. |
| Sandstone (Gasbuggy Site, Northern New Mexico) | GB-2 Well Water | 1.37 | 102. |
| Granite (Shoal Site, Nevada) | Deep Formation Water | 1.7 | 34.3 |
| Tuff (Rainier Mesa, Nevada Test Site) | Prepared Water* (Rainier Spring) | 260. | 1020. |
| Desert Alluvium (Hot Creek Valley, Nevada) | Deep Formation Water | 50-2450 | 70-2640 |

*Water prepared to have major chemical composition similar to that of referenced water source.

LTHMP groundwater sampling program has clearly focused on local domestic supply wells and springs already in place as discussed in Section 2.2.2.4.2 Second Sampling Program, Water Sampling (Chapman and Hokett, 1991, p. 36).

The alluvial deposits are separated from the emplacement horizon by great thicknesses of low permeability formations, making transport of contaminants through the geologic media unlikely. The most probable mechanism for contaminant transport to the shallow monitoring wells from the shot point at a depth of over 2,438.40 m (8,000 ft) involves contaminant transport up the test holes. However, the presence of a low-pressure horizon at a depth of about 2,194.56 m (7,200 ft) is presumed to behave as a sump between the shot depth and near-surface aquifers. This zone will prevent vertical flow into the higher pressure zones above, diverting contaminants to lateral flow along this hydrologic drain (Voegeli et al., 1970). In addition, the boreholes were plugged. The possibility of surface contamination by fallout during gas flaring operations was addressed by monitoring during flaring and presumably no longer poses a threat (Chapman and Hokett, 1991, p. 36).

Clearly, if the borehole release scenario is verifiably impossible, there is no reason to monitor the quality of the shallow aquifer. However, given that it is the only scenario proposed that could result in contamination of local supply aquifers, the LTHMP at Rulison is evaluated on the basis that contaminant transport is only possible through the boreholes drilled for the test.

During September 1995, DOE installed two shallow wells in the alluvial aquifer directly downgradient of the emplacement shaft. These two wells will be included in the EPA's annual LTHMP. The purpose of these wells is to function as early warning detection devices (for the alluvial aquifer) in the unlikely event that upward migration has occurred via the emplacement shaft.

# 6.0 Recommendations

Based on the information provided in this report, the following tasks should be completed to fill the information gaps that remain on this project:

- Complete the human health baseline risk assessment
- Collect gas/water samples from the gas wells closest to the shot cavity
- Characterize the mudpit located by the RE-X well
- Continue the Long-Term Hydrologic Monitoring Program
- Develop an action plan in the event contamination is found

## 6.1 Complete Human Health Risk Assessment

The human health baseline risk assessment for the hydrocarbon/heavy metal contaminants is in the process of being prepared by DOE. Once it is completed it can be used to: (1) identify areas in which additional information is needed, (2) to determine the relative importance of the proposed tasks, and (3) to determine if a task is necessary.

## 6.2 Collect Gas/Water Samples

One of the potential pathways for contamination from the shot cavity to reach a receptor is by tritium migrating to one of the gas producing horizons. To check this, two wells have been identified from which gas/water samples should be collected and analyzed for tritium. Permission will have to be obtained from the owners of the wells and arrangements made to collect the samples when the owners can be present.

## 6.3 Characterize the Mudpit

During drilling of the soil borings in September 1995, drilling mud was discovered near the RE-X well. The mud was contaminated primarily with total petroleum hydrocarbons (probably diesel fuel). The Toxicity Characteristic Leaching Procedure metals analyses all came back nondetect. The vertical extent of the mud was defined but not the lateral extent. Depending on the opinion the Colorado State Department of Health takes regarding this information, additional characterization and possible cleanup may be required at this site.

## 6.4 Continue the Long-Term Hydrologic Monitoring Program

The Long-Term Hydrologic Monitoring Program should be continued and expanded to include the two monitoring wells installed onsite near SGZ during 1995. Sampling of another five wells emplaced to evaluate the impacts of the contaminated pond sediments will take place quarterly for two years. Analyses will include total petroleum hydrocarbons and metals. At the end of the required two-year monitoring period, if no impacts from the hydrocarbon or metals have been detected in the groundwater, the State may waive the monitoring requirement or request that these five wells be monitored on an annual basis.

### *6.5 Develop an Action Plan*

Finally, a plan should be developed to specify what actions need to be taken in the event that contamination is found in any of the monitoring locations. At the present time, no plans exist that identify what happens in the event that radiological contamination is found in any of the sampling locations.

Implementing these recommendations will reduce the amount of money to be spent on the site by identifying exactly where it needs to be spent to fill data gaps and alleviate risks. It will also reduce DOE liability by allowing the investigations to focus on those areas that pose the greatest liability (if any).

## *7.0 References*


AEC (for reference, see U.S. Atomic Energy Commission).

*American Indian Religious Freedom Act of 1978.* Public Law 95-341.

Andrews, R. and R. Righter. 1992. *Colorado Birds: A Reference to Their Distribution and Habitat.* Denver, CO: Denver Museum of Natural History.

Austral, see Austral Oil Company, Inc.

Austral Oil Company, Inc. 1972. *Project Rulison - Post-Shot Well Test Data: PNE-R-52.* Las Vegas, NV.

Austral Oil Company, Inc. and CER Geonuclear Corporation. 1969. *Project Rulison - Site Evaluation Pre-Shot R-EX Well Test Data: PNE-R-7.* Las Vegas, NV.

BLM, see U.S. Bureau of Land Management.

Baumgardner, R.W., Jr. et al. 1988. "Site Selection for GRI Cooperative Tight Gas Field Research, Volume II: Geologic Characteristics of Selected Low-Permeability Gas Sandstones." Bureau of Economic Geology Topical Report prepared for Gas Research Institute under Contract No. 5082-211-0708. Austin, TX: University of Texas.

Boysen, G.A. U.S. Environmental Protection Agency. 1976. *Off-Site Radiological Safety Program For Project Rulison Flaring, Phase III: Monitoring Operations Division, EMSL-LV-539-8.* Washington, DC: U.S. Government Printing Office.

Brooks, L.R., J.F. Duds, and D. Falck. U.S. Geological Survey. 1933. *Land Classifications of Western Colorado.* Washington, DC: U.S. Government Printing Office.

Carlson, J. U.S. Department of Agriculture. Soil Conservation Service. 1993. Personal Communication, 4 January.

CDNR, see Colorado Department of Natural Resources.

CER Corporation. 1984. *Multi-Well Experiment MWX-3 As-Built Report: SAND84-7132.* Las Vegas, NV.

CER Corporation. 1989. *Geologic and Production Characteristics of the Tight Mesaverde Group: Piceance Basin, Colorado.* Las Vegas, NV.

CER Corporation. 1992. *Results of Field Verification Tests in the Tight Mesaverde Group: Piceance Basin, Colorado.* Las Vegas, NV.

CFR, see Office fo the Federal Register.

Chapman, J.B. and S.L. Hokett. U.S. Department of Energy, Nevada Operations Office. 1991. *Evaluation of Groundwater Monitoring at Offsite Nuclear Test Areas. #45085,* Report DOE/NV/10845-07, UC-703. Las Vegas, NV: Desert Research Institute Water Resources Center Publication #45085.

Claassen, H.C. 1971. *Radiochemical Analyses of Water Samples From Selected Streams and Precipitation Collected October 23-November 9, 1970, in Conjunction with the First Production-Test Flaring of Gas from Test Well, Project Rulison: USGS-474-108.* Denver, CO: U.S. Geological Survey.

Claassen, H.C. and P.T. Voegeli, Sr. 1971. *Radiochemical Analyses of Water Samples Collected in Connection with Calibration-Test Flaring of Gas from Test Well, August 15-October 13, 1970, Project Rulison: USGS-474-107.* Denver, CO: U.S. Geological Survey.

Coffin, D.L., F.A. Welder, and R.K. Glanzman. 1971. *Geohydrology of the Piceance Creek Structural Basin Between the White and Colorado Rivers, Northwestern Colorado: USGS Atlas HA-370*. Denver, CO: U.S. Geological Survey.

Coffin, D.L., F.A. Welder, R.K. Glanzman, and X.W. Dutton. 1968. *Geohydrologic Data from the Piceance Creek Basin, between the White and Colorado Rivers, Northwestern Colorado*. Colorado Groundwater Circular No. 12. Denver, CO.

Colorado. Department of Natural Resources (CDNR). Division of Wildlife. 1993. *WILDATA and Wildlife Habitat Relationships.* Data base accessed February 5. Grand Junction, CO.

Desert Research Institute. 1988. *CERCLA Preliminary Assessment of DOE's Nevada Operations Office Nuclear Weapons Testing Areas.* Las Vegas, NV.

Dickinson, W.R. and W.S. Snyder. 1978. "Plate tectonics of the Laramide orogeny." In *Laramide folding associated with basement block faulting in the western United States,* edited by Vincent Matthews, III. Geological Society of America Memoir 151.

DOE, see U.S. Department of Energy.

Donnell, J.R. 1968. Rulison Area Geological Maps. USGS open file.

DRI, see Desert Research Institute.

Eberline Instrument Corporation. 1977. *Rulison Radiation Contamination Clearance Report*: PNE-R-68. Sante Fe, NM.

EG&G Energy Measurements. 1995. *An Aerial Radiological Survey of Project Rulison and Surrounding Area*, EGG 11265-1094. Las Vegas, NV.

EL, see U.S. Army Corps of Engineers, Environmental Laboratory.

EPA, see U.S. Environmental Protection Agency.

ERDA, see U.S. Energy Research and Development Administration.

Fauver, D.N. 1986. *Hazardous Waste Installation Assessment Report*. Las Vegas, NV: Reynolds Electrical & Engineering Co., Inc.

FEMA, see U.S. Federal Emergency Management Agency.

Hammerson, G.A. 1986. *Amphibians and Reptiles in Colorado,* Denver, CO: Colorado Division of Wildlife.

Hart, C.M., D. Engi, R.P. Fleming, and H.E. Morris. 1984. "Fracture Diagnostics Results for the Multiwell Experiment's Paludal Zone Stimulation." Paper SPE/DOE GRI 12852 presented at the SPE/DOE Unconventional Gas Recovery Symposium, Pittsburgh, PA, 13-15 May.

*Historic Properties Preservation Act of 1966*. Public Law 89-665, 80 Stat. 915, 16 U.S.C.A. § 470 et seq. by Public Laws 91-243, 93-54, 94-422, 94-458, 96-244, and 96-515.

*Historical and Archaeological Data Preservation Act of 1974*. Public Law 93-291; 88 Stat. 174; 16 U.S.C.A. § 469.

Hurr, R.T., W.W. Wilson, F.A. Welder, and R.L. Emerson. 1969. *Records of Selected Wells and Springs in the Rulison Project Area, Garfield and Mesa Counties, Colorado: USGS-474-40*. Denver, CO: U.S. Geological Survey.

IT, see IT Corporation.

IT Corporation. 1993a. *A Class III Cultural Resources Survey of the U.S. Department of Energy Rulison Gas Stimulation Test Site, Garfield County, Colorado*, DOE/NV/10972-62. Report prepared for U.S. Department of Energy, Las Vegas, NV.

IT Corporation. 1993b. *Sensitive Species Survey Results for the Rulison and Rio Blanco Sites, Colorado*, DOE/NV/10972-55. Report prepared for U.S. Department of Energy, Las Vegas, NV.

IT Corporation. 1993c. *Floodplains and Wetlands Survey Results for the Rulison and Rio Blanco Sites, Colorado*, DOE/NV/10972-59. Report prepared for U.S. Department of Energy, Las Vegas, NV.

IT Corporation. 1995. *Corrective Action Plan, Rulison Drilling Effluent Pond*. Report prepared for U.S. Department of Energy, Las Vegas, NV.

Johnson, R.C., R.A. Crovelli, C.W. Spencer, and R.F. Mast. 1987. *An Assessment of gas resources in Low-Permeability Sandstones of the Upper Cretaceous Mesaverde Group, Piceance Basin, Colorado*. U.S. Geological Survey Open-File Report 87-357.

Knutson, C.F. 1977. *Outcrop Study of Fracture Patterns and Sandstone Geometry, Eastern Uinta Basin, Utah: Study Results and Implication to Stimulation of Tight Gas 'Sands' in the Area*. Report prepared for U.S. Energy Research and Development Administration, Nevada Operations Office, NVO-655-1, Las Vegas, NV.

Kollmorgen Corporation. 1975. *Munsell Soil Color Charts*. Baltimore, MD: Macbeth Division, Kollmorgen Corporation.

Kukal, G.C., E.H. Price, R.E. Hill, and E.R. Monson. August 1992. *Results of Field Verification Tests in the Tight Mesaverde Group: Piceance Basin, Colorado*, DOE Report DOE/MC/24120. Las Vegas, NV.

Larson, J.D. and W.A. Beetem. 1970. *Chemical and Radiochemical Analyses of Water from Streams, Reservoirs, Wells, and Springs in the Project Rulison Area, Garfield and Mesa Counties, Colorado*: USGS-474-67. Denver, CO: U.S. Geological Survey.

Lorenz, J.C. 1983. *Reservoir Sedimentology of the Mesaverde Rocks at the Multi-Well Experiment Site*. Sandia National Laboratories Report, SAND83-1078. Albuquerque, NM and Livermore, CA.

Lorenz, J.C. 1985. *Tectonic and stress Histories of the Piceance Creek Basin and the MWX Site, from 75 Million Years Ago to the Present*. Sandia National Laboratories Report, SAND84-2603. Albuquerque, NM and Livermore, CA.

Marlatt, W.E. 1973. "Climate of the Piceance Creek Basin." In *An Environmental Reconnaissance of the Piceance Creek Basin, Part I, Phase I*. Boulder, CO: Thorne Ecological Institute.

Mason, B.J. Battelle Memorial Institute. 1970. Letter to Ernest Campbell, 13 July.

Myal, F.R., E.H. Price, R.E. Hill, G.C. Kukal, P.J. Abadie, and C.C. Riecken. July 1989. Geologic and Production Characteristics of the Tight Mesaverde Group: Piceance Basin, Colorado. DOE Report DOE/MC/24120-2769. Las Vegas, NV.

*National Environmental Policy Act of 1969, Title 42, U.S.C.S. § 4332, Section 102(2)(c)*. Public Law 91-190.

Nessler, Thomas. State of Colorado, Colorado Department of Wildlife. 1995. Personal Communication, 20 April.

Nork, W.E. 1969. *Radioactivity in the Hydrologic Environment Project Rulison Final Pre-Shot Report (U)*: U.S. Atomic Energy Commission, NVO-1229-108. Las Vegas, NV.

Nork, W.E. and P.R. Fenske. 1970. *Radioactivity in Water - Project Rulison*: U.S. Atomic Energy Commission, NVO-1229-131. Las Vegas, NV.

Office of the Federal Register. National Archives and Records Administration. *Code of Federal Regulations, Executive Order 11593, "Protection and Enhancement of the Cultural Environment," 36 F.R. 8921*. Washington, DC: GPO, May 15, 1971.

Office of the Federal Register. National Archives and Records Administration. *Code of Federal Regulations, Title 10, Part 11*. Washington, DC: GPO, 1974.

Office of the Federal Register. National Archives and Records Administration. *Code of Federal Regulations, Title 10, "Energy," Part 1021, "National Environmental Policy Act Implementing Procedures."* Washington, DC: GPO, 1992.

Office of the Federal Register. National Archives and Records Administration. *Code of Federal Regulations, Title 36, "Parks, Forests, and Public Property," Part 800, "Advisory Council on Historic Preservation."* Washington, DC: GPO, 1995.

Office of the Federal Register. National Archives and Records Administration. 1992. "Compliance with Floodplain Wetlands Environmental Review Requirements," *Code of Federal Regulations, Title 10, Part 1022*. Washington, DC: U.S. Government Printing Office.

Rand McNally. *Commercial Atlas and Marketing Guide.* 1993. Chicago, IL.

Reed, P.B., Jr. U.S. Fish and Wildlife Service. 1988. “National List of Plant Species that Occur in Wetlands: National Summary,” *Biological Report 88 (24)*. Washington, DC: U.S. Government Printing Office.

Reed, A.D. State Historical Society of Colorado. 1984. *West Central Colorado Prehistoric Context*. Denver, CO: Office of Archaeology and Historic Preservation.

Reynolds, Jr., M. 1971. *Project Rulison Post-Shot Investigations Summary of Re-Entry Operations*: PNE-R-45. Houston, TX: Austral Oil Company, Inc.

Reynolds, Jr., M. Austral Oil Company. 1977. *The Rulison Field Massive Hydraulic Fracturing Experiment*: NVO/0679-1. Report prepared for the U.S. Department of Energy, Las Vegas, NV.

Sattler, A.R. 1984. “The Multiwell Experiment Core Program, II.”: Paper SPE/DOE GRI 12854 presented at the SPE/DOE Unconventional Gas Recovery Symposium, Pittsburgh, PA: 13-15 May.

SCS, see U.S. Department of Agriculture, Soil Conservation Service.

Stosur, J.J. 1977. "Current Status of Projects Gasbuggy, Rulison, and Rio Blanco and an Appraisal of Nuclear-Explosive Fracturing Potential for the Near Future." In *The Future Supply of Nature-made Petroleum and Gas; Technical Reports*, edited by R.F. Meyer. New York: Pergamon Press.

Thompson, J. 1992. *Fisheries Report.* Grand Junction, CO: United States Bureau of Land Management.

Thompson, J. Bureau of Land Management. 1993. Personal Communication, 1 July.

Tuttle, M.L., D.J. Ackerman, W.E. Dean, P.H. Briggs, and A.J. Bartel. 1983. *Chemical and Mineral Composition Data on Oil Shale and Retorted Oil-Shale Wastes From Rulison, Colorado*: USGS Open File Report 83-378.

U.S. Army Corps of Engineers, Environmental Laboratory. 1987. *Corps of Engineers Wetlands Delineation Manual*, Technical Report Y-87-1. Vicksburg, MS.

U.S. Atomic Energy Commission. Nevada Operations Office. December 1969a. *Project Rulison Post-Shot Plan and Evaluations*, NVO-61. Las Vegas, NV.

U.S. Atomic Energy Commission. Nevada Operations Office. 1969b. *Project Rulison Planning Directive*. Las Vegas, NV.

U.S. Atomic Energy Commission. Nevada Operations Office. September 1973a. *Rulison Site Cleanup Report*, NVO-136. Las Vegas, NV.

U.S. Atomic Energy Commission. Nevada Operations Office. April 1973b. *Project Rulison Manager’s Report*, NVO-71. Las Vegas, NV.

U.S. Bureau of Land Management. June 1986. *State of Colorado Wilderness Map.* Denver, CO.

U.S. Bureau of Land Management. 1980. Recreation Management Areas--Bureau of Land Management-Colorado. Revised map. Denver, CO.

U.S. Congress. Office of Technology Assessment. October 1989. *The Containment of Underground Nuclear Explosions*. OTA-ISC-414. Washington, DC: U.S. Government Printing Office.

U.S. Department of Agriculture. Soil Conservation Service. 1980. *Soil Survey of Rifle Area, Colorado*. Washington, DC: U.S. Government Printing Office.

U.S. Department of Agriculture. Soil Conservation Service. 1983. *National Soils Handbook*. Washington, DC: U.S. Government Printing Office.

U.S. Department of Agriculture. Soil Conservation Service. 1987. *Hydric Soils of the United States*. In cooperation with the National Technical Committee for Hydric Soils. Washington, DC: U.S. Government Printing Office.

U.S. Department of Energy. Nevada Operations Office. 1984. *Long-Term Hydrologic Monitoring Program Rulison Event Site, Grand Valley, Colorado*, NVO-273. Las Vegas, NV.

U.S. Energy Research and Development Administration. 1976. *Project Rulison Well Plugging and Site Abandonment Plan,* NVO-174. Las Vegas, NV.

U.S. Energy Research and Development Administration. 1977. *Project Rulison Well Plugging and Site Abandonment Final Report*, NVO-187. Las Vegas, NV.

U.S. Environmental Protection Agency. 1974. *Off-Site Surveillance Activities of the National Environmental Research Center from July through December 1970,* NERC-LV-539-17. Las Vegas, NV.

U.S. Geological Survey. 1970. *Geohydrology--Project Rulison, Garfield County, Colorado, With a Section on Aquifer Response*, USGS-474-68. Denver, CO.

U.S. Geological Survey. 1980. Rulison, Colorado, and 1952 Rock School, Colorado, 7.5 Minute Quadrangle Maps. Denver, CO.

U.S. Geological Survey. 1987. *National Wilderness Preservation System*, map. Denver, CO.

U.S. Federal Emergency Management Agency. January 3, 1986. *Flood Insurance Rate Map, Garfield County, Colorado (Unincorporated areas), Map Index,* Community-Panel Numbers 080205 0001-1900. Washington, DC: U.S. Government Printing Office.

USDA, see U.S. Department of Agriculture.

USGS, see U.S. Geological Survey.

Voegeli, P.T., Sr. 1969. *Geology and Hydrology of the Project Rulison Exploratory Hole, Garfield County, Colorado,* USGS-474-16. Denver, CO: U.S. Geological Survey.

Voegeli, P.T., Sr., S.W. West, and E.H. Cordes. 1970. *Geohydrology - Project Rulison, Garfield County, Colorado*, USGS-474-68. Denver, CO: U.S. Geological Survey.

Voegeli, P.T., Sr., and H.C. Claassen. 1971a. *Radiochemical Analyses of Water from Selected Streams, Wells, Springs, and Precipitation Collected Prior to Reentry Drilling, Project Rulison*, USGS-474-83. Denver, CO: U.S. Geological Survey.

Voegeli, P.T., Sr., and H.C. Claassen. 1971b. *Radiochemical Analyses of Water from Selected Streams, Wells, Springs, and Precipitation Collected During Reentry Drilling, Project Rulison*, USGS-474-101. Denver, CO: U.S. Geological Survey.

Whitney, S. 1992. Western Forests, *Audobon Society Nature Guides*. New York: Alfred A. Knoff, Inc.

Yeend, W.E. 1968. *Quaternary Geology of the Grand-Battlement Mesa Area, Colorado.* USGS Open File Report.

# Appendix A
# Project Rulison, Long-Term Hydrologic Monitoring Program Analytical Results, 1972-1994, Garfield County, Colorado

Rulison Tritium Results in pCi/L for 1972-1982

| | 1972 | | 1973 | | 1974 | | 1975 | | 1976 | | 1977 | | 1978 | | 1979 | | 1980 | | 1981 | | 1982 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 3H | $3H^+$ | 3H | $3H^+$ | 3H | $3H^+$ | 3H | $3H^+$ | 3H | $3H^+$ | 3H | $3H^+$ | 3H | $3H^+$ | 3H | $3H^+$ | 3H | $3H^+$ | 3H | $3H^+$ | 3H | $3H^+$ |
| HAYWARD RANCH WELL | 380±230 | | <300 | | 480±13 | | 350±12 | | 480±210 | | 440±230 | | 710±350 | | | 390±11 | | 330±11 | | 360±10 | | 370±8.4 |
| SEARCY RANCH WELL (SCHWAB) | 740±240 | | 670±250 | | 800±16 | | 380±13 | | 740±270 | | | 430±14 | 690±350 | | | 440±11 | | 360±11 | | 250±8.9 | | 320±8.3 |
| GARDNER RANCH WELL | 770±240 | | 420±240 | | 510±12 | | 510±15 | | 610±270 | 310±9.8 | 390±230 | | 650±350 | | | 310±9.8 | | 300±10 | | 240±8.8 | | 250±7.7 |
| SEFCOVIC RANCH WELL | | | | | | | 580±15 | | 420±11 | | 520±240 | | 880±350 | | | 300±10 | | 310±11 | | 290±9.5 | | 320±8.4 |
| CER TEST WELL | 770±240 | | 800±250 | | 610±15 | | 540±16 | | 350±11 | | 560±240 | | 580±350 | | | 230±8.9 | | 240±9.6 | | 190±7.7 | | 280±8.0 |
| BERNKLAU RANCH WELL | 250±230 | | 320±240 | | 350±13 | | 510±19 | | 350±9.6 | | | | | | | | | | | | | |
| GRAND VALLEY CITY SUPPLY (SPRING) | 270±230 | | <300 | | 170±11 | | 130±9.6 | | <6 | | | 56±8.3 | | <20 | | 40±6.8 | | 31±6.6 | | 46±6.1 | | 74±5.8 |
| POTTER RANCH SPRING | | | | | | | | | | | 460±240 | | 680±350 | | | 280±9.5 | | 230±9.4 | | 210±8.2 | | 270±7.6 |
| SPRING (300 YDS. N.W. OF GZ) | 510±230 | | 740±250 | | 450±13 | | 480±16 | | 270±9.3 | | | 170±11 | 730±350 | | | 180±8.5 | | 210±9.2 | | 130±7.7 | | 190±7.1 |
| BATTLEMENT CREEK (SURFACE) | 860±240 | | 510±240 | | 580±15 | | 300±12 | | 250±13 | | | 330±13 | 850±350 | | | 240±9.1 | | 140±8.2 | | 200±8.5 | | 190±7.1 |

3H = Tritium analysis by conventional method.
$3H^+$ = Tritium analysis by enrichment method.

(U.S. DOE, 1984)

# *Project Rulison, Long-Term Hydrological Monitoring Program Analytical Results, 1983-1985*

| | Collection Date | Conc. ± 2 Sigma Tritium (pCi/ℓ)[1] | % of Conc. Guide[2] | Collection Date | Conc. ± 2 Sigma Tritium (pCi/ℓ) | % of Conc. Guide | Collection Date | Conc. ± 2 Sigma Tritium (pCi/ℓ) | % of Conc. Guide |
|---|---|---|---|---|---|---|---|---|---|
| **Grand Valley, Colorado** | | | | | | | | | |
| City Spring | 5/29/83 | 110 ± 6 | 0.6 | 6/20/84 | 3.3 ± 5.0* | < 0.02 | 6/20/85 | -6.2 ± 7.7* | < 0.01 |
| Albert Gardner Ranch Well | 5/29/83 | 260 ± 7 | 1 | 6/21/84 | 200 ± 6 | 1 | 6/19/85 | 200 ± 8 | 1 |
| Battlement Creek (surface) | 5/30/83 | 200 ± 7 | 1 | 6/20/84 | 120 ± 5 | 0.6 | 6/19/85 | 130 ± 8 | 0.6 |
| Spring 300 yards NW of GZ | 5/30/83 | ----- | ----- | 6/20/84 | 130 ± 6 | 0.6 | 6/19/85 | 130 ± 8 | 0.6 |
| CER Test Well | 5/30/83 | ----- | ----- | 6/20/84 | 110 ± 6 | 0.6 | 6/19/85 | 210 ± 9 | 1 |
| **Rulison, Colorado** | | | | | | | | | |
| Lee Hayward Ranch Well | 5/29/83 | 260 ± 7 | 1 | 6/21/84 | 310 ± 7 | 2 | 6/20/85 | 280 ± 9 | 1 |
| Potter Ranch Well | 5/30/83 | 250 ± 7 | 1 | 6/21/84 | 160 ± 6 | 0.8 | 6/20/85 | 150 ± 8 | 0.8 |
| Robert Searcy (G. Schwab) Ranch Well | 5/29/83 | 170 ± 6 | 0.9 | 6/21/84 | 180 ± 6 | 0.9 | 6/20/85 | 170 ± 9 | 0.9 |
| Felix Sefcovic Ranch Well | 5/29/83 | 360 ± 8 | 2 | 6/21/84 | 240 ± 7 | 1 | 6/20/85 | 210 ± 8 | 1 |

[1]Picocurie per liter (pCi/ℓ)

[2]Established by DOE Order as 90,000 pCi/ℓ tritium.

* = Concentration is less than the minimum detectable concentration (MDC).

NA = Not applicable. Percent of concentration guide is not applicable either because the tritium result is less than the MDC or because the water is known to be nonpotable.

# *Project Rulison, Long-Term Hydrological Monitoring Program*
# *Analytical Results, 1986-1988*

| | Collection Date | Conc. ± 2 Sigma Tritium (pCi/ℓ)[1] | % of Conc. Guide[2] | Collection Date | Conc. ± 2 Sigma Tritium (pCi/ℓ) | % of Conc. Guide | Collection Date | Conc. ± 2 Sigma Tritium (pCi/ℓ) | % of Conc. Guide |
|---|---|---|---|---|---|---|---|---|---|
| **Grand Valley, Colorado** | | | | | | | | | |
| City Spring | 6/15/86 | 28 ± 8 | 0.1 | 7/27/87 | -0.13 ± 8.2* | < 0.01 | 6/25/88 | -2 ± 16* | < 0.01 |
| Albert Gardner Ranch Well | 6/15/86 | 190 ± 9 | 1 | 7/27/87 | 170 ± 8 | 0.8 | 6/25/88 | 170 ± 12 | 0.86 |
| Battlement Creek (surface) | 6/15/86 | 100 ± 8 | 0.5 | 7/27/87 | 100 ± 8 | 0.5 | 6/25/88 | 140 ± 11 | 0.70 |
| Spring 300 yards NW of GZ | ----- | ----- | ----- | 7/27/87 | 87 ± 8 | 0.4 | 6/25/88 | 84 ± 11 | 0.42 |
| CER Test Well | 6/15/86 | N/A | ----- | 7/27/87 | 160 ± 9 | 0.8 | 6/25/88 | 160 ± 12 | 0.79 |
| **Rulison, Colorado** | | | | | | | | | |
| Lee Hayward Ranch Well | 6/15/86 | 260 ± 12 | 1 | 7/27/87 | 220 ± 8 | 1 | 6/25/88 | 250 ± 12 | 1.24 |
| Potter Ranch Well | 6/16/86 | 140 ± 8 | 0.7 | 7/27/87 | 120 ± 8 | 0.6 | 6/27/88 | 140 ± 11 | 0.71 |
| Robert Searcy (G. Schwab) Ranch Well | 6/15/86 | 90 ± 9 | 0.5 | 7/27/87 | 160 ± 9 | 0.8 | 6/25/88 | 150 ± 11 | 0.76 |
| Felix Sefcovic Ranch Well | 6/15/86 | 98 ± 8 | 0.5 | 7/27/87 | 170 ± 8 | 0.8 | 6/25/88 | 160 ± 11 | 0.82 |
| | 6/15/86 | 190 ± 8 | 1 | | | | | | |

[1]Picocurie per liter (pCi/ℓ)
[2]Established by DOE Order as 90,000 pCi/ℓ tritium.
* = Concentration is less than the minimum detectable concentration (MDC).
NA = Not applicable. Percent of concentration guide is not applicable either because the tritium result is less than the MDC or because the water is known to be nonpotable.

# *Project Rulison, Long-Term Hydrological Monitoring Program*
# *Analytical Results, 1989-1991*

| | Collection Date | Conc. ± 2 Sigma Tritium (pCi/ℓ)[1] | % of Conc. Guide[2] | Collection Date | Conc. ± 1 Sigma Tritium (pCi/ℓ) | % of Conc. Guide | Collection Date | Conc. ± 1 Sigma Tritium (pCi/ℓ) | % of Conc. Guide |
|---|---|---|---|---|---|---|---|---|---|
| **Grand Valley, Colorado** | | | | | | | | | |
| City Spring | 6/13/89 | 1.1 ± 6.8* | 0.01 | 6/19/90 | 9.9 ± 4.1* | 0.05 | 6/11/91 | 0.78 ± 3.12* | NA |
| Albert Gardner Ranch Well | 6/13/89 | 140 ± 8 | 0.70 | 6/19/90 | 87 ± 5.0 | 0.43 | 6/11/91 | 113 ± 4 | 0.6 |
| Battlement Creek (surface) | 6/13/89 | 86 ± 8 | 0.43 | 6/19/90 | 22 ± 2.2 | 0.11 | 6/11/91 | 56 ± 3 | 0.3 |
| Spring 300 yards NW of GZ | 6/13/89 | 73 ± 7 | 0.36 | 6/19/90 | 18 ± 2.0 | 0.09 | 6/11/91 | 57 ± 3 | 0.3 |
| CER Test Well | 6/13/89 | 140 ± 8 | 0.70 | 6/19/90 | 41 ± 2.2 | 0.21 | 6/11/91 | 57 ± 2.1 | 0.3 |
| **Rulison, Colorado** | | | | | | | | | |
| Lee Hayward Ranch Well | 6/13/89 | 170 ± 8 | 0.85 | 6/19/90 | 88 ± 2.7 | 0.44 | 6/11/91 | 187 ± 4 | 0.9 |
| Potter Ranch Well | 6/13/89 | 120 ± 8 | 0.6 | 6/19/90 | 43 ± 2.1 | 0.22 | 6/11/91 | 119 ± 4 | 0.6 |
| Robert Searcy (G. Schwab) Ranch Well | 6/13/89 | 89 ± 8 | 0.45 | 6/19/90 | 41 ± 2.8 | 0.21 | 6/11/91 | 63 ± 4 | 0.3 |
| Felix Sefcovic Ranch Well | 6/13/89 | 77 ± 8 | 0.38 | 6/19/90 | 27 ± 2.6 | 0.13 | 6/11/91 | 133 ± 4 | 0.7 |

[1]Picocurie per liter (pCi/ℓ)
[2]Established by DOE Order as 90,000 pCi/ℓ tritium.
* = Concentration is less than the minimum detectable concentration (MDC).
NA = Not applicable. Percent of concentration guide is not applicable either because the tritium result is less than the MDC or because the water is known to be nonpotable.

# *Project Rulison, Long-Term Hydrological Monitoring Program Analytical Results, 1992-1994*

| | Collection Date | Conc. ± 2 Sigma Tritium (pCi/ℓ)[1] | % of Conc. Guide[2] | Collection Date | Conc. ± 2 Sigma Tritium (pCi/ℓ) | % of Conc. Guide | Collection Date | Conc. ± 1 Sigma Tritium (pCi/ℓ) | % of Conc. Guide |
|---|---|---|---|---|---|---|---|---|---|
| **Grand Valley, Colorado** | | | | | | | | | |
| City Spring | 6/9/92 | 0.43 ± 1.49* | NA | 6/16/93 | -1.6 ± 3.1* | NA | 5/29/94 | -1.2 ± 3.5* | NA |
| Albert Gardner Ranch Well | 6/9/92 | 98 ± 3 | 0.11 | 6/16/93 | 80 ± 4.4 | 0.09 | 5/29/94 | 82 ± 5.1 | 0.09 |
| Battlement Creek (surface) | 6/9/92 | 63 ± 2 | 0.07 | 6/16/93 | 49 ± 3.8 | 0.05 | 5/29/94 | 48 ± 4.2 | 0.05 |
| Spring 300 yards NW of GZ | 6/9/92 | 63 ± 2 | 0.07 | 6/16/93 | 57 ± 4.2 | 0.06 | 5/29/94 | 47 ± 4.0 | 0.05 |
| CER Test Well | 6/9/92 | 48 ± 2 | 50.05 | 6/16/93 | 51 ± 4.2 | 0.06 | 5/29/94 | 84 ± 4.6 | 0.09 |
| **Rulison, Colorado** | | | | | | | | | |
| Lee Hayward Ranch Well | 6/9/92 | 160 ± 3 | 0.18 | 6/16/93 | 116 ± 5.2* | 0.02 | 5/29/94 | 100 ± 4.6* | 0.11 |
| Potter Ranch Well | 6/9/92 | 67 ± 2 | 0.07 | 6/16/93 | 1.4 ± 2.9 | 0.002 | 5/29/94 | 82 ± 4.6 | 0.09 |
| Rothgery (Searcy) (Schwab) Ranch Well | 6/9/92 | 78 ± 2 | 0.09 | 6/16/93 | 57 ± 4.1 | 0.06 | 5/29/94 | 71 ± 4.7 | 0.08 |
| Felix Sefcovic Ranch Well | 6/9/92 | 57 ± 2 | 0.06 | 6/16/93 | 100 ± 4.9* | 0.11 | 5/29/94 | 87 ± 4.4 | 0.10 |

[1]Picocurie per liter (pCi/ℓ)
[2]Established by DOE Order as 90,000 pCi/ℓ tritium.
* = Concentration is less than the minimum detectable concentration (MDC).
NA = Not applicable. Percent of concentration guide is not applicable either because the tritium result is less than the MDC or because the water is known to be nonpotable.

# Appendix B
# Records of Selected Wells and Springs, Rulison Project Area

## Records of selected wells, Rulison project area, Garfield and Mesa Counties, Colorado

(Adapted from Hurr, and others, 1969, and Larson and Beetem, 1970.)

Location number: See text for well-numbering system.

Date of inventory: Date of inventory, water-level measurement, yield measurement.

Depth of well: Measured depths are given in feet and tenths below land surface (accuracy ± 0.5 ft); reported depths are given in feet.

Altitude of land surface: Altitude, estimated from 7½-minute quadrangle topographic maps, is given in feet above mean sea level.

Depth to water: Measured depths to water are given in feet and tenths below land surface; reported depths are given in feet below land surface. A "P" indicates pumping level at time of measurement.

Method of lift and type of power: J, jet; N, none; P, piston; S, submersible; T, turbine; E, electric motor; NG, natural gas engine.

Yield: All quantities are given in gallons per minute. R, reported; E, estimated.

Use of water: D, domestic; I, irrigation; Ind, industrial; N, none; S, stock.

Well permit number: Permit on file at State Engineer's office under this number.

Remarks: DC, depth well cased; Pf, perforated casing with interval shown; OH, open hole with interval shown.

| Location number | Owner or tenant | Date of inventory | Year com-pleted | Depth of well (feet) | Casing | | Altitude of land surface (feet) | Depth to water (feet) | Method of lift and power | Yield (gallons per minute) | Use of water | Temper-ature of water (°C) | Turbid-ity (milli-grams per liter) | Well permit number | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Diameter (inches) | Type | | | | | | | | | |
| SC 5-92-33aac | W. Jewell | 10-22-69 | 1962 | 35 | 6 | Steel | 5,690 | 6.5 | J,E | -- | D,S | -- | -- | P12707 | Inventoried postshot. |
| SC 6-93-15cbd | K. Johnson | 3-26-69 | 1941 | 41 | -- | -- | 5,330 | 25 | J,E | -- | D | 10 | 1 | -- | Outside 20-km radius. |
| -16bcb | Kozy Kottage Kourt | 3-27-69 | 1954 | 50 | 6 | -- | 5,300 | 20 | -- | 60R | D | -- | -- | R1198 | Pump would not start. |
| -16cdb | J. Layne | 3-27-69 | 1963 | 40 | 7 | Steel | 5,310 | 19 | J,E | 20R | D,S | -- | -- | P18318 | Pump was not working. Owner uses city water. |
| -16cdd | W. Wood | 3-27-69 | 1964 | 24 | 7 | Steel | 5,305 | 8 | J,E | 20R | N | -- | -- | P20807 | |
| -16dcc | R. Swallow | 3-27-69 | 1964 | 44 | 7 | Steel | 5,315 | 18 | -- | 20R | D | -- | -- | PF5733 | |
| -17bbd | W. Shafto | 3-26-69 | 1956 | 38 | 5 | Steel | 5,290 | 18 | J,E | 5E | D | 11 | <1 | N28 | Problems with salt and corrosion. Well cleaned out about 1 year ago. |
| -18adb | A. Wooley | 3-26-69 | 1965 | 42 | 5 | Steel | 5,290 | 31 | J,E | 10R | N | -- | -- | P25185 | |
| -18dac | Union Carbide Corp. | 3-26-69 | 1957 | 30.5 | 96 | Steel | 5,270 | 10.6P | T,E | 1,500R | Ind | 15 | 15 | -- | Two 8-inch pumps in well. |
| -20ccc | E. Hull | 3-26-69 | -- | 300 | 7 | Steel | 5,710 | 80 | P,E | -- | D | 8 | 4 | -- | |
| SC 6-94-23dca | C. Saulsbury | 3-24-69 | 1966 | 94 | -- | -- | 5,520 | -- | J,E | 5E | D | 10 | <1 | -- | |
| -26bcc | N. Mead | 3-24-69 | 1964 | 75 | 7 | Steel | 5,300 | 30 | S,E | 15R | D,S | 10 | <1 | P19365 | |
| -26cac | H. Boor | 3-24-69 | 1953 | 210 | 15 | Steel | 5,360 | 88.8 | T,NG | 650R | I | -- | -- | R13852 | Well number 1. |
| -27daa | L. Dotson | 3-24-69 | 1962 | 103 | 6 | Steel | 5,300 | -- | P,E | -- | D,S | 17 | 2 | -- | Owner reports motor needs replacing. |
| -27dda | H. Boor | 3-24-69 | 1953 | 210 | 15 | Steel | 5,340 | 83.6 | T,NG | 650R | I | -- | -- | R13851 | Well number 2. |
| -30cda | E. Becktell | 3-20-69 | 1954 | 140 | -- | -- | 5,280 | -- | S,E | -- | D | 5 | 3 | -- | |
| -31bbd | G. Ems | 3-20-69 | 1967 | 105 | 7 | Steel | 5,270 | 65 | S,E | 40R | D | 3 | <1 | -- | |
| -31bca | R. McDaniel | 3-20-69 | 1965 | 130 | 7 | Steel | 5,350 | 110 | S,E | 23R | I,D,S | 3 | <1 | -- | DC, 130 feet. |
| -31bcd | Seventh Day Adventist | 3-20-69 | 1962 | 100 | 7 | Steel | 5,360 | 80 | S,E | 20R | D | 4 | 3 | P13564 | |

--Records of selected wells, Rulison project area, Garfield and Mesa Counties, Colorado--Continued

| Location number | Owner or tenant | Date of inventory | Year completed | Depth of well (feet) | Casing: Diameter (inches) | Casing: Type | Altitude of land surface (feet) | Depth to water (feet) | Method of lift and power | Yield (gallons per minute) | Use of water | Temperature of water (°C) | Turbidity (milligrams per liter) | Well permit number | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SC 6-94-31bdc | W. Massey | 3-24-69 | 1967 | 142 | 6 | Steel | 5,380 | 70 | S,E | 8R | D | 11 | <1 | P32393 | OH, 110-142 feet. |
| -31dac | E. Robinson | 3-20-69 | 1964 | 160 | 7 | Steel | 5,600 | 15 | E | 30R | D | 10 | <1 | -- | |
| -31dbb | O. Gibbs | 3-21-69 | 1969 | 54.0 | 9 | Steel | 5,470 | 22.9 | N | -- | N | -- | -- | -- | New well,no pump. |
| SC 6-95-28cdd | O. Mahaffey | 3-20-69 | 1963 | 180 | 5 | Steel | 5,485 | 120 | S,E | 2R | D | 8 | 2 | P18113 | |
| -34cba | do. | 3-24-69 | 1963 | 88.0 | 7 | Steel | 5,220 | 69.5 | S,E | 12R | S | -- | -- | P18114 | |
| -35acd | W. Arnett | 3-27-69 | -- | 12.0 | (48x48) | Wood | 5,140 | 10.7 | N | -- | N | -- | -- | -- | |
| -36adb | C. Gardner | 3-26-69 | -- | 33 | 7 | Steel | 5,220 | -- | J,E | 5E | D | 3 | 12 | -- | |
| -36add | R. Smith | 3-24-69 | 1921 | 86 | -- | -- | 5,280 | -- | J,E | -- | D | 7 | 3 | -- | |
| -36dab | L. Dix | 3-20-69 | -- | 110.0 | 96 | Concrete | 5,280 | 44.0 | J,E | -- | D | 8 | <1 | -- | |
| SC 6-96-29daa | Sinclair Oil Co. | 3-20-69 | 1959 | 40 | 4 | Steel | 5,440 | 20 | J,E | 35R | D,S | 14 | <1 | -- | |
| -34bda | Union Oil Co. | 3-20-69 | 1951 | 88.0 | 8 | Steel | 5,445 | 65.9 | S,E | 10 | S | 12 | <1 | -- | Formerly used for irrigation. Reported to yield about 250 gpm when equipped with 4-inch turbine pump. |
| -34bdb | do. | 3-20-69 | -- | 85.0 | 4 | Steel | 5,425 | 57.9 | S,E | <10R | D | 7 | <1 | -- | Casing quite rusty. |
| -34cad | do. | 3-20-69 | 1963 | 59.0 | 6 | Steel | 5,340 | 39.0 | S,E | 5E | S | 9 | 27 | P17375 | |
| -34cbd | do. | 3-20-69 | -- | 121.4 | 6 | Steel | 5,380 | 61.0 | J,E | -- | N | -- | -- | -- | |
| -34cdb | do. | 3-20-69 | 1963 | 81.9 | 6 | Steel | 5,330 | 68.0 | J,E | 10E | S | 11 | <1 | P17376 | Casing rusty but pump in good condition. |
| SC 7-94- 6ddd | R. Bingman, Sr. | 3-22-69 | 1945 | 140 | 7 | Steel | 6,480 | 100 | P,E | -- | D,S | 6 | 1 | -- | |
| - 7bab | F. Sefcovic | 3-22-69 | 1954 | 85 | 6 | Steel | 6,460 | -- | P,E | 3R | D,S | 8 | <1 | -- | |
| - 7bba | J. Lemon | 3-28-69 | -- | -- | 6 | Steel | -- | -- | -- | -- | N | -- | -- | -- | Pump out of hole. |
| SC 7-95- 2cbc | P. Baum | 3-19-69 | 1969 | 295 | 7 | Steel | 5,860 | 130 | S,E | 5E | D | 6 | 1 | PF6667(?) | |
| - 3dcd | H. Pfost | 4- 3-69 | 1959 | 125 | 7 | Steel | 5,940 | -- | S,E | -- | N | -- | -- | -- | Pump set at 50 feet. |
| - 3ddc | C. Moore | 4- 3-69 | 1961 | 150 | 6 | Steel | 5,965 | 70 | S,E | 50R | I,D | -- | -- | PF2713 | |
| - 4ccc | J. Savage | 3-26-69 | -- | 122.5 | 5 | Galv. iron | 5,550 | 120.0 | S,E | -- | N | -- | -- | -- | |
| - 7adb | J. Lawson | 5-13-69 | 1960 | 100 | 7 | Steel | 5,160 | 30 | J,E | 1R | D | 16 | -- | P5480 | Pump pulled. |
| - 7dab | M. Zediker | 3-24-69 | 1958 | 12.5 | 36 | Concrete | 5,120 | 7.8 | P,E | 5E | I,D | 11 | <1 | -- | DC, 63 feet. |
| - 9adb | J. Smith | 5-20-69 | 1968 | 160 | 7 | Steel | 5,920 | -- | N | -- | N | -- | -- | P28859 | |
| -10acb | L. Hayward | 4- 3-69 | 1958 | 115 | 5 | Galv. iron | 6,050 | 90 | J,E | 10R | D,S | -- | -- | P924 | |
| -10acc | Sorensen | 5-20-69 | 1966 | 160 | 7 | Steel | 6,100 | 80 | N | 20R | N | -- | -- | P28863 | |
| -10adc1 | E. Schwab | 4- 3-69 | 1955 | 75 | -- | -- | 6,140 | 32 | -- | -- | I,D | -- | -- | R6280 | |
| -10adc2 | do. | 5-14-69 | 1954 | 134 | 6 | Steel | 6,140 | 13 | S,E | 50R | I,D | -- | -- | -- | |
| -10adc3 | do. | 4- 3-69 | -- | -- | -- | -- | 6,140 | -- | S,E | -- | -- | -- | -- | -- | |
| -10bda | L. Hayward | 5-14-69 | 1962 | 143 | 5 | Steel | 5,990 | 43 | S,E | -- | D | 11 | -- | -- | |
| -10dcd | do. | 5-20-69 | -- | 160 | 7 | Steel | 6,300 | 81.0 | N | -- | N | -- | -- | P28861 | |
| -12bad | B. Smith | 3-22-69 | 1951 | 80 | 8 | Steel | 6,210 | -- | S,E | -- | D,S | 12 | <1 | -- | |

--Records of selected wells, Rulison project area, Garfield and Mesa Counties, Colorado--Continued

| Location number | Owner or tenant | Date of inventory | Year completed | Depth of well (feet) | Casing: Diameter (inches) | Casing: Type | Altitude of land surface (feet) | Depth to water (feet) | Method of lift and power | Yield (gallons per minute) | Use of water | Temperature of water ($^{o}C$) | Turbidity (milligrams per liter) | Well permit number | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SC 7-95-17aab | A. McLane | 3-19-69 | 1966 | 230 | 5 | Steel | 5,660 | 100 | S,E | 3R | D | 7 | 1 | P28860 | Pf, 170-220 feet; OH, 220-230 feet. |
| -17aba | D. Dupice | 3-19-69 | 1966 | 240 | 5 | Steel | 5,600 | 160 | S,E | 7R | D | 13 | 10 | P28862 | Pf, 160-210 feet; OH, 210-240 feet. |
| -18adb | R. Nordstrom | 3-18-69 | 1949 | 100 | 7 | Steel | 5,380 | 50 | S,E | 8R | D | 14 | 2 | -- | Owner reports water is rusty. |
| -18cbb | G. Rogers | 5-13-69 | 1960 | 95 | 7 | Steel | 5,110 | 66 | S,E | 30E | D | 12 | -- | P5517 | |
| -18dad | M. Christianson | 3-18-69 | -- | -- | 6 | Steel | 5,470 | -- | S,E | -- | D | 12 | 2 | -- | |
| -20bba | A. Gardner | 3-26-69 | 1957 | 130 | 6 | Steel | 5,510 | 80 | S,E | 10E | D,S | 12 | <1 | -- | |
| SC 7-96- 1ccc | Lindauer | -- | -- | -- | -- | -- | 5,150 | -- | -- | -- | N | -- | -- | -- | Tenant reports that well is no good. It was drilled in too fine and clayey material. |
| - 2dbb | C. Alber | 3-20-69 | 1900 | 29.3 | 24 | Rock | 5,195 | 15.1 | J,E | 8R | S | -- | -- | N439 | Motor on pump reported to have failed Dec. 1968. It has not yet been repaired. |
| -12bbb | B. Lindauer | 3-20-69 | 1948 | 57 | 6 | Steel | 5,140 | 32 | J,E | 10E | D | 16 | <1 | -- | |
| -13abb | W. Gray | 3-24-69 | 1964 | 50.7 | 7 | Steel | 5,080 | 34.4 | J,E | -- | D | -- | -- | P16995 | |
| -13abd | J. Smith | 3-24-69 | 1959 | 14.6 | 24 | Concrete | 5,060 | 7.2 | J,E | 5E | D | 11 | 11 | -- | |
| -23cad | Mountain Corp. | 3-25-69 | 1959 | 13.9 | 23 | Oil drums | 5,030 | 11.0 | P,E | 5E | D | 7 | 1 | -- | |
| -34bac | A. DeMaestri | -- | -- | -- | -- | -- | 4,995 | -- | -- | -- | N | -- | -- | -- | |
| -34bbc | do. | 3-25-69 | -- | 11.0 | (24x24) | Concrete | 4,995 | 8.9 | J,E | 5E | D | 7 | <1 | -- | |
| -34bcd | R. Ellis | 3-25-69 | 1961 | 23.2 | 7 | Steel | 4,990 | 9.8 | J,E | 5E | D | 11 | 12 | -- | |
| -34bdc | C. Hayward | 3-25-69 | 1963 | 25.5 | 7 | Steel | 4,990 | 11.1 | J,E | 15R | D | 11 | 37 | P16997 | |
| SC 8-96-11acc | E. Kennon | 3-18-69 | -- | 50 | 8 | -- | 5,760 | 38 | S,E | -- | D,S | 9 | 2 | -- | |
| -11bbd | L. Knox | 3-18-69 | 1950 | 10 | 36 | None | 5,600 | 6.0 | J,E | 6E | D | 6 | 3 | -- | |
| -12aac | N. Dutton | 5-13-69 | 1949 | 165 | 6 | Steel | 6,100 | 134 | P,E | 2E | D,S | 13 | -- | -- | DC, 165 feet. |
| SC 8-97-14dad | O. Mahaffey | 3-26-69 | 1964 | 107.0 | 5 | Steel | 5,020 | 66.7 | S,E | 8R | S | -- | -- | P19065 | Outside 20-km radius. |
| SC 9-94-22acc | W. Nicoll | 3-25-69 | 1965 | 290 | 9 | Steel | 6,980 | 100 | S,E | 5E | D,S | 12 | <1 | P20032(?) | |
| -22bab | W. Severson | 5-15-69 | 1966 | 110 | 7 | Steel | 6,940 | -- | S,E | 5E | D,S | 10 | -- | -- | |
| SC 9-95-26baa | P. Hight | 5-15-69 | 1951 | 75 | 5 | Steel | 6,320 | 57 | J,E | -- | D | 15 | -- | -- | |
| -34bdb | M. Campbell | 3-25-69 | 1900 | 40 | 6 | Rock | 5,994 | -- | J,E | -- | D | 10 | <1 | -- | Pump in basement of store. Well under street about 25 feet north of store. |

--Records of selected wells, Rulison Project area, Garfield and Mesa Counties, Colorado--Continued

| Location number | Owner or tenant | Date of inventory | Year completed | Depth of well (feet) | Casing | | Altitude of land surface (feet) | Depth to water (feet) | Method of lift and power | Yield (gallons per minute) | Use of water | Temperature of water (°C) | Turbidity (milligrams per liter) | Well permit number | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Diameter (inches) | Type | | | | | | | | | |
| SC 9-95-35abc | T. Young | 5-20-69 | 1964 | 765 | 7 | Steel | 6,100 | 55 | S,E | 50E | D | -- | -- | PF6238 | DC, 765 feet. Pf, 175-200 feet, 405-510 feet, and 565-765 feet. |
| SC 10-95- 2aab | Unknown | 4- 3-69 | -- | 35 | -- | -- | 6,240 | -- | -- | -- | N | -- | -- | -- | Pump bad. Tenant hauling water. |
| - 2baa | H. Castle | 4- 3-69 | 1964 | 185 | 5 | Steel | 6,245 | 138 | J,E | 12R | D | -- | -- | P21409 | |

Records of selected springs, Rulison project area, Garfield and Mesa Counties, Colorado

(Adapted from Hurr, and others, 1969, and Larson and Beetem, 1970.)

Location number: See text for spring-numbering system.
Date of inventory: Date of inventory and yield measurement.
Altitude of land surface: Altitude of point of discharge, estimated from 7½-minute quadrangle topographic maps, is given in feet above mean sea level.
Yield: R, reported; E, estimated.
Use of water: C, commercial; D, domestic; I, irrigation; M, municipal; S, stock.
Improvements: B, box; N, none; P, pipe; U, undetermined.
Temperature: Recorded to nearest 1°C.

| Location number | Owner or tenant | Date of inventory | Altitude of land surface (feet) | Yield (gallons per minute) | Use of water | Improvements | Temperature (°C) | Turbidity (milligrams per liter) | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| SC 6-93-18aac | A. Wooley | 3-26-69 | 5,340 | 1E | C,D | B,P | 6 | <1 | Spring went dry once or twice 6 or 7 years ago. |
| -20bdd | J. Todd, Sr. | 3-26-69 | 5,400 | -- | D | U | 4 | >150 | |
| SC 6-94-26aca | L. Farris | 3-24-69 | 5,520 | -- | D | U | 10 | <1 | |
| -26adc | H. Boor | 3-24-69 | 5,500 | 12R | D | U | 7 | <1 | |
| -31bbb | B. Potter | 3-20-69 | 5,210 | 100E | I,D | B | 13 | <1 | |
| -32cca | W. Wells | 3-21-69 | 5,770 | -- | D | U | 8 | <1 | |
| -33dbd | D. Winch | 3-24-69 | 5,640 | -- | D | U | 5 | <1 | |
| -34dcc | J. Smith | 3-24-69 | 5,510 | -- | D | U | 4 | <1 | |
| SC 6-95-36aab | W. Lemon | 9- 5-69 | 5,200 | -- | D,I | N | 13 | -- | |
| -36aabl | do | 9- 5-69 | 5,200 | -- | D,I | N | 13 | -- | |
| -36abd | do | 9- 4-69 | 5,200 | -- | D,I | N | 12 | -- | |
| -36abdl | do | 9- 5-69 | 5,200 | -- | D,I | N | 13 | -- | |
| -36cdd | G. Scarrow | 3-21-69 | 5,480 | -- | D | U | 5 | 3 | |
| SC 7-94- 4acd | M. Bernklau | 3-24-69 | 5,920 | -- | D | U | 7 | <1 | |
| - 4bdc | C. Bernklau | 3-22-69 | 6,040 | -- | D | U | 5 | <1 | |
| - 6aba | E. Pettigrew | 3-21-69 | 5,840 | -- | D | U | 3 | 21 | |
| - 6bba | M. Gerst | 3-20-69 | 5,800 | -- | D,S | U | 5 | 2 | Supplies water to four houses. |

Records of selected springs, Rulison project area, Garfield and Mesa Counties, Colorado--Continued

| Location number | Owner or tenant | Date of inventory | Altitude of land surface (feet) | Yield (gallons per minute) | Use of water | Improvements | Temperature (°C) | Turbidity (milligrams per liter) | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| SC 7-95- 1aba | G. Elliott | 3-21-69 | 5,760 | -- | D | U | 6 | <1 | |
| - 1baa | C. Clark | 3-21-69 | 5,680 | -- | D | U | 4 | <1 | |
| - 2add | A. Hoagland | 3-26-69 | 5,740 | -- | D | U | 6 | <1 | |
| - 2bcd | E. Forshee | 3-21-69 | 5,580 | -- | D,S | U | 4 | 4 | |
| - 3bdb | G. Knight | 3-26-69 | 5,340 | 150E | I | N | -- | -- | Contour ditch along hillside collects water from numerous springs along 1/2 - 3/4 mile of spring line. |
| - 4acd | do. | 3-26-69 | 5,340 | 5 | D | N | 9 | 3 | |
| - 4add | do. | 3-26-69 | 5,340 | 155 | I | N | 9 | 14 | Irrigates with sprinkler. |
| - 4dbb | do. | 3-26-69 | 5,340 | 70 | I | N | 10 | 9 | |
| - 5dcd | Town of Grand Valley | 3-21-69 | 5,340 | 125 | M | B | 12 | <1 | Twenty-one separate spring boxes collect water from numerous springs along 1/2 mile of spring line. |
| - 8ccb | R. Eaton | 3-24-69 | 5,300 | 47 | D,I,S | N | 9 | 2 | Contour ditch along hillside collects water from two separate springs. |
| -18aad | do. | 3-25-69 | 5,320 | 85 | S | N | 7 | 9 | |
| -18bcd | C. Gardner | 3-26-69 | 5,120 | -- | S | U | 9 | <1 | |

Records of selected springs, Rulison project area, Garfield and Mesa Counties, Colorado--Continued

| Location number | Owner or tenant | Date of inventory | Altitude of land surface (feet) | Yield (gallons per minute) | Use of water | Improvements | Temperature (°C) | Turbidity (milligrams per liter) | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| SC 7-96-33dcd | W. Hammerick | 3-25-69 | 5,040 | 16 | D,S | N | 12 | <1 | |
| -34caa | D. Knox | 3-18-69 | 5,080 | -- | D | U | 10 | 2 | |
| -35dcb | O. Murray | 3-18-69 | 5,500 | -- | D | U | 4 | 4 | Location number is for residence. |
| SC 8-95-24acc | F. Wallace | 9-19-69 | 10,200 | -- | -- | U | 7 | 1 | Inventoried postshot. |
| SC 9-93-19bda | C. Bruton | 9- 4-69 | 7,180 | 75E | D,S,I | B | 9 | -- | Supplies water to two houses. |
| SC 9-95-26daa | City of Collbran | 3-25-69 | 6,040 | -- | M | U | 8 | <1 | |
| -33dba | Plateau Valley School | 3-25-69 | 5,720 | -- | M | U | 10 | <1 | |
| -34adb | R. Gibson | 3-25-69 | 6,040 | -- | C,D | U | 7 | <1 | Supplies a motel and the Civilian Conservation Center of the U.S. Bureau of Reclamation. |
| -35ddb | E. Chapman | 3-25-69 | 6,150 | -- | D,S | U | 2 | <1 | |

# Appendix C
# Chemical Analyses of Groundwater and Surface Water, Project Rulison Area

--Chemical analyses of water from selected wells, springs, and cisterns, Bullion project area, Garfield and Mesa Counties, Colorado.
(Adapted from Burr and others, 1969, and Larson and Beetem, 1970.)

Location number: See text for hydrologic data point numbering system.

| Location number | Well, spring, or cistern (W,S,C) | Date of collection | Silica ($SiO_2$) | Aluminum (Al) | Iron (Fe) | Manganese (Mn) | Calcium (Ca) | Magnesium (Mg) | Strontium (Sr) | Sodium (Na) | Potassium (K) | Lithium (Li) | Bicarbonate ($HCO_3$) | Carbonate ($CO_3$) | Sulfate ($SO_4$) | Chloride (Cl) | Fluoride (F) | Nitrate ($NO_3$) | Phosphate ($PO_4$) | Copper (Cu) | Zinc (Zn) | Selenium (Se) | Boron (B) | Dissolved solids (residue at 180°C) | Specific conductance (micromhos per cm at 25°C) | Hardness as $CaCO_3$: Calcium magnesium | Hardness as $CaCO_3$: Noncarbonate | pH | Tritium T.U. | Gross beta in picocuries per liter (as Sr^90-Y^90) | Gross alpha in micrograms per liter (as U equivalent) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SC5-95-35aac | S | 11-22-65 | 11 | <0.1 | [illegible] | <0.01 | 73 | [illegible] | [illegible] | [illegible] | 2.5 | <0.01 | 423 | 0 | 262 | 30 | 0.9 | 20 | <0.01 | 0.00 | 0.11 | <0.01 | 0.20 | 383 | 1,100 | 355 | 45 | 7.? | <200 | <6.5 | 17 |
| SC6-95-15cbc | W | 1-25-65 | -- | -- | [illegible] | -- | -- | -- | -- | -- | -- | -- | 898 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1,990 | -- | -- | 7.4 | -- | -- | -- |
| 17bbc | W | 1-22-65 | -- | -- | [illegible] | -- | -- | -- | -- | -- | -- | -- | 734 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 2,070 | -- | -- | 7.3 | -- | -- | -- |
| 18aac | S | 1-22-65 | -- | -- | [illegible] | -- | -- | -- | -- | -- | -- | -- | 532 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 2,220 | -- | -- | 7.8 | -- | -- | -- |
| 18aac | W | 1-22-65 | -- | -- | [illegible] | -- | -- | -- | -- | -- | -- | -- | 222 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 3,480 | -- | -- | 7.2 | -- | -- | -- |
| 20bbd | S | 1-26-65 | -- | -- | [illegible] | -- | -- | -- | -- | -- | -- | -- | 510 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1,220 | -- | -- | 7.8 | -- | -- | -- |
| 21ccc | S | 1-22-65 | -- | -- | [illegible] | -- | -- | -- | -- | -- | -- | -- | 380 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 686 | -- | -- | 7.6 | -- | -- | -- |
| SC6-94-23dca | S | 1-25-65 | -- | -- | [illegible] | -- | -- | -- | -- | -- | -- | -- | 580 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 870 | -- | -- | 7.3 | -- | -- | -- |
| 26acc | S | 1-24-65 | -- | -- | [illegible] | -- | -- | -- | -- | -- | -- | -- | 426 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1,180 | -- | -- | 7.8 | -- | -- | -- |
| 26aad | S | 1-24-65 | -- | -- | [illegible] | -- | -- | -- | -- | -- | -- | -- | 387 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1,010 | -- | -- | 7.7 | -- | -- | -- |
| 26bcc | W | 1-24-65 | -- | -- | [illegible] | -- | -- | -- | -- | -- | -- | -- | 535 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1,180 | -- | -- | 7.5 | 400 | 8.3 | 6.8 |
| 27daa | W | 1-24-65 | -- | -- | [illegible] | -- | -- | -- | -- | -- | -- | -- | 501 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1,180 | -- | -- | 7.4 | -- | -- | -- |
| 31cda | W | 1-20-65 | -- | -- | [illegible] | -- | -- | -- | -- | -- | -- | -- | 510 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 658 | -- | -- | 8.2 | -- | -- | -- |
| 31bbb | S | 3-20-65 | 34 | <0.1 | [illegible] | <0.01 | [illegible] | [illegible] | [illegible] | [illegible] | 7.1 | <0.01 | 441 | 0 | 41 | 3.7 | .8 | 4.8 | <0.01 | .03 | .01 | .00 | .06 | 350 | 600 | 347 | 0 | 7.6 | <200 | 8.4 | 11 |
| 31bbc | W | 1-20-65 | -- | -- | <.01 | -- | -- | -- | -- | -- | -- | -- | 418 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 707 | -- | -- | 7.8 | -- | -- | -- |
| 31bca | [illegible] | 1-20-65 | -- | -- | [illegible] | -- | -- | -- | -- | -- | -- | -- | 411 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 759 | -- | -- | 7.6 | -- | -- | -- |
| 31bcc | [illegible] | 1-22-65 | -- | -- | [illegible] | -- | -- | -- | -- | -- | -- | -- | 411 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 729 | -- | -- | 7.6 | -- | -- | -- |
| 31bdc | [illegible] | 1-24-65 | -- | -- | [illegible] | -- | -- | -- | -- | -- | -- | -- | 440 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 781 | -- | -- | 7.5 | -- | -- | -- |
| 31dac | S | 1-23-65 | -- | -- | [illegible] | -- | -- | -- | -- | -- | -- | -- | 357 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 656 | -- | -- | [illegible] | -- | -- | -- |
| 31eaa | S | 5-11-65 | -- | -- | [illegible] | -- | -- | -- | -- | -- | -- | -- | 837 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1,710 | -- | -- | 7.5 | <200 | 5.1 | 6.0 |
| Do. | S | 11-20-65 | 35 | <0.1 | [illegible] | <0.01 | 61 | [illegible] | [illegible] | [illegible] | 4.7 | <0.01 | 388 | 0 | [illegible] | 7.9 | .3 | 11 | <0.01 | .04 | .11 | <0.01 | .01 | 304 | 500 | 219 | 0 | 7.8 | <200 | 3.6 | 4.8 |
| 33dbd | S | 1-24-65 | -- | -- | [illegible] | -- | -- | -- | -- | -- | -- | -- | 412 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 702 | -- | -- | 7.6 | <200 | 11 | 33 |
| 34dcc | S | 1-24-65 | -- | -- | <.01 | -- | -- | -- | -- | -- | -- | -- | 448 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 854 | -- | -- | 7.7 | -- | -- | -- |
| SC6-95-22cdd | W | 1-20-65 | 80 | .1 | [illegible] | .04 | 90 | 42 | .75 | 730 | 4.0 | .05 | 725 | 0 | 1,160 | 87 | .6 | 30 | <0.01 | .06 | .49 | .05 | .42 | 2,450 | 3,250 | 399 | 0 | 7.4 | <200 | 8.1 | 34 |
| 36aab | S | 6-5-66 | -- | -- | -- | -- | 61 | 25 | -- | -- | -- | -- | 429 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | 425 | 695 | 322 | 0 | 8.0 | <200 | -- | -- |
| 36aabd | S | 6-5-66 | -- | -- | -- | -- | 61 | 31 | -- | -- | -- | -- | 431 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | 416 | 698 | 330 | 0 | 7.3 | <200 | -- | -- |
| 36abd | S | 6-4-65 | -- | -- | -- | -- | 61 | 35 | -- | -- | -- | -- | 440 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | 433 | 725 | 330 | 0 | 7.5 | <200 | -- | -- |
| 36add | S | 6-5-65 | -- | -- | -- | -- | 65 | 35 | -- | -- | -- | -- | 434 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | 428 | 712 | 330 | 0 | 8.2 | <200 | -- | -- |
| 36adb | W | 1-26-65 | -- | -- | .13 | -- | -- | -- | -- | -- | -- | -- | 375 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 660 | -- | -- | 7.1 | -- | -- | -- |
| 36add | W | 1-24-65 | -- | -- | .13 | -- | -- | -- | -- | -- | -- | -- | 411 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 708 | -- | -- | 7.6 | -- | -- | -- |
| 36acc | S | 1-21-65 | 33 | <0.1 | [illegible] | <0.01 | [illegible] | [illegible] | [illegible] | 65 | 8.9 | .03 | 500 | 0 | 43 | 7.9 | .3 | 5.4 | <0.01 | .03 | .03 | <0.01 | .09 | 507 | 850 | 349 | 0 | 7.3 | <200 | 5.6 | 28 |
| 36dab | W | 1-20-65 | -- | -- | [illegible] | -- | -- | -- | -- | -- | -- | -- | 434 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 805 | -- | -- | 8.2 | -- | -- | -- |
| SC6-96-25dda | W | 1-20-65 | 23 | <0.1 | [illegible] | .03 | [illegible] | 51 | 1.3 | 90 | 85 | .08 | 836 | 0 | 184 | 7.9 | 1.4 | 6.0 | <0.01 | .05 | .19 | .01 | .16 | 835 | 1,260 | 537 | 0 | 7.4 | <200 | 15 | 33 |
| 34dda | W | 1-20-65 | -- | -- | .21 | -- | -- | -- | -- | -- | -- | -- | 847 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1,380 | -- | -- | 7.4 | -- | -- | -- |
| 34adb | W | 1-20-65 | -- | -- | .13 | -- | -- | -- | -- | -- | -- | -- | 606 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1,340 | -- | -- | 7.4 | -- | -- | -- |
| [illegible] | [illegible] | 1-20-65 | -- | -- | [illegible] | -- | -- | -- | -- | -- | -- | -- | 637 | [illegible] | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1,640 | -- | -- | [illegible] | -- | -- | -- |
| [illegible] | [illegible] | 1-20-65 | -- | -- | [illegible] | -- | -- | -- | -- | -- | -- | -- | 615 | [illegible] | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1,800 | -- | -- | [illegible] | -- | -- | -- |
| SC7-94-06aac | [illegible] | 1-20-65 | -- | -- | <.01 | -- | -- | -- | -- | -- | -- | -- | 377 | [illegible] | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 723 | -- | -- | [illegible] | -- | -- | -- |
| 06abb | S | 11-20-65 | [illegible] | <0.1 | [illegible] | <0.01 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 11 | [illegible] | 14 | <0.01 | [illegible] | [illegible] | <0.01 | .07 | 510 | 811 | 357 | [illegible] | 7.5 | <200 | [illegible] | [illegible] |
| 06abb | S | 1-22-65 | -- | -- | [illegible] | -- | -- | -- | -- | -- | -- | -- | 408 | [illegible] | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 798 | -- | -- | 7.5 | -- | -- | -- |
| Do. | S | 11-20-65 | 32 | <0.1 | [illegible] | .03 | [illegible] | [illegible] | [illegible] | [illegible] | 3.6 | .01 | 431 | 0 | [illegible] | 11 | .2 | 14 | <0.01 | .01 | <0.01 | <0.01 | .06 | 512 | 840 | 354 | 1 | 7.5 | <200 | <3.0 | 3.6 |
| 06aba | S | 1-21-65 | 31 | <0.1 | [illegible] | .02 | [illegible] | [illegible] | [illegible] | [illegible] | 3.4 | .02 | 389 | 0 | [illegible] | 8.5 | .2 | 9.0 | <0.01 | .08 | .02 | <0.01 | .10 | 341 | 565 | 240 | 0 | 8.1 | <200 | 5.1 | 11 |
| 06bba | S | 1-20-65 | -- | -- | [illegible] | -- | -- | -- | -- | -- | -- | -- | 359 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 557 | -- | -- | 8.2 | -- | -- | -- |
| 06dda | W | 1-22-65 | -- | -- | <.01 | -- | -- | -- | -- | -- | [illegible] | -- | 389 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 545 | -- | -- | 7.7 | <200 | <4 | 5.0 |
| Do. | W | 11-20-65 | [illegible] | <0.1 | [illegible] | <0.01 | [illegible] | [illegible] | [illegible] | [illegible] | 3.2 | <0.01 | 383 | 0 | [illegible] | 7.8 | .2 | 8.1 | <0.01 | [illegible] | .19 | <0.01 | <0.01 | 356 | 545 | [illegible] | 0 | 7.7 | <200 | 8.1 | <8.5 |
| 07baa | W | 1-22-65 | -- | -- | <.01 | -- | -- | -- | -- | -- | -- | -- | 329 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 366 | -- | -- | 7.6 | -- | -- | -- |
| SC7-95-01aba | S | 1-21-65 | -- | -- | [illegible] | -- | -- | -- | -- | -- | -- | -- | 441 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 686 | -- | -- | 7.6 | -- | -- | -- |
| 01baa | S | 1-21-65 | -- | -- | [illegible] | -- | -- | -- | -- | -- | -- | -- | 679 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1,030 | -- | -- | 7.8 | -- | -- | -- |
| 01add | S | 1-26-65 | -- | -- | [illegible] | -- | -- | -- | -- | -- | -- | -- | 473 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 760 | -- | -- | 7.7 | -- | -- | -- |
| 01bcd | S | 1-21-65 | [illegible] | <0.1 | [illegible] | <0.01 | [illegible] | [illegible] | [illegible] | [illegible] | 8.9 | <0.01 | 363 | 0 | [illegible] | 7.8 | .2 | 8.6 | <0.01 | .03 | .11 | <0.01 | .03 | 388 | 590 | 318 | 0 | 7.6 | <200 | 3.4 | 11 |
| 01cbc | W | 1-19-65 | [illegible] | .1 | [illegible] | <0.01 | [illegible] | [illegible] | [illegible] | 150 | 3.5 | .05 | 389 | 0 | [illegible] | 1.1 | [illegible] | 6.1 | <0.01 | .05 | .01 | <0.01 | .30 | 587 | 940 | 300 | 0 | 7.8 | <200 | 5.8 | 17 |
| 01acc | S | 1-16-65 | -- | -- | [illegible] | -- | -- | -- | -- | -- | -- | -- | 379 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 700 | -- | -- | 7.9 | -- | -- | -- |
| 01add | S | 1-26-65 | [illegible] | <0.1 | [illegible] | .02 | [illegible] | [illegible] | [illegible] | [illegible] | 3.1 | .03 | 401 | 0 | 17 | 8.9 | .2 | 8.8 | <0.01 | <0.01 | .02 | <0.01 | .11 | 384 | 650 | 356 | 0 | 7.1 | <200 | 4.0 | 9.1 |
| 01bba | S | 1-26-65 | -- | -- | [illegible] | -- | -- | -- | -- | -- | -- | -- | 382 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 598 | -- | -- | 7.0 | -- | -- | -- |
| 01bca | S | 1-21-65 | [illegible] | <0.1 | [illegible] | <0.01 | [illegible] | [illegible] | [illegible] | [illegible] | 8.0 | .03 | 383 | 0 | [illegible] | 8.5 | .2 | 8.6 | <0.01 | .01 | .02 | <0.01 | .04 | 338 | 560 | 302 | 0 | 7.7 | <200 | 3.0 | 21 |
| Do. | S | 1-21-65 | -- | -- | [illegible] | -- | -- | -- | -- | -- | -- | -- | 310 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 514 | -- | -- | 7.8 | -- | -- | -- |
| Do. | S | 1-20-65 | -- | -- | -- | -- | [illegible] | [illegible] | -- | -- | -- | -- | 310 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | 389 | 515 | 190 | 0 | 7.9 | <200 | -- | -- |
| Do. | [illegible] | 11-19-65 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | <200 | -- | -- |
| 07adb | W | 1-13-65 | -- | -- | <.01 | -- | -- | -- | -- | -- | -- | -- | 578 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1,470 | -- | -- | 7.3 | <200 | -- | -- |
| 07daa | W | 5-24-65 | [illegible] | <0.1 | [illegible] | <0.01 | [illegible] | [illegible] | [illegible] | 115 | 3.3 | .08 | 505 | 0 | [illegible] | 30 | .4 | <0.1 | <0.01 | .30 | .05 | <0.01 | .14 | 665 | 1,080 | 375 | 0 | 7.5 | <200 | 11 | 18 |

--Chemical analyses of water from selected wells, springs, and cisterns, Rulison project area, Garfield and Mesa Counties, Colorado.--Continued
(Adapted from Barr and others, 1969, and Larson and Beeton, 1970.)

Location number: See text for hydrologic data point numbering system.

| Location number | Well, spring, or cistern (W,S,C) | Date of collection | Silica ($SiO_2$) | Aluminum (Al) | Iron (Fe) | Manganese (Mn) | Calcium (Ca) | Magnesium (Mg) | Strontium (Sr) | Sodium (Na) | Potassium (K) | Lithium (Li) | Bicarbonate ($HCO_3$) | Carbonate ($CO_3$) | Sulfate ($SO_4$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SCT-95-8ccb | S | 5-8-69 | -- | -- | 0.01 | -- | -- | -- | -- | -- | -- | -- | 370 | 0 | -- |
| Do.[5] | S | 5-8-69 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 10ab | C | 5-13-69 | -- | -- | .02 | -- | 27 | 5.5 | -- | -- | -- | -- | 95 | 18 | -- |
| 10adc | W | 5-13-69 | -- | -- | <.01 | -- | 31 | 20 | -- | -- | -- | -- | 268 | 0 | -- |
| Do. | W | 5-13-69 | -- | -- | 2.6 | -- | 23 | 7.2 | -- | -- | -- | -- | -- | -- | -- |
| 10bda | W | 5-1-69 | -- | -- | <.01 | -- | -- | -- | -- | -- | -- | -- | 427 | 0 | -- |
| 10bdb[2] | C | 10-11-69 | 3.9 | <0.1 | .13 | <0.01 | 35 | 1.9 | ? | 13 | 1.9 | <0.01 | -- | 7 | 11 |
| 10bdc[6] | -- | 10-25-69 | 20 | <.1 | .05 | <.01 | 85 | 9.8 | .33 | 11 | 1.7 | <.01 | 154 | 0 | 18 |
| 12bad | W | 3-4-69 | 36 | <.1 | .08 | <.01 | 84 | 8 | .44 | 23 | 2.1 | .01 | 373 | 0 | 37 |
| 17aab | W | 3-19-69 | 30 | .4 | .13 | <.01 | 25 | 15 | .4 | 74 | 4.0 | .04 | 337 | 0 | 68 |
| 17aba | W | 3-19-69 | -- | -- | .02 | -- | -- | -- | -- | -- | -- | -- | 359 | 0 | -- |
| 18aad | S | 3-25-69 | -- | -- | .06 | -- | -- | -- | -- | -- | -- | -- | 404 | 0 | -- |
| 18adb | W | 3-26-69 | 27 | .2 | .02 | .21 | 60 | 63 | .33 | 143 | 6.1 | .02 | 408 | 0 | 308 |
| 18bcd | S | 3-26-69 | 27 | <.1 | .01 | .21 | 80 | ? | 1.1 | 177 | 4.3 | .03 | 439 | 0 | 437 |
| 18dad | W | 3-13-69 | -- | -- | .0? | -- | -- | -- | -- | -- | -- | -- | 361 | 0 | -- |
| 20cbb | W | 3-13-69 | -- | -- | <.01 | -- | -- | -- | -- | -- | -- | -- | 375 | 0 | -- |
| 20bba | W | 3-25-69 | 1? | <.1 | .01 | .03 | 46 | ? | ? | ? | ? | .01 | 383 | 0 | 63 |
| SCT-96-12bbb[1] | W | 3-25-69 | 13 | .1 | .13 | .01 | 142 | ? | 1.1 | 258 | 9.8 | .10 | 686 | 0 | 958 |
| 13abd | W | 3-24-69 | 13 | <.1 | .16 | .11 | 130 | 103 | 1.1 | 150 | 5.6 | .06 | 851 | 0 | 657 |
| 23cad | W | 3-25-69 | 14 | <.1 | .04 | .08 | 110 | 23 | .3 | 111 | 3.1 | .03 | 313 | 0 | 178 |
| 33dcd | S | 3-25-69 | 85 | <.1 | .01 | .01 | 105 | 61 | .4 | 182 | 4.4 | .02 | 490 | 0 | 464 |
| 34bba | W | 3-25-69 | 15 | <.1 | .01 | .15 | 185 | 35 | 1.1 | 148 | 5.5 | .02 | 358 | 0 | 188 |
| 34bcd | W | 3-25-69 | -- | -- | .18 | -- | -- | -- | -- | -- | -- | -- | 392 | 0 | -- |
| 34bdc | W | 3-25-69 | -- | -- | .17 | -- | -- | -- | -- | -- | -- | -- | 353 | 0 | -- |
| 34cca | S | 3-18-69 | -- | -- | .06 | -- | -- | -- | -- | -- | -- | -- | 349 | 0 | -- |
| 35dcb | S | 3-18-69 | -- | -- | .03 | -- | -- | -- | -- | -- | -- | -- | 402 | 0 | -- |
| SCS-95-24acc | S | 6-19-69 | -- | <.1 | .02 | <.01 | 8.8 | 1.1 | .2 | 2.4 | .9 | <.01 | 39 | 0 | .5 |
| SCS-96-11acc | W | 3-18-69 | 27 | <.1 | .03 | <.01 | 69 | 25 | .4 | 35 | 2.8 | .02 | 365 | 0 | 56 |
| 11bbd | W | 3-18-69 | -- | -- | .03 | -- | -- | -- | -- | -- | -- | -- | 411 | 0 | -- |
| 12aac | W | 3-19-69 | -- | -- | <.01 | -- | -- | -- | -- | -- | -- | -- | 304 | 0 | -- |
| Do. | W | 10-21-69 | 29 | <.1 | .05 | <.01 | 46 | 41 | 1.1 | 35 | 3.7 | .08 | 399 | 0 | 108 |
| SCS-93-19bda | S | ? | -- | -- | -- | -- | 118 | 42 | -- | -- | -- | -- | 537 | 0 | -- |
| SCS-94-22acc | W | 3-25-69 | -- | -- | .13 | -- | -- | -- | -- | -- | -- | -- | 475 | 0 | -- |
| 22bas | W | 3-15-69 | -- | -- | .13 | -- | -- | -- | -- | -- | -- | -- | 443 | 0 | -- |
| SCS-95-28aaa | W | 3-15-69 | -- | -- | .22 | -- | -- | -- | -- | -- | -- | -- | 543 | 0 | -- |
| 35daa | S | 3-25-69 | 30 | <.1 | <.01 | .01 | 51 | 26 | .50 | 33 | 6.4 | .01 | 398 | 0 | 22 |
| Do. | S | 3-20-69 | -- | -- | -- | -- | 55 | 12 | -- | -- | -- | -- | 442 | 0 | -- |
| 35dba | S | 3-25-69 | -- | -- | <.01 | -- | -- | -- | -- | -- | -- | -- | 507 | 0 | -- |
| 36adb | S | 3-25-69 | -- | -- | .01 | -- | -- | -- | -- | -- | -- | -- | 398 | 0 | -- |
| 36adb | W | 3-25-69 | 35 | <.1 | .01 | <.01 | 57 | 31 | .46 | 25 | 14 | .01 | 449 | 0 | 41 |
| 35ddb | S | 3-25-69 | -- | -- | .01 | -- | -- | -- | -- | -- | -- | -- | 471 | 0 | -- |

| Location number | Chloride (Cl) | Fluoride (F) | Nitrate ($NO_3$) | Phosphate ($PO_4$) | Copper (Cu) | Zinc (Zn) | Selenium (Se) | Boron (B) | Dissolved solids (residue at 180°C) | Specific conductance (micromhos per cm at 25°C) | Hardness as $CaCO_3$: Calcium magnesium | Hardness as $CaCO_3$: Noncarbonate | pH | Tritium T.U. | Gross beta in picocuries per liter (as Sr90-Y90) | Gross alpha in micrograms per liter (as U equivalent) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SCT-95-8ccb | -- | -- | -- | -- | -- | -- | -- | -- | -- | 695 | -- | -- | 8.1 | -- | -- | -- |
| Do.[5] | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | <220 | -- | -- |
| 10ab | -- | -- | -- | -- | -- | -- | -- | -- | -- | 250 | 94 | 0 | 9.0 | -- | -- | -- |
| 10adc | -- | -- | -- | -- | -- | -- | -- | -- | -- | 480 | 160 | 0 | 7.8 | 383 | -- | -- |
| Do. | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 87 | -- | -- | -- | -- | -- |
| 10bda | -- | -- | -- | -- | -- | -- | -- | -- | -- | 710 | -- | -- | 7.8 | <220 | -- | -- |
| 10bdb[2] | 8 | 0.1 | 0.8 | <0.01 | 0.03 | <0.01 | <0.01 | 0.01 | 103 | 310 | 89 | 18 | 10.8 | 875 | 1.5 | <2.0 |
| 10bdc[6] | .6 | .1 | .2 | <.01 | .01 | <.01 | <.01 | .03 | 154 | 270 | 114 | 0 | 8.2 | 315 | 2.0 | 1.8 |
| 12bad | 11 | .1 | 8.0 | <.01 | .03 | .09 | <.01 | .01 | 408 | 665 | 309 | 3 | 7.4 | <220 | 1.5 | 5.5 |
| 17aab | .6 | .2 | 3.8 | <.01 | .03 | 2.6 | <.01 | .15 | 364 | 595 | 158 | 0 | 7.9 | <220 | 6.9 | 18 |
| 17aba | -- | -- | -- | -- | -- | -- | -- | -- | -- | 622 | -- | -- | 7.7 | -- | -- | -- |
| 18aad | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1,180 | -- | -- | 8.0 | -- | -- | -- |
| 18adb | 30 | .3 | 7.2 | <.01 | .03 | 8.0 | <.01 | .15 | 855 | 1,260 | 398 | 63 | 7.8 | <220 | 4.8 | <.4 |
| 18bcd | 40 | .3 | 4.6 | <.01 | .03 | .02 | <.01 | .07 | 1,100 | 1,500 | 482 | 122 | 7.5 | <220 | 4.0 | 20 |
| 18dad | -- | -- | -- | -- | -- | -- | -- | -- | -- | 861 | -- | -- | 7.6 | -- | -- | -- |
| 20cbb | -- | -- | -- | -- | -- | -- | -- | -- | -- | 892 | -- | -- | 7.6 | 230 | -- | -- |
| 20bba | 4.6 | .3 | 13 | <.01 | .01 | .16 | <.01 | .05 | 435 | 730 | 278 | 0 | 7.5 | 320 | 4.4 | 9.1 |
| SCT-96-12bbb[1] | 13 | .7 | .1 | <.01 | .07 | 1.3 | <.01 | .10 | 1,450 | 1,870 | 322 | 105 | 7.1 | <220 | 6.5 | 33 |
| 13abd | 27 | .6 | .4 | <.01 | .01 | .18 | <.01 | .18 | 1,730 | 2,250 | 778 | 74 | 7.4 | <220 | 8.7 | 17 |
| 23cad | 164 | .6 | <.1 | <.01 | .14 | 1.2 | <.01 | .04 | 781 | 1,200 | 391 | 134 | 7.4 | 370 | 3.4 | 8.4 |
| 33dcd | 16 | .2 | 8.6 | <.01 | .01 | .02 | <.01 | .08 | 1,140 | 1,500 | 523 | 121 | 7.4 | 830 | 5.4 | 20 |
| 34bba | 140 | .3 | <.1 | <.01 | .01 | .34 | <.01 | .03 | 953 | 1,450 | 470 | 181 | 7.6 | 590 | 1.8 | 8.7 |
| 34bcd | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1,060 | -- | -- | 7.6 | -- | -- | -- |
| 34bdc | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1,840 | -- | -- | 7.5 | -- | -- | -- |
| 34cca | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1,490 | -- | -- | 7.6 | -- | -- | -- |
| 35dcb | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1,840 | -- | -- | 8.1 | <220 | 6.7 | 11 |
| SCS-95-24acc | .3 | .1 | .3 | <.01 | -- | -- | .02 | .02 | .64 | 65 | 30 | 0 | 7.0 | <220 | -- | -- |
| SCS-96-11acc | 8.4 | .2 | 14 | <.01 | .02 | .07 | <.01 | .09 | 414 | 670 | 280 | 0 | 7.6 | <220 | 2.6 | 4.7 |
| 11bbd | -- | -- | -- | -- | -- | -- | -- | -- | -- | 711 | -- | -- | 7.5 | -- | -- | -- |
| 12aac | -- | -- | -- | -- | -- | -- | -- | -- | -- | 782 | -- | -- | 7.8 | <220 | -- | -- |
| Do. | 35 | .4 | 15 | <.01 | .01 | .47 | <.01 | .04 | 486 | 760 | 290 | 45 | 7.7 | <220 | 5.6 | 18 |
| SCS-93-19bda | -- | -- | -- | -- | -- | -- | -- | -- | 933 | 1,280 | 484 | 44 | 7.6 | <220 | -- | -- |
| SCS-94-22acc | -- | -- | -- | -- | -- | -- | -- | -- | -- | 858 | -- | -- | 7.6 | <220 | 15 | 14 |
| 22bas | -- | -- | -- | -- | -- | -- | -- | -- | -- | 675 | -- | -- | 7.6 | 616 | -- | -- |
| SCS-95-28aaa | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1,100 | -- | -- | 7.8 | 396 | -- | -- |
| 35daa | 8.6 | .4 | 3.0 | <.01 | .01 | .04 | <.01 | .08 | 384 | 590 | 243 | 0 | 7.6 | 600 | 5.9 | 10 |
| Do. | -- | -- | -- | -- | -- | -- | -- | -- | 509 | 652 | 185 | 0 | 7.7 | 387 | -- | -- |
| 35dba | -- | -- | -- | -- | -- | -- | -- | -- | -- | 706 | -- | -- | 7.6 | -- | -- | -- |
| 36adb | -- | -- | -- | -- | -- | -- | -- | -- | -- | 622 | -- | -- | 7.7 | -- | -- | -- |
| 36adb | 5.5 | .4 | 8.5 | .17 | .06 | .13 | <.01 | .06 | 465 | 700 | 281 | 0 | 7.5 | 470 | 24 | 40 |
| 35ddb | -- | -- | -- | -- | -- | -- | -- | -- | -- | 794 | -- | -- | 7.4 | -- | -- | -- |

1/ Sample taken had passed through a domestic water softener.

2/ Sample collected from tap at Bernklau home (SCS-94-33cba).

3/ Before chlorination.

4/ After chlorination.

5/ Sample collected from tap at Satterfield home (SCT-95-8ccb).

6/ Sample collected from ditch supplying Moore cistern (SCT-95-10bdb).

(Chemical analyses in milligrams per liter.)

| Station name | Altitude (feet above msl) | Date | Time (mountain daylight) | Temperature (°C) | Calcium (Ca) | Magnesium (Mg) | Bicarbonate ($HCO_3$) | Carbonate ($CO_3$) | Hardness as $CaCO_3$: Calcium magnesium | Hardness as $CaCO_3$: Noncarbonate | Dissolved solids (residue at 180°C) | Specific conductance (micromhos per cm at 25°C) | pH | Turbidity | Tritium (T.U.)[1/] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Colorado River at New Castle | 5,515 | 8-26-69 | 1225 | 19.0 | 71 | 14 | 161 | 0 | 235 | 103 | 534 | 898 | 7.3 | 6 | 368 |
| Colorado River at New Castle | 5,515 | 10-19-69 | 1600 | 8.0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | <220 |
| East Mamm Creek near Rifle | 6,220 | 9- 2-69 | 1500 | 27.0 | 51 | 60 | 671 | 0 | 374 | 0 | 1,050 | 1,460 | 8.1 | -- | <220 |
| Middle Mamm Creek near Rifle | 6,830 | 8-27-69 | 1235 | 19.5 | 44 | 21 | 261 | 0 | 197 | 0 | 237 | 450 | 7.9 | 8 | <220 |
| West Mamm Creek near Rifle | 7,080 | 8-27-69 | 1145 | 13.5 | 62 | 31 | 360 | 0 | 282 | 0 | 369 | 648 | 7.6 | 4 | <220 |
| Mamm Creek near Rifle | 5,610 | 8-27-69 | 1300 | 27.5 | 51 | 93 | 588 | 0 | 510 | 28 | 1,390 | 1,820 | 7.7 | 50 | <220 |
| Beaver Creek near Rifle | 6,685 | 3-24-69 | -- | 1.0 | | | | | | | | | | | |
| Beaver Creek near Rifle | 6,685 | 9-20-69 | 1209 | 10.0 | 36 | 8.0 | 173 | 0 | 124 | 0 | 149 | 282 | 8.1 | 15 | <220 |
| Cache Creek near Rulison | 5,950 | 8-27-69 | 1025 | 13.5 | 21 | 4.5 | 101 | 0 | 71 | 0 | 81 | 171 | 7.0 | 5 | 263 |
| Battlement Reservoir near Grand Valley | 10,200 | 9- 3-69 | 1000 | 7.0 | 7.1 | .8 | 35 | 0 | 21 | 0 | 53 | 60 | 7.0 | -- | 336 |
| Battlement Creek near Morrisania | 7,760 | 8-28-69 | 0815 | 9.5 | 10 | 2.5 | 55 | 0 | 36 | 0 | 74 | 96 | 7.1 | 10 | 229 |
| Battlement Creek near Morrisania | 7,760 | 9-20-69 | 1355 | 9.5 | 12 | 2.6 | 59 | 0 | 41 | 0 | 41 | 100 | 7.4 | 2 | <220 |
| Tributary of Battlement Creek near Morrisania | 7,880 | 8-27-69 | 1500 | 17.0 | 36 | 11 | 200 | 0 | 135 | 0 | 147 | 322 | 7.3 | <1 | <220 |
| Tributary of Battlement Creek near Morrisania | 7,880 | 9-20-69 | 1400 | 16.5 | 36 | 11 | 208 | 0 | 135 | 0 | 178 | 338 | 8.0 | 7 | <220 |
| Battlement Creek near Grand Valley | 6,630 | 8-27-69 | 1425 | 8.0 | 17 | 5.0 | 89 | 0 | 63 | 0 | 110 | 150 | 6.8 | 2 | 258 |
| Battlement Creek near Grand Valley | 6,630 | 9-20-69 | 1320 | 11.0 | .23 | 7.3 | 126 | 0 | 88 | 0 | 104 | 212 | 8.0 | 2 | <220 |
| Battlement Creek near Grand Valley | 6,630 | 10-19-69 | 1420 | 4.0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | <220 |
| Spring Creek near Grand Valley | 5,080 | 8-27-69 | 1610 | 22.0 | 29 | 38 | 334 | 0 | 229 | 0 | 471 | 790 | 7.9 | 1 | <220 |
| Colorado River near DeBeque | 4,940 | 8-26-69 | 1615 | 23.5 | 67 | 15 | 157 | 0 | 229 | 100 | 537 | 882 | 6.5 | 10 | 335 |
| Colorado River near DeBeque | 4,940 | 9-20-69 | 1515 | 17.0 | 105 | 16 | 166 | 0 | 328 | 192 | 601 | 1,030 | 8.1 | 10 | <220 |
| Colorado River near DeBeque | 4,940 | 10-19-69 | 1200 | 18.0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 288 |
| Vega Reservoir near Collbran | 7,906 | 8-26-69 | 1945 | 14.0 | 18 | 3.2 | 81 | 0 | 58 | 0 | 56 | 124 | 6.7 | 4 | 230 |
| Plateau Creek near Collbran | 7,130 | 8-27-69 | 0755 | 12.0 | 17 | 4.2 | 83 | 0 | 60 | 0 | 57 | 121 | 6.8 | 2 | 240 |
| Road Gulch near Collbran | 7,400 | 8-28-69 | 1110 | 18.5 | 51 | 10 | 295 | 0 | 168 | 0 | 276 | 475 | 7.9 | 15 | <220 |
| Buzzard Creek near Collbran | 6,955 | 8-26-69 | 1830 | 22.0 | 51 | 25 | 338 | 0 | 230 | 0 | 383 | 565 | 7.8 | 10 | 430 |
| Buzzard Creek near Collbran | 6,955 | 9-20-69 | 1800 | 14.5 | 76 | 18 | 322 | 0 | 264 | 0 | 335 | 580 | 8.2 | 2 | <220 |
| Brush Creek near Collbran | 8,183 | 8-26-69 | 1905 | 16.0 | 51 | 13 | 248 | 0 | 181 | 0 | 201 | 350 | 7.9 | 10 | 263 |
| Hawxhurst Creek near Collbran | 6,560 | 8-26-69 | 1800 | 19.0 | 51 | 29 | 430 | 0 | 247 | 0 | 370 | 605 | 7.5 | 2 | 354 |
| Hawxhurst Creek near Collbran | 6,560 | 9-20-69 | 1655 | 14.5 | 76 | 30 | 443 | 0 | 313 | 0 | 404 | 668 | 7.9 | <1 | 250 |
| Kimball Creek near Collbran | 6,880 | 8-26-69 | 1735 | 17.0 | 67 | 20 | 433 | 0 | 250 | 0 | 384 | 610 | 7.5 | <1 | <220 |
| Kimball Creek near Collbran | 6,880 | 9-20-69 | 1630 | 12.5 | 105 | 20 | 481 | 0 | 345 | 0 | 425 | 708 | 7.9 | 2 | <220 |
| Plateau Creek near Cameo | 4,836 | 8-28-69 | 0955 | 18.5 | 41 | 38 | 411 | 0 | 259 | 0 | 485 | 780 | 8.1 | 2 | <220 |
| Plateau Creek near Cameo | 4,836 | 9-20-69 | 1545 | 17.0 | 37 | 35 | 385 | 0 | 237 | 0 | 418 | 712 | 8.1 | 8 | <220 |
| Plateau Creek near Cameo | 4,836 | 10-19-69 | 1100 | 16.0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 291 |

[1/] The tritium analyses were by liquid scintillation counting and the lowest detectable concentration by this method was 220 T.U.

# Appendix D
# Radiochemical Analyses of Spring, Well, and Stream Waters, Rulison Project Area

## Radiochemical analyses of water from selected springs in western Colorado

| Owner or tenant | Sample point number[1/] | Location: Town-ship S. | Location: Range W. | Location: Section | Location: ¼ section | Latitude N.: Degrees | Latitude N.: Minutes | Latitude N.: Seconds | Longitude W.: Degrees | Longitude W.: Minutes | Longitude W.: Seconds | Distance from surface ground zero, in miles (kilometers) | Date of collection | Tritium: pCi/l | Tritium: TU | Gross alpha: (µg/l as U natural) | Gross alpha: (pCi/l as U natural) | Gross beta: (pCi/l as Sr-90/Y-90) | Gross beta: (pCi/l as Cs-137) | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mrs. Betty Potter | 20 | 6 | 94 | 31 | NW | 39 | 29 | 20 | 107 | 56 | 12 | 5.7(9.2) | 3-20-69 | <700 | <220 | 12 | 3.9 | 8.4 | 11 | -- |
| | | | | | | | | | | | | | 4-10-70 | <1,300 | <400 | 18 | 5.9 | 8.8 | 9.1 | |
| Carl Bernklau | 21 | 7 | 94 | 4 | NW | 39 | 28 | 09 | 107 | 53 | 45 | 5.1(8.2) | 10-20-69 | <960 | <300 | 10 | 3.4 | 4.6 | 5.8 | -- |
| | | | | | | | | | | | | | 4-10-70 | <960 | <300 | 10 | 3.5 | 4.3 | 4.8 | |
| Town of Grand Valley | 22 | 7 | 95 | 5 | SE | 39 | 27 | 49 | 108 | 00 | 58 | 5.3(8.5) | 3-21-69 | <700 | <220 | 21 | 6.8 | 3.0 | 3.7 | Town of Grand Valley water supply. |
| | | | | | | | | | | | | | 9-20-69 | <960 | <300 | -- | -- | -- | -- | |
| | | | | | | | | | | | | | 10-19-69 | <960 | <300 | -- | -- | -- | -- | |
| | | | | | | | | | | | | | 4-11-70 | <1,300 | <400 | 20 | 6.7 | 3.0 | 3.4 | |
| Otis Murray | 23 | 7 | 96 | 35 | SE | 39 | 23 | 23 | 108 | 04 | 28 | 6.8(11) | 3-18-69 | <700 | <220 | 11 | 3.7 | 6.7 | 8.4 | -- |
| | | | | | | | | | | | | | 4-11-70 | <1,300 | <400 | 45 | 15 | 19 | 24 | |
| Cecil Gardner | 24 | 7 | 95 | 18 | NW | 39 | 26 | 16 | 108 | 02 | 40 | 5.6(9.0) | 3-26-69 | <700 | <220 | 26 | 8.7 | 4.6 | 5.8 | -- |
| | | | | | | | | | | | | | 4-11-70 | <1,300 | <400 | 31 | 10 | 5.2 | 6.0 | |

[1/] As shown on figure 1.

(Voegeli and Claassen, 1971a)

**Radiochemical analyses of water from selected springs in western Colorado**

| Owner or tenant | Sample point number[1] | Location | | | | Latitude N. | | | Longitude W. | | | Distance from surface ground zero | | Date of collection | Tritium | | Gross alpha | | Gross beta | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Township S. | Range W. | Section | ¼ Section | Degrees | Minutes | Seconds | Degrees | Minutes | Seconds | miles | kilometers | | pCi/l | TU | (µg/l as U natural) | (pCi/l as U natural) | (pCi/l as Sr-90/Y-90) | (pCi/l as Cs-137) | |
| Mrs. Betty Potter | 20 | 6 | 94 | 31 | NW | 39 | 29 | 20 | 107 | 56 | 12 | 5.7 | 9.2 | 5-30-70 | <960 | <300 | 24 | 7.8 | 9.2 | 9.8 | -- |
| Carl Bernklau | 21 | 7 | 94 | 4 | NW | 39 | 28 | 09 | 107 | 53 | 45 | 5.1 | 8.2 | 5-30-70 | <960 | <300 | <6.3 | <2.1 | 3.2 | 3.8 | -- |
| Town of Grand Valley | 22 | 7 | 95 | 5 | SE | 39 | 27 | 49 | 108 | 00 | 58 | 5.3 | 8.5 | 5-30-70 | <960 | <300 | 7.9 | 2.6 | 3.1 | 3.4 | Town of Grand Valley water supply. |
| Otis Murray | 23 | 7 | 96 | 35 | SE | 39 | 23 | 23 | 108 | 04 | 28 | 6.8 | 11 | 5-30-70 | <960 | <300 | 11 | 3.6 | 5.5 | 6.1 | -- |
| Cecil Gardner | 24 | 7 | 95 | 18 | NW | 39 | 26 | 16 | 108 | 02 | 40 | 5.6 | 9.0 | 5-30-70 | <960 | <300 | 42 | 14 | 5.0 | 5.6 | -- |
| Fred Wallace | 25 | 8 | 95 | 24 | NE | 39 | 21 | 04 | 107 | 56 | 26 | 3.8 | 6.1 | 5-29-70 | <960 | <300 | <.6 | <.2 | 2.1 | 2.7 | -- |

(Voegeli and Claassen, 1971b)

Radiochemical analyses of water from selected wells in western Colorado

| Owner or tenant | Sample point number[1/] | Location: Town-ship S. | Location: Range W. | Location: Section | Location: ¼ section | Latitude N.: Degrees | Latitude N.: Minutes | Latitude N.: Seconds | Longitude W.: Degrees | Longitude W.: Minutes | Longitude W.: Seconds | Distance from surface ground zero, in miles (kilometers) | Date of collection | Tritium: pCi/l | Tritium: TU | Gross alpha: (µg/l as U natural) | Gross alpha: (pCi/l as U natural) | Gross beta: (pCi/l as Sr-90/Y-90) | Gross beta: (pCi/l as Cs-137) | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Norman Head | 15 | 6 | 94 | 26 | NW | 39 | 29 | 50 | 107 | 51 | 44 | 7.7(12) | 3-24-69 | 1,300 | 420 | 6.8 | 2.3 | 6.3 | 7.8 | -- |
| | | | | | | | | | | | | | 4-10-70 | 1,000 | 310 | 17 | 5.6 | 7.0 | 7.3 | |
| Russell Bingham, Sr. | 16 | 7 | 94 | 6 | SE | 39 | 27 | 41 | 107 | 55 | 12 | 4.1(6.6) | 3-22-69 | <700 | <220 | 5.0 | 1.7 | <3.5 | <4.3 | -- |
| | | | | | | | | | | | | | 10-20-69 | <960 | <300 | <4.6 | <1.5 | 2.1 | 2.7 | |
| | | | | | | | | | | | | | 4-10-70 | <1,300 | <400 | 4.8 | 1.6 | 3.9 | 4.5 | |
| Albert Gardner | 17 | 7 | 95 | 20 | NW | 39 | 25 | 49 | 108 | 01 | 37 | 4.6(7.4) | 3-26-69 | 960 | 300 | 9.1 | 3.0 | <.4 | .5 | -- |
| | | | | | | | | | | | | | 4-11-70 | <1,300 | <400 | 17 | 5.6 | 4.1 | 4.4 | |
| Sinclair Oil Co. | 18 | 6 | 96 | 29 | SE | 39 | 29 | 31 | 108 | 07 | 23 | 11.1(17.9) | 3-20-69 | <700 | <220 | 31 | 10 | 15 | 19 | -- |
| | | | | | | | | | | | | | 4-12-70 | <1,300 | <400 | 26 | 8.6 | 15 | 18 | |
| Willard Nicoll | 19 | 9 | 94 | 22 | NE | 39 | 15 | 49 | 107 | 52 | 02 | 10.6(17.1) | 3-25-69 | <700 | <220 | 14 | 4.8 | 15 | 19 | -- |
| | | | | | | | | | | | | | 4-11-70 | <1,300 | <400 | 34 | 11 | 6.0 | 7.3 | |

[1/] As shown on figure 1.

(Voegeli and Claassen, 1971a)

Radiochemical analyses of water from selected wells in western Colorado

| Owner or tenant | Sample point number 1/ | Location | | | | Latitude N. | | | Longitude W. | | | Distance from surface ground zero | | Date of collection | Tritium | | Gross alpha | | Gross beta | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Township S. | Range W. | Section | ¼ Section | Degrees | Minutes | Seconds | Degrees | Minutes | Seconds | miles | kilometers | | pCi/l | TU | (µg/l as U natural) | (pCi/l as U natural) | (pCi/l as Sr-90/Y-90) | (pCi/l as Cs-137) | |
| Norman Mead | 15 | 6 | 94 | 26 | NW | 39 | 29 | 50 | 107 | 51 | 44 | 7.7 | 12 | 5-30-70 | <960 | <300 | <9.1 | <3.0 | 9.3 | 11 | -- |
| Russell Bingham, Sr. | 16 | 7 | 94 | 6 | SE | 39 | 27 | 41 | 107 | 55 | 12 | 4.1 | 6.6 | 5-30-70 | <960 | <300 | 9.8 | 3.3 | 4.1 | 4.4 | -- |
| Albert Gardner | 17 | 7 | 95 | 20 | NW | 39 | 25 | 49 | 108 | 01 | 37 | 4.6 | 7.4 | 5-30-70 | <960 | <300 | 13 | 4.3 | 5.7 | 6.4 | -- |
| Sinclair Oil Co. | 18 | 6 | 96 | 29 | SE | 39 | 29 | 31 | 108 | 07 | 23 | 11.1 | 17.9 | 5-30-70 | <960 | <300 | 27 | 9.0 | 23 | 26 | -- |
| Willard Nicoll | 19 | 9 | 94 | 22 | NE | 39 | 15 | 49 | 107 | 52 | 02 | 10.6 | 17.1 | 5-29-70 | <960 | <300 | 13 | 4.3 | 14 | 16 | -- |

(Voegeli and Claassen, 1971b)

| Stream | Sample point number[1] | Location: Township S. | Location: Range W. | Location: Section | Location: ¼ section | Latitude N.: Degrees | Latitude N.: Minutes | Latitude N.: Seconds | Longitude W.: Degrees | Longitude W.: Minutes | Longitude W.: Seconds | Distance from surface ground zero, in miles (kilometers) | Date of collection | Tritium: pCi/l | Tritium: TU | Dissolved: Gross alpha (µg/l as U natural) | Dissolved: Gross alpha (pCi/l as U natural) | Dissolved: Gross beta (pCi/l as Sr-90/Y-90) | Dissolved: Gross beta (pCi/l as Cs-137) | Suspended: Solids mg/l | Suspended: Gross alpha (µg/l as U natural) | Suspended: Gross alpha (pCi/l as U natural) | Suspended: Gross beta (pCi/l as Sr-90/Y-90) | Suspended: Gross beta (pCi/l as Cs-137) | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Roaring Fork River near Aspen | 1 | (2/) | | | | 39 | 10 | 48 | 106 | 48 | 05 | 64(103) | 4- 6-70 | <960 | <300 | 7.8 | 2.6 | 2.3 | 2.9 | <1 | <0.4 | <0.1 | 0.6 | 0.6 | USGS gaging station 9-0734. |
| Colorado River at New Castle | 2 | 5 | 90 | 31 | SW | 39 | 34 | 06 | 107 | 32 | 26 | 25(40) | 8-26-69 | 1,100 | 350 | -- | -- | -- | -- | | -- | -- | -- | -- | USGS gaging station 9-0876. |
| | | | | | | | | | | | | | 10-19-69 | 1,100 | 350 | -- | -- | -- | -- | | -- | -- | -- | -- | |
| | | | | | | | | | | | | | 4- 6-70 | 1,300 | 390 | 28 | 9.3 | 8.7 | 11 | 16 | .9 | .3 | 1.1 | 1.3 | |
| Beaver Creek near Rifle | 3 | 6 | 93 | 20 | SE | 39 | 30 | 40 | 107 | 48 | 03 | 10.6(17.1) | 3-24-69 | <700 | <220 | <2.6 | <.9 | 2.5 | 3.1 | -- | -- | -- | -- | -- | Sample collected between settling pond and filter plant, Rifle water works. |
| | 3 | 7 | 94 | 1 | NE | 39 | 28 | 20 | 107 | 49 | 55 | 7.6(12) | 9-20-69 | <960 | <300 | -- | -- | -- | -- | | -- | -- | -- | -- | USGS gaging station 9-0925. |
| | | | | | | | | | | | | | 4-10-70 | <960 | <300 | 6.9 | 2.3 | 3.4 | 4.2 | 39 | 3.6 | 1.2 | 2.9 | 3.3 | |
| Kimball Creek near Collbran | 4 | 9 | 95 | 14 | NE | 39 | 17 | 00 | 107 | 57 | 13 | 8.4(14) | 8-26-69 | <960 | <300 | -- | -- | -- | -- | | -- | -- | -- | -- | -- |
| | | | | | | | | | | | | | 9-20-69 | <960 | <300 | -- | -- | -- | -- | | -- | -- | -- | -- | |
| | | | | | | | | | | | | | 4-11-70 | <1,300 | <400 | 7.2 | 2.4 | 7.6 | 9.4 | 10 | .5 | .2 | 5.8 | 6.4 | |
| Plateau Creek near Cameo | 5 | 10 | 97 | 18 | SW | 39 | 11 | 00 | 108 | 16 | 10 | 23(37) | 8-28-69 | <960 | <300 | -- | -- | -- | -- | | -- | -- | -- | -- | USGS gaging station 9-1050. |
| | | | | | | | | | | | | | 9-20-69 | <960 | <300 | -- | -- | -- | -- | | -- | -- | -- | -- | |
| | | | | | | | | | | | | | 10-19-69 | <960 | <300 | -- | -- | -- | -- | | -- | -- | -- | -- | |
| | | | | | | | | | | | | | 4- 6-70 | <960 | <300 | 24 | 8.0 | 7.1 | 8.9 | 98 | 6.1 | 2.0 | 3.9 | 4.9 | |
| Colorado River near DeBeque | 6 | 8 | 97 | 23 | SW | 39 | 20 | 22 | 108 | 11 | 35 | 14(23) | 8-26-69 | 960 | 300 | -- | -- | -- | -- | | -- | -- | -- | -- | Downstream 2.7 miles (4.3 kilometers) from USGS gaging station 9-0937. |
| | | | | | | | | | | | | | 9-20-69 | 960 | 300 | -- | -- | -- | -- | | -- | -- | -- | -- | |
| | | | | | | | | | | | | | 10-19-69 | <960 | <300 | -- | -- | -- | -- | | -- | -- | -- | -- | |
| | | | | | | | | | | | | | 4- 6-70 | 1,200 | 380 | 17 | 5.8 | 7.6 | 9.5 | 14 | .7 | .2 | 1.2 | 1.3 | |

[1] As shown on figure 1.

[2] Not surveyed.

(Voegeli and Claassen, 1971a)

Radiochemical analyses of water from selected [illegible]

| Stream | Sample point number[1] | Location: Township S. | Location: Range W. | Location: Section | Location: ¼ Section | Latitude N.: Degrees | Latitude N.: Minutes | Latitude N.: Seconds | Longitude W.: Degrees | Longitude W.: Minutes | Longitude W.: Seconds | Distance from surface ground zero: miles | Distance from surface ground zero: kilometers | Date of collection | Tritium: pCi/l | Tritium: TU | Dissolved: Gross alpha (µg/l as U natural) | Dissolved: Gross alpha (pCi/l as U natural) | Dissolved: Gross beta (pCi/l as Sr-90/Y-90) | Dissolved: Gross beta (pCi/l as Cs-137) | Suspended: Solids mg/l | Suspended: Gross alpha (µg/l as U natural) | Suspended: Gross alpha (pCi/l as U natural) | Suspended: Gross beta (pCi/l as Sr-90/Y-90) | Suspended: Gross beta pCi/l as Cs-137) | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Roaring Fork River near Aspen | 1 | (2/) | | | | 39 | 10 | 48 | 106 | 48 | 05 | 64 | 103 | 6- 1-70 | <960 | <300 | 2.7 | 0.9 | 4.5 | 5.5 | 30 | 4.1 | 1.4 | 3.3 | 3.8 | USGS gaging station 9-0734. |
| | | | | | | | | | | | | | | 6-25-70 | <960 | <300 | 2.2 | .7 | 3.5 | 4.3 | 6 | .8 | .3 | 1.0 | 1.1 | |
| Colorado River at New Castle | 2 | 5 | 90 | 31 | SW | 39 | 34 | 06 | 107 | 32 | 26 | 25 | 40 | 6- 1-70 | <960 | <300 | 3.5 | 1.2 | 4.3 | 5.4 | 100 | 5.7 | 1.9 | 3.8 | 4.6 | USGS gaging station 9-0876. |
| | | | | | | | | | | | | | | 6-25-70 | 1,100 | 360 | 4.4 | 1.5 | 4.4 | 5.5 | 86 | 5.6 | 1.9 | 4.6 | 5.7 | |
| Beaver Creek near Rifle | 3 | 7 | 94 | 1 | NE | 39 | 28 | 20 | 107 | 49 | 55 | 7.6 | 12 | 5-30-70 | <960 | <300 | 1.1 | .4 | 3.5 | 4.5 | 210 | 12 | 4.0 | 7.8 | 9.8 | USGS gaging station 9-0925. |
| | | | | | | | | | | | | | | 6-25-70 | 1,000 | 320 | 1.7 | .6 | 2.7 | 3.4 | 32 | 1.8 | .6 | 1.9 | 2.1 | |
| Kimball Creek near Collbran | 4 | 9 | 95 | 14 | NE | 39 | 17 | 00 | 107 | 57 | 13 | 8.4 | 14 | 5-29-70 | <960 | <300 | 2.1 | .7 | 2.1 | 2.6 | 140 | 9.8 | 3.3 | 5.4 | 6.5 | -- |
| | | | | | | | | | | | | | | 6-25-70 | 1,200 | 390 | 2.2 | .7 | 2.7 | 3.4 | 54 | 4.5 | 1.5 | 2.6 | 3.1 | |
| Plateau Creek near Cameo | 5 | 10 | 97 | 18 | SW | 39 | 11 | 00 | 108 | 16 | 10 | 23 | 37 | 5-29-70 | <960 | <300 | 3.9 | 1.3 | 5.3 | 6.5 | 330 | 27 | 8.9 | 7.4 | 9.4 | USGS gaging station 9-1050. |
| | | | | | | | | | | | | | | 6-25-70 | <960 | <300 | 12 | 4.0 | 11 | 14 | 40 | 1.6 | .5 | 2.2 | 2.5 | |
| Colorado River near DeBeque | 6 | 8 | 97 | 23 | SW | 39 | 20 | 22 | 108 | 11 | 35 | 14 | 23 | 5-29-70 | <960 | <300 | 4.7 | 1.6 | 9.9 | 13 | 180 | 14 | 4.7 | 8.0 | 10 | Downstream 2 7 miles (4.3 kilometers) from USGS gaging station 9-0937. |
| | | | | | | | | | | | | | | 6-25-70 | <960 | <300 | 3.2 | 1.1 | 6.8 | 8.5 | 78 | 5.6 | 1.9 | 3.8 | 4.7 | |

(Voegeli and Claassen, 1971b)

Radiochemical analyses of water from selected streams in western Colorado

| Stream | Sample point number[1] | Location: Township S. | Location: Range W. | Location: Section | Location: ¼ Section | Latitude N.: Degrees | Latitude N.: Minutes | Latitude N.: Seconds | Longitude W.: Degrees | Longitude W.: Minutes | Longitude W.: Seconds | Distance from surface ground zero: miles | Distance from surface ground zero: kilo-meters | Date of collection | Tritium: pCi/l | Tritium: TU | Dissolved Gross alpha: (µg/l as U natural) | Dissolved Gross alpha: (pCi/l as U natural) | Dissolved Gross beta: (pCi/l as Sr-90/Y-90 | Dissolved Gross beta: (pCi/l as Cs-137) | Suspended Solids: mg/l | Suspended Gross alpha: (µg/l as U natural) | Suspended Gross alpha: (pCi/l as U natural) | Suspended Gross beta: pCi/l as Sr-90/Y-90 | Suspended Gross beta: pCi/l as Cs-137) | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Roaring Fork River near Aspen | 1 | (2/) | | | | 39 | 10 | 48 | 106 | 48 | 05 | 64 | 103 | 8-17-70 | 880 | 280 | | | | | | | | | | USGS gaging station 9-0734. |
| | | | | | | | | | | | | | | 9-30-70 | 1,100 | 330 | | | | | | | | | | |
| | | | | | | | | | | | | | | 10-10-70 | 740 | 230 | | | | | | | | | | |
| Colorado River at New Castle | 2 | 05 | 90 | 31 | SW | 39 | 34 | 06 | 107 | 32 | 26 | 25 | 40 | 8-17-70 | 1,000 | 320 | | | | | | | | | | USGS gaging station 9-0876. |
| | | | | | | | | | | | | | | 9-30-70 | 1,100 | 330 | | | | | | | | | | |
| | | | | | | | | | | | | | | 10-10-70 | <700 | <220 | | | | | | | | | | |
| Beaver Creek near Rifle | 3 | 07 | 94 | 01 | NE | 39 | 28 | 20 | 107 | 49 | 55 | 7.6 | 12 | 8-17-70 | <700 | <220 | | | | | | | | | | USGS gaging station 9-0925. |
| | | | | | | | | | | | | | | 9-30-70 | 910 | 280 | | | | | | | | | | |
| | | | | | | | | | | | | | | 10-10-70 | <700 | <220 | | | | | | | | | | |
| Kimball Creek near Collbran | 4 | 09 | 95 | 14 | NE | 39 | 17 | 00 | 107 | 57 | 13 | 8.4 | 14 | 8-17-70 | <700 | <220 | | | | | | | | | | -- |
| | | | | | | | | | | | | | | 9-30-70 | <700 | <220 | | | | | | | | | | |
| | | | | | | | | | | | | | | 10-11-70 | <700 | <220 | | | | | | | | | | |
| Plateau Creek near Cameo | 5 | 10 | 97 | 18 | SW | 39 | 11 | 00 | 108 | 16 | 10 | 23 | 37 | 8-17-70 | 990 | 310 | 15 | 4.9 | 8.7 | 11 | 69 | 3.1 | 1.0 | 2.4 | 3.0 | USGS gaging station 9-1050. |
| | | | | | | | | | | | | | | 9-30-70 | 1,000 | 320 | 22 | 7.5 | 6.4 | 8.0 | 18 | <.5 | <.2 | <.9 | <1.0 | |
| | | | | | | | | | | | | | | 10-11-70 | 810 | 250 | 36 | 12 | 10 | 13 | 790 | 82 | 27 | 25 | 27 | |
| Colorado River near DeBeque | 6 | 08 | 97 | 23 | SW | 39 | 20 | 22 | 108 | 11 | 35 | 14 | 23 | 8-17-70 | 1,000 | 320 | 5.7 | 1.9 | 3.8 | 4.8 | 33 | 1.9 | .6 | 2.0 | 24 | Downstream 2.7 miles (4.3 kilometers) from USGS gaging station 9-0937. |
| | | | | | | | | | | | | | | 9-30-70 | 1,000 | 320 | 15 | 4.9 | 4.2 | 5.3 | 10 | <.6 | <.2 | <1.3 | <1.4 | |
| | | | | | | | | | | | | | | 10-11-70 | 800 | 250 | 15 | 4.9 | 9.5 | 12 | 490 | 39 | 13 | 20 | 26 | |

1/ As shown on figure 1.

2/ Not surveyed.

(Claassen and Voegeli, 1971)

Radiochemical analyses of water from selected streams in western Colorado

| Stream | Sample point number 1/ | Location: Township S. | Location: Range W. | Location: Section | Location: ¼ Section | Latitude N.: Degrees | Latitude N.: Minutes | Latitude N.: Seconds | Longitude W.: Degrees | Longitude W.: Minutes | Longitude W.: Seconds | Distance from surface ground zero: miles | Distance from surface ground zero: kilometers | Date of collection | Tritium: pCi/l | Tritium: TU | Dissolved: Gross alpha (µg/l as U natural) | Dissolved: Gross alpha (pCi/l as U natural) | Dissolved: Gross beta (pCi/l as Sr-90/Y-90) | Dissolved: Gross beta (pCi/l as Cs-137) | Suspended: Solids mg/l | Suspended: Gross alpha (µg/l as U natural) | Suspended: Gross alpha (pCi/l as U natural) | Suspended: Gross beta (pCi/l as Sr-90/Y-90) | Suspended: Gross beta (pCi/l as Cs-137) | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Roaring Fork River near Aspen | 1 | (2/) | | | | 39 | 10 | 48 | 106 | 48 | 05 | 64 | 103 | 10-23-70<br>11- 4-70 | 1,000<br>990 | 320<br>310 | | | | | | | | | | USGS gaging station 9-0734. |
| Colorado River at New Castle | 2 | 05 | 90 | 31 | SW | 39 | 34 | 06 | 107 | 32 | 26 | 25 | 40 | 10-23-70<br>3/11- 4-70<br>11- 9-70 | 1,000<br>--<br>860 | 330<br>--<br>270 | -- | -- | -- | -- | -- | -- | -- | -- | -- | USGS gaging station 9-0876. |
| Beaver Creek near Rifle | 3 | 07 | 94 | 01 | NE | 39 | 28 | 20 | 107 | 49 | 55 | 7.6 | 12 | 10-23-70<br>3/11- 5-70<br>11- 9-70 | 880<br>--<br><700 | 280<br>--<br><220 | -- | -- | -- | -- | -- | -- | -- | -- | -- | USGS gaging station 9-0925 |
| Kimball Creek near Collbran | 4 | 09 | 95 | 14 | NE | 39 | 17 | 00 | 107 | 57 | 13 | 8.4 | 14 | 10-24-70<br>3/11- 5-70<br>11- 9-70 | <700<br>--<br><700 | <220<br>--<br><220 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Plateau Creek near Cameo | 5 | 10 | 97 | 18 | SW | 39 | 11 | 00 | 108 | 16 | 10 | 23 | 37 | 10-24-70<br>11- 5-70 | 940<br>990 | 290<br>310 | 26<br>20 | 8.6<br>6.7 | 10<br>25 | 13<br>32 | 62<br>37 | 1.2<br>.9 | 0.4<br>.3 | 4.2<br>1.6 | 4.8<br>1.9 | USGS gaging station 9-1050 |
| Colorado River near DeBeque | 6 | 08 | 97 | 23 | SW | 39 | 20 | 22 | 108 | 11 | 35 | 14 | 23 | 10-23-70<br>3/11- 5-70<br>11- 9-70 | 900<br>--<br>900 | 280<br>--<br>280 | 24<br>--<br>11 | 8.0<br>--<br>3.5 | 6.6<br>--<br>62 | 8.1<br>--<br>78 | 16<br>--<br>8 | 2.6<br>--<br>2.2 | .9<br>--<br>.7 | 4.3<br>--<br>2.5 | 4.6<br>--<br>2.7 | Downstream 2.7 miles (4.3 kilometers) from USGS gaging station 9-0937. |

1/ As shown on figure 1.

2/ Not surveyed.

3/ Samples for tritium, gross alpha, and gross beta collected and stored.

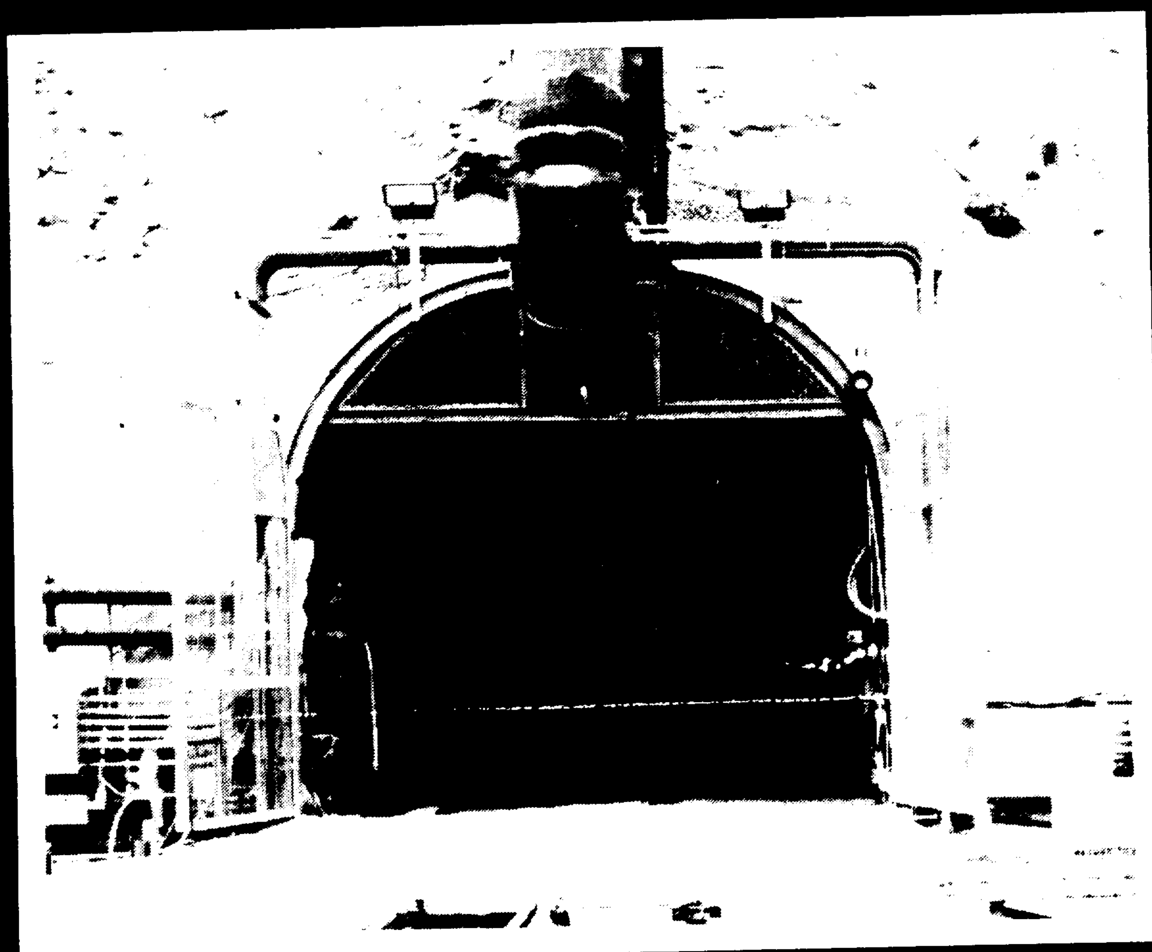
(Claassen, 1971, p. 4)

**Distribution List**

| | Copies |
|---|---|
| U.S. Department of Energy<br>Nevada Operations Office<br>Technical Information Resource Center<br>P.O. Box 98518<br>Las Vegas, NV  89193-8518 | 1 |
| U.S. Department of Energy<br>Office of Scientific and Technical Information<br>175 Oak Ridge Turnpike<br>Post Office Box 62<br>Oak Ridge, Tennessee  37831 | 2 |
| U.S. Department of Energy<br>Public Reading Room<br>P.O. Box 98521, M/S NLV040<br>Las Vegas, NV 89193-8521 | 1 |
| Donna Stoner<br>Colorado Department of Public Health & Environment<br>Hazardous Materials & Waste Management Division<br>722 South 6th Street, Room 232<br>Grand Junction, Colorado 81501 | 1 |
| Parachute Branch Library<br>Rulison Public Reading Room<br>244 Grand Valley Way<br>Parachute, Colorado 81635 | 1 |
| Central Files<br>IT Corporation<br>2621 Losee Rd., Bldg. B-1, 3050-01<br>North Las Vegas, Nevada 89030 | 1 |

# The Containment of
# UNDERGROUND NUCLEAR EXPLOSIONS





CONGRESS OF THE UNITED STATES OFFICE OF TECHNOLOGY ASSESSMENT

# The Containment of
# UNDERGROUND NUCLEAR EXPLOSIONS

CONGRESS OF THE UNITED STATES OFFICE OF TECHNOLOGY ASSESSMENT

Recommended Citation:

U.S. Congress, Office of Technology Assessment, *The Containment of Underground Nuclear Explosions*, OTA-ISC-414 (Washington, DC: U.S. Government Printing Office, October 1989).

Library of Congress Catalog Card Number 89-600707

For sale by the Superintendent of Documents
U.S. Government Printing Office, Washington, DC 20402-9325
(order form can be found in the back of this report)

## Workshop 1: Containment
## Monday, Sept. 26, 1988
## Environmental Research Center
## University of Nevada, Las Vegas

Neville G. Cook, *Chair*
Department of Material Science and Mineral Engineering
University of California

Frederick N. App
Section Leader
Containment Geophysics
Los Alamos National Laboratory

Norman R. Burkhard
Containment Program Leader
Lawrence Livermore National Laboratory

Jim Carothers
Chairman
Containment Evaluation Panel
Lawrence Livermore National Laboratory

Jack Evernden
Lawrence Livermore National Laboratory
U.S. Geological Survey

Robert A. Fulkerson
Executive Director
Citizen Alert

Jack W. House
Containment Program Manager
Los Alamos National Laboratory

Billy C. Hudson
Deputy Containment Program Leader
Lawrence Livermore National Laboratory

Evan Jenkins
U.S. Geological Survey

Joseph LaComb
Chief
Nevada Operations Office
Defense Nuclear Agency

James K. Magruder
Assistant Manager for Operations and Engineering
Nevada Operations Office
U.S. Department of Energy

Paul Orkild
U.S. Geological Survey

Edward W. Peterson
Containment Project Director
S-CUBED

John Stewart
Director
Test Operations Division
Nevada Operations Office
U.S. Department of Energy

# Foreword

Within weeks after the ending of World War II, plans for the first nuclear test series "Operation Crossroads" were underway. The purpose then, as now, was to develop new weapon systems and to study the effects of nuclear explosions on military equipment. The development of the nuclear testing program has been paralled by public opposition from both an arms control and an environmental perspective. Much of the criticism is due to the symbolic nature of testing nuclear weapons and from the radiation hazards associated with the early practice of testing in the atmosphere. Recently, however, specific concerns have also been raised about the current underground testing program; namely:

- Are testing practices safe?
- Could an accidental release of radioactive material escape undetected?
- Is the public being fully informed of all the dangers emanating from the nuclear testing program?

These concerns are fueled in part by the secrecy that surrounds the testing program and by publicized problems at nuclear weapons production facilities.

At the request of the House Committee on Interior and Insular Affairs and Senator Orrin G. Hatch, OTA undertook an assessment of the containment and monitoring practices of the nuclear testing program. This special report reviews the safety of the nuclear testing program and assesses the technical procedures used to test nuclear weapons and ensure that radioactive material produced by test explosions remains contained underground. An overall evaluation considers the acceptability of the remaining risk and discusses reasons for the lack of public confidence.

In the course of this assessment, OTA drew on the experience of many organizations and individuals. We appreciate the assistance of the U.S. Government agencies and private companies who contributed valuable information, the workshop participants who provided guidance and review, and the many additional reviewers who helped ensure the accuracy and objectivity of this report.

John H Gibbons

JOHN H. GIBBONS
*Director*

# OTA Project Staff—The Containment of Underground Nuclear Explosions

Lionel S. Johns, *Assistant Director, OTA*
*Energy, Materials, and International Security Division*

Peter Sharfman, *International Security and Commerce Program Manager**

Alan Shaw, *International Security and Commerce Program Manager***

**Gregory E. van der Vink,** *Project Director*

***Administrative Staff***

Jannie Horne (through November 1988)

Marie C. Parker (through April 1989)

Jackie Robinson

Louise Staley

*Through February 1989.

**From March 1989.

## Workshop 2: Monitoring
## Tuesday, Sept. 27, 1988
## Environmental Research Center
## University of Nevada, Las Vegas

Melvin W. Carter, *Chair*
Neely Professor Emeritus
Georgia Institute of Technology

Lynn R. Anspaugh
Division Leader
Environmental Sciences Division
Lawrence Livermore National Laboratory

Bruce Church
Assistant Manager for Environmental Safety and Health
Nevada Operations Office
U.S. Department of Energy

Charles F. Costa
Director
Nuclear Radiation Assessment Division
United States Environmental Protection Agency

Donald R. Elle
Chief, Technical Projects Branch
Health Physics and Environmental Division
Nevada Operations Office
U.S. Department of Energy

Bernd Franke
IFEU

Robert A. Fulkerson
Executive Director
Citizen Alert

Michael A. Marelli
Chief, Health Protection Branch
Health Physics and Environmental Division
Nevada Operations Office
U.S. Department of Energy

Darryl Randerson
Weather Service
Nuclear Office

## Workshop 2: Monitoring
## Tuesday, Sept. 27, 1988
## Environmental Research Center
## University of Nevada, Las Vegas

Melvin W. Carter, *Chair*
Neely Professor Emeritus
Georgia Institute of Technology

Lynn R. Anspaugh
Division Leader
Environmental Sciences Division
Lawrence Livermore National Laboratory

Bruce Church
Assistant Manager for Environmental Safety and Health
Nevada Operations Office
U.S. Department of Energy

Charles F. Costa
Director
Nuclear Radiation Assessment Division
United States Environmental Protection Agency

Donald R. Elle
Chief, Technical Projects Branch
Health Physics and Environmental Division
Nevada Operations Office
U.S. Department of Energy

Bernd Franke
IFEU

Robert A. Fulkerson
Executive Director
Citizen Alert

Michael A. Marelli
Chief, Health Protection Branch
Health Physics and Environmental Division
Nevada Operations Office
U.S. Department of Energy

Darryl Randerson
Weather Service
Nuclear Office

# Contents

## Acknowledgments

OTA gratefully acknowledges the valuable contributions made by the following:

Lynn R. Anspaugh
Lawrence Livermore National Laboratory

Frederick N. App
Los Alamos National Laboratory

Nick Aquilina
U.S. Department of Energy

Charles Archambeau
CIRES, University of Colorado, Boulder

Stuart C. Black
U.S. Environmental Protection Agency

Carter Broyles
Sandia National Laboratory

Norman R. Burkhard
Lawrence Livermore National Laboratory

John H. Campbell
U.S. Department of Energy

Jim Carothers
Lawrence Livermore National Laboratory

Melvin W. Carter
International Radiation Protection Consultant

Bruce Church
U.S. Department of Energy

Neville G. Cook
University of California, Berkeley

Charles F. Costa
U.S. Environmental Protection Agency

Jeff Duncan
Office of Congressman Edward J. Markey

Donald R. Elle
U.S. Department of Energy

Gerald L. Epstein
John F. Kennedy School of Government, Harvard University

Jack Evernden
U.S. Geological Survey

Anthony Fainberg
Office of Technology Assessment, U.S. Congress

Pete Fitzsimmons
U.S. Department of Energy

Janet Fogg
U.S. Department of Energy

Bernd Franke
IFEU

Robert A. Fulkerson
Citizen Alert

Larry Gabriel
Defense Nuclear Agency

David Graham
Moore College of Art

Jack W. House
Los Alamos National Laboratory

Billy C. Hudson
Lawrence Livermore National Laboratory

Evan Jenkins
U.S. Geological Survey

Gerald W. Johnson
University of California

Joseph W. LaComb
Defense Nuclear Agency

James K. Magruder
U.S. Department of Energy

Michael A. Marelli
U.S. Department of Energy

LTC Samuel D. McKinney
Defense Nuclear Agency

David N. McNelis
University of Las Vegas, Nevada

Paul Orkild
Lawrence Livermore National Laboratory

Edward W. Peterson
S-CUBED

Dorothy F. Pope
Defense Nuclear Agency

Darryl Randerson
Weather Service, Nuclear Office

Karen Randolph
U.S. Department of Energy

R.L. Rhodes
Diebold, Inc.

Patrick Rowe
REECo

Robert Shirkey
Defense Nuclear Agency

John O. Stewart
U.S. Department of Energy

Robert Titus
Weather Service, Nuclear Office

Dean R. Townsend
Fenix & Scission, Inc.

Chris L. West
U.S. Department of Energy

Barbara Yoers
U.S. Department of Energy

NOTE: OTA appreciates and is grateful for the valuable assistance and thoughtful critiques provided by the contributors. The contributors do not, however, necessarily approve, disapprove, or endorse this report. OTA assumes full responsibility for the report and the accuracy of its contents.

Chapter 1

# Executive Summary

## CONTENTS



### *Table*

# Executive Summary

*The chances of an accidental release of radioactive material have been made as remote as possible. Public concerns about safety are fueled by concerns about the testing program in general and exacerbated by the government's policy of not announcing all tests.*

## INTRODUCTION

During a nuclear explosion, billions of atoms release their energy within a millionth of a second, pressures reach several million pounds per square inch, and temperatures are as high as one-million degrees centigrade. A variety of radioactive elements are produced depending on the design of the explosive device and the contribution of fission and fusion to the explosion. The half-lives of the elements produced range from less than a second to more than a million years.

Each year over a dozen nuclear weapons are detonated underground at the Nevada Test Site.[1] The tests are used to develop new nuclear weapons and to assess the effects of nuclear explosions on military systems and other hardware. Each test is designed to prevent the release of radioactive material. The objective of each test is to obtain the desired experimental information and yet successfully contain the explosion underground (i.e., prevent radioactive material from reaching the atmosphere).

## HOW SAFE IS SAFE ENOUGH?

Deciding whether the testing program is safe requires a judgment of how safe is safe enough. The subjective nature of this judgment is illustrated through the decision-making process of the Containment Evaluation Panel (CEP) which reviews and assesses the containment of each test.[2] The panel evaluates the probability of containment using the terms "high confidence," "adequate degree of confidence," and "some doubt." But the Containment Evaluation Panel has no guidelines that attempt to quantify or describe in probabilistic terms what constitutes for example, an "adequate degree of confidence." Obviously, there can never be 100 percent confidence that a test will not release radioactive material. Whether "adequate confidence" translates into a chance of 1 in 100, 1 in 1,000, or 1 in 1,000,000, requires a decision about what is an acceptable level of risk. In turn, decisions of acceptable level of risk can only be made by weighing the costs of an unintentional release against the benefits of testing. Consequently, those who feel that testing is important for our national security will accept greater risk, and those who oppose nuclear testing will find even small risks unacceptable.

Establishing an acceptable level of risk is difficult, not only because of the value judgments associated with nuclear testing, but also because the risk is not seen as voluntary by those outside the testing program. A public that readily accepts the risks associated with voluntary activities—such as sky diving or smoking—may still consider the much lower risks associated with nuclear testing unacceptable.

## HOW SAFE HAS IT BEEN?

Some insight into the safety of the nuclear testing program can be obtained by reviewing the containment record. Releases of radioactive material are categorized with terms that describe both the volume of material released and the conditions of the release:

[1] Currently, all U.S. nuclear test explosions are conducted at the Nevada Test Site.

[2] The Containment Evaluation Panel is a group of representatives from various laboratories and technical consulting organizations who evaluate the proposed containment plan for each test without regard to cost or other outside considerations (see ch. 2 for a complete discussion).

*Containment Failures:* Containment failures are unintentional releases of radioactive material to the atmosphere due to a failure of the containment system. They are termed "ventings," if they are prompt, massive releases; or "seeps," if they are slow, small releases that occur soon after the test.

*Late-Time Seeps:* Late-time seeps are small releases that occur days or weeks after a test when gases diffuse through pore spaces of the overlying rock and are drawn to the surface by decreases in atmospheric pressure.

*Controlled Tunnel Purging:* A controlled tunnel purging is an intentional release to allow either recovery of experimental data and equipment or reuse of part of the tunnel system.

*Operational Release:* Operational releases are small, consequential releases that occur when core or gas samples are collected, or when the drill-back hole is sealed.

The containment record can be presented in different ways depending on which categories of releases are included. **Reports of total numbers of releases are often incomplete because they include only announced tests or releases due to containment failure.** The upper portion of table 1-1 includes **every** instance (for both announced and unannounced tests) where radioactive material has reached the atmosphere **under any circumstances whatsoever** since the 1970 Baneberry test.

Since 1970, 126 tests have resulted in radioactive material reaching the atmosphere with a total release of about 54,000 Curies (Ci). Of this amount, 11,500 Ci were due to containment failure and late-time seeps. The remaining 42,500 Ci were operational releases and controlled tunnel purgings—with Mighty Oak (36,000 Ci) as the main source. The lower portion of the table shows that the release of radioactive material from underground nuclear testing since Baneberry (54,000 Ci) is extremely small in comparison to the amount of material released by pre-Baneberry underground tests (25,300,000 Ci), the early atmospheric tests at the Nevada Test Site (12,000,000,000 Ci), or even the amount that would be released by a single 1-kiloton explosion conducted aboveground (10,000,000 Ci).

**Table 1-1—Releases From Underground Tests (normalized to 12 hours after event[a])**

| | |
|---|---|
| All releases 1971-1988: | |
| Containment Failures: | |
| Camphor, 1971[b] | 360 Ci |
| Diagonal Line, 1971 | 6,800 |
| Riola, 1980 | 3,100 |
| Agrini, 1984 | 690 |
| Late-time Seeps: | |
| Kappeli, 1984 | 12 |
| Tierra, 1984 | 600 |
| Labquark, 1986 | 20 |
| Bodie, 1986[3] | 52 |
| Controlled Tunnel Purgings: | |
| Hybla Fair, 1974 | 500 |
| Hybla Gold, 1977 | 0.005 |
| Miners Iron, 1980 | 0.3 |
| Huron Landing, 1982 | 280 |
| Mini Jade, 1983 | 1 |
| Mill Yard, 1985 | 5.9 |
| Diamond Beech, 1985 | 1.1 |
| Misty Rain, 1985 | 63 |
| Mighty Oak, 1986 | 36,000 |
| Mission Ghost, 1987[c] | 3 |
| Operational Releases: | |
| 108 tests from 1970-1988[d] | 5,500 |
| Total since Baneberry: | 54,000 Ci |
| Major pre-1971 releases: | |
| Platte, 1962 | 1,900,000 Ci |
| Eel, 1962 | 1,900,000 |
| Des Moines, 1962 | 11,000,000 |
| Baneberry, 1970 | 6,700,000 |
| 26 others from 1958-1970 | 3,800,000 |
| Total: | 25,300,000 Ci |
| Other Releases for Reference | |
| NTS Atmospheric Testing 1951-1963: | 12,000,000,000 Ci |
| 1 Kiloton Aboveground Explosion: | 10,000,000 |
| Chernobyl (estimate): | 81,000,000 |

[a]R+12 values apply only to containment failures, others are at time of release.
[b]The Camphor failure includes 140 Ci from tunnel purging.
[c]Bodie and Mission Ghost also had drill-back releases.
[d]Many of these operational releases are associated with tests that were not announced.

SOURCE: Office of Technology Assessment, 1989.

From the perspective of human health risk:

**If the same person had been standing at the boundary of the Nevada Test Site in the area of maximum concentration of radioactivity for every test since Baneberry (1970), that**

**person's total exposure would be equivalent to 32 extra minutes of normal background exposure (or the equivalent of 1/1000 of a single chest x-ray).**

A worst-case scenario for a catastrophic accident at the test site would be the prompt, massive venting of a 150-kiloton test (the largest allowed under the 1974 Threshold Test Ban Treaty). The release would be in the range of 1 to 10 percent of the total radiation generated by the explosion (compared to 6 percent released by the Baneberry test or an estimated 10 percent that would be released by a test conducted in a hole open to the surface). Such an accident would be comparable to a 15-kiloton **above-ground** test, and would release approximately 150,000,000 Ci. Although such an accident would be considered a major catastrophe today, during the early years at the Nevada Test Site 25 **aboveground** tests had individual yields equal to or greater than 15 kilotons.

## SPECIFIC CONCERNS

Recently, several specific concerns about the safety of the nuclear testing program have arisen, namely:[3]

1. *Does the fracturing of rock at Rainier Mesa pose a danger?*

The unexpected formation of a surface collapse crater during the 1984 Midas Myth test focused concern about the safety of testing in Rainier Mesa. The concern was heightened by the observation of ground cracks at the top of the Mesa and by seismic measurements indicating a loss of rock strength out to distances greater than the depth of burial of the nuclear device. The specific issue is whether the repeated testing in Rainier Mesa had fractured large volumes of rock creating a "tired mountain" that no longer had the strength to successfully contain future underground tests. The inference that testing in Rainier Mesa poses a high level of risk implies that conditions for conducting a test on Rainier are more dangerous than conditions for conducting a test on Yucca Flat.[4] But, in fact, tests in Rainier Mesa are buried deeper and spaced further apart than comparable tests on Yucca Flat.[5] Furthermore, drill samples show no evidence of any permanent decrease in rock strength at distances greater than two cavity radii from the perimeter of the cavity formed by the explosion. The large distance of decreased rock strength seen in the seismic measurements is almost certainly due to the momentary opening of pre-existing cracks during passage of the shock wave. Most fractures on the top of the mesa are due to surface spall and do not extend down to the region of the test. Furthermore, only minimal rock strength is required for containment. **Therefore, none of the conditions of testing in Rainier Mesa—burial depth, separation distance, or material strength—imply that leakage to the surface is more likely for a tunnel test on Rainier Mesa than for a vertical drill hole test on Yucca Flat.**

2. *Could an accidental release of radioactive material go undetected?*

A comprehensive system for detecting radioactive material is formed by the combination of:

- the monitoring system deployed for each test;
- the onsite monitoring system run by the Department of Energy (DOE) and;
- the offsite monitoring system, run by Environmental Protection Agency (EPA), including the community monitoring stations.

**There is essentially no possibility that a significant release of radioactive material**

[3]Detailed analysis of these concerns is included in chs. 3 and 4.

[4]Approximately 90 percent of all nuclear test explosions are vertical drill hole tests conducted on Yucca Flat. See ch. 2 for an explanation of the various types of tests.

[5]The greater depth of burial is due to convenience. It is easier to mine tunnels lower in the Mesa.

**from an underground test could go undetected.**

3. *Are we running out of room to test at the Test Site?*

Efforts to conserve space for testing in Rainier Mesa have created the impression that there is a "real estate problem" at the test site.[6] The concern is that a shortage of space would result in unsafe testing practices. Although it is true that space is now used economically to preserve the most convenient locations, other less convenient locations are available within the test site. **Suitable areas within the test site offer enough space to continue testing at present rates for several more decades.**

4. *Do any unannounced tests release radioactive material?*

A test will be preannounced in the afternoon 2 days before the test if it is determined that the maximum possible yield of the explosion is such that it could result in perceptible ground motion in Las Vegas. An announcement will be made after a test if there is a prompt release of radioactive material, or if any late-time release results in radioactivity being detected off the test site. The Environmental Protection Agency is dependent on the Department of Energy for notification of any late-time releases within the boundaries of the test site. However, if EPA is not notified, the release will still be detected by EPA's monitoring system once radioactive material reaches outside the test site. **If it is judged that a late-time release of radioactive material will not be detected outside the boundaries of the test site, the test may (and often does) remain unannounced.**

## OVERALL EVALUATION

Every nuclear test is designed to be contained and is reviewed for containment.[7] In each step of the test procedure there is built-in redundancy and conservatism. Every attempt is made to keep the chance of containment failure as remote as possible. This conservatism and redundancy is essential, however; because no matter how perfect the process may be, it operates in an imperfect setting. For each test, the containment analysis is based on samples, estimates, and models that can only simplify and (at best) approximate the real complexities of the Earth. As a result, predictions about containment depend largely on judgments developed from past experience. Most of what is known to cause problems—carbonate material, water, faults, scarps, clays, etc.—was learned through experience. To withstand the consequences of a possible surprise, redundancy and conservatism is a requirement not an extravagance. Consequently, all efforts undertaken to ensure a safe testing program are necessary, and must continue to be vigorously pursued.

The question of whether the testing program is "safe enough" will ultimately remain a value judgment that weighs the importance of testing against the risk to health and environment. In this sense, concern about safety will continue, largely fueled by concern about the nuclear testing program itself. However, given the continuance of testing and the acceptance of the associated environmental damage, the question of "adequate safety" becomes replaced with the less subjective question of whether any improvements can be made to reduce the chances of an accidental release. In this regard, no areas for improvement have been identified. This is not to say that future improvements will not be made as experience increases, but only that essentially all suggestions that increase the safety margin have been implemented. **The safeguards built into each test make the chances of an accidental release of radioactive material as remote as possible.**

[6]See for example: William J. Broad, "Bomb Tests: Technology Advances Against Backdrop of Wide Debate," *New York Times*, Apr. 15, 1986, pp. C1-C3.

[7]See ch. 3 for a detailed accounting of the review process.

The acceptability of the remaining risk will depend on public confidence in the nuclear testing program. This confidence currently suffers from a lack of confidence in the Department of Energy emanating from problems at nuclear weapons production facilities and from radiation hazards associated with the past atmospheric testing program. In the case of the present underground nuclear testing program, this mistrust is exacerbated by DOE's reluctance to disclose information concerning the testing program, and by the knowledge that not all tests releasing radioactive material to the atmosphere (whatever the amount or circumstances) are announced. As the secrecy associated with the testing program is largely ineffective in preventing the dissemination of information concerning the occurrence of tests, the justification for such secrecy is questionable.[8]

The benefits of public dissemination of information have been successfully demonstrated by the EPA in the area of radiation monitoring. Openly available community monitoring stations allow residents near the test site to independently verify information released by the government, thereby providing reassurance to the community at large. **In a similar manner, public concern over the testing program could be greatly mitigated if a policy were adopted whereby all tests are announced, or at least all tests that release radioactive material to the atmosphere (whatever the conditions) are announced.**

[8]See for example: Riley R. Geary, "Nevada Test Site's dirty little secrets," *Bulletin of the Atomic Scientists*, April 1989, pp. 35-38.

Chapter 2

# The Nuclear Testing Program

# Chapter 2
# The Nuclear Testing Program

*The nuclear testing program has played a major role in developing new weapon systems and determining the effects of nuclear explosions.*

## INTRODUCTION

In the past four decades, nuclear weapons have evolved into highly sophisticated and specialized devices. Throughout this evolution, the nuclear testing program has played a major role in developing new weapon systems and determining the effects of nuclear explosions.

## THE HISTORY OF NUCLEAR TESTING

On July 16, 1945 the world's first nuclear bomb (code named "Trinity") was detonated atop a 100-foot steel tower at the Alamogordo Bombing Range, 55 miles northwest of Alamogordo, New Mexico.[1] The explosion had a yield of 21 kilotons (kts), the explosive energy equal to approximately 21,000 tons of TNT.[2] The following month, American planes dropped two atomic bombs ("Little Boy," 13 kilotons; "Fat Man," 23 kilotons) on the Japanese cities of Hiroshima and Nagasaki, ending World War II and beginning the age of nuclear weapons.[3]

Within weeks after the bombing of Hiroshima and Nagasaki, plans were underway to study the effects of nuclear weapons and explore further design possibilities. A subcommittee of the Joint Chiefs of Staff was created, on November 10, 1945, to arrange the first series of nuclear test explosions. President Truman approved the plan on January 10, 1946. The Bikini Atoll was selected as the test site and the Bikinians were relocated to the nearby uninhabited Rongerik Atoll. Two tests ("Able" and "Baker") were detonated on Bikini in June and July of 1946 as part of "Operation Crossroads," a series designed to study the effects of nuclear weapons on ships, equipment, and material.[4] The Bikini Atoll, however, was found to be too small to accommodate support facilities for the next test series and so "Operation Sandstone" was conducted on the nearby Enewetak Atoll. The tests of Operation Sandstone ("X-ray," "Yoke," and "Zebra") were proof tests for new bomb designs.

As plans developed to expand the nuclear arsenal, the expense, security, and logistical problems of testing in the Pacific became burdensome. Attention turned toward establishing a test site within the continental United States. The Nevada Test Site was chosen in December 1950 by President Truman as a continental proving ground for testing nuclear weapons. A month later, the first test—code named "Able"—was conducted using a device dropped from a B-50 bomber over Frenchman Flat as part of a five-test series called "Operation Ranger." The five tests were completed within 11 days at what was then called the "Nevada Proving Ground."

Although the Nevada Test Site was fully operational by 1951, the Pacific continued to be used as a test site for developing thermonuclear weapons (also called hydrogen or fusion bombs). On October 31, 1952, the United States exploded the first hydrogen (fusion) device on Enewetak Atoll.[5] The test, code named "Mike," had an explosive yield of 10,400 kilotons—over 200 times the largest previous test.

[1]The Alamogordo Bombing Range is now the White Sands Missile Range.

[2]A kiloton (kt) was originally defined as the explosive equivalent of 1,000 tons of TNT. This definition, however, was found to be imprecise for two reasons. First, there is some variation in the experimental and theoretical values of the explosive energy released by TNT (although the majority of values lie in the range from 900 to 1,100 calories per gram). Second, the term kiloton could refer to a short kiloton ($2 \times 10^6$ pounds), a metric kiloton ($2.205 \times 10^6$ pounds), or a long kiloton ($2.24 \times 10^6$ pounds). It was agreed, therefore, during the Manhattan Project that the term "kiloton" would refer to the release of $10^{12}$ (1,000,000,000,000) calories of explosive energy.

[3]John Malik, "The Yields of the Hiroshima and Nagasaki Nuclear Explosions," Los Alamos National Laboratory report LA-8819, 1985.

[4]The target consisted of a fleet of over 90 vessels assembled in the Bikini Lagoon including three captured German and Japanese ships; surplus U.S. cruisers, destroyers, and submarines; and amphibious craft.

[5]The first test of an actual hydrogen *bomb* (rather than a *device* located on the surface) was "Cherokee" which was dropped from a plane over Bikini Atoll on May 20, 1956. Extensive preparations were made for the test that included the construction of artificial islands to house measuring equipment. The elaborate experiments required that the bomb be dropped in a precise location in space. To accomplish this, the Strategic Air Command held a competition for bombing accuracy. Although the winner hit the correct point in every practice run, during the test the bomb was dropped 4 miles off-target.

The test was followed 2 weeks later by the 500 kiloton explosion "King," the largest fission weapon ever tested.

At the Nevada Test Site, low-yield fission devices continued to be tested. Tests were conducted with nuclear bombs dropped from planes, shot from cannons, placed on top of towers, and suspended from balloons. The tests were designed both to develop new weapons and to learn the effects of nuclear explosions on civilian and military structures. Some tests were conducted in conjunction with military exercises to prepare soldiers for what was then termed "the atomic battlefield."

In the Pacific, the next tests of thermonuclear (hydrogen) bombs were conducted under "Operation Castle," a series of six tests detonated on the Bikini Atoll in 1954. The first test, "Bravo," was expected to have a yield of about 6,000 kilotons. The actual yield, however, was 15,000 kilotons—over twice what was expected.[6] The radioactive fallout covered an area larger than anticipated and because of a faulty weather prediction, the fallout pattern was more easterly than expected. A Japanese fishing boat, which had accidentally wandered into the restricted zone without being detected by the Task Force, was showered with fallout. When the fishing boat docked in Japan, 23 crew members had radiation sickness. The radio operator died of infectious hepatitis, probably because of the large number of required blood transfusions.[7] The faulty fallout prediction also led to the overexposure of the inhabitants of two of the Marshall Islands 100 miles to the East. In a similar though less severe accident, radioactive rain from a Soviet thermonuclear test fell on Japan.[8] These accidents began to focus worldwide attention on the increased level of nuclear testing and the dangers of radioactive fallout. Public opposition to atmospheric testing would continue to mount as knowledge of the effects of radiation increased and it became apparent that no region of the world was untouched.[9]

Attempts to negotiate a ban on nuclear testing began at the United Nations Disarmament Conference in May 1955. For the next several years efforts to obtain a test ban were blocked as agreements in nuclear testing were linked to progress in other arms control agreements and as differences over verification requirements remained unresolved. In 1958, President Eisenhower and Soviet Premier Khrushchev declared, through unilateral public statements, a moratorium on nuclear testing and began negotiations on a comprehensive test ban. The United States adopted the moratorium after conducting 13 tests in seven days at the end of October 1958. Negotiations broke down first over the right to perform onsite inspections, and then over the number of such inspections. In December 1959, President Eisenhower announced that the United States would no longer consider itself bound by the "voluntary moratorium" but would give advance notice if it decided to resume testing. Meanwhile (during the moratorium), the French began testing their newly acquired nuclear capability. The Soviet Union, which had announced that it would observe the moratorium as long as the western powers would not test, resumed testing in September 1961 with a series of the largest tests ever conducted. The United States resumed testing two weeks later (figure 2-1).[10]

Public opposition to nuclear testing continued to mount. Recognizing that the U.S. could continue its development program solely through underground testing and that the ratification of a comprehensive test ban could not be achieved, President Kennedy proposed a limited ban on tests in the atmosphere, the oceans, and space. The Soviets, who through their own experience were convinced that their test program could continue underground, accepted the proposal. With both sides agreeing that such a treaty could be readily verified, the Limited Test Ban Treaty (LTBT) was signed in 1963, banning all aboveground or underwater testing.

In addition to military applications, the engineering potential of nuclear weapons was recognized by the mid-1950's. The Plowshare Program was formed in 1957 to explore the possibility of using nuclear explosions for peaceful purposes.[11] Among the

[6]Bravo was the largest test ever detonated by the United States.

[7]See "The Voyage of the Lucky Dragon," Ralph E. Lapp, 1957, Harper & Brothers Publishers, New York.

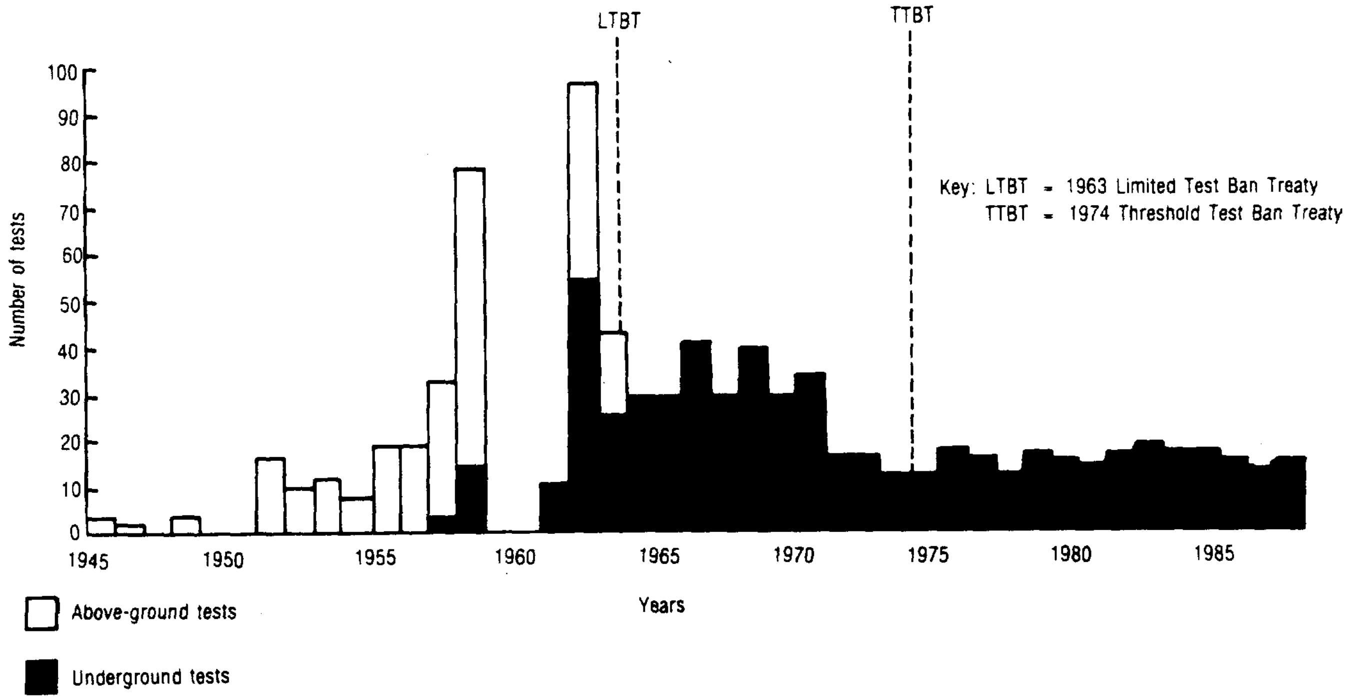
[8]"Arms Control and Disarmament Agreements," United States Arms Control and Disarmament Agency, Washington, DC, 1982 Edition, p. 34.

[9]Since the large thermonuclear tests, all people have strontium-90 (a sister element of calcium) in their bones, and cesium-137 (a sister element of potassium) in their muscle. Also, the amount of iodine-131 in milk in the United States correlates with the frequency of atmospheric testing.

[10]See "Arms Control and Disarmament Agreements," United States Arms Control and Disarmament Agency, 1982 edition.

[11]The name is from ". . . . they shall beat their swords into plowshares," Isaiah 2:4.

**Figure 2-1—U.S. Nuclear Testing**




SOURCE: Data from the Swedish Defense Research Institute.

applications considered were the excavation of canals and harbors, the creation of underground storage cavities for fuel and waste, the fracturing of rock to promote oil and gas flow, and the use of nuclear explosions to cap oil gushers and extinguish fires. It was reported that even more exotic applications, such as melting glaciers for irrigation, were being considered by the Soviet Union.

The first test under the Plowshare Program, "Gnome," was conducted 4 years later to create an underground cavity in a large salt deposit. The next Plowshare experiment, Sedan in 1962, used a 104 kiloton explosion to excavate 12 million tons of earth. In 1965, the concept of "nuclear excavation" was refined and proposed as a means of building a second canal through Panama.[12] Three nuclear excavations were tested under the Plowshare program ("Cabriolet," Jan. 26, 1968; "Buggy," Mar. 12, 1968; and "Schooner," Dec. 12, 1968). Schooner, however, released radioactivity off site and, as a consequence, no future crater test was approved. Consideration of the radiological and logistical aspects of the project also contributed to its demise. Estimates of the engineering requirements indicated that approximately 250 separate nuclear explosions with a total yield of 120 megatons would be required to excavate the canal through Panama. Furthermore, fallout predictions indicated that 16,000 square kilometers of territory would need to be evacuated for the duration of the operation and several months thereafter.[13] Because it was also clear that no level of radioactivity would be publicly acceptable, the program was terminated in the early 1970s.

In 1974, President Richard Nixon signed the Threshold Test Ban Treaty (TTBT) restricting all nuclear test explosions to a defined test site and to yields no greater than 150 kilotons. As a result, all U.S. underground nuclear tests since 1974 have been conducted at the Nevada Test Site. As part of the earlier 1963 Limited Test Ban Treaty, the United States established a series of safeguards. One of them, "Safeguard C," requires the United States to maintain the capability to resume atmospheric testing in case the treaty is abrogated. The Department of Energy (DOE) and the Defense Nuclear Agency continue today to maintain a facility for the

[12] The 1956 war over the Suez Canal created the first specific proposals for using nuclear explosions to create an alternative canal.

[13] Bruce A. Bolt, "Nuclear Explosions and Earthquakes, The Parted Veil" San Francisco, CA: W.H. Freeman & Co., 1976, pp. 192-196.

Photo credit: David Graham 1988

Sedan Crater

atmospheric testing of nuclear weapons at the Johnston Atoll in the Pacific Ocean.

## LIMITS ON NUCLEAR TESTING

The testing of nuclear weapons by the United States is currently restricted by three major treaties that were developed for both environmental and arms control reasons. The three treaties are:

1. the 1963 Limited Nuclear Test Ban Treaty, which bans nuclear explosions in the atmosphere, outer space, and underwater, and restricts the release of radiation into the atmosphere,

2. the 1974 Threshold Test Ban Treaty, which restricts the testing of underground nuclear weapons by the United States and the Soviet Union to yields no greater than 150 kilotons, and

3. the 1976 Peaceful Nuclear Explosions Treaty (PNET), which is a complement to the Threshold Test Ban Treaty (TTBT). It restricts individual peaceful nuclear explosions (PNEs) by the United States and the Soviet Union to yields no greater than 150 kilotons, and group explosions (consisting of a number of individual explosions detonated simultaneously) to aggregate yields no greater than 1,500 kilotons.

Although both the 1974 TTBT and the 1976 PNET remain unratified, both the United States and the Soviet Union have expressed their intent to abide by the yield limit. Because neither country has indicated an intention not to ratify the treaties, both parties are obligated to refrain from any acts that would defeat their objective and purpose.[14] Consequently, all nuclear test explosions compliant with treaty obligations must be conducted underground, at specific test sites (unless a PNE), and with yields no greater than 150 kilotons. The test must also be contained to the extent that no radioactive debris is detected outside the territorial limits of the country that conducted the test.[15] Provisions do exist, however, for one or two slight, unintentional breaches per year of the 150 kiloton limit due to the technical uncertainties associated with predicting the exact yields of nuclear weapons tests.[16]

[14]Art. 18, 1969 Vienna Convention on the Law of Treaties.

[15]Art. I, 1(b), 1963 Limited Test Ban Treaty.

[16]Statement of understanding included with the transmittal documents accompanying the Threshold Test Ban Treaty and the Peaceful Nuclear Explosions Treaty when submitted to the Senate for advice and consent to ratification on July 29, 1979.

## OTHER LOCATIONS OF NUCLEAR TESTS

U.S. nuclear test explosions were also conducted in areas other than the Pacific and the Nevada Test Site.

Three tests with yields of 1 to 2 kilotons were conducted over the South Atlantic as "Operation Argus." The tests ("Argus I," Aug. 27, 1958; "Argus II," Aug. 30, 1958; and "Argus III," Sept. 6, 1958) were detonated at an altitude of 300 miles to assess the effects of high-altitude nuclear detonations on communications equipment and missile performance.

Five tests, all involving chemical explosions but with no nuclear yield, were conducted at the Nevada Bombing Range to study plutonium dispersal. The tests, "Project 57 NO 1," April 24, 1957; "Double Tracks," May 15, 1963; "Clean Slate I," May 25, 1963; "Clean Slate II," May 31, 1963; and "Clean Slate III," June 9, 1963; were safety tests to establish storage and transportation requirements.

Two tests were conducted in the Tatum Salt Dome near Hattiesburg, Mississippi, as part of the Vela Uniform experiments to improve seismic methods of detecting underground nuclear explosions. The first test "Salmon," October 22, 1964, was a 5.3 kiloton explosion that formed an underground cavity. The subsequent test "Sterling," December 3, 1966, was 0.38 kt explosion detonated in the cavity formed by Salmon. The purpose of the Salmon/Sterling experiment was to assess the use of a cavity in reducing the size of seismic signals produced by an underground nuclear test.[17]

Three joint government-industry tests were conducted as part of the Plowshare Program to develop peaceful uses of nuclear explosions. The experiments were designed to improve natural gas extraction by fracturing rock formations. The first test, "Gasbuggy," was a 29 kiloton explosion detonated on December 10, 1967, near Bloomfield, New Mexico. The next two were in Colorado: "Rulison" was a 40 kiloton explosion, detonated near Grand Valley on September 10, 1969; and "Rio Blanco" was a salvo shot of three explosions, each with a yield of 33 kt, detonated near Rifle on May 17, 1973.

Three tests were conducted on Amchitka Island, Alaska. The first (October 29, 1965), "Long Shot" was an 80 kiloton explosion that was part of the Vela Uniform project. The second test, "Milrow," October 2, 1969, was about a one megaton explosion to "calibrate" the island and assure that it would contain a subsequent test of the Spartan Anti-Ballistic Missile warhead. The third test, "Cannikin," November 6, 1971, was the Spartan warhead test with a reported yield of "less than five megatons." This test, by far the highest-yield underground test ever conducted by the United States, was too large to be safely conducted in Nevada.[18]

Three individual tests were also conducted in various parts of the western United States. "Gnome" was a 3 kiloton test conducted on December 10, 1961 near Carlsbad, New Mexico, to create a large underground cavity in salt as part of a multipurpose experiment. One application was the possible use of the cavity for the storage of oil and gas. "Shoal" was a 12 kiloton test conducted on October 26, 1963 near Fallon, Nevada as part of the Vela Uniform project. "Faultless" was a test with a yield of between 200 and 1,000 kiloton that was exploded on January 19, 1968, at a remote area near Hot Creek Valley, Nevada. Faultless was a ground-motion calibration test to evaluate a Central Nevada Supplemental Test Area. The area was proposed as a alternative location for high-yield tests to decrease the ground shaking in Las Vegas.

## THE NEVADA TEST SITE

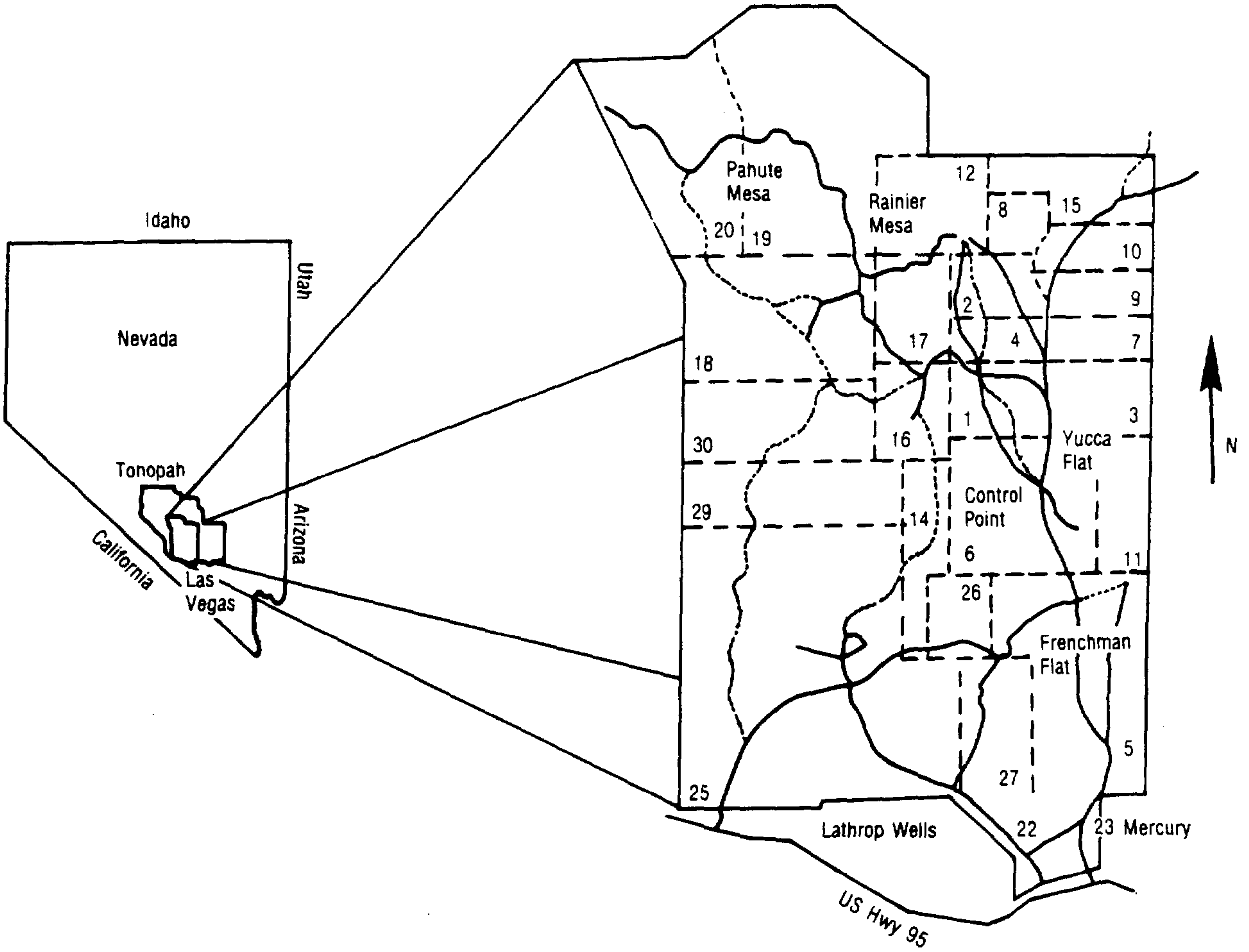
The Nevada Test Site is located 65 miles northwest of Las Vegas. It covers 1,350 square miles, an area slightly larger than Rhode Island (figure 2-2). The test site is surrounded on three sides by an additional 4,000 to 5,000 square miles belonging to Nellis Air Force Base and the Tonopah Test Range. The test site has an administrative center, a control point, and areas where various testing activities are conducted.

At the southern end of the test site is Mercury, the administrative headquarters and supply base for

[17] For a complete discussion of the issues related to Seismic Verification see, U.S. Congress, Office of Technology Assessment, *Seismic Verification of Nuclear Testing Treaties*, OTA-ISC-361, Washington, DC: U.S. Government Printing Office, May 1988.

[18] The predictions of ground motion suggested that an unacceptable amount (in terms of claims and dollars) of damage would occur to structures if the test was conducted in Nevada.

**Figure 2-2—Nevada Test Site**




SOURCE: Modified from Department of Energy.

DOE contractors and other agencies involved in Nevada Operations. Mercury contains a limited amount of housing for test site personnel and other ground support facilities.

Near the center of the test site, overlooking Frenchman Flat to the South and Yucca Flat to the North, is the Control Point (CP). The CP is the command headquarters for testing activities and is the location from which all tests are detonated and monitored.

Frenchman Flat is the location of the first nuclear test at the test site. A total of 14 atmospheric tests occurred on Frenchman Flat between 1951 and 1962. Most of these tests were designed to determine the effects of nuclear explosions on structures and military objects. The area was chosen for its flat terrain which permitted good photography of detonations and fireballs. Also, 10 tests were conducted underground at Frenchman Flat between 1965 and 1971. Frenchman Flat is no longer used as a location for testing. The presence of carbonate material makes the area less suitable for underground testing than other locations on the test site.[19]

Yucca Flat is where most underground tests occur today. These tests are conducted in vertical drill holes up to 10 feet in diameter and from 600 ft to more than 1 mile deep. It is a valley 10 by 20 miles extending north from the CP. Tests up to about 300 kilotons in yield have been detonated beneath Yucca

[19]During an explosion, carbonate material can form carbon dioxide which, under pressure, can cause venting.

Photo credit: David Graham, 1988

Test Debris on Frenchman Flat

Flat, although Pahute Mesa is now generally reserved for high-yield tests.

Tests up to 1,000 kilotons in yield have occurred beneath Pahute Mesa, a 170 square mile area in the extreme north-western part of the test site. The deep water table of Pahute Mesa permits underground testing in dry holes at depths as great as 2,100 feet. The distant location is useful for high-yield tests because it minimizes the chance that ground motion will cause damage offsite.

Both Livermore National Laboratory and Los Alamos National Laboratory have specific areas of the test site reserved for their use. Los Alamos uses areas 1, 3, 4(east), 5, and 7 in Yucca Flat and area 19 on Pahute Mesa; Livermore uses areas 2, 4(west), 8, 9, and 10 in Yucca Flat, and area 20 on Pahute Mesa (figure 2-2). While Los Alamos generally uses Pahute Mesa only to relieve schedule conflicts on Yucca Flat, Livermore normally uses it for large test explosions where the depth of burial would require the test to be below the water table on Yucca Flat.

The Nevada Test Site employs over 11,000 people, with about 5,000 of them working on the site proper. The annual budget is approximately $1 billion divided among testing nuclear weapons (81%) and the development of a storage facility for radioactive waste (19%). The major contractors are Reynolds Electrical & Engineering Co., Inc. (REECo)

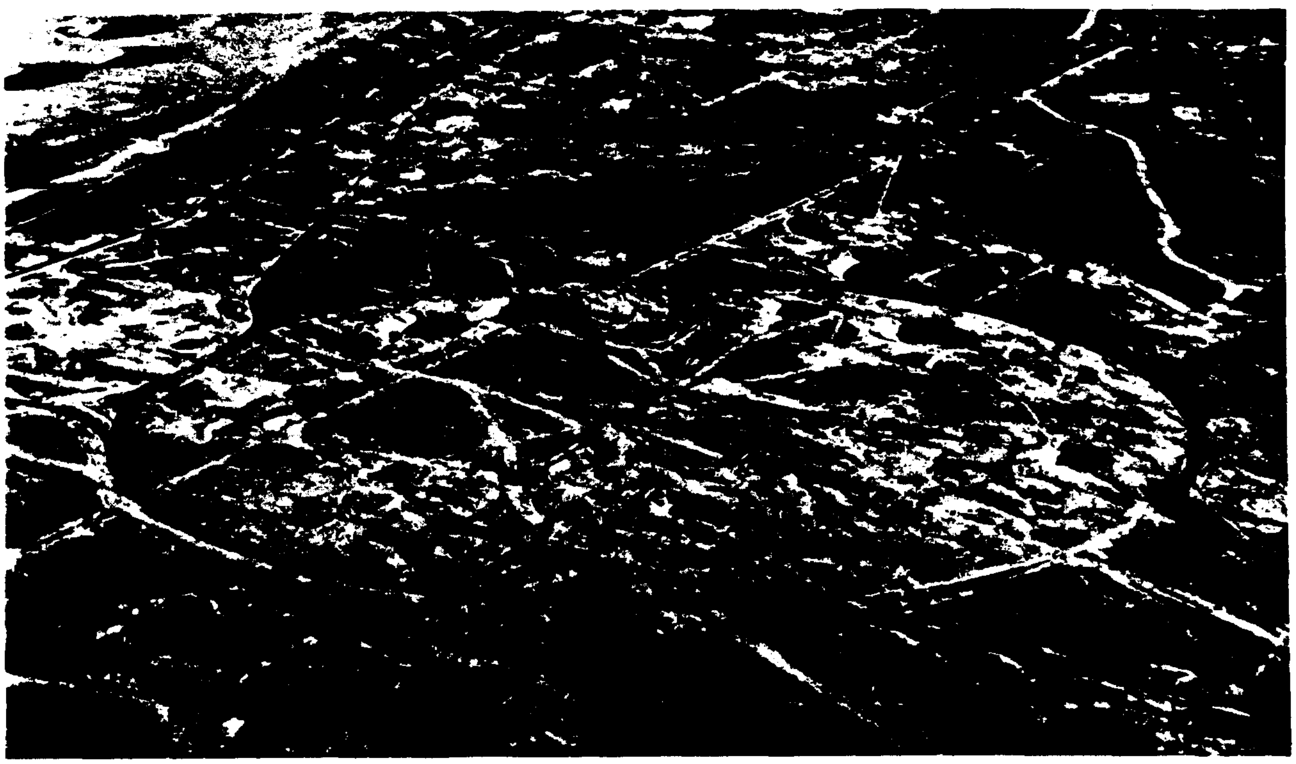


Photo credit: Department of Energy

Aerial View of Yucca Flat

Edgerton, Germeshausen & Greer (EG&G), Fenix & Scisson, Inc., and Holmes & Narver, Inc. REECo has 5,000 employees at the test site for construction, maintenance, and operational support, which includes large diameter drilling and tunneling, on-site radiation monitoring, and operation of base camps. EG&G has 2,200 employees, who design, fabricate, and operate the diagnostic and scientific equipment. Fenix & Scisson, Inc. handles the design, research, inspection, and procurement for the drilling and mining activities. Holmes & Narver, Inc. has responsibility for architectural design, engineering design, and inspection. In addition to contractors, several government agencies provide support to the testing program: the Environmental Protection Agency (EPA) has responsibility for radiation monitoring outside the Nevada Test Site; the National Oceanic and Atmospheric Administration (NOAA) provides weather analyses and predictions; and the United States Geological Survey (USGS) provides geological, geophysical, and hydrological assessments of test locations.

## TYPES OF NUCLEAR TESTS

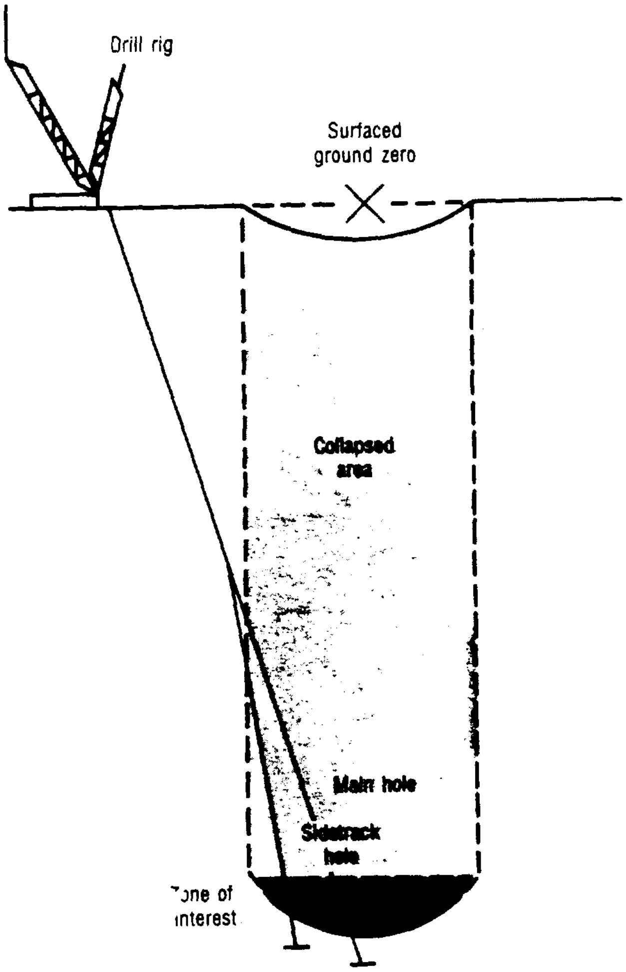
Presently, an average of more than 12 tests per year are conducted at the Nevada Test Site. Each test is either at the bottom of a vertical drill hole or at the end of a horizontal tunnel. The vertical drill hole tests are the most common (representing over 90% of all tests conducted) and occur either on Yucca Flat or, if they are large-yield tests, on Pahute Mesa. Most vertical drill hole tests are for the purpose of developing new weapon systems. Horizontal tunnel tests are more costly and time-consuming. They only occur once or twice a year and are located in tunnels mined in the Rainier and Aqueduct Mesas. Tunnel tests are generally for evaluating the effects (radiation, ground shock, etc.) of various weapons on military hardware and systems. In addition, the United Kingdom also tests at a rate of about once a year at the Nevada Test Site.

It takes 6 to 8 weeks to drill a hole depending on depth and location. The holes used by Livermore and Los Alamos differ slightly. Los Alamos typically uses holes with diameters that range from about 4

*Photo credit: Department of Energy*

Emplacement Tower for Vertical Drill Hole Test

**Figure 2-3—Drill-Back Operation**




SOURCE: Modified from Michael W. Butler, *Pastshot Drilling Handboc* Lawrence Livermore National Laboratory, Jan. 19, 1984.

1/2 up to 7 ft; while Livermore typically uses 8-ft diameter holes and an occasional 10-ft diameter hole.[20] Livermore usually places its experimental devices above the water table to avoid the additional time and expense required to case holes below the water table.

When the device is detonated at the bottom of a vertical drill hole, data from the test are transmitted through electrical and fiber-optic cables to trailers containing recording equipment. Performance information is also determined from samples of radioactive material that are recovered by drilling back into the solidified melt created by the explosion (figure 2-3). On rare occasions, vertical drill holes have been used for effects tests. One such test, "Huron King," used an initially open, vertical "line-of-sight" pipe that extended upwards to a large enclosed chamber located at the surface. The chan ber contained a satellite inside a vacuum to simula the conditions of space. The radiation from tł explosion was directed up the hole at the satellit The explosion was contained by a series of mecha ical pipe closures that blocked the pipe immediate after the initial burst of radiation. The purpose of tł test was to determine how satellites might affected by the radiation produced by a nucle explosion.

Tunnel tests occur within horizontal tunnels tł are drilled into the volcanic rock of Rainier Aqueduct Mesa. From 1970 through 1988, the

[20] Livermore has considered the use of 12 ft diameter holes, but has not yet used one.

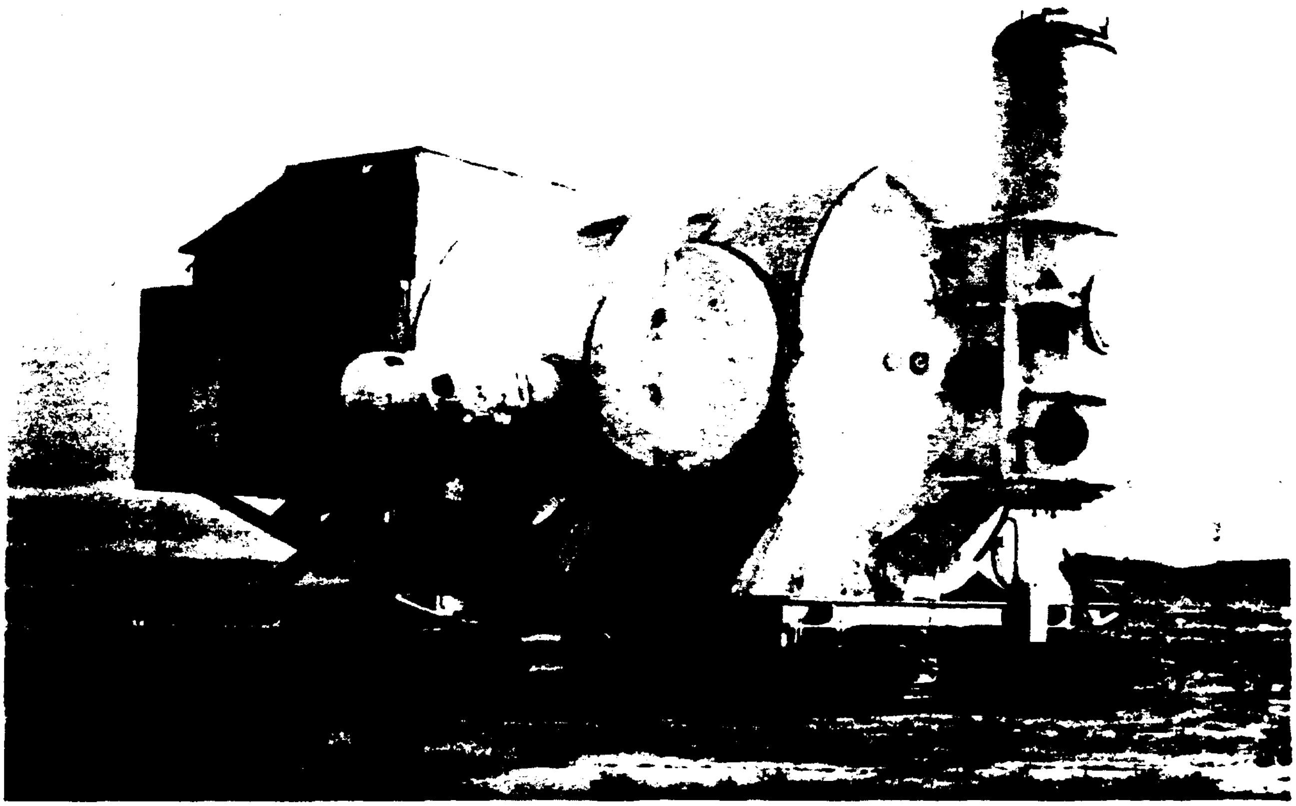


Photo credit: David Graham 1988

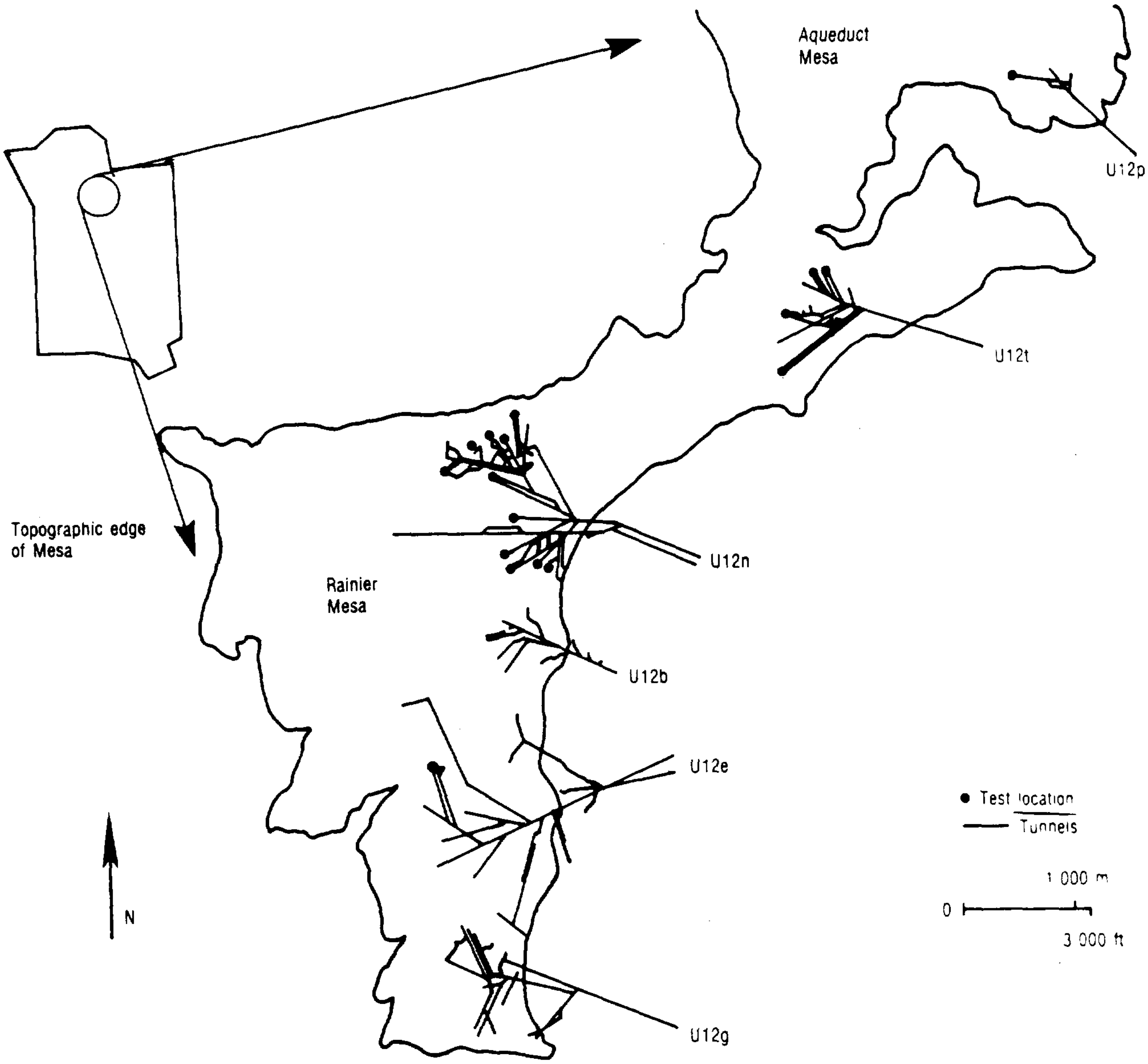
Huron King Test

have been 31 tunnel tests conducted in Rainier and Aqueduct Mesas (figure 2-4). It may require 12 months of mining, using three shifts a day, to remove the 1 million cubic feet of rock that may be needed to prepare for a tunnel test.

Effects tests performed within mined tunnels are designed to determine the effects of nuclear explosion-produced radiation on missile nose cones, warheads, satellites, communications equipment, and other military hardware. The tunnels are large enough so that satellites can be tested at full scale in vacuum chambers that simulate outer space. The tests are used to determine how weapons systems will withstand radiation that might be produced by a nearby explosion during a nuclear war. Nuclear effects tests were the first type of experiments performed during trials in the Pacific and were an extensive part of the testing program in the 1950s. At that time, many tests occurred above ground and included the study of effects on structures and civil defense systems.

Effects tests within cavities provide a means of simulating surface explosions underground. A large hemispherical cavity is excavated and an explosion is detonated on or near the floor of the cavity. The tests are designed to assess the capability of above-ground explosions to transmit energy into the ground. This information is used to evaluate the capability of nuclear weapons to destroy such targets as missile silos or underground command centers.

**Figure 2-4—Locations of Tunnel Tests in Rainier and Aqueduct Mesas**




SOURCE: Modified from Defense Nuclear Agency.

## ANNOUNCEMENT OF NUCLEAR TESTS

The existence of each nuclear test conducted prior to the signing of the LTBT on August 5, 1963, has been declassified. Many tests conducted since the signing of the LTBT, however, have not been announced. Information concerning those tests is classified. The yields of announced tests are presently reported only in the general categories of eithe less than 20 kilotons, or 20 to 150 kilotons. Th DOE's announcement policy is that a test will b pre-announced in the afternoon 2 days before the tes if it is determined that the maximum credible yiel is such that it could result in perceptible groun motion in Las Vegas. The test will be post an nounced if there is a prompt release of radioactiv material or if any late-time release results i

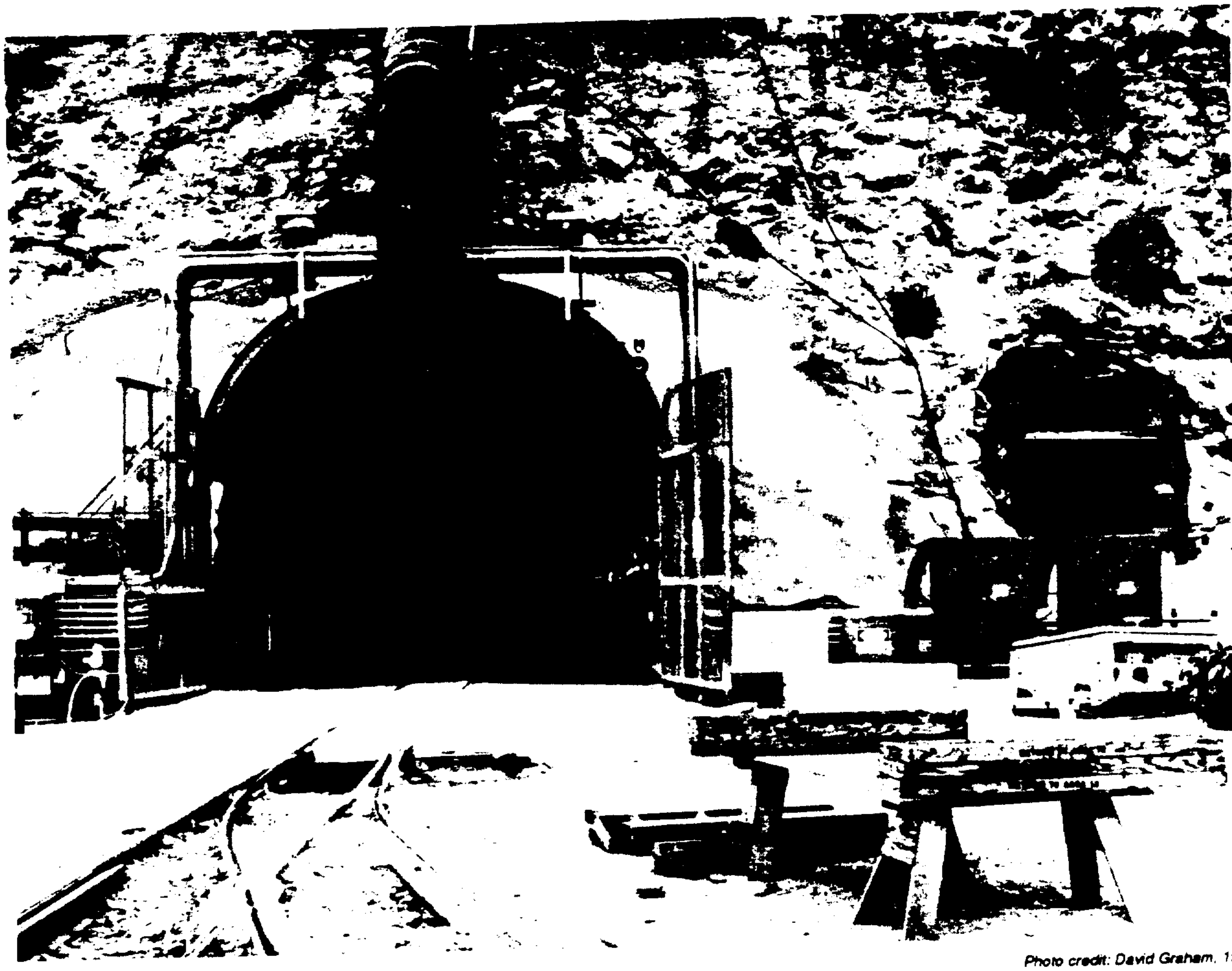


Photo credit: David Graham, 1988

Tunnel Entrance

radioactive material being detected off the test site. In the case of late-time release, however, the test will be announced *only if radioactive material is detected off-site*.

Starting with Trinity, names have been assigned to all nuclear tests. The actual nuclear weapon or device and its description are classified. Consequently, test planners assign innocuous code words or nicknames so that they may refer to planned tests. Early tests used the military phonetic alphabet (Able, Baker, Charlie, etc.). As more tests took place, other names were needed. They include names of rivers, mountains, famous scientists, small mammals, counties and towns, fish, birds, vehicles, cocktails, automobiles, trees, cheeses, wines, fabrics, tools, nautical terms, colors, and so forth.

## DETONATION AUTHORITY AND PROCEDURE

The testing of nuclear weapons occurs under the authority of the Atomic Energy Act of 1946 (as amended in 1954), which states:

"The development, use, and control of Atomic Energy shall be directed so as to make the maximum contribution to the general welfare, subject at all times to the paramount objective of making the maximum contribution to the common defense and security."

The act authorizes the U.S. Atomic Energy Commission (now Department of Energy), to "con-

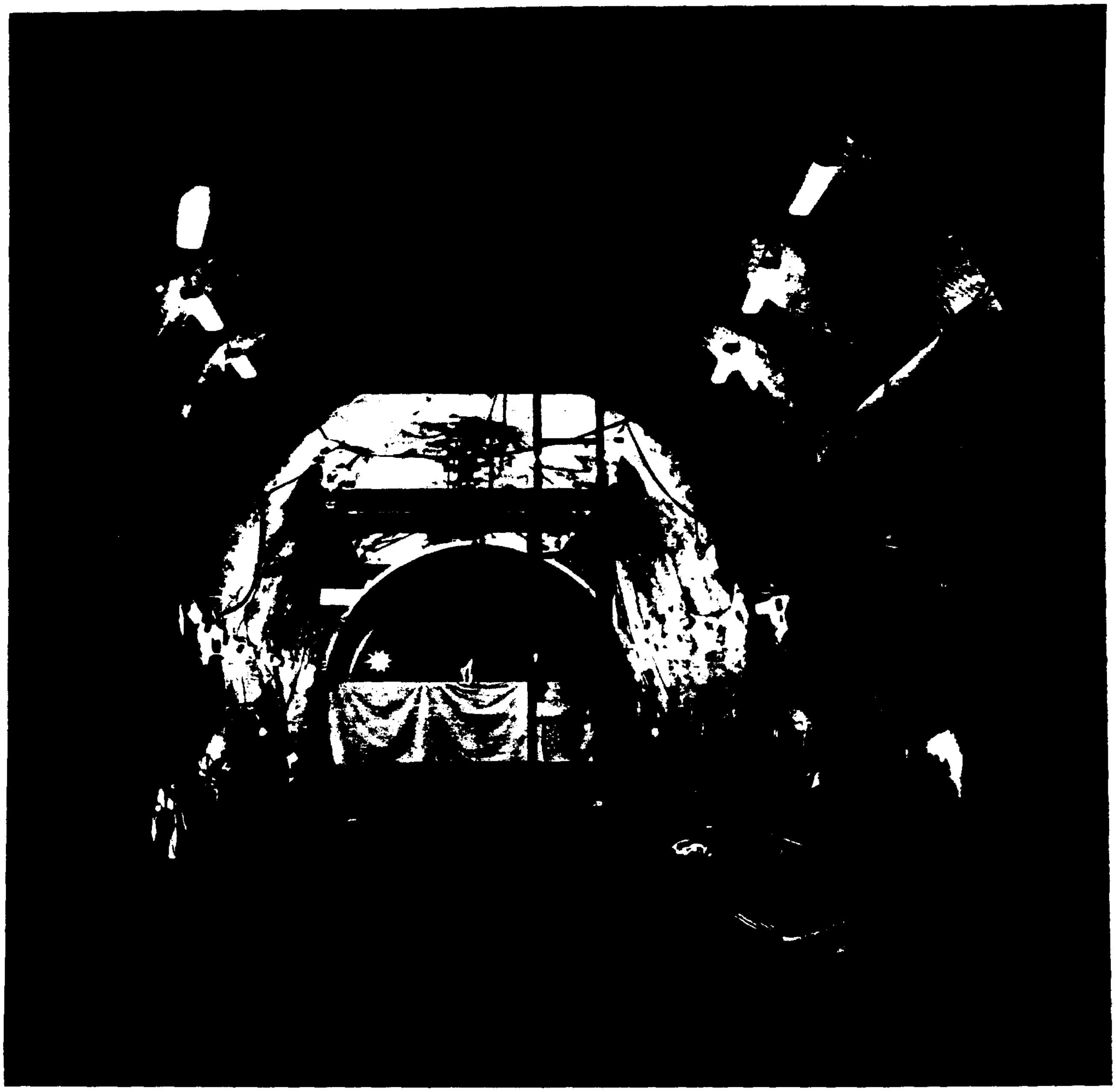


Photo credit Department of Energy

Interior Tunnel

duct experiments and do research and development work in the military application of atomic energy."

The fiscal year testing program receives authorization from the President. Each fiscal year, the Department of Defense (DoD), Department of Energy (DOE), and the weapons laboratories (Lawrence Livermore National Laboratory and Los Alamos National Laboratory) develop a nuclear testing program. The Secretary of Energy proposes the upcoming year's program in a letter to the President through the National Security Council. The National Security Council solicits comments on the test program from its members and incorporates those

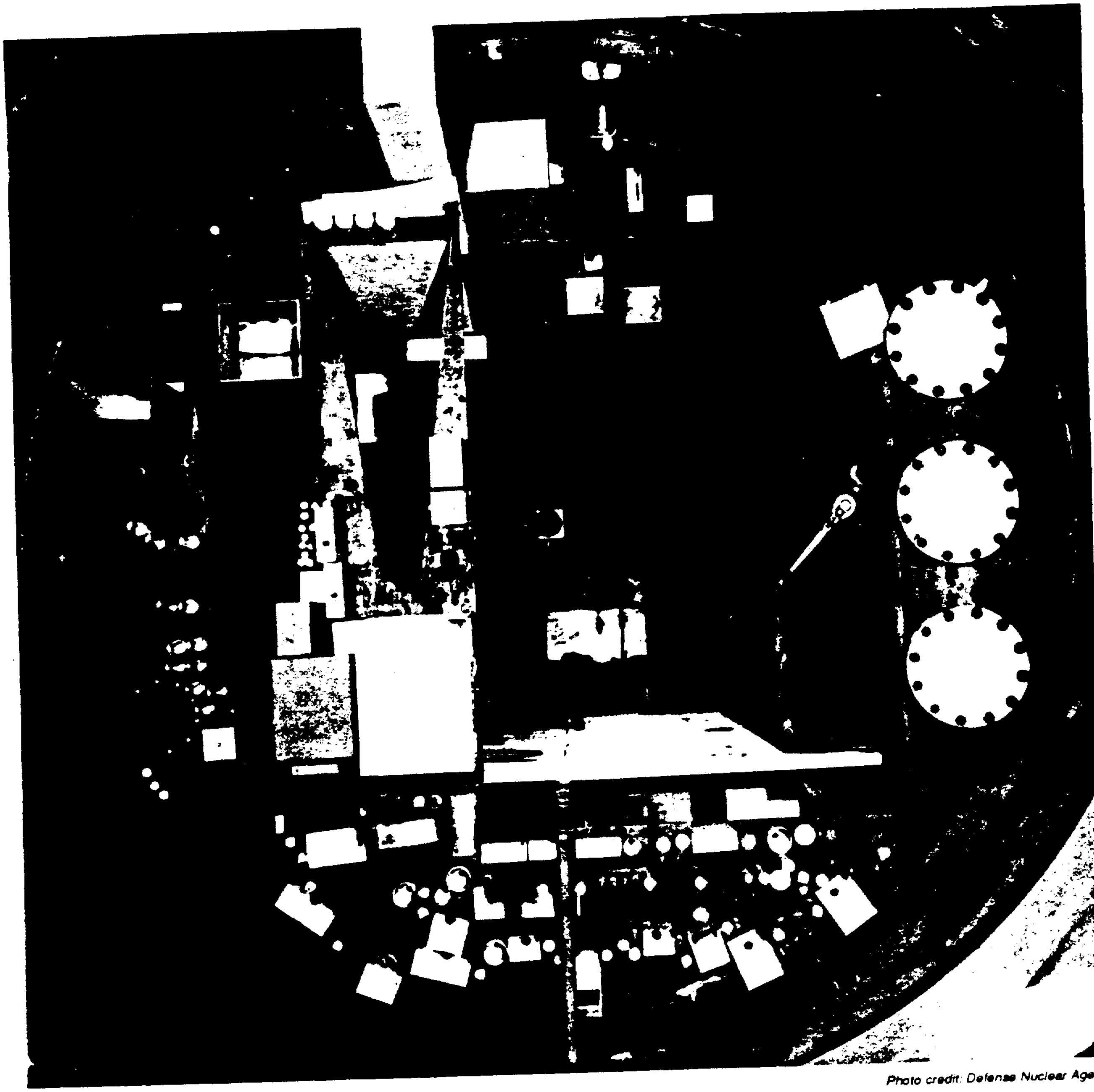


Photo credit: Defense Nuclear Agency

End of Tunnel

comments in its recommendation letter to the President. The Nevada Operations Office plans the individual tests with the responsible laboratory.

Both Livermore and Los Alamos maintain stockpiles of holes in various areas of the test site.[21] When a specific test is proposed, the lab will check its inventory to see if a suitable hole is available or if a new one must be drilled.

Once a hole is selected, the sponsoring laboratory designs a plan to fill-in (or "stem") the hole to contain the radioactive material produced by the explosion. The USGS and Earth scientists from several organizations analyze the geology surround-

[21]Each laboratory operates its own drilling crews continuously to maximize the economy of the drilling operation.

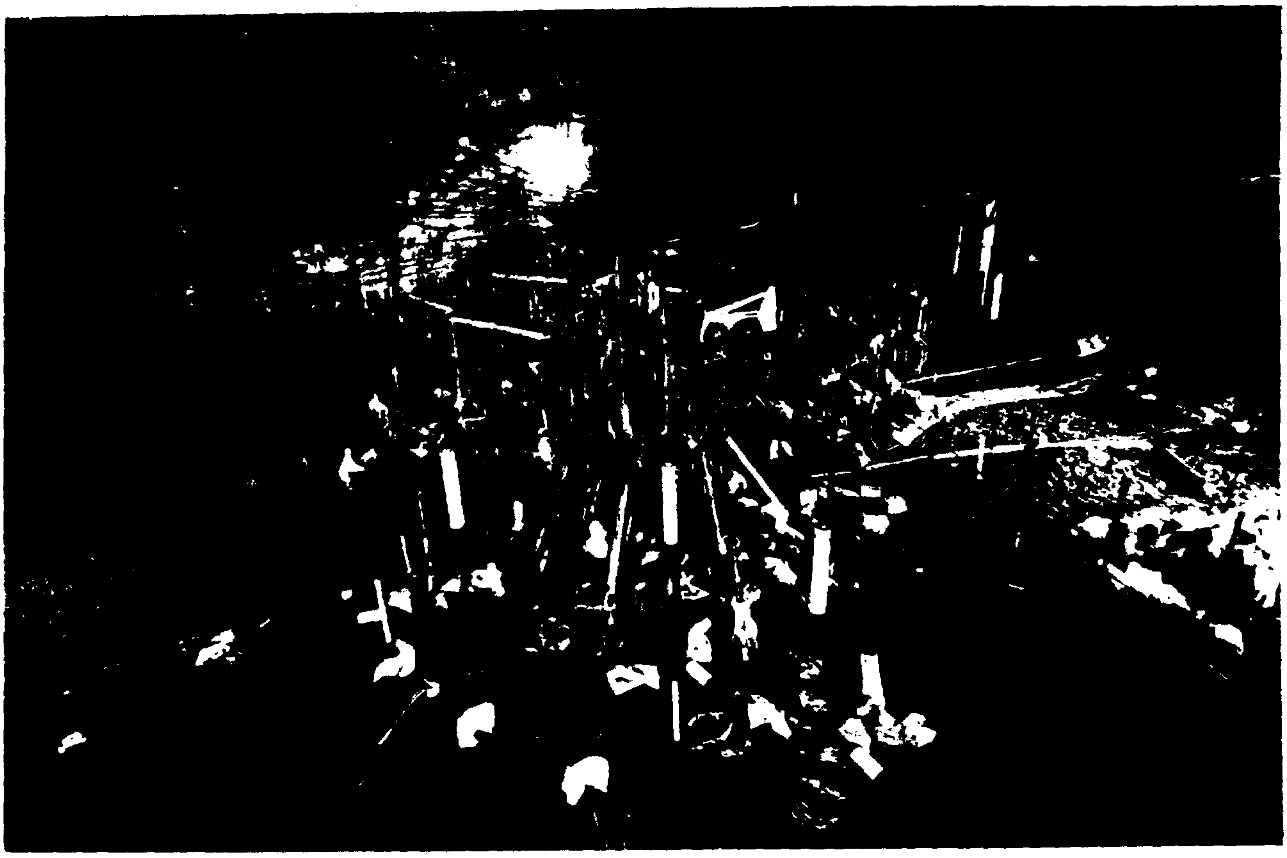


*Photo credit: Defense Nuclear Agenc*

Tunnel Cavity

ing the proposed hole and review it for containment. The laboratory then presents the full containment plan to the Containment Evaluation Panel (CEP) 2 to 3 months in advance of the detonation. The CEP is a panel of experts that review and evaluate the containment plan for each test.[22] Each CEP panel member goes on record with a statement concerning his judgment of the containment. The CEP chairman summarizes the likelihood of containment and gives his recommendation to the manager of Nevada Operations.

Following the CEP meeting, a Detonation Authority Request (DAR) package is prepared. The DAR package contains a description of the proposed test, the containment plan, the recommendations of the CEP, the chairman's statement, a review of the environmental impact, a nuclear safety study,[23] a review of compliance with the TTBT, the public announcement plans, and any noteworthy aspects of the test. The DAR package is sent to the DOE Office of Military Application for approval. Although test preparations are underway throughout the approval process, no irreversible action to conduct the test is taken prior to final approval.

After the test has been approved, the Test Group Director of the sponsoring Laboratory will then request "authority to move, emplace, and stem" the nuclear device from the Nevada test site "Test Controller" for that specific test. The Test Controller also has an advisory panel consisting of a Chairman and three other members. The Chairman (called the Scientific Advisor) is a senior scientis

[22]See Ch. 3, "Containment Evaluation Panel."

[23]The nuclear safety study prepared by DOE Safety Division contains safety considerations not related to containment, such as the possibility of premature or inadvertent detonation.

[24]In the case of tests sponsored by the Defense Nuclear Agency (DNA), the Scientific Advisor is from Sandia National Laboratory.

from the sponsoring laboratory.[24] The three members are all knowledgeable about the weapons-testing program and consist of:

1. an EPA senior scientist with expertise in radiation monitoring,
2. a weather service senior scientist knowledgeable in meteorology, and
3. a medical doctor with expertise in radiation medicine.

Once the test has been approved for execution by the Test Controller's panel, the Test Controller has sole responsibility to determine when or whether the test will be conducted. The Test Controller and Advisory Panel members conduct the following series of technical meetings to review the test:[25]

*D-7 Safety Planning Meeting*: The "D-7 Safety Planning Meeting" is held approximately 1 week before the test. This meeting is an informal review of the test procedure, the containment plan, the expected yield, the maximum credible yield, the potential for surface collapse, the potential ground shock, the expected long-range weather conditions, the location of radiation monitors, the location of all personnel, the security concerns (including the possibility of protesters intruding on the test site), the countdown, the pre-announcement policy, and any other operational or safety aspects related to the test.

*D-1 Safety Planning Meeting*: The day before the test, the D-1 Safety Planning Meeting is held. This is an informal briefing that reviews and updates all the information discussed at the D-7 meeting.

*D-1 Containment Briefing*: The D-1 Containment Briefing is a formal meeting. The laboratory reviews again the containment plan and discusses whether all of the stemming and other containment requirements were met. The meeting determines the extent to which the proposed containment plan was carried out in the field.[26] The laboratory and contractors provide written statements on their concurrence of the stemming plan.

*D-1 Readiness Briefing*: The D-1 Readiness Briefing is a formal meeting to review potential weather conditions and the predicted radiation fallout pattern for the case of an accidental venting.

The night before the test, the weather service sends out observers to release weather balloons and begin measuring wind direction and speed to a height of 1,400 ft above the ground. The area around the test (usually all areas north of the Control Point complex) is closed to all nonessential personnel. The Environmental Protection Agency deploys monitoring personnel off-site to monitor fallout and coordinate protective measures, should they be necessary.

*D-Day Readiness Briefing*: The morning of the test, the Test Controller holds the "D-Day Readiness Briefing." At this meeting, updates of weather conditions and forecasts are presented. In additon, the weather service reviews the wind and stability measurements to make final revisions to the fallout pattern in the event of an accidental venting. The fallout pattern is used to project exposure rates throughout the potential affected area. The exposure rates are calculated using the standard radiological models of whole-body exposure and infant thyroid dose from a family using milk cows in the fallout region. The status of on-site ground-based and airborne radiation monitoring is reviewed. The location of EPA monitoring personnel is adjusted to the projected fallout pattern, and the location of all personnel on the test site is confirmed. At the end of the meeting, the Scientific Advisor who is chairman of the Test Controller's Advisory Panel makes a recommendation to the Test Controller to proceed or delay.

If the decision is made to proceed, the Test Controller gives permission for the nuclear device to be armed. The operation of all radiation monitors, readiness of aircraft, location of EPA personnel, etc., are confirmed. If the status remains favorable and the weather conditions are acceptable, the Test Controller gives permission to start the countdown and to fire. If nothing abnormal occurs, the countdown proceeds to detonation. If a delay occurs, the appropriate preparatory meetings are repeated.

---

[24] In the case of tests sponsored by the Defense Nuclear Agency (DNA), the Scientific Advisor is from Sandia National Laboratory.

[25] Although the test has been planned to be contained, test preparations include provisions for an accidental release of radioactive material. Such provisions include the deployment of an emergency response team for each test.

[26] For example, readings from temperature sensors placed in the stemming plugs are examined to determine whether the plugs have hardened.

Photo credit: Department of Energy

Test Control Center

Chapter 3

# Containing Underground Nuclear Explosions

# CONTENTS



## *Box*



## *Figures*



## *Table*

Chapte

# Containing Underground Nuclear Explosic

*Underground nuclear tests are designed and reviewed for containment, with redundancy an conservatism in each step.*

## INTRODUCTION

The United States' first underground nuclear test, codenamed "Pascal-A," was detonated at the bottom of a 499-foot open drill-hole on July 26, 1957.[1] Although Pascal-A marked the beginning of underground testing, above ground testing continued for another 6 years. With testing simultaneously occurring aboveground, the release of radioactive material from underground explosions was at first not a major concern. Consequently, Pascal-A, like many of the early underground tests that were to follow, was conducted "roman candle" style in an open shaft that allowed venting.[2]

As public sensitivity to fallout increased, guidelines for testing in Nevada became more stringent. In 1956, the weapons laboratories pursued efforts to reduce fallout by using the lowest possible test yields, by applying reduced fission yield or clean technology, and by containing explosions underground. Of these approaches, only underground testing offered hope for eliminating fallout. The objective was to contain the radioactive material, yet still collect all required information. The first experiment designed to contain an explosion completely underground was the "Rainier" test, which was detonated on September 19, 1957. A nuclear device with a known yield of 1.7 kilotons was selected for the test. The test was designed with two objectives: 1) to prevent the release of radioactivity to the atmosphere, and 2) to determine whether diagnostic information could be obtained from an underground test. The test was successful in both objectives. Five more tests were conducted the following year to confirm the adequacy of such testing for nuclear weapons development.

In November 1958, public concern over radioactive fallout brought about a nuclear testing moratorium that lasted nearly 3 years. After the United States resumed testing in September, 1961, almost all testing in Nevada was done underground, while atmospheric testing was conducted in the Chris Island and Johnston Island area of the Pacific. I 1961 through 1963, many of the underground vented radioactive material. The amounts small, however, in comparison to releases aboveground testing also occurring at that tim

With the success of the Rainier test, efforts made to understand the basic phenomenolo contained underground explosions. Field e included tunneling into the radioactive zone, la tory measurements, and theoretical work to r the containment process. Through additional experience was gained in tunnel-stemming esses and the effects of changing yields. The attempts to explain the physical reason why u ground nuclear explosions do not always fr rock to the surface did little more than postula hypothetical existence of a "mystical magical brane." In fact, it took more than a deca underground testing before theories for the ph basis for containment were developed.

In 1963, U.S. atmospheric testing ended wh United States signed the Limited Test Ban prohibiting nuclear test explosions in any en ment other than underground. The treaty prohibits any explosion that:

> . . . causes radioactive debris to be present out the territorial limits of the State under w jurisdiction or control such explosion is conduc

With the venting of radioactive debris underground explosions restricted by treaty tainment techniques improved. Although man tests continued to produce accidental relea radioactive material, most releases were only able within the boundaries of the Nevada Te In 1970, however, a test codenamed "Bane resulted in a prompt, massive venting. Radic material from Baneberry was tracked as far Canadian border and focused concern about b environmental safety and the treaty complia

[1]The first underground test was the United States' 100th nuclear explosion.

[2]It is interesting to note that even with an open shaft, 90% of the fission products created by Pascal-A were contained underground.

[3]Article I.1(b). 1963 Limited Test Ban Treaty

the testing program.[4] Testing was suspended for 7 months while a detailed examination of testing practices was conducted by the Atomic Energy Commission. The examination resulted in new testing procedures and specific recommendations for review of test containment. The procedures initiated as a consequence of Baneberry are the basis of present-day testing practices.

Today, safety is an overriding concern throughout every step in the planning and execution of an underground nuclear test. Underground nuclear test explosions are designed to be contained, reviewed for containment, and conducted to minimize even the most remote chance of an accidental release of radioactive material. Each step of the testing authorization procedure is concerned with safety; and conservatism and redundancy are built into the system.[5]

## WHAT HAPPENS DURING AN UNDERGROUND NUCLEAR EXPLOSION

The detonation of a nuclear explosion underground creates phenomena that occur within the following time frames:

### *Microseconds*

Within a microsecond (one-millionth of a second), the billions of atoms involved in a nuclear explosion release their energy. Pressures within the exploding nuclear weapon reach several million pounds per square inch; and temperatures are as high as 100 million degrees Centigrade. A strong shock wave is created by the explosion and moves outward from the point of detonation.

### *Milliseconds*

Within tens of milliseconds (thousandths of a second), the metal canister and surrounding rock are vaporized, creating a bubble of high pressure steam and gas. A cavity is then formed both by the pressure of the gas bubble and by the explosive momentum imparted to the surrounding rock.

### *Tenths of a Second*

As the cavity continues to expand, the internal pressure decreases. Within a few tenths of a second, the pressure has dropped to a level roughly comparable to the weight of the overlying rock. At this point, the cavity has reached its largest size and can no longer grow.[6] Meanwhile, the shock wave created by the explosion has traveled outward from the cavity, crushing and fracturing rock. Eventually, the shock wave weakens to the point where the rock is no longer crushed, but is merely compressed and then returns to its original state. This compression and relaxation phase becomes seismic waves that travel through the Earth in the same manner as seismic waves formed by an earthquake.

### *A Few Seconds*

After a few seconds, the molten rock begins to collect and solidify in a puddle at the bottom of the cavity.[7] Eventually, cooling causes the gas pressure within the cavity to decrease.

### *Minutes to Days*

When the gas pressure in the cavity declines to the point where it is no longer able to support the overlying rock, the cavity may collapse. The collapse occurs as overlying rock breaks into rubble and falls into the cavity void. As the process continues, the void region moves upward as rubble falls downward. The "chimneying" continues until:

- the void volume within the chimney completely fills with loose rubble,
- the chimney reaches a level where the shape of the void region and the strength of the rock can support the overburden material, or
- the chimney reaches the surface.

If the chimney reaches the surface, the ground sinks forming a saucer-like subsidence crater. Cavity collapse and chimney formation typically occur within a few hours of the detonation but sometimes take days or months.

[4]See for example, Bruce A. Bolt, *Nuclear Explosions and Earthquakes* San Francisco, CA. (W.H. Freeman & Co., 1976).

[5]See "Detonation Authority and Procedures" (ch. 2).

[6]See the next section, "How explosions remain contained," for a detailed explanation of cavity formation.

[7]The solidified rock contains most of the radioactive products from the explosion. The performance of the nuclear weapon is analyzed when samples of this material are recovered by drilling back into the cavity.

### Box 3-A—Baneberry

The exact cause of the 1970 Baneberry venting still remains a mystery. The original explanation postu the existence of an undetected water table. It assumed that the high temperatures of the explosion produced s that vented to the surface. Later analysis, however, discredited this explanation and proposed an alternative sce based on three geologic features of the Baneberry site: water-saturated clay, a buried scarp of hard rock, and a n fault. It is thought that the weak, water-saturated clay was unable to support the containment structure; the hard strongly reflected back the energy of the explosion increasing its force; and the nearby fault provided a pat that gases could travel along. All three of these features seem to have contributed to the venting. Whatever its c the Baneberry venting increased attention on containment and, in doing so, marked the beginning of the presen containment practices.

Photo credit: Department o

The venting of Baneberry, 1970.

Photo credit: Harold E. Edgerton

Early phase of fireball from nuclear explosion.

## WHY NUCLEAR EXPLOSIONS REMAIN CONTAINED

Radioactive material produced by a nuclear explosion remains underground due to the combined efforts of:

- the sealing nature of compressed rock around the cavity,
- the porosity of the rock,
- the depth of burial,
- the strength of the rock, and
- the stemming of the emplacement hole.

**Counter to intuition, only minimal rock strength is required for containment.**

At first, the explosion creates a pressurized cavity filled with gas that is mostly steam. As the cavity pushes outward, the surrounding rock is compressed (figure 3-1(a)). Because there is essentially a fixed quantity of gas within the cavity, the pressure decreases as the cavity expands. Eventually the pressure drops below the level required to deform the surrounding material (figure 3-1(b)). Meanwhile, the shock wave has imparted outward motion to the material around the cavity. Once the shock wave has passed, however, the material tries to return (rebound) to its original position (f
3-1(c)). The rebound creates a large compre
stress field, called a stress "containment c
around the cavity (figure 3-1(d)). The physics
stress containment cage is somewhat analogo
how stone archways support themselves. In the
of a stone archway, the weight of each stone p
against the others and supports the archway.
case of an underground explosion, the rebou
rock locks around the cavity forming a stress
that is stronger than the pressure inside the c
The stress "containment cage" closes any frac
that may have begun and prevents new frac
from forming.

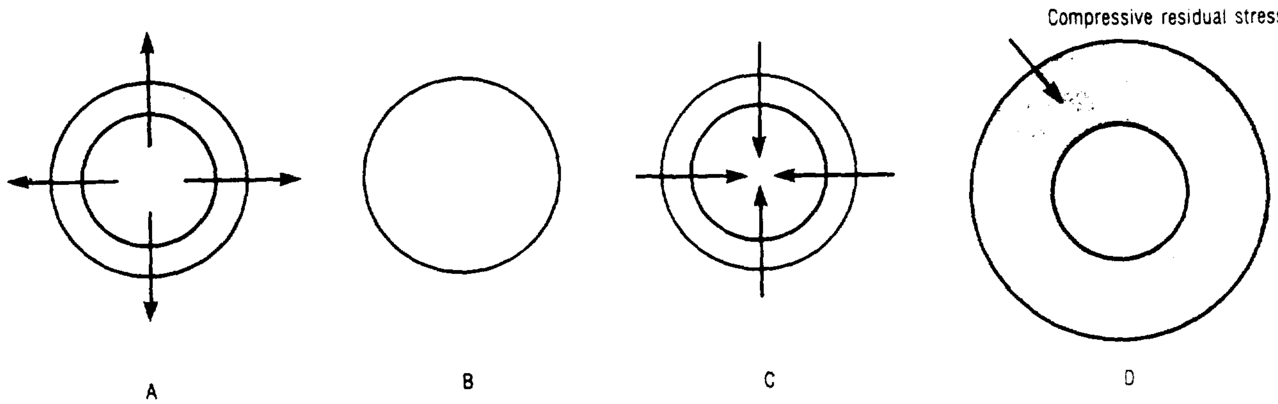
The predominantly steam-filled cavity even
collapses forming a chimney. When collapse o
the steam in the cavity is condensed through c
with the cold rock falling into the cavity
noncondensible gases remain within the
chimney at low pressure. Once collapse o
high-pressure steam is no longer present to
gases from the cavity region to the surface.

If the test is conducted in porous material, s
alluvium or tuff, the porosity of the mediun
provide volume to absorb gases produced b
explosion. For example, all of the steam gen
by a 150 kiloton explosion beneath the wate
can be contained in a condensed state with
volume of pore space that exists in a hemisph
pile of alluvium 200 to 300 feet high. Althoug
steam condenses before leaving the cavity r
the porosity helps to contain noncondensible
such as carbon dioxide ($CO_2$) and hydrogen
The gas diffuses into the interconnected pore
and the pressure is reduced to a level that is to
to drive the fractures. The deep water table an
porosity of rocks at the Nevada Test Site fac
containment.

Containment also occurs because of the pr
of overlying rock. The depth of burial prov
stress that limits fracture growth. For exampl
fracture initiated from the cavity grows, gas
from the fracture into the surrounding ma
Eventually, the pressure within the fractu
creases below what is needed to extend the fr
At this point, growth of the fracture stops and
simply leaks into the surrounding material.

Rock strength is also an important asp
containment, but only in the sense that an ext
weak rock (such as water-saturated clay)

**Figure 3-1—Formation of Stress "Containment Cage"**




1) Cavity expands outward and deforms surrounding rock. 2) Natural resistance to deformation stops expansion. 3) Cavity contracts (rebounds) from elastic unloading of distant rock. 4) Rebound locks in compressive residual stress around cavity.

SOURCE: Modified from Lawrence Livermore National Laboratory.

support a stress containment cage. Detonation within weak, saturated clay is thought to have been a factor in the release of the Baneberry test. As a result, sites containing large amounts of water-saturated clay are now avoided.

The final aspect of containment is the stemming that is put in a vertical hole after the nuclear device has been emplaced. Stemming is designed to prevent gas from traveling up the emplacement hole. Impermeable plugs, located at various distances along the stemming column, force the gases into the surrounding rock where it is "sponged up" in the pore spaces.

How the various containment features perform depends on many variables: the size of the explosion, the depth of burial, the water content of the rock, the geologic structure, etc. Problems may occur when the containment cage does not form completely and gas from the cavity flows either through the emplacement hole or the overburden material.[8] When the cavity collapses, the steam condenses and only noncondensible gases such as carbon dioxide ($CO_2$) and hydrogen ($H_2$) remain in the cavity.[9] The $CO_2$ and $H_2$ remain in the chimney if there is available pore space. If the quantity of noncondensible gases is large, however, they can act as a driving force to transport radioactivity through the chimney or the overlying rock. Consequently the amount of carbonate material and water in the rock near the explosion and the amount of iron available for reaction are considered when evaluating containment.[10]

## SELECTING LOCATION, DEPTH, AND SPACING

The site for conducting a nuclear test is, at first selected only on a tentative basis. The final decision is made after various site characteristics have been reviewed. The location, depth of burial, and spacing are based on the maximum expected yield for the nuclear device, the required geometry of the test, and the practical considerations of scheduling, convenience, and available holes. If none of the inventory holes are suitable, a site is selected and a hole drilled.[11]

The first scale for determining how deep a explosion should be buried was derived from the Rainier test in 1957. The depth, based on the cube root of the yield, was originally:

$$\text{Depth} = 300\,(\text{yield})^{1/3}$$

where depth was measured in feet and yield i

[8]Lack of a stress "containment cage" may not be a serious problem if the medium is sufficently porous or if the depth of burial is sufficent

[9]The $CO_2$ is formed from the vaporization of carbonate material; while the $H_2$ is formed when water reacts with the iron in the nuclear device ar diagnostics equipment.

[10]The carbonate material in Frenchman Flat created $CO_2$ that is thought to have caused a seep during the Diagonal Line test (Nov. 24, 1971) Diagon Line was the last test on Frenchman Flat; the area is currently considered impractical for underground testing largely because of the carbonate materi

[11]See ch. 2, "The Nevada Test Site," for a description of the areas each Laboratory uses for testing.

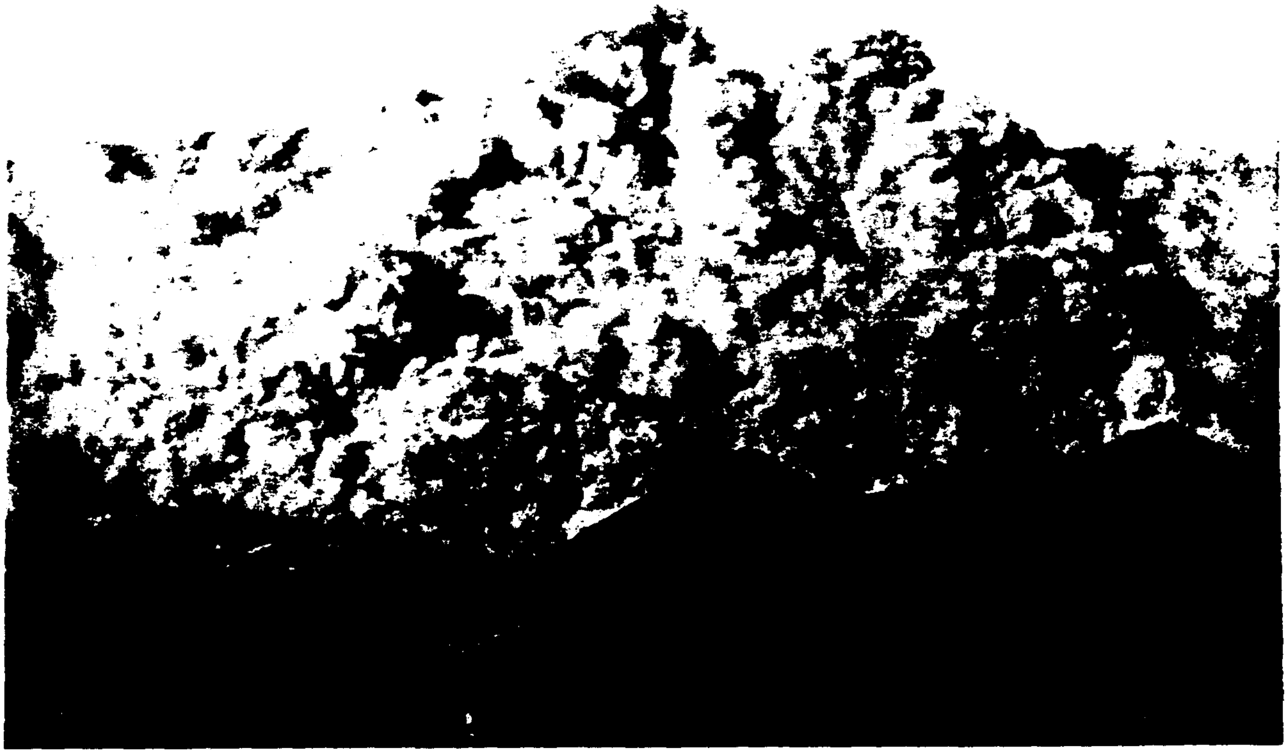


*Photo credit: Department of Energy*

Blanca containment failure, 1958.

kilotons. The first few tests after Rainier, however, were detonated at greater depths than this formula requires because it was more convenient to mine tunnels deeper in the Mesa. It was not until "Blanca," October 30, 1958, that a test was conducted exactly at 300 (yield)$^{1/3}$ feet to test the depth scale. The containment of the Blanca explosion, however, was unsuccessful and resulted in a surface venting of radioactive material. As a consequence, the depth scale was modified to include the addition of a few hundred feet as a safety factor and thus became: 300 (yield)$^{1/3}$ "plus-a-few-hundred-feet."

Today, the general depth of burial can be approximated by the equation:

$$\text{Depth} = 400\ (\text{yield})^{1/3},$$

where depth is measured in feet and yield in kilotons.[12] The minimum depth of burial, however, is 600 feet.[13] Consequently, depths of burial vary from 600 feet for a low-yield device, to about 2,100 feet for a large-yield test. The depth is scaled to the

[12] "Public Safety for Nuclear Weapons Tests," United States Environmental Protection Agency, January, 1984.

[13] The 600-foot depth was chosen as a minimum after a statistical study showed that the likelihood of a seep of radioactive material to the surface for explosions buried 600 feet or more was about 1/2 as great as for explosions at less than 500 feet, even if they were buried at the same scale depth in each case.

"maximum credible yield" that the nuclear device is thought physically capable of producing, not to the design yield or most likely yield.[14]

Whether a test will be conducted on Pahute Mesa or Yucca Flat depends on the maximum credible yield. Yucca Flat is closer to support facilities and therefore more convenient, while the deep water table at Pahute Mesa is more economical for large yield tests that need deep, large diameter emplacement holes. Large yield tests in small diameter holes (less than 7 feet) can be conducted in Yucca Flat. A test area may also be chosen to avoid scheduling conflicts that might result in a test damaging the hole or diagnostic equipment of another nearby test. Once the area has been chosen, several candidate sites are selected based on such features as: proximity to previous tests or existing drill holes; geologic features such as faults, depth to basement rock, and the presence of clays or carbonate materials; and practical considerations such as proximity to power lines, roads, etc.

In areas well suited for testing, an additional site selection restriction is the proximity to previous tests. For vertical drill hole tests, the minimum shot separation distance is about one-half the depth of burial for the new shot (figure 3-2). For shallow shots, this separation distance allows tests to be spaced so close together that in some cases, the surface collapse craters coalesce. The ½ depth of burial distance is a convention of convenience, rather than a criteron for containment.[15] It is, for example, difficult to safely place a drilling rig too close to an existing collapse crater.

Horizontal tunnel tests are generally spaced with a minimum shot separation distance of twice the combined cavity radius plus 100 feet, measured from the point of detonation (called the "working point") (figure 3-3). In other words, two tests with 100 foot radius cavities would be separated by 300 feet between cavities, or 500 feet (center to center). The size of a cavity formed by an explosion is proportional to the cube root of the yield and can be estimated by:

$$\text{Radius} = 55\ (\text{yield})^{1/3},$$

where the radius is measured in feet and the yield in kilotons. For example, an 8 kiloton explosion wo be expected to produce an underground cavity approximately a 110 foot radius. Two such explosions would require a minimum separa distance of 320 feet between cavities or 540 between working points.

Occasionally, a hole or tunnel is found tc unsuitable for the proposed test. Such a situat however, is rare, occurring at a rate of about 1 o 25 for a drill hole test and about 1 out of 15 f tunnel test.[16] Usually, a particular hole that is fc unacceptable for one test can be used for another at a lower yield.

## REVIEWING A TEST SITE LOCATION

Once the general parameters for a drill-hole been selected, the sponsoring laboratory reque pre-drill Geologic Data Summary (GDS) from U.S. Geological Survey. The GDS is a geol interpretation of the area that reviews the three t elements: the structures, the rock type, and the v content. The U.S. Geological Survey looks features that have caused containment problen the past. Of particular concern is the presence o faults that might become pathways for the relea radioactive material, and the close location of basement rock that may reflect the energy create the explosion. Review of the rock type check features such as clay content which would ind a weak area where it may be difficult for the hc remain intact, and the presence of carbonate that could produce $CO_2$. Water content is reviewed to predict the amount of steam and H might be produced. If the geology indicates less ideal conditions, alternate locations may be gested that vary from less than a few hundrec from the proposed site to an entirely different a the test site.

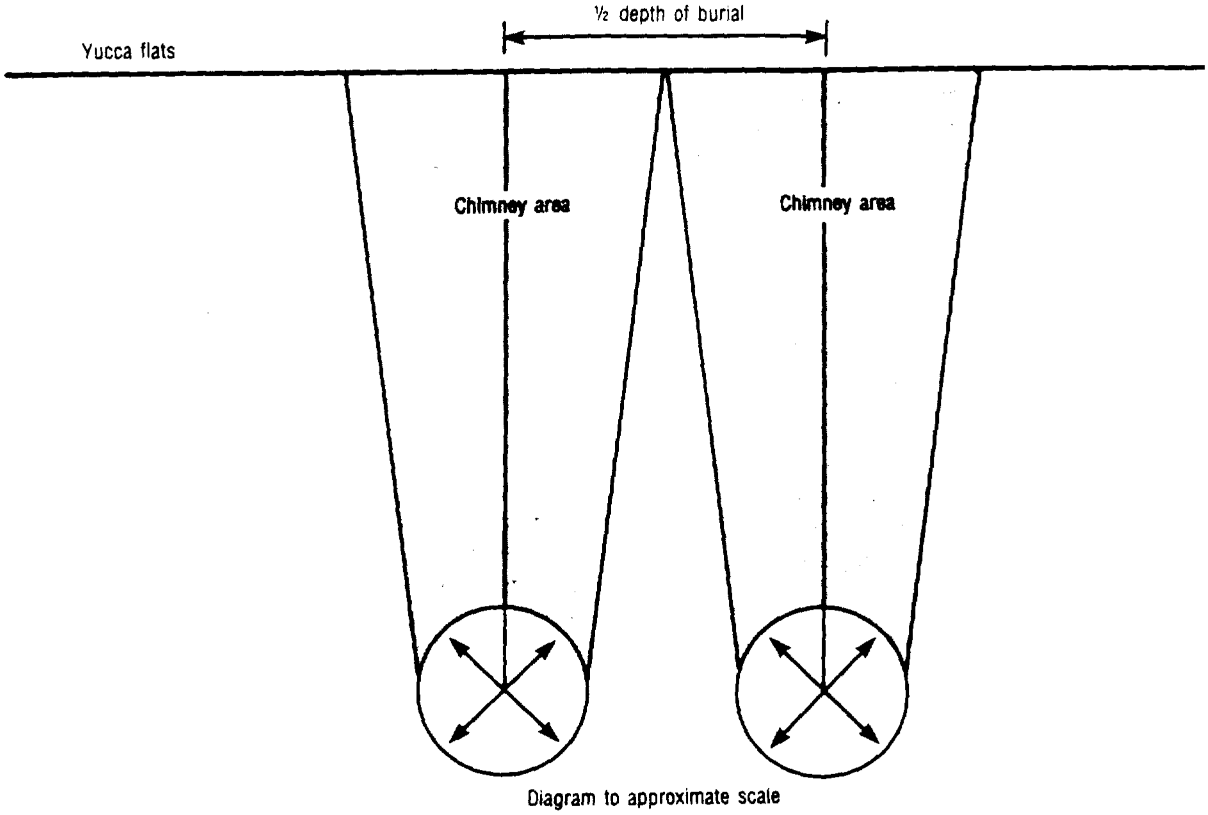
When the final site location is drilled, dat collected and evaluated by the sponsoring la tory. Samples and geophysical logs, including d hole photography, are collected and analyzed U.S. Geological Survey reviews the data, co with the laboratory throughout the process reviews the accuracy of the geologic interpreta

[14] In many cases the maximum credible yield is significantly larger than the expected yield for a nuclear device.

[15] As discussed later, testing in previously fractured rock is not considered a containment risk in most instances.

[16] On three occasions tunnels have been abandoned because of unanticipated conditions such as the discovery of a fault or the presence of to water.

**Figure 3-2—Minimum Shot Separation for Drill Hole Tests**




Scale illustration of the minimum separation distance (1/2 depth of burial) for vertical drill hole tests. The depth of burial is based on the maximum credible yield.

SOURCE: Office of Technology Assessment, 1989

To confirm the accuracy of the geologic description and review and evaluate containment considerations, the Survey also attends the host laboratory's site proposal presentation to the Containment Evaluation Panel.

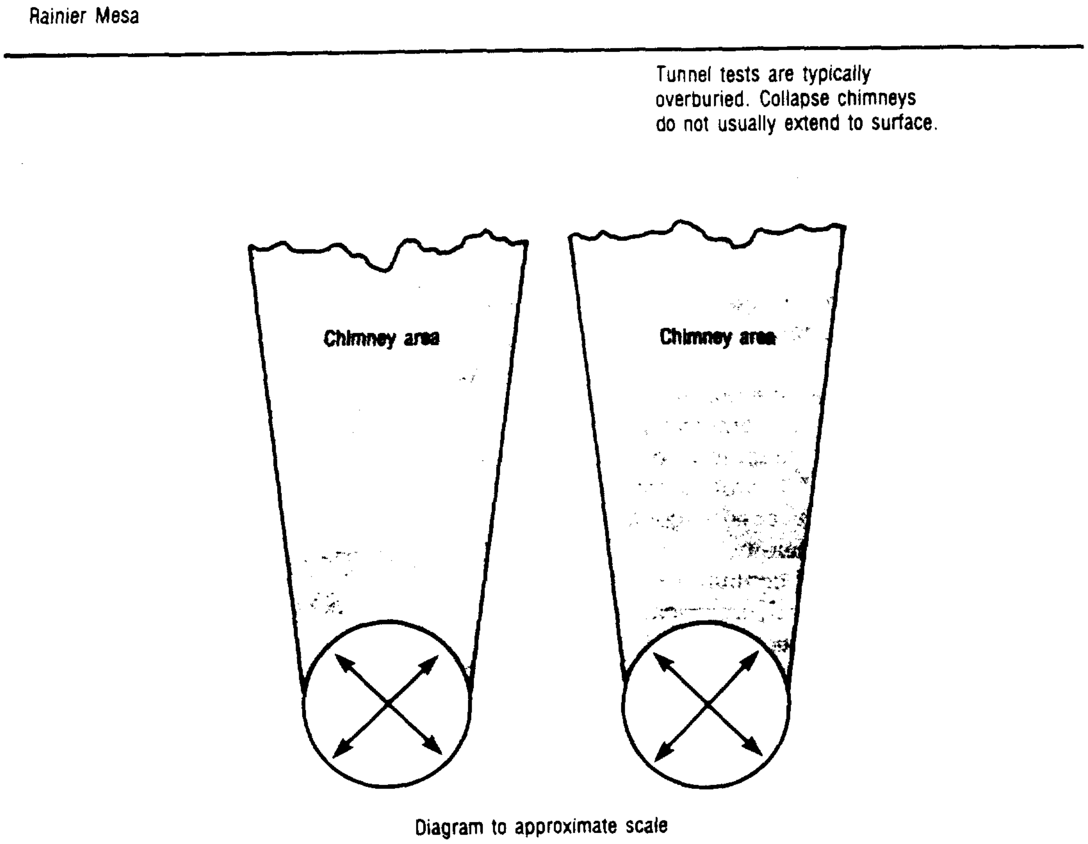
## CONTAINMENT EVALUATION PANEL

One consequence of the Baneberry review was the restructuring of what was then called the Test Evaluation Panel. The panel was reorganized and new members with a wider range of geologic and hydrologic expertise were added. The new panel was named, the Containment Evaluation Panel (CEP); and their first meeting was held in March, 1971.

The Containment Evaluation Panel presently consists of a Chairman and up to 11 panel members. Six of the panel members are representatives fron Lawrence Livermore National Laboratory, Los Alamo National Laboratory, Defense Nuclear Agency, San dia National Laboratory, U.S. Geological Survey and the Desert Research Institute. An additional 3 t 5 members are also included for their expertise i disciplines related to containment. The chairman c the panel is appointed by the Manager of Nevad Operations (Department of Energy), and pane members are nominated by the member institutio with the concurrence of the chairman and approv of the Manager. The panel reports to the Manager c Nevada Operations.

Practices of the Containment Evaluation Pan have evolved throughout the past 18 years; howeve their purpose, as described by the Containmer

**Figure 3-3—Minimum Shot Separation for Tunnel Tests**




Scale illustration of the minimum separation distance (2 combined cavity radii plus 100 feet) for horizontal tunnel tests. Tunnel tests are typically overburied. Collapse chimneys do not usually extend to the surface.

SOURCE: Office of Technology Assessment, 1989

Evaluation Charter, remains specifically defined as follows:[17]

1. evaluate, as an independent organization reporting to the Manager of Nevada Operations, the containment design of each proposed nuclear test;
2. assure that all relevant data available for proper evaluation are considered;
3. advise the manager of Nevada Operations of the technical adequacy of such design from the viewpoint of containment, thus providing the manager a basis on which to request detonation authority; and
4. maintain a historical record of each evaluation and of the data, proceedings, and discussions pertaining thereto.

Although the CEP is charged with rendering a judgment as to the adequacy of the design of the containment, the panel does not vote. Each member provides his independent judgment as to the prospect of containment, usually addressing his own area of expertise but free to comment on any aspect of the test. The Chairman is in charge of summarizing these statements in a recommendation to the manager on whether to proceed with the test, based only on the containment aspects. Containment Evaluation Panel guidelines instruct members to make their judgments in such a way that:

[17] Containment Evaluation Charter, June 1, 1986, Section II.

> Considerations of cost, schedules, and test objectives shall not enter into the review of the technical adequacy of any test from the viewpoint of containment.[18]

Along with their judgments on containment, each panel member evaluates the probability of containment using the following four categories:[19]

1. *Category A*: Considering all containment features and appropriate historical, empirical, and analytical data, the best judgment of the member indicates a high confidence in successful containment as defined in VIII.F. below.
2. *Category B*: Considering all containment features and appropriate historical, empirical, and analytical data, the best judgment of the member indicates a less, but still adequate, degree of confidence in successful containment as defined in VIII.F. below.
3. *Category C*: Considering all containment features and appropriate historical, empirical, and analytical data, the best judgment of the member indicates some doubt that successful containment, as described in VIII.F. below, will be achieved.
4. *Unable to Categorize*

Successful containment is defined for the CEP as:

> . . . no radioactivity detectable off-site as measured by normal monitoring equipment and no unanticipated release of activity on-site.

The Containment Evaluation Panel does not have the direct authority to prevent a test from being conducted. Their judgment, both as individuals and as summarized by the Chairman, is presented to the Manager. The Manager makes the decision as to whether a Detonation Authority Request will be made. The statements and categorization from each CEP member are included as part of the permanent Detonation Authority Request.

Although the panel only advises the Manager, it would be unlikely for the Manager to request detonation if the request included a judgment by the CEP that the explosion might not be contained. The record indicates the influence of the CEP. Since formation of the panel in 1970, there has never been a Detonation Authority Request submitted for approval with a containment plan that received a "C" ("some doubt") categorization from even one member.[20 21]

The Containment Evaluation Panel serves an additional role in improving containment as a consequence of their meetings. The discussions of the CEP provide an ongoing forum for technical discussions of containment concepts and practices. As a consequence, general improvements to containment design have evolved through the panel discussions and debate.

## CONTAINING VERTICAL SHAFT TESTS

Once a hole has been selected and reviewed, a stemming plan is made for the individual hole. The stemming plan is usually formulated by adapting previously successful stemming plans to the particularities of a given hole. The objective of the plan is to prevent the emplacement hole from being the path of least resistance for the flow of radioactive material. In doing so, the stemming plan must take into account the possibility of only a partial collapse: if the chimney collapse extends only half way to the surface, the stemming above the collapse must remain intact.

Lowering the nuclear device with the diagnostics down the emplacement hole can take up to 5 days. A typical test will have between 50 and 250 diagnostic cables with diameters as great as $1^5/_8$ inches packaged in bundles through the stemming column. After the nuclear device is lowered into the emplacement hole, the stemming is installed. Figure 3-4 shows a typical stemming plan for a Lawrence

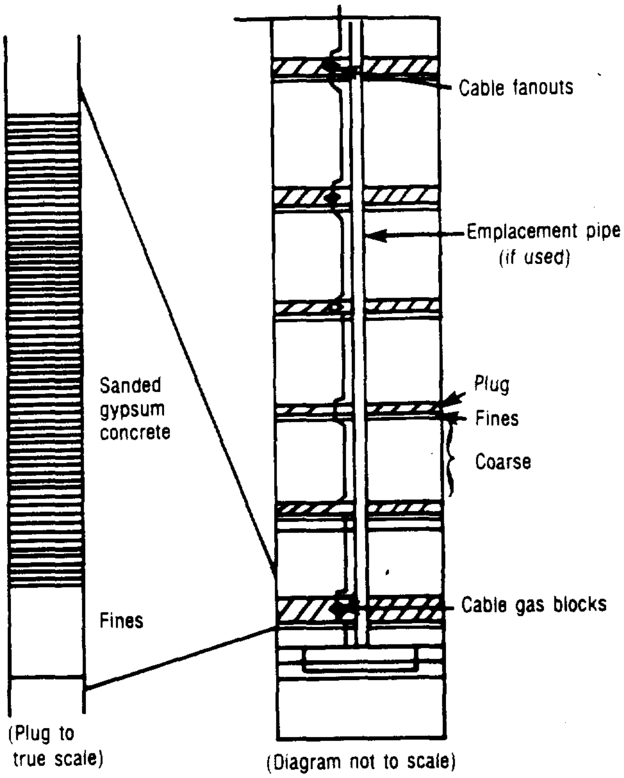
[18]Containment Evaluation Panel Charter, June 1, 1986, Section III.D.

[19]Containment Evaluation Panel Charter, June 1, 1986, Section VII.

[20]The grading system for containment plans has evolved since the early 1970's. Prior to April, 1977, the Containment Evaluation Panel categorized tests using the Roman numerals (I-IV) where I-III had about the same meaning as A-C and IV was a D which eventually was dropped as a letter and just became "unable to categorize."

[21]However, one shot (Mundo) was submitted with an "unable to categorize" categorization. Mundo was a joint US-UK test conducted on May 1, 1984.

**Figure 3-4—"Typical" Stemming Plan**




Typical stemming sequence of coarse material, fine material, and sanded gypsum plug used by Lawrence Livermore National Laboratory for vertical drill hole tests.

SOURCE: Modified from Lawrence Livermore National Laboratory.

Livermore test with six sanded gypsum concrete plugs.[22] The plugs have two purposes: 1) to impede gas flow, and 2) to serve as structural platforms that prevent the stemming from falling out if only a partial collapse occurs. Under each plug is a layer of sand-size fine material. The sand provides a base for the plug. Alternating between the plugs and the fines, coarse gravel is used to fill in the rest of the stemming. The typical repeating pattern used for stemming by Los ALamos, for example, is 50 feet of gravel, 10 feet of sand, and a plug.

All the diagnostic cables from the nuclear device are blocked to prevent gas from finding a pathway through the cables and traveling to the surface. Cable fan-out zones physically separate the cables at plugs so that the grout and fines can seal betwee Frequently, radiation detectors are installed plugs to monitor the post-shot flow of r through the stemming column.

## CONTAINING HORIZONT TUNNEL TESTS

The containment of a horizontal tunne different from the containment of a vertical c test because the experimental apparatus is i to be recovered. In most tests, the objecti allow direct radiation from a nuclear expl reach the experiment, but prevent the e debris and fission products from destro Therefore, the containment is designed tasks: 1) to prevent the uncontrolled re radioactive material into the atmosphere fo safety, and 2) to prevent explosive deb reaching the experimental test chamber.

Both types of horizontal tunnel tests (eff and cavity tests) use the same containment of three redundant containment "vessels" inside each other and are separated by plug 3-5).[23] Each vessel is designed to indep contain the nuclear explosion, even if t vessels fail. If, for example, gas leaks from into vessel II, vessel II has a volume large e that the resulting gas temperatures and would be well within the limits that the designed to withstand. The vessels are org follows:

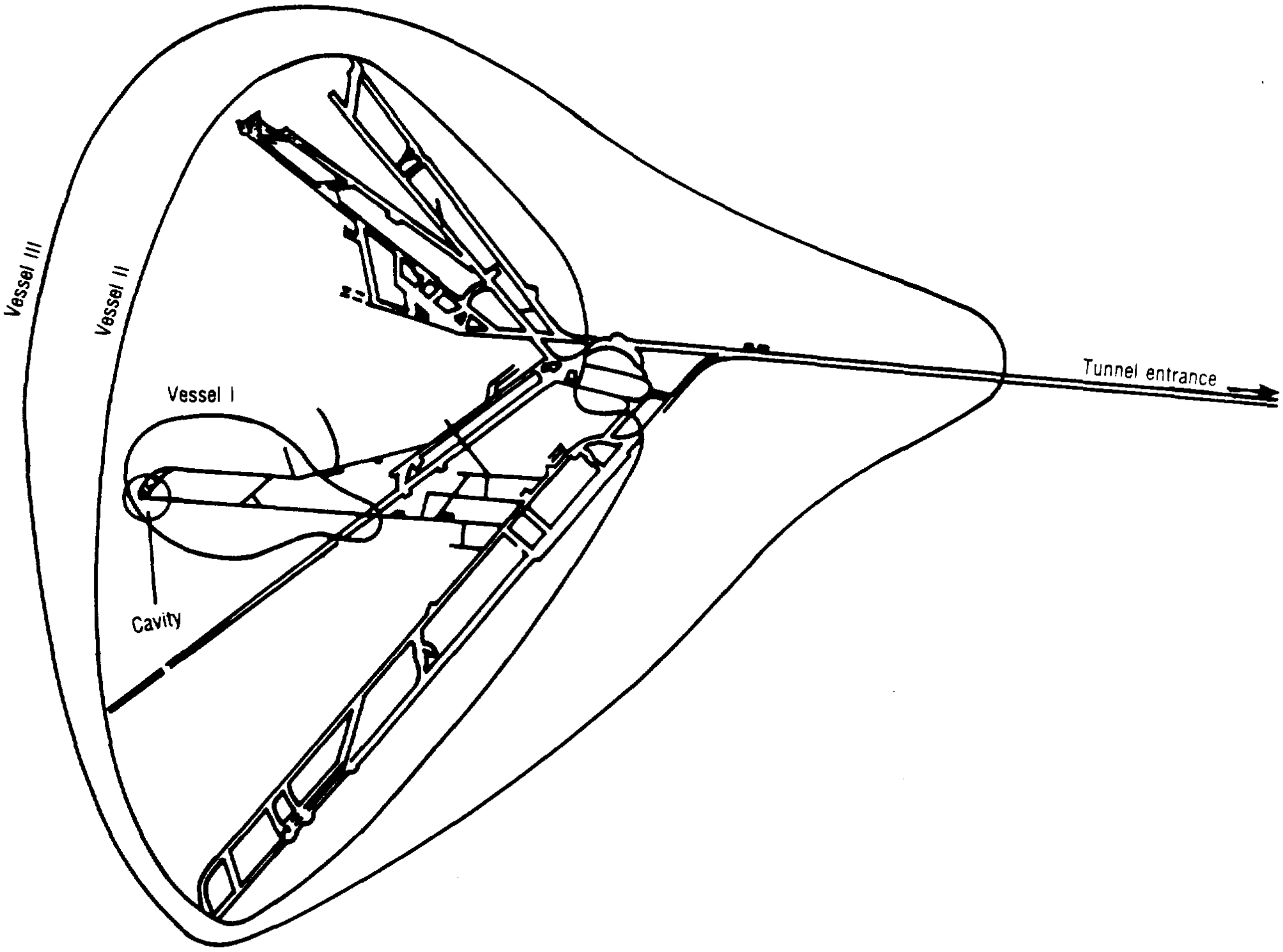
> Vessel I is designed to protect the experin preventing damage to the equipment and allo to be recovered.
>
> Vessel II is designed to protect the tunnel so that it can be reused even if vessel I fails experimental equipment is lost.
>
> Vessel III is designed purely for conta such that even if the experimental equipmen and the tunnel system contaminated, rad material will not escape to the atmosphere.

In addition to the three containment vess is a gas seal door at the entrance of the tunn that serves as an additional safety measure seal door is closed prior to detonation an

[22] Although Livermore and Los Alamos use the same general stemming philosophy, there are some differences: For example, Livermor gypsum concrete plugs while Los Alamos uses plugs made of epoxy. Also, Livermore uses an emplacement pipe for lowering the device do Los Alamos lowers the device and diagnostic cannister on a wire rope harness.

[23] See ch. 2 for a discussion of types of nuclear tests.

**Figure 3-5—Three Redundant Containment Vessels (Plan View)**




Three containment vessels for the Mighty Oak Test conducted in the T-Tunnel Complex.

SOURCE: Modified from Defense Nuclear Agency.

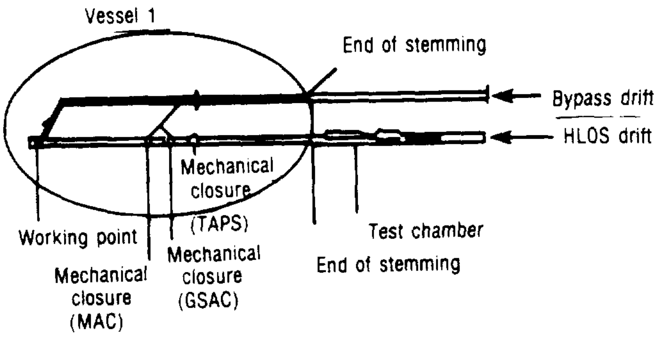
between it and the vessel III plug is pressurized to approximately 10 pounds per square inch.

The plugs that separate the vessels are constructed of high strength grout or concrete 10 to 30 feet thick. The sides of the vessel II plugs facing the working point are constructed of steel. Vessel II plugs are designed to withstand pressures up to 1,000 pounds per square inch and temperatures up to 1,000 °F. Vessel III plugs are constructed of massive concrete and are designed to withstand pressures up to 500 pounds per square inch and temperatures up to 500 °F.

Before each test, the tunnel system is checked for leaks. The entire system is closed off and pressurized to 2 pounds per square inch with a gas containing tracers in it. The surrounding area is then monitored for the presence of the tracer gas. Frequently, the chimney formed by the explosion is also subjected to a post-shot pressurization test to ensure that no radioactive material could leak through the chimney to the surface.

The structure of vessel I, as shown in figure 3-6, is designed to withstand the effects of ground shock and contain the pressure, temperatures, and radiation of the explosion. The nuclear explosive is located at the working point, also known as the "zero room." A long, tapered, horizontal line-of-sight (HLOS) pipe extends 1,000 feet or more from the working point to the test chamber where the experimental equipment is located. The diameter of the pipe may only be a few inches at the working point, but typically increases to about 10 feet before it reaches

**Figure 3-6—Vessel I**




Key: GSAC = gas seal auxiliary closure; MAC = modified auxiliary closure; TAPS = Tunnel and pipe seal

The HLOS Vessel I is designed to protect the experimental equipment after allowing radiation to travel down the pipe.

SOURCE: Modified from Defense Nuclear Agency.

the test chamber.[24] The entire pipe is vacuum pumped to simulate the conditions of space and to minimize the attenuation of radiation. The bypass drift (an access tunnel), located next to the line of sight pipe, is created to provide access to the closures and to different parts of the tunnel system. These drifts allow for the nuclear device to be placed in the zero room and for late-time emplacement of test equipment. After the device has been emplaced at the working point, the bypass drift is completely filled with grout. After the experiment, parts of the bypass drift will be reexcavated to permit access to the tunnel system to recover the pipe and experimental equipment.

The area around the HLOS pipe is also filled with grout, leaving only the HLOS pipe as a clear pathway between the explosion and the test chamber. Near the explosion, grout with properties similar to the surrounding rock is used so as not to interfere with the formation of the stress containment cage. Near the end of the pipe strong grout or concrete is used to support the pipe and closures. In between, the stemming is filled with super-lean grout designed to flow under moderate stress. The super-lean grout is designed to fill in and effectively plug any fractures that may form as the ground shock collapses the pipe and creates a stemming plug.

As illustrated in figure 3-6, the principal components of an HLOS pipe system include a working point room, a muffler, a modified auxiliary c (MAC), a gas seal auxiliary closure (GSAC), tunnel and pipe seal (TAPS). All these closu installed primarily to protect the experimental ment. The closures are designed to shut off th after the radiation created by the explosic traveled down to the test chamber, but material from the blast can fly down the pi destroy the equipment.

The working point room is a box desig house the nuclear device. The muffler is panded region of the HLOS pipe that is desig reduce flow down the pipe by allowing exp and creating turbulence and stagnation. The (figure 3-7(a)) is a heavy steel housing that c two 12-inch-thick forged-aluminum doors de to close openings up to 84 inches in diamet doors are installed opposite each other, perp lar to the pipe. The doors are shut by high p gas that is triggered at the time of deto Although the doors close completely withi seconds (overlapping so that each door f tunnel), in half that time they have met in the and obscure the pipe. The GSAC is simila MAC except that it is designed to provide a g closure. The TAPS closure weighs 40 tons design (figure 3-7(b)) resembles a large toil The door, which weighs up to 9 tons, is hinge top edge and held in the horizontal (open) p When the door is released, it swings down by and slams shut in about 0.75 seconds. Any p remaining in the pipe pushes on the door ma seal tighter. The MAC and GSAC will w pressures up to 10,000 pounds per square in TAPS is designed to withstand pressures up pounds per square inch, and temperature 1,000 °F.

When the explosion is detonated radiatio down the HLOS pipe at the speed of lig containment process (figure 3-8(a-e), trigger time of detonation, occurs in the following s to protect experimental equipment and radioactive material produced by the explos

- After 0.03 seconds (b), the cavity create explosion expands and the shock wav away from the working point and ap the MAC. The shock wave collapses the MAC. The shock wave collapses t squeezing it shut, and forms a st "plug." Both the MAC and the GSAC

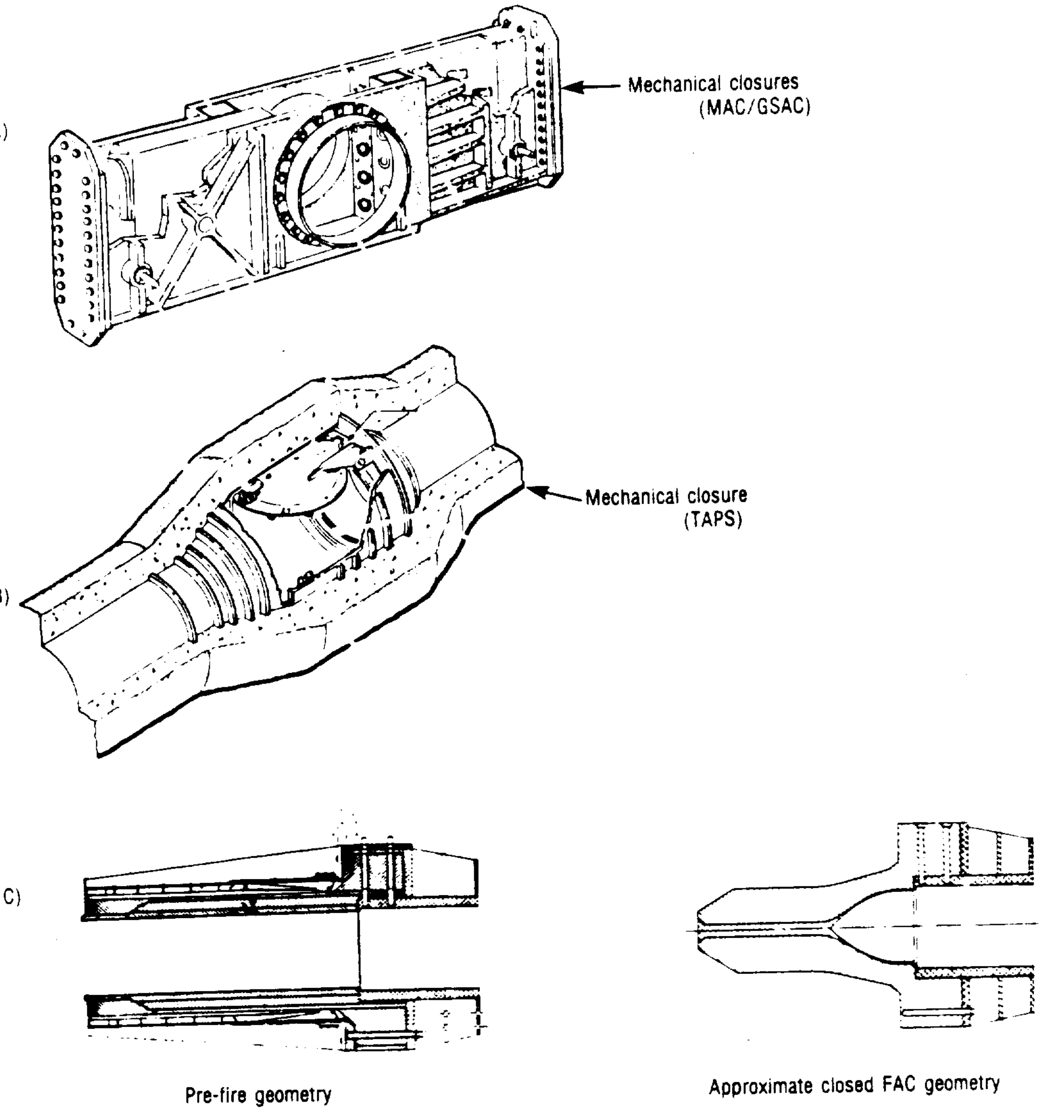
[24] On occasion, the diameter of the pipe has increased to 20 feet.

**Figure 3-7—Vessel I Closures**

A)

B)

C)



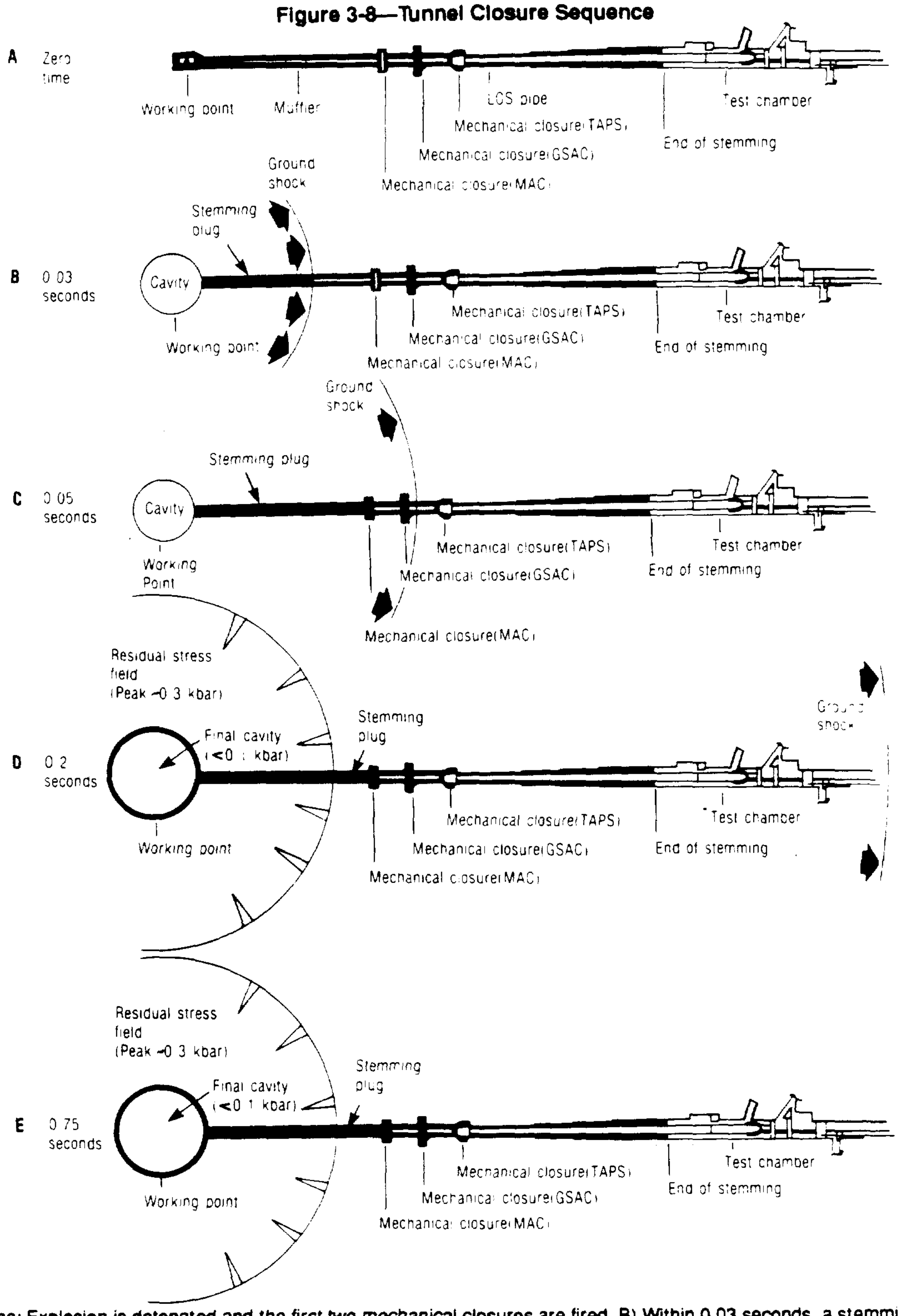

A) Mechanical Closures (MAC/GSAC)
B) Tunnel and Pipe Seal (TAPS)
C) Fast Acting Closure (FAC)

SOURCE: Modified from Defense Nuclear Agency.

the pipe ahead of the shock wave to prevent early flow of high-velocity gas and debris into the experiment chamber.

- After 0.05 seconds (c), the ground shock moves past the second closure and is no longer strong enough to squeeze the pipe shut. The stemming plug stops forming at about the distance where the first mechanical pipe closure is located.
- After 0.2 seconds (d), the cavity growth is complete. The rebound from the explosion

**Figure 3-8—Tunnel Closure Sequence**




A) Zero Time: Explosion is detonated and the first two mechanical closures are fired. B) Within 0.03 seconds, a stemming plug is being formed and mechanical pipe closure has occurred. C) Within 0.05 seconds, the stemming plug has formed. D) Within 0.2 seconds, cavity growth is complete and a surrounding compressive residual stress field has formed. E) Within 0.75 seconds, closure is complete.

SOURCE: Modified from Defense Nuclear Agency.

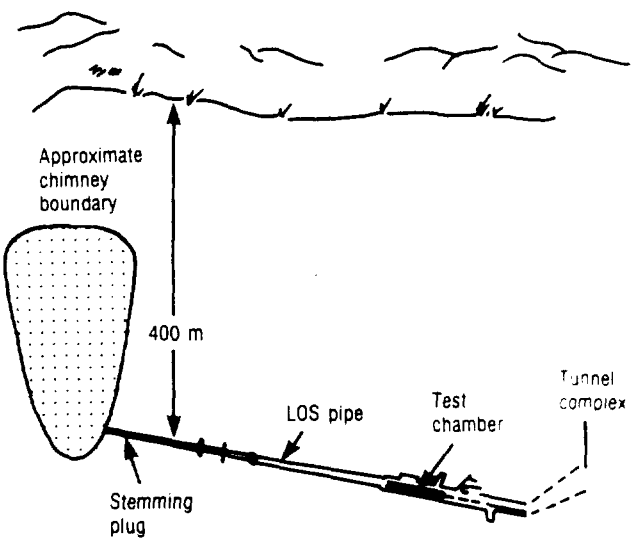
locks in the residual stress field, thereby forming a containment cage. The shock wave passes the test chamber.

- After 0.75 seconds (e), the final mechanical seal (TAPS) closes, preventing late-time explosive and radioactive gases from entering the test chamber.

The entire closure process for containment takes less than 3/4 of a second. Because the tests are typically buried at a depth greater than necessary for containment, the chimney does not reach the surface and a collapse crater normally does not form. A typical post-shot chimney configuration with its approximate boundaries is shown in figure 3-9.

In lower yield tests, such as those conducted in the P-tunnel complex, the first mechanical closure is a Fast Acting Closure (FAC) rather than a MAC.[25] The FAC (figure 3-7(c)) closes in 0.001 seconds and can withstand pressures of 30,000 pounds per square inch. The FAC acts like a cork, blocking off the HLOS pipe early, and preventing debris and stemming material from flying down the pipe. A similar closure is currently being developed for larger yield tunnel tests.

**Figure 3-9—Typical Post-Shot Configuration**




Tunnel shots are typically overburied and the collapse chimney rarely extends to the surface.

SOURCE: Modified from Defense Nuclear Agency.

## TYPES OF RADIATION RELEASES

Terms describing the release or containment of underground nuclear explosions have been refined to account for the volume of the material and the conditions of the release. The commonly used terms are described below.

### *Containment Failure*

Containment failures are releases of radioactive material that do not fall within the strict definition of successful containment, which is described by the Department of Energy as:

> Containment such that a test results in no radioactivity detectable off site as measured by normal monitoring equipment and no unanticipated release of radioactivity onsite. Detection of noble gases that appear onsite long after an event, due to changing atmospheric conditions, is not unanticipated. Anticipated releases will be designed to conform to specific guidance from DOE/HQ.[26]

Containment failures are commonly described as:

#### Ventings

Ventings are prompt, massive, uncontrolled releases of radioactive material. They are characterized as active releases under pressure, such as when radioactive material is driven out of the ground by steam or gas. "Baneberry," in 1970, is the last example of an explosion that "vented."

#### Seeps

Seeps, which are not visible, can only be detected by measuring for radiation. Seeps are characterized as uncontrolled slow releases of radioactive material with little or no energy.

### *Late-Time Seep*

Late-time seeps are small releases of noncondensable gases that usually occur days or weeks after a vertical drill hole test. The noncondensable gases diffuse up through the pore spaces of the overlying rock and are thought to be drawn to the surface by a decrease in atmospheric pressure (called "atmospheric pumping").

[25] The P-tunnel complex is mined in Aqueduct Mesa and has less overburden than the N-tunnel complex in Rainier Mesa. Therefore, P tunnel is generally used for lower yield tests.

[26] Section VIII.F, Containment Evaluation Panel Charter.

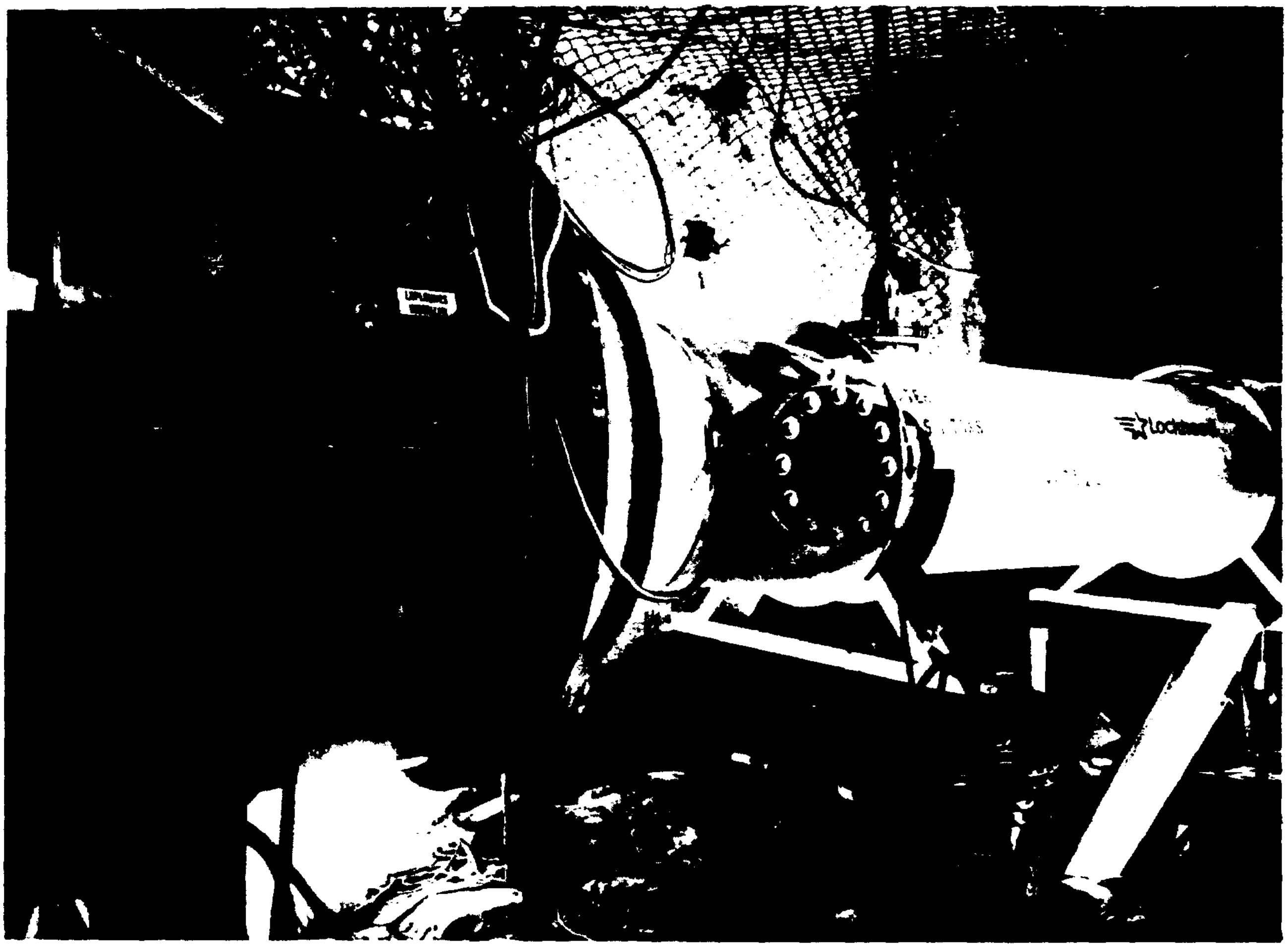


Photo credit: David Graham

Fast acting closure.

### Controlled Tunnel Purging

Controlled tunnel purging is an intentional release of radioactive material to recover experimental equipment and ventilate test tunnels. During a controlled tunnel purging, gases from the tunnel are filtered, mixed with air to reduce the concentration, and released over time when weather conditions are favorable for dispersion into sparsely populated areas.

### Operational Release

Operational releases are small releases of radioactivity resulting from operational aspects of vertical drill hole tests. Activities that often result in operational releases include: drilling back down to the location of the explosion to collect core samples (called "drill back"), collecting gas samples from the explosion (called "gas sampling"), and sealing the drill back holes (called "cement back")

## RECORD OF CONTAINMENT

The containment of underground nuclear explosions is a process that has continually evolved through learning, experimentation, and experience. The record of containment illustrates the various types of releases and their relative impact.

### Containment Evaluation Panel

The Containment Evaluation Panel defines successful containment as no radioactivity detectable offsite and no unanticipated release of activity onsite. By this definition, the CEP has failed to predict unsuccessful containment on four occasions since 1970:

| | |
|---|---|
| Camphor: | June 29, 1971, horizontal tunnel test, less than 20 kilotons, radioactivity detected only on-site. |
| Diagonal Line: | November 24, 1971, vertical shaft test, less than 20 kilotons, radioactivity detected off-site. |
| Riola: | September 25, 1980, vertical shaft test, less than 20 kilotons, radioactivity detected off-site. |
| Agrini: | March 31, 1984, vertical shaft test, less than 20 kilotons, radioactivity detected only on-site. |

These are the only tests (out of more than 200) where radioactive material has been unintentionally released to the atmosphere due to containment failure. In only two of the cases was the radioactivity detected outside the geographic boundary of the Nevada Test Site.

There have, however, been several other instances where conditions developed that were not expected. For example, during the Midas Myth test on February 15, 1984, an unexpected collapse crater occurred above the test tunnel causing injuries to personnel. In addition, the tunnel partially collapsed, damaging experimental equipment. During the Mighty Oak test on April 10, 1986, radioactive material penetrated through two of the three containment vessels. Experimental equipment worth $32 million was destroyed and the tunnel system ventilation required a large controlled release of radioactive material (table 3-1). In the case of Midas Myth, no radioactive material was released (in fact, all radioactive material was contained within vessel I). In the case of Mighty Oak, the release of radioactive material was intentional and controlled. Consequently, neither of these tests are considered containment failures by the CEP.

**Table 3-1—Releases From Underground Tests (normalized to 12 hours after event[a])**

| | |
|---|---|
| All releases 1971-1988: | |
| Containment Failures: | |
| Camphor, 1971[b] | 360 Ci |
| Diagonal Line, 1971 | 6,800 |
| Riola, 1980 | 3,100 |
| Agnni, 1984 | 690 |
| Late-time Seeps: | |
| Kappeli, 1984 | 12 |
| Tierra, 1984 | 600 |
| Labquark, 1986 | 20 |
| Bodie, 1986[3] | 52 |
| Controlled Tunnel Purgings: | |
| Hybla Fair, 1974 | 500 |
| Hybla Gold, 1977 | 0.005 |
| Miners Iron, 1980 | 0.3 |
| Huron Landing, 1982 | 280 |
| Mini Jade, 1983 | 1 |
| Mill Yard, 1985 | 5.9 |
| Diamond Beech, 1985 | 1.1 |
| Misty Rain, 1985 | 63 |
| Mighty Oak, 1986 | 36,000 |
| Mission Ghost, 1987[c] | 3 |
| Operational Releases: | |
| 108 tests from 1970-1988[d] | 5,500 |
| Total since Baneberry: | 54,000 Ci |
| Major pre-1971 releases: | |
| Platte, 1962 | 1,900,000 Ci |
| Eel, 1962 | 1,900,000 |
| Des Moines, 1962 | 11,000,000 |
| Baneberry, 1970 | 6,700,000 |
| 26 others from 1958-1970 | 3,800,000 |
| Total: | 25,300,000 Ci |
| Other Releases for Reference | |
| NTS Atmospheric Testing 1951-1963: | 12,000,000,000 Ci |
| 1 Kiloton Aboveground Explosion: | 10,000,000 |
| Chernobyl (estimate): | 81,000,000 |

[a]R+12 values apply only to containment failures, others are at time of release.
[b]The Camphor failure includes 140 Ci from tunnel purging.
[c]Bodie and Mission Ghost also had drill-back releases.
[d]Many of these operational releases are associated with tests that were not announced.
SOURCE: Office of Technology Assessment, 1989

### *Vertical Drill Hole Tests*

As discussed previously, vertical drill-hole tests commonly use a stemming plan with six sanded gypsum plugs or three epoxy plugs. Approximately 50 percent of the vertical drill hole tests show all radiation being contained below the first plug. In some cases, radiation above the plug may not signify plug failure, but rather may indicate that radioactive material has traveled through the medium around the plug.

All three of the vertical drill hole tests that released radioactive material through containment failure were low yield tests of less than 20 kilotons. In general, the higher the yield, the less chance there is that a vertical drill hole test will release radioactivity.[27]

### *Horizontal Tunnel Tests*

There have been no **uncontrolled** releases of radioactive material detected **offsite** in the 31 tunnel tests conducted since 1970. Furthermore, all but one test, Mighty Oak, have allowed successful recovery

[27]Higher yield tests are more likely to produce a containment cage and result in the formation of a collapse crater. As discussed earlier in this chapter "why nuclear explosions remain contained," such features contribute to the containment of the explosion.

of the experimental equipment. Mighty Oak and Camphor are the only tests where radioactivity escaped out of vessel II. In no test, other than Camphor, has radioactive material escaped out of vessel III. Camphor resulted in an **uncontrolled** release of radioactive material that was detected only **on site**.

There have been several instances when small amounts of radioactivity were released intentionally to the atmosphere through **controlled** purging. In these cases, the decision was made to vent the tunnel and release the radioactivity so the experimental results and equipment could be recovered. The events that required such a controlled release are the 10 tests where radioactive material escaped out of vessel I and into vessel II, namely:

Hybla Fair, October 28, 1974.

Hybla Gold, November 1, 1977.

Miners Iron, October 31, 1980.

Huron Landing, September 23, 1982.

Mini Jade, May 26, 1983.

Mill Yard, October 9, 1985.

Diamond Beech, October 9, 1985.

Misty Rain, April 6, 1985.

Mighty Oak, April 10, 1986.

Mission Ghost, June 20, 1987[28]

In most cases, the release was due to the failure of some part of the experiment protection system.

Table 3-1 includes *every* instance (for both announced and unannounced tests) where radioactive material has reached the atmosphere under *any circumstances whatsoever* from 1971 through 1988. The lower part of table 3-1 summarizes underground tests prior to 1971 and provides a comparison with other releases of radioactive material.

Since 1970, 126 tests have resulted in radioactive material reaching the atmosphere with a total release of about 54,000 Curies(Ci). Of this amount, 11,500 Ci were due to containment failure and late-time seeps. The remaining 42,500 Ci were operational releases and controlled tunnel ventilations—with Mighty Oak (36,000 Ci) as the main source. Section 3 of the table shows that the release of radioactive material from underground nuclear testing since Baneberry (54,000 Ci) is extremely small in comparison to the amount of material released by pre-Baneberry underground tests (25,300,000 Ci), the early atmospheric tests at the Nevada Test Site, or even the amount that would be released by a 1-kiloton explosion conducted above ground (10,000,000 Ci).

### *From the Perspective of Human Health Risk*

**If a single person had been standing at the boundary of the Nevada Test Site in the area of maximum concentration of radioactivity for every test since Baneberry (1970), that person's total exposure would be equivalent to 32 extra minutes of normal background exposure (or the equivalent of 1/1000 of a single chest x-ray).**

## A FEW EXAMPLES:

Although over 90 percent of all test explosions occur as predicted, occasionally something goes wrong. In some cases, the failure results in the loss of experimental equipment or requires the controlled ventilation of a tunnel system. In even more rare cases (less than 3 percent), the failure results in the unintentional release of radioactive material to the atmosphere. A look at examples shows situations where an unexpected sequence of events contribute to create an unpredicted situation (as occurred in Baneberry (see box 3-1)), and also situations where the full reason for containment failure still remains a mystery.

1. *Camphor* (June 29, 1971, horizontal tunnel test, less than 20 kilotons, radioactivity detected only on-site.)

The ground shock produced by the Camphor explosion failed to close the HLOS pipe fully. After about 10 seconds, gases leaked through and eroded the stemming plug. As gases flowed through the stemming plug, pressure increased on the closure door behind the experiment. Gases leaked around the cable passage ways and eroded open a hole. Pressure was then placed on the final door, which held but leaked slightly. Prior to the test, the containment plan for Camphor received six "I"s from the CEP.[29]

[28]The Mission Ghost release was due to a post-shot drill hole.

[29]Op. cit., footnote 20.

2. *Diagonal Line* (November 24, 1971, vertical shaft test, less than 20 kilotons, radioactivity detected off-site.)

In a sense, the Diagonal Line seep was predicted by the CEP. Prior to the test, Diagonal Line received all "A" categorizations, except from one member who gave it a "B."[30] It was a conclusion of the panel that due to the high $CO_2$ content, a late-time (hours or days after detonation) seepage was a high probability. They did not believe, however, that the level of radiation would be high enough to be detectable off-site. Permission to detonate was requested and granted because the test objectives were judged to outweigh the risk. Diagonal Line was conducted in the northern part of Frenchman Flat. It is speculated that carbonate material released $CO_2$ gas that forced radioactive material to leak to the surface. Diagonal Line was the last test detonated on Frenchman Flat.

3. *Riola* (September 25, 1980, vertical shaft test, less than 20 kilotons, radioactivity detected off-site.)

Ironically, Riola was originally proposed for a different location. The Containment Evaluation Panel, however, did not approve the first location and so the test was moved. At its new location, Riola was characterized by the CEP prior to the test with 8 "A"s. Riola exploded with only a small fraction of the expected yield. A surface collapse occurred and the failure of a containment plug resulted in the release of radioactive material.

4. *Agrini* (March 31, 1984, vertical shaft test, less than 20 kilotons, radioactivity detected only on-site.)

The Agrini explosion formed a deep subsidence crater 60 feet west of the emplacement hole. A small amount of radioactive material was pushed through the chimmney by noncondensible gas pressure and was detected onsite. The containment plan for Agrini received seven "A"s and two "B"s from the CEP prior to the test. The "B"s were due to the use of a new stemming plan.

5. *Midas Myth* (February 15, 1984, horizontal tunnel test, less than 20 kilotons, no release of radioactive material.)

All of the radioactive material produced by the Midas Myth test was contained within vessel I, with no release of radioactivity to either the atmosphere or the tunnel system. It is therefore not considered a containment failure. Three hours after the test, however, the cavity collapsed and the chimney reached the surface forming an unanticipated subsidence crater. Equipment trailers were damaged and personnel were injured (one person later died as a result of complications from his injuries) when the collapse crater formed.[31] Analysis conducted after the test indicated that the formation of the collapse crater should have been expected. Shots conducted on Yucca Flat with the same yield and at the same depth of burial did, at times, produce surface collapse craters. In the case of Midas Myth, collapse was not predicted because there had never been a collapse crater for a tunnel event and so the analysis was not made prior to the accident. After analyzing the test, the conclusion of the Surface Subsidence Review Committee was:

> That the crater is not an indication of some unusual, anomalous occurrence specific to the U12T.04 emplacement site. Given the normal variation in explosion phenomena, along with yield, depth of burial, and geologic setting, experience indicates an appreciable chance for the formation of a surface subsidence crater for Midas Myth.

Prior to the test, the Containment Evaluation Panel characterized Midas Myth with nine "A"s.

6. *Misty Rain* ( April 6, 1985, horizontal tunnel test, less than 20 kilotons, no unintentional release of radioactive material.)

Misty Rain is unusual in that it is the only tunnel test since 1970 that did not have three containment vessels. In the Misty Rain test, the decision was made that because the tunnel system was so large, a vessel II was not needed.[32] Despite the lack of a vessel II, the CEP categorized the containment of Misty Rain with eight "A"s, and one "B."[33] During the test, an early flow of energy down the HLOS pipe prevented the complete closure of the MAC doors. The MAC doors overlapped, but stopped a couple inches short of full closure. The TAPS door closed only 20 percent before the deformation from ground shock prevented it from closing. A small amount of

[30]Ibid.

[31]The injuries were due to the physical circumstances of the collapse. There was no radiation exposure.

[32]The drifts in the tunnel system created over 4 million cubic feet of open volume.

[33]One CEP member did not initially categorize the test, after receiving additional information concerning the test, he categorized the test with an "A."

radioactive material escaped down the pipe and then seeped from the HLOS pipe tunnel into the bypass tunnel. Subsequently, the tunnel was intentionally vented so that experimental equipment could be recovered.

7. *Mighty Oak* (April 10, 1986, horizontal tunnel test, less than 20 kilotons, no unintentional release of radioactive material.)

During the Mighty Oak test, the closure system near the working point was over-pressured and failed. The escaped pressure and temperature caused both the MAC and the GSAC to fail. The loss of the stemming plug near the working point left the tunnel an open pathway from the cavity. Temperatures and pressures on the closed TAPS door reached 2,000 °F and 1,400 pounds per square inch. After 50 seconds, the center part (approximately 6 feet in diameter) of the TAPS door broke through. With the closures removed, the stemming column squeezed out through the tunnel. Radioactive material leaked from vessel I, into vessel II, and into vessel III, where it was successfully contained. Approximately 85 percent of the data from the prime test objectives was recovered, although about $32 million of normally recoverable and reusable equipment was lost.[34] Controlled purging of the tunnel began 12 days after the test and continued intermittently from April 22 to May 19, when weather conditions were favorable. A total of 36,000 Ci were released to the atmosphere during this period.

## IS THERE A REAL ESTATE PROBLEM AT NTS?

There have been over 600 underground and 100 aboveground nuclear test explosions at the Nevada Test Site. With testing continuing at a rate of about a dozen tests a year, the question of whether there will eventually be no more room to test has been raised. While such a concern may be justified for the most convenient areas under the simplest arrangements, it is not justified for the test area in general. Using the drill-hole spacing of approximately one-half the depth of burial, high-yield tests can be spaced about 1,000 feet apart, and low-yield tests can be spaced at distances of a few hundred feet. Consequently, a suitable square mile of test site may provide space for up to 25 high-yield tests or over 300 low-yield tests. Even with testing occurring at a rate of 12 tests a year, the 1,350 square miles of test site provide considerable space suitable for testing.

In recent years, attempts have been made to use space more economically, so that the most convenient locations will remain available. Tests have traditionally been spaced in only 2-dimensions. It may be possible to space tests 3-dimensionally, that is, with testing located below or above earlier tests. Additionally, the test spacing has been mostly for convenience. If available testing areas become scarce, it may become possible to test at closer spacing, or even to test at the same location as a previous test.

Area for horizontal tunnel tests will also be available for the future. The N-tunnel area has been extended and has a sizable area for future testing. P-tunnel, which is used for low-yield effects tests, has only been started. (See figure 2-4 in ch. 2 of this report.) Within Rainier and Aqueduct Mesa alone, there is enough area to continue tunnel tests at a rate of two a year for at least the next 30 years. Consequently, lack of adequate real estate will not be a problem for nuclear testing for at least several more decades.

## TIRED MOUNTAIN SYNDROME?

The "Tired Mountain Syndrome" hypothesis postulates that repeated testing in Rainier Mesa has created a "tired" mountain that no longer has the strength to contain future tests. Support for this concern has come from the observation of cracks in the ground on top of the Mesa and from seismological measurements, indicating that large volumes of rock lose strength during an underground test. Debate exists, however, over both the inference that the weakened rock is a danger to containment, and the premise that large volumes of rock are being weakened by nuclear testing.

Basic to the concern over tired mountain syndrome is the assumption that weakened rock will adversely affect containment. As discussed previously, only in an extreme situation, such as detonating an explosion in water-saturated clay, would rock strength be a factor in contributing to a leak of radioactive material.[35] For example, many tests have

[34] *Containment and Safety Review for the Mighty Oak Nuclear Weapon Effects Test*, U.S. Department of Energy, Nevada Operations Office, NVO-311, May 1, 1987.

[35] See earlier section "Why do nuclear tests remain contained?"

Photo credit: Department of Energy

Fracture on Rainier Mesa.

been detonated in alluvial deposits, which are essentially big piles of sediment with nearly no internal strength in an unconfined state. Despite the weakness and lack of cohesiveness of the material, such explosions remain well contained.

Compared to vertical drill hole tests, tunnel tests are overburied and conservatively spaced. The tunnel system in Rainier Mesa is at a depth of 1,300 feet. By the standards for vertical drill hole tests (using the scaled depth formula[36]), this is deep enough to test at yields of up to 34 kilotons; and yet all tunnel tests are less than 20 kilotons.[37] Consequently, all tunnel tests in Rainier Mesa are buried at depths comparatively greater than vertical drill hole tests on Yucca Flat. Furthermore, the minimum separation distance of tunnel shots (twice the combined cavity radii plus 100 feet) results in a greater separation distance than the minimum separation distance of vertical drill hole shots ($^1/_2$ depth of burial) for tests of the same yield (compare figures 3-2 and 3-3). **Consequently, neither material strength, burial depth, nor separation distance would make leakage to the surface more likely for a tunnel test on Rainier Mesa than for a vertical drill hole tests on Yucca Flat.**

Despite the relative lack of importance of strength in preventing possible leakage to the surface, the volume of material weakened or fractured by an explosion is of interest because it could affect the performance of the tunnel closures and possible leakage of cavity gas to the tunnel complex. Dispute over the amount of rock fractured by an underground nuclear explosion stems from the following two, seemingly contradictory, but in fact consistent observations:

1. Post-shot measurements of rock samples taken from the tunnel complex generally show no change in the properties of the rock at a distance greater than 3 cavity radii from the point of the explosion. This observation implies that rock strength is measurably decreased only within the small volume of radius = 165 (yield)$^{1/3}$,[38] where the radius is measured in feet from the point of the explosion and the yield is measured in kilotons (figure 3-10).

2. Seismic recordings of underground explosions at Rainier Mesa include signals that indicate the loss of strength in a volume of rock whose radius is slightly larger than the scaled depth of burial. This observation implies that the rock strength is decreased throughout the large volume of radius = 500 (yield)$^{1/3}$, where the radius is measured in feet from the point of the explosion and the yield is measured in kilotons (figure 3-11). The loss of strength in a large volume seems to be further supported by cracks in the ground at the top of Rainier Mesa that were created by nuclear tests.

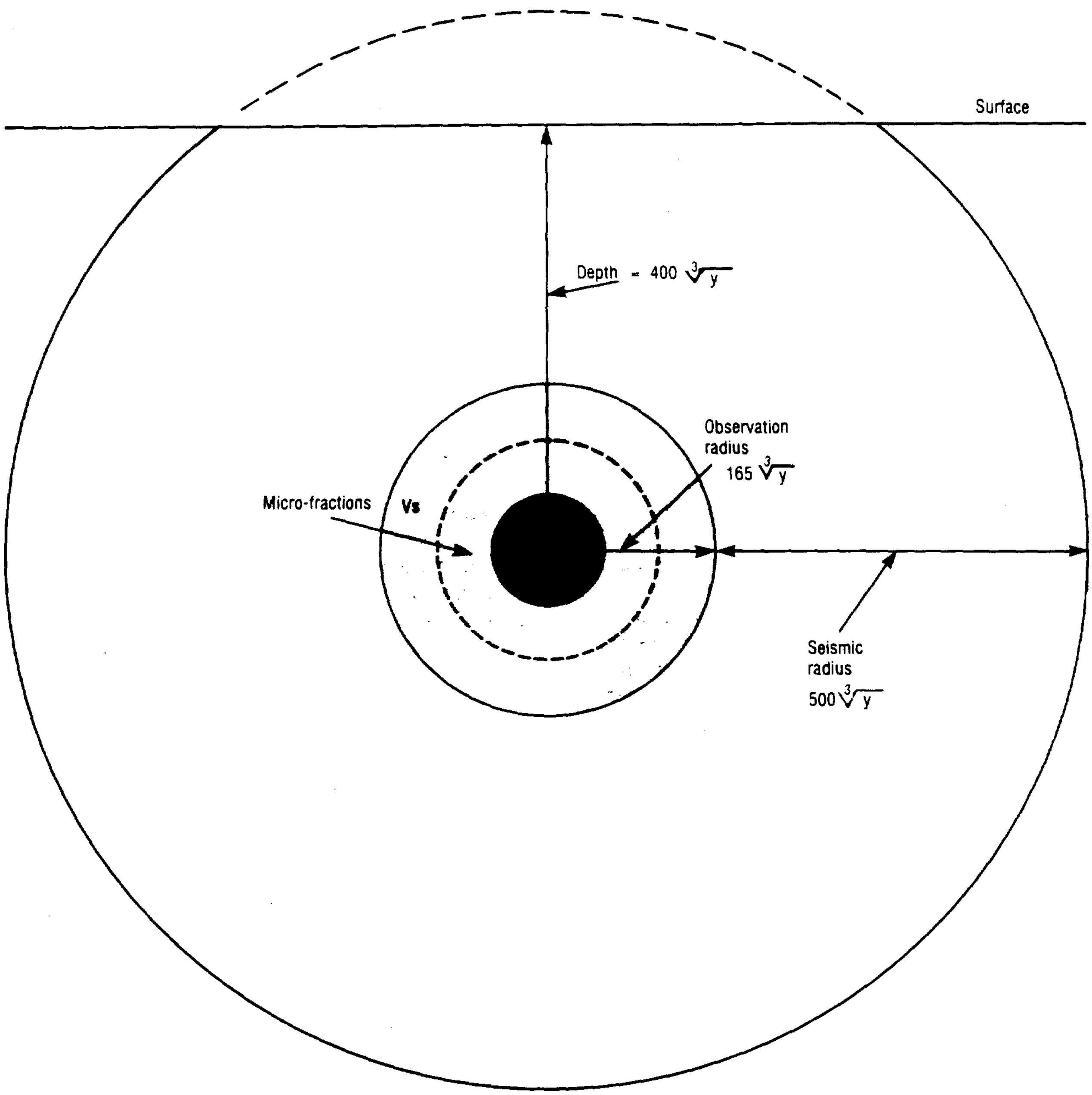
The first observation is based on tests of samples obtained from drilling back into the rock surrounding the tunnel complex after a test explosion. The core samples contain microfractures out to a distance from the shot point equal to two cavity radii. Although microfractures are not seen past two cavity radii, measurements of seismic shear velocities

[36]Depth(ft) = 400 (yield(kt))$^{1/3}$

[37]"Announced United States Nuclear Tests, July 1945 through December 1987," United States Department of Energy, NVO-209(Rev.8), April, 1988.

[38]If the radius of a cavity produced by an explosion is equal to 55 (yield)$^{1/3}$, a distance of three cavity radii would be equal to three times this, or 165 (yield)$^{1/3}$.

**Figure 3-10—Radius of Decrease in Rock Strength**




Seismic measurements and measurements taken from drill-back samples indicate a seemingly contradictory (but in fact consistent) radius of decrease in rock strength.

SOURCE: Office of Technology Assessment, 1989.

continue to be low out to a distance of three cavity radii. The decrease in seismic shear velocity indicates that the rock has been stressed and the strength decreased. At distances greater than three cavity radii, seismic velocity measurements and strength tests typically show no change from their pre-shot values, although small disturbances along bedding planes are occasionally seen when the tunnels are re-entered after the test. Such measurements suggest that the explosion only affects rock strength to a distance from the shot point to about three cavity radii (165 (yield)$^{1/3}$).

The second observation, obtained from seismic measurements of tectonic release, suggests a larger radius for the volume of rock affected by an explosion. The seismic signals from underground nuclear explosions frequently contain signals created by what is called "tectonic release." By fracturing the rock, the explosion releases any preexisting natural stress that was locked within the rock. The release of the stress is similar to a small earthquake. The tectonic release observed in the seismic recordings of underground explosions from Rainier Mesa indicate the loss of strength in a volume of rock with a minimum radius equal to 500 (yield)$^{1/3}$.

Although the drill samples and the seismic data appear to contradict each other, the following explanation appears to account for both: The force of the explosion creates a cavity and fractures rock out to the distance of 2 cavity radii from the shot point. Out to 3 cavity radii, existing cracks are extended and connected, resulting in a decrease in seismic shear velocity. Outside 3 cavity radii, no new cracks form. At this distance, existing cracks are opened and strength is reduced, but only temporarily. The open cracks close immediately after the shock wave passes due to the pressure exerted by the overlying rock. Because the cracks close and no new cracks are formed, the rock properties are not changed. Post-shot tests of seismic shear velocity and strength are the same as pre-shot measurements. This is consistent with both the observations of surface fractures and the slight disturbances seen along bedding planes at distances greater than 3 cavity radii. The surface fractures are due to surface spall, which would indicate that the rock was overloaded by the shock wave. The disturbances of the bedding planes would indicate that fractures are being opened out to greater distances than 3 cavity radii. In fact, the bedding plane disturbances are seen out to a distance of 600 (yield)$^{1/3}$, which is consistent with the radius determined from tectonic release.

The large radius of weak rock derived from tectonic release measurements represents the **transient** weakening from the shot. The small radius of weak rock derived from the post-shot tests represents the volume where the rock properties have been **permanently** changed. From the point of view of the integrity of the tunnel system, it is the smaller area where the rock properties have been permanently changed (radius = 165 (yield)$^{1/3}$) that should be considered for containment. **Because the line-of-sight tunnel is located so that the stemming plug region and closures are outside the region of permanently weakened or fractured material, the closure system is not degraded.**

## HOW SAFE IS SAFE ENOUGH?

Every nuclear test is designed to be contained and is reviewed for containment. In each step of the test procedure there is built-in redundancy and conservatism. Every attempt is made to keep the chance of containment failure as remote as possible. This conservatism and redundancy is essential, however; because no matter how perfect the process may be, it operates in an imperfect setting. For each test, the containment analysis is based on samples, estimates, and models that can only simplify and (at best) approximate the real complexities of the Earth. As a result, predictions about containment depend largely on judgments developed from past experience. Most of what is known to cause problems—carbonate material, water, faults, scarps, clays, etc.—was learned through experience. To withstand the consequences of a possible surprise, redundancy and conservatism is a requirement not an extravagance. Consequently, all efforts undertaken to ensure a safe testing program are necessary, and they must continue to be vigorously pursued.

Deciding whether the testing program is safe requires a judgement of how safe is safe enough. The subjective nature of this judgement is illustrated through the decision-making process of the CEP, which reviews and assesses the containment of each test.[39] They evaluate whether a test will be contained using the categorizations of "high confidence," "adequate degree of confidence," and "some doubt." But, the CEP has no guidelines that attempt to quantify or describe in probabilistic terms what constitutes for example, an "adequate degree of confidence." Obviously one can never have 100 percent confidence that a test will not release radioactive material. Whether "adequate confi-

[39] The Containment Evaluation Panel is a group of representatives from various laboratories and technical consulting organizations who evaluate the proposed containment plan for each test without regard to cost or other outside considerations (see ch. 2 for a complete discussion).

dence" translates into a chance of 1 in 100, 1 in 1,000, or 1 in 1,000,000, requires a decision about what is an acceptable risk level. In turn, decisions of acceptable risk level can only be made by weighing the costs of an unintentional release against the benefits of testing. Consequently, those who feel that testing is important for our national security will accept greater risk, and those who oppose nuclear testing will find even small risks unacceptable.

Establishing an acceptable level of risk is difficult not only because of value judgments associated with nuclear testing, but also because the risk is not seen as voluntary to those outside the testing program. Much higher risks associated with voluntary, everyday activities may be acceptable even though the much lower risks associated with the nuclear test site may still be considered unacceptable.

The question of whether the testing program is "safe enough" will ultimately remain a value judgment that weighs the importance of testing against the risk to health and environment. In this sense, concern about safety will continue, largely fueled by concern about the nuclear testing program itself. However, given the continuance of testing and the acceptance of the associated environmental damage, the question of "adequate safety" becomes replaced with the less subjective question of whether any improvements can be made to reduce the chances of an accidental release. In this regard, no areas for improvement have been identified. This is not to say that future improvements will not be made as experience increases, but only that essentially all suggestions that increase the safety margin have been implemented. **The safeguards built into each test make the chances of an accidental release of radioactive material as remote as possible.**

Chapter 4

# Monitoring Accidental Radiation Releases

## CONTENTS



### *Figures*



### *Tables*

# Monitoring Accidental Radiation Releases

*Each test is conducted under conditions in which remedial actions could be effective should an accidental release of radioactive material occur.*

## INTRODUCTION

Although nuclear tests are designed to minimize the chance that radioactive material could be released to the atmosphere, it is assumed as a precaution for each test that an accident may occur. To reduce the impact of a possible accident, tests are conducted only under circumstances whereby remedial actions could be taken if necessary. If it is estimated that the projected radioactive fallout from a release would reach an area where remedial actions are not feasible, the test will be postponed.

Responsibility for radiation safety measures for the nuclear testing program is divided between the Department of Energy (DOE) and the Environmental Protection Agency (EPA). The Department of Energy oversees monitoring within the boundaries of the Nevada Test Site (NTS). The Environmental Protection Agency monitors the population around the test site and evaluates the contribution of nuclear testing to human radiation exposure through air, water, and food.

## WHAT IS RADIATION?

The nuclei of certain elements disintegrate spontaneously. They may emit particles, or electromagnetic waves (gamma rays or x-rays), or both. These emissions constitute radiation. The isotopes are called radionuclides. They are said to be radioactive, and their property of emitting radiation is called radioactive decay. The rate of decay is characteristic of each particular radionuclide and provides a measure of its radioactivity.

The common unit of radioactivity was the curie (Ci), defined as $3.7 \times 10^{10}$ decays per second, which is the radioactivity of one gram of radium. Recently, a new unit, the becquerel (Bq), has been adopted, defined as one decay per second. Exposure of biological tissue to radiation is measured in terms of rems (standing for roentgen equivalent man). A roentgen (R) is a unit of exposure equivalent to the quantity of radiation required to produce one coulomb of electrical charge in one kilogram of dry air. A rem is the dose in tissue resulting from the absorption of a rad of radiation multiplied by a "quality factor" that depends on the type of radiation. A rad is defined as 100 ergs (a small unit of energy) per gram of exposed tissue. Recently accepted international units of radiation are now the gray (Gy), equal to 100 rads, and the sievert (Sv), equal to 100 rems.

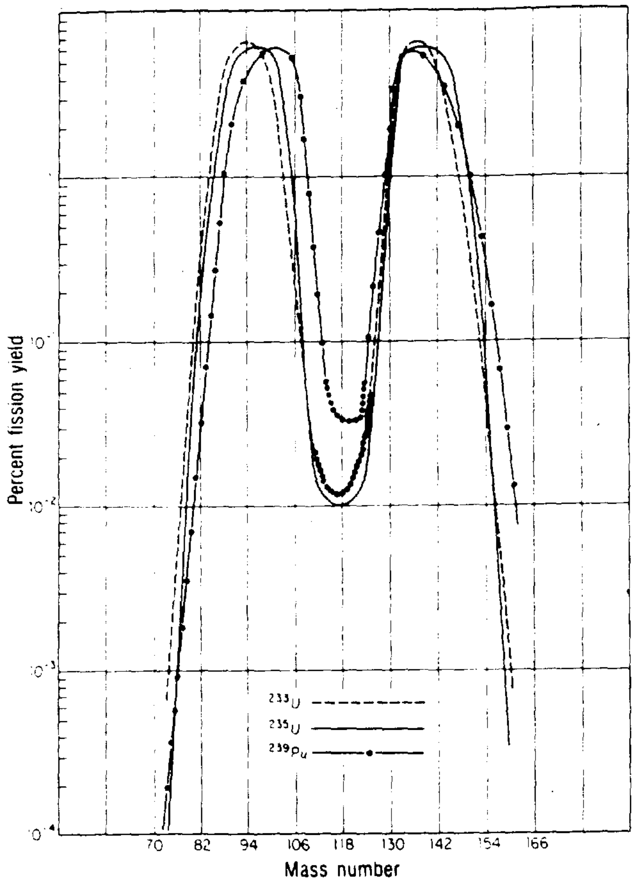
## PRODUCTS OF A NUCLEAR EXPLOSION

A nuclear explosion creates two sources of radioactivity: the first source is the direct products of the nuclear reaction, and the second is the radioactivity induced in the surrounding material by the explosion-generated neutrons. In a fission reaction, the splitting of a nucleus creates two or more new nuclei that are often intensely radioactive. The products occur predominantly in two major groups of elements as shown in figure 4-1. The neutrons produced by the reaction also react with external materials such as the device canister, surrounding rock, etc., making those materials radioactive as well. In addition to these generated radioactivities, unburned nuclear fission fuel (especially plutonium) is also a radioactive containment. The helium nuclei formed by fusion reactions are not radioactive.[1] However, neutrons produced in the fusion reaction still will make outside material radioactive. Depending on the design of the explosive device and its percentage of fission and fusion, a wide range of radioactive material can be released with half lives of less than a second to more than a billion years.[2] The debris from nuclear detonations contain a large number of radioactive isotopes, which emit predominantly gamma and beta radiation. Some of the more common radionuclides involved in a nuclear explosion are listed in table 4-1.

[1] This, incidentally, is why commercial fusion reactors (if they could be created) would be a relatively clean source of energy.

[2] The half-life is the time required for half of the atoms of a radioactive substance to undergo a nuclear transformation to a more stable element.

**Figure 4-1—The Typical Bimodal Curve for Fission-Product Yield**




Products of a nuclear explosion occur predominantly in two major groups of nuclides.

SOURCE: *Modified from* Lapp and Andrews, Prentice-Hall, Inc., 1972.

An individual radioactive species follows the half-life rule of decay—that is, half of the nuclei disintegrate in a characteristic time, called a "half-life." However, a mixture of fission products has a more complicated decay pattern. The general rule of thumb for a nuclear explosion is that the total activity decreases by a factor of 10 for every sevenfold increase in time. In other words, if the gamma radiation 1 hour after an explosion has an intensity of 100 units, then 7 hours later it will have an intensity of 10. Consequently, the time after the explosion has a dramatic effect on the amount of radioactivity. A 1 kiloton explosion in the atmosphere will produce 41 billion curies 1 minute after determination, but this will decrease to 10 million curies in just 12 hours.

**Table 4-1—Common Radionuclides Involved in a Nuclear Explosion**

| Radionuclide | Half-Life |
|---|---|
| Uranium-238 | 4,500,000,000 years |
| Plutonium-239 | 24,300 years |
| Carbon-14 | 5,800 years |
| Radium-226 | 1,620 years |
| Cesium-137 | 30 years |
| Strontium-90 | 28 years |
| Tritium | 12.3 years |
| Krypton-85 | 10.9 years |
| Iodine-131 | 8 days |
| Xenon-133 | 5.2 days |
| Iodine-132 | 2.4 hours |

The type of release is also important in predicting what radionuclides will be present. For example, atmospheric tests release all radionuclides created. Prompt, massive ventings have released a nonnegligible fraction of the radionuclides created. Late-time, minor seeps, like those since 1970, release only the most volatile radionuclides. In an underground explosion, radionuclides also separate (called "fractionation") according to their chemical or physical characteristics. Refractory particles (particles that do not vaporize during the nuclear explosion) settle out fast underground, while more volatile elements that vaporize easily condense later. This has a strong effect on radioactive gases that seep slowly through the soil from an underground explosion. In an underground explosion, nearly all the reactive materials are filtered out through the soil column, and the only elements that come up through the soil to the atmosphere are the noble gases, primarily krypton and xenon.

## CRITERIA FOR CONDUCTING A TEST

Although every attempt is made to prevent the accidental release of radioactive material to the atmosphere, several safety programs are carried out for each test. These programs are designed to minimize the likelihood and extent of radiation exposure offsite and to reduce risks to people should an accidental release of radioactive material occur. The Environmental Protection Agency monitors the population around the test site and has established plans to protect people should an accident occur. EPA's preparations are aimed toward reducing the whole-body exposure of the off-site populace and to minimizing thyroid dose to offsite residents, particularly from the ingestion of contaminated milk.[3] The whole-body dose is the main concern. However, deposition of radioactive material on pastures can lead to concentration in milk obtained from cows that graze on those pastures. The infant thyroid doses from drinking milk from family cows is also assessed.[4]

The Department of Energy's criteria for conducting a test are:

> For tests at the Nevada Test Site, when considering the event-day weather conditions and the specific event characteristics, calculations should be made using the most appropriate hypothetical release models which estimate the off-site exposures that could result from the most probable release scenario. Should such estimates indicate that off-site populations, in areas where remedial actions to reduce whole-body exposures are not feasible, could receive average whole-body dose in excess of 0.17 R/year (170 mR/year), the event shall be postponed until more favorable conditions prevail. In addition, events may proceed only where remedial actions against uptake of radionuclides in the food chain are practicable and/or indications are that average thyroid doses to the population will not exceed 0.5 R/year (500 mR/year).[5]

These criteria mean that a test can only take place if the estimate of the fallout from an accidental release of radioactivity would not be greater than 0.17 R/year in areas that are uncontrollable, i.e., where "remedial actions to reduce whole-body exposures are not feasible." Thus, tests are not conducted when the wind is blowing in the general direction of populated areas considered to be uncontrollable, except under persistent light wind conditions that would limit the significant fallout to the immediate vicinity of the NTS. Areas considered to be uncontrollable by EPA are shown in figure 4-2.

The EPA and DOE have also defined a *controllable* area (figure 4-2), within which remedial actions are considered feasible. Criteria for the controllable area, as defined by the DOE are:

> . . . those areas where trained rad-safe monitors are available, where communications are effective (where the exposure of each individual can be documented), where people can be expected to comply with recommended remedial actions, and where remedial actions against uptake of radionuclides in the food chain are practicable.

The controllable area is the zone within approximately 125 miles of the test control point (see figure 4-2) for which EPA judges that its remedial actions would be effective. Within this area, EPA has the capability to track any release and perform remedial actions to reduce exposure, including sheltering or evacuation of all personnel (as needed); controlling access to the area; controlling livestock feeding practices, i.e., providing feed rather than allowing grazing; replacing milk; and controlling food and water.

In the case of the controllable area, a test may be conducted if the fallout estimate implies that individuals in the area would not receive whole-body doses in excess of 0.5 R/year and thyroid doses of 1.5 R/year. If winds measured by the weather service indicate that the cloud of radioactive debris produced by the assumed venting would drift over controllable areas, such as to the north, the test is permitted when EPA's mobile monitors are in the downwind areas at populated places. EPA must be ready to measure exposure and to assist in moving people under cover or evacuating them, if necessary, to keep their exposures below allowable levels.

As a consequence of the geometry of the controllable area, tests are generally not conducted if winds aloft blow toward Las Vegas or towards other nearby populated locations. In addition, the test will not be conducted if there is less than 3 hours of daylight remaining to track the cloud.

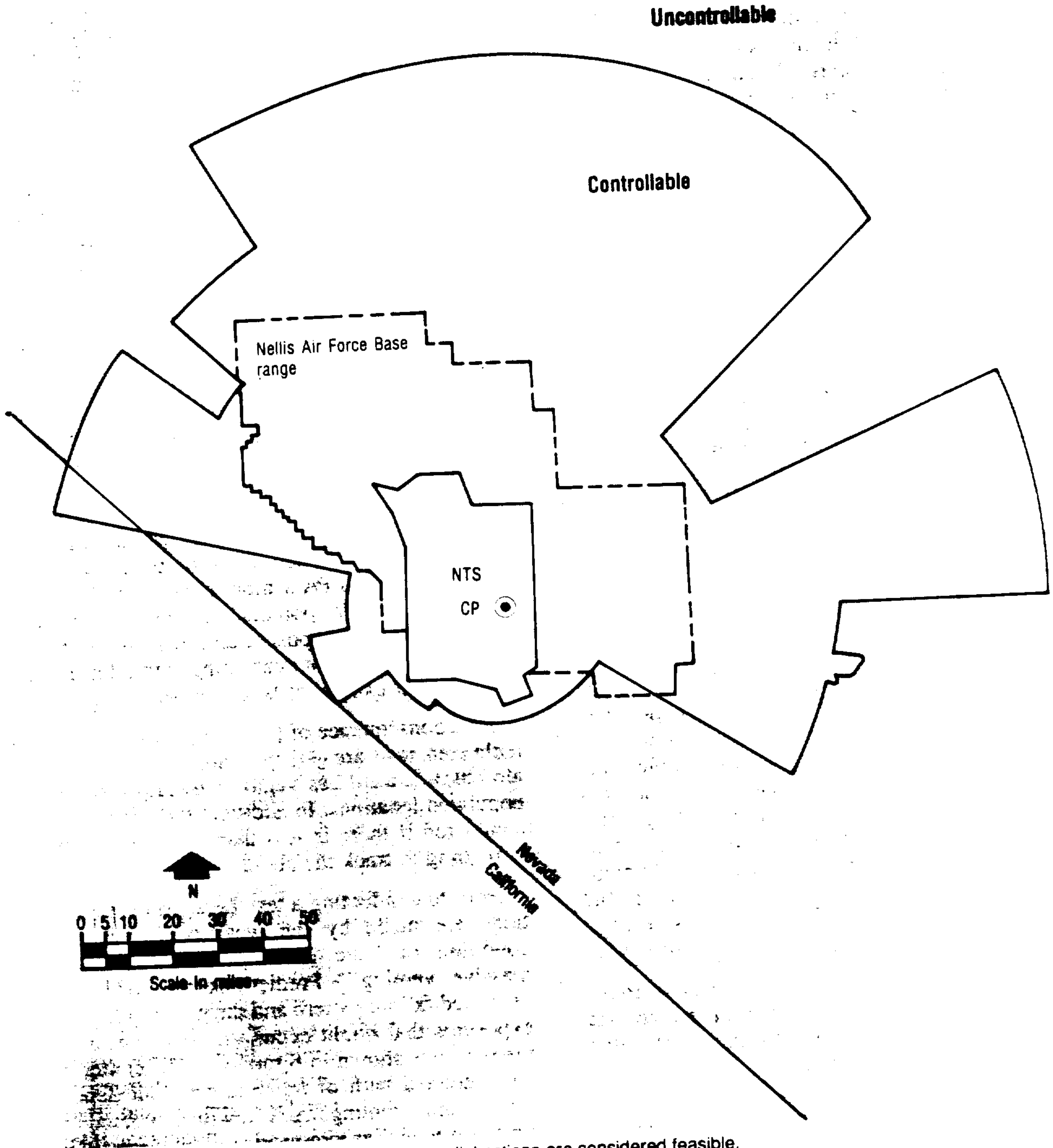
Prior to conducting a test, detailed fallout projections are made by the weather service for the condition of "the unlikely event of a prompt massive venting." Predictions are made of the projected fallout pattern and the maximum radiation exposures that might occur. An example of such a prediction is shown in figure 4-3. The center line is the predicted path of maximum fallout deposition for a prompt venting, marked with estimated arrival times (in hours) at various distances. Lines to either side indicate the width of the fallout area. The two dashed lines indicate the 500 mR/year area and the

[3]See "Offsite Remedial Action Capability for Underground Nuclear Weapons Test Accidents," U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory—Las Vegas, NV, October 1988.

[4]In the case of an accident, however, the actual dose would be minimized because the milk would be replaced as much as possible.

[5]See "Offsite Remedial Action Capability for Underground Nuclear Weapons Test Accidents," U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory—Las Vegas, NV, October 1988.

**Figure 4-2—Controllable and Uncontrollable Areas**

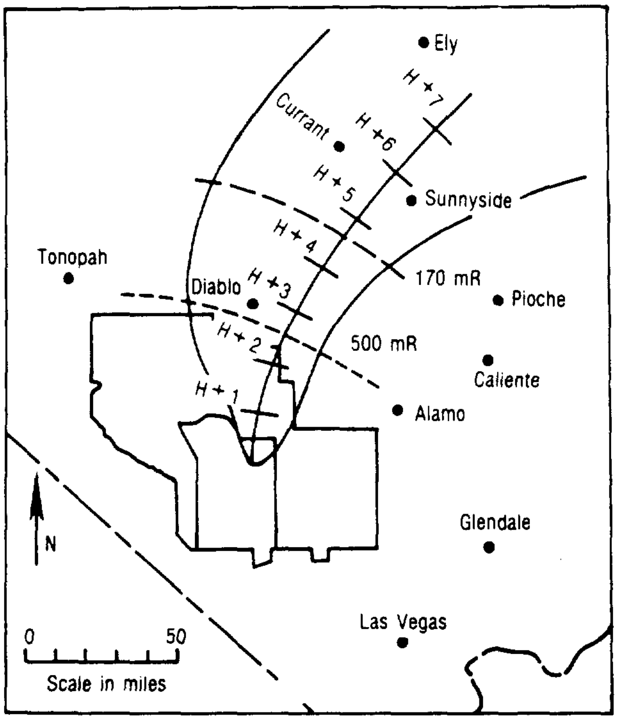



The controllable area is the region within which remedial actions are considered feasible.

SOURCE: Modified from Environmental Protection Agency.

170 mR/year level. If 0.17 mR/year (the maximum external exposure allowed during a 12-month period for an uncontrolled population) or more is predicted to fall outside the controllable area, the test will be postponed. Within the predictions shown in figur 4-3, the test could be conducted if EPA monitoı were prepared to be at each of the ranches, mine and other populated areas within the dispersic

**Figure 4-3—Projected Fallout Dispersion Pattern**




Key: H+ number= time of detonation plus elapsed hours; mR= milliREM

**Predicted fallout pattern for the case of an accidental venting.**

SOURCE: Modified from: "Public Safety for Nuclear Weapons Tests," U.S. Environmental Protection Agency, January 1984.

pattern to measure exposure and perform remedial actions should they be necessary.

The preferred weather conditions for a test are a clear sky for tracking, southerly winds (winds from the south), no thunderstorms or precipitation that would inhibit evacuation, and stable weather patterns. During the test preparations, the Weather Service Nuclear Support Office provides the Test Controller with predicted weather conditions. This information is used by the Weather Service to derive the estimated fallout pattern should an accidental release occur. About one-third of all nuclear tests are delayed for weather considerations; the maximum delay in recent years reached 16 days.

# PREDICTING FALLOUT PATTERNS

The predicted fallout pattern from an underground test depends on many variables related to the type of nuclear device, the device's material composition, type of venting, weather conditions, etc. With so many variables and so little experience with actual ventings, fallout predictions can only be considered approximations. The accuracy of this approximation, however, is critical to the decision of whether a test can be safely conducted. Fallout predictions are made by the Weather Service Nuclear Support Office using up-to-date detailed weather forecasts combined with a model for a "prompt massive venting." The model uses scaling technique based on the actual venting of an underground test that occurred on March 13, 1964. The test, named "Pike," was a low-yield (less than 20 kilotons) explosion detonated in a vertical shaft. A massive venting occurred 10 to 15 seconds after detonation.[6] The venting continued for 69 seconds, at which time the overburden rock collapsed forming a surface subsidence crater and blocking further venting. The vented radioactive debris, consisting of gaseous and particulate material, rose rapidly to about 3,000 feet above the surface.

The Pike scaling model has been used to calculate estimates of fallout patterns for the past 20 years because: 1) the large amount of data collected from the Pike venting allowed the development of a scaling model, and 2) Pike is considered to be the worst venting in terms of potential exposure to the public.[7]

The Pike model, however, is based on a very small release of radioactive material compared to what would be expected from an aboveground test of the same size.[8] The percentage of radioactive material released from the Baneberry venting (7 percent from table 3-1), for example, is many times greater than the percentage of material released from the Pike test.[9] It would therefore appear that Baneberry provides a more conservative model than Pike. This, however, is not the case because Baneberry was not

[6] Pike was conducted in alluvium in Area 3 of the test site. The release was attributed to a fracture that propagated to the surface. Other factors contributing to the release were an inadequate depth of burial and an inadequate closure of the line-of-sight pipe.

[7] "1985 Analyses and Evaluations of the Radiological and Meteorological Data from the Pike Event," National Oceanic and Atmospheric Administration, Weather Service Nuclear Support Office, Las Vegas, NV, December, 1986, NVO-308.

[8] The exact amount of material released from the 1964 Pike test remains classified.

[9] See table 3-1 for a comparison of various releases.

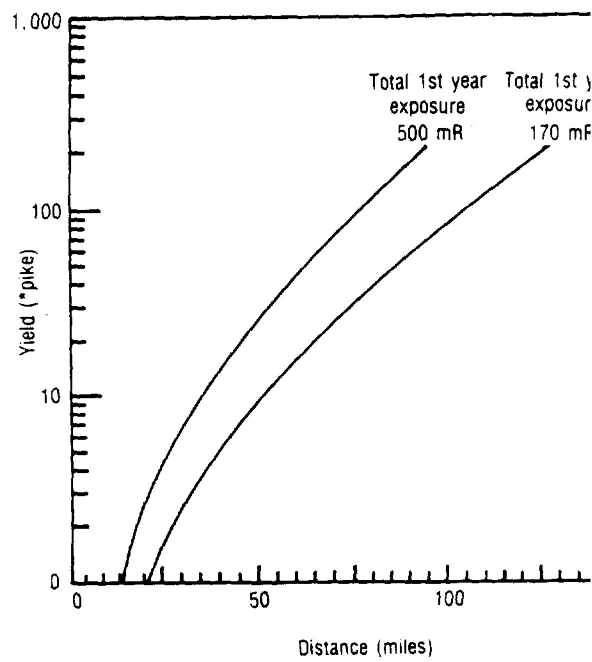
a *prompt* venting. Baneberry vented through a fissure and decaying radioactive material was pumped out over many hours. Baneberry released more curies than Pike; however, due to its slower release, a higher percentage of the Baneberry material was in the form of noble gases, which are not deposited. The data suggest that much less than 7 percent of the released material was deposited.[10] Therefore, it is thought that Pike is actually a more conservative model than Baneberry.

The sensitivity of the Pike model can be judged by looking at the degree to which its predictions are affected by the amount of material released. For example, consider a test in which 10 percent of the radioactive material produced by the explosion is accidentally released into the atmosphere; in other words, 10 percent of the material that would have been released if the explosion had been detonated aboveground. This also roughly corresponds to the amount of material that would be released if the explosion had been detonated underground at the bottom of an open (unstemmed) hole. The 10 percent release can therefore be used as a rough approximation for the worst case release from an underground test. To evaluate the adequacy of the Pike model predictions to withstand the full range of uncertainty of an accidental release, the question is: what effect would a release of 10 percent rather than, say 1 percent, have on the location of 170-mR and 500-mR exposure lines? As figure 4-4 illustrates, changing the yield of an explosion by an order of magnitude (in other words, increasing the release from say 1 percent to 10 percent) increases the distance of the 170-mR and 500-mR lines by roughly a factor of 2. Therefore, assuming a worst case scenario of a 10 percent prompt massive venting (as opposed to the more probable scenario of around a 1 percent prompt massive venting), the distance of the exposure levels along the predicted fallout lines would only increase by a multiple of 2. The Pike model therefore provides a prediction that is *at least* within a factor of about 2 of almost any possible worst-case scenario.

## ACCIDENT NOTIFICATION

Any release of radioactive material is publicly announced if the release occurs during, or immediately following, a test. If a late-time seep occurs, the release will be announced if it is predicted that the

**Figure 4-4—Yield v. Distance**




**Constant Pike Parameters**

Wind speed = 15mph

Vertical wind shear = 20°

Cloud rise = 5,000ft

**Variab**

Yield ×

Yield (in kilotons) v. distance (in miles) for projected fallout the Pike Model. TYE indicates total first year exposure. Incre the yield by a factor of 10 roughly doubles the downwind dist of the projected fallout pattern.

SOURCE: Provided by National Oceanic and Atmospheric Administ National Weather Service Nuclear Support Office, 1988.

radioactive material will be detected outside boundaries of the test site. **If no detection off-si predicted, the release may not be announ** Operational releases that are considered rou (such as small releases from drill-back operati are similarly announced *only* if it is estimated they will be detected off-site.

The Environmental Protection Agency is pre at every test and is therefore immediately awa any prompt release. The Environmental Prote Agency, however, is not present at post-test back operations. In the case of late-time releas operational releases, the Environmental Prote Agency depends on notification from the De ment of Energy and on detection of the release (

[10] Baneberry, however, had a limited data set of usable radioactive readings.

it has reached outside the borders of the test site) by the EPA offsite monitoring system.

Estimates of whether a particular release will be detected offsite are made by the Department of Energy or the sponsoring laboratory. Such judgments, however, are not always correct. During the drill-back operations of the Glencoe test in 1986, minor levels of radioactive material were detected offsite contrary to expectations. During the Riola test in 1980, minor amounts of radioactive inert gases were detected offsite. In both cases, DOE personnel did not anticipate the release to be detected offsite and therefore did not notify EPA.[11] Although the releases were extremely minor and well-monitored within the test site by DOE, EPA was not aware of the release until the material had crossed the test site boundaries. Both cases fueled concern over DOE's willingness to announce accidents at the test site. **The failure of DOE to publicly announce all releases, regardless of size or circumstance, contributes to public concerns over the secrecy of the testing program and reinforces the perceptions that all the dangers of the testing program are not being openly disclosed.**

### *Onsite Monitoring by the Department of Energy*

The Department of Energy has responsibility for monitoring within the boundaries of the Nevada Test Site to evaluate the containment of radioactivity onsite and to assess doses-to-man from radioactive releases as a result of DOE operations. To achieve these objectives, DOE uses a comprehensive monitoring system that includes both real-time monitoring equipment and sample recovery equipment. The real-time monitoring system is used for prompt detection following a test, the sample recovery equipment is used to assess long-term dose and risk.

The heart of the real-time monitoring system is a network of Remote Area Monitors (RAMs). For all tests, RAMs are arranged in an array around the test hole (figure 4-5). Radiation detectors are also frequently installed down the stemming column so the flow of radioactive material up the emplacement hole can be monitored. In tunnel shots, there are RAMs above the shot point, throughout the tunnel complex, outside the tunnel entrance, and in each containment vessel (figure 4-6). In addition to RAMs positioned for each shot, a permanent RAM network with stations throughout the test site is in continual operation.

During each test, a helicopter with closed-circuit television circles the ground zero location. Nearby, a second helicopter and an airplane are prepared to track any release that might occur. A third helicopter and an airplane remain on stand-by should they be needed. In addition, a team (called the "Bluebird Team"), consisting of trained personnel in 2 four-wheel drive vehicles outfitted with detection equipment and personnel protection gear is stationed near the projected fallout area to track and monitor any release. Approximately 50 radiation monitoring personnel are available on the Nevada Test Site to make measurements of exposure rates and collect samples for laboratory analysis should they be needed. Prior to the test, portions of the test site are evacuated unless the operation requires manned stations. If manned stations are required, direct communication links are established with the workers and evacuation routes are set-up.

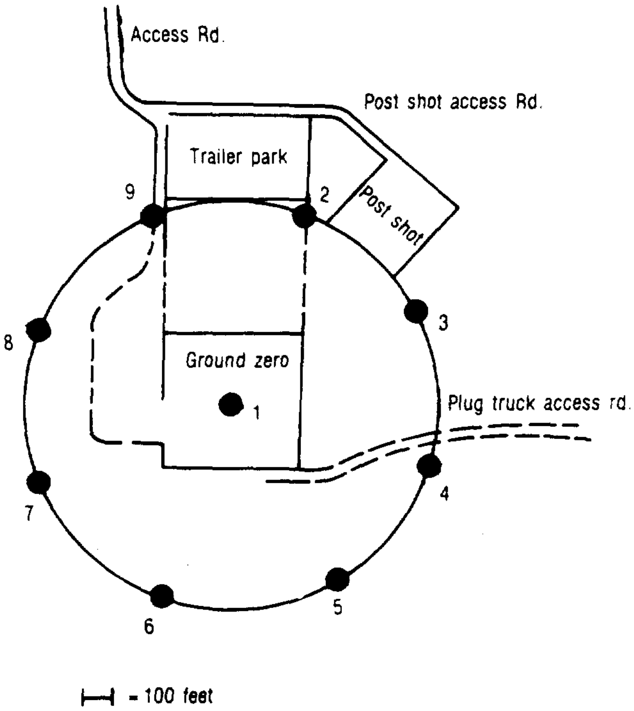
In addition to the real-time monitoring network, air and water samples are collected throughout the Test Site and analyzed at regular intervals. This comprehensive environmental monitoring program is summarized in table 4-2. The network of samplers located throughout the Test Site includes 160 thermoluminescent dosimeters; over 40 air samplers that collect samples for analysis of radioiodines, gross beta, and plutonium-239; and about half a dozen noble gas samplers. Each year over 4,500 samples are collected and analyzed for radiological measurement and characterization of the Nevada Test Site. All sample collection, preparation, analysis, and review are performed by the staff of the Laboratory Operations Section of REECO's Environmental Sciences Department.

In the case of a prompt, massive accidental release of radioactive material, the following emergency procedures would be initiated:

1. any remaining test site employees downwind of the release would be evacuated,
2. monitoring teams and radiological experts would be dispatched to offsite downwind areas,

[11] In the case of Riola, the release occurred in the evening and was not reported until the following morning. As a result, it was 12½ hours before EPA was notified.

**Figure 4-5—Typical RAMs Array for Vertical Drill-Hole Shot**




In addition to the RAMs located down the drill hole, nine RAMs are placed at the surface around the test hole.

SOURCE: Modified from Department of Energy.

3. ground and airborne monitoring teams would measure radioactive fallout and track the radioactive cloud,
4. Federal, State, and local authorities would be notified, and
5. if necessary, persons off-site would be requested to remain indoors or to evacuate the area for a short time.[12]

### *Offsite Monitoring by the Environmental Protection Agency*

Under an interagency agreement with the Department of Energy, the Environmental Protection Agency is responsible for evaluating human radiation exposure from ingesting air, water, and food that may have been affected by nuclear testing. To accomplish this, EPA collects over 8,700 samples each year and performs over 15,000 analytical measurements on water, milk, air, soil, humans, plants, and animals.[13] The sampling system and results are published annually in EPA's "Offsite Environmental Monitoring Report, Radiation Monitoring Around United States Nuclear Test Areas."

The heart of the EPA monitoring system is the network of 18 community monitoring stations. The community monitoring program began in 1981 and was modeled after a similar program instituted in the area surrounding the Three Mile Island nuclear reactor power plant in Pennsylvania. Community participation allows residents to verify independently the information being released by the government and thereby provide reassurance to the community at large. The program is run in partnership with several institutions. The Department of Energy funds the program and provides the equipment. The Environmental Protection Agency maintains the equipment, analyzes collected samples, and interprets results. The Desert Research Institute manages the network, employs local station managers, and independently provides quality assurance and data interpretation. The University of Utah trains the station managers selected by the various communities. Whenever possible, residents with some scientific training (such as science teachers) are chosen as station managers.

There are 18 community monitoring stations (shown as squares in figure 4-7) located around the test site. The equipment available to each station includes:[14]

**Noble Gas Samplers**: These samplers compress air in a tank. The air sample is then analyzed to measure the concentration of such radioactive noble gases as xenon and krypton.

**Tritium Sampler**: These samplers remove moisture from the air. The moisture is then analyzed to measure the concentration of tritium in the air.

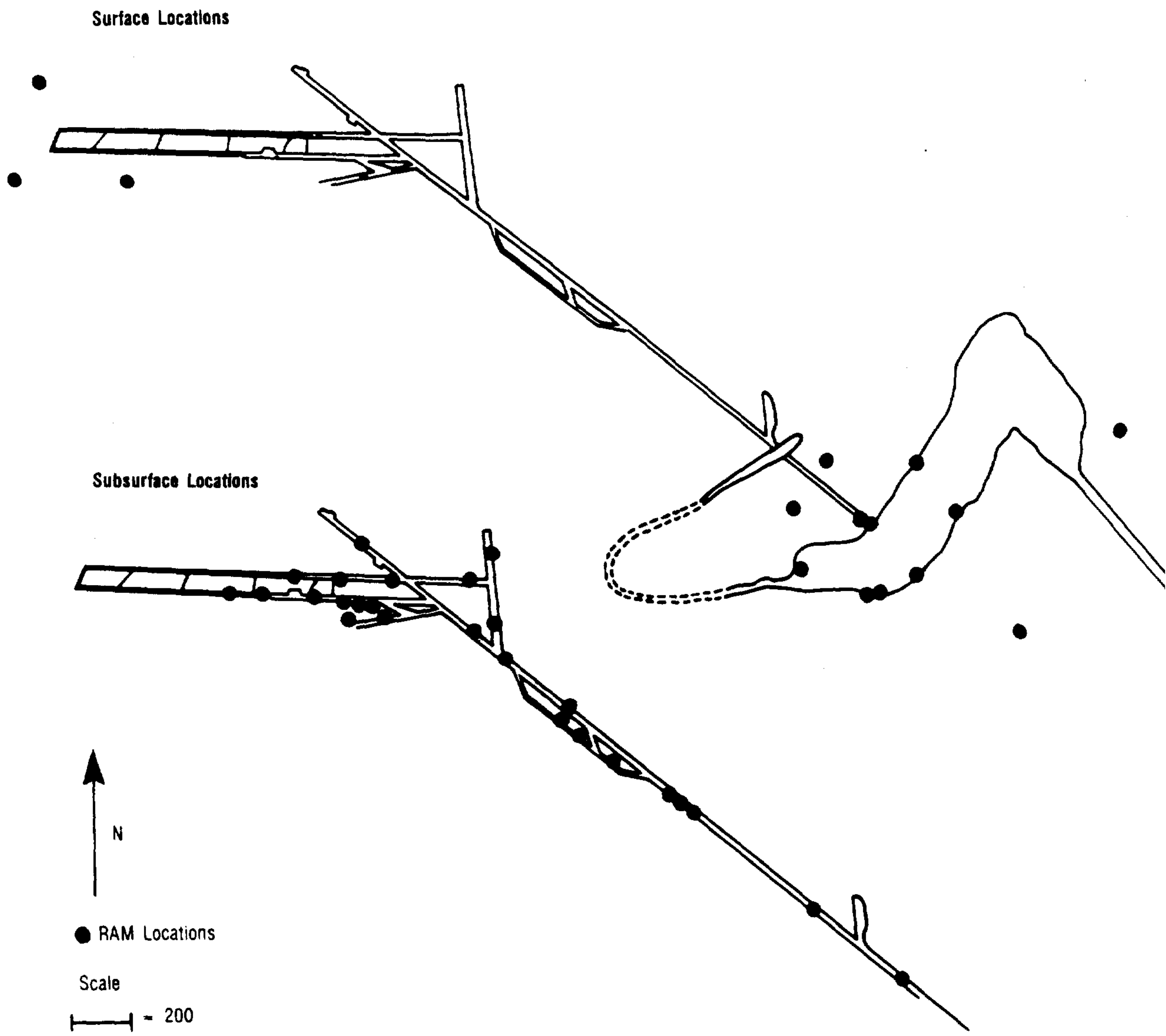
**Particulates and Reactive Gases Sampler**: These samplers draw 2 cubic feet of air per minute through a paper filter and then through a canister of activated charcoal. The paper filter collects particles and the charcoal collects reactive gases. Both are analyzed for radioactivity.

[12] Modified from "Onsite Environmental Report for the Nevada Test Site" (January 1987 through December 1987), Daniel A. Gonzalez, REECo., Inc., DOE/NV/10327-39.

[13] In addition, EPA annually visits each location outside the Nevada Test Site where a nuclear test has occurred.

[14] "Community Radiation Monitoring Program," U.S. Environmental Protection Agency, January 1984.

**Figure 4-6—Typical RAMs Array for Tunnel Shot ("Mission Cyber," Dec. 2, 1988)**




A total of 41 RAMs (15 above the surface, 26 belowground) are used to monitor the containment of radioactive material from a horizo tunnel test.

SOURCE: Modified from Department of Energy.

**Thermoluminescent Dosimeter (TLD)**: When heated (thermo-), the TLD releases absorbed energy in the form of light (-luminescent). The intensity of the light is proportional to the gamma radiation absorbed, allowing calculation of the total gamma radiation exposure.

**Gamma Radiation Exposure Rate Recorder**: A pressurized ion chamber detector for gamma radiation is connected to a recorder so that a continuous record of gamma radiation is obtained and chan in the normal gamma radiation level are easily se

**Microbarograph**: This instrument measures records barometric pressure. The data are usefu interpreting gamma radiation exposure rate reco At lower atmospheric pressure, naturally occurr radioactive gases (like radon) are released in gre amounts from the Earth's surface and their radio tive decay contributes to total radiation exposur

**Table 4-2—Summary of Onsite Environmental Monitoring Program**

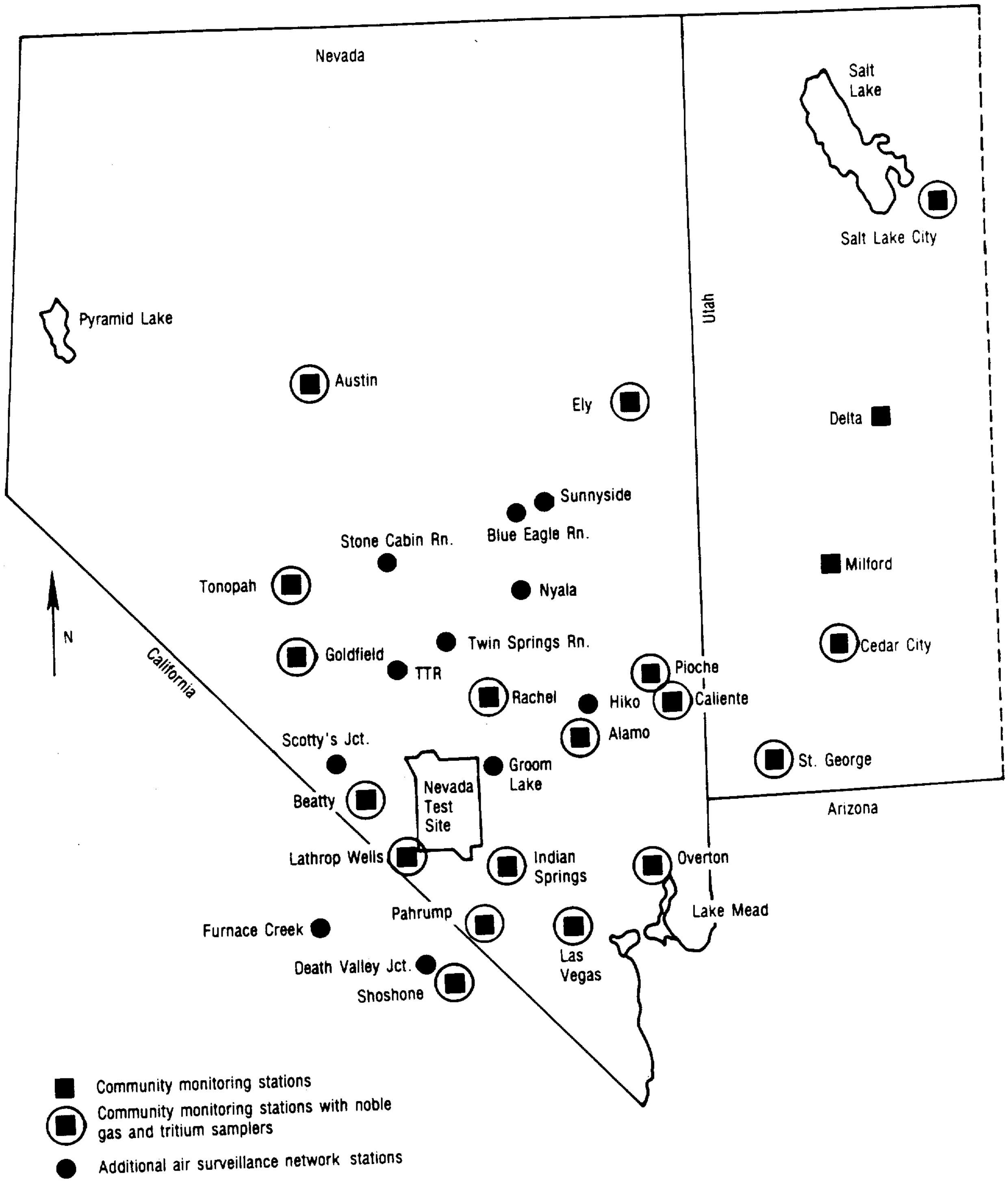
| Sample type | Description | Collection frequency | Number of locations | Analysis |
|---|---|---|---|---|
| Air | Continuous sampling through gas filter & charcoal cartridge | Weekly | 44 | Gamma Spectroscopy gross beta, Pu-239 |
| | Low-volume sampling through silica gel | Biweekly | 16 | Tritium (HTO) |
| | Continuous low volume | Weekly | 7 | Noble gases |
| Potable water | 1-liter grab sample | Weekly | 7 | Gamma Spectroscopy gross beta,tritium Pu-239 (quarterly) |
| Supply wells | 1-liter grab sample | Monthly | 16 | Gamma Spectroscopy gross beta,tritium Pu-239 (quarterly) |
| Open reservoirs | 1-liter grab sample | Monthly | 17* | Gamma Spectroscopy gross beta,tritium Pu-239 (quarterly) |
| Natural springs | 1-liter grab sample | Monthly | 9* | Gamma Spectroscopy gross beta,tritium Pu-239 (quarterly) |
| Ponds (contaminated) | 1-liter grab sample | Monthly | 8* | Gamma Spectroscopy gross beta,tritium Pu-239 (quarterly) |
| Ponds (effluent) | 1-liter grab sample | Monthly | 5 | Gamma Spectroscopy gross beta,tritium Pu-239 (quarterly) |
| External gamma radiation levels | Thermoluminescent Dosimeters | Semi-annually | 153 | Total integrated exposure over field cycle |

*Not all of these locations were sampled due to inaccessibility or lack of water.

*Photo credit: David Graham, 1988*

Community Monitoring Station, Las Vegas, NV.

**Figure 4-7—Air Monitoring Stations**




SOURCE: Modified from Environmental Protection Agency.

The monitoring stations are extremely sensitive; they can detect changes in radiation exposure due to changing weather conditions. For example, during periods of low atmospheric pressure, gamma exposure rates are elevated on the order of 2 to 4 uR/hr because of the natural radioactive products being drawn out of the ground. To inform the public, data from the community monitoring stations are posted at each station and sent to local newspapers (figure 4-8).

In addition to the 18 community monitoring stations, 13 other locations are used for the Air Surveillance Network (shown as circles in figure 4-7) to monitor particulates and reactive gases. The air surveillance network is designed to cover the area within 350 kilometers of the Nevada Test Site, with a concentration of stations in the prevailing downwind direction. The air samplers draw air through glass fiber filters to collect airborne particles (dust). Charcoal filters are placed behind the glass fiber filters to collect reactive gases. These air samplers are operated continuously and samples are collected three times a week. The Air Surveillance Network is supplemented by 86 standby air sampling stations located in every State west of the Mississippi River (figure 4-9). These stations are ready for use as needed and are operated by local individuals or agencies. Standby stations are used 1 to 2 weeks each quarter to maintain operational capability and detect long-term trends.

Noble gas and tritium samplers are present at 17 of the air monitoring stations (marked with asterisk in figure 4-7). The samplers are located at stations close to the test site and in areas of relatively low altitude where wind drains from the test site. Noble gases, like krypton and xenon, are nonreactive and are sampled by compressing air in pressure tanks. Tritium, which is the radioactive form of hydrogen, is reactive but occurs in the form of water vapor in air. It is sampled by trapping atmospheric moisture. The noble gas and tritium samplers are in continuous operation and samples are recovered and analyzed weekly.

To monitor total radiation doses, a network of approximately 130 TLDs is operated by EPA. The network encircles the test site out to a distance of about 400 miles with somewhat of a concentration in the zones of predicted fallout (figure 4-10). The TLD network is designed to measure environmental radiation exposures at a location rather than exposures to a specific individual. By measuring exposures at fixed locations, it is possible to determine the maximum exposure an individual would have received had he or she been continually present at that location. In addition, about 50 people living near the test site and all personnel who work on the test site wear TLD's. All TLD's are checked every 3 months for absorbed radiation.

Radioactive material is deposited from the air onto pastures. Grazing cows concentrate certain radionuclides, such as iodine-131, strontium-90, and cesium-137 in their milk. The milk therefore becomes a convenient and sensitive indicator of the fallout. The Environmental Protection Agency analyzes samples of raw milk each month from about 25 farms (both family farms and commercial dairies) surrounding the test site (figure 4-11). In addition to monthly samples, a standby milk surveillance network of 120 Grade A milk producers in all States west of the Mississippi River can provide samples in case of an accident (figure 4-12). Samples from the standby network are collected annually.

Another potential exposure route of humans to radionuclides is through meat of local animals. Samples of muscle, lung, liver, kidney, blood, and bone are collected periodically from cattle purchased from commercial herds that graze northeast of the test site. In addition, samples of sheep, deer, horses, and other animals killed by hunters or accidents are used (figure 4-13). Soft tissues are analyzed for gamma-emitters. Bone and liver are analyzed for strontium and plutonium; and blood/urine or soft tissue is analyzed for tritium.

A human surveillance program is also carried out to measure the levels of radioactive nuclides in families residing in communities and ranches around the test site (figure 4-14). About 40 families living near the test site are analyzed twice a year. A whole-body count of each person is made to assess the presence of gamma-emitting radionuclides.

## GROUNDWATER

About 100 underground nuclear tests have been conducted directly in the groundwater. In addition, many pathways exist for radioactive material from other underground tests (tests either above or below the water table) to migrate from the test cavities to the groundwater. To detect the migration of radioactivity from nuclear testing to potable water sources, a long-term hydrological monitoring program is

Photo credit [illegible] 1988

Whole Body Counter, Environmental Protection Agency.

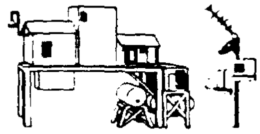
managed by the Environmental Protection Agency at the Department of Energy's direction with advice on sampling locations being obtained from the U.S. Geological Survey. Whenever possible, water samples are collected from wells downstream (in the direction of movement of underground water) from sites of nuclear detonations. On the Nevada Test Site, about 22 wells are sampled monthly (figure 4-15). The 29 wells around the Nevada Test Site (figure 4-16) are also sampled monthly and analyzed for tritium semiannually.

The flow of groundwater through the Nevada Test Site is in a south-southwesterly direction. The flow speed is estimated to be about 10 feet per year, although in some areas it may move as fast as 600 feet per year. To study the migration of radionuclides from underground tests, DOE drilled a test well near a nuclear weapons test named "Cambric." Cambric had a yield of 0.75 kilotons and was detonated in a vertical drill hole in 1965. A test well was drilled to a depth of 200 feet below the cavity created by Cambric. It was found that most of the radioactivity produced by the test was retained within the fused rock formed by the explosion, although low concentrations of radioactive material were found in the water at the bottom of the cavity.[15] A satellite well was also drilled 300 feet from the cavity. More than 3 billion gallons of water were pumped from the satellite well in an effort to draw water from the region of the nuclear explosion. The only radioactive materials found in the water were extremely small quantities (below the permitted

[15]See "Radionuclide Migration in Groundwater at NTS," U.S. Department of Energy, September, 1987.

**Figure 4-8—Sample Press Release**

# Alamo, NV

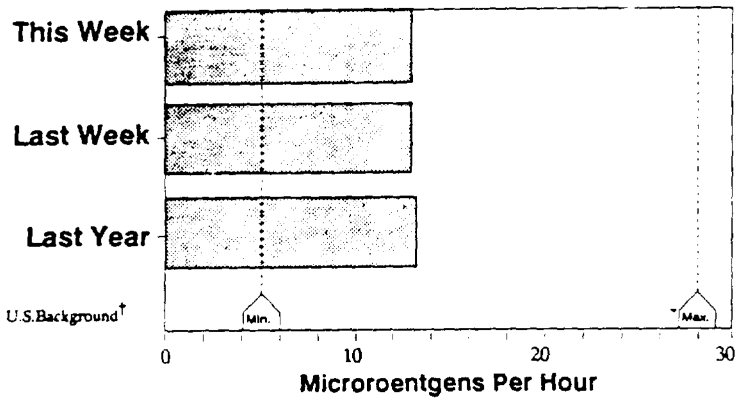


**July 11 to July 20, 1988**
**The Nevada Test Site**
**COMMUNITY RADIATION MONITORING REPORT**

EPA

Dell Sullivan, Manager of the Community Radiation Monitoring Station in Alamo, NV reported the results of the radiation measurements at this station for the period July 11 to July 20, 1988. The average gamma radiation exposure rate recorded by a Pressurized Ion Chamber at this station was 13.0 microroentgens* per hour as shown on the chart.

**AVERAGE GAMMA RADIATION EXPOSURE RATE RECORDED ON THE PRESSURIZED ION CHAMBER AT ALAMO, NV, DURING THE WEEK ENDING JULY 20, 1988**




The averages of the 16 Community Monitoring Stations operated for the Environmental Protection Agency, Department of Energy and the Desert Research Institute varied from 6.2 microroentgens per hour at Las Vegas, NV to 20.2 microroentgens per hour at Austin, NV. All of the rates for the past week were within the normal background range for the United States as shown on the accompanying chart. Environmental radiation exposure rates vary with altitude and natural radioactivity in the soil. Additional information and detailed data obtained from Community Radiation Monitoring Network Stations, including an annual summary of the results from all monitoring around the Nevada Test Site, can be obtained from Mr. Sullivan (702) 725-3544 or by calling Charles F. Costa at the EPA in Las Vegas (702) 798-2305.

*The roentgen is a measure of exposure to X or gamma radiation. A microroentgen is 1 millionth of a roentgen. For comparison, one chest x-ray results in an exposure of 10,000 to 20,000 microroentgens.

† Sum of cosmic plus terrestrial dose rates in air in the U.S.(pp37,42, BEIR III, 1980).

Example of community radiation monitoring report that is posted at each monitoring station and sent to the press.

SOURCE: Environmental Protection Agency.

**Figure 4-9—Standby Air Surveillance Network Stations**

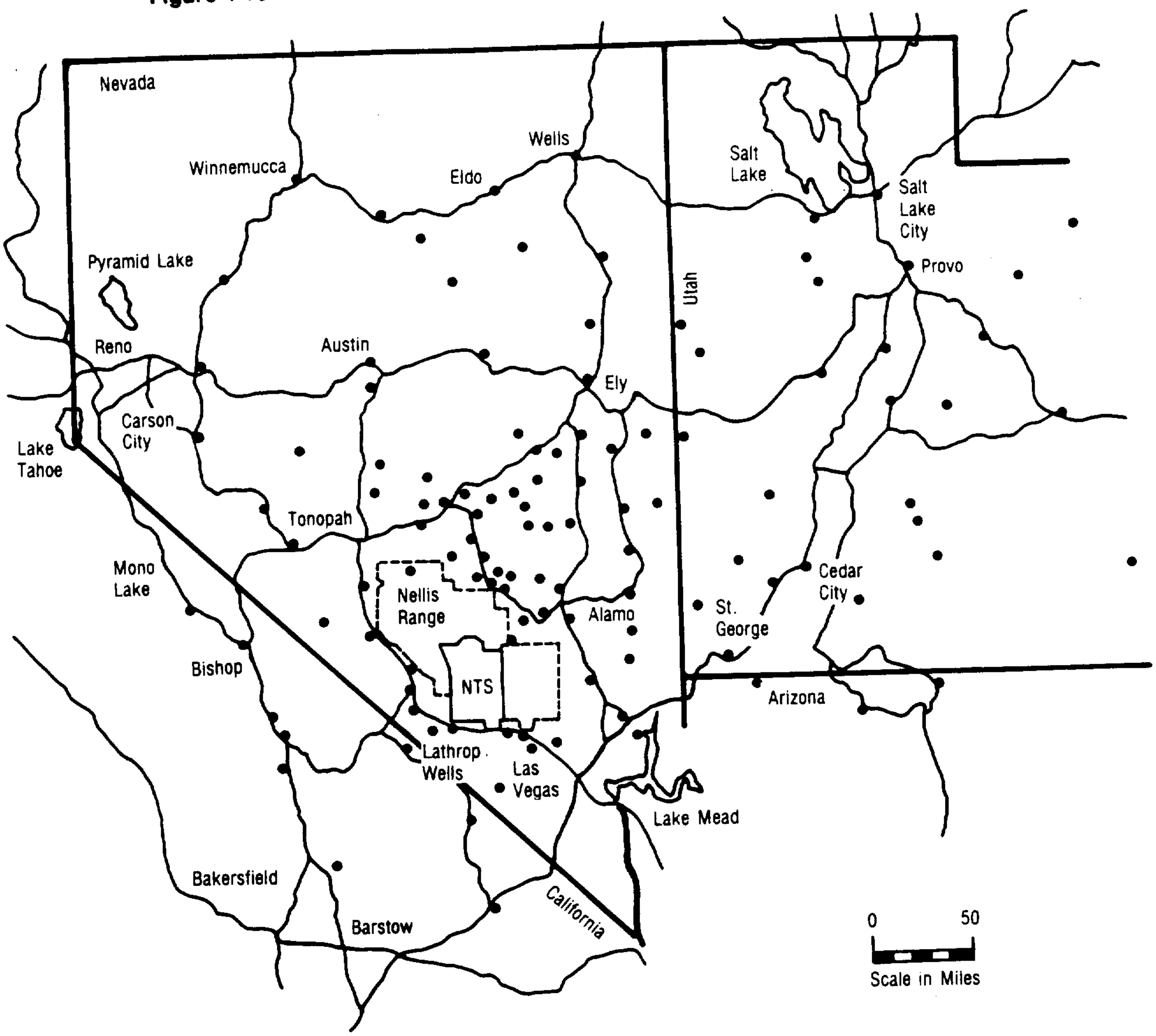

86 standby air surveillance stations are available and samples are collected and analyzed every 3 months to maintain a data base.

SOURCE: Modified from Environmental Protection Agency.

level for drinking water) of krypton-85, chlorine-36, ruthenium-106, technetium-99 and iodine-129.

Radioactive material from nuclear testing moves through the groundwater at various rates and is filtered by rock and sediment particles. Tritium, however, is an isotope of hydrogen and becomes incorporated in water molecules. As a result, tritium moves at the same rate as groundwater. Tritium is therefore the most mobile of the radioactive materials. Although tritium migrates, the short half-life of tritium (12.3 years) and slow movement of the groundwater prevents it from reaching the Test Site boundary. No analysis of groundwater has ever found tritium at a distance greater than a few hundred meters from some of the old test sites. None of the water samples collected outside the bounda-

Figure 4-10—Locations Monitored With Thermoluminescent Dosimeters (TLDs)




One hundred thirty locations are monitored with TLDs. All TLDs are checked every 3 months for absorbed radiation.

SOURCE: Modified from Environmental Protection Agency.

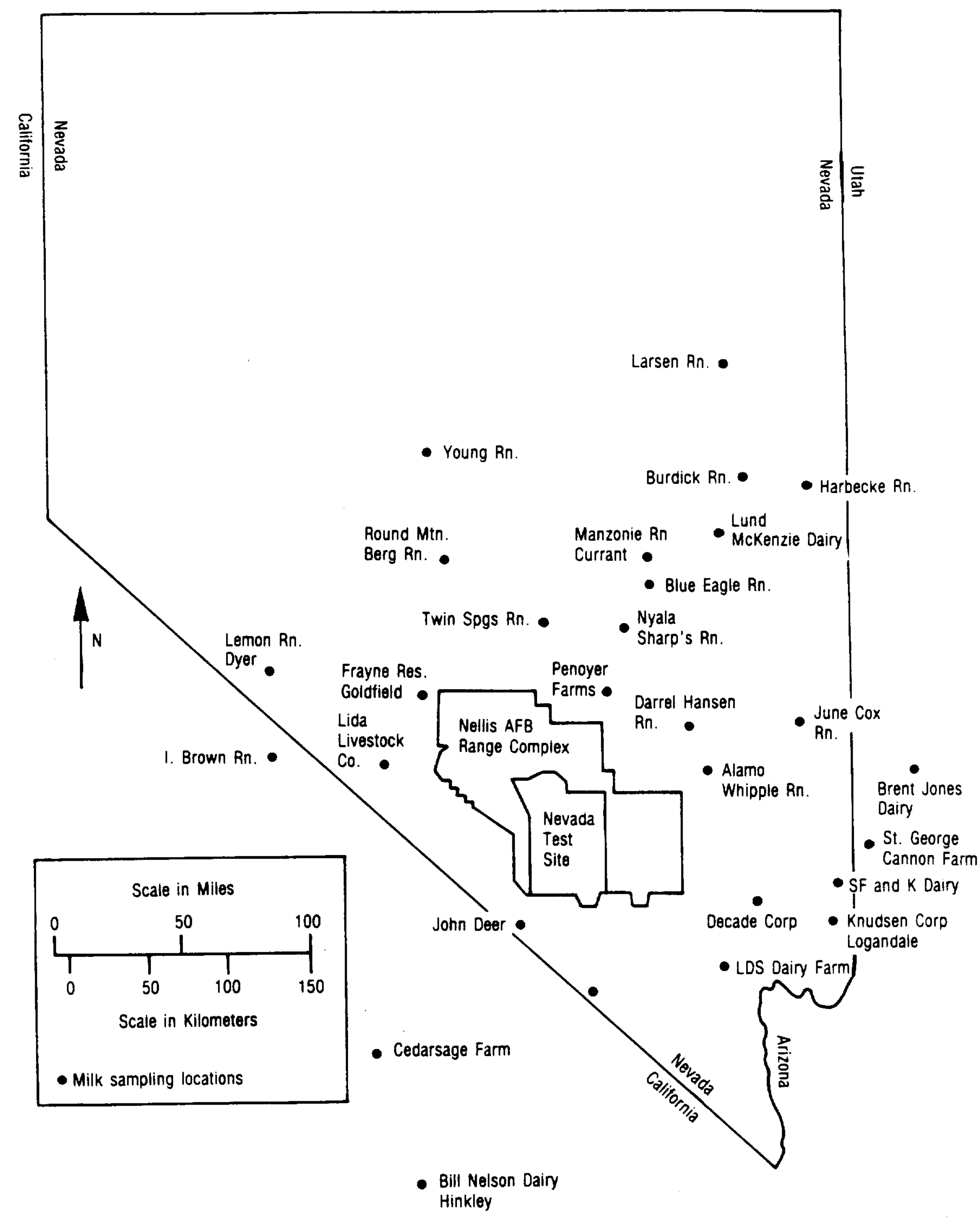
ries of the test site has ever had detectable levels of radioactivity attributable to the nuclear testing program. An independent test of water samples from around the test site was conducted by Citizen Alert (Reno, Nevada) at 14 locations (table 4-3).

Citizen Alert found no detectable levels of tritium or fission products in any of their samples. Withstanding any major change in the water table, there currently appears to be no problem associated with groundwater contamination offsite of the Nevada Test Site.

## MONITORING CAPABILITY

The combination of: 1) the monitoring system deployed for each test, 2) the onsite monitoring system run by DOE, and 3) the offsite monitoring system run by EPA, forms a comprehensive detection system for radioactive material. There is

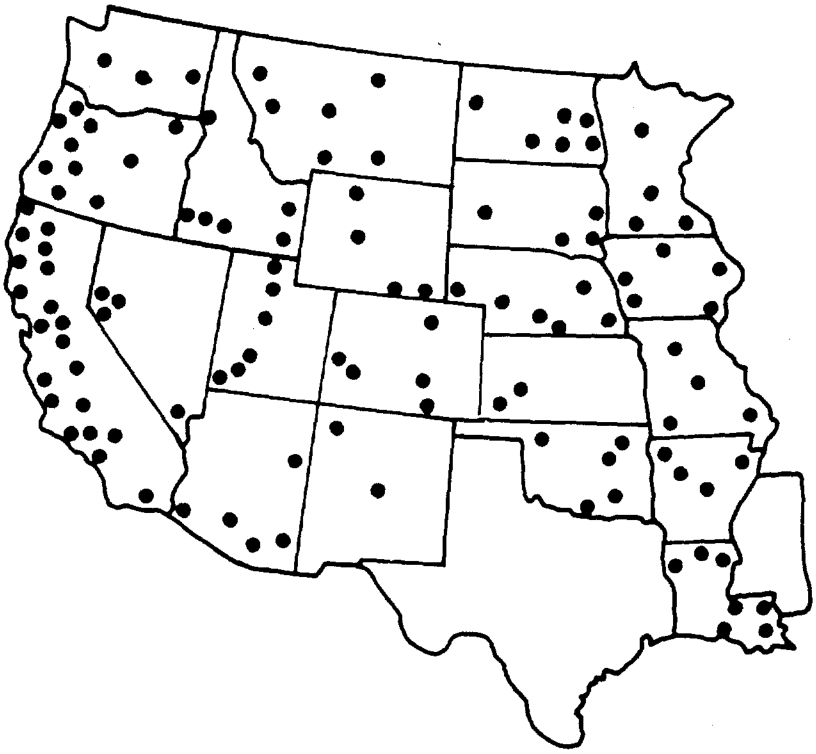
**Figure 4-11—Milk Sampling Locations**




**Samples of raw milk are collected each month from about 25 farms surrounding the test site.**

SOURCE: Modified from Environmental Protection Agency.

Figure 4-12—Standby Milk Surveillance Network



All major milksheds west of the Mississippi River are part of the standby milk surveillance network. Samples are collected and analyzed annually.

SOURCE: Modified from Environmental Protection Agency.

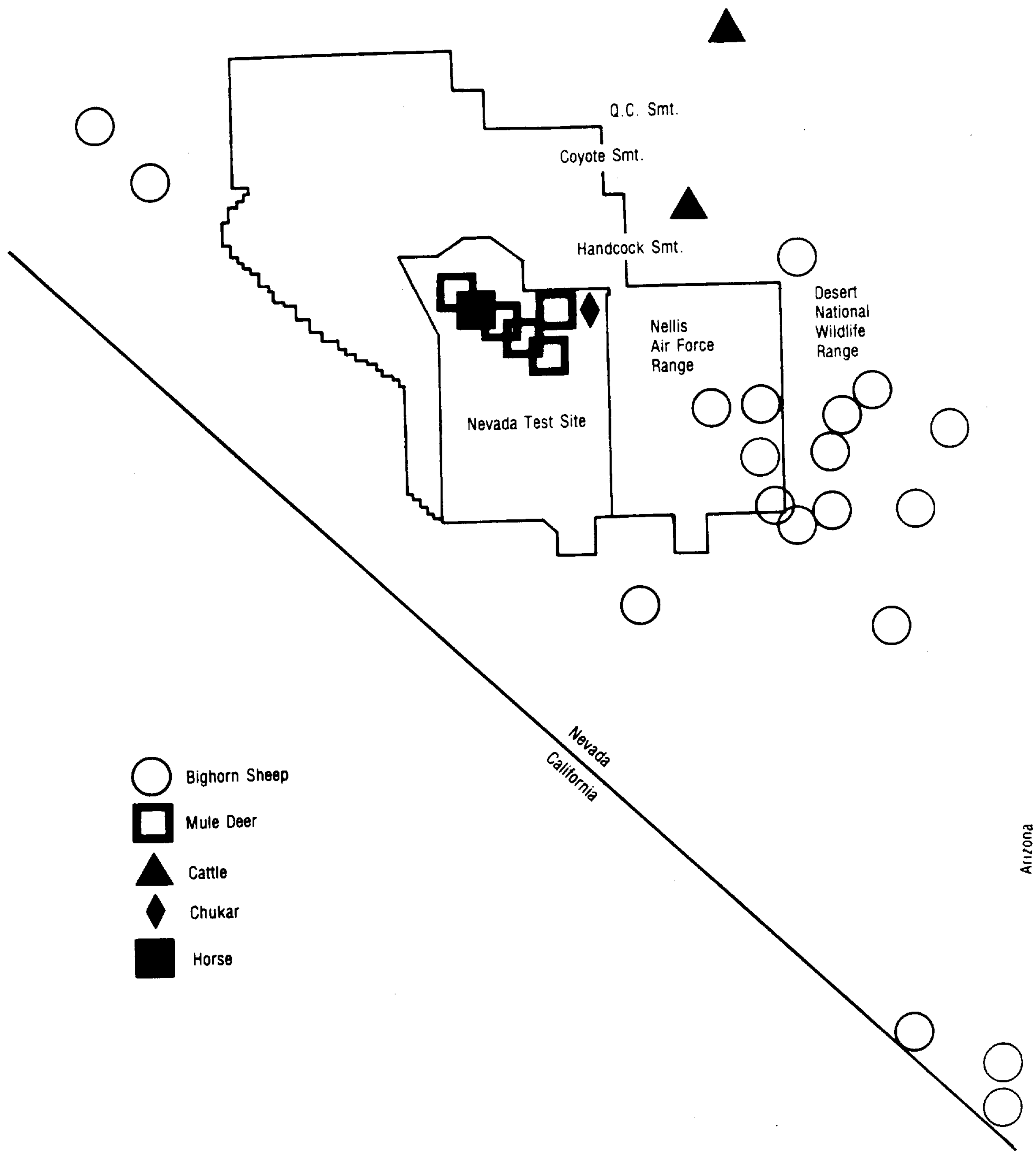
**essentially no possibility that a significant release of radioactive material from an underground nuclear test could go undetected. Similarly, there is essentially no chance that radioactive material could reach a pathway to humans and not be discovered by the Environmental Protection Agency.** Allegations that a release of radioactive material could escape from the test site undetected are based on partial studies that only looked at a small portion of the total monitoring system.[16] Such criticisms are invalid when assessed in terms of the total monitoring system.

The radiation monitoring system continues to improve as new measurement systems and techniques become available and as health risks from radiation become better understood. Assuming that the monitoring effort will continue to evolve, and that such issues as the migration of radioactive material in groundwater will continue to be aggressively addressed, there appear to be no valid criticisms associated with the containment of underground nuclear explosions. This is not to say that future improvement will not be made as experience increases, but only that essentially all relevant suggestions made to date that increase the safety margin have been implemented.

Public confidence in the monitoring system suffers from a general lack of confidence in the Department of Energy that emanates from the enivronmental problems at nuclear weapons production facilities and from the radiation hazards associated with past atmospheric tests. In the case of the

[16]See for example, "A review of off-site environmental monitoring of the Nevada Test Site," Bernd Franke, Health Effects of Underground Nuclear Tests, Oversight Hearing before the Subcommittee on Energy and the Environment of the Committee on Interior and Insular Affairs, House of Representatives, Sept. 25, 1987, Serial No. 100-35, pp. 120-144.

**Figure 4-13—Collection Site for Animals Sampled in 1987**




Depending on availability, an assortment of animals are analyzed each year.

SOURCE: Modified from Environmental Protection Agency.

**Table 4-3—Citizen Alert Water Sampling Program**

| Location | Type of Sample |
|---|---|
| Springdale Ranch | Well (hose) |
| Barley Hot Springs | Stream |
| 3 mi. south of Flourspar Canyon | Amargosa River |
| Lathrop Wells | Spigot at gas station |
| Point of Rock Spring, Ash Meadows | Pond |
| Devils Hole, Ash Meadows | Pool |
| Shoshone, CA | Stream |
| Amargosa Junction | Well (hose) |
| Goldfield | Well (spigot at gas station) |
| Moore's Station | Pond |
| Six Mile Creek | Stream |
| Tybo and Route 6 (DOE facility) | Well (tap) |
| Hot Creek and Route 6 | Stream |
| Blue Jay | Well (hose) |

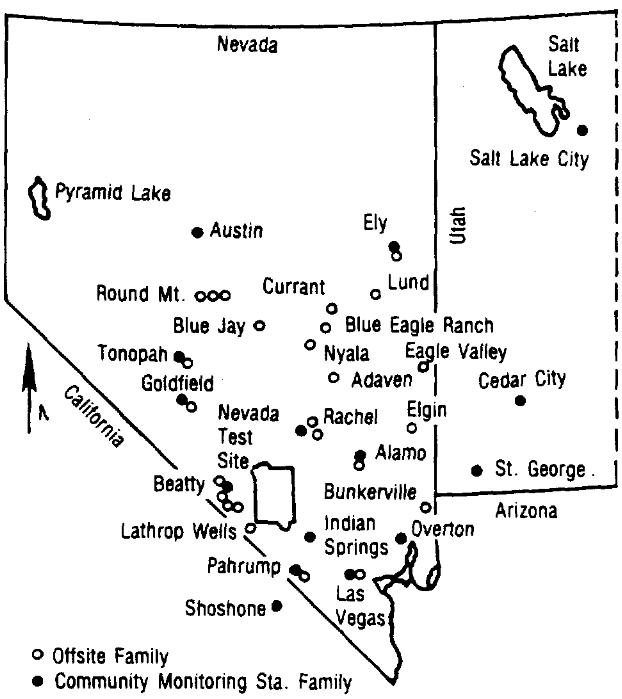
SOURCE: Citizen Alert, 1988

underground nuclear testing program, this mistrust is exacerbated by the reluctance on the part of the Department of Energy to disclose information concerning the nuclear testing program, and by the knowledge that not all tests that release radioactive material to the atmosphere (whatever the amount or circumstances) are announced. This has led to allegations by critics of the testing program that:

> . . . the Energy Department is continuing its misinformation campaign by refusing to disclose the size of most underground tests, by hushing up or downplaying problems that occur and by not announcing most tests in advance, thereby leaving people downwind unprepared in the event of an accidental release of radioactive materials.[17]

Such concern could be greatly mitigated if a policy were adopted such that all tests were announced, or at least that all tests that released any radioactive material to the atmosphere (whatever the amount or circumstances) were announced.

**Figure 4-14—Locations of Families in the Offsite Human Surveillance Program**

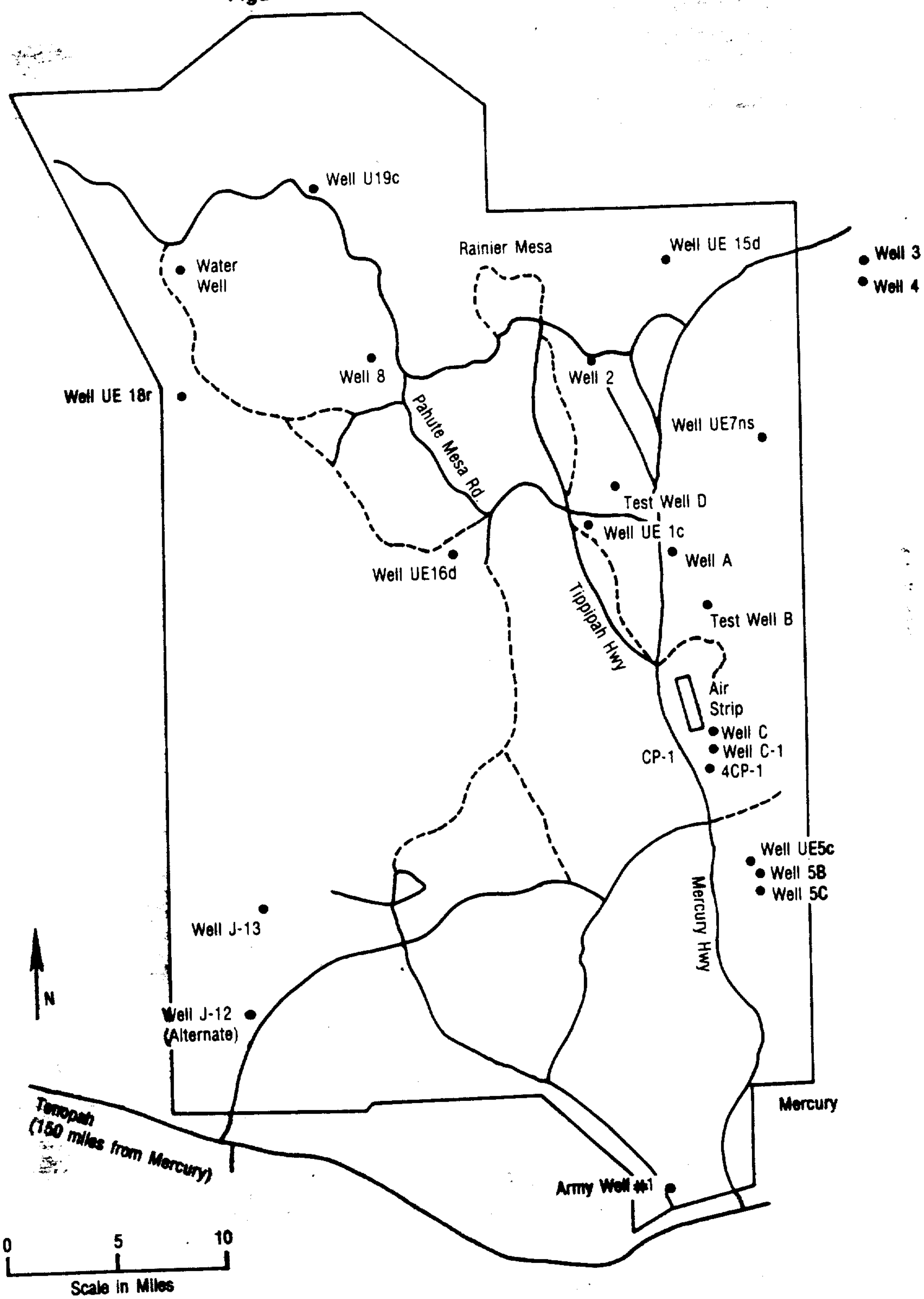



About 40 families from around the test site are brought in to EPA twice a year for whole-body analysis.

SOURCE: Modified from Environmental Protection Agency.

[17]John Hanrahan, "Testing Underground," *Common Cause*, vol. 15, No. 1, January/February 1989.

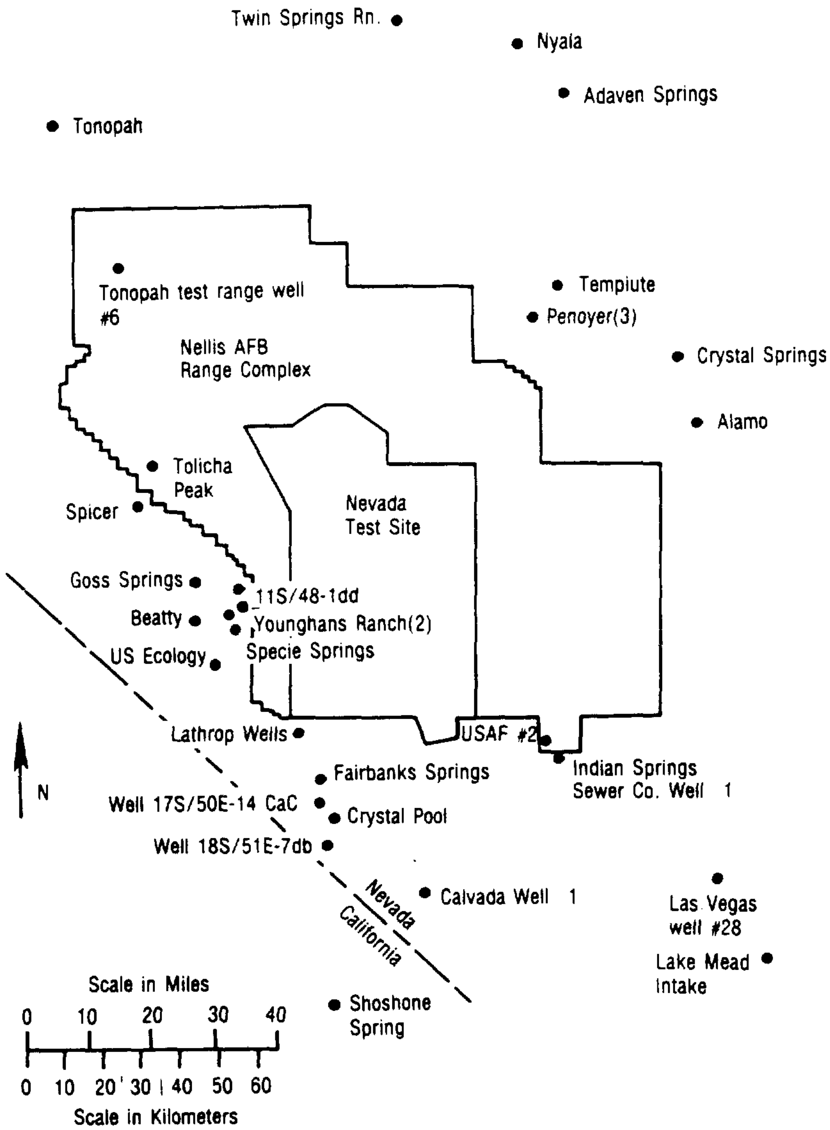
**Figure 4-15—Well Sampling Locations Onsite**




22 wells on the Nevada Test Site are sampled monthly.

SOURCE: Modified from Department of Energy.

**Figure 4-16—Well Sampling Locations Offsite**




31 wells around the Nevada Test Site are sampled twice a year.

SOURCE: Modified from Department of Energy.

## Related OTA Report

- *Seismic Verification of Nuclear Testing Treaties.*
  OTA-ISC-361, 5/88; 139 pages. GPO stock #052-003-01108-5; $7.50.
  NTIS order #PB 88-214 853/XAB.

NOTE: Reports are available from the U.S. Government Printing Office, Superintendent of Documents, Washington, D.C. 20402-9325 (202-783-3238); and the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161-0001 (703-487-4650).

# Office of Technology Assessment

The Office of Technology Assessment (OTA) was created in 1972 as an analytical arm of Congress. OTA's basic function is to help legislative policymakers anticipate and plan for the consequences of technological changes and to examine the many ways, expected and unexpected, in which technology affects people's lives. The assessment of technology calls for exploration of the physical, biological, economic, social, and political impacts that can result from applications of scientific knowledge. OTA provides Congress with independent and timely information about the potential effects—both beneficial and harmful—of technological applications.

Requests for studies are made by chairmen of standing committees of the House of Representatives or Senate; by the Technology Assessment Board, the governing body of OTA; or by the Director of OTA in consultation with the Board.

The Technology Assessment Board is composed of six members of the House, six members of the Senate, and the OTA Director, who is a nonvoting member.

OTA has studies under way in nine program areas: energy and materials; industry, technology, and employment; international security and commerce; biological applications; food and renewable resources; health; communication and information technologies; oceans and environment; and science, education, and transportation.

OTA-ISC-414

OCTOBER 1989