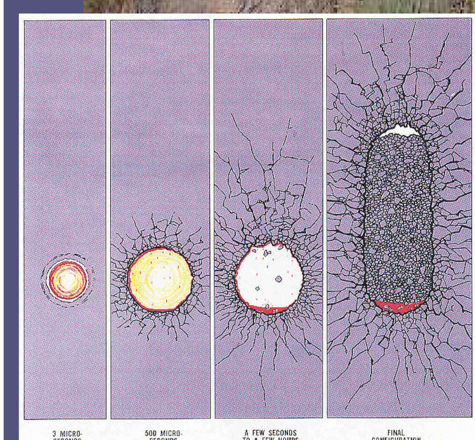
DOE/NV/26383-22

CULTURAL RESOURCES TECHNICAL REPORT NO. 111
DIVISION OF EARTH AND ECOSYSTEM SCIENCES
DESERT RESEARCH INSTITUTE
LAS VEGAS, NEVADA

THE OFF-SITE PLOWSHARE AND VELA UNIFORM PROGRAMS:

Assessing Potential Environmental Liabilities through an Examination of Proposed Nuclear Projects, High Explosive Experiments, and High Explosive Construction Activities

VOLUME 1 of 3



by
Colleen M. Beck, Susan R. Edwards, and Maureen L. King

with contributions by
Harold Drollinger, Robert Jones, and Barbara Holz

September 2011

Disclaimer

Available for sale to the public from:

U.S. Department of Commerce
National Technical Information Service
5301 Shawnee Road
Alexandria, VA 22312
Phone: 800.553.6847
Fax: 703.605.6900
E-mail: orders@ntis.gov
Online ordering: http://www.ntis.gov/help/ordermethods.aspx

Available electronically at http://www.osti.gov/bridge

Available for a processing fee to the U.S. Department of Energy and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
Phone: 865.576.8401
Fax: 865.576.5728
E-mail: reports@adonis.osti.gov

Cover Illustrations: The Project Bronco Site in northwestern Colorado and a schematic of a nuclear explosive-created rubble chimney. Bronco was a planned but never executed Plowshare project designed for the application of nuclear explosives to fracture underground oil shale deposits for in situ retorting and recovery (Photos by C. Beck, July 2005; Graphic from Lekas et al 1967, Figure 3).

DOE/NV/26383-22

THE OFF-SITE PLOWSHARE AND VELA UNIFORM PROGRAMS:

Assessing Potential Environmental Liabilities through an Examination of Proposed Nuclear Projects, High Explosive Experiments, and High Explosive Construction Activities

VOLUME 1 of 3

by

Colleen M. Beck, Susan R. Edwards, and Maureen L. King

with contributions by
Harold Drollinger, Robert Jones, and Barbara Holz

Prepared for

U.S. Department of Energy
National Nuclear Security Administration
Nevada Site Office, Las Vegas, Nevada

Cultural Resources Technical Report No. 111
Division of Earth and Ecosystem Sciences
Desert Research Institute
Las Vegas, Nevada

September 2011

The work upon which this report is based was supported by the U.S. Department of Energy under Contract #DE-AC52-06NA26383.

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

This document presents the results of nearly six years (2002-2008) of historical research and field studies concerned with evaluating potential environmental liabilities associated with U.S. Atomic Energy Commission projects from the Plowshare and Vela Uniform Programs. The Plowshare Program's primary purpose was to develop peaceful uses for nuclear explosives. The Vela Uniform Program focused on improving the capability of detecting, monitoring and identifying underground nuclear detonations.

As a result of the Project Chariot site restoration efforts in the early 1990s, there were concerns that there might be other project locations with potential environmental liabilities. The Desert Research Institute conducted archival research to identify projects, an analysis of project field activities, and completed field studies at locations where substantial fieldwork had been undertaken for the projects. Although the Plowshare and Vela Uniform nuclear projects are well known, the projects that are included in this research are relatively unknown. They are proposed nuclear projects that were not executed, proposed and executed high explosive experiments, and proposed and executed high explosive construction activities off the Nevada Test Site. The research identified 170 Plowshare and Vela Uniform off-site projects and many of these had little or no field activity associated with them. However, there were 27 projects that merited further investigation and field studies were conducted at 15 locations.

THIS PAGE INTENTIONALLY LEFT BLANK

ACKNOWLEDGMENTS

The authors would like to thank the U.S. Department of Energy, National Nuclear Security Administration, Nevada Site Office for supporting this research, particularly Steve Mellington, Cindy Lockwood, Charles Morgan, Rick Betteridge, Linda Cohn, Pat Bodin, Hilda Hernandez, Runore Wycoff, and Bobbie McClure. National Security Technologies employees Loretta Bush, Nevada Site Office Technical Library, and Martha DeMarre, Nuclear Testing Archive, were of great assistance to us. The review of documents at the Lawrence Livermore National Laboratory and the Lawrence Berkeley National Laboratory was made possible by the efforts of Paul McGuff, who sponsored and organized our visits. At the Lawrence Livermore National Laboratory, Nancy Garcia conducted database searches for technical reports and facilitated our records search at the Technical Reports Library. Maxine Trost, with the Archives and Research Center, located documents for our review and with assistance from Pat Rhiner, devoted days to our research and report copying needs. Also, thanks to Milo Nordyke for his willingness to share his Plowshare project knowledge with us. At the Lawrence Berkeley National Laboratory Archives and Records Office, Trina Baker identified pertinent records prior to our arrival and made them available for our review. Thanks also go to the staff at the Bureau of Land Management Pinedale Field Office in Wyoming and at the two Bureau of Land Management offices in Colorado, the White River Field Office and the Glenwood Springs Field Office, for their time and efforts. Bureau of Land Management staff at the Colorado, Montana, Utah and Wyoming State Offices assisted us with searches for land records and various reports on file. Staff at the U.S. Army Corps of Engineers Albuquerque District, Trinidad Lake Project Office provided us with first-person accounts of Project Trinidad and directions to the project locations. We also thank the staff at the U.S. Army Corps of Engineers Omaha District, Fort Peck Lake Office, especially JoAnn Solem for her interest in this project and significant assistance with our research efforts. Our colleagues at the Desert Research Institute were invaluable. David Shafer provided support and, most importantly, shared his insights on this research topic. Charlotte Franky provided advice on this document and Hilary Green was the editor. Annette Risley and Lisa Wable prepared the maps, and Stefanie Rowland-Fleischmann, Crystal Chang, and Donna Schlemmer assisted with the production of this report.

THIS PAGE INTENTIONALLY LEFT BLANK

Table of Contents

List of Figures

List of Tables

THIS PAGE INTENTIONALLY LEFT BLANK

CHAPTER 1.0 INTRODUCTION

In the early 1990s, the U.S. Department of Energy Nevada Operations Office was notified that a location in Alaska where work was done by the U.S. Atomic Energy Commission had possible environmental issues that needed to be addressed. When contacted, the U.S. Department of Energy personnel were neither aware of this location nor familiar with the project. This project, named Chariot, was part of the U.S. Atomic Energy Commission's Plowshare Program. The purpose of the project was to excavate a harbor at Cape Thompson using nuclear explosives, but eventually the project was terminated. Almost 30 years had passed since the location was abandoned and it took some effort for the U.S. Department of Energy to find the historical information related to this work due to the loss of corporate memory. Between 1958 and 1962, there had been a feasibility study for Chariot that included fieldwork at the proposed project location. During the field evaluations, the United States Geological Survey conducted tracer studies in the soil using a small amount of radioactive isotopes. At the conclusion of the fieldwork, these soils were buried below clean soil in a disposal mound that was left on the landscape. To remediate this situation, the U.S. Department of Energy had this soil removed, shipped south, and then transported to the Nevada Test Site for burial at a cost of millions of dollars.

The Project Chariot restoration efforts raised questions regarding the potential for the existence of environmental liabilities associated with other U.S. Atomic Energy Commission projects conducted outside the Nevada Test Site. In the mid 1990s, the U.S. Department of Energy initiated a review of the Plowshare and Vela Uniform programs for other project names and locations. Twenty-six projects were identified and general information was found describing their purpose, location, and field activities. In 2002, the Environmental Management Division of the U.S. Department of Energy, Nevada Site Office requested that the Desert Research Institute continue this research and determine if any potential environmental liabilities are associated with these projects. The Desert Research Institute was tasked with conducting archival research to obtain additional information on the 26 projects, to conduct field studies at project locations, and evaluate whether or not potential liabilities associated with the projects exist. The researchers were also asked to identify additional Plowshare and Vela Uniform project names and to conduct the same research effort for these as for the original 26 projects. Although the Plowshare and Vela Uniform nuclear projects are well known, the projects that are included in this research are relatively unknown. They are proposed nuclear projects that were not conducted, proposed and executed high explosive experiments, and proposed and completed high explosive construction activities.

On August 23, 2010, the Nevada Test Site was renamed the Nevada National Security Site. The Nevada Test Site name is used throughout this document to retain the historic context for the research discussed here, to alleviate potential confusion regarding historic decisions and discussions, and to keep the text in concordance with the bibliographic references.

This report is divided into three volumes and contains the results of the historical investigation into this subset of Plowshare and Vela Uniform projects. Chapter 2 is an overview of the history of the Plowshare and Vela Uniform programs and an explanation of the methodology used for the research and evaluation of the projects. In Chapter 3, comprehensive descriptions of the 27 projects with medium to high potential for environmental liabilities are presented along with the results of the field studies and land status research. Chapter 4 has long descriptions of some of the projects with low to no potential for environmental liabilities. However, most of these projects are described in short summaries in Chapter 5. It was not feasible to present long descriptions for the 143 projects in this category and some projects in chapter 5 are more obscure. In Chapter 6, the research results are summarized, potential environmental liabilities are discussed, and other issues are identified. Both the short and long project descriptions were written as stand alone documents with independent chronological bibliographies at the conclusion of each discussion. This approach provides all project information in one place rather than scattered throughout the report. As a result of designing the project descriptions as stand alone documents, the use of acronyms was problematical and so they are not applied within the report. Appendix A contains Project Data Summaries for the projects discussed in Chapters 3 and 4 and is a quick reference for project information. The report concludes with a Master Bibliography of all Plowshare and Vela Uniform documents used in this research and in this report.

CHAPTER 2.0 RESEARCH, CONTEXT, AND METHODOLOGY

The purpose of this historical research is to identify little known project locations associated with the Plowshare and Vela Uniform programs with the potential to have environmental liabilities. Excluded from this effort were projects planned or conducted at a federal testing facility and other project sites currently under the jurisdiction of the U.S. Department of Energy. A list of 26 projects previously identified was the starting point for the research with an overarching goal to identify any additional project names and locations that might be of concern. Field studies were to be scheduled for locations where substantial activities occurred, followed by a determination as to whether or not the U.S. Department of Energy maintains obligations for a site under a land withdrawal. Central to this research is an understanding of the scope and breadth of the Plowshare and Vela Uniform Programs.

2.1 Plowshare and Vela Uniform Programs

On June 27, 1957, the U.S. Atomic Energy Commission approved the formation of the Plowshare Program in the Division of Military Applications. A few days later, on July 1, 1957, the Plowshare Program was formally established at the Lawrence Livermore National Laboratory, then known as the Livermore branch of the University of California Radiation Laboratory at Berkeley, to investigate the “possible non-military uses of nuclear explosive devices” with primary emphasis given to the potential excavation. A year earlier, an incident resulted in the first proposed application of nuclear detonations for civil engineering. On July 26, 1956, in response to political events, Egypt’s president nationalized the Suez Canal, a move that triggered international reactions and fears that Egypt would close the canal to certain foreign interests with great impact on world economies. In case this happened, options for a second canal from the Red Sea through Israel were under discussion. Of major concern was the amount of time it would take to create a new shipping lane. A suggestion by a nuclear scientist in the United States that such a canal could be excavated by nuclear explosives quickly stimulated considerable international interest in this possibility. In late December of 1956, before serious planning for a second canal was undertaken, the Suez situation was resolved without the closure of the canal. The crisis, however, brought to the forefront the idea that nuclear detonations could be used to engineer changes in landscapes.

The Plowshare Program mandate was expanded a few months later, based on the results of the Rainier test, an underground tunnel test conducted on September 19, 1957 at the Nevada Test Site. This test was the first fully contained, underground nuclear test in the world. This was a major accomplishment and fully containing a nuclear test opened up another range of possibilities for peaceful applications utilizing underground nuclear cavities, broadening the Plowshare Program’s scope. A few weeks later, in October, the U.S. Army Corps of Engineers with their extensive experience in construction projects reached an arrangement with the U.S. Atomic Energy Commission to provide support services to the program.

On June 6, 1958, the existence of the Plowshare Program and its goal to utilize nuclear explosives for peaceful purposes were unveiled to the public, noting the name was intended to reflect the biblical reference to beating swords into plowshares. By this time, theoretical possibilities were abundant with scientists proposing using nuclear detonations for civil works projects, often referred to as geographical engineering, and for industrial applications. Commonly cited examples of proposed civil works projects were to construct dams, harbors, canals, highways and railroad lines. Proposed industrial applications, in general, involved increasing production of ore, oil, and gas. Projects were discussed for both domestic and international non-military locations. Besides the scientific community, members of industry and the public as well, as government entities brought forward their ideas to the U.S. Atomic Energy Commission and to the Lawrence Livermore National Laboratory. Most ideas received serious consideration with some progressing to the project stage.

As the program developed and geographical locations began to be proposed for projects, management duties increased. Accordingly, the Peaceful Nuclear Explosives branch was established in late 1958 within the Division of Military Applications to handle the Plowshare Program. Direct supervision of the work of the Lawrence Livermore National Laboratory (then known as the Lawrence Radiation Laboratory at Livermore) was conducted by the U.S. Atomic Energy Commission's San Francisco Office. Two other agencies, the U.S. Geological Survey and the U.S. Bureau of Mines, agreed to participate in the Plowshare Program.

The Plowshare Program was affected when the United States entered into a nuclear testing moratorium with the Soviet Union on October 31, 1958. There was uncertainty as to how long the program could survive if Plowshare nuclear experiments could not be executed. However, work continued in anticipation of the moratorium's eventual end, and no nuclear tests of any type occurred until after the Soviet Union broke the moratorium on September 1, 1961. In the intervening period, the Plowshare Program carried out planning, feasibility studies and field studies for proposed locations for various projects in the United States and in other countries. To compensate for their inability to obtain nuclear testing information, a number of high explosives tests were conducted at the Nevada Test Site to obtain data that could be converted or scaled to the level of a nuclear test. These high explosive scaling experiments were primarily in alluvium and hard rock. However, some media, such as salt and clay, do not exist within the Nevada Test Site's boundaries and the scientists recognized a need to obtain information at locations with different subsurface environments and their planning reflected this. In spite of the on-going moratorium, the U.S. Atomic Energy Commission created a new division for the Plowshare Program, the Division of Peaceful Nuclear Explosives.

There were intersections between the Plowshare Program and the Vela Uniform Program, a joint effort between the U.S. Atomic Energy Commission's Division of Military Applications and the U.S. Department of Defense's Advanced Research Projects Agency. The purpose of the Vela Uniform Program was to develop the technological capability to detect and identify underground and underwater nuclear detonations. The program was initiated as a result of the negotiations for a treaty for the termination of the testing of nuclear weapons. These negotiations were underway during the 1958 voluntary testing moratorium. The United States maintained a position that in order to reach this type of agreement, there would have to be a proven method to verify that no nuclear tests were being conducted.

Towards this end, an international team of experts met for almost two months in mid-1958 and recommended that a test control system be developed that focused on the seismic and acoustical signatures of nuclear detonations. They proposed control stations with seismic detection equipment on several continents, some islands, and ships. These stations also were to be equipped with the ability to detect and record atmospheric pressure pulses, radioactivity, and electromagnetic signals with acoustical detection devices placed deep in the ocean. A number of technological issues had to be overcome, primarily the development of the ability to distinguish a nuclear detonation from an earthquake or high explosives, and the identification of a nuclear test in spite of efforts to hide such a detonation from detection by means such as concurrent chemical explosions and dense geological media. Also, there was concern about device placement prior to detonation, such as decoupling where the device is not adjacent to a cavity surface. In late 1958 and early 1959, the Cowboy high explosive tests were conducted in a salt mine near Winnfield, Louisiana. The Vela Uniform Program initially was referred to as the seismic program, but on October 2, 1959, it officially was given the Vela Uniform name along with designated funding.

In order to develop this technology, a high explosives and nuclear testing program was undertaken in the United States to obtain the data needed for establishing an effective system. The Advanced Research Projects Agency had the overall management responsibility. The U.S. Atomic Energy Commission was responsible for providing and firing the nuclear devices, providing the sites and cavities for the tests, and the recording of the measurements data from the firing of the device. For high explosives tests at the Nevada Test Site, the U.S. Atomic Energy Commission was responsible for similar support. The Air Force Technical Applications Center, besides acting as an advisor, agreed to define test requirements, conduct and analyze off-site detection measurements, and design and build the control stations. The Defense Atomic Support Agency was responsible for coordinating the U.S. Department of Defense activities, overseeing the measurement projects at the Nevada Test Site, and conducting the off-site chemical high explosives tests. At a worldwide level, the U.S. Coast and Geodetic Survey was responsible for providing and deploying detection equipment at more than 100 control stations in order to obtain global seismic data with these data available to interested researchers. Within a few years of the initiation of Vela Uniform, the control stations were up and running, along with several permanent seismic observatories.

While the Plowshare Program was only under the jurisdiction of the U.S. Atomic Energy Commission, the Vela Uniform Program was jointly managed by the U.S. Atomic Energy Commission and the U.S. Department of Defense. There were times when a Plowshare Project could furnish data for the Vela Uniform Program and vice-versa. For example, a Plowshare experiment could produce useful information for seismic signature studies or a Vela Uniform event could produce information on structural seismic effects for the

Plowshare Program. When this happened, there was coordination between the agencies with each responsible for their own data acquisition. During the 1958 moratorium, both programs had an active high explosives testing program at the Nevada Test Site and elsewhere.

For the Vela Uniform Program, there were seven nuclear tests. Three were conducted at the Nevada Test Site, projects Scroll (1968), Diamond Dust (1970), and Diamond Mine (1971). Four underground nuclear tests were executed off the Nevada Test Site between 1964 and 1973. Project Long Shot (1965) was on Amchitka Island in Alaska. There were two detonations for the Dribble Program in Mississippi, Salmon (1964) and Sterling (1966). The last one, Project Shoal (1973), was in Nevada near Fallon. A few other locations in the United States were proposed for other Vela Uniform nuclear tests, but these projects were not conducted.

Shortly after the beginning of the 1958 moratorium, fieldwork for the Plowshare Program was undertaken in a salt medium in southeastern New Mexico for the Pre-Gnome high explosives experiment. This high explosives test was conducted as a precursor to the Gnome nuclear test to study the seismic effects from the high explosives in order to model the expected ground shock from the Gnome event. Another large project involved the extensive fieldwork conducted to determine the feasibility of Project Chariot, a proposed nuclear excavation of a harbor and channel near Cape Thompson, Alaska. After four years of effort, this project was not executed. To test concepts related to oil shale fracturing, the Pinot high explosives tracer test was conducted in 1960 in an existing mine near Rifle, Colorado. Also in 1960, the Plowboy high explosives tests were carried out at the same Louisiana location as the Project Cowboy Vela Uniform tests in order to study the fracturing properties of salt deposits.

Following the end of the moratorium, the first Plowshare nuclear test, Gnome, was executed on December 10, 1961 in southeastern New Mexico. Its purpose was to determine if the underground nuclear detonation in a salt medium could produce steam that could run an electric generator and also to obtain information regarding the recovery of radioisotopes for medical and other purposes. A second nuclear explosive project to produce radioactive isotopes, called Coach, was also planned for this location in 1963 but was never done.

By 1962, the Plowshare Program had solid direction and goals. Overall, the Livermore Plowshare research program focused on two efforts. The first was the analysis of the field data and laboratory studies to create models that would predict the effect of nuclear explosives under a wide range of conditions, such as the physical effects of the explosives in various types of geological conditions. The second was the utilization of the models to develop and execute proposed civil works and industrial applications.

In early 1962, the Secretary of Defense was directed by executive orders to make formal arrangements for the U.S. Army Corps of Engineers' cooperation and participation in the U.S. Atomic Energy Commission's development of nuclear excavation technology. This resulted in the assignment of a group from the Corps to the Lawrence Livermore National

Laboratory. This group was called the U.S. Army Engineer Nuclear Cratering Group. It was agreed that the U.S. Atomic Energy Commission would be responsible for the experimental nuclear detonations, the development of the excavation and device technology, and the safety and site surveys. The Nuclear Cratering Group would conduct an experimental, high-explosive program in support of the nuclear efforts and develop the engineering technology for construction techniques. In addition to the Plowshare Program efforts, the Nuclear Cratering Group was also involved in research and experiments for the military to develop data for using nuclear explosives for military engineering purposes. In March of 1962, the Nuclear Cratering Group participated in the Danny Boy nuclear cratering experiment in basalt at the Nevada Test Site. This was a weapons effects test that provided post-shot data on the engineering properties and cratering characteristics of the basalt media, data useful to the Plowshare Program.

About this time, one international project began to gain broad-based support. Since the late 1940s, interest had been increasing in excavating a second canal in the region near the Panama Canal due to concerns that the canal was quickly reaching capacity. In April of 1962, the U.S. Atomic Energy Commission and the U.S. Army Corps of Engineers were asked by President Kennedy to conduct a five-year program to investigate the technical feasibility of using nuclear explosives for canal excavation. Following this directive, the Plowshare Program was given a milestone by the U.S. Atomic Energy Commission that technology for nuclear excavation would be developed by the end of 1967. A few months later, the second Plowshare nuclear experiment and the first Plowshare nuclear test at the Nevada Test Site was conducted on July 6, 1962. With a yield of 104 kt, the detonation, called Sedan, displaced 12 million tons of alluvium and formed a crater 320 feet deep and 1,280 feet in diameter. Today, the Sedan crater is the largest manmade crater in the world and is listed on the U.S. National Register of Historic Places. This experiment demonstrated the feasibility of using nuclear explosives for large-scale excavation projects, such as a canal, and provided information on large-scale cratering in alluvium. Following Sedan, legislation was presented to Congress regarding the trans-isthmian canal. This legislation provided authorization for the Panama Canal Company to conduct surveys of possible routes for the construction of the canal. However, this legislation did not receive Congressional approval until 1964.

Sedan also provided the opportunity to study safety issues. It was the policy of the U.S. Atomic Energy Commission that all safety factors were to be considered systematically in planning tests and experiments. Prior to 1962, the Plowshare Program was supported by the Albuquerque Operations Office and the Oak Ridge Operations Office but in 1962, the Nevada Operations Office was established and assumed these support duties in tandem with its responsibility for the detonation operations and the programs for industrial, environmental, and radiological safety. This office was in charge of basic and applied research projects in earth science studies, hazards predictions, and effects predictions for the tests. Included in these research efforts were projects in hydrology, meteorology, oceanography, and ground motion. This public safety program focused on eliminating or reducing to an acceptable minimum any effects of nuclear tests or explosive experiments which might harm people directly or indirectly, or damage public or private property or natural resources. Hazard evaluations were performed during the conceptual planning of a project, followed by a formal safety plan for each field test that established the criteria for conducting the experiment within acceptable standards. This applied to all aspects of the nuclear testing program including Plowshare.

Everyone involved in the Plowshare Program recognized the need for nuclear devices that dispersed less radioactive debris. The Lawrence Livermore National Laboratory pursued designing such a device throughout the Plowshare Program and a number of the Nevada Test Site nuclear tests were conducted to obtain data towards achieving this objective. The Nevada Test Site became the place to perfect techniques to be applied elsewhere under the Plowshare Program's goals of providing more effective and economical methods for civil works and industrial projects. In 1963, preliminary work continued on the Trans-Isthmian canal with other scientific studies progressing.

When work was conducted off the Nevada Test Site, the Nevada Operations Office used some of the same technical experts that were involved in testing at the site. Holmes and Narver provided architect-engineer services related to field construction and land surveys for the Plowshare and Vela Uniform Programs. Fenix and Scisson was an engineering and consultant contractor for drilling activities. Edgerton, Germeshausen and Grier served as a technical support contractor specializing in timing and firing, diagnostics, and technical photography. The U.S. Public Health Service was responsible for monitoring radiation levels after a test. The U.S. Geological Survey conducted geologic, hydrologic, subsurface, and terrain studies. The U.S. Bureau of Mines provided pre- and post-shot evaluations of mines and sometimes conducted special studies related to mining safety and techniques, and public safety. For some tests, the U.S. Coast and Geodetic Survey was responsible for providing the instrumentation and recording the seismic motion. Roland F. Beers, Inc. made prediction of ground motion and containment for selected tests. John A Blume and Associates conducted architectural studies pre-shot to provide predictions of the motion of structures for consideration in safety planning and then conducted post-shot surveys to document any damage in order to refine future predictions.

Before the beginning of the 1958 moratorium, President Eisenhower had asked that the Plowshare Program be exempt from the moratorium because he did not want to lose time in developing peaceful applications. However, the various countries did not agree to this. In the meantime, international talks continued towards a test ban treaty. On October 10, 1963, these countries entered into the Limited Test Ban Treaty. This treaty prohibited nuclear weapons tests or any other nuclear explosion in the atmosphere, in outer space, and under water. Although it did not ban tests underground, the treaty did prohibit nuclear explosions in this environment if they caused "radioactive debris to be present outside the territorial limits of the State under whose jurisdiction or control" the explosions were conducted. In accepting limitations on testing, the nuclear powers accepted as a common goal "an end to the contamination of man's environment by radioactive substances."

In the 1960s, a number of off-site projects were discussed and some were proposed for execution. The program was buoyed by interest in the nuclear excavation technology by the Atchison, Topeka, and Santa Fe Railway Company. The company wanted to reroute the railway through the Bristol Mountains in the Mojave Desert and the California

Department of Transportation was interested in realigning Highway 40 in the same general area, facilitating travel between Barstow and Needles. Although this project, Carryall, was not executed, it provided a platform for studying the civil engineering benefits of nuclear excavation.

About the same time, U.S. Army Corps of Engineer offices throughout the United States were tasked with identifying projects that could potentially be executed using nuclear explosives. Projects were proposed in eight districts: Mobile, Pittsburgh, Omaha, Alaska, Portland, San Francisco, Los Angeles, and Honolulu. The Nuclear Cratering Group, the Lawrence Livermore National Laboratory, and the U.S. Atomic Energy Commission considered these projects proposals. In 1963, the Nuclear Cratering Group funding schedule showed costs for the nuclear explosive feasibility studies for these projects running from 1963 through 1966, indicating the expectation that appropriate nuclear explosives technology would be available by 1967. Many of these projects involved water management activities, such as creating dams, reservoirs, and canals as well as reconfiguring existing waterways for easier ship passage. Other projects were road cuts, railway bed construction and harbor excavation. Some projects did not proceed beyond the concept phase, but for others, there were field studies and planning for nuclear excavation. The Nuclear Cratering Group was also involved in a number of high explosives projects. Many of these were high explosives modeling studies for future nuclear excavation applications, including the 1962-1963 Pre-Buggy I and II row charge experiments and the 1964 Pre-Schooner I cratering studies at the Nevada Test Site.

On September 22, 1964, President Kennedy signed Public Law 88-609 "to provide for an investigation and study to determine a site for the construction of a sea-level canal connecting the Atlantic and Pacific Oceans." The Atlantic-Pacific Interoceanic Canal Study Commission was responsible for the research for site selection and the studies on construction methodology, including excavating with nuclear explosives. This canal program received widespread publicity and involved much time and effort on feasibility studies by Lawrence Livermore National Laboratory and the Nuclear Cratering Group. The mid-1960s Pre-Gondola high explosives project in Montana was a modeling test for nuclear excavation in a wet clay environment, predominant in the canal studies location search.

While Lawrence Livermore National Laboratory worked on developing the technology for the Plowshare Program, industry and local governments approached the U.S. Atomic Energy Commission regarding the possibility of utilizing nuclear explosives to meet their needs. After the project concepts were approved by the U.S. Atomic Energy Commission and the Plowshare Advisory Committee, projects usually entered the preliminary design stage, followed by a feasibility study and varying levels of fieldwork.

The Plowshare Program was heavily involved in the development of industrial and other applications. The Gnome test focused on generating heat for electrical power. The 1967 Gasbuggy nuclear experiment in northwestern New Mexico, and the 1969 Rulison, and 1973 Rio Blanco nuclear experiments in western Colorado were conducted with industrial partners, such as El Paso Natural Gas, Austral Oil Corporation, and CER Geonuclear

Corporation. The purpose was to stimulate the production of natural gas in areas with a subsurface environment that restricted the gas flow. CER Geonuclear Corporation was a nuclear engineering firm that partnered with industry on a number of projects. Lawrence Livermore National Laboratory was the technical lead on all but the Rulison test where Los Alamos National Laboratory was given this role by the U.S. Atomic Energy Commission. Also, some projects were conducted to further scientific knowledge of explosives in different media. For example, Pre-Schooner II was a 1965 high explosives cratering experiment in basalt in southwestern Idaho.

For each project conducted, there were many more locations considered for gas and oil projects in various parts of the United States, with most concentrated in existing, developed oil and gas fields. Other projects not executed included Bronco (Colorado) Dragon Trail (Colorado), Ketch (Pennsylvania), Utah (Utah), WASP (Wyoming), and Wagon Wheel (Wyoming). For copper ore fracturing, Project Sloop in Arizona was seriously considered and for coal gasification Project Thunderbird in Wyoming.

There is no indication that U.S. Atomic Energy's milestone that technology for nuclear excavation would be developed by the end of 1967 was met, and it is not known how much progress was made by the Lawrence Livermore National Laboratory scientists towards a cleaner nuclear device. However, research continued on a number of Plowshare domestic and international locations and the program continued to planning in three to five year increments.

At the end of 1967, the Plowshare Program was notified of a budget reduction for 1968 that was twice the amount anticipated. At this time, the funding needs of the Vietnam War were increasing and the financial resources for civilian projects were being reduced for various agencies and programs in the United States. The 1968 funding cut came with direction to complete the nuclear cratering test Cabriolet and conduct the Buggy row charge detonations at the Nevada Test Site in early 1968. With the funding reduction, purchasing and travel were curtailed, computing was reduced by 25 percent, all copper and gold leaching experiments were stopped, and work on planned off-site projects, such as Sloop, Ketch, Rulison, and Wagon Wheel were restricted to no more than a total of 8 hours a month. The effect on the Plowshare Program was immense.

By 1968, the Nuclear Cratering Group's research had identified the potential uses for nuclear explosives in civil works. Although other types of construction projects had been studied, these were the most promising. Nuclear quarrying was chosen because the subsurface detonation of nuclear explosives could produce a large volume of broken rock easily and cheaply. Nuclear ejecta dams involved detonating a nuclear explosive in the side of a canyon in order to eject material in a way that would create an embankment or dam for water storage. Nuclear harbors were feasible using nuclear cratering technology which would produce an underwater crater. Nuclear excavated cuts or trenches built with a row of nuclear explosives could produce navigable waterways, canals, highways or railroad cuts. In 1969 and 1970, the Nuclear Cratering Group conducted two major high explosives tests off the Nevada Test Site. Trinidad in Colorado involved testing cratering and railroad cut technology. Tugboat was a successful harbor excavation project in Hawaii.

As of August 1, 1971, the U.S. Army Engineer Nuclear Cratering Group was replaced by the U.S. Army Engineer Explosive Excavation Research Office (later Laboratory replaced Office). This office was set up as a field activity of the U.S. Army Engineer Waterways Experiment station. The change in name and status did not involve changes in personnel or location. The new office also retained the missions to work on the development of nuclear and large-scale chemical explosives applications, conduct military funded research, and provide technical expertise and assistance for explosive excavation engineering. The work was referred to as Rapid Excavation with Explosives. At this time, there were about 40 civil works projects in the United States under consideration for execution. Some were initially considered for nuclear excavation and others for high explosives. Several of these projects were conducted in the next couple years but the possibility of using nuclear explosives for excavation became increasingly remote.

In the two years following the March 1968 Buggy row charge nuclear test, only six more nuclear Plowshare detonations were conducted at the Nevada Test Site. Of these, only Schooner was a cratering test. The last Plowshare test at the Nevada Test Site was Miniata, conducted on July 8, 1971. The last Plowshare nuclear test in the United States was off the Nevada Test Site in Colorado. This test, Rio Blanco, was a gas stimulation experiment conducted on May 17, 1973.

After the execution of 27 nuclear projects and at least 18 high explosives projects on and off the Nevada Test Site, the Plowshare Program ended on June 30, 1975. Technical, financial, environmental and political issues led up to its demise. There was a perceived lack of progress on the program. In December 1970, the Canal Study Commission's final report indicated that U.S. canal policy should not be made with the expectation that nuclear excavation technology would be used for canal construction. The diversion of funding for the Vietnam War drastically reduced the dollars available for the research. The passage of the National Environmental Policy Act of 1969 had already altered the way government projects were conducted by increasing the costs and time for any federal undertaking. This law required more public involvement and agency analysis of the potential effects of its actions on the environment. This added to the already increasing objections and ultimately led to more Congressional scrutiny and the cessation of the program. Ironically, in April 1976, the Peaceful Nuclear Explosions Treaty was signed and pertains to all nuclear explosions carried out at locations outside the weapons test sites and in other countries within the limits of the 1974 Threshold Test Ban Treaty.

2.2 Research Methodology

The methodology was designed to meet the research goal of identifying Plowshare and Vela Uniform projects proposed or conducted outside the Nevada Test Site that may have potential environmental liabilities. Excluded from this research was the proposed location for Project Chariot project because it was remediated in the early 1990s. Also not included were the eight locations in five states where nuclear devices were detonated and, until recently, were under the jurisdiction of the U.S. Department of Energy, Nevada Site Office. The projects and sites are: 1) the Tatum Salt Dome in southern Louisiana, the location of the 1964 Salmon and 1966 Sterling tests (Vela Uniform), 2) the 1961 Gnome event site in southeastern New Mexico (Plowshare), 3) the 1967 Gasbuggy event site in northwestern New Mexico (Plowshare), 4) the 1969 Rulison event location in western Colorado (Plowshare), 5) the 1973 Rio Blanco event location also in western Colorado (Plowshare), 6) the Central Nevada Test Area where the 1968 Faultless test occurred (Weapons Related), 7) the Project Shoal location in northern Nevada (Vela Uniform), and 8) Amchitka Island in Alaska where the 1965 Long Shot (Vela Uniform), the 1971 Cannikin (Weapons Related), and the 1969 Milrow (Weapons Related) tests were conducted. These off-site locations are now monitored under the jurisdiction of the U.S. Department of Energy, Office of Legacy Management, Grand Junction, Colorado. High explosives tests at Lawrence Livermore National Laboratory's Site 300 and Sandia National Laboratory's Coyote Test Field were not considered for inclusion in this research.

Six separate tasks were identified for the research and formalized as data quality objectives. The first was to collect data related to Plowshare and Vela Uniform projects previously discussed in research reported on by David Shafer, Steve Mellington, and William Beck in an unpublished manuscript prepared in the mid-1990s. The second task was to locate additional project names, if they existed, and to obtain information on them. The third was to organize the collected information for each project according to the data quality objectives established at the beginning of the research. Fourth was to analyze these data to determine the types of work conduced at project locations and assign activity levels. Fifth was to visit project locations with a medium to high risk of potential environmental liabilities in order to locate and document features associated with each project. The sixth task was to review land status records to determine if there were any active land withdrawals still held by the U.S. Department of Energy.

Records and documents research began with two existing Plowshare syntheses, the 1997 *Plowshare Program Executive Summary* and *The Plowshare Program* (undated draft), both prepared by the U.S. Department of Energy, Nevada Operations Office. General internet research and specific research at on-line document databases, such as the Office of Science and Technical Information and the National Technical Information Service were carried out. Locally in Nevada, records were obtained from the University of Nevada, Las Vegas Lied Library; the U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office Archival Records Center at the Nevada Test Site; the Technical Library at the Nevada Support Facility, and the Nuclear Testing Archive. The Technical Library was able to obtain records from other facilities. In California, research was conducted at the Lawrence Berkeley National Laboratory Archives and Records Office, the Lawrence Livermore National Laboratory Archives and Research Center and the Technical Reports Library. Also reviewed were the archival documents at the U.S. Army Corps of Engineers Fort Peck Lake Office in Montana. Most documents and photographs were copied or scanned and are on file at the Desert Research Institute. Final disposition of this Plowshare archive will be to either the National Nuclear Security

Administration Nevada Site Office Local Records Center or Nuclear Testing Archive in Las Vegas, Nevada.

The data gathered varied in content from project to project, and the organization and evaluation of the data according to the spatial, temporal and field activity characteristics in the data quality objectives were critical. These data characteristics ensured that information was evaluated systematically and that important data gaps or completeness of information for a project could be identified annually, guiding the next year's research. There are nine key project characteristics: 1) the project purpose and scope, 2) the project location, 3) the beginning date of the project, 4) the dates of fieldwork, 5) a description of the field activities, 6) the level of field activity, 7) the ending date of the project, 8) the land ownership (or agency jurisdiction) and, 9) the agencies and companies identified as participants in the project.

The decision rules for identifying potential liability were: 1) if a Plowshare or Vela Uniform Project was proposed and a location identified, then there is a potential for liability; 2) if there is a potential for liability, then identify the level of activity associated with the project; 3) if there was no field activity, then there is no liability. The field activity levels were determined through a categorization of project activities into one of five levels. The five levels were: 1) locations where radioactive materials were used for tracer experiments; 2) locations where high explosives were used for the project; 3) locations where geologic or hydrologic tests or other substantial work was conducted to evaluate a site for a project or in preparation for an experiment; 4) locations where existing facilities, such as mines, wells, and drill holes, were utilized for data collection; and 5) locations where activity was confined to conceptual designs, background research, and visual field inspections. In cases where there were structured field activities that exceeded casual visual inspections, the project was assigned to a Level 4. If a project location is classified as category 1 or 2, then the level of potential liability is high. If the location is classified as category 3, then the level of potential liability is medium. If the location is classified as category 4 or 5, then the level of liability is low or none. If there was no field activity, then there is no liability. These determinations were done on a project by project basis with the result captured in the project characteristics data forms (see Appendix A).

Field research at project locations was confined to those locations with a high or medium level of liability. The project locations were prioritized according to the types of activities and if the activities occurred on public federal land. Not all locations categorized as medium to high could be visited because of budgetary restraints, but the confidence level that all locations with potential U.S. Department of Energy liabilities were recorded is high. For example, a copper mine owned by a private company in Arizona was not a priority because the mining company was actively involved in the project and it is unlikely that any issues related to the Plowshare project exist there decades later.

In preparation for the field visits, the researchers obtained current topographic and road maps of each region and contacted the appropriate land management agencies in order to determine potential site access problems. Historic maps were compared with current maps in order to determine the precise location of each project and plot the most efficient route to the field sites. To assist in the identification of the project sites and their associated features, selected reference materials were compiled for each of the locations. This documentation included historic photographs, schematic drawings, maps, scientific site plans, location data, and written descriptions of project field activities and facilities. In addition, any archives or agencies near the project locations that might possess historic materials relevant to the Plowshare or Vela Uniform experiments were identified for possible research.

Field recordation at all of the Plowshare and Vela Uniform project locations selected for field studies followed a standard protocol. Each project location was plotted on the most recent version of the appropriate U.S. Geological Survey 7.5' quadrangle map(s). As long as access was not an issue, an intensive, systematic pedestrian survey of each site was conducted in order to locate evidence of field activities and ground disturbance. Detailed notes were taken describing the extent and nature of the materials, structures, and disturbance identified. UTM coordinates, obtained using handheld GPS units, were recorded for each structure or feature, such as craters, trenches, drill holes, equipment storage, bladed areas, and trash/debris concentrations. Both 35 mm and digital photographs were taken of the project area and each structure or feature to document the site's current condition and to illustrate the type of materials present.

Land status research was conducted using the location data. The land records were examined at the field offices and state offices of federal agencies and, when necessary, the state land office. The purpose was to determine if there had been a land withdrawal by the U.S. Atomic Energy Commission and, if so, when the land withdrawal had been terminated and jurisdiction returned to the other federal agency. Also, when available, lease information was obtained for a location.

For projects with activities categorized as Levels 1, 2, and 3, comprehensive project descriptions were prepared because these projects had the most potential for environmental liabilities. For Levels 4 and 5 projects, as many as possible of these were written up as comprehensive descriptions. The others are presented as short summaries.

CHAPTER 3.0 PROJECT DESCRIPTIONS: FIELD ACTIVITY LEVELS 1 THROUGH 3

There are 27 Plowshare and Vela Uniform projects (Table 3.0-1) with field activity levels that are categorized as high (Levels 1 and 2) and medium (Level 3). The three levels are: 1) locations where radioactive materials were used for tracer experiments; 2) locations where high explosives were used; and 3) locations where geologic or hydrologic tests or other substantial work was conducted to evaluate a site for a project or in preparation for an experiment.

Project Pinot is the only Level 1 project. This was a Plowshare high explosive oil shale stimulation experiment in an existing mine. Radioactive tracers were utilized in the project. For Level 2, there are 15 projects. Fourteen are high explosives projects that were completed. The other was a proposed nuclear explosives project (Sergius Narrows) that evolved into a completed high explosive project with an objective different from the original plan for the nuclear project. Three projects, CHASE, Cowboy, and Pre-Dribble are Vela Uniform projects. The other 12 fall under the Plowshare umbrella. Three Plowshare projects (Pre-Gnome, Pre-Gondola, and Pre-Schooner II) and the Vela Uniform Pre-Dribble project were high explosives tests conducted to obtain data for use in the nuclear tests that were planned to follow. Another Plowshare project (Operation Breakup) was developed to obtain scaling data. Eight projects occurred in the late 1960s and early 1970s towards the end of the Plowshare Program. The U.S. Army Engineer Nuclear Cratering Group at Lawrence Livermore National Laboratory (reorganized as the U.S Army Engineer Explosive Excavation Research Office) was the lead on these. Trencher was a project that supported the last phase of Pre-Gondola. Sergius Narrows was a series of preliminary high explosives cratering tests conducted for the planned project execution. The other six projects (Drum Inlet, Libby, Lost Creek, R. D. Bailey, Trinidad, and Tugboat) were civil works projects with Plowshare applicability.

For Level 3, there are 11 projects. Ten are Plowshare and one, Rufus, is Vela Uniform. Three of the 10 Plowshare projects were not nuclear projects. Projects Iki involved drilling for geothermal data and Plowboy focused on studying salt fractures from the Cowboy high explosives project. For the third project, Excavator, the work included the drilling of one test hole for characterization data. The seven other Plowshare projects were planned nuclear explosives projects (Bronco, Dragon Trail, Thunderbird, Travois, Utah, Wagon Wheel, and WASP) that were not executed. The field activities for these projects ranged from minimal characterization studies to preparing the infrastructure and ground zero for a nuclear detonation.

Fifteen of these projects were selected for field studies and land status research: Bronco, Dragon Trail, Excavator, Iki, Pinot, Pre-Gondola, Pre-Schooner II, Thunderbird, Travois, Trencher, Trinidad, Tugboat, Utah, Wagon Wheel, and WASP. All belong to the Plowshare Program. Selection was based on the probability of project associated features and remains at the location, proximity to other projects, and feasibility of conducting the field studies within the directives and constraints of the study herein.

There are two projects with potential environmental liabilities. Pinot involved using a radioactive tracer test in a mine. Radioactive materials were not used at the other project locations. At Pre-Schooner II there is extensive testing debris that may become an issue. Evidence of past Plowshare project activities are the changes in the landscapes from the use of high explosives and the equipment or debris that was left in place. There are no existing land withdrawals for any of the projects and those that existed were with the Bureau of Land Management.

The project descriptions are presented in alphabetical order. A brief summary of the data for each project is in Appendix A.

Table 3.0-1. Project Descriptions: Field Activities Levels 1 through 3

Name	**Description**	**Activity Level**
Pinot	High Explosives for Oil Shale Stimulation Research	Level 1
CHASE (Vela Uniform)	High Explosive Long Range Seismic Monitoring Experiments	Level 2
Cowboy (Vela Uniform)	High Explosive Seismic Monitoring Experiment	Level 2
Drum Inlet	High Explosives for Channel Excavation	Level 2
Libby	High Explosive Experiment for a Highway Cut	Level 2
Lost Creek	High Explosive Experimental Mounding and Controlled Blasting Series	Level 2
Operation Breakup	High Explosive Ice Cratering Experiment	Level 2
Pre-Dribble (Vela Uniform)	High Explosive Seismic Effects Research	Level 2
Pre-Gnome	High Explosives Seismic Experiment	Level 2
Pre-Gondola	High Explosives for Waterway Construction	Level 2
Pre-Schooner II	High Explosive Cratering Experiment	Level 2
R. D. Bailey	High Explosive Experiment for Dam Spillway Excavation	Level 2
Sergius Narrows	Explosive Studies for Channel Improvement	Level 2
Trencher	High Explosive Excavation Experiment	Level 2
Trinidad	High Explosives for Railroad Construction	Level 2
Tugboat	High Explosive Excavation for Harbor Construction	Level 2
Bronco	Nuclear Explosives for Fracturing Oil Shale Underground	Level 3
Dragon Trail	Nuclear Explosives for Gas Stimulation	Level 3

Table 3.0-1. Project Descriptions: Field Activity Levels 1 through 3 (continued)

Name	**Description**	**Activity Level**
Excavator	High Explosive Calibration Experiment	Level 3
Iki	Geothermal Energy Experiment	Level 3
Plowboy	High Explosives Salt Fracture Research	Level 3
Rufus (Vela Uniform)	Surface Detonation of Nuclear Explosives	Level 3
Thunderbird	Nuclear Explosives for Coal Extraction	Level 3
Travois	Nuclear Quarrying for Dam Construction	Level 3
Utah	Nuclear Explosives to Fracture Oil Shale for Underground Retorting	Level 3
Wagon Wheel	Nuclear Explosives for Stimulation of Underground Natural Gas Reservoirs	Level 3
WASP	Nuclear Explosives for Stimulation of Underground Natural Gas Reservoirs	Level 3

THIS PAGE INTENTIONALLY LEFT BLANK

3.1 BRONCO

Plowshare Program
Nuclear Explosives for Fracturing Shale Underground
Colorado

Project Bronco was designed for the application of nuclear technology to oil shale stimulation and recovery. The idea of using a nuclear explosion to create fractured shale for retorting in situ was discussed as a possible Plowshare application at a symposium in 1959. The concept was developed in response to concerns regarding the nation's energy supplies. There was increasing concern regarding whether domestic production of petroleum and natural gas could meet the energy needs forecast for the 1980s. In general, there was agreement that consumption in the United States would double by 1980 with demand greater than production. Four alternatives were proposed to alleviate a future crisis: 1) increase known petroleum reserves through exploration; 2) obtain more oil from known reserves through more efficient recovery methods; 3) develop cost effective processes for production from oil shale, coal, and tar sands; and 4) increase the supply of imported oil. By the mid to late 1960s, most studies concluded that the first two alternatives could contribute to increasing the oil reserves, but alone they would not produce enough oil to meet the projected demand for petroleum. Therefore, the focus shifted to the third alternative.

The Green River Formation in Colorado, Utah, and Wyoming was estimated to contain the majority of the world's known oil shale reserves with the potential to produce 480 billion barrels of oil (Figure 3.1-1). Oil and gas companies were researching several new types of retorting techniques in an attempt to reduce the cost of obtaining petroleum from oil shale. The most expensive component of the process was not the actual oil production but the mining, transporting, crushing and disposal of spent shale; therefore, in situ production would create the most cost savings. A few pilot projects using non-nuclear in situ production methods were on-going. Concurrently, serious consideration was being given to the possibility of using nuclear explosions for this type of production, resulting in discussions for an experiment to test the utility of nuclear explosives for oil shale retorting. This experiment was named Project Bronco.

The search for an appropriate location for Project Bronco began in 1964, indicating that conceptualization and approval for preliminary feasibility studies were initiated in the early 1960s (Figure 3.1-2). The Piceance Creek Basin in western Colorado was selected for the experiment. The location was north of Grand Junction and west of Rifle, Colorado (Figure 3.1-3). The objectives for Project Bronco were to assess the technical and economic feasibility of in situ retorting in a nuclear fractured zone, to refine knowledge regarding nuclear explosions in oil shale, and to study the radioactivity after detonation and during in situ retorting.

In 1965 and 1966, the U.S. Atomic Energy Commission and the U.S. Bureau of Mines drilled two exploratory core holes eight miles apart as part of the feasibility study:

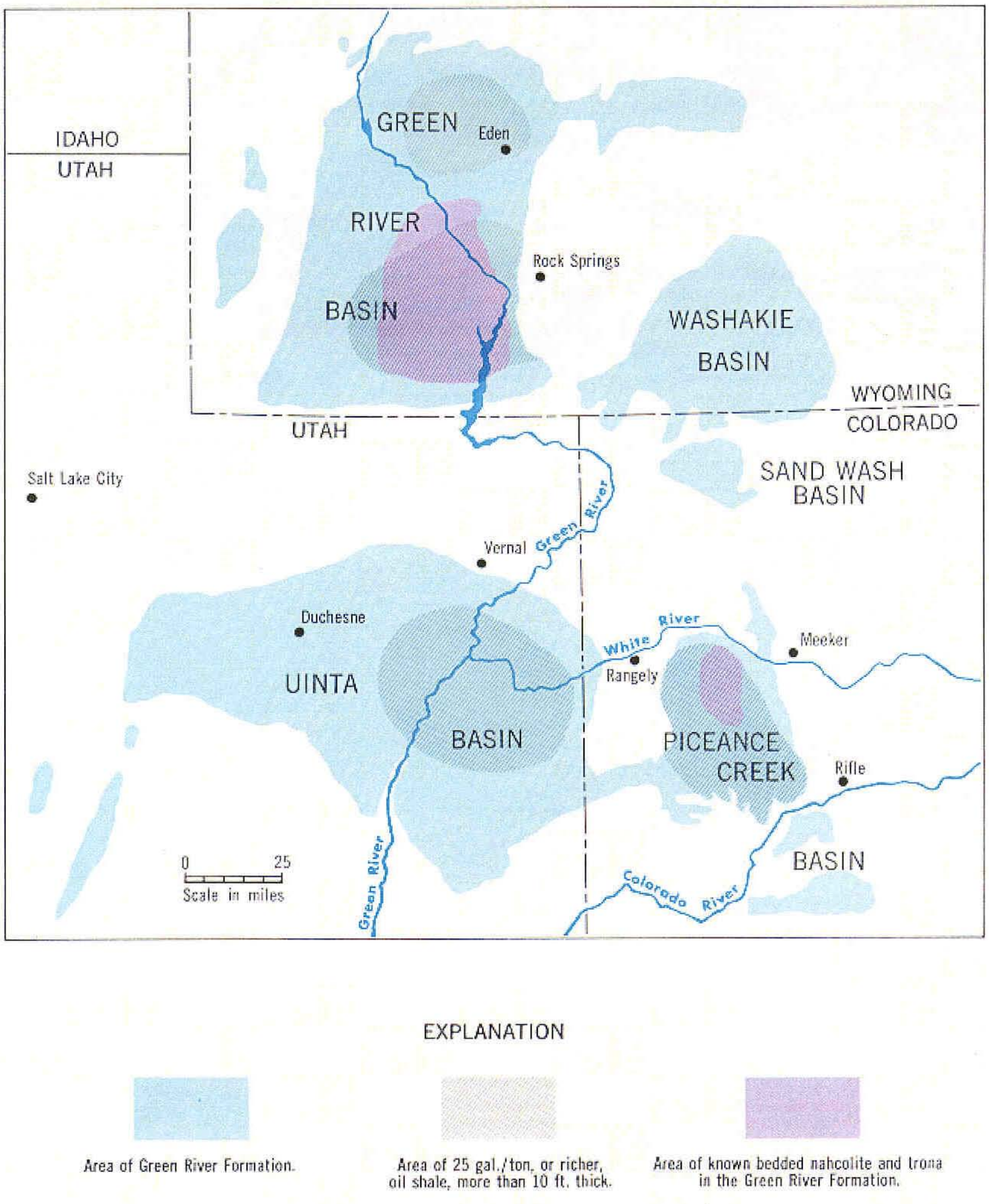


Figure 3.1-1. Distribution of the Green River Formation (Lekas et al 1967, Figure 1).

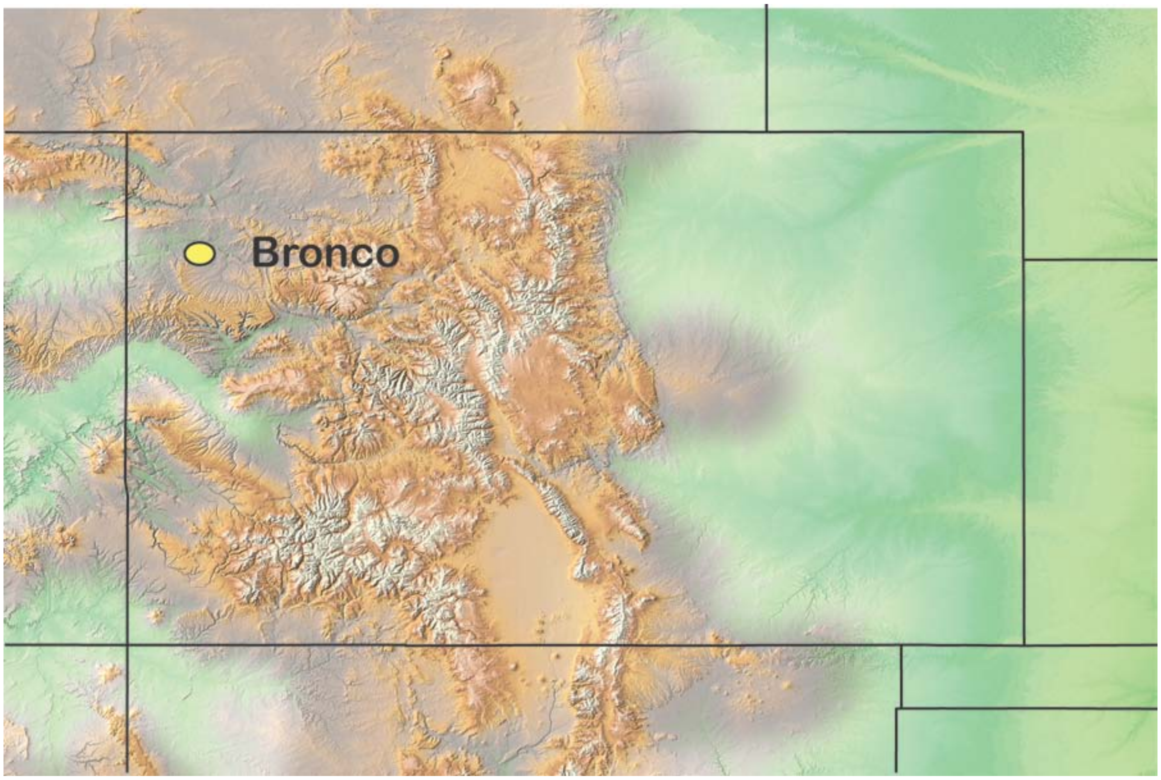


Figure 3.1-2. Location of Project Bronco (adapted from USA Relief Maps 2004).

1) USBM/AEC Core Hole No. 1 on the east side of Yellow Creek in the NW1/4NE1/4SE1/4, Sec. 13, T 1N R98W, Rio Blanco County, Colorado, and 2) USBM/AEC Core Hole No. 2 at 0.75 miles south of Duck Creek in the SE1/4NW1/4NE1/4, Sec. 14, T 1S R99W, Rio Blanco County, Colorado. The results from Core Hole No. 1 were the most positive with the thickness of oil shale in some places reaching 2,000 ft. The project team chose a nearby location on public lands in the southeast corner of Sec. 15, T 1N R98W for the Bronco experiment. The design, siting decision, and yield were chosen to minimize any possible adverse effects from the explosion, such as atmospheric effluent release, groundwater contamination, and seismic property damage.

On October 13, 1967, the feasibility study was issued. The plan called for drilling pre-shot exploratory holes to obtain geologic and hydrologic data and for instrumentation use during the explosion. The emplacement hole for Bronco also would be drilled at the same time with the project design envisioning a 50-kt explosion at 3,350 ft for as much as 18 million tons of oil shale. Post-shot drilling would include a hole on top of the nuclear chimney for data on the underground radioactivity and chimney rubble (Figure 3.1-4). Other drill holes would augment these data. After these efforts, an in situ retorting experiment would be conducted in the chimney and in fracture zones outside the chimney. In situ retorting of the fractured deposit would be accomplished by injecting hot natural or combustible gases and air. Production wells drilled into the bottom of the rubble pile would recover the liquid oil. Besides these oil production wells, the plan called for monitoring wells and a retort facility (Figure 3.1-5).

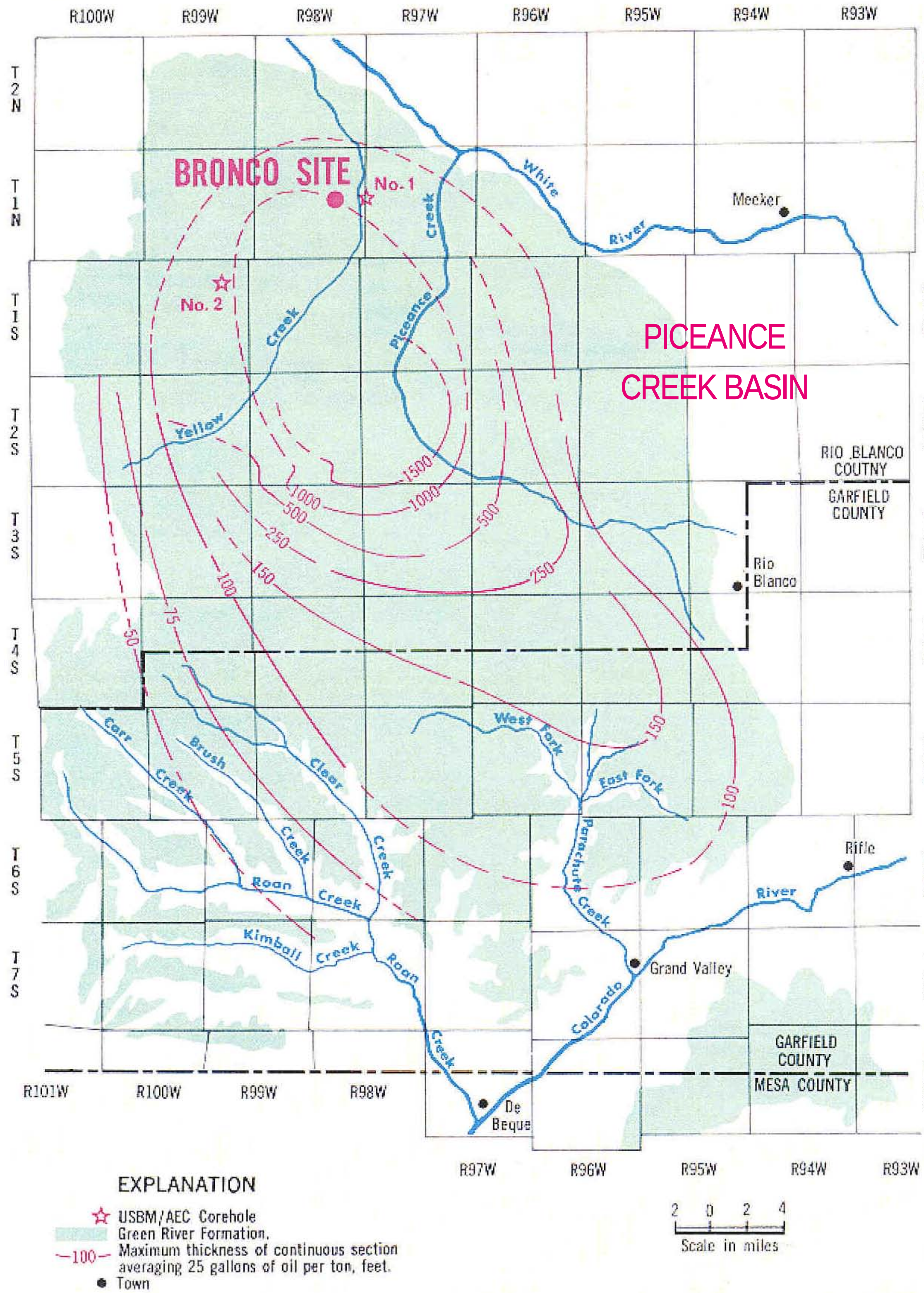


Figure 3.1-3. Bronco location within the Piceance Creek Basin of the Green River Formation (adapted from Lekas et al 1967, Figure 2).

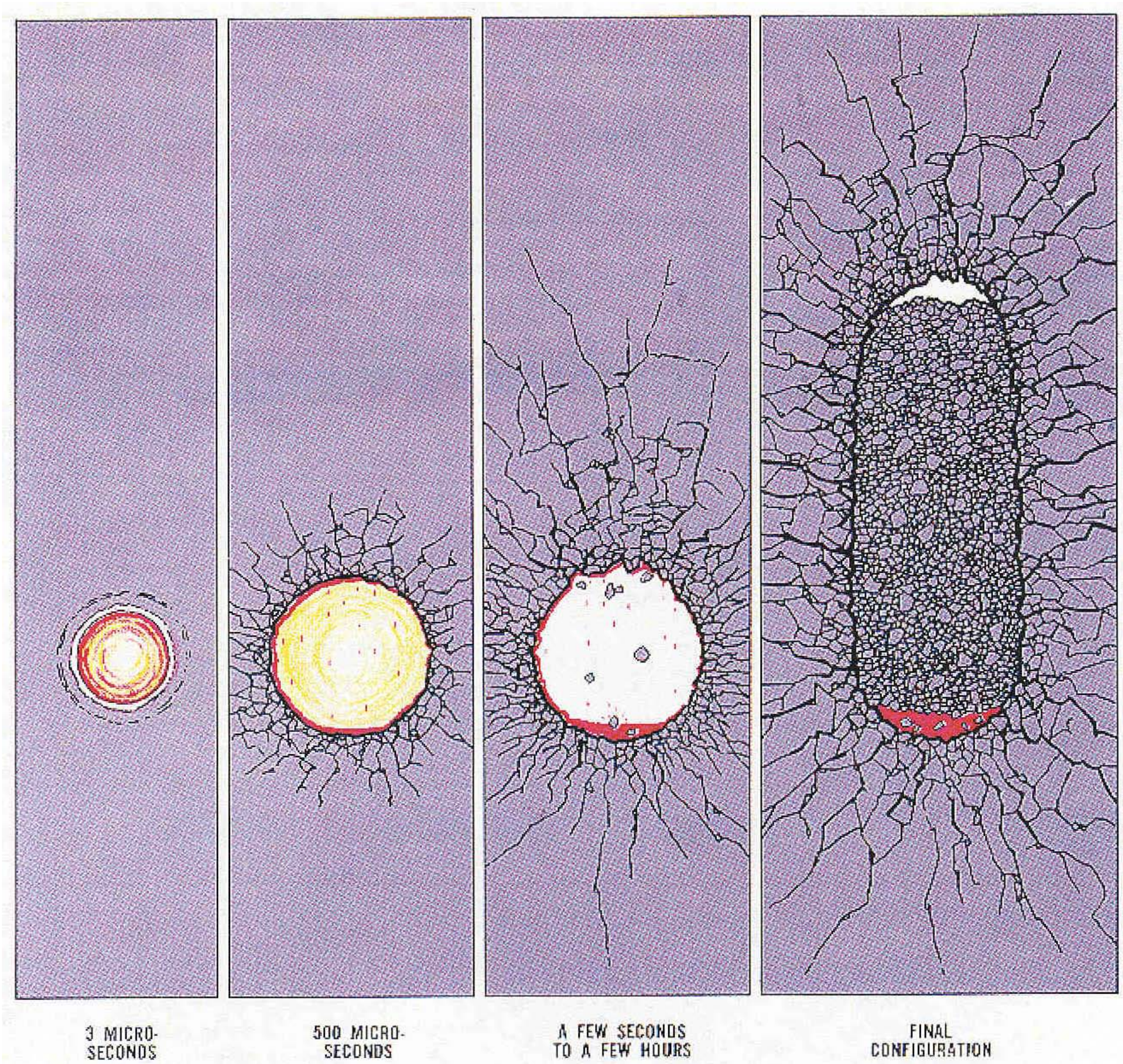


Figure 3.1-4. Proposed sequence of underground detonations for Project Bronco (Lekas et al 1967, Figure 3).

Proposed facilities expected at Bronco included a Red Shack (timing and firing building), a firing/recording facility at the Control Point, and at least one repeater to get the signal to the Control Point (probably in the town of Vernal, Utah and possibly placed on Cathedral Bluffs in Sec. 33, T1S R100W). The Cathedral Bluffs repeater also would be used for Project Dragon Trail. It also might be necessary to build small towers, less than 100 ft, at the Control Point and Ground Zero. Facilities at Ground Zero would be an office trailer for operations and a living trailer that could also be used as office space, a mechanical shop trailer, nine air sampling units, three geophones, one unmanned ground camera station backed up by an airborne photo mission, and possibly closed circuit television coverage on the microwave link. There would be a single security post starting on the day the explosive arrived or when the dry runs began. In addition, a trailer and equipment would be needed for the Control Point. After the detonation, Hazards Control support facilities, probably limited to an access control/clothing trailer along the

Figure 3.1-5. U.S. Bureau of Mines/ U.S. Atomic Energy Commission above ground experimental oil shale retort at the U.S. Bureau of Mines Petroleum Research Center, Laramie, Wyoming (Lekas et al 1967, Figure 5).

re-entry route, would be needed. Classified discussions could be held at the Atomic Energy Commission field office in Grand Junction, Colorado. The U.S. Atomic Energy

Commission, Nevada Operations Office was responsible for conducting all Atomic Energy Commission nuclear detonations. This office reviewed the field program according to established safety criteria and had responsibility for on and off-site safety for personnel and property.

After review of the feasibility study, in the latter part of 1967, CER Geonuclear, on behalf of 18 oil companies, formally proposed to conduct the Bronco experiment jointly with the U.S. Atomic Energy Commission and the U.S. Department of the Interior. The various oil companies participating in Project Bronco included Atlantic Richfield Co., Cities Service Oil Co., Continental Oil Co., El Paso Natural Gas Co., Equity Oil Co., Getty Oil Co., Marathon Oil Co., Mobil Oil Co., Shell Oil Co., Sinclair Oil & Gas Co., Sohio Petroleum Co., Sun Oil Co., Tenneco Oil Co., Texaco Inc., The Cleveland-Cliffs Iron Co., The Superior Oil Co., Union Pacific Railroad Co., and Western Oil Shale Corporation. The entire project was estimated to require five years to complete. The timetable scheduled pre-shot drilling for the summer of 1969 with an actual test date of early 1970. Post-shot investigations, including rubble characterization, experimental heating/burning of the deposit, and additional fracture zone testing, would extend through 1973. Commercial production could be developed by the mid-1970s.

Sometime following the feasibility study, USBM/AEC Colorado Core Hole No. 3 (Bronco BR-1), located in the SW1/4SW1/4SW1/4, Sec. 15, T1N R98W, was drilled to a depth of 3,797 ft. Core analysis was used to determine the subsurface geologic, geophysical, and hydrologic regime and potential oil yield. This hole provided the supporting information needed for the emplacement hole.

As of January 24, 1968, the Atomic Energy Commission had not approved Project Bronco and Congress had appropriated no money. Later in 1968, a contract was negotiated between the government and the oil companies. Ultimately the contract negotiations were unsuccessful because not all of the oil companies accepted the contract.

Although papers presented at a January 1970 symposium discussed the planning and research for Project Bronco, including the possibility of developing an efficient methodology to extract other minerals from oil shale, Project Bronco had not progressed since the contract negotiations stalled in 1968. A memo dated May 8, 1970 relating information from an informal presentation at the Office of Peaceful Nuclear Explosives in the Nevada Operations Office stated that Project Bronco was considered inactive. Other documents indicate that no further action was anticipated. Project Bronco was never executed.

Project Bronco was a Level 3 activity which corresponds to fieldwork limited to drilling wells, setting up limited support facilities, and grading access roads. The project sites were visited in FY2003 and FY2005.

FIELD VISIT

The FY 2003 field visit to the Bronco project area occurred on August 12, 2003. The roads into the area were poorly marked and access was difficult. Due to time constraints, Desert Research personnel were only able to reach USBM Core Hole No. 1 location.

During a return visit to the Bronco project area in July 2005, the DRI researchers were able to assess two of the three wells drilled for the project; USBM Core Hole No. 1 and USBM Core Hole No. 2.

The first drill hole, USBM Core Hole No. 1 is at the eastern edge of the broad and deeply incised Yellow Creek drainage channel in the NW1/4NE1/4SE1/4, Sec. 13, T1N R98W, Rio Blanco County, Colorado. To reach Core Hole No. 1, begin at the town of Rangely, Colorado and proceed east on State Route 64 for approximately 38 miles until reaching the junction of State Route 64 and County Road 5 at White River City. Turn right (south) onto County Road 5, which follows Piceance Creek. Travel approximately 4.4 miles and turn right (west) onto a dirt road, County Road 20, leading towards the *Piceance Creek State Wildlife Area-Yellow Creek Unit.* Proceed about 4.1 miles until reaching a "Y" in the road with another two-track dirt road that heads north along the eastern margin of the steep-sided Yellow Creek drainage. Travel 0.55 miles north on the right fork. The USBM Core Hole No. 1 is less than 50 ft west of the road and is clearly visible in spite of the dense vegetation. The 9-inch diameter well casing extends about 3.5 ft above the ground surface and has been capped (Figure 3.1-6). As first noted in 2003, the well is still monitored periodically by the Office of the State Engineer, Colorado Division of Water Resources. According to the attached placard, the well has been monitored regularly since 1991, with the most recent visit on September 21, 2004 (Figure 3.1-7).

Figure 3.1-6. Project Bronco USBM Core Hole No.1 (photo taken July 2005 on file at Desert Research Institute).

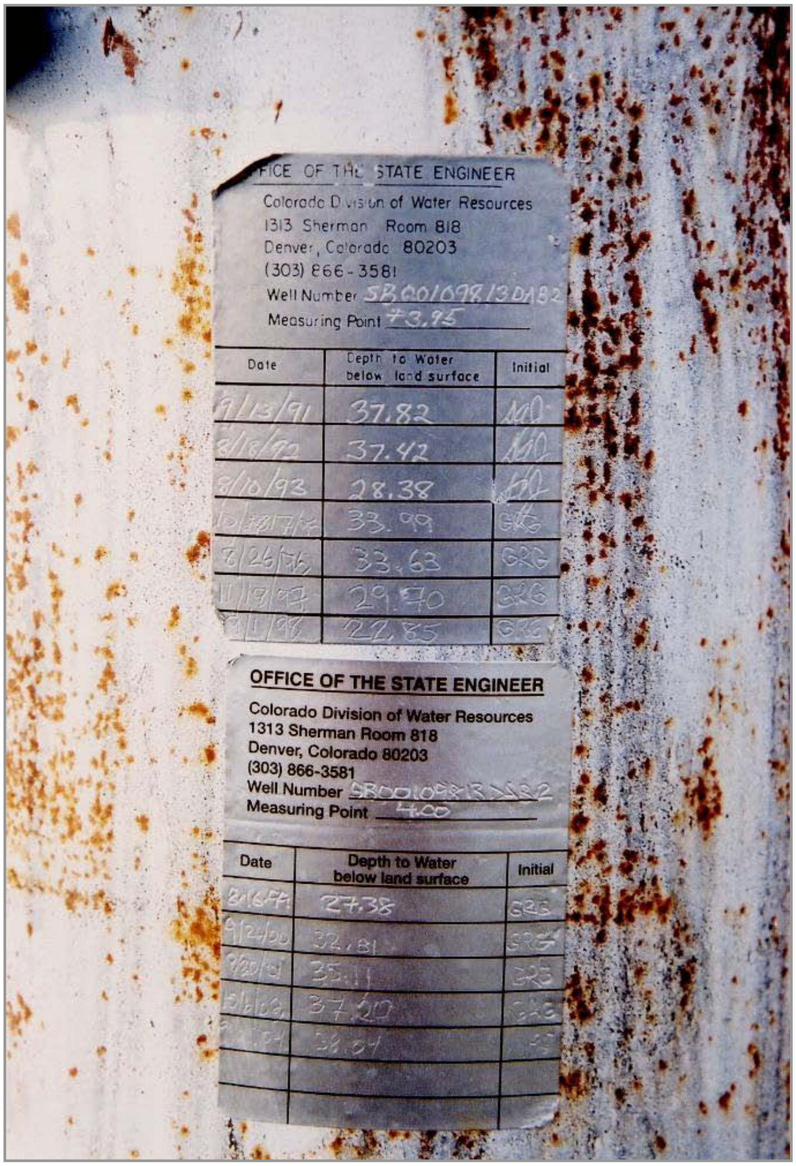


Figure 3.1-7. Office of the State Engineer, Colorado Division of Water Resources monitoring tags on Core Hole No. 1 (photo taken July 2005 on file at Desert Research Institute).

During the July 2005 reconnaissance, the investigators also identified four heavy gauge, galvanized steel, eye-bolt anchors embedded in the ground surrounding the well. These probably served to secure the original drill rig that bored the well in 1965. Other debris noted included concrete chunks, wood fragments, metal banding, well casing sections, a few cans, and some broken glass bottle fragments. No other drilling-related debris was observed in the area.

USBM Core Hole No. 2 is located about 0.75 miles south of Duck Creek and 0.5 miles southeast of the junction of Rio Blanco County roads 80 and 24X. Currently, there is a great deal of renewed interest in the gas and oil potential of the entire region and numerous parcels are under development. Situated between two active oil and gas leases, Core Hole No. 2 sits on a low knoll to the west of County Road 24X (Figure 3.1-8). It consists of a 4-inch diameter vertical iron pipe that extends approximately 4 ft above the ground surface. The casing is capped and locked. The casing is welded with the well designation in block lettering (Figure 3.1-9):

BM. AEC. HOLE #2 SWNWNE SEC. 14. T1S. R99W ELEV. 6597'

Figure 3.1-8. Project Bronco USBM Core Hole No. 2 (photo taken July 2005 on file at Desert Research Institute).

Two silver tags on the casing document visits from the Office of the State Engineer, Colorado Division of Water Resources. As with Core Hole No. 1, this well has been monitored regularly since 1991 with the most recent visit occurring on September 23,

Figure 3.1-9. Welding on Project Bronco Core Hole No. 2 casing (photo taken July 2005 on file at Desert Research Institute).

Figure 3.1-10. Office of the State Engineer, Colorado Division of Water Resources monitoring tags at Core Hole No. 2 (photo taken July 2005 on file at Desert Research Institute).

2004 (Figure 3.1-10). The site is very clean. The only debris noted were a few lumber fragments; some wooden lath; a couple pieces of metal; a red rubber gasket; a steel-sided, soft-top pull-tab beverage can (c. 1964-72) and two more recent pop-top aluminum soft-drink cans.

The condition of the third drill hole location was not evaluated during either the FY 2003 or FY 2005 field visits. Access problems and time constraints prevented DRI personnel from reaching USBM Core Hole No. 3. However, it is assumed that the physical setting and condition of this drill hole location will be similar to those noted for Core Hole Nos. 1 and 2.

A review of the land status records on file at the National Nuclear Security Administration, Nevada Site Office in Las Vegas confirmed that the legal jurisdiction for the Bronco Experiment Site was returned to the U.S. Department of the Interior, Bureau of Land Management from the U.S. Department of Energy in 2001.

CHRONOLOGICAL BIBLIOGRAPHY

Denver Post, 1966. Opportunity Brightens for Oil Shale. *Denver Post,* June 28.

Rabb, David D., 1966. Plowshare Program, October 1, 1965 – July 15, 1966, Vol. II, No. 2. University of California, Lawrence Radiation Laboratory, *Report UCRL*-50008-66-1, July 15. Livermore, CA. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-030.

Rabb, David D., 1966. Plowshare Program, July 16, 1966 – October 31, 1966, Vol. II, No. 3. University of California, Lawrence Radiation Laboratory, *Report UCRL*-50008-66-2, October 31. Livermore, CA. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-030.

Werth, Glenn C., [between 1966 and 1973]. Handwritten notes on Plowshare program meetings from Glenn C. Werth, U.S. Atomic Energy Commission, Division of Peaceful Nuclear Explosives, 1966-1973. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-118.

Rabb, David D., 1967. Plowshare Program, November 1, 1966 - January 31, 1967, Vol. II. No. 4. University of California, Lawrence Radiation Laboratory, *Report UCRL*-50008-66-4, January 31. Livermore, CA. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-030.

Werth, Glenn C., 1967. Program Activities for Plowshare. University of California, Lawrence Livermore National Laboratory, *Report UCRL*-124785, February 3. Livermore, CA. On file at: Technical Reports Library, Lawrence Livermore National Laboratory, Livermore, CA.

Cameron and Jones, Incorporated, 1967. Oil Shale and Related Fuels. Cameron and Jones, Incorporated, Quarterly Report, Vol. 4, No. 1, Denver, CO, March 1.

U.S. Atomic Energy Commission, 1967. Nuclear Underground Tests in Planning or Feasibility Stage. Table, March 6. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0188117.

Nordyke, Milo D., 1967. "Status Review of Field Project Studies." Memo from Milo Nordyke, Lawrence Radiation Laboratory, to G. Higgins, April 14. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore CA, File PLO-026.

U.S. Atomic Energy Commission, 1967. "Statement on the Civilian Applications of Nuclear Explosives (Plowshare) Program, U.S. Atomic Energy Commission FY 1968 Authorization Hearings Before the Joint Committee on Atomic Energy." Statement from U.S. Atomic Energy Commission, April 17. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-028.

Rabb, David D., 1967. Plowshare Program February 1, 1967 – April 30, 1967, Vol. II, No. 5. University of California, Lawrence Radiation Laboratory, *Report UCRL*-50008-67-2, April 30. Livermore, CA. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-030.

Rabb, David D., 1967. Plowshare Program May 1, 1967 – July 31, 1967, Vol. II, No. 6. University of California, Lawrence Radiation Laboratory, *Report UCRL*-50008-67-3, July 31. Livermore, CA. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-030.

Renfro, H. B., 1967. "Plowshare Committee, Atomic Industrial Forum." Memo from H. B. Renfro to G. Werth, August 18.

Lombard, David B., Bruce G. Bray, Harold W. Sohns, Thomas S. Sterrett, Robert S. Brundage, and Harry C. Carpenter, 1967. A Design for Project Bronco, An Experiment for Nuclear Fracturing and In Situ Retorting of Oil Shale. University of California, Lawrence Radiation Laboratory, University of California, *Report UCRL*-50339, October 1. Livermore, CA. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0333001.

Bronco Oil Shale Study, 1967. The Bronco Oil Shale Study. Report PNE 1400, October 13. National Bureau of Standards, U.S. Department of Commerce, Springfield, VA.

Kinnamon, R. L., D. W. Hendricks, and R. A. Johnson, 1967. Preliminary Safety Evaluation for Project Bronco, In The Bronco Oil Shale Study, pp. 58-62, Report PNE 1400, October 13. National Bureau of Standards, U.S. Department of Commerce, Springfield, VA.

Lekas, Mitchell A., Bruce G. Bray, Harry C. Carpenter, Gerald U. Dinneen, H. H. Aronson, and J. D. Downen, 1967. The Feasibility of Using Nuclear Explosives in the Production of Shale Oil, In The Bronco Oil Shale Study, pp. 1-21, Report PNE 1400, October 13. National Bureau of Standards, U.S. Department of Commerce, Springfield, VA.

Lombard, David B., Bruce G. Bray, Harold W. Sohns, Thomas S. Sterrett, Robert S. Brundage, and Harry C. Carpenter, 1967. A Design for Project Bronco: An Experiment for Nuclear Fracturing and In Situ Retorting of Oil Shale, In The Bronco Oil Shale Study, pp. 22-45, Report PNE 1400, October 13. National Bureau of Standards, U.S. Department of Commerce, Springfield, VA.

Kelly, John S., 1967. "Redirection of Plowshare Industrial Effort." Memo from John S. Kelly through General Manager, U.S. Atomic Energy Commission, to Seaborg et al., November 21. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-027.

Engineering and Mining Journal, 1967. "Can Nuclear Retorting Unlock Oil Shale?' *Engineering and Mining Journal*, December 1967, pp. 72-75.

Jackson, Melvin W., 1967. Ten Years of Plowshare. *Civil Engineering*, December. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029.

Oil, Gas Projects, 1967. Oil, Gas Projects Perk Up AEC's Plowshare. Government, 1967. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-030.

U.S. Atomic Energy Commission, 1967. *Plowshare Program During 1966: Based on the Annual Report to Congress for 1966 of the U.S. Atomic Energy Commission.* U.S. Atomic Energy Commission, U.S. Government Printing Office, Washington, D.C. On file at Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029; and Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Applied Nuclear Company, [Post 1967], Applied Nuclear Company and Plowshare. Report to U.S. Atomic Energy Commission from Applied Nuclear Company, La Jolla, CA. On file at: Technical Reports Library, Lawrence Livermore National Laboratory, Livermore, CA.

U.S. Atomic Energy Commission, 1968. Chapter 11 - The Plowshare Program. In *Annual Report to Congress of the Atomic Energy Commission for 1967,* pp. 199-208, January. U.S. Government Printing Office, Washington, D.C.

Vermillion, Henry G., 1968. Letter from H. G. Vermillion to G. K. Plumleigh, January 24. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0188360.

U.S. Atomic Energy Commission, 1968. "Civilian Applications of Nuclear Explosives (Plowshare) Program – Operating Costs, FY 1969 Budget Estimates: Appropriation – Operating Costs." On file at: Archives and Records Office, Lawrence Berkeley National Laboratory, Berkeley, CA, File 434-900205, 28/48.

Rabb, David D., 1968. Plowshare Program November 1, 1967 – January 31, 1968, Vol. II, No. 8 University of California, Lawrence Radiation Laboratory, *Report UCRL-*50008-68-1, January 31. Livermore, CA. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-030.

Seaborg, Glenn T., 1968. The Progress of the Peaceful Atom. Paper presented at the Governor's Industrial Safety Conference, February 7, 1968, San Francisco, California. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Las Vegas, NV, Accession No. NV0148558.

Bray, Bruce G., 1968. Letter from Bruce. G. Bray, CER Geonuclear Corporation, to Harold W. Sohns and David B. Lombard, February 15. On file at: Archives and Research Center, Lawrence Radiation Laboratory, Livermore, CA, File PLO-030.

Miller, David F., 1968. "Press Query Regarding Bronco." Memo from David F. Miller, U.S. Atomic Energy Commission, Nevada Operations Office, to Files. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0325234.

Woodruff, Wayne R., 1968. Execution Plan Concept for Project Bronco. Report from Lawrence Radiation Laboratory, Report UOPKJ 68-10, K Division, T-105, Livermore, CA. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0162343.

McCool, W. B., 1968. "Atomic Energy Commission Status of Plowshare Industrial Projects." Memo with Encl. ("Status of Plowshare Industrial Projects," memo from John S. Kelly, U.S. Atomic Energy Commission, Division of Peaceful Nuclear Explosives, to List) from W. B. McCool, U.S. Atomic Energy Commission to Distribution, April 26. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029 [OUO].

Rabb, David D., 1968. Plowshare Program February 1, 1968 – April 30, 1968, Vol. II, No. 1. University of California, Lawrence Radiation Laboratory, *Report UCRL-*50008-68-2, April 30. Livermore, CA. On file at Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-030.

U.S. Department of the Interior. Bureau of Mines, 1968. Prospects for Oil Shale Development, Colorado, Utah, and Wyoming. Manuscript, May. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Kelly, John S., 1968. Letter from John S. Kelly, U.S. Atomic Energy Commission, to Glenn C. Werth, September 4. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0312989.

Werth, Glenn C., 1968. "Alternate #1, Tentative Schedule – Plowshare Program – LRL Related." Schedule from Lawrence Radiation Laboratory, September 10. On file at: Archives and Records Office, Lawrence Berkeley National Laboratory, Berkeley, CA, File 434-900205, 28/48.

Werth, Glenn C., 1968. "Alternate #2, Tentative Schedule - Plowshare Program - LRL Related." Schedule from Lawrence Radiation Laboratory, September 10. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-118.

U.S. Atomic Energy Commission, 1968. Plowshare Program. Booklet. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029.

Plowshare Advisory Committee, 1968. Plowshare Advisory Committee, Report on Eighteenth Meeting. Meeting held at Oak Ridge National Laboratory, Oak Ridge, TN, November 21-22. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029 [OUO].

Ege, J. R., R. D. Carroll, R. J. Way, and J. E. Magner, 1968. Evaluation of Core Data, Physical Properties, and Oil Yield, USBM/Atomic Energy Commission Colorado Core Hole No. 3 (Bronco BR-1). Interagency Report Oil Shale-1. Special Projects Branch, U.S. Geologic Survey, Denver, CO.

U.S. Atomic Energy Commission, 1969. Chapter 11 - Peaceful Nuclear Explosions. In *Annual Report to Congress of the Atomic Energy Commission for 1968,* pp.195-202, January. U.S. Government Printing Office, Washington, D.C.

Plowshare Advisory Committee, 1969. Plowshare Advisory Committee, Report on Nineteenth Meeting. Meeting held at Lawrence Radiation Laboratory, Livermore, CA, November 4-5. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029 [OUO].

Cordes, E. H., 1969. Oil Shale-6, Hydraulic Testing and Sampling of USBM-AEC Colorado Core Hole 3, Rio Blanco County, Colorado. Report to the U.S. Atomic Energy Commission, from U.S. Department of the Interior, Geological Survey, Denver CO.

U.S. Atomic Energy Commission. Division of Technical Information, 1969. Status of Nuclear Test Reports. U.S. Atomic Energy Commission, Report TID-9533. Washington, D.C. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0105641. Note: Document location?

U.S. Atomic Energy Commission, 1970. Chapter 11 - Peaceful Nuclear Explosives. In *Annual Report to Congress of the Atomic Energy Commission for 1969,* pp. 195-203, January. U.S. Government Printing Office, Washington D.C.

U.S. Atomic Energy Commission, 1970. "Plowshare Program Statement, JCSE FY 1971 Authorization Hearings." Statement from U.S. Atomic Energy Commission, March 5. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-028.

Arnold, W. D., and D. J. Crouse, 1970. Radioactive Contamination of Oil Produced from Nuclear-Broken Shale. In *Symposium on Engineering with Nuclear Explosives: Proceedings,* Report CONF-700101, Vol. 2, pp.1597-1612, May. The American Nuclear Society, Hinsdale, IL.

Lombard, David B., Bruce G. Bray, and Harold W. Sohns, 1970. Technical Considerations for Plowshare Applications to Oil Shale. In *Symposium on Engineering with Nuclear Explosives: Proceedings,* Report CONF-700101, Vol. 2, pp. 1343-136, May. American Nuclear Society, Hinsdale, IL.

Evans, Roy B., and David E. Bernhardt, 1970. “Probable Scheduling of Plowshare Events.” Memo from Roy B. Evans and David E. Bernhardt, U.S. Department of Health, Education, and Welfare, Southwestern Radiological Health Laboratory, to Francis N. Buck, May 8. On file at Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0173142 [OUO].

Bulletin of the Atomic Scientists, 1970. *Bulletin of the Atomic Scientists*, pp. 88-91, June. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029.

West, Chris L., 1970. “Answer to Inquiry Status of Bronco, WASP, and Wagon Wheel.” Letter from Chris L. West, U.S. Atomic Energy Commission, Nevada Operations Office, to Files, October 7. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0325747.

Coffer, H. F., and G. H. Higgins, 1970. Future Contained Nuclear Explosives Experiments. In *Education for Peaceful Uses of Nuclear Explosives*, Lynn E. Weaver, editor, pp. 45-63. University of Arizona Press, Tucson, AZ.

U.S. Atomic Energy Commission, 1970. *Plowshare Program During 1969: Based on the Annual Report to Congress for 1969 of the U.S. Atomic Energy Commission.* U.S. Atomic Energy Commission, U.S. Government Printing Office, Washington, D.C. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Whan, Glenn A., 1973. Plowshare Technology Assessment, Final Report, Implications to State Governments. Report to the Western Interstate Nuclear Board, Lakewood, CO, from Glenn A. Whan, Chemical and Engineering Department, University of New Mexico. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Crump, Joseph R., 1975. PNE (Peaceful Nuclear Explosion) Activity Projections for Arms Control Planning, Vol. I. Report to the U.S. Arms Control and Disarmament Agency, Contract No. ACDE/PAB-253, from Gulf Universities Research Consortium, Galveston, TX, April 10.

Ballou, L., M. Nordyke, and G. Werth, 1977. A Summary of U.S. PNE Experience. Report prepared for U.S. Energy Research & Development Administration from Lawrence Livermore Laboratory, *Report UCID*-17649, November 17. On file at: Defense Threat Reduction Information Analysis Center, Albuquerque, NM; and Technical Reports Library, Lawrence Livermore National Laboratory, Livermore, CA.

Lawrence Livermore National Laboratory, 1982. Project Plowshare: A Brief History. *Energy and Technology Review*, pp. 13 -20, September. Lawrence Livermore National Laboratory, Livermore, CA.

Shafer, David S., William. C. Beck, Dwight Treadwell, and Stephen. A. Mellington, 1995. Inventory of Potential Environmental Restoration Liabilities Associated with Plowshare And Vela Uniform Program Sites. Manuscript, U.S. Department of Energy, Office of Environmental Restoration. On file at: Desert Research Institute, Las Vegas, NV.

U.S. Department of Energy. Nevada Operations Office, 1997. Plowshare Program Executive Summary. Report from U.S. Department of Energy, December 22.

Dragon Trail and Bronco, n.d. Dragon Trail and Bronco: Time and Mileage to Sites. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-012.

Engineering and Mining Journal, n.d. Behind the By-lines. *Engineering and Mining Journal*. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-030.

Hanna, Bert, n.d. A-Blast Use Expected to Make Colorado. No. 1 in Oil, Gas. *Denver Post*. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-030.

Holmes & Narver, Inc., n.d. "Area Map – Bronco, Dragon Trail, and, Rulison: Tentative Locations in Rio Blanco and Garfield Counties, Colorado." Map. On file at: Engineering Records Library, Nevada Test Site, Mercury, NV, Index No. 187324.

Lawrence Livermore National Laboratory, n.d. Bronco-b photo. Negative No. GLC-674-2752. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

Lawrence Livermore National Laboratory, n.d. Bronco-c photo. Negative No. GLC-674-2753. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

Lawrence Livermore National Laboratory, n.d. Bronco-d photo. Negative No. 67J6 630. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

Lawrence Livermore National Laboratory, n.d. "Project Bronco - Explosion Effects." Explosion effects drawing, Bronco-a. Negative No. GLC 6810-6453. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

Plowshare Public Health Evaluation, n.d. Plowshare Public Health Evaluation. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0316824.

U.S. Department of Energy. Nevada Operations Office, n.d. The Plowshare Program (Draft). Report from U.S. Department of Energy.

THIS PAGE INTENTIONALLY LEFT BLANK

3.2 CHASE

Vela Uniform Program
High Explosive Long Range Seismic Monitoring Experiments
Pacific Ocean, Alaska and California; and Atlantic Ocean, Virginia

In September 1959, the U.S. Department of Defense and its newly formed Advanced Research Projects Agency were tasked with developing a program for detecting and monitoring nuclear explosions by foreign powers. The Vela Uniform Program, as it was called, provided the technical basis for United States nuclear monitoring activities and supplied the data needed to address Nuclear Test Ban Treaty verification issues. The Long Range Seismic Measurements program was a fundamental component of the Vela Uniform Program. The Advanced Research Projects Agency's Nuclear Test Detection Office administered the various Long Range Seismic Measurements projects. Originally established to record and analyze both short- and long-period seismic data from a series of planned underground nuclear tests, the project's goal was the development of methods for distinguishing between explosive and natural seismic sources in order to monitor compliance with the proposed Test Ban Treaty. Gathering comparative seismic data from both nuclear and chemical explosions was critical to this mission.

Project CHASE was a series of seismic monitoring experiments designed to provide baseline data on underwater blasts in order to identify differences between the seismic signatures of dry land-centered seismic occurrences and water-centered detonations. The research took advantage of the U.S. Bureau of Naval Weapons' practice of disposing of surplus munitions on obsolete vessels. In Operation CHASE (for "Cut Holes and Sink 'Em) decommissioned ships, filled with munitions, were towed out to sea and sunk. Most of the sinkings involved the detonation of conventional ammunition and starting with the third operation in the CHASE series, CHASE III, the U.S. Office of Naval Research in collaboration with the Advanced Research Projects Agency, planned at least four joint seismic experiments – CHASE III through CHASE VI. These were located off the coast of Virginia (CHASE III and IV), off the northern coast of California (CHASE V), and near the Aleutian Islands (CHASE VI) (Figure 3.2-1).

The Office of Naval Research executed the CHASE III 0.7 kt detonation on July 15, 1965 at 37°20'N Latitude 74°35'W Longitude in the Atlantic Ocean off the coast of Virginia. CHASE IV was a 0.3 detonation on September 16, 1965 slightly south and east of the previous blast at 37°19'N Latitude 74°44'W Longitude (Figure 3.2-2). Both of the controlled explosive detonations were at a depth of approximately 900 feet below the water surface. No documentation has been found describing the details and results of the CHASE III and CHASE IV seismic experiments.

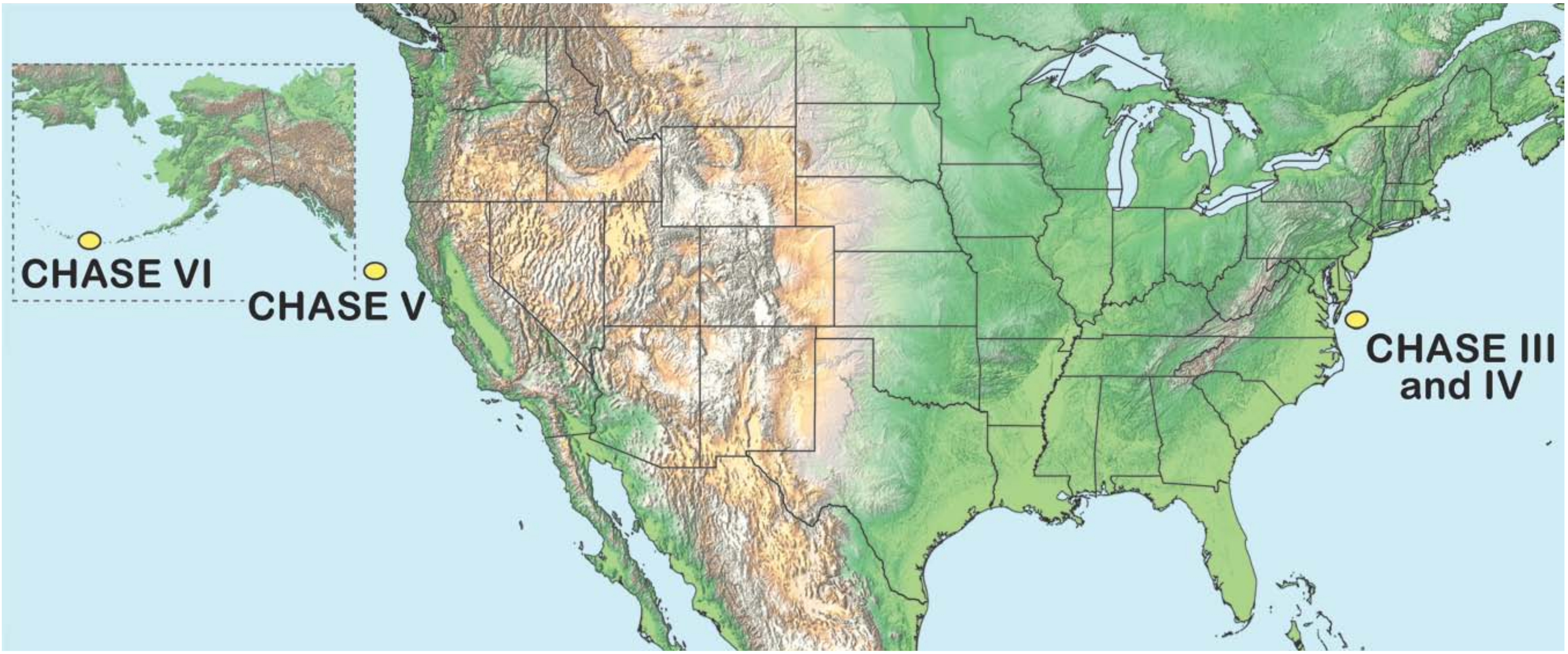


Figure 3.2-1. Location of the CHASE seismic experiments (adapted from USA Relief Maps 2004).

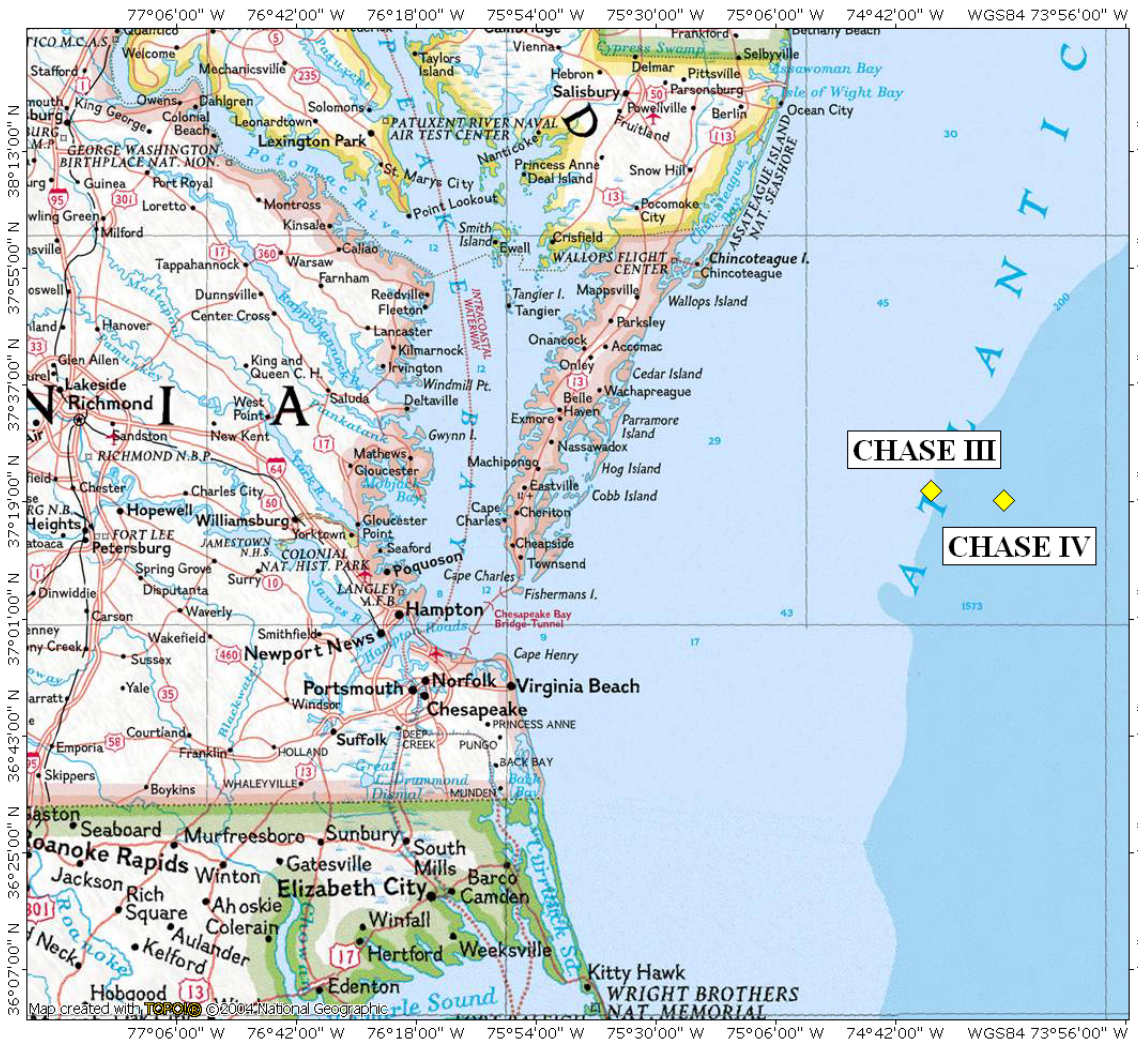


Figure 3.2-2. Location of the CHASE III and CHASE IV detonations in the Atlantic Ocean off the coast of Virginia (adapted from National Geographic Topographic Maps 2006).

In early 1965, a CHASE seismic experiment was proposed for a location off the coast of northern California near the Mendocino Escarpment near Cape Mendocino. The project was named CHASE V. When it was executed in 1966, it involved the detonation of surplus ammunition with an approximate yield of 1,000 tons of TNT equivalent. Unspecified operational problems accelerated the test date by a day and at a different location than originally planned. The U.S. Office of Naval Research conducted the test on May 24, 1966 at 05:49:06 GMT at 39°28'N Latitude 125°48'W Longitude with the vessel anchored in water 12,500 ft deep. The ammunition detonated at 3,750 ft below the water surface. Of interest, a natural seismic event, a 4.6 magnitude (Richter Scale) earthquake centered near Chico, California, occurred approximately two hours before the CHASE V test, providing comparative data between the underwater detonation and the earthquake of similar magnitude.

Both the Advanced Research Projects Agency and the U.S. Office of Naval Research funded data collection activities for the CHASE V experiment. The Advanced Research Projects Agency relied on land-based seismic stations, while the U.S. Office of Naval Research focused on ocean-based instrumentation. The Advanced Research Projects Agency sponsored monitoring facilities for earlier (c. 1961-62) Long Range Seismic Measurements projects, such as the Colona, Hebgen Lake, and New Madrid earthquakes (see Chapters 4.10, 4.19 and 4.25) were limited to mobile seismic recording vans. By the time the CHASE V experiment was conducted, however, several larger permanent seismographic observatories had been constructed. The purpose of these observatories was to continually monitor natural seismic activity, as well as record data from a series of underground nuclear detonations conducted by the United States. The fixed installations established included the Wichita Mountains Seismological Observatory in Lawton, Oklahoma; the Blue Mountains Seismological Observatory in Baker, Oregon; the Uinta Basin Seismological Observatory in Vernal, Utah; the Cumberland Plateau Seismological Observatory in McMinnville, Tennessee; and the Tonto Forest Seismological Observatory in Payson, Arizona. In addition to the observatories, 20 mobile seismic recording stations were deployed for the CHASE V experiment. Dispersed at various locations these facilities consisted of vans outfitted with portable monitoring equipment consisting of both short-pulse and long-pulse seismographs. Equipment used in earlier seismic monitoring recorded the data on both 35-mm film and magnetic tape, but the portable systems used during CHASE V relied on magnetic tape exclusively.

All five of the observatories recorded seismic signals from the CHASE V detonation, while 19 of the mobile locations received data (Figure 3.2-3). Only the Belleview, Florida station failed to record signals from the explosion. The remaining locations registered short-period signals, but none recorded long period seismic phases. Based on the data from the seismic monitoring stations, the calculated epicenter of the CHASE V blast was at 39°21’53” N Latitude 125°51’16”W Longitude, approximately 11 km south and 7 km west of the geographic epicenter. The explosion generated a shock wave measured at a magnitude of 4.67.

In addition to the Advanced Research Projects Agency monitoring project, the U.S. Office of Naval Research supported hydroacoustic wave investigations of the CHASE V blast. The Scripps Institute, the University of Oregon, and the University of Hawaii all deployed research vessels equipped with hydrophones and ocean-bottom seismographs in advance of the CHASE V experiment (Figure 3.2-4). These ships recorded the hydroacoustic signals created by both the direct blast sound waves and topographic reflections. The data analysis indicated that underwater blasts have a distinctive signature in the bubble-pulses that follow the direct blast wave.

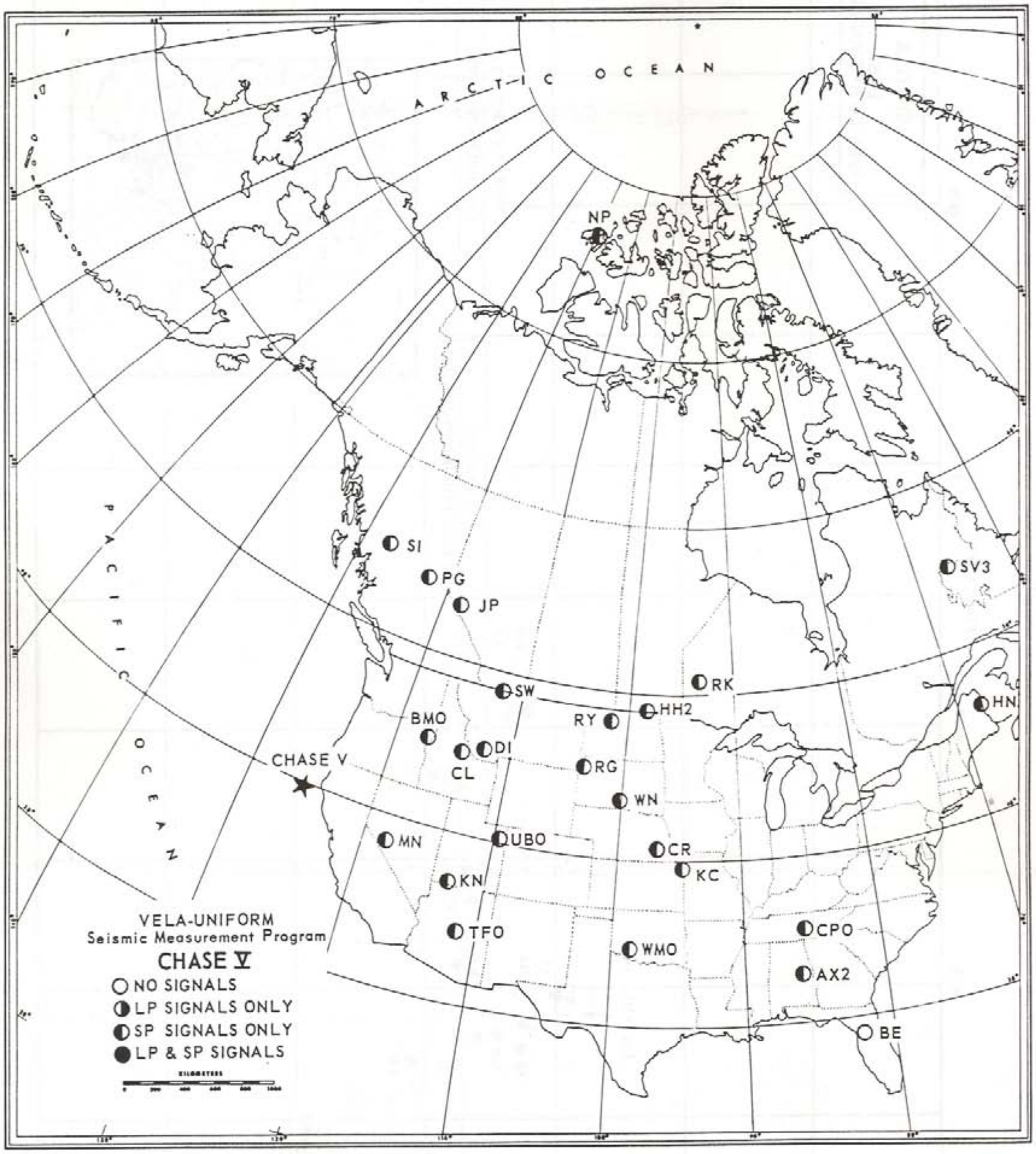


Figure 3.2-3. Distribution of North American seismic recording stations and signals received for the CHASE V Detonation (Reakes et al. 1966, Figure 1).

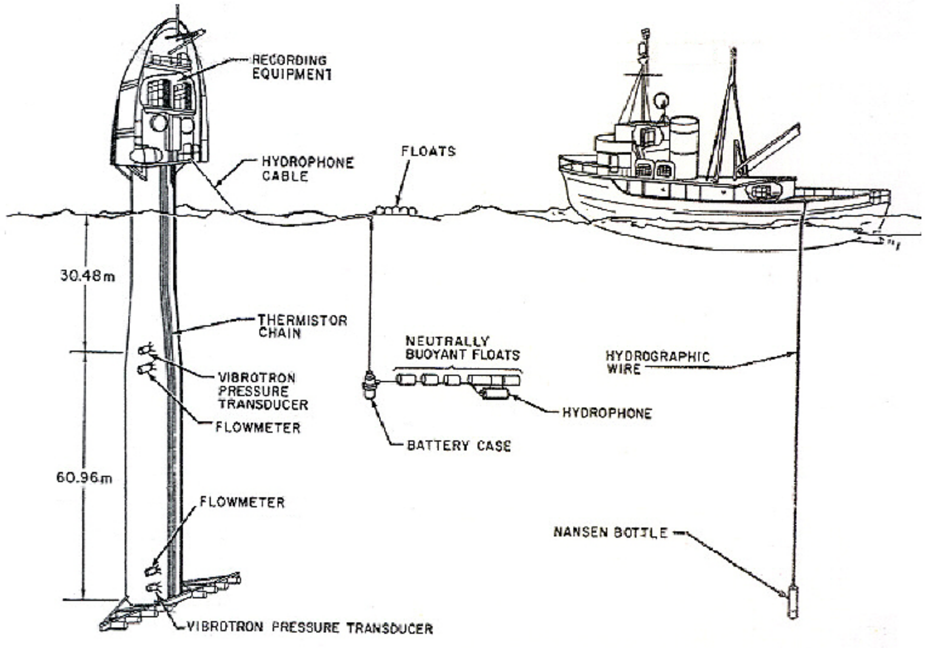


Figure 3.2-4. Hydrophone suspension system used for monitoring the CHASE V Detonation (Northrop 1968, Figure 2).

The U.S. Air Force Office of Scientific Research was also involved with the CHASE V experiment. This agency supported data gathering efforts for the underwater event from an extensive West Coast (Berkeley) network of 40 permanent and 9 temporary seismic stations (Figure 3.2-5). Most of these monitoring facilities were located in California, an area of high natural seismic activity. Although not part of the original experiment design, these stations registered seismic signals from both the Chico earthquake and the CHASE V event making their records ideal for comparative studies. The researchers demonstrated that the CHASE V and Chico earthquake exhibited significant differences in their seismic signatures in terms of energy wave type and amplitude as well as duration and frequency spectrum.

The initial Long Range Seismic Measurements data analysis for Project CHASE V appears to have been completed by 1966, although several research organizations continued to make comparative studies using the seismic recordings from the detonation and the Chico earthquake. Field activity was limited to the use of existing permanent facilities and the temporary placement of the mobile seismic monitoring vans and research vessels. As with other seismic detection projects, many of the portable units were relocated shortly after the CHASE V event, while a few remained in place for future use (see Project Colona Earthquake and Project West Virginia Earthquake). The research ships returned to their homeports.

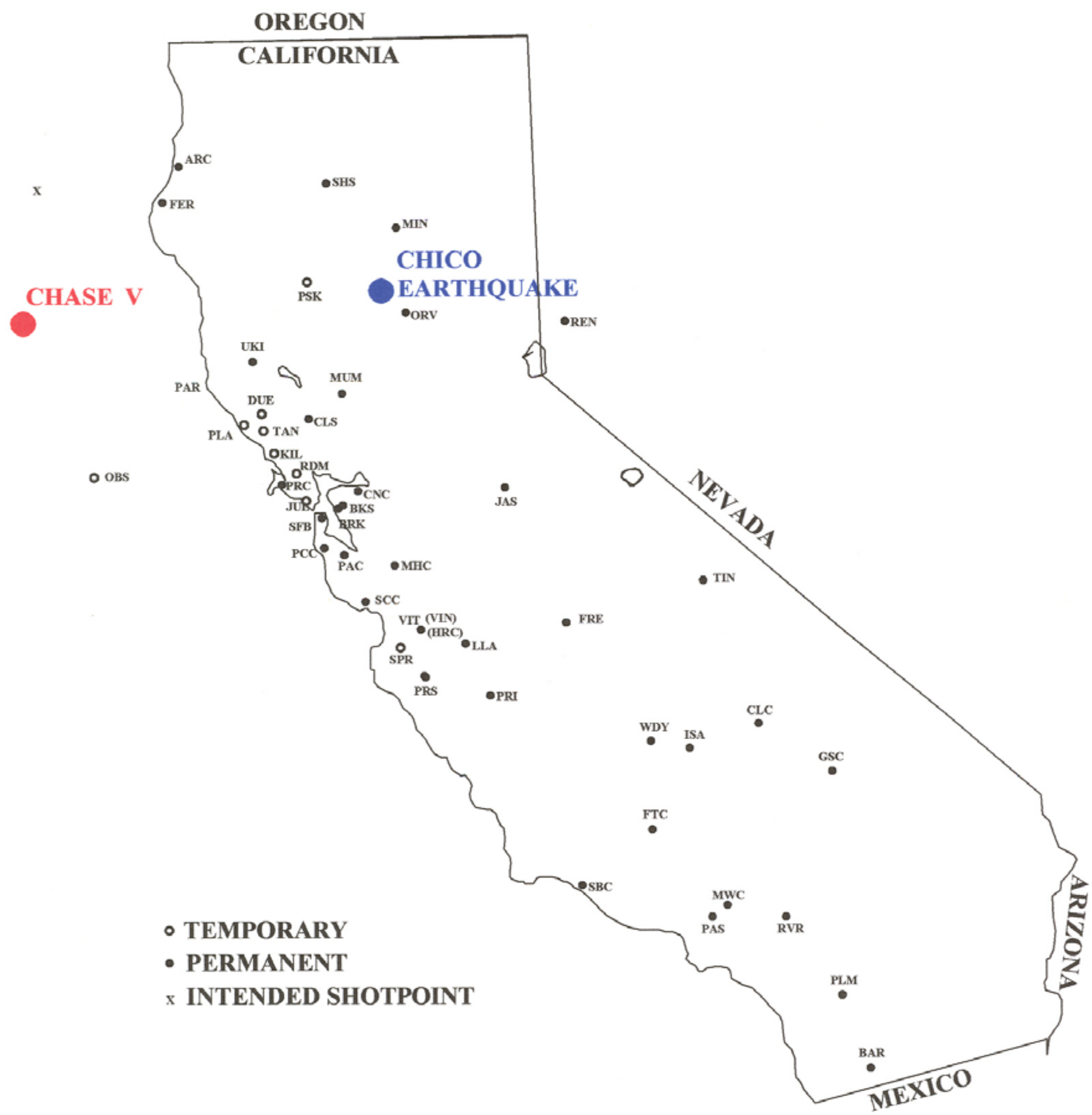


Figure 3.2-5. Distribution of the West Coast (Berkeley) Network of Seismic Recording Stations for the CHASE V Detonation (adapted from Reakes et al. 1966, Figure 1).

Information about a seismic experiment in the Arctic Ocean of Alaska, CHASE VI, is available in a letter dated April 7, 1967 from the Advanced Research Projects Agency to the Alaska Department of Fish and Game. The letter references another letter dated April 26, 1966 (not available) that informed the Alaska Department of Fish and Game about a plan to conduct CHASE VI, a deep water explosive experiment off the coast of Alaska. The tentative plan was to conduct the test during the summer of 1966, and the 1966 letter requested comment on proposed sites for the detonation. However, by May 1966 the CHASE VI munitions disposal had been postponed until the summer of 1967. In early 1967, the Advanced Research Projects Agency was in the initial planning stages for an Aleutian seismic field experiment, and it was thought that the CHASE VI disposal in the Aleutian Islands would provide a controlled source for a seismic experiment and complement the Aleutian seismic study. The Aleutian seismic field experiment was designed to provide data on the thickness and seismic velocity of the crust and upper mantle, and the deep structure of the Aleutian volcanic arc. The experiment called for placing ocean-bottom seismographs at a series of points along two profiles across the Aleutian arc with the Aleutian Island as a center point. High explosives would be detonated at locations along the profiles to obtain seismic data. While the number and yield of these explosions had not yet been determined there would be 10 to 20 detonations with a yield of approximately 5 tons each, and 4 to 5 detonations of about 10 tons each. One purpose of the study was to determine the cause of time-travel bias that was recorded during the Long Shot experiment. Long Shot, an 80 kt underground nuclear explosion detonated on Amchitka Island in October 1965, was a Vela Uniform project.

The idea was that the planned CHASE VI munitions disposal in conjunction with the Aleutian arc seismic experiment would provide supplemental data to investigate the underwater error bias observed during the Long Shot experiment. CHASE VI was planned as a munitions disposal of 100 tons of TNT equivalent surplus ammunition, 1,000 ft below the ocean surface in 1,500 fathoms of water. The proposed site for CHASE VI was the location of a previously documented earthquake in the Pacific Ocean, 35 miles west of Amchitka Island at 51°12'N Latitude 178°26'E Longitude (Figure 3.2-6). The U.S. Navy had confirmed that a ship would be ready to be towed to the project area in mid-June, 1967, and CHASE VI was tentatively scheduled for early July. The goal was to generate an underground explosion of sufficient magnitude to be detectable at seismic stations that recorded the Long Shot event, and to verify the accuracy of the recorded earthquake.

A letter dated April 7, 1967 from S. Lukasik of the Department of Defense to the Alaska Department of Fish and Game solicited input on possible impact of the Aleutian arc seismic experiment and the CHASE VI project on marine life. S. J. Lukasik, the Director for Nuclear Detection, requested that any comments be provided prior to a meeting planned to finalize operational details, tentatively scheduled for May 9-10, 1967 at the Naval Ammunition Depot in Bangor, Washington. An additional document, a letter dated to April 10, 1967, confirms that the CHASE VI project was planned for early July, and that the Advanced Research Projects Agency was preparing a public release for the project. However, no additional documentation has been found concerning CHASE VI, and it is unknown if CHASE VI and/or the Aleutian seismological field experiment were ever conducted. Presumably the CHASE VI munitions disposal was conducted, but it is not known if the Vela Uniform seismic study program was executed concurrently.

CHASE III, IV, and V were Level 2 activities due to the use of conventional munitions. The activity level of CHASE VI is not known.

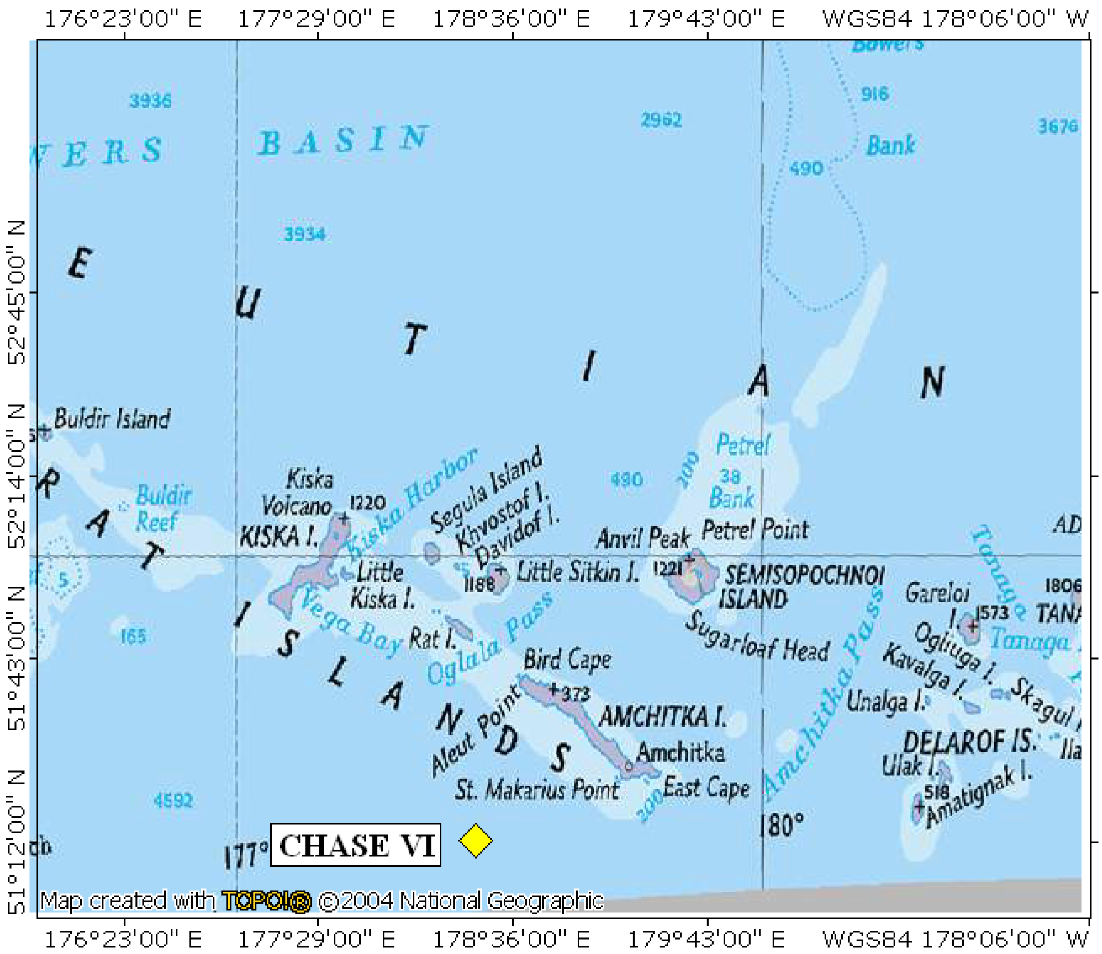


Figure 3.2-6. Location of the proposed CHASE VI seismic experiment off Amchitka Island in the Pacific Ocean (adapted from National Geographic Topographic Maps 2006).

CHRONOLOGICAL BIBLIOGRAPHY

Reakes, R. G., J. Newson, W. H. Frye, and A. S. Child, 1966. Long Range Seismic Measurements - Chase V, 24 May 1966. Report to Air Force Technical Applications Center, Washington, D.C., from Teledyne Industries, Geotech Division, Garland, TX, July 15. On file at: Technical Reports Library, Lawrence Livermore National Laboratory, Livermore, CA.

Lukasik, S. J., 1967. Letter from S. J. Lukasik, U.S. Department of Defense, Advanced Research Projects Agency, to W. Kirkness. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0083882.

Test, H. H., 1967. Letter from H. H. Test, U.S. Department of Defense, Advanced Research Projects Agency, to C. V. Glines, April 10. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0083881.

Lomnitz, C. and B. A. Bolt, 1967. Evidence on Crustal Structure in California from the Chase V Explosion and the Chico Earthquake of May 24, 1966. *Bulletin of the Seismological Society of America*, Vol. 57, No. 5, pp. 1093-1114, October.

Northrop, John, 1968. Submarine Topographic Echoes from Chase V. *Journal of Geophysical Research,* Vol. 73, No. 12, pp. 3909-3916, June 15.

Lomnitz, C. and B. A. Bolt, 1968. A Comparative Study of the Chase V Explosion and the Chico, California Earthquake of May 24, 1966. *The Geological Society of America, Inc., Abstracts for 1967*:337. Boulder, CO.

Kibblewhite, A. C., and R. N. Denham, 1971. The Chase V Explosion: Submarine Topographic Reflections from the Vicinity of Pitcairn Island. *Deep-Sea Research and Oceanographic Abstracts*, Vol. 18, No. 9, pp. 905-911, September.

3.3 COWBOY

Vela Uniform Program
High Explosives Seismic Monitoring Experiment
Louisiana

The successful containment of an underground nuclear test at the Nevada Test Site in 1957 led to new avenues of scientific inquiry. Project Cowboy was designed to investigate seismic disturbances generated by contained underground explosions. It was structured to test the validity of certain seismic decoupling theories using a series of high explosive detonations in a salt medium. According to the decoupling theories, detonating a nuclear device in a large underground cavity can significantly reduce the blast's long-range seismic signature. This information also was important for detecting other countries' nuclear tests and enhancing the surveillance program. Operations associated with the surveillance program were the detection of a seismic event, determination of its location, and identification of the event as either an earthquake or an explosion.

The proposed testing program consisted of two phases. Project Cowboy was the first of these and involved a series of chemical explosions in a salt dome. A salt dome was chosen because salt occurs in massive geologically competent formations, is relatively homogeneous, exhibits favorable elastic properties, and its soft consistency minimizes construction problems. The primary goal of Cowboy was to determine the degree of decoupling possible. If the Cowboy results proved encouraging, the program's second phase using nuclear explosives would be pursued.

The project concept and design began before March of 1959 when the U.S. Geological Survey received a request to conduct a survey of salt mines in order to identify those appropriate for Project Cowboy. Criteria included 1,000 ft of overburden and a high-quality homogenous salt medium with a radius of at least 300 ft. On April 24, 1959, the U.S. Geological Survey issued its report and identified six that met the criteria: 1) United Salt Corporation Mine, Hockley, Texas; 2) Morton Salt Company Mine, Grand Saline, Texas; 3) Myles Salt Company Mine, Jefferson Island, New Iberia, Louisiana; 4) International Salt Company Mine, Weeks Island, New Iberia, Louisiana; 5) Morton Salt Company Mine, Weeks Island, New Iberia, Louisiana; and 6) Carey Salt Company Mine, Winnfield, Louisiana. The Carey Salt Company Mine in north-central Louisiana, approximately 110 miles southeast of Shreveport, was chosen based on the features of the salt dome, location, and logistical considerations (Figures 3.3-1 and 3.3-2). The mine is near the southwest corner of Sec. 19, T11N R3W. The dome lies approximately 400 ft below the surface and is nearly 1.25 miles in diameter. The deposit is part of the interior belt of salt domes that roughly parallels the Gulf Coast. A service and construction contract was discussed with the Carey Salt Company's owners on June 10, 1959 and on July 20, 1959 Carey Salt Company signed a contract for the work.

On July 31, 1959, the technical director's operation plan was issued for Project Cowboy. The plan for Cowboy specified approximately 20 shots divided into two phases based on

Figure 3-3.1. Location of Project Cowboy in northern Louisiana
(adapted from USA Relief Maps 2004).

yield. Phase I consisted of seven shots, five shots with yields up to 100 lbs detonated in a 12-ft diameter sphere (decoupled) and two tamped (coupled) 100-lb calibration shots detonated in vertical holes. Phase II focused on higher yield blasts, including a one-ton point source explosion fired in a spherical cavity. Plans also called for six pairs of shots with a yield of 200 lbs to five tons. One shot of each pair would take place in a 30-ft diameter sphere. The other would be a closely tamped calibration detonation of the same yield. The initial project schedule proposed that construction begin on August 3, 1959. Experiments were to be conducted between October 19th and December 1st with all data analyzed by December 31, 1959. The only planned surface facilities at the site were the addition of several temporary trailers for office space and data analysis and a dining facility (Figures 3.3-3 and 3.3-4). Existing commercial facilities and housing in the nearby town of Winnfield would also be used.

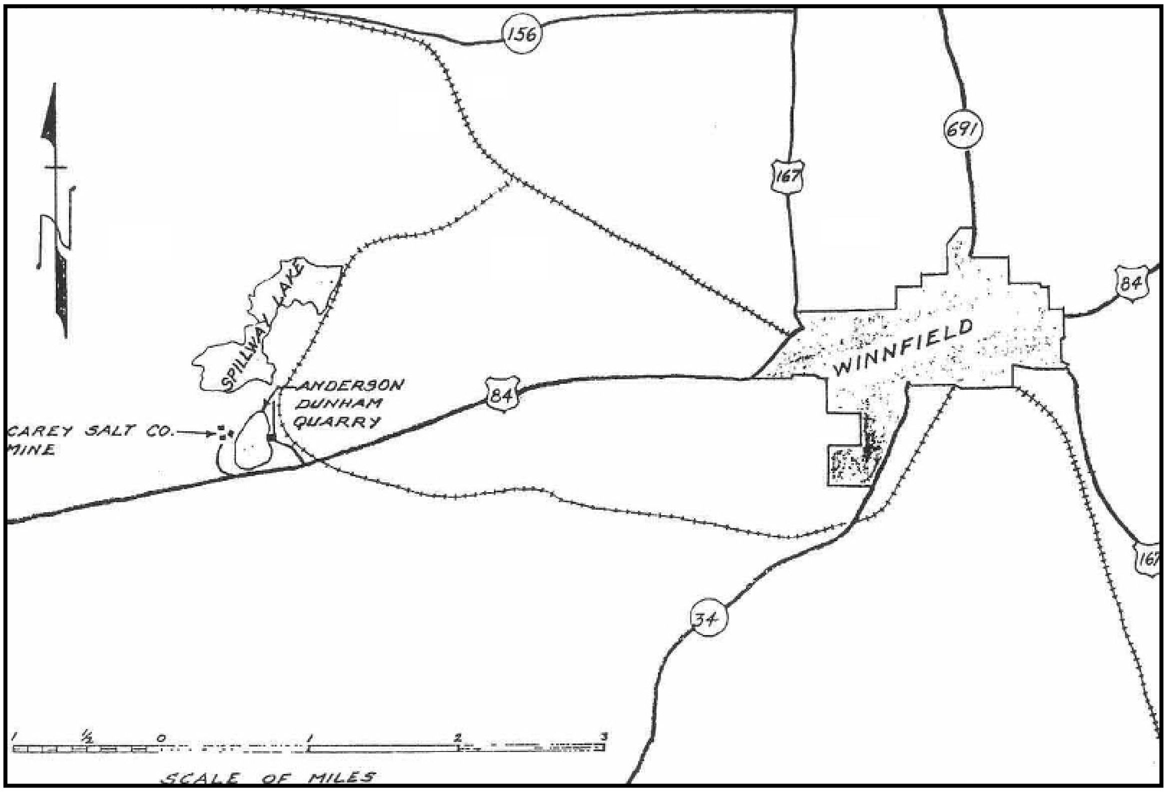


Figure 3.3-2. Location of Carey Salt Company Mine in relationship to Winnfield, Louisiana [best available copy] (Shelton 1959, no number).

Figure 3.3-3. Facilities at Carey Salt Mine Company (Lawrence Livermore National Laboratory n.d., Cowboy_1c1 photo).

Between December 17, 1959 and March 4, 1960, a series of 17 high explosive detonations in tamped, completely contained holes (coupled) and in spherical open cavities (decoupled) were conducted for Project Cowboy (Table 10-1). The Cowboy detonations occurred approximately 800 ft below the surface in a section of the Carey mine that was not under production at the time (Figures 3.3-5 and 3.3-6). All of the Cowboy explosions used charges of Pelletol, a TNT explosive in the form of free-flowing oval pellets about 3/32-inch in diameter. The chemical explosions in the 30 ft diameter Cowboy cavity were fully decoupled meaning the explosive device was not in direct contact with the earth. To complement the salt experiments, three non-nuclear high explosive shots in tuff were planned for the Nevada Test Site beginning around the end of March 1960.

Table 3.3-1. Coupled and Decoupled Shots (Nicholls et al. 1960:46)

Shot No.	Date	Time (CST)	Yield (lbs)	Station	Type
1	17 Dec. 1959	0015	20	1.2	Coupled – 45’ hole
2	17 Dec. 1959	0045	20	1.1	Decoupled – 12’ diam. sphere
3	19 Dec. 1959	0000	100	1.1	Decoupled – 12’ diam. sphere
4	19 Dec. 1959	0015	100	1.3	Coupled – 45’ hole
5	23 Jan. 1960	0000:00.113	198.35	2.1	Decoupled – 30’ diam. sphere
6	30 Jan. 1960	0001:00.112	200.0	2.1	Decoupled – 30’ diam. sphere
7	30 Jan. 1960	0101:00.112	199.65	2.2	Coupled – 110’ hole
8	06 Feb. 1960	0001:00.115	477.4	2.1	Decoupled – 30’ diam. sphere
9	06 Feb. 1960	0101:00.113	499.7	2.3	Coupled – 110’ hole
10	13 Feb. 1960	1901:00.113	954.0	2.1	Decoupled – 30’diam. sphere
11	13 Feb. 1960	2001:00.114	1003.0	2.4	Coupled – 110’ hole
12	20 Feb. 1960	0001:00.112	929.0	1.1	Decoupled – 12’ diam. sphere
13	20 Feb. 1960	0100:59.614	987.6	2.5	Coupled – 110’ hole
14	27 Feb. 1960	0001:00.127	1902.4	1.1	Decoupled – 12’ diam. sphere
15	28 Feb. 1960	0401:00.131	936.2	2.6	Coupled – 110’ hole
16	03 Mar. 1960	2301:00.128	199.5	1.4	Coupled – 45’ hole
17	04 Mar. 1960	0001:00.130	199.8	1.3-1	Coupled – 45’ hole

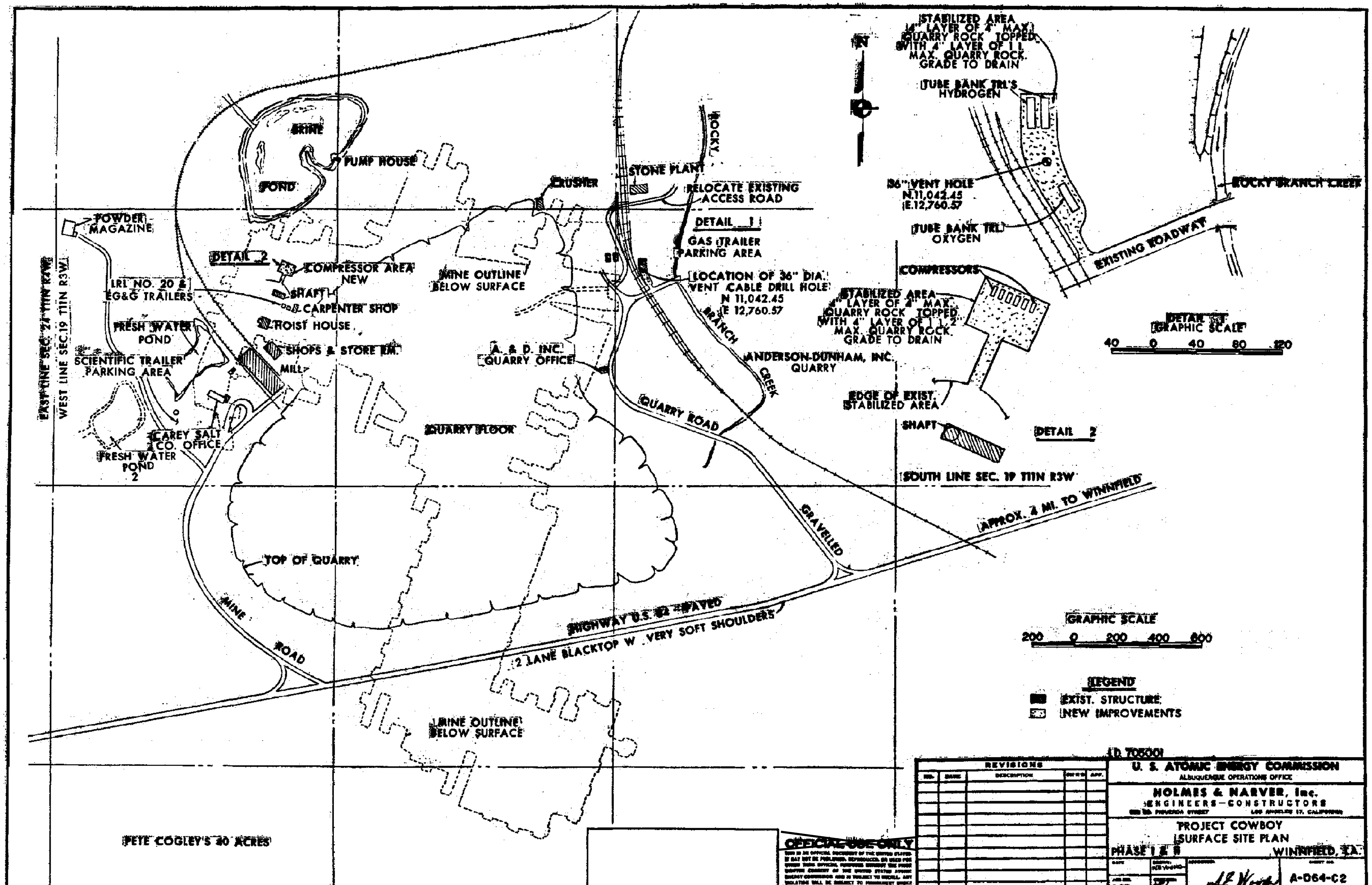


Figure 3.3-4. Project Cowboy site plan [best available copy] (Holmes & Narver, Inc. 1959, Drawing No. A-064-C2).

THIS PAGE INTENTIONALLY LEFT BLANK

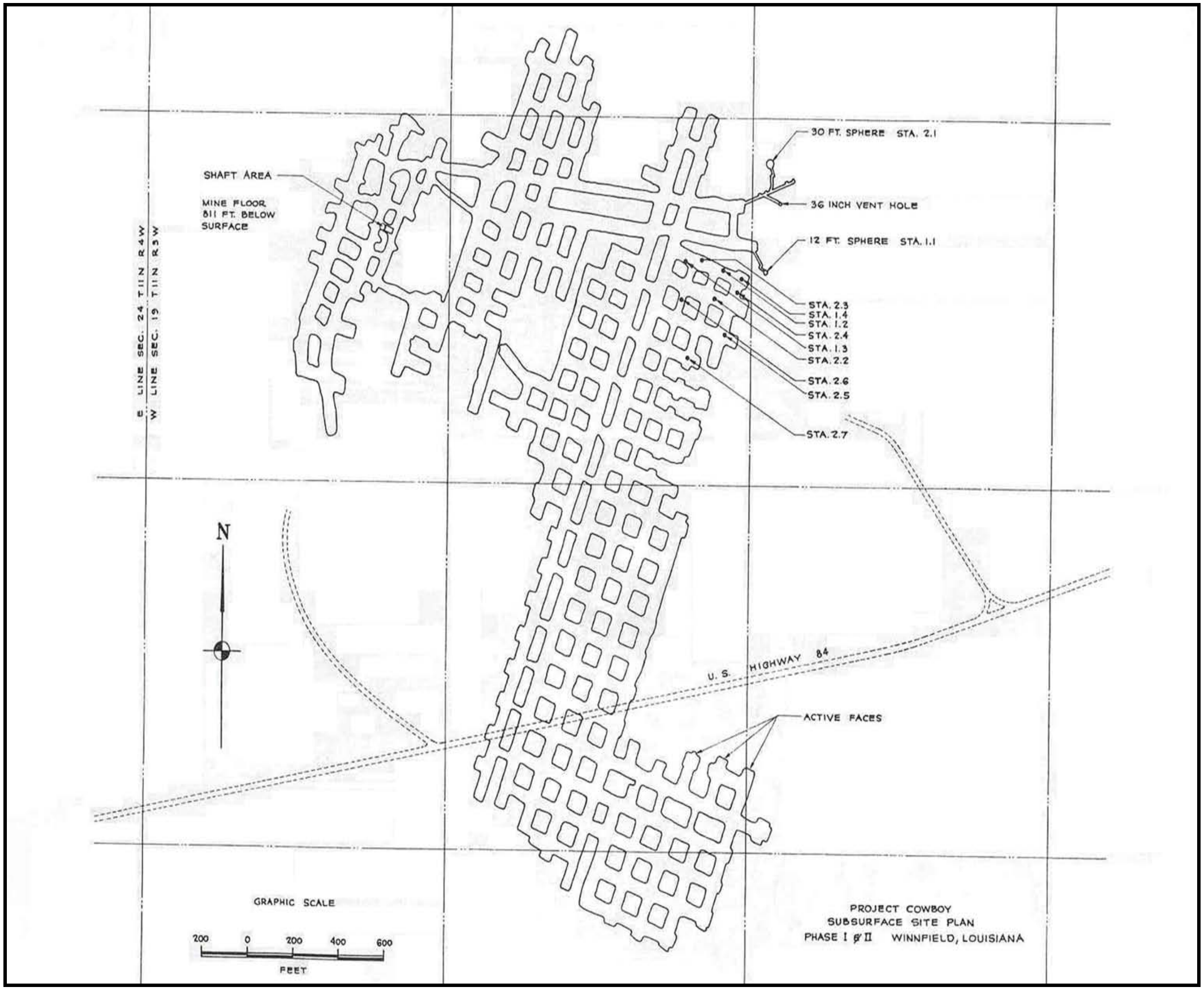


Figure 3.3-5. Project Cowboy subsurface site plan (Short 1960, Figure 2).

Figure 3.3-6. Cowboy subsurface work area (Lawrence Livermore National Laboratory n.d, Cowboy_1e1 photo).

On Project Cowboy, the U.S. Bureau of Mines investigations included the detonation of several small high-explosive tests in a separate drift of the Carey Salt Mine. These tests were in linear arrays to determine propagation laws for strain in salt and crater tests to determine dynamic breaking strength of salt. The linear array tests totaled 24 and ranged from 2 to 40 lbs of four different types of high explosives. The 15 crater tests all used 8 lbs of one type of high explosive. These tests were done following the instrumentation of several coupled and decoupled shots on Project Cowboy.

The U.S. Atomic Energy Commission, Albuquerque Operations Office, provided general overall project support and coordination including logistical, construction and architectural-engineering support. They also requested the Project Director and Support Director as well as all the administrative staff to advise on safety issues, legal questions and other U.S. Atomic Energy Commission responsibilities. Lawrence Radiation Laboratory supplied the project's Technical Director and assumed operational support and coordination responsibilities for Cowboy's various technical programs. They also took the lead for measuring the shock pressure of the detonations and conducting the surveys for the deformation studies and subsequent data analysis. Sandia Corporation was in charge of procurement, storage, emplacement and arming of the high explosives along with making the close-in earth motion measurements using accelerometers and velocity gauges.

Edgerton, Germeshausen, and Grier, Inc., assumed responsibility for all timing and firing functions for the Cowboy detonations. The U.S. Coast and Geodetic Survey provided, installed, and monitored the instrumentation within the existing Carey Mine shaft prior to the experiment and installed and monitored the seismic stations for the detonations. The U.S. Bureau of Mines served as the advisory agency on general mine safety providing guidance on accepted mining construction and operation standards.

On March 5, 1960, a meeting was held with Carey Salt Company regarding mothballing some of the Cowboy facilities for two to three years. A letter dated March 8, 1960, details the arrangements to be made between the U.S. Atomic Energy Commission and the Carey Salt Company. Carey agreed to maintain the facilities for two to three years allowing for limited office space, as well as corrosion protection maintenance of the shaft every six months and monthly inspections by a qualified engineer and a cabling crew. This letter was followed the same day by a memo authorizing construction of a storage shed for mothballing some of the equipment at the salt mine and mentions other mothballing activities that would be undertaken through a contract.

As part of the Plowshare Program's efforts to explore possible industrial applications of nuclear explosions, the Cowboy series was viewed as an opportunity to test theoretical predictions for fracture geometry and mechanical deformation in a relatively homogeneous medium, i.e., salt. Data obtained from the salt blasts would be applicable to the upcoming Gnome test scheduled for detonation in a Permian salt formation near Carlsbad, New Mexico. A Plowshare program, designated Plowboy, was established to investigate several of the Cowboy explosions. The Plowboy investigations consisted of mining directly into the detonation point of one of these blasts and exploratory drilling around several others.

In June, following completion of the Plowboy investigations, all equipment was dismantled and moved out of the mine. Piping and ducts were dismantled and stored in the mine. The areas utilized in the mine were cleaned and restored to pre-project condition. The disposition of government-owned equipment and shipments of materials from Winnfield were completed in July 1960.

The Cowboy Project is an activity Level 2 due to the use of conventional explosives.

CHRONOLOGICAL BIBLIOGRAPHY

Read, Charles B., 1958. "Site for Plowshare Experiment in Salt." Letter from Charles B. Read to Gerald W. Johnson, April 16. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Wells, Robert L., 1958. "Proposal for the Utilization of Heat from Underground Nuclear Detonations." Letter from Robert L. Wells, Westinghouse Electric Corporation, Atomic Power Department, to Harold A. Fidler, May 16. On file at: Archives and Records Office, Archives and Records Office, Lawrence Berkeley National Laboratory, Berkeley, CA, File 434-900157, 7/18.

Westinghouse Electric Corporation. Atomic Power Department, 1958. Proposal for the Utilization of Heat from Underground Nuclear Detonations. Report to U.S. Atomic Energy Commission, from Westinghouse Electric Corporation, Pittsburgh, PA, May 16. On file at: Archives and Records Office, Lawrence Berkeley Laboratory, Berkeley, CA, File 434-900157, 7/18.

Shelton, A. V., 1959. "Transmittal of Technical Director's Operations Plan for Project "COWBOY." Memo with encl. ("Technical Director's Operations Plan for Project Cowboy") from A. V. Shelton, Lawrence Radiation Laboratory, to Distribution, July 31. On file at: Nuclear Testing Archive, Nevada Site Office, National Nuclear Security Administration, Las Vegas, NV, File NV0069544.

Reeves, James E., 1959. "Operations Order 3-59 - Project Cowboy." Memo from James E. Reeves, U.S. Atomic Energy Commission, Albuquerque Operations Office, to Distribution, September 25. On file at Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Accession No. NV0069240.

Wynkoop, Ernest, 1959. Project Cowboy Diary, September 17 - October 1, 1959. Diary of Ernest Wynkoop, U.S. Atomic Energy Commission, Albuquerque Operations Office, October 2. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0069484.

Wynkoop, Ernest, 1959. Project Cowboy Diary, October 2 - October 7, 1959. Diary of Ernest Wynkoop, U.S. Atomic Energy Commission, Albuquerque Operations Office, October 7. On file at: Nuclear Testing Archive, Nevada Site Office, National Nuclear Security Administration, Las Vegas, NV, Accession No. NV0069534.

Holmes & Narver, Inc., 1959. "Project Cowboy - Construction Schedule." Drawing No. A-064-C5, October 9. On file at: Engineering Records Library, Nevada Test Site, Mercury, NV.

Wynkoop, Ernest, 1959. Project Cowboy Diary, October 15 - October 30, 1959. Diary of Ernest Wynkoop, U.S. Atomic Energy Commission, Albuquerque Operations Office, October 30. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0069549.

Thompson, Morgan H., 1959. Project Cowboy Diary, October 31 - November 12, 1959. Diary of Morgan H. Thompson, U.S. Department of Energy, Albuquerque Operations Office, November 12. On file at: National Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0069618

Wynkoop, Ernest, 1959. Project Cowboy Diary, November 12 - December 4, 1959. Diary of Ernest Wynkoop, U.S. Atomic Energy Commission, Albuquerque Operations Office, December 4. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0069621.

Holmes & Narver, Inc., 1959. "Project Cowboy - Location Plan." Drawing No. A-064-C1. On file at: Engineering Records Library, Nevada Test Site, Mercury, NV.

Holmes & Narver, Inc., 1959. "Project Cowboy - Surface Site Plan." Drawing No. A-064-C2. On file at: Engineering Records Library, Nevada Test Site, Mercury, NV.

Reeves, James E., 1960. "Operations Order 3-59 - Project Cowboy (Revision)." Memo from James E. Reeves, U.S. Atomic Energy Commission, Albuquerque Office, to Distribution, February 10. On file at: Nuclear Testing Archive, Nevada Operations Office, National Nuclear Security Administration, Las Vegas, NV, Accession No. NV0064489.

Shelton, A. V., 1960. "Cowboy Shot Schedule." Memo from A. Vay Shelton, Lawrence Radiation Laboratory, to Distribution, February 12. On file at: Nuclear Testing Archive, Nevada Site Office, National Nuclear Security Administration, Las Vegas, NV, File NV0069381.

Wynkoop, Ernest, 1960. Letter from Ernest Wynkoop, U.S. Atomic Energy Commission, Albuquerque Operations Office, to Craig Ellis, February 17. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0069281.

Holmes & Narver, Inc., 1960. "Project Cowboy - Revised Piping Plan and Details." Drawing No. J/S-A-090-M1, March 23. On file at: Engineering Records Library, Nevada Test Site, Mercury, NV.

Blue, C. L., 1960. "Lockheed Aircraft Corporation - Analog to Digital Conversation." Memo with encl. ("Scope of Work, Lockheed Aircraft Corporation") from C. L. Blue, Lockheed Aircraft Corporation, Missile Systems Division, to D. A. Bruce, February 24. On file at: Archives and Records Office, Lawrence Berkeley National Laboratory, Berkeley, CA, File 434-900157, 7/18.

Holmes & Narver, Inc., 1960. "Project Cowboy - Trailer Park Power Distribution." Drawing No. J/S-A-080-E7, March 25. On file at: Engineering Records Library, Nevada Test Site, Mercury, NV.

U.S. Atomic Energy Commission. Nevada Operations Office, 1960. Press Release, Subject: non-nuclear high explosive experiments, from U.S. Atomic Energy Commission, March 4. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0322679.

Thompson, Morgan H., 1960. Letter from Morgan H. Thompson, U.S. Atomic Energy Commission, Albuquerque Operations Office, to W. H. Cameron, March 8. On file at: Archives and Research Center, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0110944.

Thompson, Morgan H., 1960. "Mothballing Work for Project Cowboy." Memo from Morgan H. Thompson, Atomic Energy Commission, Albuquerque Operations Office, March 8. On file at: Archives and Research Center, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0110945.

Johnson, Gerald W., 1960. Letter from Gerald W. Johnson, Lawrence Radiation Laboratory, to E. C. Shute, March 17. On file at: Archives and Records Office, Lawrence Berkeley National Laboratory, Berkeley, CA, File 434-900157, 7/18.

Thornbrough, A. D., E. S. Ames, and H. L. Hawk, 1960. Instrumentation Systems-Project Cowboy. Report from Sandia Corporation, Report No. SC-4470 (RR) Supplement, September. Albuquerque, NM.

Nicholls, H. R., V. Hooker, and W. I. Duvall, 1960. Dynamic Rock Mechanics Investigations: Project Cowboy. Report to U.S. Atomic Energy Commission from U.S. Bureau of Mines, Applied Physics Research Laboratory, Report APRL 38-3.2, September 1. College Park, MD.

Short, Nicholas M., 1960. Project Cowboy: Fracturing of Rock Salt by a Contained High Explosive. University of California, Lawrence Radiation Laboratory, *Report UCRL*-6054, September 10. Livermore, CA.

Lawrence Radiation Laboratory, 1960. Project Dribble, AEC Program Concept, 4 November 1960. Manuscript, Lawrence Radiation Laboratory, Livermore, CA, November 4. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

U.S. Atomic Energy Commission, 1961. Civil Uses of Nuclear Explosives, In *Annual Report to Congress of the Atomic Energy Commission,* pp.152-156, January. Government Printing Office, Washington, D. C.

Preston, R. G., 1961. Predicted Phenomenology and Effects for Project Dribble Test Detonations Vela-UNIFORM Explosion Series: Progress Report No. 1. Manuscript (UOPAC-61-27), Lawrence Radiation Laboratory, Livermore, CA, January 30. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Reeves, James E., 1961. "Glossary of Seismic Projects, Plowshare Program, and Reactor Programs." Memo from James E. Reeves, U.S. Atomic Energy Commission, Albuquerque Office, to List, March 17. On file at Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV [OUO].

Preston, R. G., and W. M. Adams, 1961. Letter from Paul L. Russell, U.S. Department of the Interior, Bureau of Mines, to J. S. Kahn, October 13. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-061.

Carder, D. S., and W. V. Mickey, 1962. Ground Effects from Underground Explosions. *Bulletin of the Seismological Society of America*, Vol. 52, No. 1, pp: 67-75, January.

U.S. Atomic Energy Commission. Division of Technical Information, 1969. Status of Nuclear Test Reports. U.S. Atomic Energy Commission, Report TID-9533. Washington, D.C. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0105641.

Rodean, H. C., 1971. Cavity Decoupling of Nuclear Explosions. University of California, Lawrence Radiation Laboratory, *Report UCRL*-51097, August 2. Livermore, CA. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Shafer, David S., William. C. Beck, Dwight Treadwell, and Stephen. A. Mellington, 1995. Inventory of Potential Environmental Restoration Liabilities Associated with Plowshare And Vela Uniform Program Sites. Manuscript, U.S. Department of Energy, Office of Environmental Restoration. On file at: Desert Research Institute, Las Vegas, NV.

Lawrence Livermore National Laboratory, n.d. Cowboy_1a photos. Photos No. CO-283 and CO-284. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

Lawrence Livermore National Laboratory, n.d. Cowboy_1b AEC office photos. Photos No. CO-287 and CO-288. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

Lawrence Livermore National Laboratory, n.d. Cowboy_1c Carey Salt Mine photos. Photos No. CO-267 and CO-268. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

Lawrence Livermore National Laboratory, n.d. Cowboy_1c1 Carey Salt Mine photo. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

Lawrence Livermore National Laboratory, n.d. Cowboy_1d photos. Photos No. CO-195 and CO-196. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

Lawrence Livermore National Laboratory, n.d. Cowboy_1d1 photo. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

Lawrence Livermore National Laboratory, n.d. Cowboy_1e photo. Photos No. Co-197 and CO-198. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

Lawrence Livermore National Laboratory, n.d. Cowboy_1e1 photo. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

Lawrence Livermore National Laboratory, n.d. Cowboy_1f photo. Photo No. CO-168. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

Lawrence Livermore National Laboratory, n.d. Cowboy_1g1 photo. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

Lawrence Livermore National Laboratory, n.d. Cowboy_1g photo. Photos No. CO-395 and CO-396. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

Lawrence Livermore National Laboratory, n.d. Cowboy_1h photo. Photos No. CO-409 and CO-410. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

Lawrence Livermore National Laboratory, n.d. Cowboy_2a photo. Photos No. CO-667 and CO-668. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

Lawrence Livermore National Laboratory, n.d. Cowboy_2b photo. Photos No. CO-669 and CO-670. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

THIS PAGE INTENTIONALLY LEFT BLANK

3.4 DRAGON TRAIL

Plowshare Program
Nuclear Explosives for Gas Stimulation
Colorado

Continental Oil Company contacted the U.S. Atomic Energy Commission in July of 1966 regarding the possibility of using nuclear explosives to increase natural gas production near the Dragon Trail Unit in the Douglas Creek gas field in Rio Blanco County in northwestern Colorado. The proposed experiment site was approximately 50 miles north of Grand Junction and 20 miles south of Rangeley, Colorado in the western portion of the Piceance Creek Basin (Figure 3.4-1). Two months later, Continental Oil Company's office in Oklahoma submitted a formal proposal to the U.S. Atomic Energy Commission that contained a general engineering feasibility study of the area, detailing the geographic and geologic setting and its appropriateness for inclusion in natural gas stimulation experiments using nuclear explosives. In the Douglas Creek gas field, Continental Oil Company had several producing gas wells and a gas distribution system was already in place in this area. The wells were on land owned by the federal government with leases obtained from the U.S. Geological Survey.

Continental Oil Company recognized that Project Dragon Trail would be an experiment on the feasibility of nuclear explosives for gas stimulation and marketed it to the U.S. Atomic Energy Commission as a sci entific extension to Project Gasbuggy. The initial proposal was followed by a more general proposal from Continental Oil Company's Houston office. CER Geonuclear Corporation worked with Continental Oil Company on the proposals with long-term responsibility of advising and assisting Continental Oil Company in carrying out the Dragon Trail experiment. The second proposal reiterated Continental's position that Dragon Trail would be a valuable contribution to the Plowshare Program and detailed expected scientific data resulting from the test. Projected scientific data were: 1) the amount of increase in gas productivity from the use of a nuclear device, 2) the extent of fracturing beyond the chimney, 3) the post-shot geometry for a nuclear explosive in the area and formations with similar lithological characteristics, 4) the extent to which the area around the well-bore is effectively drained by the fracture system, 5) the permeability of the fracture system, and 6) that nuclear stimulation is both technically and commercially feasibility. The geologic zone targeted for the experiment was the Mancos B zone, a unit composed of very thin interbedded layers of sand and shale. The Mancos B zone contained natural gas, but due to the geology, the production rates were too low for commercial development. Continental Oil Company hoped that a successful test could lead to further development on a commercial basis in some part of the widespread Mancos B zone or a more commercially viable field.

The U.S. Atomic Energy Commission was interested in the project and in June of 1967 Lawrence Radiation Laboratory issued a draft Technical Program Operation Plan for the project that subsequently was revised. On October 2, 1967, the Nevada Operations Office

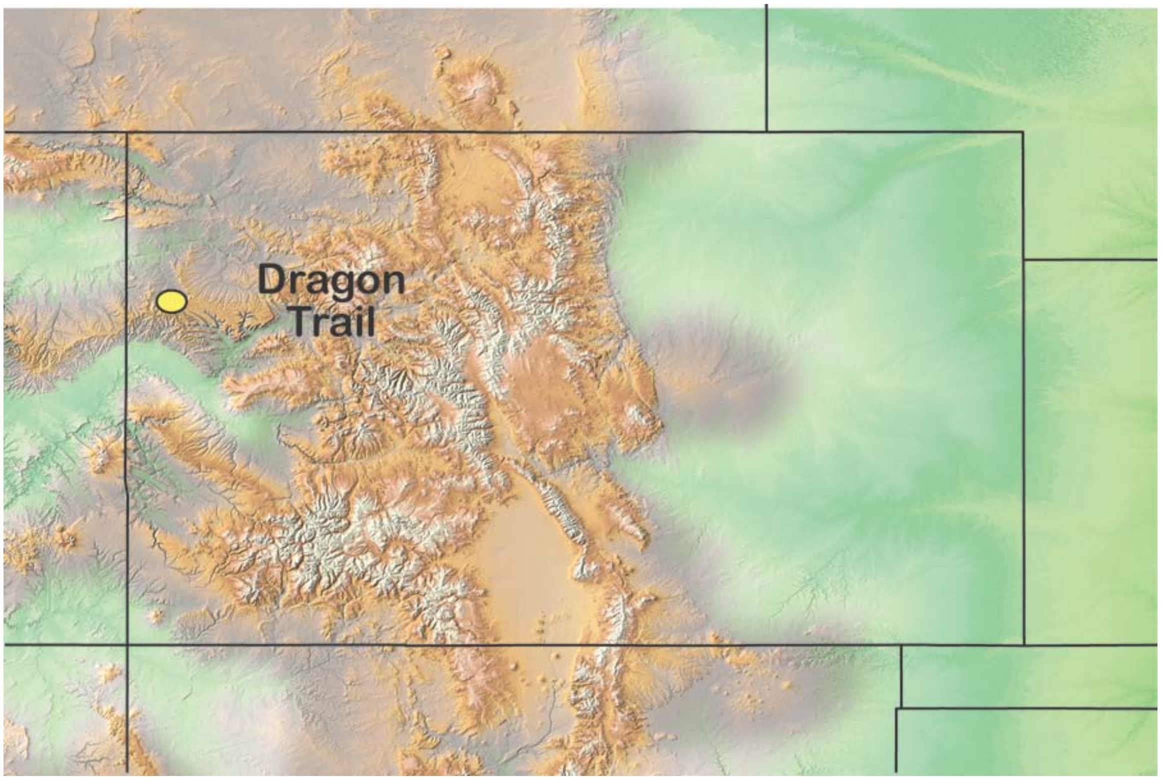


Figure 3.4-1. Location of Project Dragon Trail in Colorado (adapted from USA Relief Maps 2004).

issued the Project Manager's Plan for Project Dragon Trail. Its purpose was to present a summary of nuclear operations including cost and time estimates involved in supporting Project Dragon Trail. It was based on the Lawrence Radiation Laboratory plan and detailed responsibilities according to agency and company. The Nevada Operations Office was responsible for the development of detailed operational plans and direction of field programs including safety, security and site operations. Project Dragon Trail was to be detonated 2,700 ft underground in the Mancos Oil Shale Formation (Figure 3.4-2) under a cooperative arrangement between the U.S. Atomic Energy Commission, Continental Oil Company, and CER Geonuclear Corporation. The proposed drilling program was outlined and the pre-shot hole designations are presented in Table 3.4-1.

Table 3.4-1. Proposed Pre-Shot Drilling

DT-A	Test Hole
DT-B	Instrument Hole
DT-C	Instrument Hole
DT-EX	Exploratory Hole
DT-E	Emplacement Hole
DT-H	Test Hole

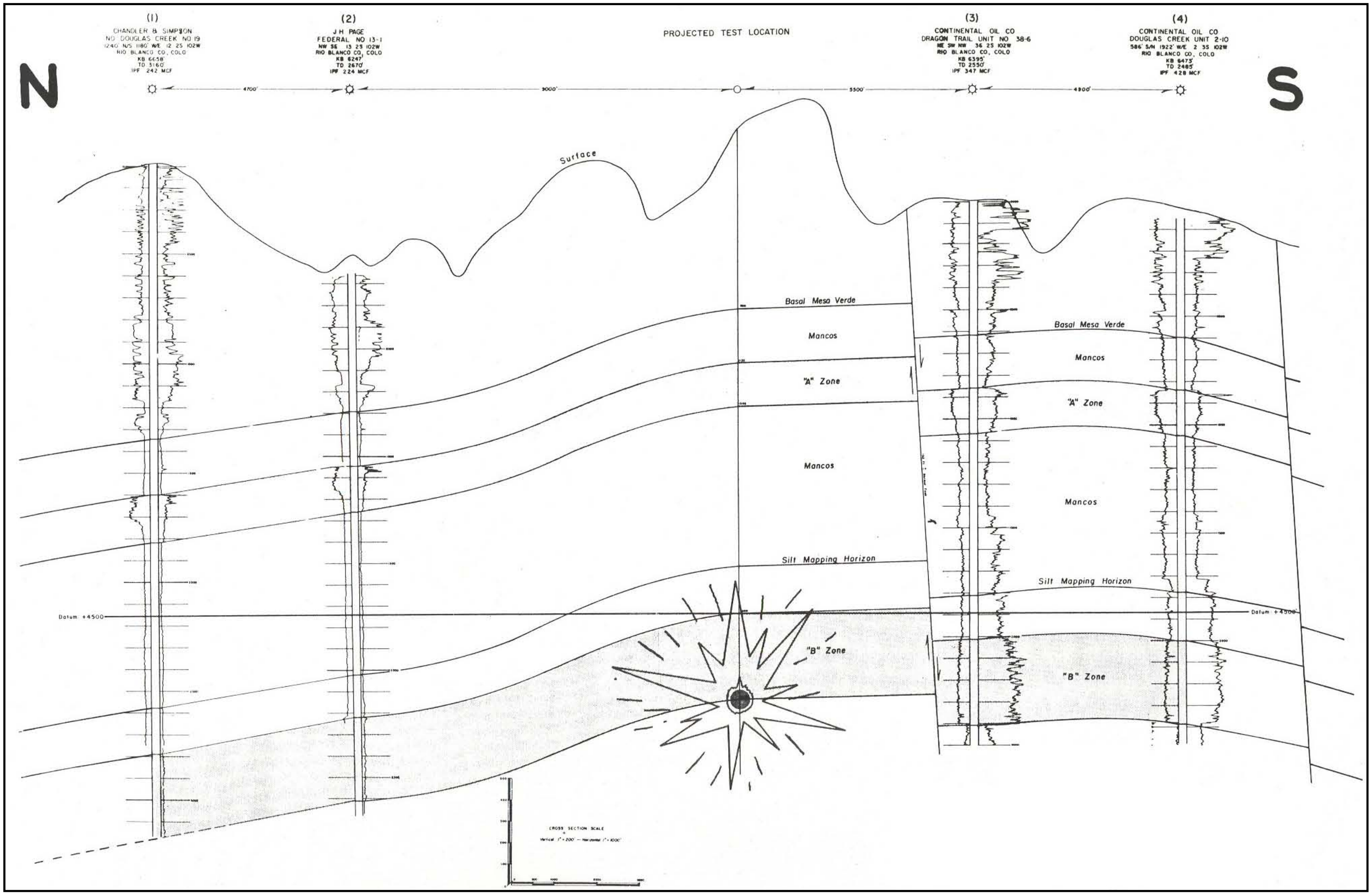


Figure 3.4-2. Generalized cross section of target formation (Continental Oil Company 1966, Figure 5).

During 1966 and 1967, Continental Oil Company conducted substantial fieldwork to document pre-shot production characteristics (Figure 3.4-3). In 1966, two wells were drilled, cored, and logged as conventional pre-shot test wells. The wells were Southeast Douglas Creek No. 1 (NW1/4NW1/4, Sec. 2, T3S R101W) and East Dragon Trail No. 2 (660 ft from the south line, 425 ft from the west line, SW1/4SW1/4, Sec. 20, T2S R101W). A third well, Dragon Trail Unit No. 25-11 (SW1/4SW1/4, Sec. 25, T2S R102W), was drilled as a conventional production well with its data helping to further define the area's potential. Dragon Trail #2 was renamed DT-A and was the first location considered for a Dragon Trail pre-shot test. It produced data that initially showed the area was suitable for a nuclear detonation experiment. Subsequent testing by Continental Oil Company indicated that a fault might affect the reliability of a pre-shot evaluation of the gas reservoir. The second site, DT-B, was 1,877 ft from the north line, 1,382 ft from the west line, Sec. 20, T2S R101W, one-half mile northeast of the first location. There was not an existing gas well at DT-B that could be used to evaluate the location, so DT-B was drilled.

In October 1967, Lawrence Radiation Laboratory visited Project Dragon Trail to observe the coring and in-hole logging of the DT-B drill hole, to tentatively locate two hydrology test holes (DT-H1 and DT-H2), to record new construction (road and drill pad), and locate a potential site for a recording trailer park. The analysis of the data from this well was not promising, indicating there was not enough gas flow for the study. In December 1967, a new site was selected. The third location was near Gas Well Continental 24-3 and was initially named DT 24-3. DT 24-3 was seven miles west of the original DT-A and DT-B holes at 2,322 ft from the south line, 1,875 ft from the east line, Sec. 24, T2S R103W. In 1968, DT 24-3 was renamed DT-EX. Two wells were needed to determine the reservoir characteristics. The second well reused the DT-A designation. It was drilled 685 ft north-northeast of DT-EX, and as of January 1969, preliminary data indicated that gas production was sufficient for the experiment. In addition, hydrologic data obtained from this DT-A showed that there was no ground water problem at the site. For the location of the nuclear device emplacement (DT-E), Continental Oil Company determined that it was better to drill a separate hole rather than ream out test well DT-A. DT-E was to be located 685 ft north-northeast of DT-EX, on an arc 75 ft southeast of DT-A. It is not known weather DT-E was drilled or not. The terminal depth of the pre-existing wells or newly drilled wells also is not known. In February 1969, Lawrence Livermore Laboratory distributed a detailed geologic study of the DT-EX location with well data showing there were no geologic factors that would preclude the use of this location for the Dragon Trail experiment.

A January 24, 1968 letter from the U.S. Atomic Energy Commission stated that five Plowshare projects were under consideration by the U.S. Atomic Energy Commission: Projects Bronco, Dragon Trail, Ketch, Rulison, and Sloop. The Commission had not yet approved any of these projects and Congress had not appropriated funds, so no dates had been set for Dragon Trail. In the same year, Lawrence Radiation Laboratory and CER Geonuclear Corporation issued a planning document for project Dragon Trail. Originally conceived as a 40-kt detonation, the revised technical concept employed a 20-kt device of less than 15-inch diameter. Unlike Gasbuggy, which used a casing, the Dragon Trail plan called for an open-hole shot. After the detonation and a six-month cooling off period,

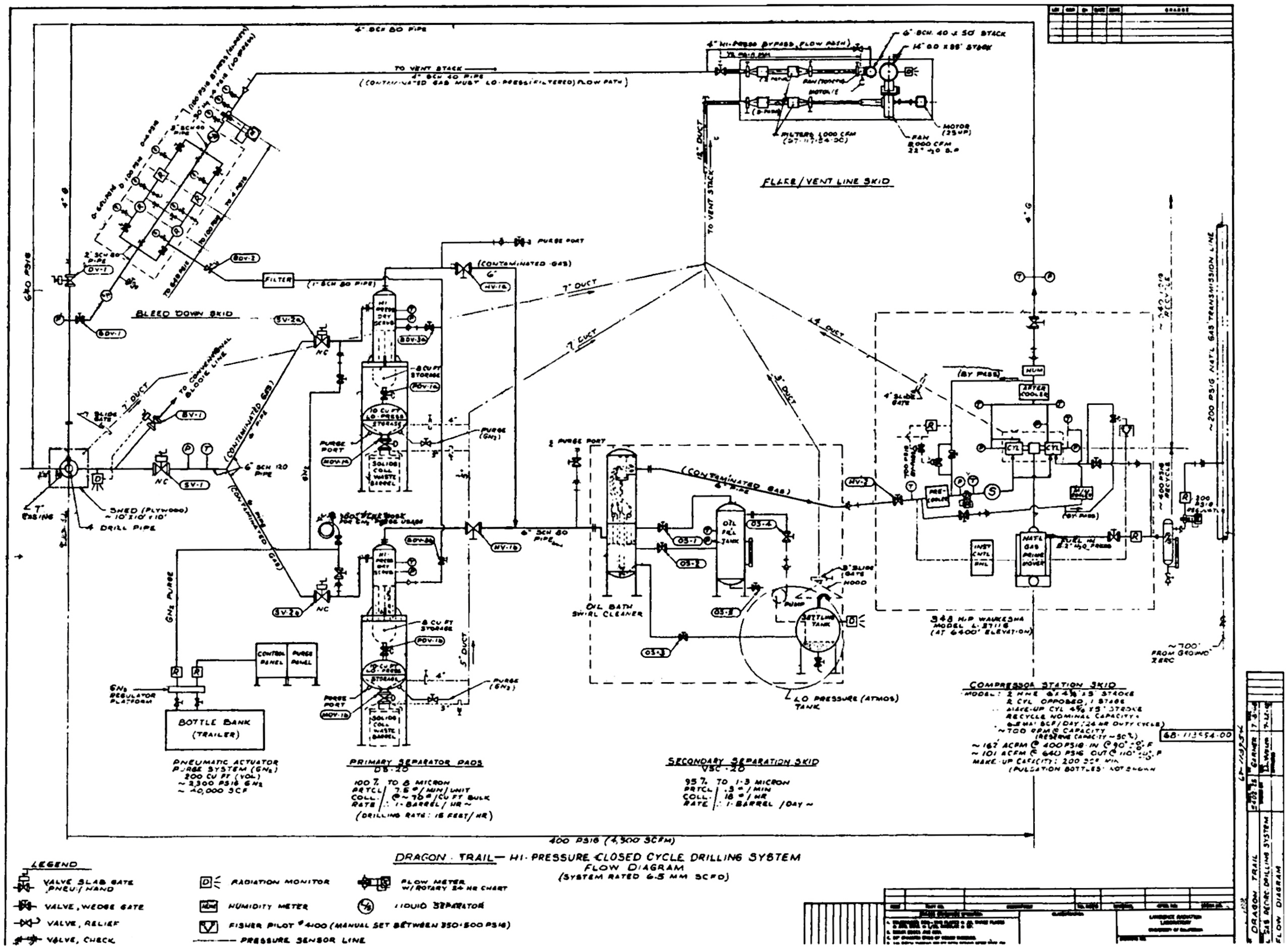


Figure 3.4-3. Closed cycle drilling system for Project Dragon Trail [best copy available] (Lawrence Radiation Laboratory 1968, Drawing No. 68-113954).

THIS PAGE INTENTIONALLY LEFT BLANK

planned post-shot activities included four post-shot drill holes for sampling, testing, and monitoring. Data obtained from the investigations would be used to evaluate flow capacity and production characteristics as well as develop a nuclear reservoir stimulation model.

In January 1969, Lawrence Radiation Laboratory attended a Test Evaluation Panel meeting and a meeting on Dragon Trail hydrology in Las Vegas. The Test Evaluation Panel asked for more calculations before approving the final stemming plan for Dragon Trail, including shock pressure on the shot horizon. Lawrence Radiation told the panel that the yield range on Dragon Trail would be between 19 and 22 kt. CER Geonuclear Corporation needed additional information to include in their Total Project Plan and revisions to their drawing for the Control Point and Ground Zero layout. CER Geonuclear would submit the Total Project Plan for Dragon Trail by February 1, 1969. The plan would be reviewed and forwarded to Washington, D.C. with recommendations by March 1, 1969. On April 1, 1969, the U.S. Atomic Energy Commission Headquarters and the U.S. Bureau of Mines would have reviewed the plan and told the Nevada Operations Office to start contract negotiations. By May 1, 1969, the contract between the U.S. Atomic Energy Commission and Continental Oil Company would be signed. The money would be available to Lawrence Radiation Laboratory for the project by mid-May with a ready date for detonation between September 1, 1969 and October 1, 1969. In March 1969, it became apparent that funding would not be received until late June or early July and this created a conflict with the Yawl Program and mid-winter field operations. It was decided that Dragon Trail would have to be executed by mid-November or wait until March-April of 1970. Lawrence Radiation Laboratory was working on ways to cut the time between receiving funding and project execution and felt there could be some timesavings. The laboratory also supported a mid-winter operation as feasible. As of March 1969, CER Geonuclear Corporation was still waiting for Continental Oil Company to sign off on the Total Project Plan.

In May 1969, Continental Oil Company advised the U.S. Atomic Energy Commission that they did not plan to move forward with the project because of the expense of drilling to depths greater than originally planned. Another factor that made Dragon Trail a less attractive project was the absence of sufficient gas reserves for subsequent commercial shots. Also, it was expected that data from Gasbuggy and Rulison events would be sufficient to answer many of the questions regarding oil and gas stimulation and Dragon Trail was not needed. Project Rulison, a 40-kt gas stimulation test at a depth of 8,426 ft, was conducted on September 10, 1969, at a site in northwestern Colorado.

In February 1970, the U.S. Atomic Energy Commission announced that Dragon Trail was to be shelved as "time had passed it by." A newspaper article published on February 27, 1970 reported that Project Dragon Trail was terminated because the actual detonation of Rulison and the planned detonation of Wagon Wheel made the purely experimental 3,000 ft deep Dragon Trail test obsolete. As stated in a May 8, 1970 memo, Project Dragon Trail was inactive. A new project, Rio Blanco, considered a replacement for Dragon Trail, was under study for western Colorado.

Project Dragon Trail was a Level 3 activity which corresponds to fieldwork limited to drilling wells, setting up support facilities, and grading access roads.

FIELD VISITS

The Desert Research Institute initially visited the Dragon Trail project area on August 13, 2003. To access the Dragon Trail Unit from Rangely, Colorado, begin at the junction of State Route 64 and State Route 139; then go south on State Route 139, the Dinosaur Diamond Scenic and Historic Byway. From here the researchers followed several dirt roads that intersected State Route 139 from the west and paralleled drainages. Several locations were identified as potential Project Dragon Trail experiment sites. Renumbering of wells, re-issuance of gas leases, and extensive new development made it difficult to make a definitive identification of associated drill holes, pressure release pits, flow meters, telemetry shacks, dehydrators, and other structures. Subsequently, additional documentation was obtained from archives and the Bureau of Land Management, Meeker Field Office that provided precise and, presumably, correct location information. A second trip to the multiple Dragon Trail project locations was required to verify and record pertinent data. Equipped with better documentation, more precise location information and new maps, the report authors, Beck and Edwards, returned to the region in August 2005 to complete the field activity assessment.

The Project Dragon Trail study wells are distributed in two areas. Four of the seven well locations are in the eastern half of the Dragon Trail-Douglas Creek gas production unit, while the remaining three are concentrated along the western side.

Eastern Project Area Wells

The four eastern well locations can be accessed from Rangely, Colorado by following State Route 139 south. Begin at the junction of State Routes 64 and 139 and proceed south for approximately 15 miles on State Route 139, the Dinosaur Diamond Scenic and Historic Byway. Three of the study wells, East Dragon Trail No.2 (aka DT-A), DT-B, and DTU 25-11, are located to the west of the highway and can be reached by following the network of dirt roads leading through Little Bull Draw and Little Horse Draw (County Road 116). The Douglas Creek Well No. 1 is east of State Route 139 and can be reached by following County Road 27 southeast to Pollock Canyon.

The DRI researchers visited the eastern study wells on August 01, 2005 beginning with the Douglas Creek Well No. 1. Situated in Pollock Canyon, the well was located on the west side of the drainage about 40 ft east of the dirt road leading through the canyon at UTM coordinates Zone 12, 696320m E, 4410515m N. The gas well is inactive and has been plugged. A 6-inch diameter casing extending 5-ft 2-inches above the ground surface marks the location of the well. The end has been welded shut with an “orange peel” closure (Figure 3.4-4). The casing is welded with the well designation in block lettering:

S.E. DOUGLAS CREEK WELL NO.1 466’ FNL 210’ FWL SEC. 2. T 3S R101W
RIO BLANCO COUNTY, COLO. CONTINENTAL OIL CO.

No other debris was noted in the area except for several fragments of clear bottle glass and an aluminum juice can.

The next location evaluated was well DT-B at UTM coordinates Zone 12, 691658m E, 4414772m N. This study site was one of the most extensively developed for the Dragon Trail project. Equipment had to be hauled in to drill a new well because there was no

Figure 3.4-4. Project Dragon Trail study well Douglas Creek No.1 (photo taken August 2005 on file at Desert Research Institute).

pre-existing gas or hydrologic test well. The DT-B well (aka East Dragon Trail Well No. 5) required the construction of a graded access road and a large bladed area for the drill pad, recording trailer, drill pipe storage areas, and equipment sheds (Figure 3.4-5). A 1967 photograph shows the drill rig boring the test well at the DT-B study site (Figure 3.4-6). When Project Dragon Trail was cancelled in the spring of 1970, the DT-B well was plugged and the temporary facilities removed. Today the well is marked by a 6-inch diameter by 4-ft 6-in high iron pipe with an orange peel closure (Figure 3.4-7). The well designation is welded on the pipe and reads (Figure 3.4-8):

EAST DRAGON TRAIL WELL No. 5 1877’ FNL 1382’ FWL SEC. 20, T2S R101W
RIO BLANCO COUNTY, COLO. CONTINENTAL OIL CO.

The bladed area surrounding the well is about 600 ft long by 300 ft wide. A concrete pad (Figure 3.4-9) that held the recording trailer remains, as do the remnants of a wooden structure, possibly an equipment shed (Figure 3.4-10). Other debris scattered across the well site includes lumber, plywood, wood lath, braided steel cable, iron pipe sections, metal cable anchors, broken glass, and a few cans.

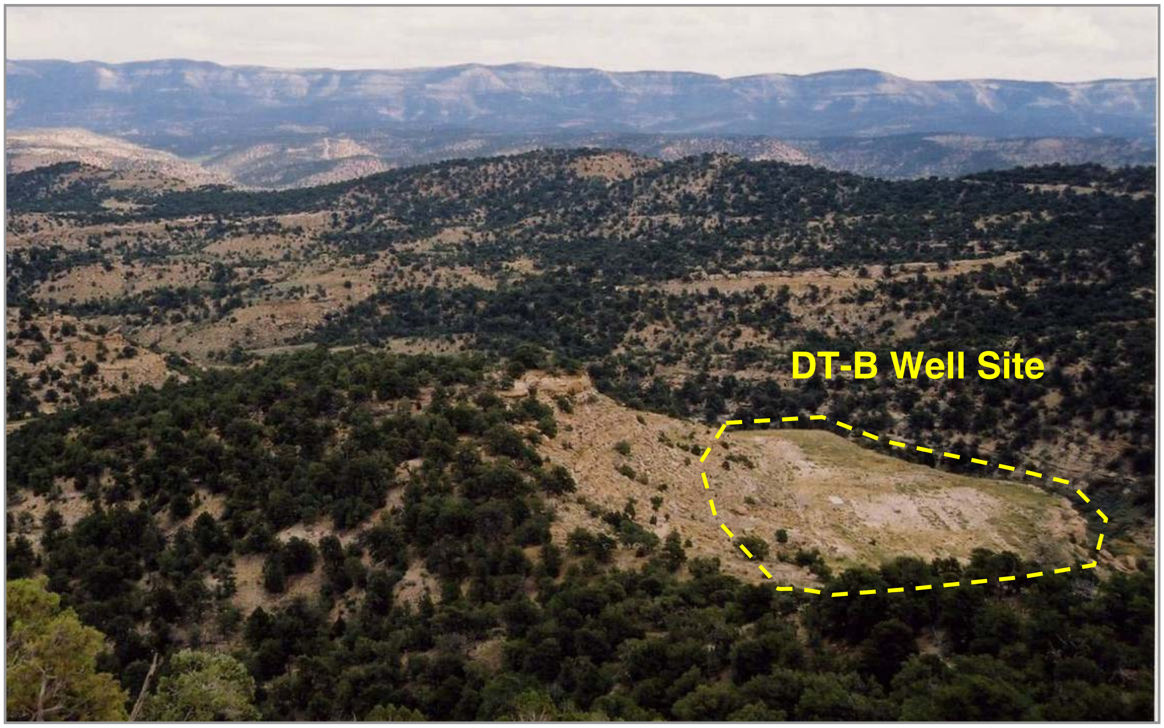


Figure 3.4-5. Overview of Project Dragon Trail study well DT-B site (photo taken August 2005 on file at Desert Research Institute).

Figure 3.4-6. Photo from 1967 drilling operation at the DT-B study well site for Project Dragon Trail (on file at Atomic Testing Archives, Las Vegas, NV).

Figure 3.4-7. Project Dragon Trail study well DT-B has been plugged (photo taken August 2005 on file Desert Research Institute).

Figure 3.4-8. Close-up of welding on Project Dragon Trail study well DT-B (photo taken August 2005 on file at Desert Research Institute).

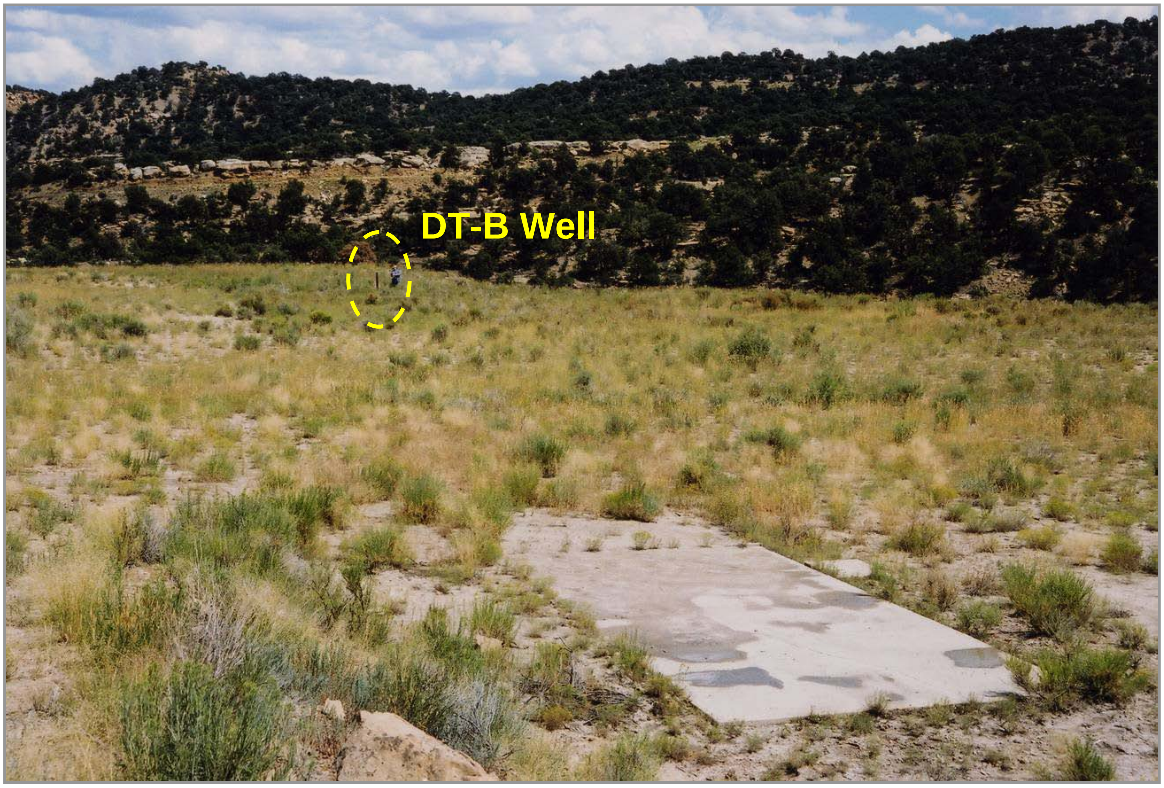


Figure 3.4-9. Concrete pad for recording trailer at the well DT-B site (photo taken August 2005 on file at Desert Research Institute).

Figure 3.4-10. Remains of a wooden structure (equipment shed?) at the well DT-B site (photo taken August 2005 on file at Desert Research Institute).

The East Dragon Trail No. 2 well (aka DT-A) was the third study well visited. It is located at UTM coordinates Zone 12, 691350m E, 4413940m N at the southwest end of Little Bull Draw. As with most of the region, there are numerous active gas leases throughout the area. East Dragon Trail No. 2, however, has been abandoned. The plugged well is situated approximately 15 ft east of the dirt road that parallels the main drainage channel (Figure 3.4-11). Marked by a 6-in diameter pipe that stands 5-ft 2-in high, the well sits in a bladed area about 150 ft long along the road. The drill pad extends 100 ft east of the road to the edge of the drainage and 20 ft west of the road to the base of the ridge.

The well designation on the pipe reads (Figure 3.4-12):

EAST DRAGON TRAIL WELL No. 2 660' FSL 425' FWL SEC. 20, T2S R101W
RIO BLANCO COUNTY, COLO. CONTINENTAL OIL CO.

The only debris noted was an amber glass beer bottle.

Figure 3.4-11. Project Dragon Trail study well East Dragon Trail No. 2 (aka DT-A) has been abandoned (photo taken August 2005 on file at Desert Research Institute).

The last of the eastern group of Project Dragon Trail study wells is DTU 25-11. County Road 116 on the north side of Little Horse Draw leads to a well field road that winds through a series of Encana Gas & Oil Corporation leases that includes well DTU 25-11. Well DTU-25-11 has been renamed DTU 1011. Located at UTM coordinates Zone 12, 688549m E, 4412218m N, the study well is situated in a cleared area at the apex of a hairpin turn.

Figure 3.4-12. Close-up of welding on study well East Dragon Trail No. 2 (photo taken August 2005 on file at Desert Research Institute).

Well DTU 25-11 is still in production (Figure 3.4-13). A pit with an automatic pressure release valve is adjacent to the solar powered monitoring shed enclosing the wellhead. Lease holder information is displayed on a placard on the monitoring shed's door (Figure 3.4-14). The placard reads:

ENCANA GAS & OIL (USA) INC.	DRAGON TRAIL UNIT #1011
SW/NW SEC. 36, T2S R102W	LEASE #: COC-02864
CA #: COC-047615A	RIO BLANCO, CO

However, there is an error in this location data. The GPS readings and topographic data confirm that DTU 25 is located in Section 25 not Section 36 as noted on the placard.

Figure 3.4-13. The DTU 25-11 well site. The well head is on the left in the photo and the monitoring shed and pressure relief pit are on the right (photo taken August 2005 on file at Desert Research Institute).

Figure 3.4-14. Well DTU 25-11 monitoring shed with current lease holder information (photo taken August 2005 on file at Desert Research Institute).

Western Project Area Wells

DRI researchers, Edwards and Beck, visited the three western Project Dragon Trail study well locations on August 03, 2005. To access the three well locations (DT-EX [aka DT-24-3], DT-A(2), and DT-E) in the western portion of the project area, proceed south from Rangely beginning at the junction of State Route 64 and County Road 23. Travel southwest along County Road 23 for approximately 17.8 miles to County Road 107. Turn east onto County Road 107 about 2 miles to reach the well locations along Red Wash.

All three of these well sites are located along bluffs overlooking the Red Wash drainage. The DT-EX study well was the U.S. Atomic Energy Commission's third attempt to find a suitable location for the Proposed Dragon Trail experiment. Also known as DT 24-3, the DT-EX well has been renamed DTU #1303. The lease has been transferred from the Continental Oil Company to Encana Oil & Gas, Inc. Located at UTM coordinates Zone 12, 679433m E, 4413835m N, the well is still active (Figure 3.4-15). Today, the study site consists of the active well, a monitoring shed with a flow regulator and telemetry equipment, and an adjacent automatic pressure relief vent and pit. The placard on the monitoring shed door provides lease holder and location information (Figure 3.4-16). The placard reads:

ENCANA GAS & OIL (USA) INC.	DRAGON TRAIL UNIT #1303
NW/SE SEC. 24, T2S R103W	LEASE #: COC-042349
CA #: COC-047615A	RIO BLANCO, CO

Figure 3.4-15. The Project Dragon Trail exploratory well DT-EX (photo taken August 2005 on file at Desert Research Institute).

There is a light scatter of debris spread across the well pad area and an abandoned well, MD Garmin Well No. 2, sits about 125 ft west of the DT-EX well head. A pair of galvanized steel eye-bolt anchors remains along the edge of the pad. The debris noted includes bailing wire, wood lath, miscellaneous metal fragments, and a few pull-tab and pop-top aluminum beverage cans.

Figure 3.4-16. The DT-EX study well is still active and has been renamed DTU 1303. Encana Oil & Gas, Inc. is the current leaseholder (photo taken August 2005 on file at Desert Research Institute).

The DT-A(2) hydrologic test well was approximately 685 ft north-northeast of the DT-EX study well. The field visit confirmed that there is an abandoned well at this location (Figure 3.4-17). The DT-EX well is visible from the DT-A(2) well site. Situated less than 5 ft southwest of a dirt two-track road that leads down to the main Red Wash drainage, the well's UTM coordinates are Zone 12, 679532m E, 4414015m E. The site is marked by a 6-inch diameter by 5-ft 8-in high pipe with a welded "orange peel" closure. The welding on the pipe reads (Figure 3.4-18):

WEST DOUGLAS CR. MANCOS B	SEC. 24, T2S R103W	
RIO BLANCO, COLO.	CONOCO INC.	DTU. 307

Figure 3.4-17. Project Dragon Trail exploratory hole DT-A(2) (photo taken August 2005 on file at Desert Research Institute).

Figure 3.4-18. Close-up of welding on the DT-A(2) test well (photo taken August 2005 on file at Desert Research Institute).

The area surrounding the well was bladed and leveled prior to drilling. There is very little debris around the well pad. Only a couple of pieces of lumber and several pull-tab beverage cans were noted.

From the documentation, it was unclear if the DT-E emplacement hole was actually drilled. A thorough reconnaissance of the proposed location failed to identify any active wells or plugged drill hole that could be identified as the DT-E drill hole. It appears that the project was shelved before drilling for the DT-E emplacement hole was ever started. The only subsequent fieldwork related to the Dragon Trail project was the removal of the temporary support/storage structures and drilling equipment from the various well locations. The field visits conducted in FY 2003 and FY 2005 completed the field activity evaluations for Project Dragon Trail.

During FY 2006, a review of the land status records on file at the Colorado State Office of the Bureau of Land Management in Denver confirmed that all of the Project Dragon Trail drill hole sites are on land administered by that agency. Currently, most of the old Dragon Trail locations are on active gas leases.

CHRONOLOGICAL BIBLIOGRAPHY

Continental Oil Company, 1966. Project Dragon Trail: The Stimulation of a Natural Gas Reservoir by a Contained Nuclear Explosion. Technical Feasibility Study to the U.S. Atomic Energy Commission from Continental Oil Company, Ponca City, OK. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Malott, J. P., 1966. Letter from J. P. Malott, Continental Oil Company, to Glenn T. Seaborg, September 16. On file at Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

U.S. Atomic Energy Commission, 1967. Chapter 11 - Plowshare Program. In *Annual Report to Congress of the Atomic Energy Commission for 1966,* pp. 239-258, January. U.S. Atomic Energy Commission, U.S. Government Printing Office, Washington D.C.

U.S. Atomic Energy Commission, 1967. Report on Project Ketch Meeting, Nuclear Excavation for Underground Gas Storage. Notes from meeting with U.S. Atomic Energy Commission, Commonwealth, and Columbia Gas System Service Corporation, January 24. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0188125.

Philip, John F., 1967. Letter from John F. Philip, U.S. Atomic Energy Commission, San Francisco Operations Office, to Glenn C. Werth, January 25. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-011.

Werth, Glenn C., 1967. Letter from Glenn C. Werth, Lawrence Radiation Laboratory, to John F. Philip, January 31. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-011.

Werth, Glenn C., 1967. Program Activities for Plowshare. University of California, Lawrence Livermore National Laboratory, *Report UCRL*-124785, February 3. Livermore, CA. On file at: Technical Reports Library, Lawrence Livermore National Laboratory, Livermore, CA.

U.S. Atomic Energy Commission, 1967. Nuclear Underground Tests in Planning or Feasibility Stage. Table, March 6. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0188117.

Werth, Glenn C., 1967. Plowshare Program Goals. University of California, Lawrence Livermore National Laboratory, *Report UCRL*-126674, March 13. Livermore, CA. On file at Technical Reports Library, Lawrence Livermore National Laboratory, Livermore, CA.

Nordyke, Milo D., 1967. "Status Review of Field Project Studies." Memo from Milo Nordyke, Lawrence Radiation Laboratory, to G. Higgins, April 14. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore CA, File PLO-026.

U.S. Atomic Energy Commission, 1967. "Statement on the Civilian Applications of Nuclear Explosives (Plowshare) Program, U.S. Atomic Energy Commission FY 1968 Authorization Hearings Before the Joint Committee on Atomic Energy." Statement from U.S. Atomic Energy Commission, April 17. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-028.

Rabb, David D., 1967. Plowshare Program February 1, 1967 – April 30, 1967, Vol. II, No. 5. University of California, Lawrence Radiation Laboratory, *Report UCRL*-50008-67-2, April 30. Livermore, CA. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-030.

Renfro, H. B., 1967. "Plowshare Committee, Atomic Industrial Forum." Memo from H. B. Renfro to G. Werth, August 18.

U.S. Atomic Energy Commission. Nevada Operations Office, 1967. Project Dragon Trail Project Manager's Plan. Manuscript, U.S. Atomic Energy Commission, October 2. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-012.

Sterrett, T. S., 1967. "Recent Visit to Project Dragon Trail Site and the Drilling of DT-B Drill Hole." Memo from T. S. Sterrett, Lawrence Radiation Laboratory, to M.D. Nordyke. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-012.

Kelly, John S., 1967. "Redirection of Plowshare Industrial Effort." Memo from John S. Kelly through General Manager, U.S. Atomic Energy Commission, to Seaborg et al., November 21. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-027.

Jackson, Melvin W., 1967. Ten Years of Plowshare. *Civil Engineering*, December. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029.

Oil, Gas Projects, 1967. Oil, Gas Projects Perk Up AEC's Plowshare. Government, 1967. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-030.

U.S. Atomic Energy Commission, 1967. *Plowshare Program During 1966: Based on the Annual Report to Congress for 1966 of the U.S. Atomic Energy Commission.* U.S. Atomic Energy Commission, U.S. Government Printing Office, Washington, D.C. On file at Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029; and Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Werth, Glenn C., [between 1966 and 1973]. Handwritten notes on Plowshare program meetings from Glenn C. Werth, U.S. Atomic Energy Commission, Division of Peaceful Nuclear Explosives, 1966-1973. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-118.

U.S. Atomic Energy Commission, 1968. Chapter 11 - The Plowshare Program. In *Annual Report to Congress of the Atomic Energy Commission for 1967,* pp. 199-208, January. U.S. Government Printing Office, Washington, D.C.

Vermillion, Henry G., 1968. Letter from H. G. Vermillion to G. K. Plumleigh, January 24. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0188360.

U.S. Atomic Energy Commission, 1968. "Civilian Applications of Nuclear Explosives (Plowshare) Program – Operating Costs, FY 1969 Budget Estimates: Appropriation – Operating Costs." On file at: Archives and Records Office, Lawrence Berkeley National Laboratory, Berkeley, CA, File 434-900205, 28/48.

Rabb, David D., 1968. Plowshare Program November 1, 1967 – January 31, 1968, Vol. II, No. 8 University of California, Lawrence Radiation Laboratory, *Report UCRL-*50008-68-1, January 31. Livermore, CA. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-030.

Higgins, Gary H., and Leo A. Rogers, 1968. "Summary of the Dragon Trail Proposal." Memo from Gary H. Higgins and Leo A. Rogers, Lawrence Radiation Laboratory, to Distribution, February 16. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-012.

McDonald, Robert E., 1968. Feasibility Study, Nuclear Stimulation of Green River Basin, Wyoming and Piceance Creek Basin, Colorado Natural Gas Reservoirs. Report from Wolf Exploration Company, Denver, CO. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

McCool, W. B., 1968. "Atomic Energy Commission Status of Plowshare Industrial Projects." Memo with Encl. ("Status of Plowshare Industrial Projects," memo from John S. Kelly, U.S. Atomic Energy Commission, Division of Peaceful Nuclear Explosives, to List) from W. B. McCool, U.S. Atomic Energy Commission to Distribution, April 26. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029 [OUO].

Lawrence Radiation Laboratory, 1968. "Dragon Trail - Hi-Pressure Closed Cycle Drilling System Flow Diagram." Drawing No. 68-113954 from Lawrence Radiation Laboratory, July 22. On file at: Engineering Records Library, Nevada Test Site, Mercury, NV, Index No. 044407.

Kelly, John S., 1968. Letter from John S. Kelly, U.S. Atomic Energy Commission, to Glenn C. Werth, September 4. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0312989.

Dorn, Joseph L., 1968. "Gasbuggy, Rulison and Dragon Trail; Releases re."Letter from Joseph L. Dorn, Gyrodyne Company of America, Inc., St. James, New York, to U.S. Atomic Energy Commission, September 9. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0188363.

Werth, Glenn C., 1968. "Alternate #1, Tentative Schedule – Plowshare Program – LRL Related." Schedule from Lawrence Radiation Laboratory, September 10. On file at: Archives and Records Office, Lawrence Berkeley National Laboratory, Berkeley, CA, File 434-900205, 28/48.

Werth, Glenn C., 1968. "Alternate #2, Tentative Schedule - Plowshare Program - LRL Related." Schedule from Lawrence Radiation Laboratory, September 10. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-118.

Sandia Laboratories, 1968. Plowshare Quarterly Progress Report (Period Ending September 30, 1968) . Report to U.S. Atomic Energy Commission from Sandia Laboratories, Albuquerque, NM, September 30. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

U.S. Atomic Energy Commission, 1968. Plowshare Program. Booklet. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029.

Lawrence Radiation Laboratory, 1968. FY 1969, Plowshare Program Plan #6. Budget from U.S. Atomic Energy Commission. On file at: Archives and Records Office, Lawrence Berkeley National Laboratory, Berkeley, CA, File 434-900205, 28/48.

U.S. Atomic Energy Commission, 1969. Chapter 11 - Peaceful Nuclear Explosions. In *Annual Report to Congress of the Atomic Energy Commission for 1968,* pp.195-202, January. U.S. Government Printing Office, Washington, D.C.

Sterrett, T. S., 1969. Detailed Geology of the Proposed Dragon Trail Experimental Site, Rio Blanco County, Colorado. University of California, Lawrence Radiation Laboratory, *Report UCRL*-50566. Livermore, CA.

Woodruff, Wayne R., 1969. Memo from Wayne R. Woodruff, Lawrence Radiation Laboratory, to Thomas S. Sterrett, January 16. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-012.

Miller, Robert E., 1969. Letter from Robert E. Miller, U.S. Atomic Energy Commission, Nevada Operations Office, to Herbert E. Grier, January 27. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-012.

Kelly, John S., 1969. "Plowshare Capability." Letter from John S. Kelly, U.S. Atomic Energy Commission, to Robert E. Miller, March 7. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-030.

Sterrett, T. S., 1969. "Project Dragon Trail Status Report and Proposed Time Reductions of Critical Paths to Project Execution." Memo from T. S. Sterrett, Lawrence Radiation Laboratory, to Memorandum to A. Holzer, March 27. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-012.

Nordyke, Milo D., 1969. Underground Engineering Applications. Paper prepared for The Symposium on Public Health Aspects of Peaceful Uses of Nuclear Explosives, Las Vegas, April. University of California, Lawrence Radiation Laboratory, *Preprint UCRL*-71453, April. Livermore, CA. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-103.

U.S. Atomic Energy Commission, 1969. " United States Atomic Energy Commission, Plowshare Program Statement, JCAE FY 1970 Authorization Hearings." Statement from U.S. Atomic Energy Commission, April 18. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-028.

Miller, Robert E., 1969. Letter from Robert E. Miller, U.S. Atomic Energy Commission, Nevada Operations Office, to H. E. Grier, June 10. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-012.

Werth, Glenn C., 1969. Planned Applications of Peaceful Nuclear Explosives. University of California, Lawrence Radiation Laboratory, *Report UCRL*-71901, August 13. Livermore, CA. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-037.

Plowshare Advisory Committee, 1969. Plowshare Advisory Committee, Report on Nineteenth Meeting. Meeting held at Lawrence Radiation Laboratory, Livermore, CA, November 4-5. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029 [OUO].

Continental Oil Company, [196-?], Project Dragon Trail: The Stimulation of a Natural Gas Reservoir by a Contained Nuclear Explosion. Proposal to the U.S. Atomic Energy Commission from Continental Oil Company, Ponca City, OK. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-011.

U.S. Atomic Energy Commission, 1970. Chapter 11 - Peaceful Nuclear Explosives. In *Annual Report to Congress of the Atomic Energy Commission for 1969,* pp. 195-203, January. U.S. Government Printing Office, Washington D.C.

Daily Sentinel, 1970. Dragon Trail Nuclear Shot Plan Shelved. *Daily Sentinel,* February 27. Grand Junction, CO. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0193699.

Evans, Roy B., and David E. Bernhardt, 1970. "Probable Scheduling of Plowshare Events." Memo from Roy B. Evans and David E. Bernhardt, U.S. Department of Health, Education, and Welfare, Southwestern Radiological Health Laboratory, to Francis N. Buck, May 8. On file at Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0173142 [OUO].

Coffer, H. F., and G. H. Higgins, 1970. Future Contained Nuclear Explosives Experiments. In *Education for Peaceful Uses of Nuclear Explosives*, Lynn E. Weaver, editor, pp. 45-63. University of Arizona Press, Tucson, AZ.

U.S. Atomic Energy Commission, 1970. *Plowshare Program During 1969: Based on the Annual Report to Congress for 1969 of the U.S. Atomic Energy Commission.* U.S. Atomic Energy Commission, U.S. Government Printing Office, Washington, D.C. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

U.S. Atomic Energy Commission, 1971. Chapter 9 - Peaceful Nuclear Explosives. In *Annual Report to Congress of the Atomic Energy Commission for 1970,* pp. 195-202, January. U.S. Government Printing Office, Washington D.C.

U.S. Atomic Energy Commission, 1972. Plowshare Program. In *Annual Report to Congress of the Atomic Energy Commission for 1971,* pp. 139-142, January. U.S. Government Printing Office, Washington D.C.

Whan, Glenn A., 1973, Plowshare Technology Assessment, Final Report, Implications to State Governments. Report to the Western Interstate Nuclear Board, Lakewood, CO, from Glenn A. Whan, Chemical and Engineering Department, University of New Mexico. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Crump, Joseph R., 1975. PNE (Peaceful Nuclear Explosion) Activity Projections for Arms Control Planning, Vol. I. Report to the U.S. Arms Control and Disarmament Agency, Contract No. ACDE/PAB-253, from Gulf Universities Research Consortium, Galveston, TX, April 10.

Shafer, David S., William. C. Beck, Dwight Treadwell, and Stephen. A. Mellington, 1995. Inventory of Potential Environmental Restoration Liabilities Associated with Plowshare And Vela Uniform Program Sites. Manuscript, U.S. Department of Energy, Office of Environmental Restoration. On file at: Desert Research Institute, Las Vegas, NV.

U.S. Department of Energy. Nevada Operations Office, 1997. Plowshare Program Executive Summary. Report from U.S. Department of Energy, December 22.

Dragon Trail and Bronco, n.d. Dragon Trail and Bronco: Time and Mileage to Sites. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-012.

Hanna, Bert, n.d. A-Blast Use Expected to Make Colorado. No. 1 in Oil, Gas. *Denver Post*. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-030.

Holmes & Narver, Inc., n.d. "Area Map – Bronco, Dragon Trail, and, Rulison: Tentative Locations in Rio Blanco and Garfield Counties, Colorado." Map. On file at: Engineering Records Library, Nevada Test Site, Mercury, NV, Index No. 187324.

Lawrence Livermore National Laboratory, n.d. Dragon Trail photo, dt-a. Negative No. 67J 627. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

Lawrence Livermore National Laboratory, n.d. Dragon Trail photo, dt-b. Negative No. 67J 637. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

Lawrence Livermore National Laboratory, n.d. Dragon Trail photo, dt-c. Negative No. 67J 628. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

Lawrence Livermore National Laboratory, n.d. "Project Dragon Trail." Dragon Trail drawing. Negative No. GLC-6811-7459+D954. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

Plowshare Public Health Evaluation, n.d. Plowshare Public Health Evaluation. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0316824.

U.S. Department of Energy. Nevada Operations Office, n.d. The Plowshare Program (Draft). Report from U.S. Department of Energy.

3.5 DRUM INLET

Plowshare Program
High Explosive Channel Excavation
North Carolina Coast

The U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Laboratory (formerly the Nuclear Cratering Group) was responsible for developing explosive excavation techniques for use on large-scale civil construction projects that would provide a cost competitive alternate to conventional blasting and hauling techniques. Drum Inlet was an explosive excavation project under the guidance of the Explosive Excavation Research Laboratory to complete the excavation of a ch annel through the Core Banks off the North Carolina coast (Figure 3.5-1). In the case of Drum Inlet, explosive excavation was considered a safer approach than other construction methods. The project also had the potential to provide technical developments in the design of explosive excavation projects in a saturated medium and/or underwater excavation.

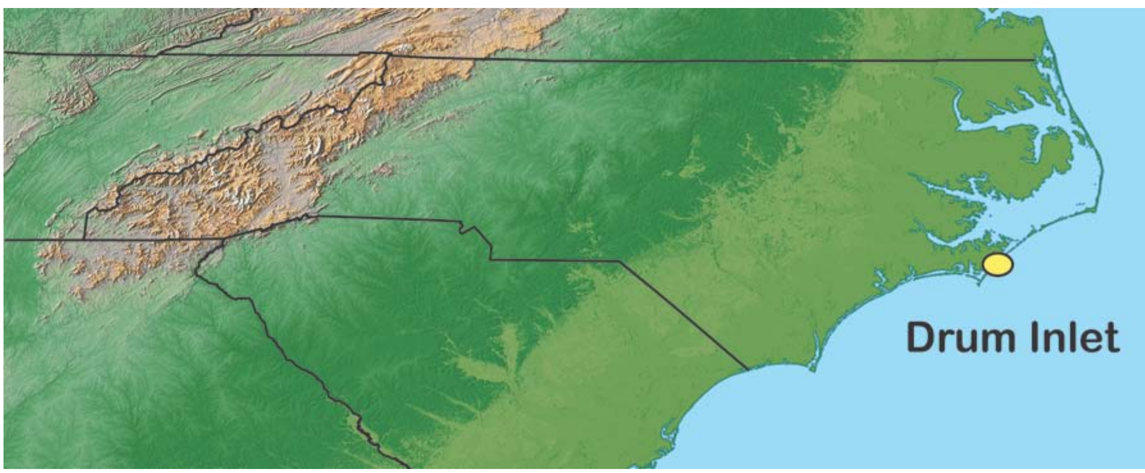


Figure 3.5-1. Map showing the general location of Drum Inlet on the Core Banks off the coast of North Carolina (adapted from USA Relief Maps 2004).

The Core Banks is a series of low-relief barrier islands extending from Ocracoke Inlet in the north to Cape Lookout in the south. The barrier islands are separated from the North Carolina shoreline by the narrow and shallow waters of Core Sound (Figure 3.5-2). This geographic feature contains a number of natural inlets that provide navigable channels and active tidal exchange between the Core Sound and the Atlantic Ocean, including Drum Inlet (now called Old Drum Inlet). Old Drum Inlet was opened in 1933 when water breached the barrier reef. Between 1933 and 1971 the inlet underwent periodic migration, and, as a result of shoal formation processes, was not always deep enough for small craft. The inlet became completely closed off during a seasonal storm in early 1971. Excavation of a new navigable channel, New Drum Inlet, was proposed to replace the

Old Drum Inlet for economic and environmental reasons. Access to Raleigh Bay on the Atlantic Ocean via a short route for commercial and sport fishing was favorable for local economic development, and reopening the inlet to restore the salinity balance of the Core Sound was considered beneficial for native shellfish populations.

Figure 3.5-2. Map of the Cape Lookout National Seashore showing the location of the Old Drum Inlet and the New Drum Inlet on the Core Banks off the coast of North Carolina (adapted from National Geographic Topographic Maps 2006).

Once the project to build a new inlet was approved, the U.S. Army Corps of Engineers, Wilmington District, undertook a site selection and design study. A location approximately 2 miles south of the original Drum Inlet site was selected. In this area the barrier island was only about 1,000 ft wide and, therefore, a probable site for a natural storm breach. The basic design involved dredging a channel in the Core Sound approximately 1.8 miles long and 150 ft wide with a depth of 7-9 ft. An alternate excavation technique was needed to complete the excavation across the Core Banks since inlet breaching with a hydraulic wedge presented unacceptable risk to the dredging plant. Explosive excavation was considered a feasible option to complete excavation of the inlet because it could provide instantaneous removal of the final section of the channel. Thus, construction of the channel was planned in two phases: dredging of the Core Sound and Core Banks, and explosive excavation of the final segment of the Core Banks to the Atlantic Ocean. The two phases were administered under separate contracts by the U.S. Army Corps of Engineers, Wilmington District. The first phase included dredging a 1.8 mile section of the channel from the Core Sound into the Core Banks and began in October 1971 and was completed on November 20, 1971 . The Explosive Excavation Research Laboratory provided design specifications, technical advice, and monitoring for the second explosive excavation phase and the contract was awarded to the JERAC Corporation, San Diego, California.

The channel construction Drum Inlet design called for an excavation 470 ft in length and 80 ft in width with a depth of 6 ft below mean low water. Prior to designing the explosive excavation a series of unnamed laboratory-scale modeling tests were conducted at the Site 300 high explosive test facility in Tracy, California. The objectives of the modeling tests were to determine if the charge emplacement would meet project specifications, to examine the time delay scheme between time-delayed and simultaneous row-charge detonations, and to study the possible effect of wash back between the Atlantic Ocean and the Core Sound on the dimensions of the excavated channel. The tests were completed by t he end of September 1971. However, the results of the small-scale modeling tests were inconclusive, so data from dry land single and row charge cratering curves for alluvium were used to design the Drum Inlet excavation. These data were from high explosive tests on the Nevada Test Site and elsewhere. The data were summarized in a 1971 Nuclear Cratering Group report on explosive excavation technology.

To produce a cr ater suitable for the desired channel configuration, an emplacement design with a row charge series of 2 rows of 13 c anisters, each containing 1-ton explosive, blasted simultaneously was planned (Figure 3.5-3). However, due to beach erosion on the ocean side of the Core Banks, only 22 of the 26 charges were emplaced and the length of the explosive cut was reduced to 385 ft. An ammonium nitrate slurry blasting agent was used and the explosives were primed with Du Pont HDP#1 non-nitroglycerine boosters. Explosive containers were designed so the charges could be emplaced in the sand with a crane and high-pressure water jetting rig. These containers were cylinders 8.5 ft in length and 2 ft in diameter. The spacing of the charges between the two rows varied from 36 to 44 ft and within-row spacing ranging from 30 to 39 ft. The two 11-charge rows of explosives and 4 disposal charges in the dredged channel were detonated simultaneously on December 23, 1971.

The Drum Inlet event was viewed as a success. The explosion created a crater at least 80 ft in width and successfully removed the sand barrier and completed the channel without supplemental dredging (Figure 3.5-4). On December 24 a fishing trawler traveled through the inlet and reported a depth of at least 9.5 ft. In the following days, tidal forces continued to excavate the inlet and by December 27 the channel had a width of 700 ft. However, a sand shoal began to form within the Core Sound portion of the channel and dredge operations were undertaken in January 1972. One year after the project wave action had formed a channel 800 to 900 ft wide in the Core Banks and about 3500 ft wide on ocean side. Figure 3.5-5 is a satellite image of the Middle Core Banks that shows the Old Drum Inlet (reopened in 1999 during Hurricane Dennis) and the New Drum Inlet.

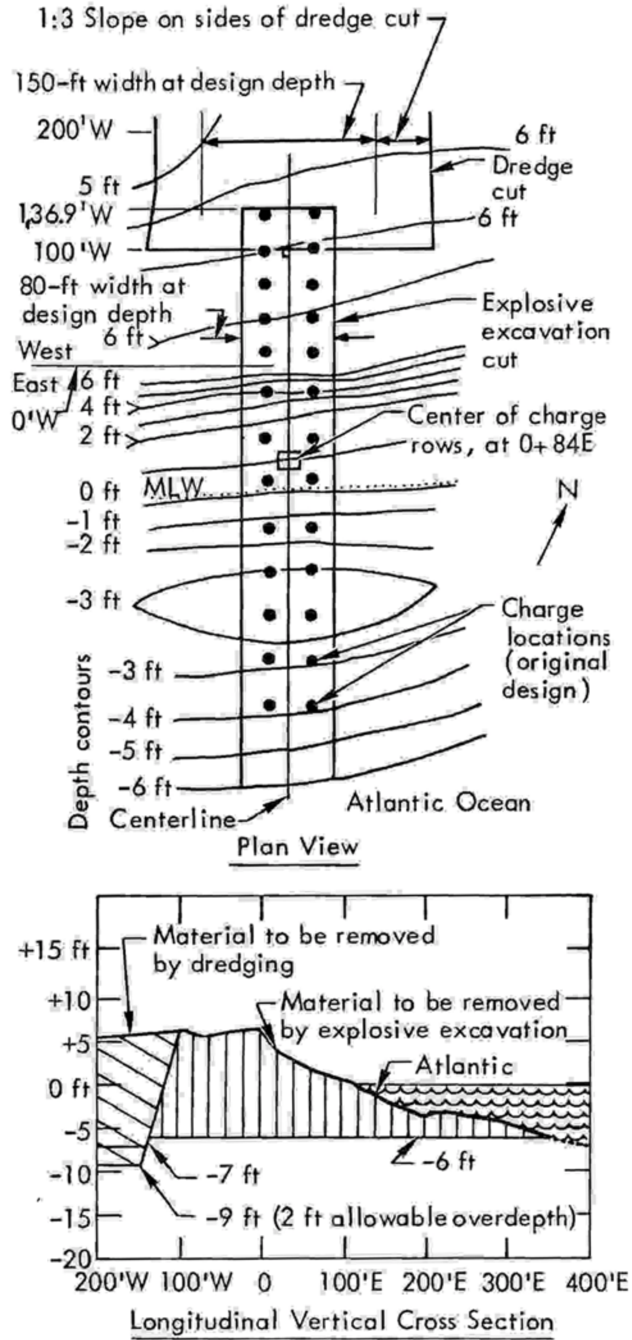


Figure 3.5-3. Illustration of the plan view and vertical cross section for the excavation and emplacement design of Drum Inlet (from Snell and Gillespie 1973, Figure 9).

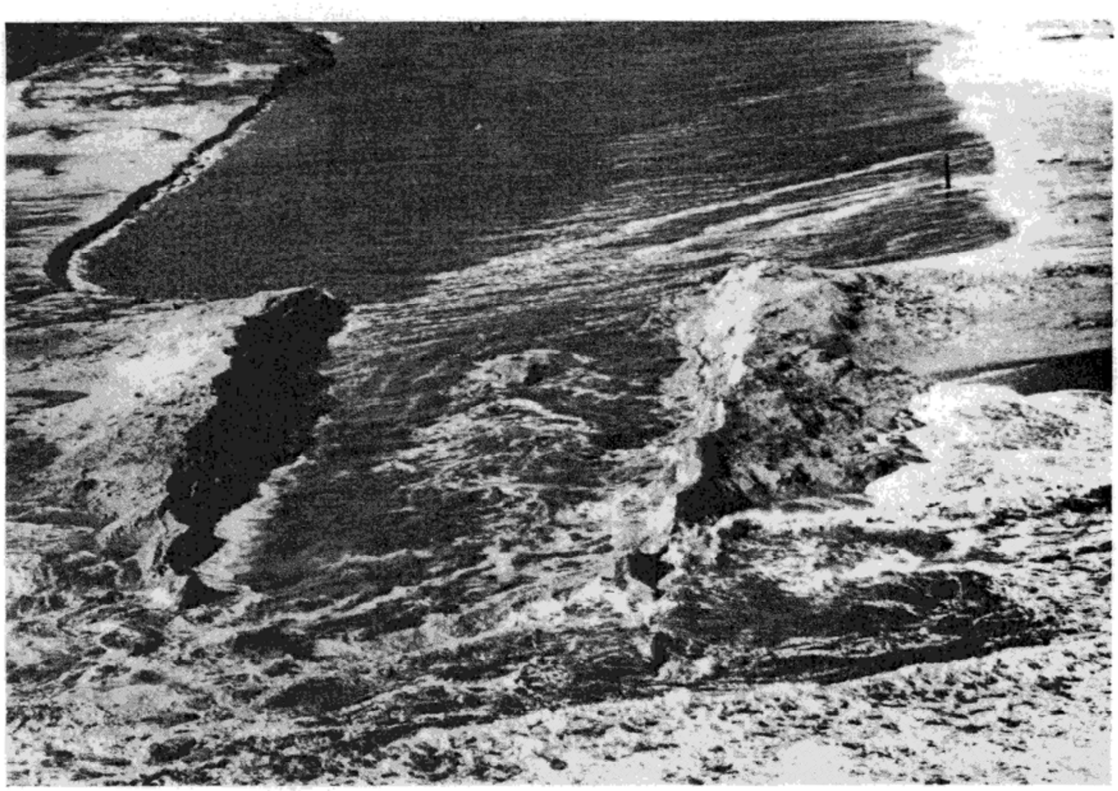


Figure 3.5-4. Post-detonation photograph of the Drum Inlet channel with a view toward the Core Sound showing the dredged channel in the background and explosive excavation in the foreground (from Snell and Gillespie 1973, Figure 17).

A number of technical programs were conducted by the Explosive Excavation Research Laboratory in conjunction with the Drum Inlet event. These included: verification of the correct detonation of a saturated medium with and without seawater overlay; sand-surface and water-surface peak velocities; observations of dimension of the dust cloud; a measurement of ejecta velocities and ranges; and evaluation of the crater dimensions. Discussions about these programs as well as the design and execution of the project are included in the final technical report for the project issued in August 1973. A number of studies concerned with inlet dynamics and ecosystems were undertaken by the U.S. Army Engineer Waterways Experiment Station Hydraulics Laboratory, Coastal Engineering Research Center, the National Park Service, and the North Carolina State Department of Fisheries. The Middle Core Banks is currently part of the Cape Lookout National Seashore authorized in 1974 and administered by the National Park Service.

Drum Inlet was a Level 2 activity because high explosives were used to complete the inlet channel.

Figure 3.5-5. View of the Old Drum Inlet (northern-most inlet reopened in 1999) and the New Drum Inlet on the Middle Core Banks (adapted from Europa Technologies Image 2008).

CHRONOLOGICAL BIBLIOGRAPHY

Johnson, Stanley M., 1971. Explosive Excavation Technology. U.S. Army Engineer Nuclear Cratering Group NCG Technical Report No. 21, June. Livermore, CA.

LaFrenz, Robert L., 1971. "Status Report - Rapid Excavation with Explosives." Letter with encl. ("Status Report, Effective Date: 30 September 1971") from Robert L. LaFrenz, Explosive Excavation Research Office, Corps of Engineers, to Director, U.S. Army Engineer Waterways Experiment Station, October 29. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-108.

LaFrenze, Robert L., and Walter C. Day, 1972. Explosive Excavation Development for Construction and Combat Applications. U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Office, AD750344. Livermore, CA.

U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Laboratory, 1972. "Listing and Publication Schedule of EERO Reports." Schedule from Explosive Excavation Research Laboratory, Livermore, CA, March 31. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-108.

LaFrenze, Robert L., and Walter C. Day, 1972. Explosive Excavation Research: Projects Tugboat and Trinidad. *Nuclear Technology,* Vol. 15, pp. 75-84, July.

U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Laboratory, 1972. "Listing and Publication Schedule of EERL Reports." Schedule from Explosive Excavation Research Laboratory, Livermore, CA, September. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-108.

Snell, Charles M., and Richard H. Gillespie, 1973. Technical Report E-73-5 Project Drum Inlet: Explosive Excavation in Saturated Sand. U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Laboratory, TID-4500, UC-35, August. Livermore, CA.

Riggs, Stanley R., and Dorothea V. Ames, 2007. Effect of Storms on Barrier Island Dynamics, Core Banks, Cape Lookout National Seashore, North Carolina, 1960-2001. *U.S. Geological Survey Scientific Investigations Report* 2006-5309.

THIS PAGE INTENTIONALLY LEFT BLANK

3.6 EXCAVATOR

Plowshare Program
High Explosive Calibration Experiment
Twin Springs, Idaho

Civil works projects with a major earth-moving component were the principal focus of the U.S. Army Engineer Nuclear Cratering Group's Plowshare Program activities. Water control projects such as dams, reservoirs, and canals fell into this category. Project Travois (see Chapter 3.21) and its accompanying high explosive calibration test, Project Excavator, was a joint experiment between the U.S. Atomic Energy Commission and the U.S. Army Corps of Engineers. The projects were structured to either determine the feasibility of using nuclear explosives for the in situ creation of an ejecta or slide dam across a river or to produce aggregate for rockfill dam construction.

The proposed Twin Springs Dam project was chosen as the site for the nuclear quarrying experiment (Figure 3.6-1) after a site along the Chowchilla River in California had been ruled out (a site in Oregon would also be considered at a later date – see page 3.6-7). Located approximately 47 road miles east of Boise and 15 miles southeast of Idaho City, the proposed dam site spanned the Boise River at Twin Springs, Idaho. The Arrow Rock Dam and Reservoir were just over 20 miles downstream (Figure 3.6-2). A 13-mile stretch of the Boise River Canyon extending from the mouth of the river's South Fork to the confluence of the Middle and North Forks was chosen for the high explosives test series.

The first feasibility study for a nuclear quarrying experiment at the Twin Springs Dam site appeared in November 1966. Subsequent correspondence indicates that planning for Project Travois and the high explosives calibration series, Project Excavator, was well underway by January 1968. Initially, when the California location had been considered for the nuclear quarrying experiment, the calibration shots had been designated Project Angledozer. The calibration series originally called for four detonations – three in sloping terrain and one conducted on level ground. The high explosive calibration tests were renamed when the experiment moved to Idaho. By April 1968, the calibration tests had been revised and renamed Project Excavator. The new plan was scheduled as "Phase II" of the multiphase Travois project. Excavator had several objectives, which required a series of three high explosive detonations. The experiment's primary goal centered on the investigation of two different construction techniques. The first concept involved the use of explosive charges to produce aggregate suitable for construction of a rockfill dam (Figure 3.6-3), while the second approach employed a direct blasting technique to produce an ejecta dam (Figure 3.6-4). Project Excavator's second purpose was to supply data for a more accurate determination of the nuclear design parameters required for the Project Travois detonation. High explosive tests in the same terrain and geological conditions were needed to verify the predictive models and volume estimates concerning the projected dimensions of the nuclear crater and the quantity and distribution of aggregate and/or ejecta. The final goal was to verify the suitability of the Twin Springs location.

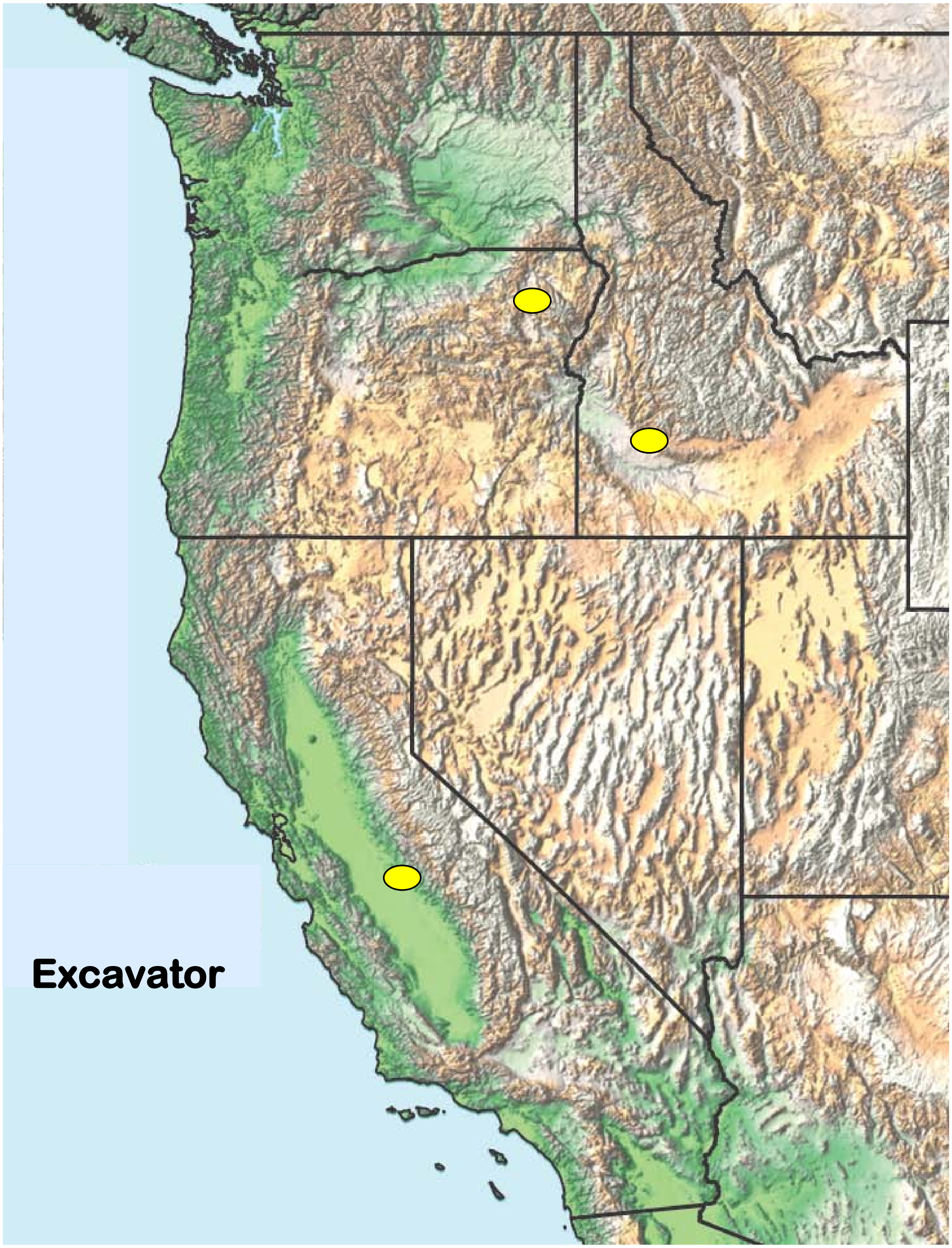


Figure 3.6-1. The three proposed locations for Project Excavator in California, Idaho and Oregon. The Twin Springs Dam project in Idaho was the primary site (adapted from USA Relief Maps 2004).

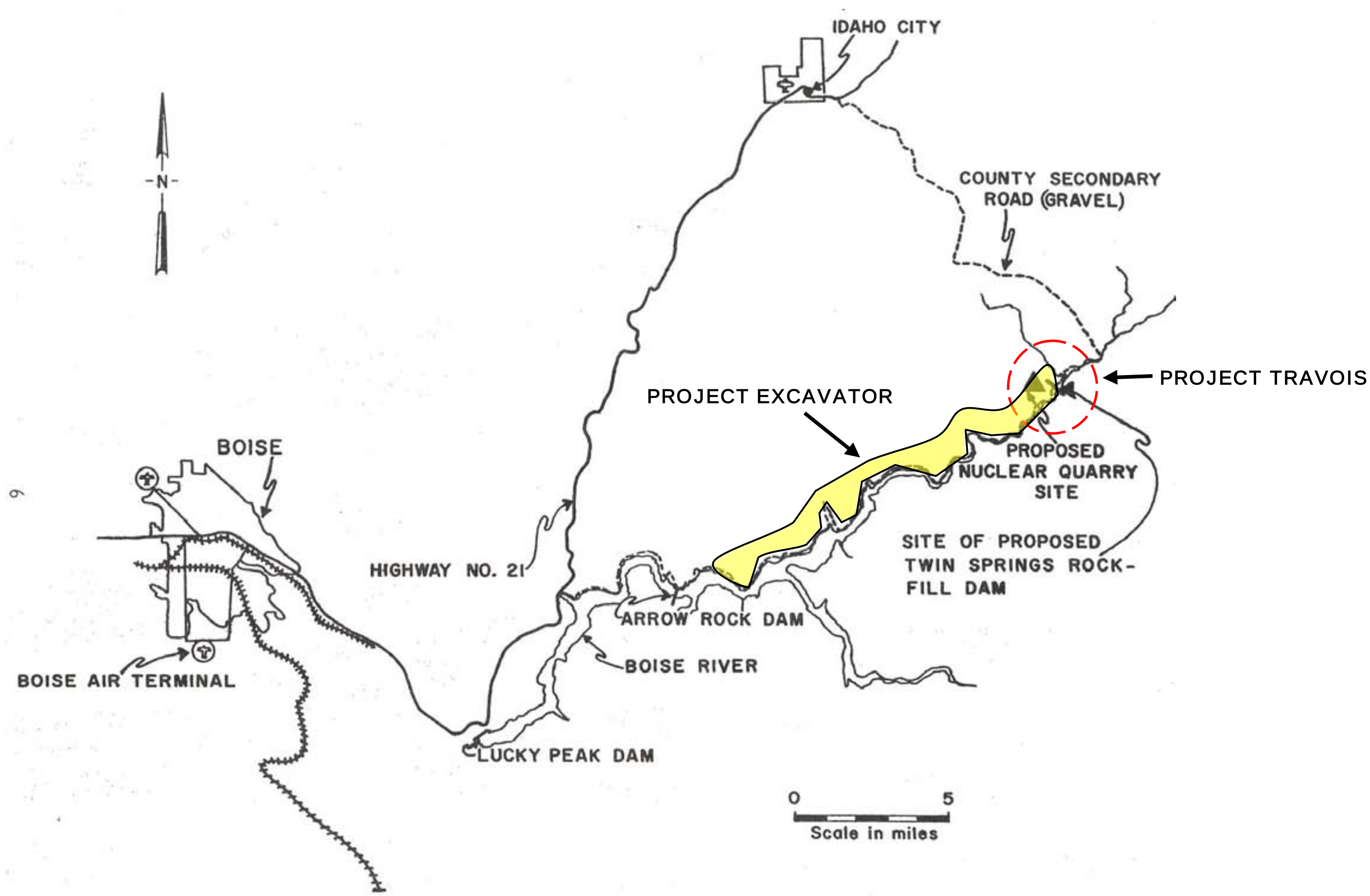


Figure 3.6-2. Areas proposed for the Project Excavator high explosive calibration experiment and the Project Travois nuclear quarrying experiment and embankment dam along the Boise River in Idaho (adapted from U.S. Army Engineer Nuclear Cratering Group 1968, Figure 3).

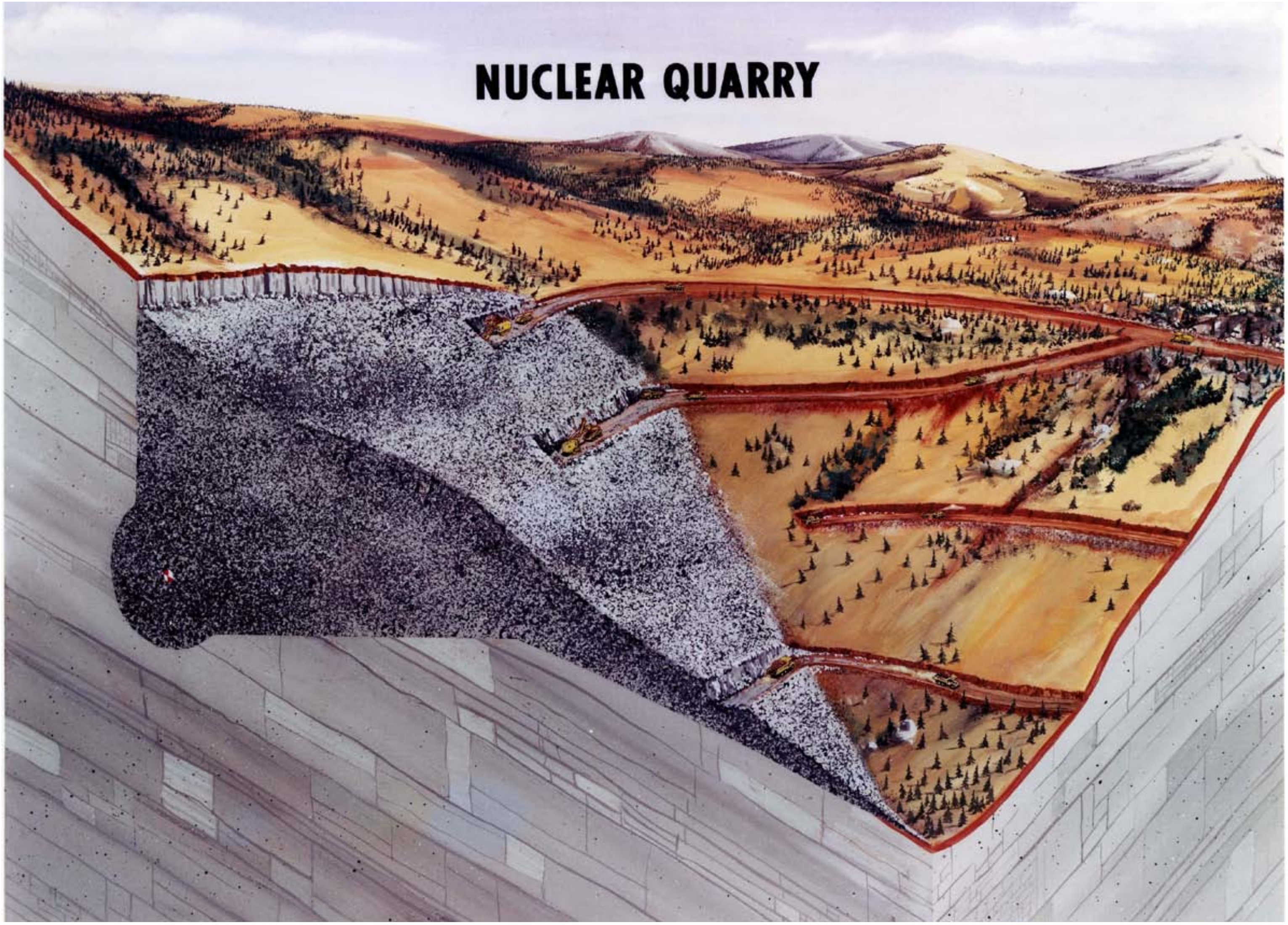


Figure 3.6-3. Schematic of the nuclear quarry concept (Lawrence Livermore National Laboratory n.d., Negative No. GLC-683-2151).

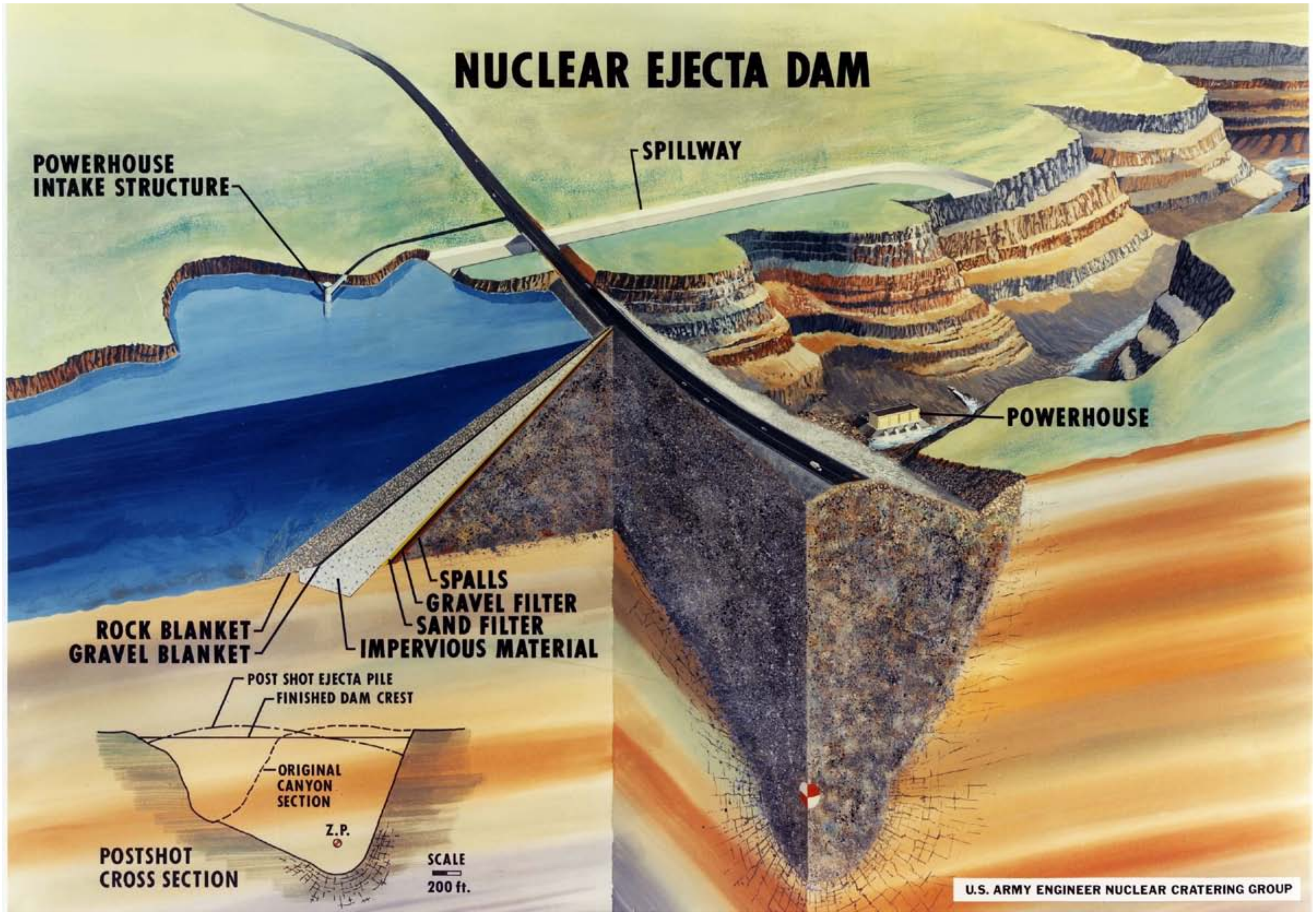


Figure 3.6-4. Nuclear ejecta dam concept (Lawrence Livermore National Laboratory n.d., Negative No. GLC-683-2152A).

The three Project Excavator detonations were designated Alpha, Bravo, and Charlie. All were originally planned as 40-ton nitromethane detonations at a depth of roughly 80 ft below the surface, although later documentation gives a yield range of 40 to 100 tons. The Alpha and Bravo tests were quarrying experiments designed to determine the suitability of explosively produced aggregate for use as embankment fill and riprap (slope stabilizer). The Charlie event's purpose was to test the feasibility of using a deeply-buried single charge explosion to form a water-storage embankment by ejecting rock across a natural ravine.

Documentation indicates that the site selected for the Alpha test was Bore Hole QH-5 in terrain with a 30° slope. The Bravo test was planned for similar terrain while the Charlie test would require a narrow, steep sided ravine with a slope of at least 45° and a depth of about 125 ft. The locations for these two experiments had not been determined when the preliminary planning concept was distributed in May 1968. The planning document, however, did indicate that extensive pre-shot geological investigations including core drilling and hydraulic pressure testing were planned for two of the event sites.

The Nuclear Cratering Group had budgeted FY 1969 funds for Project Excavator with site construction activities set for the second quarter and execution scheduled for the fourth quarter. They estimated that the three High Explosives calibration experiments and associated scientific and technical programs would require six months. Subsurface site characterization explorations (Phase I) to establish the suitability of the rock for use in dam construction had been underway since the summer of 1967. The Project Travois nuclear detonation was slated for FY 1971, assuming the Excavator tests had a positive outcome. If scientific or safety deficiencies in the proposed Twin Springs site were discovered during either the Phase I Site Exploration investigations or the Phase II Calibration Tests, an alternate site or project would be selected. The time frame and budget priorities for the nuclear dam project would also require revisions.

Technical and scientific investigations associated with the high explosives tests included the use of bowling ball and flare photography techniques to obtain surface motion measurements, seismic and air blast pressure instrumentation, and the testing and evaluation of various aggregate recovery methods. Engineering properties studies related to particle size and distribution would be accomplished by excavating one of the High Explosives craters and one of the retarc mounds. The seismic motion investigations planned for Project Excavator were of particular importance because they would help better characterize the seismic propagation paths to the surrounding population centers (i.e., Boise) and the area's existing dams and reservoirs. Accurate seismic predictive models were essential prior to the Project Travois 40-kt nuclear detonation.

Both Project Excavator and Project Travois appeared on schedule for the Idaho location through August 1968 when a public hearing held in Boise confirmed the spring 1969 time frame for the Excavator high explosive calibration series. Less than 10 weeks later, the U.S. Army Corps of Engineers informed the U.S. Atomic Energy Commission that they had decided to discontinue Project Excavator and Project Travois activities at the Twin

Springs Dam Site and were exploring other possible locations for a nuclear dam construction project. No reason was given for abandoning the Idaho location.

By the end of October 1968, the U.S. Army Corps of Engineers had identified an alternative site for both Project Travois and the Excavator high explosives calibration series. The Walla Walla Engineer District had already started preparation of a feasibility study for the new location – Catherine Creek in northeastern Oregon near the Washington/Oregon/Idaho border (Figure 3.6-1). The proposed Catherine Creek Dam project was much smaller in scale than the Twin Spring undertaking requiring only 1,000,000 cubic yards of rockfill. A tentative schedule for the calibration series was set for the 2nd or 3rd quarter of FY 1970 with the nuclear quarry detonation scheduled for the second or third quarter of FY 1972. Briefings for the appropriate congressional delegations were recommended. No other documentation related to Project Excavator or Project Travois and the Oregon site has been identified.

Project Excavator participants were limited. The U.S. Atomic Energy Commission, Lawrence Radiation Laboratory and the Nuclear Cratering Group were the driving forces behind the project. The Nuclear Cratering Group served as the overall organizational lead. Most of the operational functions and project logistics fell to the U.S. Army Corps of Engineers, Walla Walla Engineer District. The Nuclear Cratering Group also assumed responsibility for project security and conducting the surface motion studies, crater and retarc measurements, and engineering properties technical programs. Lawrence Radiation Laboratory was in charge of code calculations, assembling and arming the high explosive charges, and designing the timing and firing systems. Lawrence Radiation Laboratory and the U.S. Atomic Energy Commission Nevada Operations Office shared development of the seismic investigation program. Edgerton, Germeshausen, and Grier Inc. was to provide photographic support for the overall project along with scientific photo documentation for the experiments and technical programs. Meteorological support was supplied by Environmental Science Service Administration. The Nevada Operations Office also handled the safety issues for Project Excavator.

Project Excavator was a Level 3 activity which corresponds to fieldwork limited to using existing characterization holes, drilling at least one core hole (QH-5) for the Alpha test, and grading several access roads. The Twin Springs Idaho project site was visited in FY2004.

FIELD VISIT

Both the Project Travois and Project Excavator sites are located on the Boise River near the small community of Twin Springs, Idaho. The Excavator and Travois project sites can be accessed by following Forest Service Road #268, a graded but narrow dirt road that follows the north bank of the Boise River. Situated approximately 2.2 mi northeast of Twin Springs, the proposed Project Travois dam location is at a narrow portion of the steep-walled river canyon (Figure 3.6-5). On June 27, 28 and July 2, 2004, Beck and

Figure 3.6-5. Overview of the proposed Project Travois dam site looking southwest (downstream) (photo taken July 2004 on file at Desert Research Institute).

Figure 3.6-6. Bedrock outcrop that may have been the site of geological characterization activities for Project Travois (photo taken July 2004 on file at Desert Research Institute).

Edwards conducted a visual inspection of the north side of the canyon beginning approximately 0.2 mi upstream of the proposed dam site and continuing downstream for 2.2 miles, searching for evidence of any drill holes or sampling locations related to either Project Excavator or Project Travois, as well as the jeep trail leading to the proposed quarry site situated 1 mi northwest of the dam site. Approximately 0.7 mi south of the dam site, the researchers located an old jeep trail leading up to the proposed quarry area adjacent to a rocky outcrop that may have been the location of the geological characterization drill hole mentioned in the project documentation (Figure 3.6-6). The weathered granite outcrop, its crest and slopes covered with broken rock, is surrounded by an old, partially collapsed barbed-wire fence. Pull-tab beverage containers (1964-1972 vintage), bailing wire, insulated electrical wire, metal fragments, several rusted food tins, and broken glass litter the base of the outcrop. The datable material in the trash scatter is consistent with the time-period for the Plowshare projects, but the scatter could also simply be related to recreational use of the Forest Service road and the Boise River. No drill hole or drilling equipment was found. The steep jeep trail has been blocked with a 3-ft high earth and rock berm making it impassable. A 1/3 mi hike up the road beyond the berm was enough to confirm that the road was in extremely poor condition. While additional attempts to reach the quarry location and look for the Alpha test Borehole QH-5 were abandoned because of time constraints, the researchers were able to examine the proposed quarry location from a distance by using telephoto lenses. The quarry site, clearly visible from the outcrop and the Forest Service road below, showed no obvious signs of disturbance. Continued visual inspection of the north side of the river canyon to a point just downstream from the community of Twin Springs revealed no other indication of Projects Excavator or Travois site characterization activities.

From the documentation, it does not appear that any more than a single hole was drilled for site characterization studies or the calibration shots (Alpha test Borehole QH-5). As the record suggests, it appears that the project was shelved before drilling for the Project Excavator high explosive calibration shots could be completed. The only other activity that may have taken place was the grading of an access road to the proposed nuclear quarry location or the Borehole QH-5 location. The field visit conducted in FY 2004 completed the field activity evaluations for Project Excavator.

During FY 2004, a review of the land status records on file at the Idaho State Office of the Bureau of Land Management in Boise revealed that both the Excavator and Travois project areas fell within lands administered by the U.S. Forest Service as part of the Boise National Forest. That agency continues to administer the land today.

CHRONOLOGICAL BIBLIOGRAPHY

U.S. Army Corps of Engineers. Walla Walla District, 1966. Nuclear Quarrying Feasibility Study: Twin Springs Dam and Reservoir, Boise River, Idaho. Report to U.S. Army Engineer Nuclear Cratering Group, Livermore, CA, from Walla Walla District, Walla Walla, WA, November. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0330824 [OUO].

Hughes, Bernard C., 1968. "Status Report - Nuclear Explosives Studies for Civil Construction (RCS ENGCW-P-6 (R-1))." Letter with Encl. ("Status Report, Effective Date: 31 December 1967") from Bernard C. Hughes, Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, to Chief of Engineers, Department of the Army, January 13. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029.

Hughes, Bernard C., 1968. Letter from Bernard C. Hughes, Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, to Glenn C. Werth, February 2. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

Noble, Charles C., 1968. Letter from Charles C. Noble, Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, to John S. Kelly, April 9. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

Hughes, Bernard C., 1968. Letter from Bernard C. Hughes, Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, to Glenn C. Werth, April 18. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065 [OUO].

Lawrence Radiation Laboratory. U.S. Army Engineer Nuclear Cratering Group, 1968. Project Excavator Preliminary Planning Concept, Twin Springs, Idaho. Manuscript, May. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065 [OUO].

Hughes, Bernard C., 1968. "Preliminary Planning Concept for Project Excavator." Letter from Bernard C. Hughes, Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, to Distribution, May 10. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

Toman, John, 1968. "Selection of Dob's for Project Excavator." Memo from John Toman, Lawrence Radiation Laboratory, to Bernard C. Hughes, May 28. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

Lawrence Radiation Laboratory, 1968. Technical Concept, Project Travois Aggregate Production Experiment. Manuscript, June 6. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065 [OUO].

Hughes, Bernard C., 1968. "Meeting with Director of Idaho Water Resource Board." Memo from Bernard C. Hughes, Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, to Record, June 11. On file at: Archives and Research, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029 [OUO].

Reynolds, Harry L., 1968. "TRAVOIS - Comments on SDK 68-24." Memo from Harry L. Reynolds, Lawrence Radiation Laboratory, to Glenn Werth, June 26. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

Lawrence Radiation Laboratory, 1968. "Background Discussion Paper for 27 June 1968 Travois Meeting." Manuscript, Lawrence Radiation Laboratory, June 27. Livermore, CA. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065 [OUO].

Lawrence Radiation Laboratory, 1968. "Proposed Agenda Topics – Travois Meeting, 27 June 1968, Summary of Scientific and Technical Programs and Time Estimates for Project Travois." Agenda for Travois Meeting, Nevada Operations Office, June 27. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

Werth, Glenn C., 1968. Letter from Glenn C. Werth, Lawrence Radiation Laboratory, to John S. Kelly, July 9. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

Knox, J. B., 1968. Water Quality Considerations - Project Travois. University of California, Lawrence Radiation Laboratory, *Report UCRL*-124984, July 16. Livermore, CA.

Harris, John A., 1968. "August 2 Hearing in Boise on Twin Springs Dam Project." Telex from John A. Harris, U.S. Atomic Energy Commission, to List, July 26. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, PLO-065.

Day, Walter C., 1968. "Trip Report, Idaho Water Resources Board Public Hearing on Lucky Peak Power House and Town Springs Dam Project." Memo with Encls. (Lee 7/10/68; "Statement to Be Made by Col. Giesen of the Corps of Engineers, Walla Walla District, at a public hearing in Boise, Idaho; and "Statement Provided for the Minutes of the Hearing for Release to Interested Persons following the Hearing") from Walter C. Day, Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, to Record, August 6. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

Crookham, George L., Jr., 1968. Letter from George L. Crookham, Jr., Idaho Water Resource Board, to Len B. Jordan, U.S. Senator, October 10.

Kelly, John S., 1968. Letter from John S. Kelly, U.S. Atomic Energy Commission, Division of Peaceful Nuclear Explosives, to Glenn C. Werth, October 14. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

McCarvill, Thomas J., 1968. "Proposed Alternate Site for Project Travois--Catherine Creek, Oregon." Letter with Encl. ("Catherine Creek Project," Memo from Thomas W. Nelson, Department of the Army, to Thomas McCarvill, October 24 [OUO]) from Thomas J. McCarvill, U.S. Atomic Energy Commission, Division of Peaceful Nuclear Explosives, October 31. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

Lawrence Livermore National Laboratory, n.d. "Nuclear Ejecta Dam." Nuclear ejecta dam_b drawing. Negative No. GLC-683-2152A. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

Lawrence Livermore National Laboratory, n.d. "Nuclear Quarry." Nuclear quarry-a drawing. Negative No. GLC-683-2151. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

3.7 IKI

Plowshare Program
Geothermal Energy Experiment
Kilauea Volcano, Hawaii

From its inception, scientists associated with the Plowshare Program were interested in nuclear stimulation or creation of commercial energy sources. Geothermal power production was one potential industrial application of nuclear explosives. The various geothermal energy sources that might generate enough heat for electrical power production included hot water or steam deposits, hot dry rock, or underground magma reservoirs. Only hot water/steam deposits had been commercially exploited. The November 1959 eruption of the Kilauea Volcano on the island of Hawaii afforded researchers the opportunity to investigate the thermal energy potential of molten rock. Project Iki (Figure 3.7-1), conducted in 1960, was designed to determine if the industrial use of sub-surface pools of molten rock – either natural or those that might be formed by deep underground nuclear explosions – was technically and economically feasible.

The Kilauea Iki Crater originally formed sometime after A.D. 1450 when the lava shield on the eastern slope of the Kilauea volcano collapsed. Over the next 500 years, several eruptions partially filled the Iki Crater. The spectacular November 14, 1959 event was particularly notable for its 1,800 ft high lava fountain. This eruption lasted until December 21 and filled the crater more than halfway to its rim creating a lake 400 ft deep with a volume of about 80-100 million metric tons of molten lava. Essentially a miniature "unroofed" magma chamber, lava lakes provide a natural laboratory for studying the cooling, crystallization, and geothermal properties of small bodies of magma. Plowshare investigators believed that the Iki investigation would yield valuable data concerning the engineering of equipment and development of appropriate methodology to study and recover power from molten rock formed either by deep underground nuclear detonations or from natural surface lava flows contained in man-made nuclear excavated craters.

The U.S. Atomic Energy Commission and Lawrence Radiation Laboratory personnel came up with a preliminary concept for the project by February 1960 and began discussions with the University of Hawaii and the National Park Service, the agency responsible for administering the Hawai'i Volcanoes National Park. Two LRL K-Division scientists traveled to Hawaii in early March 1960 to meet with faculty from the University's Geophysics Department to make arrangements for core drilling of the lava flow. By late March, assurances had been received that both the Park Director and Assistant Park Superintendent would grant permission for the experiment once the application was submitted. Over the next few months the scientists deliberated over the project's technical elements, scheduling and costs for a drilling program in the newly formed Iki lava lake. The primary objectives of the experiment were to obtain information on the drilling problems associated with probing into molten rock and to obtain gas and core samples of the melt for thermal characterization and future power

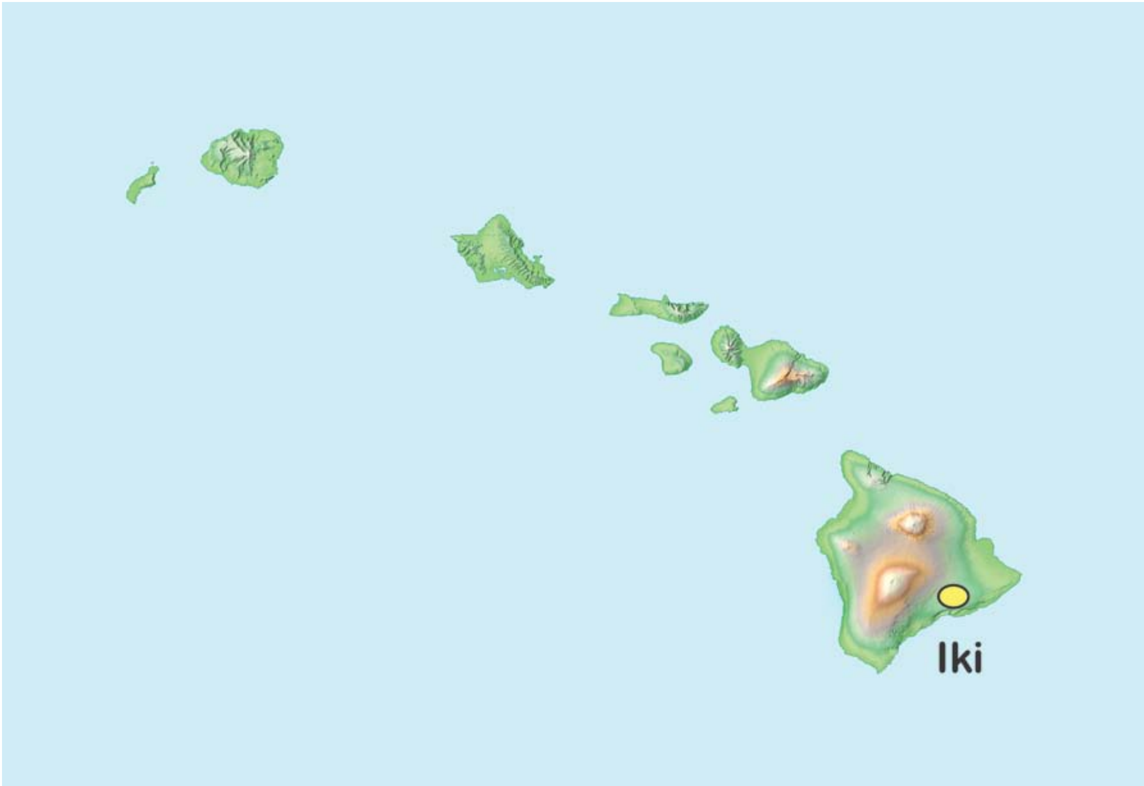


Figure 3.7-1. Location of Project Iki in Hawaii (adapted from USA Relief Maps 2004).

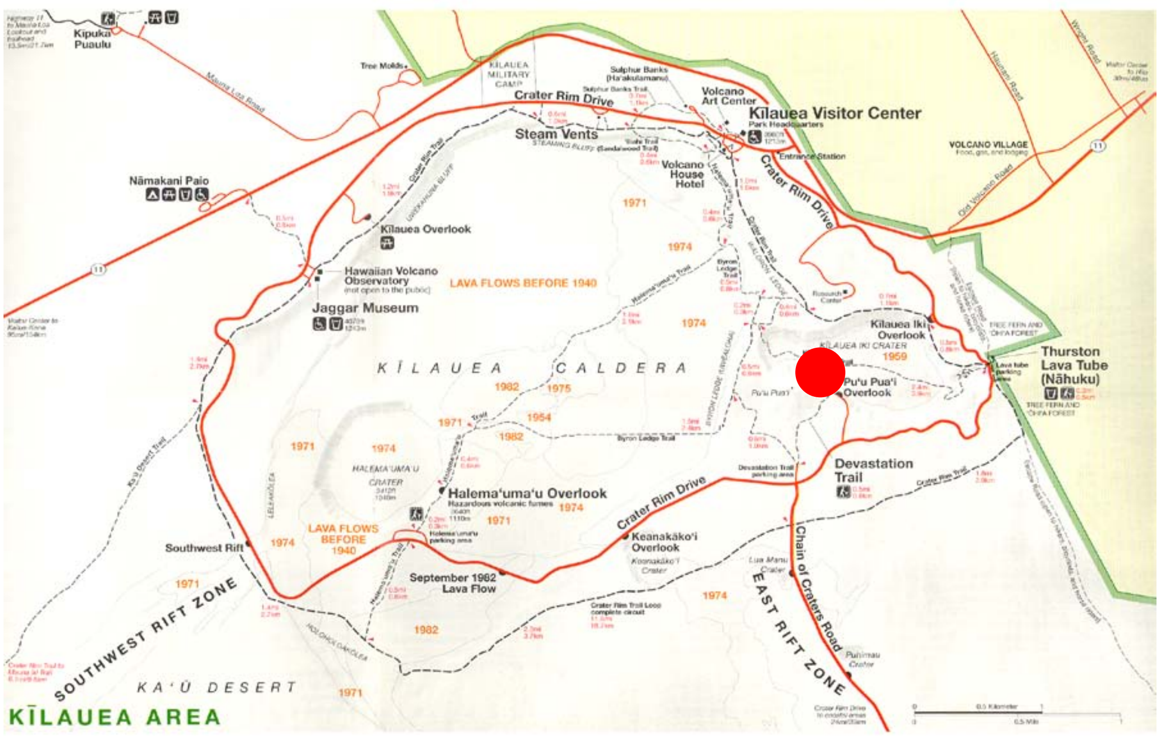


Figure 3.7-2. The island of Hawaii. Red dot marks the location of the Kilauea Iki Crater drilling experiment (adapted from National Park Service 2002).

recovery studies. By the summer of 1960, the use application had been approved by the Park Service and the Plowshare researchers had contracted with a local drilling company and finalized the experimental methodology for the project (Figure 3.7-2).

Researchers from the U.S. Geological Survey, Lawrence Radiation Laboratory, Sandia Laboratories, the University of California at Los Angeles, and the University of Hawaii worked with drilling contractor Nat Whiton and his crew to conduct the Project Iki field activities in July 1960. Using a winch and cable system, they placed a Concore type E5 portable core-drilling rig on the crater floor (Figures 3.7-3 and 3.7-4). An air compressor positioned on the crater rim supplied the rig through a 1,400 ft long hose. Using standard drill coring bits, a 3½ -inch diameter hole was drilled using compressed air to cool the drill head and remove the cuttings. This method was successful at temperatures up to 850°C. An air and water coolant mixture was needed to effectively cool the standard drilling equipment at temperatures above this level. In the case of the Iki lava lake, 850°C was reached at a depth of 12 ft. On July 25, 1960, the crust was pierced 19.1 ft below the surface, making it possible to take temperature measurements in the molten lava and collect samples of the melt and gases (Figure 3.7-5).

The drilling program confirmed that conventional core drilling equipment and methods were acceptable as long as a water injection coolant system was employed at high (>850°C) temperatures (Figure 3.7-6). The successful experiment also demonstrated that field tests of various power generation schemes were possible. Based on the Project Iki results, scientists proposed three possible methods of power recovery from the lava pools. The first method, called the "water-tube boiler," involved drilling a lattice of cased holes through the crust or rock into a lava pool or magma chamber (Figure 3.7-7). Water pumped downward through the smaller internal conduit of a coaxial pipe would be heated by conduction through the outer pipe wall. The resulting hot fluid and steam would be extracted from the exterior chamber of the coaxial pipe to power a turbine. The second energy recovery process, "the bubbler technique," involved introducing air below the crust of a lava pool creating a steam collection chamber. Water rapidly injected into the bottom of the pool via a large pipe would bubble up through the molten lava creating superheated steam that would collect in the chamber, which would be tapped to drive a turbine. The final approach required the formation of a thin horizontal cavity over the entire top of the pool just under the crust. Referred to as the "pancake technique," this concept required the slow injection of water through a central pipe into the viscous layer adjacent to the crust. The resulting steam, trapped in the "pancake-like" chamber, would be extracted from its periphery through a network of pipes leading to a turbine.

The scientists concluded that power recovery was technically feasible although current (i.e., c.1960) technology made it cost prohibitive. Yet they believed that the tremendous energy potential of molten rock and lava warranted further investigation. If an economically viable method of power generation could be developed, exploitation of just the Kilauea Iki lava pool would have tripled Hawaii's power production for at least ten years.

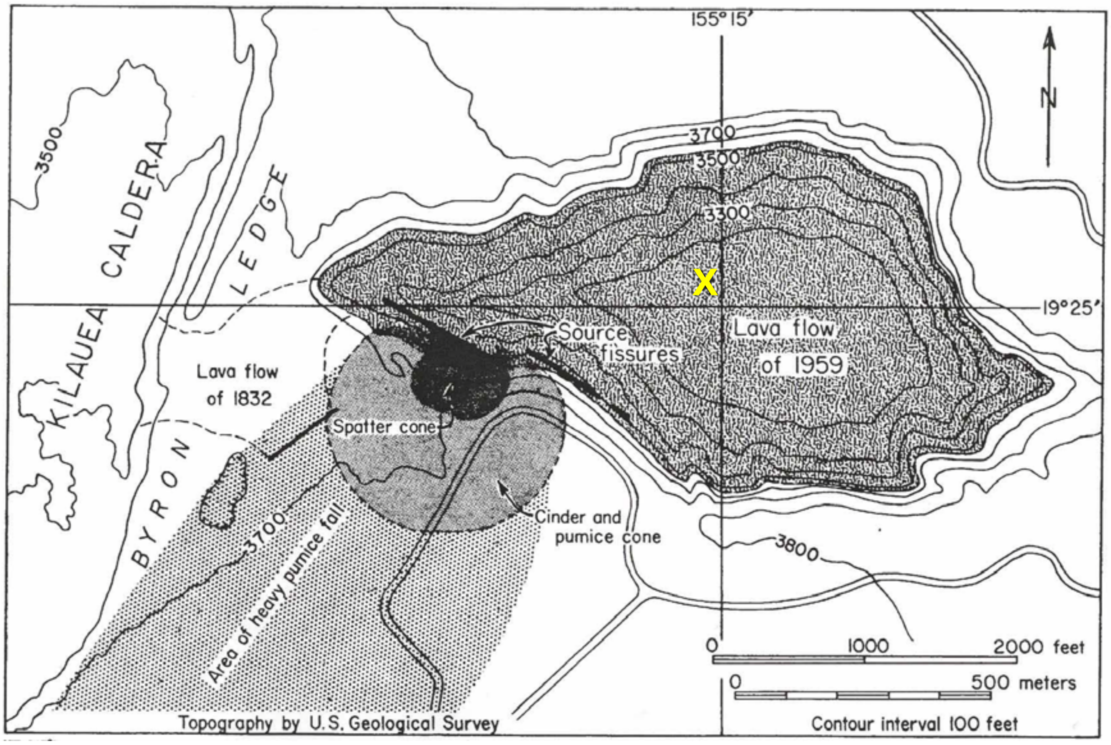


Figure 3.7-3. Kilauea Iki Lava Lake. Drilling location marked by the yellow **X** (adapted from Rawson and Bennett 1961, Figure 2).

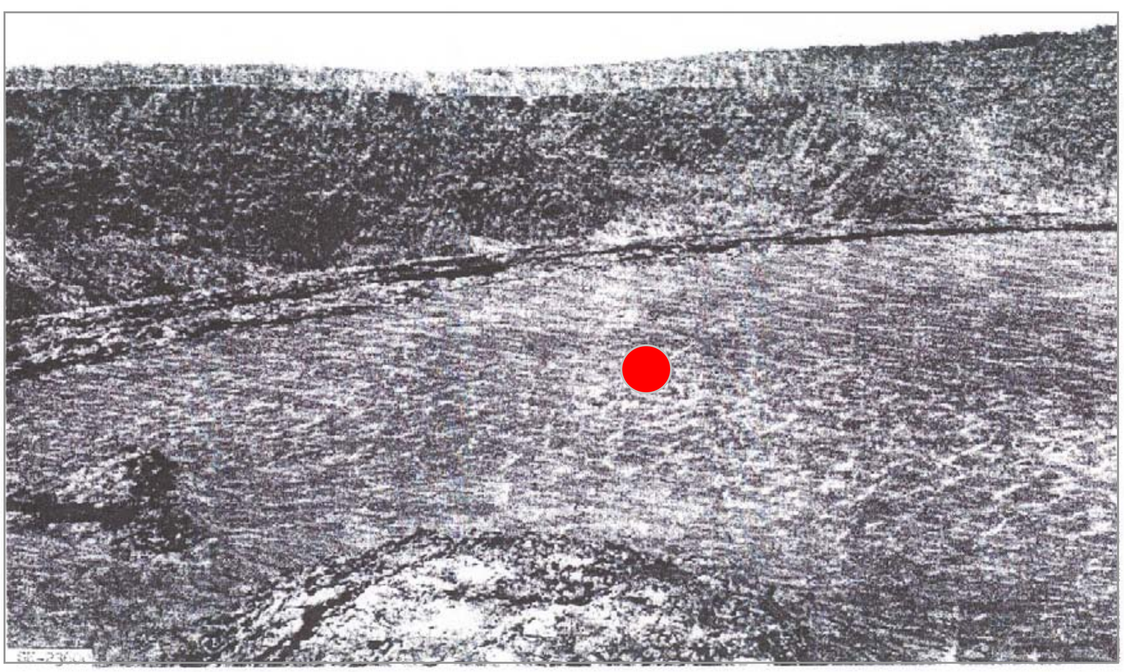


Figure 3.7-4. Kilauea Iki Lava Lake shortly after the 1959 eruption. Red dot marks the future drilling location (adapted from Rawson and Bennett 1961, Figure 3).

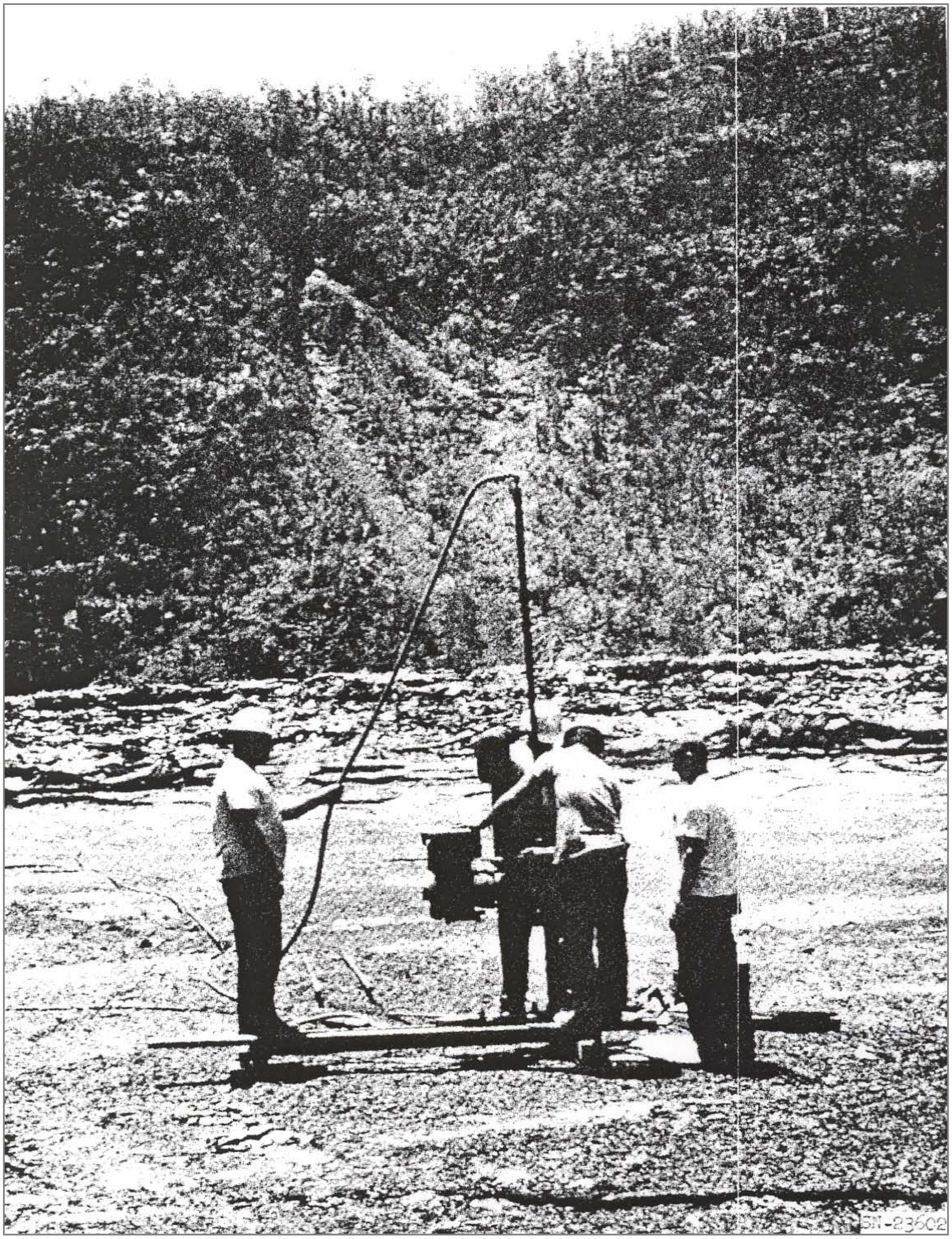


Figure 3.7-5. Drill rig and crew working on the crater floor after the Kilauea Iki Lava Lake had cooled enough to form a crust (Rawson and Bennett 1961, Figure 4).

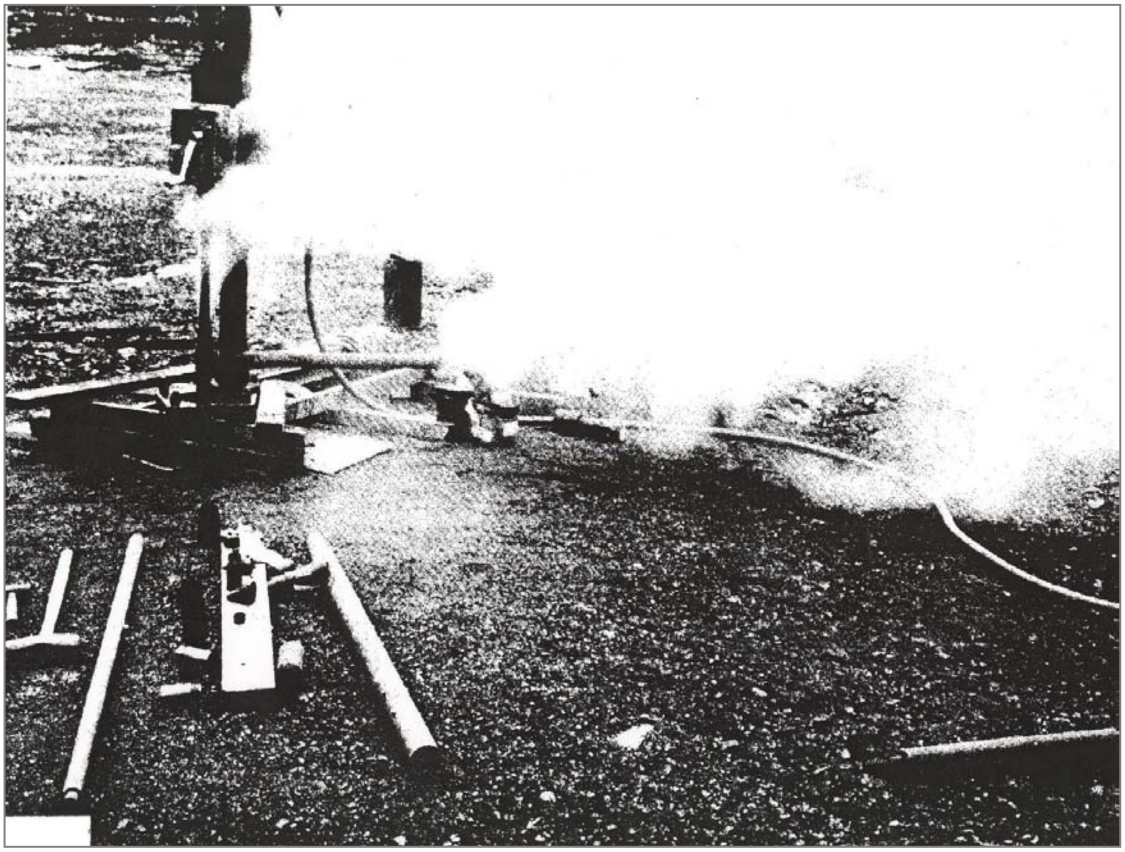


Figure 3.7-6. Steam from cooling system (Rawson and Bennett 1961, Figure 5).

Interest in directly tapping the geothermal potential of magma chambers and lava pools continued into the 1970s and 1980s, but the idea of using nuclear explosives to create underground magma chambers or craters to trap surface lava flows into usable thermal reservoirs disappeared. The post-1965 literature focuses on naturally occurring molten rock sources as potential geothermal energy reserves.

Project Iki was a Level 3 activity. Fieldwork was limited to drilling a well and setting up support and sampling equipment. The project site was visited in FY2003.

FIELD VISIT

On June 10-11, 2003, the Desert Research Institute scientists visited the Project Iki area at Hawai'i Volcanoes National Park in the southeastern part of the Island of Hawaii. The land is under the jurisdiction of the National Park Service. Access to the park is from Highway 11. The most direct route to Iki Crater is through the park entrance station that leads to the Kilauea Visitor Center. Between the entrance station and the Visitor Center, turn left on Crater Rim Drive, the road that encircles the Kilauea Caldera. Travel approximately 2.5 miles to the Kilauea Iki Overlook. Upon arrival, on the afternoon of

June 10th, mist enveloped the crater and, on the morning of June 11th, there was less mist but photography was difficult and it was not possible to access the crater floor (Figure 3.7-8). As per the National Park Service requirements, the winch and cable system, the portable rig, and the air compressor and attached hose were removed after drilling the 3-½ inch hole, and today there is no evidence of the 1960 drilling operation.

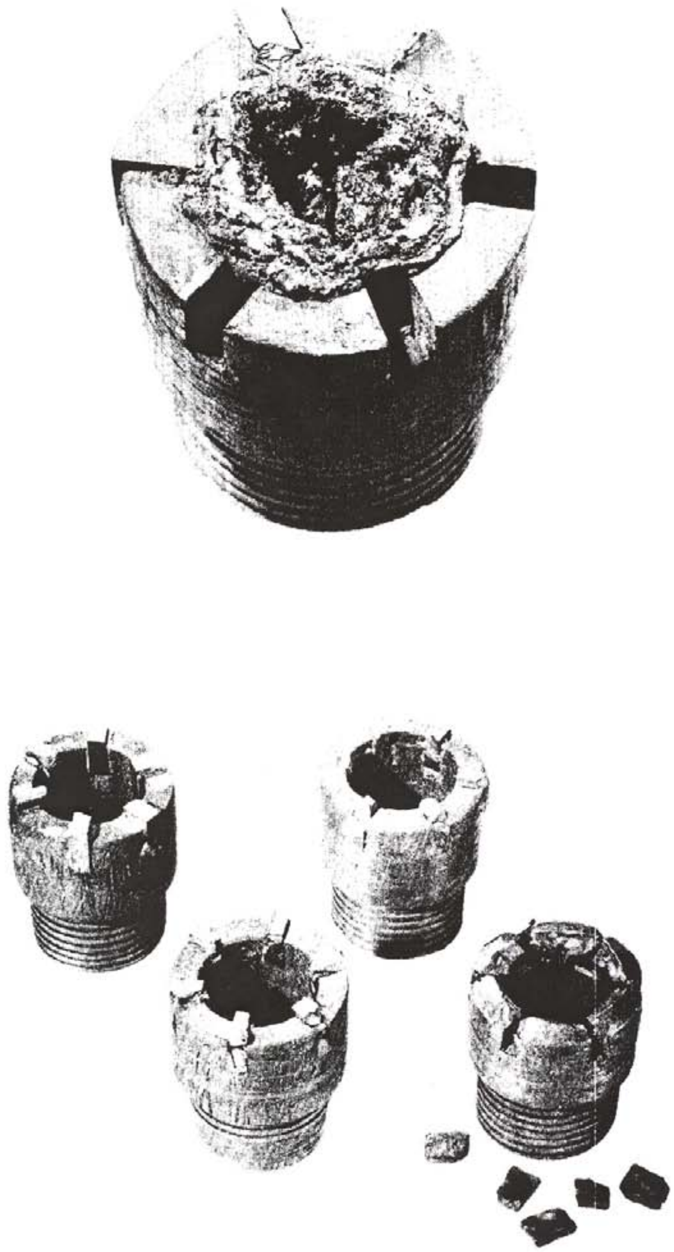


Figure 3.7-7. Expended drill bits from the Iki experiment. Top bit contains a cooled sample of molten lava (Rawson and Bennett 1961, Figures 6 and 7).

Figure 3.7-8. Overview of Kilauea Iki Crater. Steam rises from cracks in the crust over the lava pool (photo taken June 11, 2003 on file at Desert Research Institute).

The National Park Service maintains administrative responsibility for the land within the boundaries of the Hawai'i Volcanoes National Park and has had this charge since the Park's inception. The temporary special use application the U.S. Atomic Energy Commission filed with the Park Service expired shortly after Project Iki was completed.

CHRONOLOGICAL BIBLIOGRAPHY

Blue, C. L., 1960. "K Division Core Drilling - Hawaii." Memo from C. L. Blue, Lawrence Radiation Laboratory, to Distribution, February 29. On file at: Lawrence Berkeley National Laboratory, Berkeley, CA, File 434-900157, 7/18.

Blue, C. L., 1960. Letter from C. L. Blue, Lawrence Radiation Laboratory, to Paul Spain, March 24. On file at: Lawrence Berkeley National Laboratory, Berkeley, CA, File 434-900157, 7/18.

Craddick, E. C., 1960. Letter from E. C. Craddick, Pacific Drilling Company, Honolulu, HI, to C. L. Blue, June 13. On file at: Lawrence Berkeley National Laboratory, Berkeley, CA, File 434-900157, 7/18.

Whiton, Nat, 1960. Letter from Nat Whiton, Drilling Contractor, Honolulu, HI, to C. L. Blue, June 13. On file at: Lawrence Berkeley National Laboratory, Berkeley, CA, File 434-900157, 7/18.

Blue, C. L., 1960. "University of Hawaii - P.O. 6731307." Memo with encl. ("Appendix A to Purchase Order No. 6731307") from C. L. Blue, Lawrence Radiation Laboratory, to D. A. Bruce. On file at: Lawrence Berkeley National Laboratory, Berkeley, CA, File 434-900157, 7/18.

Blue, C. L., 1960. "Nat Whiton, Drilling Contractor, Honolulu, Hawaii." Memo from C. L. Blue, Lawrence Radiation Laboratory, to D. A. Bruce, June 21. On file at: Lawrence Berkeley National Laboratory, Berkeley, CA, File 434-900157, 7/18.

Lawrence Radiation Laboratory, 1960. "Purchase Order Agreement 6731407, N at Whiton, Honolulu, HI." Letter from Lawrence Radiation Laboratory to E. C. Shute, August 3. On file at: Lawrence Berkeley National Laboratory, Berkeley, CA, File 434-900157, 7/18.

Plowshare Advisory Committee, 1960. Plowshare Advisory Committee Meeting. LRL Statements for 4th Plowshare Advisory Committee Meeting, Albuquerque New Mexico, October 19 and 20, 1960. Report, October 20. On file at Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Rawson, D. E., 1960. Drilling into Molten Lava in the Kilauea Iki Volcanic Crater, Hawaii. *Nature,* Vol. 188, pp. 930-931, December 10.

Kennedy, G. C. and D. T. Griggs, 1960. Power Recovery fro the Kilaueau Iki Lava Pool. Report No. RM-2696-AEC, Rand Research Corporation, Santa Monica, CA, December 12. On file at: Technical Reports Library, Lawrence Livermore National Laboratory, Livermore, CA.

Rawson, Donald. E., and Walter. P. Bennett, 1961. Results and Power Generation Implications from Drilling into the Kilauea Iki Lava Lake, Hawaii. University of California, Lawrence Radiation Laboratory, *Report UCRL*-6374, March 24. Livermore, CA.

Teller, Edward, 1963. Plowshare. University of California, Lawrence Radiation Laboratory *Report UCRL*-7222, February 4. Livermore, CA. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029.

Furumoto, A .S., 1976. A Coordinated Exploration Program for Geothermal Sources on the Island of Hawaii. In Proceedings from United Nations Symposium on the Development and Use of Geothermal Resources, Second Meeting, Vol. 2, pp. 99 3-1001, May 1975. San Francisco, CA.

Hawaii Geothermal Project, 1976. Hawaii Geothermal Project Well Completion Report, HGP-A. Kingston, Reynolds, Thom and Allardice, Ltd. Auckland, New Zealand.

Peck, Dallas L., Thomas L. Wright, and Robert W. Decker, 1979. The Lava Lakes of Kilauea. *Scientific American*, Vol. 241, pp.114-129.

Wolfe, E. W., and Jean Morris, 1996. Geological Map of the Island of Hawaii, 1:100,000. Geological Survey Investigations Series Map I-2524-A, U.S. Department of the Interior, U.S. Geological Survey, Washington D.C.

Hazlett, Richard W., 2002. *Geological Field Guide Kilauea Volcano*, Revised edition. Hawaii Natural History Association.

National Park Service, 2002. Hawai'i Volcanoes, Hawai'i Volcanoes National Park, Hawaii. Brochure GPO:2001-472/40148, Government Printing Office, U.S. Department of the Interior, National Park Service, Washington, D. C.

3.8 LIBBY

Plowshare Program
High Explosive Experiment for a Highway Cut
Montana

The U.S. Army Engineer Explosive Excavation Research Office conducted high explosive experiments to develop excavation techniques that were cost-competitive for civil works projects. The Libby project was one of these experiments. Specifically, the Libby project was a demonstration of the use of high explosives to produce side hill cuts with steep back slopes in high-strength rock. The project, located in northwestern Montana (Figure 3.8-1), was planned as part of the relocation of Montana State Highway Route 37 for the Libby Dam, a U.S. Army Corps of Engineers, North Pacific Division, Seattle District project. The proposed Libby Dam would inundate about 42 miles of the highway along the Kootenai River and thus, the plan was to relocate the highway to higher ground on the east side of the dam impoundment. The experimental high explosive excavation of a hill side slope in conjunction with the highway relocation was a project that focused on design and execution procedures that would reduce excavation costs for the highway relocation over conventional methods.

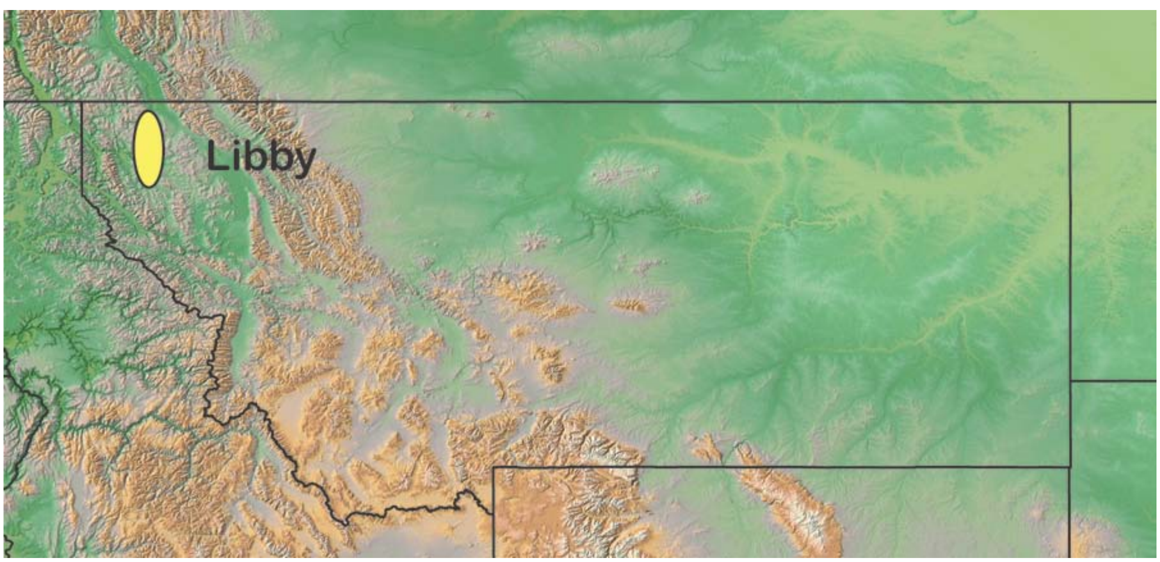


Figure 3.8-1. Location of Project Libby in northwestern Montana (adapted from USA Relief Maps 2004).

The design for the Libby project called for using high explosive charges with a depth of burst that would result in a configuration between cratering and mounding. In theory the explosion would displace a portion of the fractured rock out of the cut onto the downhill slope. Conventional equipment would be used to remove the remaining fractured rock in the cut to establish the specified road grade. One or two rows of small drill holes on the uphill slope were planned for detonation prior to the road cut operation to prevent damage to the slope. Controlled blasting with drill hole detonations would be necessary to provide a zone of weakness for the crater boundary to prevent up-thrust and fracturing along the uphill slope Controlled blasting was also planned for pre-splitting to produce a clean excavation side slope (Figure 3.8-2).

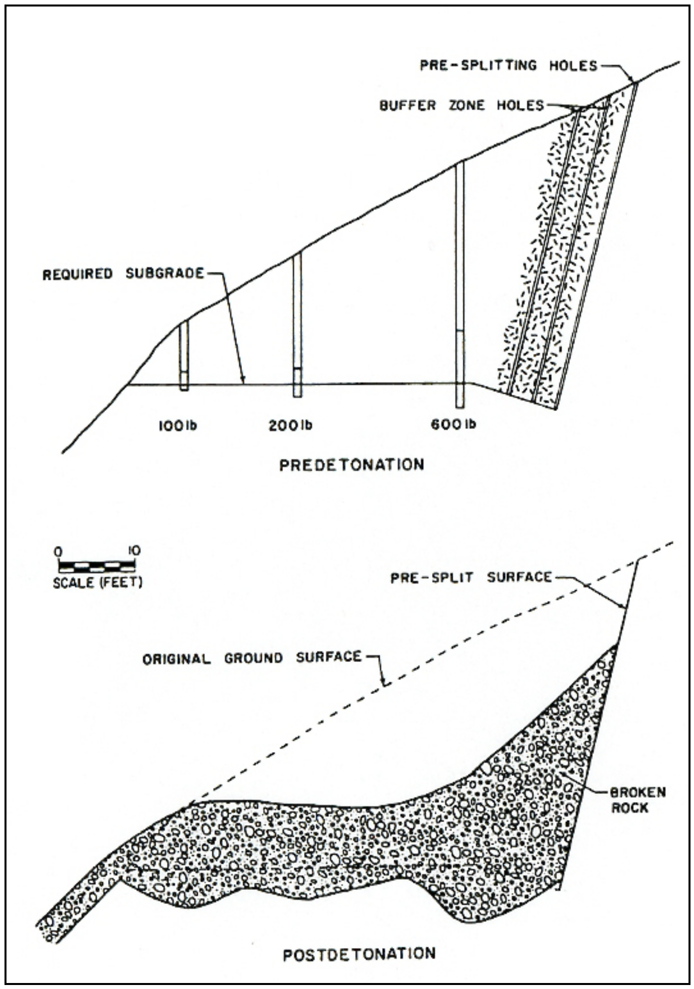


Figure 3.8-2. Schematic design for the Libby road cut experiment showing pre- and post-detonation cross sections (LaFrenz and Day 1972, Figure 8).

Status reports from the Explosive Excavation Research Office with effective dates from September 30, 1971 to September 30, 1972 provide an overview of Project Libby. These reports show that a project meeting was held with the U.S. Army Corps of Engineers, Seattle District during March 1971, and an award was made on a contract bid for the project on September 30, 197 1, By April 1972 construction of the highway was underway and emplacement and firing of the pre-splitting line had been completed. On

June 8, 1972 a 300 ft segment of the highway cut was accomplished following an explosive excavation design that was submitted to the Seattle District. Post detonation construction activities were planned once improved access had been established.

Today Montana State Highway 37 stretches for a distance of 42 miles along the eastern shore of the Libby Dam reservoir, named Lake Koocanusa, between Libby Dam and the town of Rexford (Figure 3.8-3). While there are a number of locations along the highway that required excavation of steep hill slopes for the highway relocation project, documentation detailing the precise location of the explosive experiment is not available, nor is documentation concerning the explosive excavation design, the results of the Libby experiment, or post-detonation construction activities. As of June 30, 1972 a listing and publication schedule suggests that a draft report on Project Libby was being prepared by J. E. Lattery from the Explosive Excavation Research Laboratory (Technical Report No. 42), but there is no record that either a final draft or final report of the project was ever

Figure 3.8-3. Map showing the stretch of Montana State Highway 34 between Libby Dam and Rexford (adapted from National Geographic Topographic Maps 2006).

completed. In 1978, the U.S. Army Corps of Engineers Seattle District issued a design memorandum for the relocation of the state highway that might provide a discussion of the explosive excavation, but this document has not been located.

Libby Dam is about 422 ft high and ½ mile long. The dam forms a reservoir, Lake Koocanusa, which backs water up 42 miles into Canada. Construction of the dam powerhouse began in May of 1972 and continued through 1985. Commercial power generation began in 1975. State Highway 37 runs along the east side of the reservoir and a forest development road was established on the west side. The dam is operated by the U.S. Army Corps of Engineers, Seattle District (Figure 3.8-4).

Project Libby was a Level 2 activity; high explosives were used in the excavation.

Figure 3.8-4. View northwest of the Libby Dam showing a forest development road on the west side and Montana State Highway 37 on the east side of Lake Koocanusa (U.S. Army Corps of Engineers, http://eportal.usace.army.mil/sites/DVL/default.aspx, last accessed February 2008).

CHRONOLOGICAL BIBLIOGRAPHY

Lawrence Radiation Laboratory. U.S. Army Engineer Nuclear Cratering Group, [1966]. Demonstration Project Summary. Manuscript. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-103 [OUO].

LaFrenz, Robert L., 1971. "Status Report - Rapid Excavation with Explosives." Letter with encl. ("Status Report, Effective Date: 30 September 1971") from Robert L. LaFrenz, Explosive Excavation Research Office, Corps of Engineers, to Director, U.S. Army Engineer Waterways Experiment Station, October 29. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-108.

LaFrenz, Robert L., 1972. "Status Report - Rapid Excavation with Explosives." Letter with encl. ("Status Report, Effective Date: 31 March 1972") from Robert L. LaFrenz, Explosive Excavation Research Office, Corps of Engineers, to Director, U.S. Army Engineer Waterways Experiment Station, April 10. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-108.

LaFrenze, Robert L., and Walter C. Day, 1972. Explosive Excavation Development for Construction and Combat Applications. U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Office, AD750344. Livermore, CA.

LaFrenze, Robert L., and Walter C. Day, 1972. Explosive Excavation Research: Projects Tugboat and Trinidad. *Nuclear Technology,* Vol. 15, pp. 75-84, July.

Mills, Robert R., Jr., 1972. "Status Report - Rapid Excavation with Explosives." Letter with encl. ("Status Report, Effective Date: 30 June 1972") from Robert R. Mills, Jr., U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Laboratory, Corps of Engineers, to Director, U.S. Army Engineers Waterways Experiment Station, July 28. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-108.

Mills, Robert R., Jr., 1972. "Status Report - Rapid Excavation with Explosives." Letter with encl. ("Status Report, Effective Date: 30 September 1972") from Robert R. Mills, Jr., U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Laboratory, Corps of Engineers, to Director, U.S. Army Engineer Waterways Experiment Station, October 10. On file at Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-108.

U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Laboratory, 1972. "Listing and Publication Schedule of EERL Reports." Schedule from Explosive Excavation Research Laboratory, Livermore, CA, June 30. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-108.

U.S. Army Corps of Engineers. Seattle District, 1978. Libby Additional Units and Reregulating Dam Project, Kootenai River, Montana; Design Memorandum No.8, Montana State Highway 37 and Forest Development Road 92.7 Relocation (document not available).

THIS PAGE INTENTIONALLY LEFT BLANK

3.9 LOST CREEK

Plowshare Program
High Explosive Experimental Mounding and Controlled Blasting Series
Oregon

Project Lost Creek was a blasting experiment by the Explosive Excavation Research Laboratory (successor to the Nuclear Cratering Group) of the U.S. Army Engineer Waterways Experiment Station. In September 1971, the Planning and Research Division of the Laboratory presented a proposal to the U.S. Army Corps of Engineers, Portland District to perform a mounding experiment and controlled blasting series at a rock quarry for the Lost Creek Dam in southwestern Oregon (Figure 3.9-1). The Portland District agreed and a planning meeting and site visit were scheduled for October.

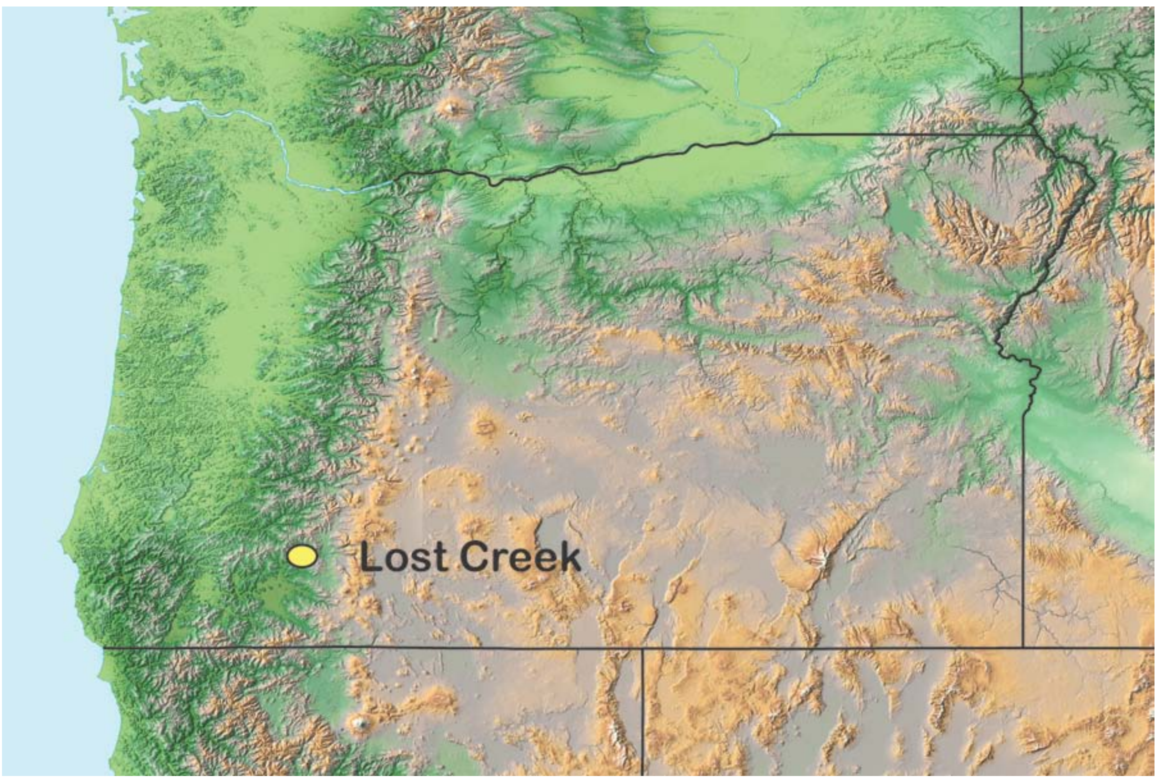


Figure 3.9-1. Location of Project Lost Creek in Oregon (adapted from USA Relief Maps 2004).

The Lost Creek dam was planned as part of the Rogue River flood control project for Jackson County, northwest of Medford, Oregon. The quarry site for the dam and the site for the experimental blast series were located on the top of a ridge east of the dam in Sec. 35, T33S R1E (Figure 3.9-2). According to the Explosive Excavation Research Laboratory the goal of the experimental detonations was to obtain data to produce more effective blasting and quarrying techniques, while producing usable rock for construction of the embankment for the dam. One main focus was to investigate the concept of mounding using concentrated charges. Mounding is a phenomenon where fractured rock from a controlled blast is induced upward from the ground surface. Mounding can be contrasted to cratering where rock breakage is induced downward. The occurrence of mounding versus cratering is controlled by the depth at which explosive charges are placed (Figure 3.9-3). Another focus of the project was to investigate the use of controlled blasting with concentrated charges. In all, five specific technical objectives were outlined for the Lost Creek Project, these were:

1) developing design criteria for mounding detonations in hard rock;
2) comparison of fragment sizes from mounding explosions in a strong, moderately fractured rock with those produced by conventional quarrying operations;
3) comparison of three blasting agents by the attributes of crater dimension and degree of rock fragmentation;
4) to test the effectiveness of controlled blasting techniques in preventing overbreak (fractures and planes of weakness created in the rock mass adjacent to the blast block), improving side slope control, and in reducing blast-induced stress wave damage beyond the excavation zone; and
5) evaluation of the suitability of relatively large but compact explosive charges for production of rock fill.

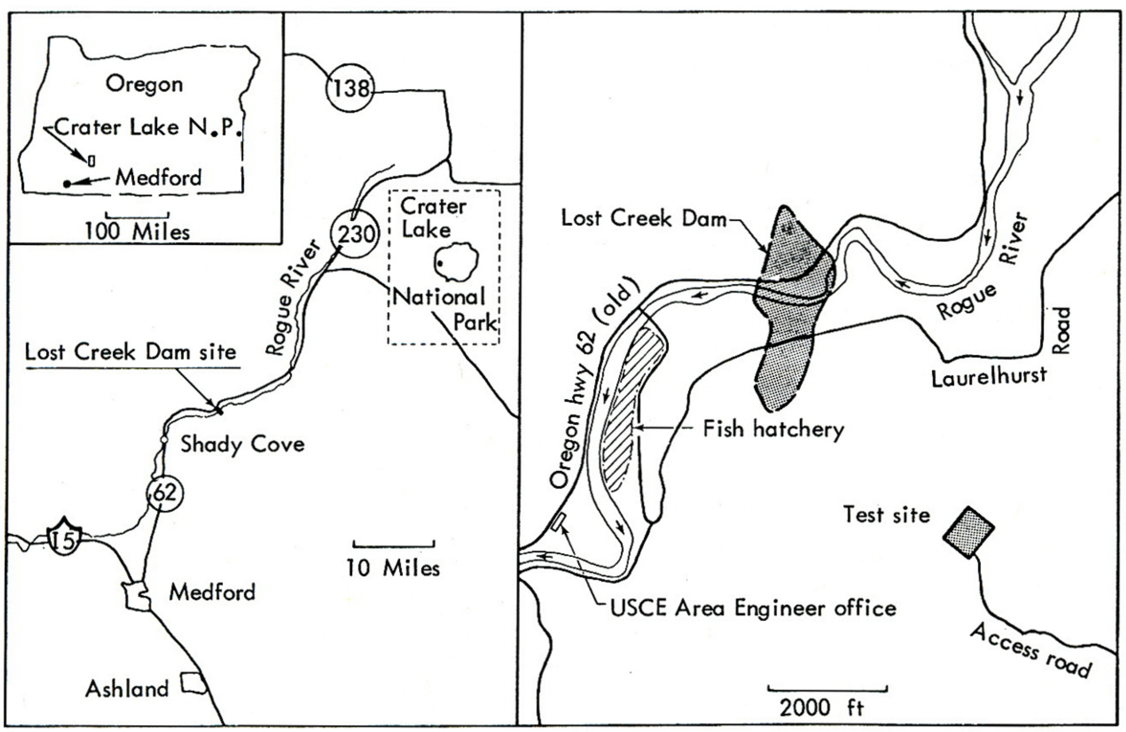


Figure 3.9-2. Location of Project Lost Creek high explosive experimental test site (McAneny 1975, Figure 1).

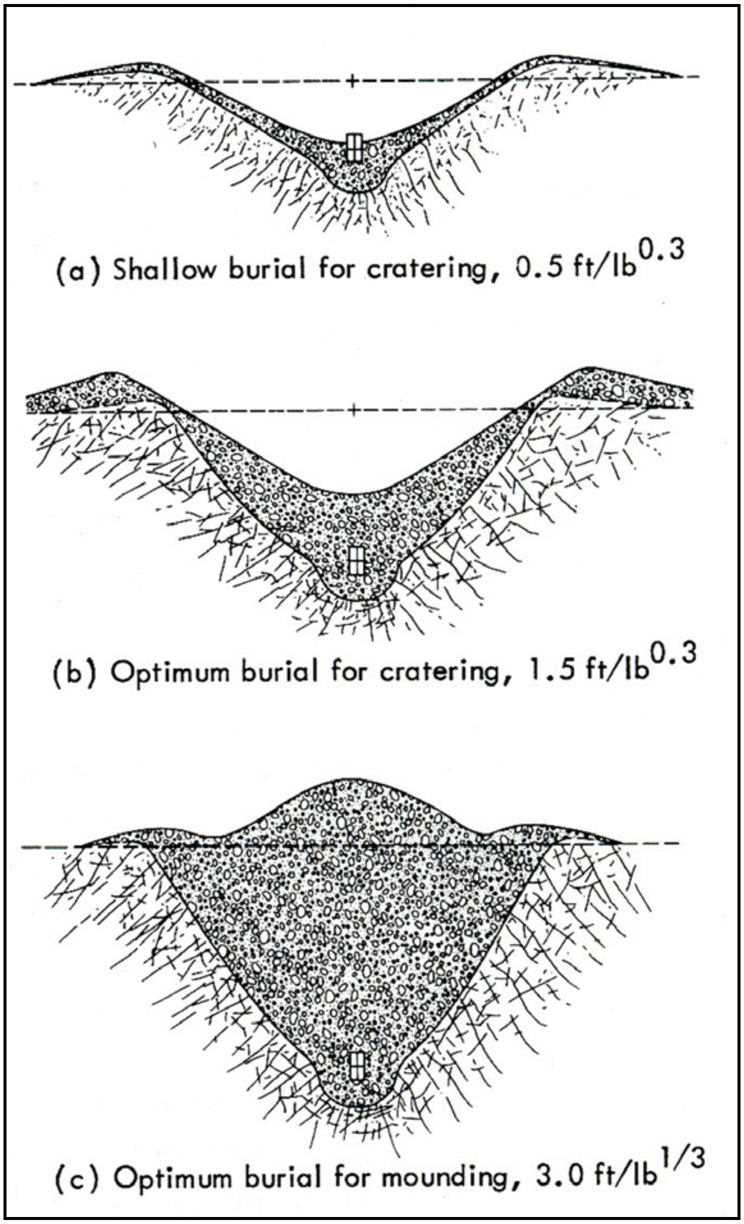


Figure 3.9-3. Illustration of the relationship between cratering and mounding as a function of depth of burst (McAneny 1975, Figure 3).

The explosive tests were designed and conducted by personnel from the Explosive Excavation Research Laboratory with the aid of various agencies within the U.S. Army Corps of Engineers (Figure 3.9-4). A contractor through the Portland District provided all the explosives and prepared the quarry area, including drilling and excavation. The 41 high explosive events, consisting of single and row charge experiments, were in a basaltic andesite rock, and were conducted in May and June 1972. The tests were categorized into four main experimental series according to the variables of spacing (VS), constant spacing (CS), multiple lift (ML), and in-house laboratory independent research (ILIR) (Figure 3.9-5). The VS test series investigated the mounding effects of different explosives and effects of varying spaces between charges. The CS series tested the effect of simultaneous and delayed equal-spaced charges. The ML test consisted of two different explosions of controlled mounding charge. The ILIR test series measured the ability of controlled blasting panels. Several supplemental blasting experiments were also carried out and given ILIR series designations, although not part of the original ILIR concept. Six seismic stations were placed in the area to record the blast waves.

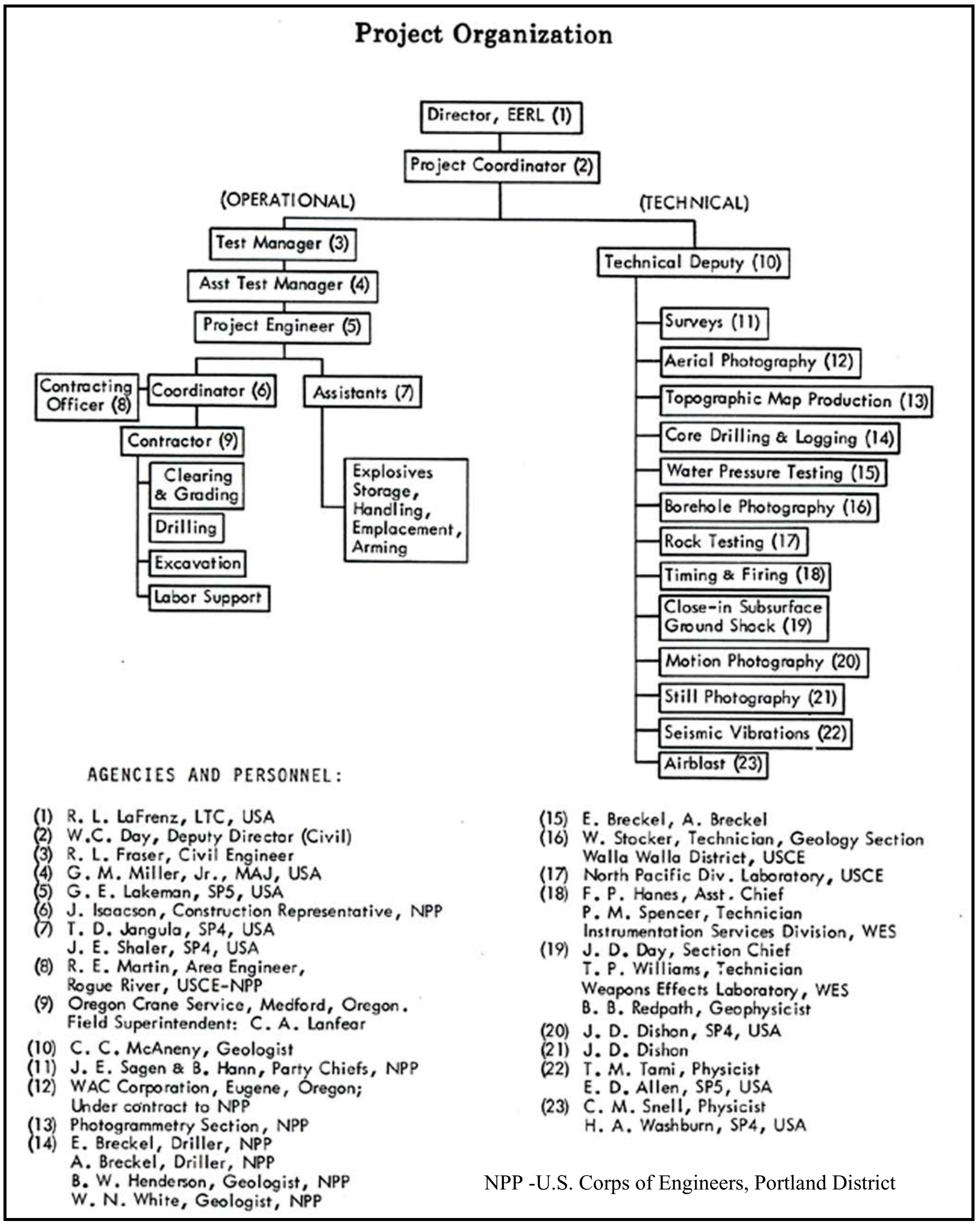


Figure 3.9-4. Organization Chart for Lost Creek project (from McAneny 1975, Figure A-1).

Three different bulk explosives, two slurry explosives and ammonium nitrate fuel oil, and several cartridge explosives were used during the tests. Ten-inch holes were used for emplacement of mounding charges, and 6-inch holes were drilled to emplace particle velocity gauges. Small diameter blast holes were drilled for presplit and buffer-zone panels to control the configuration of the side slopes, and in one case to probe through overburden, and to determine bedrock depths. After the project was completed the site was used as a quarry for the Lost Creek Dam, and there was likely considerable additional ground disturbance. However, there is no documentation to clarify how quarrying activities for the dam overlapped with the area used for the Lost Creek Project blasting experiments.

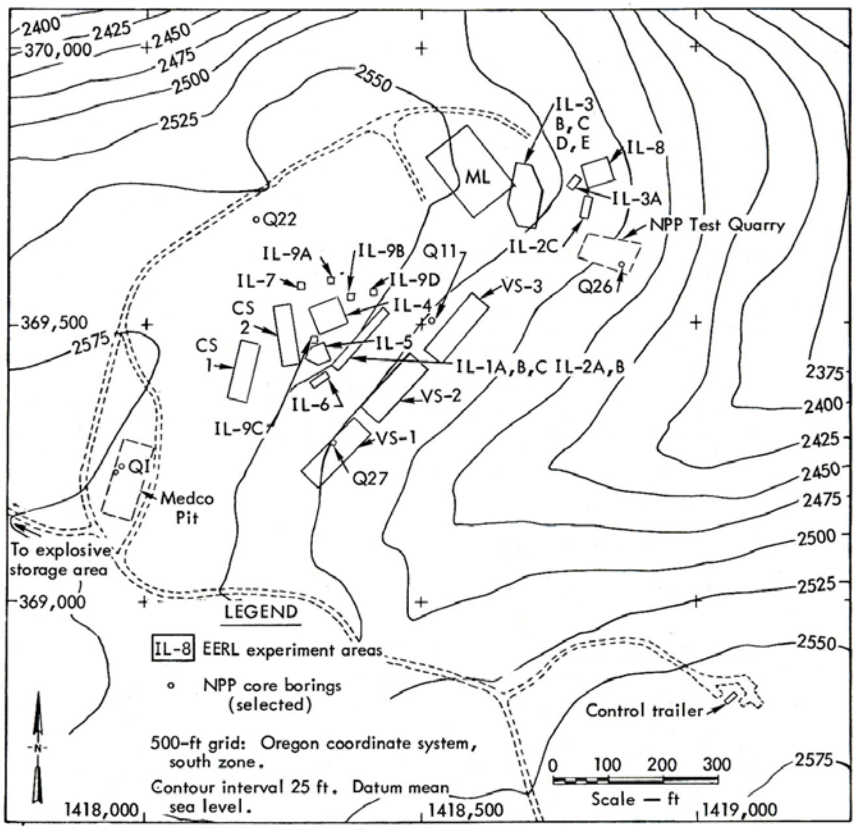


Figure 3.9-5. Site map of Project Lost Creek showing the location of experimental series of high explosive tests (McAneny 1975, Figure 2).

Construction of the Lost Creek Dam, a rock-fill structure with a gated spillway, began in 1972 and was completed in 1977. In 1996, the dam was renamed the William L. Jess Dam and is currently operated by the U.S. Army Corps of Engineers (Figure 3.9-6). The quarry was within the original Lost Creek Project boundaries and may be part of a land withdrawal by the U.S. Army Crops of Engineers, Portland District.

The Lost Creek Project was a Level 2 activity-high explosive tests were conducted in the quarry area for the dam. Additional documentation is needed to clarify the spatial relationship between the Lost Creek Project area and quarrying activities that were conducted during construction of the dam.

Figure 3.9-6. Photograph of the William L. Jess Dam, formerly the Lost Creek Dam, showing location of quarry area (adapted from U.S. Army Corps of Engineers. Portland District 2004).

CHRONOLOGICAL BIBLIOGRAPHY

LaFrenz, Robert L., 1971. "Status Report - Rapid Excavation with Explosives." Letter with encl. ("Status Report, Effective Date: 30 S eptember 1971") from Robert L. LaFrenz, Explosive Excavation Research Office, Corps of Engineers, to Director, U.S. Army Engineer Waterways Experiment Station, October 29. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-108.

LaFrenz, Robert L., 1972. "Status Report - Rapid Excavation with Explosives." Letter with encl. ("Status Report, Effective Date: 31 March 1972") from Robert L. LaFrenz, Explosive Excavation Research Office, Corps of Engineers, to Director, U.S. Army Engineer Waterways Experiment Station, April 10. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-108.

U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Laboratory, 1972. "Listing and Publication Schedule of EERL Reports." Schedule from Explosive Excavation Research Laboratory, Livermore, CA, June 30. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-108.

Mills, Robert R., Jr., 1972. "Status Report - Rapid Excavation with Explosives." Letter with encl. ("Status Report, Effective Date: 30 June 1972") from Robert R. Mills, Jr., U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Laboratory, Corps of Engineers, to Director, U.S. Army Engineers Waterways Experiment Station, July 28. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-108.

Mills, Robert R., Jr., 1972. "Status Report - Rapid Excavation with Explosives." Letter with encl. ("Status Report, Effective Date: 30 S eptember 1972") from Robert R. Mills, Jr., U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Laboratory, Corps of Engineers, to Director, U.S. Army Engineer Waterways Experiment Station, October 10. On file at Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-108.

McAneny, Colin, C., 1975. Project Lost Creek: Field Tests of Mounding and Controlled Blasting. U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Laboratory, Technical Report No. E-75-1, January. On file at: Technical Reports Library, Lawrence Livermore National Laboratory, Livermore, CA.

U.S. Army Corps of Engineers. Portland District, 2004. Rogue River Basin Projects. U.S. Army Corps of Engineers, Portland District. <http://www.nwp.usace.army.mil/op/R/projects.html>, last accessed on August 24, 2004.

THIS PAGE INTENTIONALLY LEFT BLANK

3.10 OPERATION BREAKUP

Plowshare Program
High Explosive Ice Cratering Experiment
Alaska

During the winter of 1966, the U.S. Army Engineer Nuclear Cratering Group in coordination with Lawrence Radiation Laboratory conducted a series of single and row charge chemical detonations in ice named Operation Breakup. The objective of Operation Breakup was to determine the capability of explosives to crater ice sheets and to study the physics and techniques of cratering ice sheets with row charges. The experiment was designed to support theoretical studies and supply data useful for civil applications.

Operation Breakup is described in a Nuclear Cratering Group Technical Memorandum that was completed in November 1966. The specific goals of the project were: 1) to determine the cratering effects of single and row charges detonated below an ice layer, 2) to study bubble coalescence, and 3) to support theoretical studies of cratering physics for both conventional and nuclear explosives. The high explosive tests were conducted at Blair Lakes, 33 miles southeast of Fairbanks, Alaska (Figure 3.10-1). Blair Lakes includes three lakes, and the largest, centrally located lake was selected for the study (Figure 3.10-2). This lake is approximately one mile in diameter, with depths reaching 40 to 52 ft over an area 2,500 by 2,300 ft. During the winter months ice cover varies in thickness from 30 to 36 in. Blair Lakes was selected for the high explosive study because it had a number of favorable attributes. First, the lakes froze in the winter with sufficient ice thickness for the ice cratering experiments. Second, the location, on a military bombing and gunnery range, provided the isolation and access controls needed to conduct the project. Finally, the U.S. Army would be able to provide construction, operational, and logistical support.

Technical programs for Operation Breakup included crater measurements, ice surface motion measurements, and fish studies. Field activities for the project began in November 1965 with depth surveys of the lake. In late January and early February 1966, access roads to the lake were built, the field camp was set up, and the control point, camera shelters, and photo targets were constructed. The experiment was undertaken from February 17 to March 1, 1966. Several series of chemical detonations were executed to accomplish technical objectives of the program. These consisted of eight single-charge cratering calibration shots, seven bottom reflection single shots, one yield-scaling shot, and three row charges with each row containing five charges. The main explosive charges used in Operation Breakup were composition C4 at a yield of 136 lbs encased in an aluminum sphere. A 940 lb charge was used for the yield-scaling shot (Figures 3.10-3 and 3.10-4). An additional two shots were executed using two locally fabricated charges consisting of 160 lbs of ANFO and 150 lbs of TNT. The fabricated charge tests were conducted to provide comparative effects information. Emplacement holes for the explosive series were sawed or chipped into the ice, and the high explosive was placed into an aluminum sphere that was lowered through the hole in the ice to the desired depth. The hole was backfilled with the cut ice and snow for stemming and allowed to refreeze at least one day prior to detonation.

Figure 3.10-1. Location of Operation Breakup at Blair Lakes south of Fairbanks, Alaska (adapted from USA Relief Maps 2004).

The State of Alaska Department of Fish and Game undertook a study concurrent with Operation Breakup to assess the effects of under ice explosions on fish at Blair Lakes and included both fish indigenous to the lake and fish imported for the study. Cages and nets were used to contain and retrieve the fish during and after the detonation series.

On March 4, 1966, the field camp for Operation Breakup was demobilized and the final report was issued during November, 1966. According to the report, the high explosive ice experiments provided data on the phenomenology of ice cratering, and the high explosive series could be extrapolated to a nuclear explosive energy range. Possible civil engineering applications of ice cratering with explosives included clearing ice jams, maintaining open waterways in winter, and clearing ice over open water. Also, information on ice cratering physics could be used to support studies by the U.S. Army Corps of Engineers in connection with emergency operations.

Operation Breakup was a Level 2 activity. Conventional explosives were used in the lake to test the properties of ice cratering.

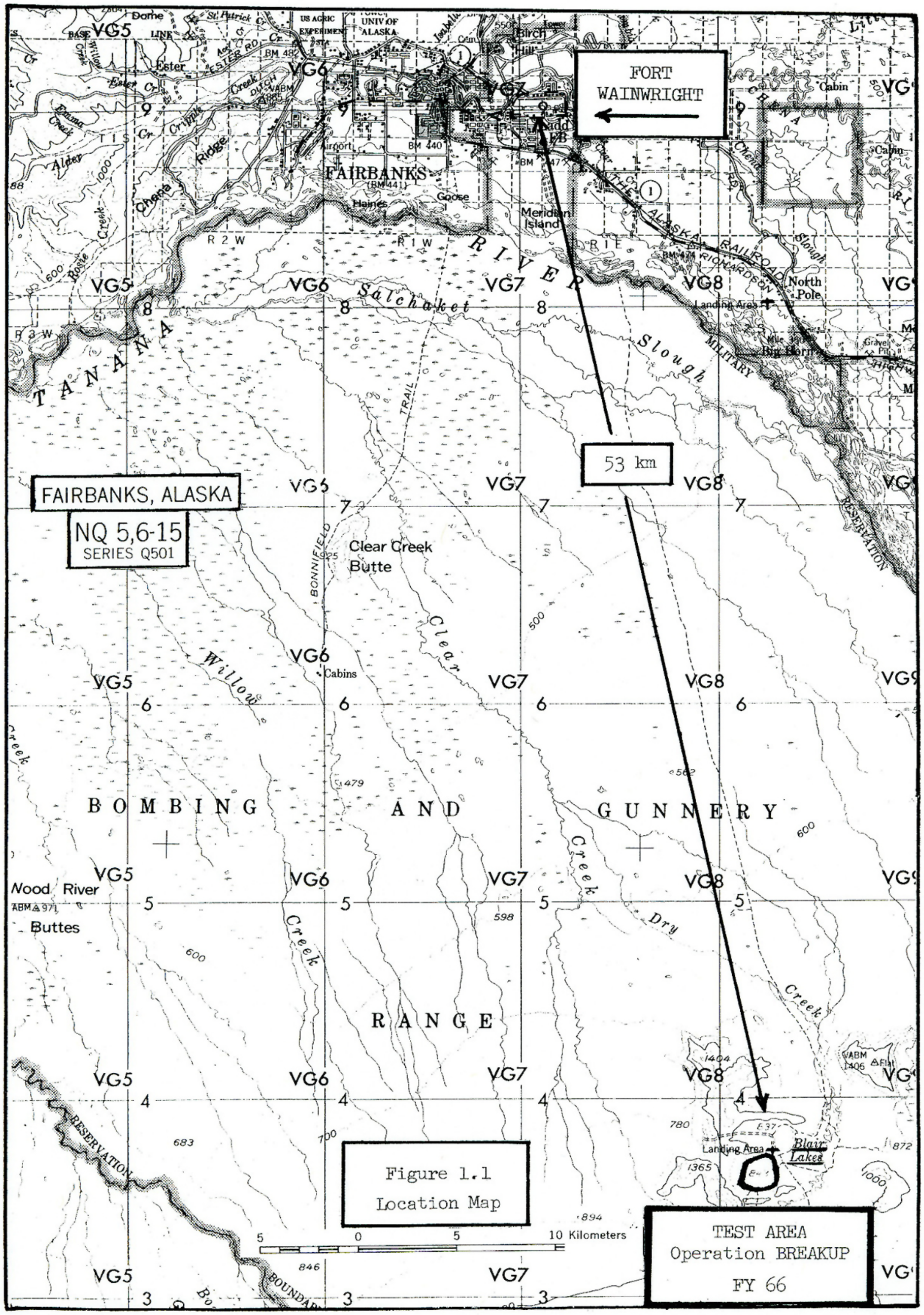


Figure 3.10-2. Map showing location of Operation Breakup at Blair Lakes (Kurtz 1966, Figure 1.1).

Figure 3.10-3. View of Operation Breakup yield scaling shot, Shot 31- a 940 pound charge was used (Kurtz 1966, Figure 4.11).

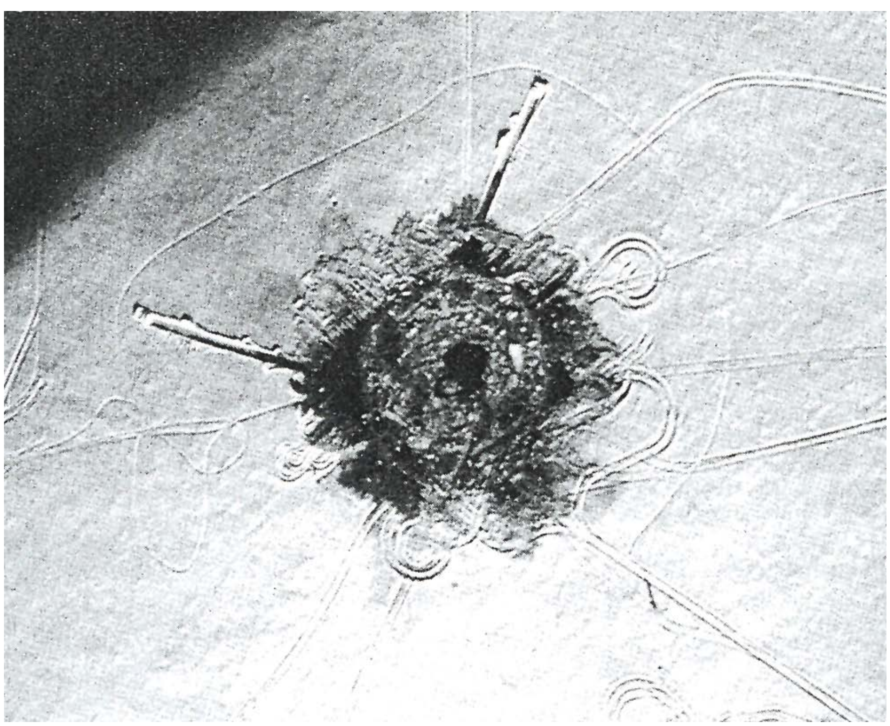


Figure 3.10-4. Operation Breakup yield scaling Shot 31 c rater viewed from above (Kurtz 1966, Figure 4.10).

CHRONOLOGICAL BIBLIOGRAPHY

Kurtz, Maurice K., 1966. Consolidated Report Operation Breakup, FY66, Ice Cratering Experiments, Blair Lake, Alaska. University of California, Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, *NCG Technical Memorandum* No. NCG/TM 66-7, November 25. Livermore, CA.

THIS PAGE INTENTIONALLY LEFT BLANK

3.11 PINOT

Plowshare Program
High Explosives for Oil Shale Stimulation Research
Colorado

Lawrence Radiation Laboratory proposed a high explosives test in oil shale in 1959 in order to obtain data on gas evolution and migration and related health and safety issues for nuclear detonations in this media. The experiment was designed to provide information on the extent to which gases from a confined underground explosion in oil shale would migrate along the bedding planes. It was expected that the pressure from the blast would force apart the layers and gas would move parallel to the bedding planes. While it was anticipated that this movement would be minimal, determining this information on the containment of explosive gases was important for designing future experiments using a nuclear explosive for oil shale stimulation and the recovery of petroleum products. The proposed project received approval and support from the U.S. Atomic Energy Commission. Lawrence Radiation Laboratory then requested the U.S. Bureau of Mines to identify an existing mine that met the research criteria. A potential mine was found near Rifle, Colorado, where a 25 to 50-ton high explosives experiment could be conducted. The U.S. Bureau of Mines presented this information in a report to Lawrence Radiation Laboratory in July 1959.

Originally, the purpose of the high explosive experiment was very broad. In addition to the gas migration and safety studies, the technical programs included were designed to 1) gather data on the effects of explosions on oil shale; 2) to correlate the seismic effect in shale to previous data from other media; and 3) to obtain data for a predictive model of the effects of a 10 kt nuclear detonation in oil shale - the planned Vintage experiment. First proposed in mid-1958, Vintage was an experiment to determine if contained underground nuclear detonations could release oil from Colorado-Utah type oil shale and make it available for mining or in situ retorting (see Chapter 5.85).

The U.S. Bureau of Mines submitted a preliminary research proposal for the Plowshare Program high explosive experiment at the Rifle Oil-Shale Mine in November 1959. Reflecting its association with the proposed Vintage nuclear experiment, the test was initially called the Pre-Vintage experiment and had an estimated cost of $1 million reflecting its ambitious suite of technical programs. However, uncertainty about the feasibility of the Vintage project and federal budget pressures led to a substantial revision of the test program. Lawrence Radiation Laboratory developed the detailed project concept for a scaled-back version of the high explosive test completing the task on February 16, 1960. The revised experiment was called “pre-Pre-Vintage” but its name officially changed to Project Pinot on March 29, 1960.

Project Pinot was located at the Anvil Points Experimental Oil Shale Station, a facility under the jurisdiction of the U.S. Navy, Office of the Naval Petroleum and Oil Shale Reserves (Figure 3.11-1). However, the experiment was in an existing mine controlled by

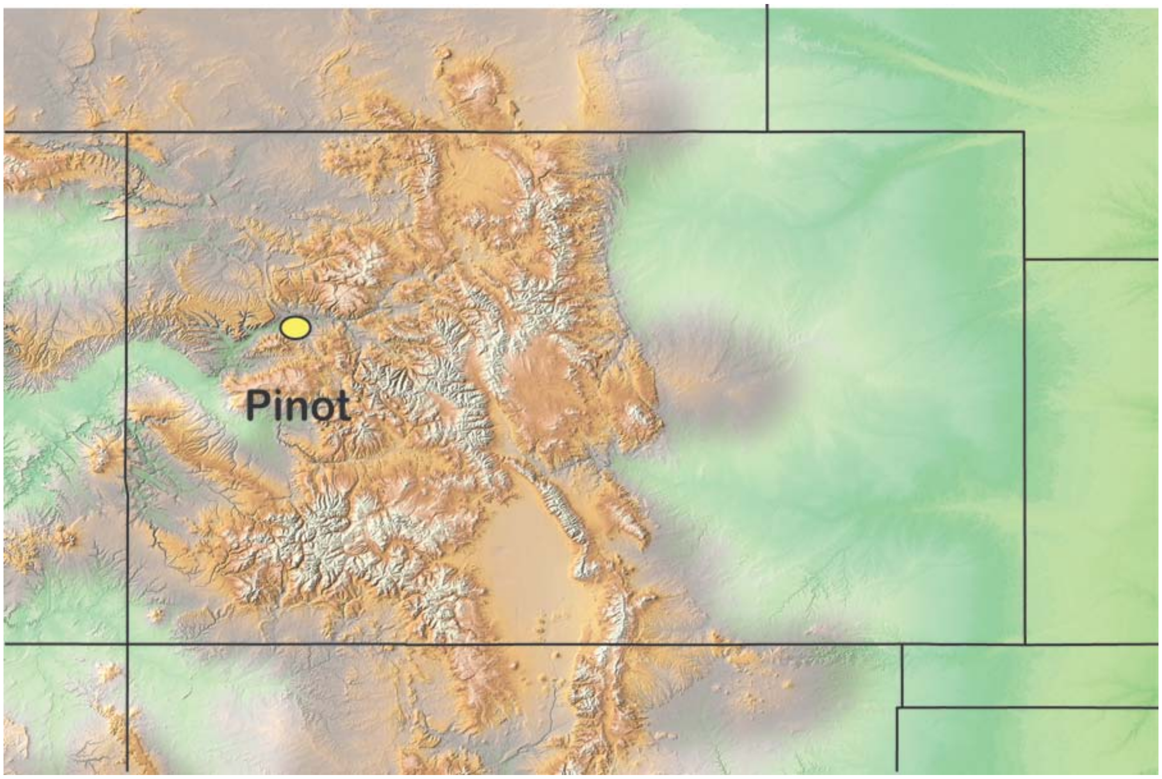


Figure 3.11-1. Location of Project Pinot in Colorado (adapted from USA Relief Maps 2004).

the U.S. Bureau of Mines. The mine was in the SW1/4, Sec. 12, T6S R95W about 2.5 miles from the Colorado River, 2 miles north of Highways 6 and 70 (Figure 3.11-2). This location was at the southern edge of the Piceance Creek Basin in Garfield County. The Mahogany Ledge, the richest oil shale bed of the Green River Formation, occurs about 500 ft below the top of the mesa overlooking the Grand Valley of the Colorado River.

At the request of the U.S. Atomic Energy Commission, Albuquerque Operations Office, Holmes & Narver began work on the operational plan for engineering, construction, and general project support. Work was initiated on the design after the criteria were received from Lawrence Radiation Laboratory on March 2, 1960. The report was completed in May 1960. The rapid schedule was possible because the preliminary field engineering data work had been done in November 1959 under authorization for Project Pre-Vintage. In addition, an expected budget reduction for FY 1961 increased the importance of conducting the project in FY 1960. This report provided the specific task plan for the Pinot experiment and formed the basis for developing a budget for their effort.

Because the project used an existing mine and associated facilities, construction for the experiment was limited to refurbishing and repairing the original structures such as the mine ventilation system and access road. Holmes & Narver, Inc. was responsible for all architectural and engineering requirements on the project, while mine safety and most of the logistical support services were provided by the U.S. Bureau of Mines. A local drilling company was retained to bore the emplacement and instrumentation holes for the

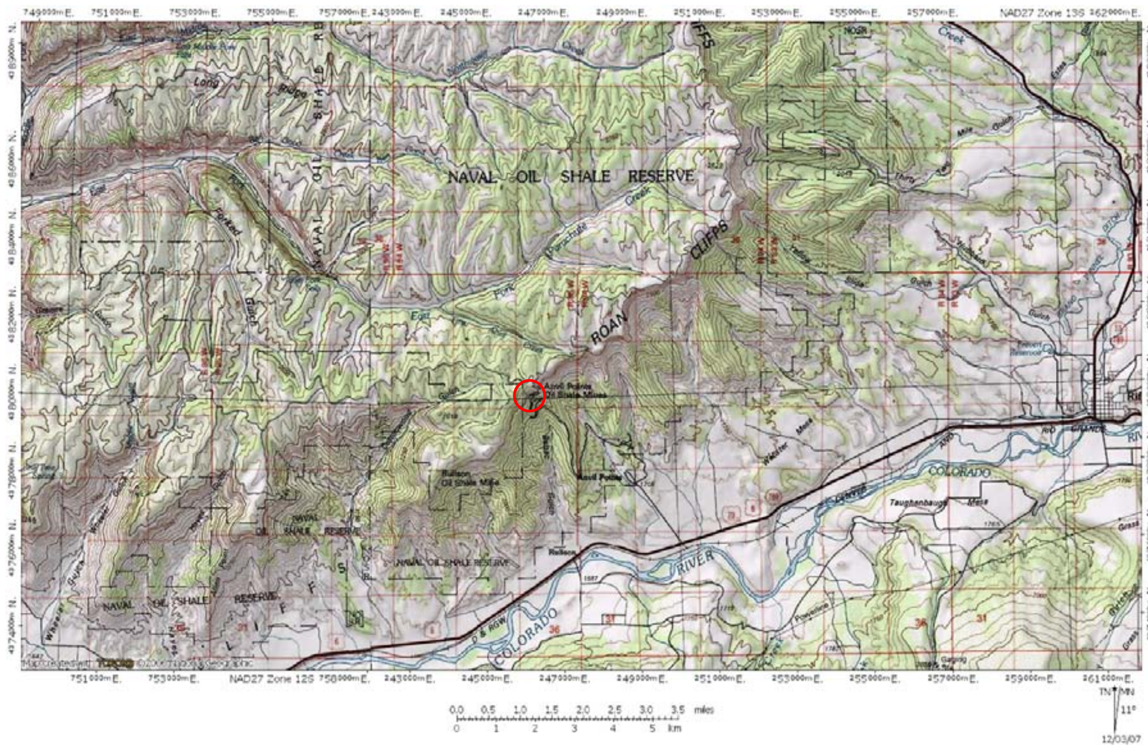


Figure 3.11-2. The Anvil Points Experimental Oil Shale Station was the site of Project Pinot (marked in red) conducted in August 1960 (adapted from National Geographic Topographic Maps 2006).

experiment. The U.S. Bureau of Mines provided office space for the project headquarters at its Anvil Points Camp located about 5 1/2 mi from the mine entrance. Camp facilities used by the project included the machine shop, warehouse space, the high explosives storage area, and some limited housing for personnel. All utilities – water, power, telephone, and trash disposal - were provided by the Bureau, as were office furniture and supplies, construction equipment, fire protection, plant security, a manned guard station, grounds maintenance, and maintenance of the mine access road. Prior to the detonation, the U.S. Atomic Energy Commission entered into an agreement with the U.S. Bureau of Mines to cover any damages to Bureau structures at the mine portal site. It is unknown if such damages occurred.

The San Francisco Operations Office received authorization to conduct Project Pinot on April 26, 1960, and the U.S. Atomic Energy Commission released a press announcement on the project on April 27, 1960. Public concerns were expressed regarding technical validity of the project and environmental issues. In early May, the U.S. Bureau of Mines in Denver completed a safety inspection of the mine and made a number of recommendations that would increase safety for workers and the experiment. Fieldwork on the project began the same month. The schedule called for the first detonation on June 25, 1960 and the second on July 4, 1960. Due to construction delays, the first shot was rescheduled for August 2, 1960 with the second shot slated for August 4, 1969. Mobil Oil

Company's research department in New Jersey expressed interest in the project and was approved to observe the detonations.

The Pinot design consisted of two chemical high explosive shots in vertical drill holes, one approximately 125 ft below the floor of the existing mine and the second at 115 ft. Both emplacement holes were in Adit #3 spaced about 220 ft apart (Figure 3.11-3). The detonations were planned for stemmed holes using liquid nitromethane as the explosive. The first shot was to be a 1,000-pound charge and the second, a larger 5,000-pound blast. Each test would require multiple sampling drill holes. Six pre-shot gas-sampling holes were drilled in an array from 20 to 125 ft from ground zero (Figure 3.11-4). Another sampling array for the second test was drilled at the same time. These holes were positioned from 185 to 345 ft from the Shot No. 2 detonation point. The explosive, consisting of 946 pounds of nitromethane and a small amount (about 1 curie) of Krypton 85, was set in a 20-inch diameter cavity at the bottom of a 10-inch diameter drill hole (Figure 3.11-5). Krypton 85 gas was selected because it was chemically inert and would not react with water or materials in the earth.

The test occurred in Shot Hole No. 1 at 0800 on August 2, 1960 with no visible damage to the mine adit or any associated structures. Reentry for sampling began two hours after zero time and samples were taken from all six holes within one half hour. Krypton 85 was found in each of the first array of sampling holes. Additionally, gas containing about 20 percent of the Krypton 85 tracer vented into the mine adit through a vertical joint near ground zero and a crack in the grout. Because the set of sampling holes for the 5,000-lb test was located in the same range as those drilled for the first shot, it was thought that these holes would also contain Krypton 85. Therefore, the second detonation was cancelled because this situation would preclude getting the needed qualitative data from the test.

Based on the results from this experiment, Lawrence Radiation Laboratory concluded that radioactive gases would not move preferentially in the direction parallel to the bedding planes, but would expand spherically from the shot point. In other words, the experiment showed that the original concerns that a nuclear explosion would distribute gas parallel to the oil shale bedding planes to be unfounded. Shortly before the first detonation, project personnel realized that the oil shale near the ground zero was not impermeable, but interconnected below the surface and it was not known if this type of structure is characteristic of oil shale. The Lawrence Radiation Laboratory recommended more experiments, including nuclear explosions in a variety of media, in order to better understand the movement of explosive gases in oil shale.

Although the Vintage experiment was effectively shelved by the end of 1960, interest in oil shale stimulation with nuclear explosives continued as evidenced by an inquiry to Lawrence Radiation Laboratory in January 1961 by a reporter with the Daily Rocket, a Rock Springs, Wyoming newspaper. The reporter was interested in the laboratory's Pinot test in the summer of 1960 using explosives to recover oil from oil shale because there were large deposits of oil shale in Sweetwater County, Wyoming that might be suitable for an experiment. Later Plowshare Program programs such as Bronco and Utah (see

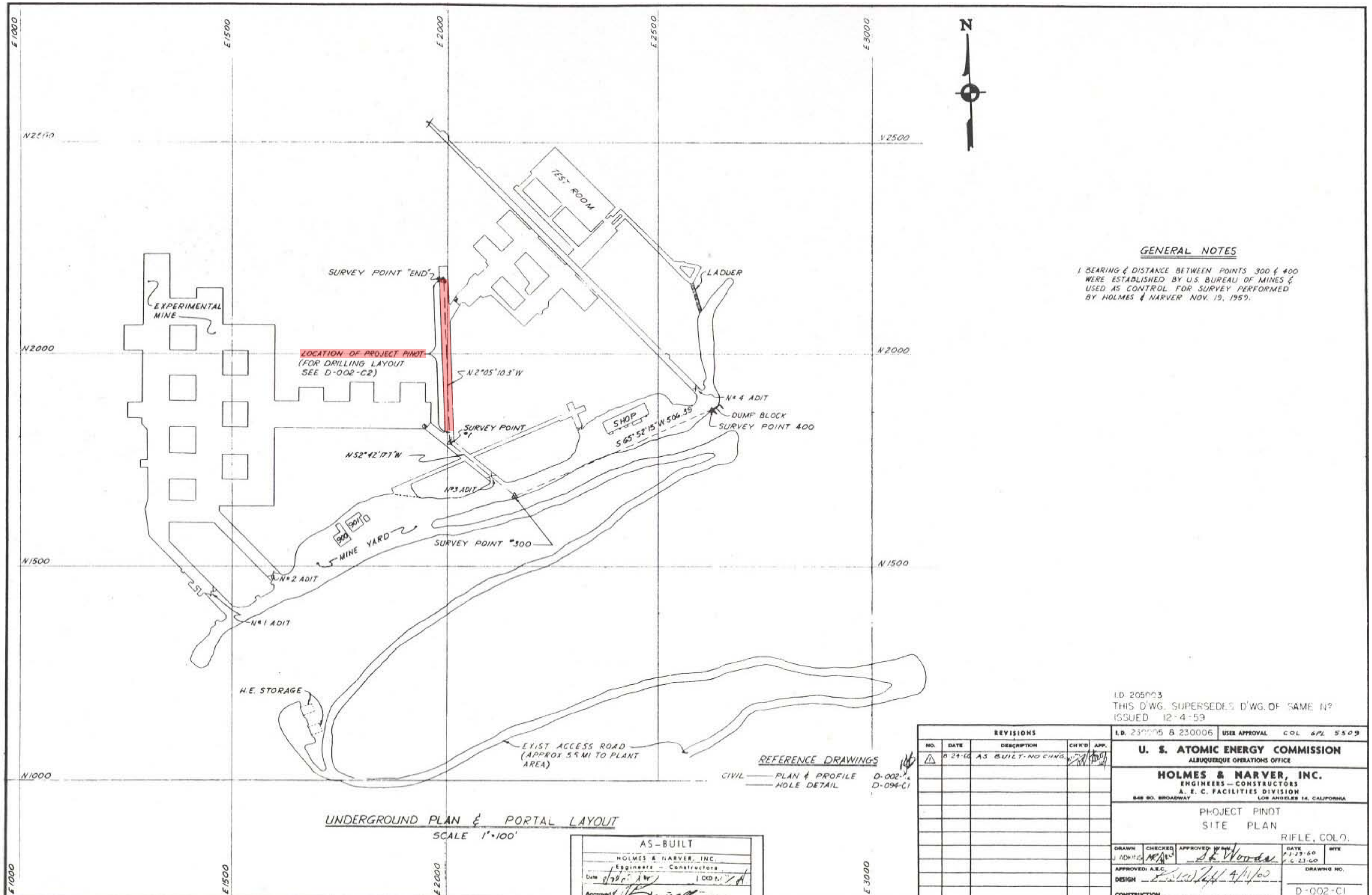


Figure 3.11-3. Project Pinot general site plan (adapted from Holmes & Narver, Inc. 1960, Drawing No. D-002-C1).

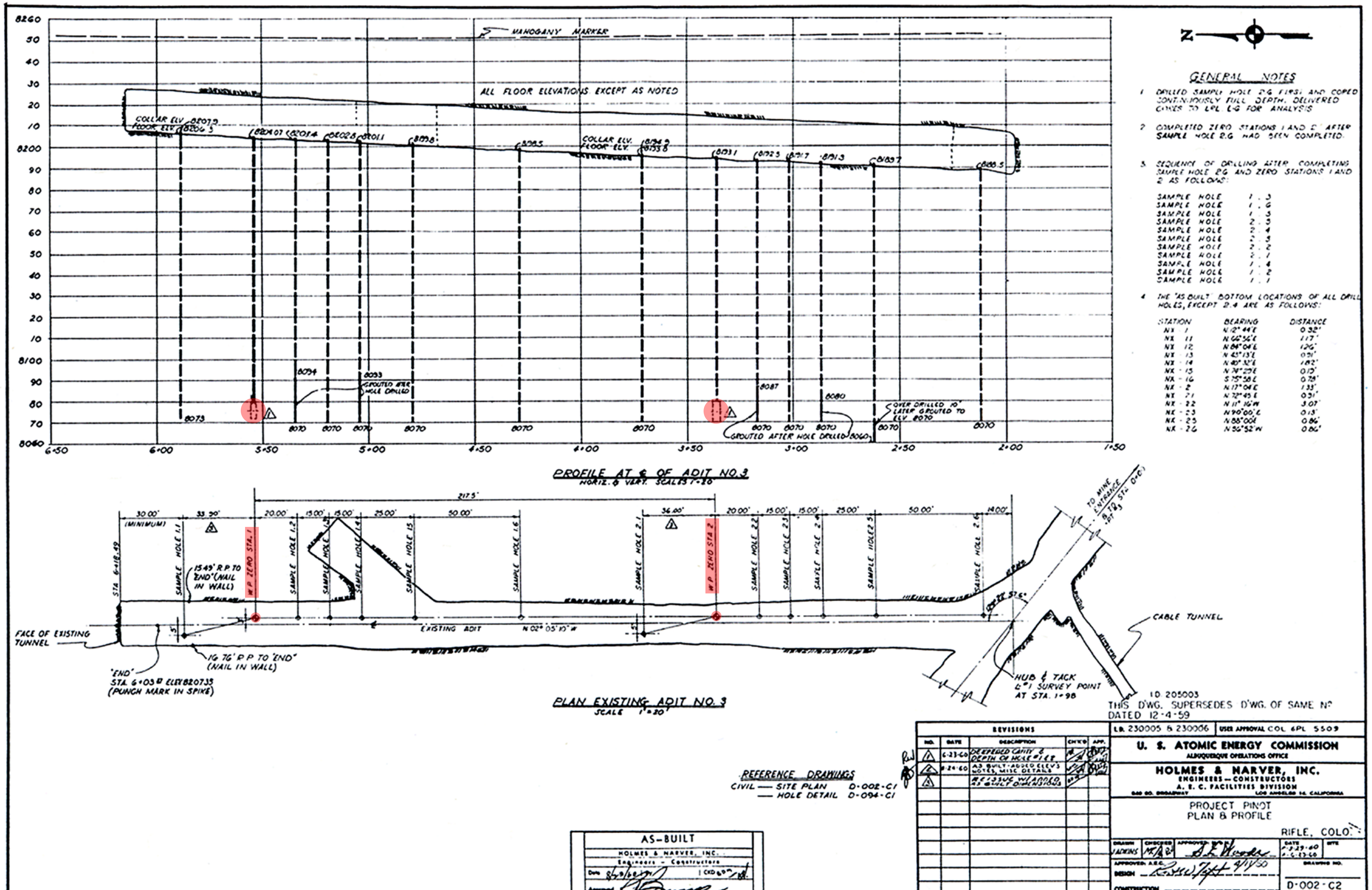


Figure 3.11-4. Plan of existing Adit No. 3 with the Shot No.1 and Shot No. 2 ground zeros and sampling hole locations for Project Pinot (adapted from Holmes & Narver, Inc. 1960, Drawing No. D-002-C2).

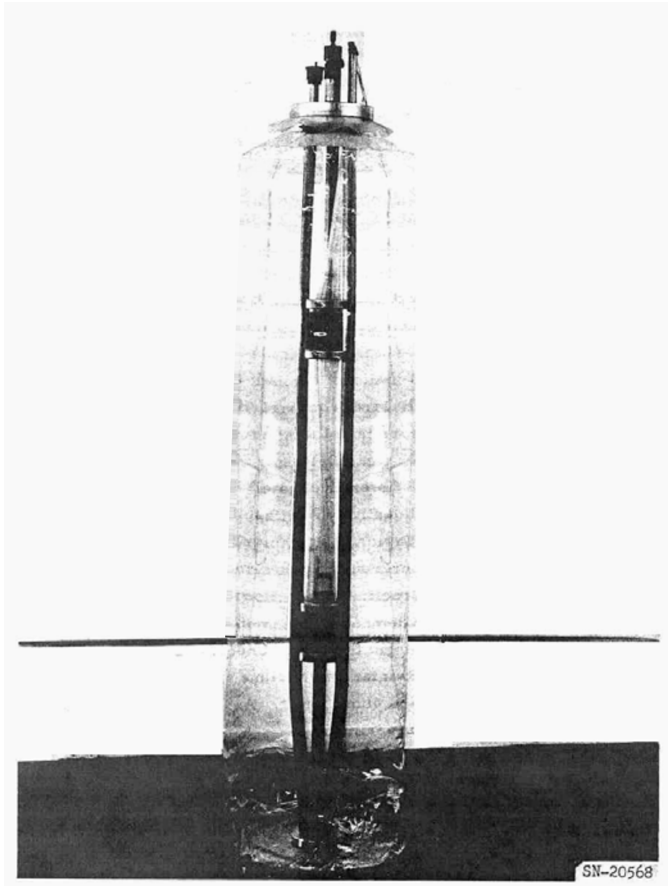


Figure 3.11-5. Project Pinot 1,000 lb convetional explosive device package consisted of two booster blocks enclosed in a polyethylene bag, a stainless steel canister with the tracer, and an outer polyethylene bag for the nitromethane (Adelman et al. 1960, Figure 5).

Chapters 3.1 and 3.25) also demonstrate a persistent belief in the potential of nuclear explosives to meet America's energy needs

Project Pinot was a Level 1 activity with a high explosives test containing a radioactive tracer, Krypton 85 an inert gas. The location was visited in FY 2003.

FIELD VISIT

In order to ascertain current site conditions and investigate land status, Desert Research Institute researchers visited the Project Pinot experiment site on August 14, 2003. To access the Project Pinot location, begin at the intersection of State Route 13 and State Route/Highway 6 in Rifle, Colorado and head west towards Grand Junction on old Highway 6, which serves as a frontage road for Interstate 70. Remain on Highway 6 for approximately 5.7 miles until reaching Anvil Points Road (aka 246 Road). Turn right (northwest) and proceed 1.3 miles. Turn right (northeast) again onto a dirt road just before entering the current Anvil Points facility. Remain on this road for about 5.4 miles as it curves back to the north and northwest following a series of switchbacks up the backside of the Roan Cliffs. The Anvil Points Oil Shale Mines, site of the Pinot experiment, are at the end of this road at an elevation of approximately 8,200 ft. The Pinot experiment mine entrance is in a south facing escarpment some 800 ft above the Colorado River overlooking the Grand Valley. Because of on-going mining and well operations, the lower portion of the road is graded and wide enough for two vehicles, but above 6,000 ft the road is not maintained. A washboard surface with washouts and crumbling embankments plagues the route, which narrows to the width of a single vehicle. The upper switchbacks, ascending over 1,000 ft in elevation in only 1,600 ft, were impassable and Desert Research personnel were unable to reach the entrance to the mines because of safety concerns. The adits and locked barricades (Figure 3.11-6), however, were clearly visible from the road at the base of the switchbacks at an elevation of 7,200 ft (Figure 3.11-7). An abandoned weather station constructed for Pinot still stands alongside the dirt road at about 7,040 ft (Figure 3.11-8) and the old utility line leading to the mine entrance remains in place (Figure 3.11-9).

Figure 3.11-6. Overview of the final series of switchbacks on the road leading to the Project Pinot mine. Entrance marked by arrow (photo taken August 14, 2003 on file at Desert Research Institute).

Figure 3.11-7. Locked steel barricades preventing access to Project Pinot mine adits. The arrow marks the mine entrance (photo taken August 14, 2003 on file at Desert Research Institute).

To verify the land status of the Pinot experiment location, Desert Research Institute personnel visited the Bureau of Land Management Glenwood Springs Resource Area Office and reviewed the realty records for the project site. At the time of the Pinot Experiment, the land was part of the Naval Oil Shale Reserve Nos. 1 and 3 under the jurisdiction of the U.S. Navy, Office of the Naval Petroleum and Oil Shale Reserves and the mine the experiment was conducted in was controlled by the U.S. Bureau of Mines. Ownership of the petroleum reserves was transferred from the U.S. Navy to the U.S. Department of Energy as part of the Department of Energy Organization Act of 1977. In 1997, administrative responsibility for the land was transferred to the U.S. Department of Interior.

Bureau of Land Management personnel were knowledgeable about the land status history of the Naval Oil Shale Reserves because the most recent jurisdictional transfer (1997) was discussed in detail in the *Glenwood Springs Resource Area Oil & Gas Draft Special Environmental Impact Statement* completed in June 1998. However, no one was aware of the 1960 Pinot Experiment although they knew about Project Rulison, another Plowshare project conducted within the Glenwood Springs Resource Area.

Figure 3.11-8. Abandoned weather station alongside the road leading to mines (photo taken August 14, 2003 on file at Desert Research Institute).

Figure 3.11-9. Utility line supplied power for the Pinot mine location. Mine entrance marked by arrow (photo taken August 14, 2003 on file at Desert Research Institute).

CHRONOLOGICAL BIBLIOGRAPHY

Denton, Vern, 1958. "Notes Covering Trip to Rifle, Colorado, Nov. 11-15, 1958." Memo from Vern Denton, Lawrence Radiation Laboratory, to Distribution, November 17. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105.

Denton, Vern, 1958. "Trip Report, 11/19/58, Laramie - Bureau of Mines." Memo from Vern Denton, Lawrence Radiation Laboratory, to Distribution, November 25. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105.

Thorne, H. M., 1958. Letter from H. M. Thorne, U.S. Department of the Interior, Bureau of Mines, to Harold Fidler, November 25. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105.

Stanfield, K. E., 1958. Letter with encl. ("Possible Sites for 'Vintage' Oil-Shale Test Under the Plowshare Project") from K. E. Stanfield, U.S. Department of the Interior, Bureau of Mines, to Charles E. Violet, December 9. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105.

Violet, C. E., 1958. "Technical Steering Committee, Project Vintage." Memo from C. E. Violet, Lawrence Radiation Laboratory, to Distribution, December 11. On file at: Archives and Records Office, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105.

Murphy, Walter I. R., 1958. Memo from Walter I. R. Murphy, U.S. Department of the Interior, Bureau of Mines, to Rodney L. Southwick, December 22. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105.

U.S. Department of the Interior. Bureau of Mines, 1959. Application Nuclear Explosions to Oil-Shale Utilization. Report for Bureau of Mines - U.S. Atomic Energy Commission Industry Meeting, Dallas, TX, January. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105.

Shute, Ellison C., 1959. Remarks to U.S. Bureau of Mines - AEC - Petroleum Industry Meeting, Dallas, TX, from Ellison C. Shute, U.S. Atomic Energy Commission, San Francisco Operations Office, January 6. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-106.

Gaskell, T. F., 1959. Atom Bombs to Free Oil? *The New Scientist*, January 15. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-106.

Frank, Wilson J., 1959. Telex from Wilson J. Frank, Lawrence Radiation Laboratory, to U.S. Atomic Energy Commission, February 2. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105.

Savage, John W., and Henry W. Hough, 1959. *Rocky Mountain Oil Reporter,* pp. 18-23, March. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105.

U.S. Atomic Energy Commission, 1959. "For Shute - Info to Gerald Johnson - From Keto." Telex from U.S. Atomic Energy Commission to U.S. Atomic Energy Commission, San Francisco District, May 27. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105.

Denton, Vern, 1959. Letter from Vern Denton, Lawrence Radiation Laboratory, to Paul L. Russell, June 10. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105.

Johnson, Gerald W., 1959. Letter from Gerald W. Johnson, Lawrence Radiation Laboratory, to Fred C. Hartley, July 2. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105.

Petrie, R. B., 1959. "Oil Shale H.E. Test." Memo from R. B. Petrie, Lawrence Radiation Laboratory, to C. M. Bacigalupi, August 11. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-032 [OUO].

Johnson, Gerald W.. 1959. "Ref: TWK Keto to Shute re Bureau of Mines Agreement for Vintage." Letter from Gerald W. Johnson, Lawrence Radiation Laboratory, to Russell Ball, August 21. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105.

U.S. Department of the Interior. Bureau of Mines, 1959. High-Explosive Experiment at the Rifle Oil-Shale Mine, A Preliminary Research Proposal for the Plowshare Program. Manuscript, U.S. Department of the Interior, November. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Violet, C. E., 1959. Letter from C. E. Violet, Lawrence Radiation Laboratory, to John E. Crawford, November 4. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105.

Ball, R. H., 1959. "LRL, SAN, and the U.S. Bureau of Mines Have All Agreed to Initiate a Plowshare Project." Telex from R. H. Ball, U.S. Atomic Energy Commission, San Francisco Operations Office, to James E. Reeves, November 6. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105 [OUO].

Plowshare Advisory Committee, 1959. Oil Shale (Project Vintage). Report prepared for Plowshare Advisory Committee Briefing, November 12-13, October 30. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029.

Plowshare Advisory Committee, 1959. Plowshare Advisory Committee Briefing, November 12-13, 1959, agenda. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029.

Plowshare Advisory Committee, 1959. Report of the Plowshare Advisory Committee, November 12-13. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029 [OUO].

Edgerton, Germeshausen & Grier, Inc., 1959. Pre-Vintage Operational Plan. Manuscript, Edgerton, Germeshausen & Grier, Inc., Boston, MA, November 17. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Johnson, Gerald W., 1959. Letter from Gerald W. Johnson, Lawrence Radiation Laboratory, to General Alfred D. Starbird, November 18. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105.

Petrie, R. B., 1959. "Pre-Vintage Cost Estimate - Basic Construction Only." Memo from R. B. Petrie, Lawrence Radiation Laboratory, to Frank Adelman, November 19. On file at: Archives and Records Office, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105.

Petrie, R. B., 1959. "Project Pre-Vintage, Construction Time Schedule." Memo from R. B. Petrie, Lawrence Radiation Laboratory, to Frank Adelman, November 19. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, PLO-105.

Violet, C. E., 1959. Memo from C. E. Violet, Lawrence Radiation Laboratory, to List, November 20. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105 [OUO].

U.S. Atomic Energy Commission. Albuquerque Operations Office, 1959. "Pre-Vintage Meetings to be Held at LRL." Telex to U.S. Bureau of Mines, December. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105.

Edgerton, Germeshausen & Grier, Inc., 1959. Telex from Edgerton, Germeshausen & Grier, Inc., Boston, MA, to List, December 2. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105.

U.S. Atomic Energy Commission. Albuquerque Operations Office, 1959. " Special Provisions Involved in the Bureau of Mines Support to Project Pre-Vintage." Telex from U.S. Atomic Energy Commission, San Francisco Operations Office, to Russell Ball, December 9. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105.

Frank, James, and John Nuckolls, 1959. "The Pre-Vintage Experiment." Memo from James Frank and John Nuckolls to Frank Adelman, December 17. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105.

Edgerton, Germeshausen & Grier, Inc., 1959. Revised Pre-Vintage Operational Plan. Manuscript, Edgerton, Germeshausen & Grier, Inc., Boston, MA, December 29. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Adelman, Frank L., 1960. "Pre-Vintage." Memo from Frank L. Adelman to Distribution, January 7. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105.

Denton, Vern, 1960. "Pre-Pre-Vintage." Memo from Vern Denton, Lawrence Radiation Laboratory, to G. W. Johnson, January 28. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105.

Johnson, Gerald W., 1960. Letter from Gerald W. Johnson, Lawrence Radiation Laboratory, to E. C. Shute, February 16. On file at: Archives and Records Office, Lawrence Berkeley National Laboratory, Berkeley, CA, File 434-900157, 7/18 and Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105 [OUO].

Mansfield, R., 1960. "Adit No. 3, Plan and Profile, Project Pre-Vintage, Colorado." Drawing No. L-6-10894 from Lawrence Radiation Laboratory, March 2. On file at: Archives and Records Office, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105 [OUO].

Miller, Robert E., 1960. Telex from R. E. Miller, U.S. Atomic Energy Commission, Albuquerque Operations Office, to Holmes & Narver, March 23. On file at: Nuclear Testing Archives, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0069202.

Holmes & Narver, Inc., 1960. "Project Pinot - Site Plan." Drawing No. D-002-C1, March 29. On file at: Engineering Records Library, Nevada Test Site, Mercury, NV, Index No. 042817.

Holmes & Narver, Inc., 1960. "Project Pinot - Plan and Profile." Drawing No. D-002-C2, March 29. On file at: Engineering Records Library, Nevada Test Site, Mercury, NV, Index No. 042818.

Shute, E. C., 1960. Telex from E. C. Shute, U.S. Atomic Energy Commission, San Francisco Operations Office, to Brigadier General A. D. Starbird, March 29. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-032 [OUO].

Sanders, J. B., 1960. Telex from J. B. Sanders, U.S. Atomic Energy Commission, Albuquerque Office, to S. P. Howell et al., April 8. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0064309.

Bacigalupi, C. M., 1960. "Sandia Participation on Project PINOT." Letter from C. M. Bacigalupi, Lawrence Radiation Laboratory, to R. Tockey, April 11. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-032 [OUO].

Shute, E. C., 1960. Telex from E. C. Shute, U.S. Atomic Energy Commission, to U.S. Department of the Interior, Bureau of Mines, April 12. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-032.

Starbird, Alfred D., 1960. "AEC to Conduct High Explosive Experiment in Colorado Oil Shale Mine." Telex from Alfred D. Starbird, Brigadier General, U.S. Atomic Energy Commission, to San Francisco Operations Office, April 20. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-032.

Starbird, Alfred D., 1960. Telex from Alfred D. Starbird, Brigadier General, U.S. Atomic Energy Commission, to San Francisco Operations Office, April 22. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-032.

Southwick, Rodney L., 1960. Letter with encl. (Press Release, Subject: "AEC to Conduct High Explosive Experiment in Colorado Oil Shale Mine," San Francisco Operations Office, for release April 27) from Rodney L. Southwick, Lawrence Radiation Laboratory, to C. L. Fankhouser, April 25. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-032.

Reeves, James E., 1960. "Operations Order OTO-2-60 - Project Pinot." Memo from James E. Reeves, U.S. Atomic Energy Commission, Albuquerque Office, to Distribution, April 29. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-032.

Holmes & Narver, Inc., 1960. Operational Plan: Engineering, Construction, Support, Project Pinot, Plowshare Program. Report to U.S. Atomic Energy Commission, Albuquerque Operations Office, from Holmes & Narver, Inc., May. On file at. Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV and Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0173332.

Rodriguez, Ernest R., and I. J. Ratliff, 1960. Safety Inspection Report: Proposed Project Pinot, United States Atomic Energy Commission, at Oil-Shale Mine, Bureau of Mines near Rifle, Garfield County, Colorado, May 3-4 1960. Manuscript, United States Department of the Interior, Bureau of Mines, Denver, CO. On file at: National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0069346.

Ryland, H. L., 1960. "Test Manager's Operations Order, Project Pinot." Memo from H. L. Ryland, U.S. Atomic Energy Commission, to James E. Reeves, May 12. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. 0110939.

Reeves, James E., and H. L. Ryland, 1960. "Project Engineer's Weekly Activity Report - April 28 thru May 6, 1960." Letter from James E. Reeves and H. L. Hyland, U.S. Atomic Energy Commission, Albuquerque Office, May 20. On file at Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0069340.

Adelman, Frank L., 1960. Pinot. Manuscript, May 26. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-032.

Ryland, Henry L., 1960. Letter from Henry L. Ryland, U.S. Atomic Energy Commission, to B. Guthrie, May 30. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. 0069331.

Sanders, Joe. B., and Harry L. Ryland, 1960. "Project Engineer's Weekly Activity Report - June 18-24, 1960." Letter from Joe B. Sanders and Harry L. Ryland, U.S. Atomic Energy Commission and Bureau of Mines, June 27. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0069311.

Sanders, Joe B., and Harry L. Ryland, 1960. "Project Engineer's Weekly Activity Report - June 25-July 1, 1960." Letter from Joe B. Sanders and Harry L. Ryland, U.S. Atomic Energy Commission and Bureau of Mines, July 5. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0069303.

Bacigalupi, C. M., 1960. "Project Pinot, Operational Completion Report - Preliminary." Memo from C. M. Bacigalupi, Lawrence Radiation Laboratory, to Distribution, September 12. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-032.

Plowshare Advisory Committee, 1960. Plowshare Advisory Committee Meeting. LRL Statements for 4th Plowshare Advisory Committee Meeting, Albuquerque New Mexico, October 19 and 20, 1960. Report, October 20. On file at Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Adelman, Frank L., Clifford M. Bacigalupi, and Floyd F. Momyer, 1960. Final Report on the Pinot Experiment. University of California, Lawrence Radiation Laboratory, *Report UCRL*-6274, December 27. Livermore, CA. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0330835.

U.S. Atomic Energy Commission, 1961. Civil Uses of Nuclear Explosives, In *Annual Report to Congress of the Atomic Energy Commission,* pp.152-156, January. Government Printing Office, Washington, D. C.

Hall, Roberta, 1961. Letter from Roberta Hall, *The Daily Rocket*, Rock Springs Newspaper, Inc., January 24. n file to Lawrence Radiation Laboratory," The Daily Rocket, Rock Springs Newspapers, Inc., to Lawrence Radiation Laboratory, January 24. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-032.

Adelman, Frank L., 1961. Letter from Frank L. Adelman, Lawrence Radiation Laboratory, to Roberta Hall, February 3. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-032.

Reeves, James E., 1961. "Glossary of Seismic Projects, Plowshare Program, and Reactor Programs." Memo from James E. Reeves, U.S. Atomic Energy Commission, Albuquerque Office, to List, March 17. On file at Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV [OUO].

U.S. Atomic Energy Commission. Albuquerque Operations Office, 1961, Project Manager's Report Project Pinot, Plowshare Program. Manuscript, U.S. Atomic Energy Commission, May. Albuquerque, NM. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV and Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-032.

Rabb, David D., 1961. Letter from David D. Rabb, Plowshare Division, Lawrence Radiation Laboratory, to Russell J. Cameron, May 1. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105.

Teller, Edward, 1963. Plowshare. University of California, Lawrence Radiation Laboratory *Report UCRL*-7222, February 4. Livermore, CA. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029.

Hosmer, Craig, 1969. Remarks of Rep. Craig Hosmer to Joint Committee on Atomic Energy, Symposium on the Public Health Aspects of Peaceful Nuclear Explosives, Las Vegas, NV, April 8. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029.

U.S. Atomic Energy Commission. Nevada Operations Office, 1973. Significant Peaceful Nuclear Explosion Events and Related Activities. U.S. Atomic Energy Commission, Nevada Operations Office, Report NVO-134, Las Vegas, NV. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029.

Shafer, David S., William. C. Beck, Dwight Treadwell, and Stephen. A. Mellington, 1995. Inventory of Potential Environmental Restoration Liabilities Associated with Plowshare And Vela Uniform Program Sites. Manuscript, U.S. Department of Energy, Office of Environmental Restoration. On file at: Desert Research Institute, Las Vegas, NV.

U.S. Department of Energy. Nevada Operations Office, 1997. Plowshare Program Executive Summary. Report from U.S. Department of Energy, December 22.

U.S. Department of the Interior. Bureau of Land Management, 1998. GSRA Oil & Gas Draft SEIS. U.S. Department of the Interior, June.

U.S. Department of Energy. Nevada Operations Office, n.d. The Plowshare Program (Draft). Report from U.S. Department of Energy.

Starbird, Alfred D., [1958]. Letter from Alfred D. Starbird, Brigadier General, U.S. Atomic Energy Commission, to Edward Teller. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105.

U.S. Atomic Energy Commission, [1958]. Letter from U.S. Atomic Energy Commission to Fred A. Seaton. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105.

THIS PAGE INTENTIONALLY LEFT BLANK

3.12 PLOWBOY

Plowshare Program
High Explosives Salt Fracture Research
Louisiana

Plowboy was planned as a postshot investigation of fractures in a salt structure from two high explosive detonations during Cowboy. Between December 1959 and March 1960, the Project Cowboy series of chemical explosion experiments were conducted in a salt dome as part of the U.S. Atomic Energy Commission's Vela Uniform program of seismic detection studies. This test series consisted of 17 high explosive detonations in a salt dome near Winnfield, Louisiana, approximately 110 miles southeast of Shreveport near the southwest corner of Sec. 19, T11N R3W (Figures 3.12-1 and 3.12-2). The Cowboy detonations occurred approximately 800 ft below the surface in a section of a mine operated by the Carey Salt Company not under production.

On March 5, 1960 a meeting was held with Carey Salt Company regarding mothballing some of the Cowboy facilities for two to three years. A letter dated March 8, 1960, details the arrangements between the U.S. Atomic Energy Commission and the Carey Salt Company. Carey agreed to maintain the facilities for two to three years allowing for limited office space, as well as corrosion protection maintenance of the shaft every six months and monthly inspections by a qualified engineer and a cabling crew. This letter was followed the same day by a memo authorizing construction of a storage shed for mothballing some of the equipment at the salt mine and mentions that other mothballing activities would be taken care through a contract.

Plowshare program researchers tasked with exploring possible industrial applications of nuclear explosions identified the Cowboy series as an opportunity to test theoretical predictions for fracture geometry and mechanical deformation in a relatively homogeneous medium, i.e., salt. They also believed that data obtained from the salt blasts would be applicable to the upcoming Gnome test scheduled for detonation in a Permian salt formation near Carlsbad, New Mexico. The Lawrence Radiation Laboratory group established Project Plowboy to investigate several of the Cowboy explosions. The objective was to study the phenomenology of explosions in salt, principally from a 1,000-lb high explosive 110 ft below the mine floor. Lawrence Radiation Laboratory supplied technical personnel, a physicist, geologist, engineer, photographer, and a logistics man.

The two shot locations selected for Project Plowboy were Cowboy Shot No. 4, Station 1.3 and Cowboy Shot No. 13, Station 2.5. Station 1.3 was the site of a coupled detonation in a 45 ft deep hole. Conducted on December 19, 1959, the blast had a 100 lb yield. The Pelletol explosion at Station 2.5 was considerably larger. A 1,000-lb device was set in a 110 ft deep drill hole. The coupled detonation occurred on February 20, 1960 with an effective yield of 987.6 lbs.

Figure 3.12-1. Location of Project Plowboy in Louisiana (adapted from USA Relief Maps 2004).

Initial construction and support criteria for Project Plowboy were presented in a March 15, 1960 letter from Lawrence Radiation Laboratory. By March 23, 1960, Holmes & Narver, Inc. had prepared an *Operational Plan for Engineering, Construction and Support*. They received authorization to proceed with the project in a U.S.Atomic Energy Commission work authorization dated April 11, 1960. Construction activities at the Project Plowboy location began on April 12, 1960 with work completed on June 24, 1960. Holmes & Narver, Inc. provided the engineering design, construction supervision and inspection as well as general support to the on-site scientific personnel. The U.S. Army Engineer Waterways Experiment Station was responsible for the drilling and coring and the U.S. Bureau of Mines for mine safety activities. Carey Salt Company conducted the mining and excavation activities of the salt formation (Figures 3.12-2 and 3.12-3). The U.S. Government Service Administration supplied the vehicles.

Station 2.5 was studied first. To examine the fracture zone surrounding Station 2.5, an 8x8-ft shaft was excavated to a depth of approximately 120 ft with two horizontal drifts.

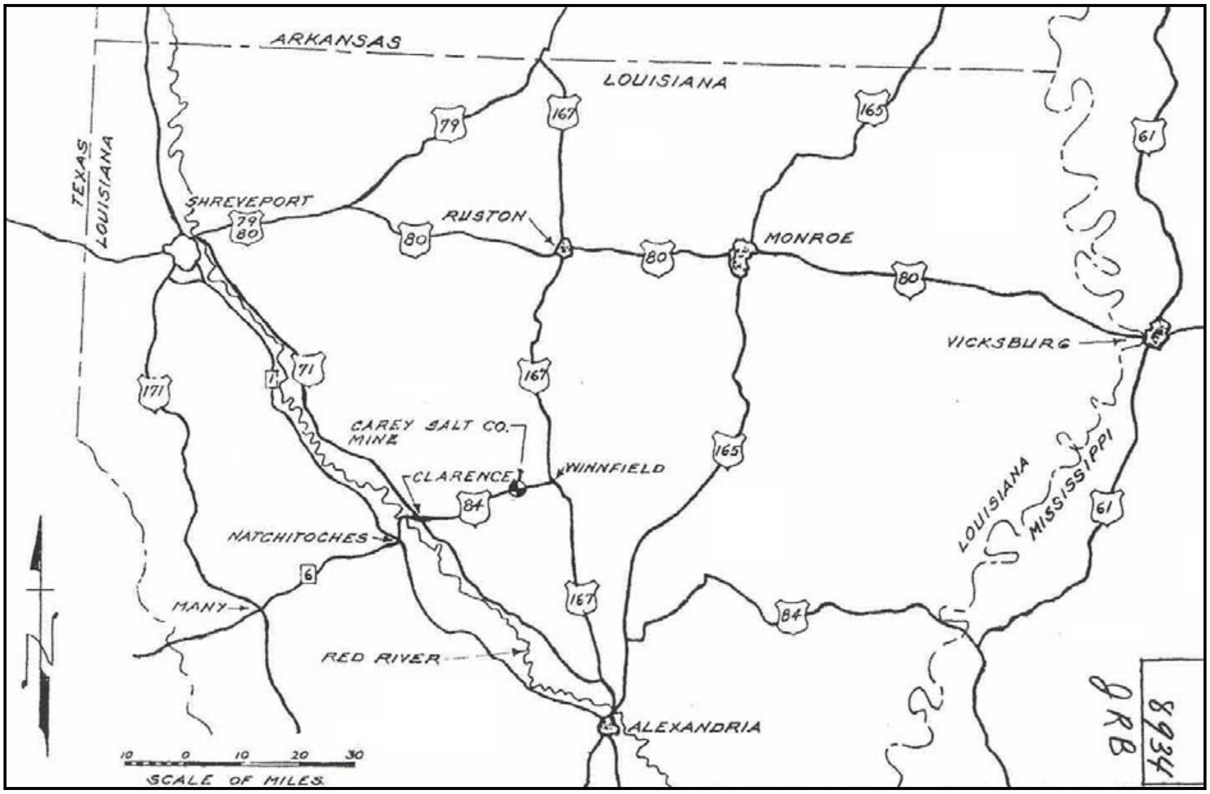


Figure 3.12-2. Location of Carey Salt Company Mine near Winnfield (Shelton 1959, no figure number).

Shaft excavation began on April 12, 1960 and was completed on May 13, 1960. Excavation techniques included the use of small blasts from conventional explosives. Adit excavation began immediately, with stoppage on May 17, 1960 to wait for Lawrence Radiation Laboratory personnel. Lawrence Radiation Laboratory personnel arrived on May 23, 1960 and the excavation work was completed on June 24, 1960. The material removed was hauled out of the mine to the south end of Carey Drift No. 1, approximately 90 ft.

The work at Station 2.5 was accomplished in 12 phases, including excavating shafts and drifts to access the detonation zero point, expose blast-induced fractures and then trace their course. The study found that beyond the innermost foot next to the blast cavity, all the fractures were tight ranging from only 1/64 to 1/16 inch. While the rock salt medium failed by plastic deformation, ductile fracturing, and some tensile fracturing, the salt adjacent to the cavity did not melt or crush and the expanded cavity did not collapse, remaining competent to stand. The report concluded that extrapolation of the effects of high explosive detonations in salt to nuclear tests in similar media should be done with caution. Nuclear detonations would definitely result in vaporization, melting, and crushing, thereby increasing the probability of cavity collapse.

The smaller detonation at Station 1.3 was examined by taking core samples through the shot point from different directions by means of four holes. On May 24, 1960, the Waterway

Experiment Station crew began setting up the drilling operation on Hole No. 1, completing it on May 31, 1960. Holes Nos. 2 and 3 were finished by June 7, 1960. Hole No. 4 was drilled on June 14, 1960. Photographers from the Dallas Laboratory, U.S. Corps of Engineers, photographed the cores and holes at Station 1.3.

Stations 2.4 and 2.6 were added to the program at this time. Postshot re-entry holes were not drilled into these shot cavities as part of Project Cowboy. Station 2.4 was Cowboy Hole No. 11. The detonation at this hole occurred on February 13, 1960 with 1,003 lb yield in a coupled 110 ft hole. Station 2.6 was Cowboy Hole No. 15. Detonation occurred on February 18, 1960 with a yield of 936.2 lbs in a coupled 110-ft hole. On June 8, 1960 the re-entry hole at Station 2.4 was drilled into the shot cavity. On June 9, 1960, the re-entry hole for Station 2.6 was started but missed the cavity and a second hole was drilled 1 ft away. This hole hit relief pipe installed during Cowboy and the hole was abandoned on June 13, 1960.

On June 28, 1960, following completion of the Plowboy investigations, all equipment was dismantled and moved out of the mine, except at Station 2.5 where the mine head frame was left in place with the sides boarded up to serve as a barricade to the shaft (Figure 3.12-3). Piping and ducts were dismantled and stored in the mine. Tools were cleaned and stored in an underground bunker. The areas utilized in the mine were cleaned and restored to pre-project condition. The disposition of government-owned Cowboy and Plowboy equipment and shipments of materials from Winnfield were completed in July 1960. Most of the equipment was delivered to Carlsbad, New Mexico for the Gnome test and to Mercury, Nevada for use at the Nevada Test Site. The Carey Salt Company purchased the rest. On July 19, 1960, the U.S. Atomic Energy Commission authorized Holmes & Narver, Inc. to prepare a completion report. The *Completion Report for Project Plowboy Plowshare Program* was issued in September 1960.

Project Plowboy was a Level 3 activity with drill holes and shafts constructed and used during the fieldwork.

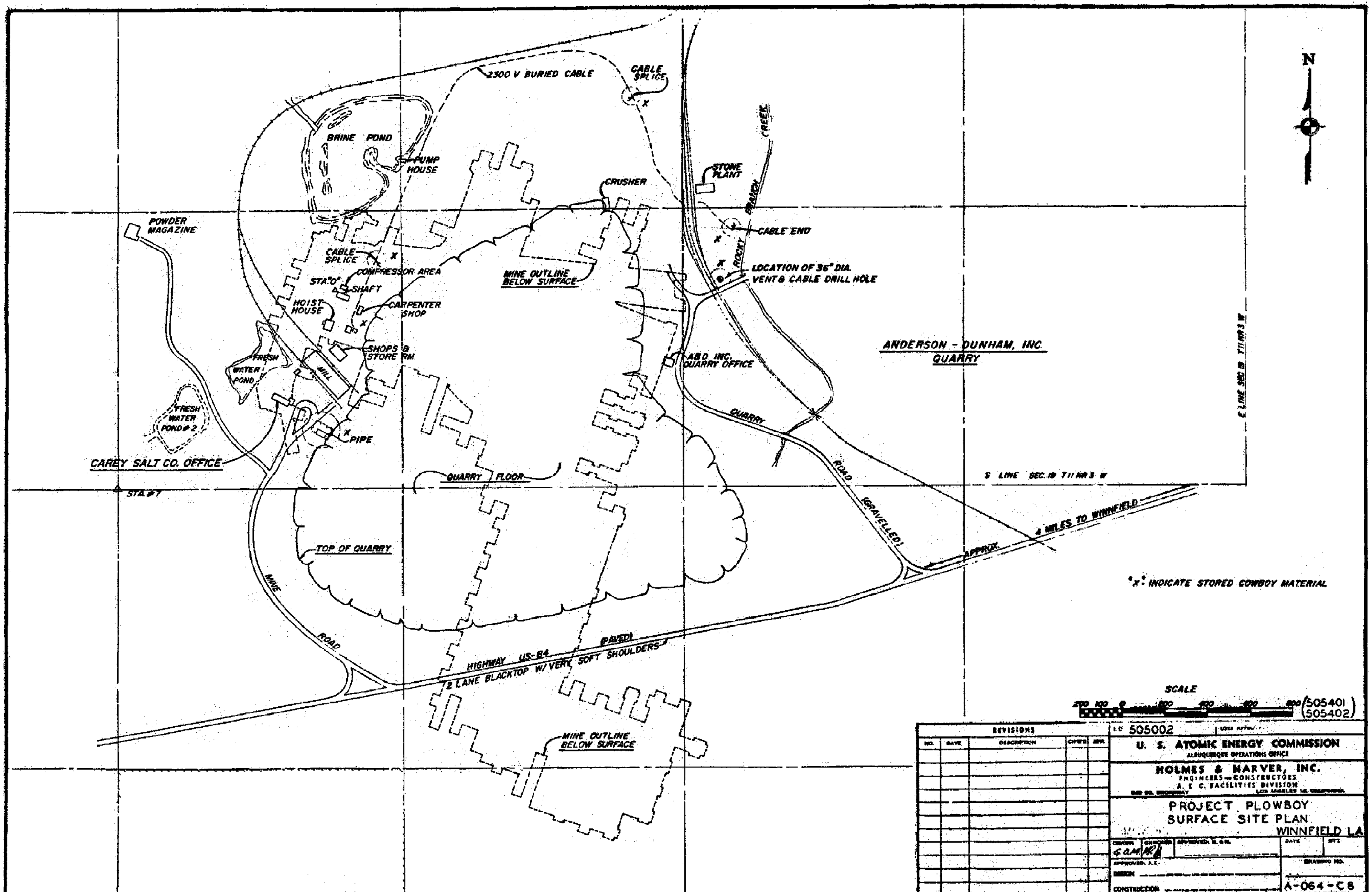


Figure 3.12-3. Plowboy surface site plan (Holmes & Narver1960, Drawing No. A-064-C8)

THIS PAGE INTENTIONALLY LEFT BLANK

CHRONOLOGICAL BIBLIOGRAPHY

Reed, Charles B., 1958. “Site for Plowshare Experiment in Salt.” Letter from Charles B. Read to Gerald W. Johnson, April 16. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Westinghouse Electric Corporation. Atomic Power Department, 1958. Proposal for th Utilization of Heat from Underground Nuclear Detonations. Report to U.S. Atomic Energy Commission, from Westinghouse Electric Corporation, Pittsburgh, PA, May 16. On file at: Archives and Records Office, Lawrence Berkeley Laboratory, Berkely, CA, File 434-900157, 7/18.

Shelton, A. V., 1959. "Transmittal of Technical Director's Operations Plan for Project "COWBOY." Memo with encl. ("Technical Director's Operations Plan for Project Cowboy") from A. V. Shelton, Lawrence Radiation Laboratory, to Distribution, July 31. On file at: Nuclear Testing Archive, Nevada Site Office, National Nuclear Security Administration, Las Vegas, NV, File NV0069544.

Holmes & Narver, Inc., 1960. "Project Plowboy - Surface Site Plan." Drawing No. A-064-C8. On file at: Engineering Records Library, Nevada Test Site, Mercury, NV.

Project Plowboy, 1960. Project Plowboy (Special Projects). Manuscript. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV064320.

Petrie, R., and F. Warren, 1960. Telex from R. Petrie and F. Warren, Lawrence Radiation Laboratory, to W. D. Gibbins, March 9. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession NV0069371.

Miller, Robert E., 1960. Telex from R. E. Miller, U.S. Atomic Energy Commission, Albuquerque Operations Office, to Holmes & Narver, March 23. On file at: Nuclear Testing Archives, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0069202.

Holmes & Narver, Inc., 1960. "Project Plowboy - Construction Schedule." Drawing No. A-064-C10, March 29. On file at: Engineering Records Library, Nevada Test Site, Mercury, NV.

Holmes & Narver, Inc., 1960. "Project Plowboy - Core Holes." Drawing No. A-1.3-C1, April 9. On file at: Engineering Records Library, Nevada Test Site, Mercury, NV.

Holmes & Narver, Inc., 1960. Completion Report, Project Plowboy, Plowshare Program. Report to U.S. Atomic Energy Commission from Holmes & Narver, Inc., Special Projects Division, September. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0173335.

Short, Nicholas M., 1960. Project Cowboy: Fracturing of Rock Salt by a Contained High Explosive. University of California, Lawrence Radiation Laboratory, *Report UCRL*-6054, September 10. Livermore, CA.

U.S. Atomic Energy Commission, 1961. Civil Uses of Nuclear Explosives, In *Annual Report to Congress of the Atomic Energy Commission,* pp.152-156, January. Government Printing Office, Washington, D. C.

Shafer, David S., William. C. Beck, Dwight Treadwell, and Stephen. A. Mellington, 1995. Inventory of Potential Environmental Restoration Liabilities Associated with Plowshare And Vela Uniform Program Sites. Manuscript, U.S. Department of Energy, Office of Environmental Restoration. On file at: Desert Research Institute, Las Vegas, NV.

3.13 PRE-DRIBBLE

Vela Uniform Program
High Explosive Seismic Effects Research
Mississippi

Pre-Dribble was a high explosive study located in southern Mississippi (Figure 3.13-1), to study the possible seismic effects or ground motion that was expected to result from the three planned nuclear explosive seismic monitoring experiments for the Dribble Program (Salmon, Sand and Tar). Project Dribble (originally named Ripple) was a program of the Vela Uniform series, designed to investigate seismic signatures of underground explosions in decoupling cavities in salt to compare with tamped detonations. The Advanced Research Projects Agency of the U.S. Department of Defense was responsible for the Vela Uniform program, and Dribble was a joint U.S. Atomic Energy Commission and U.S. Department of Defense project. The test program for Pre-Dribble was undertaken by the U.S. Geological Survey supported by the U.S. Coast and Geodetic Survey. The high explosive detonation program was conducted during the spring and early summer of 1963.

According to a report issued in August 1963, the Pre-Dribble experiments consisted of a series of detonations near the towns of Collins, McNeil, Raleigh and Ansley, Mississippi, and several locations near the planned Dribble tests on the Tatum Salt Dome (Figure 3.13-2). The Dribble location (currently named the Salmon Site Test Area) is a 1,470-acre tract of land in Lamar County, 21 miles southwest of Hattiesburg. A 1964 summary report on Project Dribble mentions that approximately 20 high explosive shots were conducted for the seismic effects program. Some reference data is available for a series of eight tests conducted on or near the Tatum Salt Dome and in the vicinity of Collins and McNeil. This information is summarized below. There is no information about tests conducted near Raleigh and Ansley. Instrumentation locations are also unknown.

Data about eight approximately 1,000 lb chemical explosive tests are included in a report on seismic effects issued in August 1963. The tests were conducted in salt and sedimentary deposits and include at least 15 detonations that ranged from 50 lb to 1,000 lb charges using different types of chemical explosives (Table 3.13-1). The McNeil 1 and Collins 2 tests were conducted in sedimentary deposits off the salt dome. The McNeil 1 test had two charges (Hole 1, 550 lb charge, Hole 2, 450 lb charge) and occurred on April 5, 1963, near McNeil. For this test both charges were at a depth of 245 ft. The Collins 2 test was conducted near the town of Collins on April 6, 1963. The test included four detonations (Hole 2, 350 lb charge, Hole 3, 50 lb charge, Hole 4, 200 lb charge, and Hole 5, 400 lb charge) all at a depth of 195 ft. Three tests were conducted in sedimentary deposits near the dome: Dribble 5, Dribble 6, and Dribble 3A. Dribble 5 occurred on April 5, 1963 with two charges (Hole 14, 500 lb; and Hole 15, 500 lb) both at 250 ft. Two explosives were used for the Dribble 6 test (Hole 16, 500 lb and 150 lb) on April 6, 1963 at 250 ft. The Dribble 3A test on April 24, 1963, had a total charge of 1000 lb, although

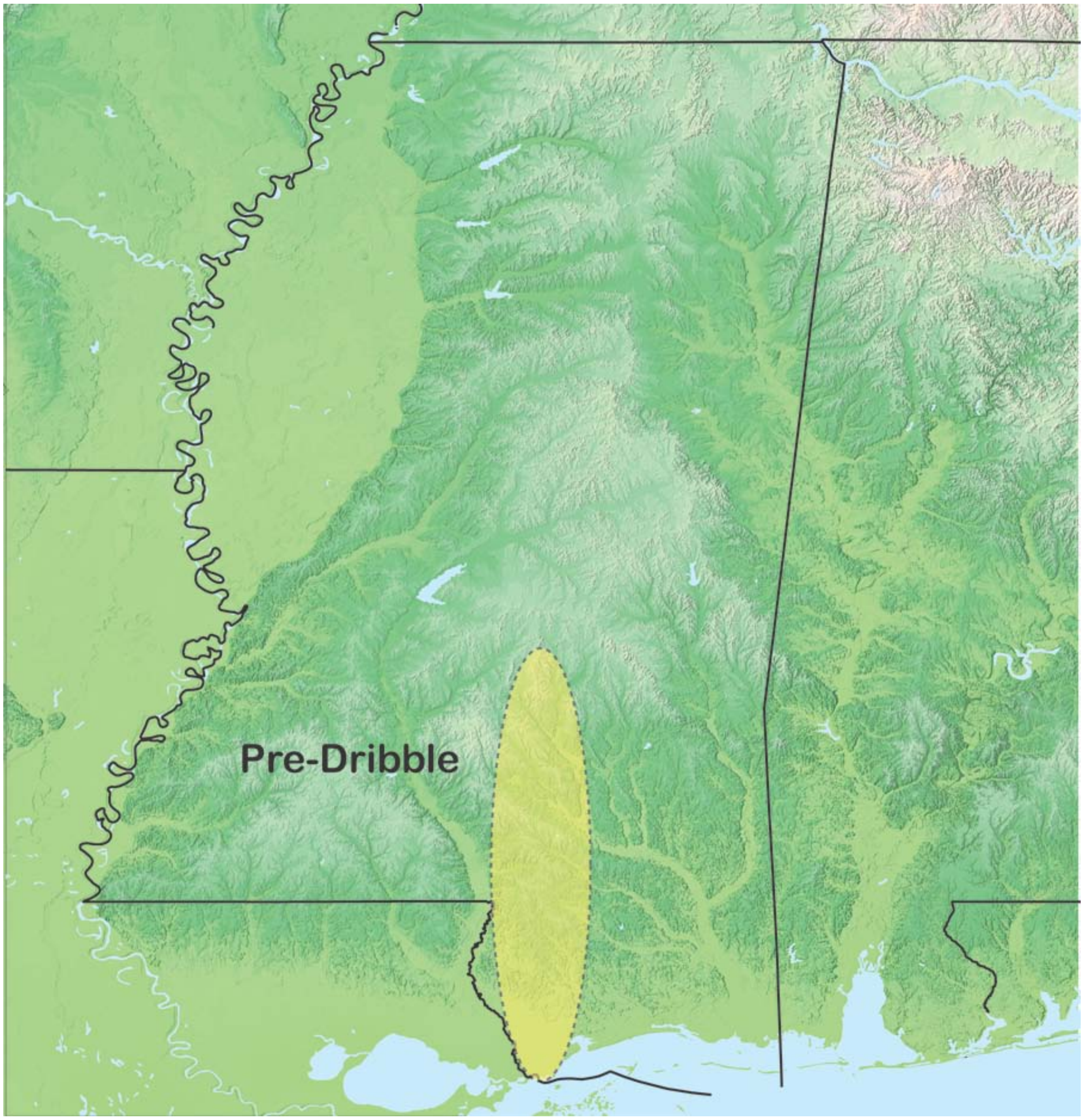


Figure 3.13-1. General area of the Pre-Dribble high explosive tests in Mississippi (adapted from USA Relief Maps 2004).

the number of holes, depth, and charge distribution is not known. A minimum of two charges is assumed for this test. Finally, three explosive tests were conducted at the Dribble site location on the Tatum Salt Dome (Test E-1 #2, E-12, and E-13). The precise locations for these tests are shown on Figure 3.13-3. Test E-1 #2, executed on May 9, 1963, consisted of a 985 lb charge in the salt dome at a depth of 2,092 ft. Test E-12 and E-13 were both 1,000 lb explosives detonated at depths of approximately 2,860 ft on June 13, 1963.

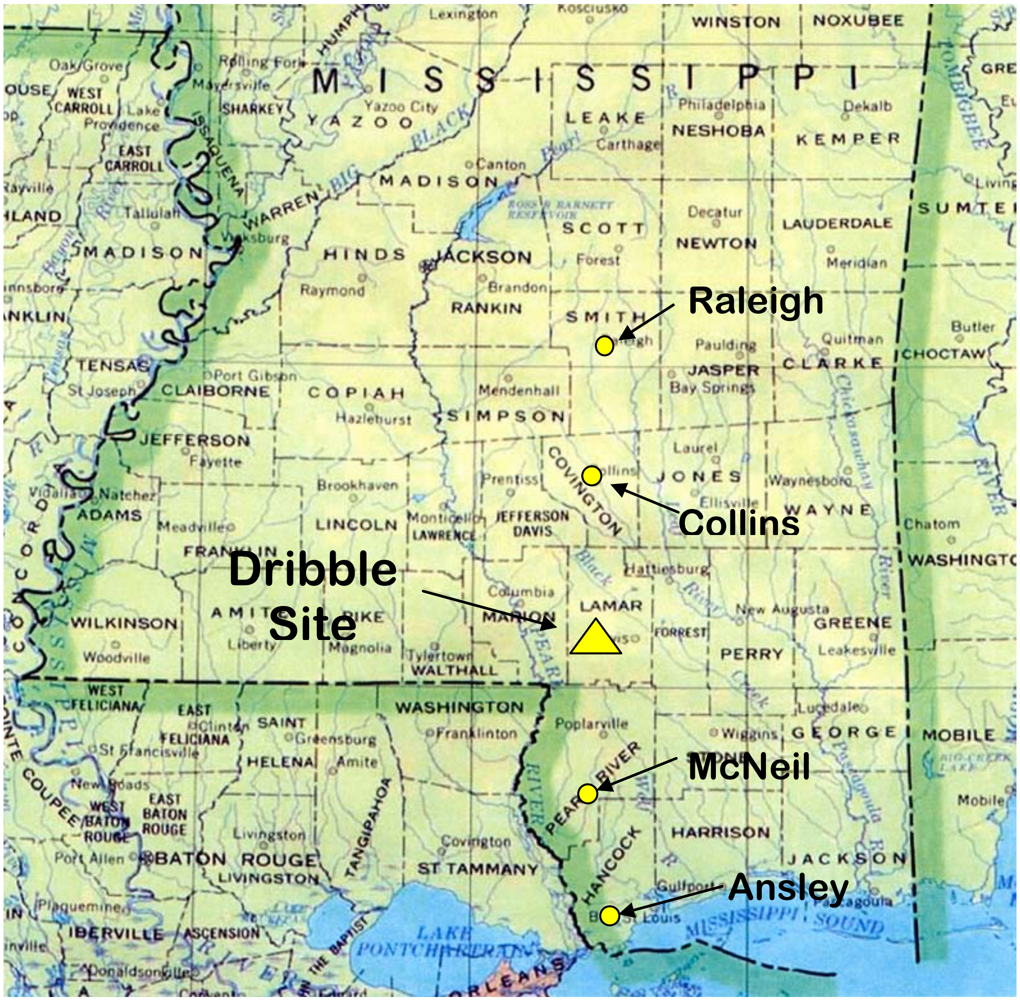


Figure 3.13-2. Location of the Dribble Site on the Tatum Salt Dome; and the towns of Raleigh, Collins, McNeil, and Ansley (adapted from http://www.lib.utexas.edu/maps/mississippi/html).

A press release issued on September 10, 1964, summarized the predicted force of ground motion expected from the planned 5 kt Salmon test based on the results of the Pre-Dribble tests. Expected seismic effects were described on a gradient from the explosive point to a distance of 30 miles. According to the release there would be a sharp jolt at the detonation site radiating out to a sharp roll, grading to a series of gentler rolls. At a distance of 20 miles from the detonation, ground motion would be difficult to detect and would be characterized by a slight ripple motion. No ground motion was expected to be felt in communities beyond 30 miles.

Following the Pre-Dribble seismic effects tests, three experiments were eventually conducted at the Tatum Salt Dome: the Salmon nuclear test in 1964, the Sterling nuclear test in 1966, and the non-nuclear Miracle Play Program (detonable gas explosions). The originally planned Sand and Tar detonations were not executed. As of August 1, 2006 the test area, now called the Salmon Site Test Area, is the responsibility of the Office of Legacy Management under the Long-Term Surveillance and Maintenance Plan. Detailed location information is not available for the other explosive tests; therefore, the status of the land associated with these tests is unknown.

Table 3.13-1. Eight Explosive Tests for Pre-Dribble

Test Name	Location	Date of Shot (1963)	Hole No.	Charge	Description (ft below surface)
McNeil 1	Off Dome	April 5	No.1	550 lb	245 ft
			No. 2	450 lb	245 ft
Collins 2	Off Dome	April 6	No. 2	350 lb	195 ft, 60% Vibrogel
			No. 3	50 lb	195 ft, 60% Vibrogel
			No. 4	200 lb	195 ft, 60% Vibrogel
			No. 5	400 lb	195 ft, 60% Vibrogel
Dribble 5	Near Dome	April 5	No. 14	500 lb	250 ft
			No. 15	500 lb	250 ft
Dribble 6	Near Dome	April 6	No. 16	500 lb	250 ft, 60% Vibrogel explosive
				150 lb	Flogel explosive
Dribble 3A	Near Dome	April 24		1000 lb total charge	No. of holes and charge distribution not known, at least 2 charges
E-1 #2	Tatum Salt Dome	May 9		985 lb	2092 ft, Vibrogel #3 explosive, 14.6 lb primers
E-12	Tatum Salt Dome	June 13		1000 lb	2860 ft, C4 explosive
E-13	Tatum Salt Dome	June 13		1000 lb	2860 ft, C4 explosive

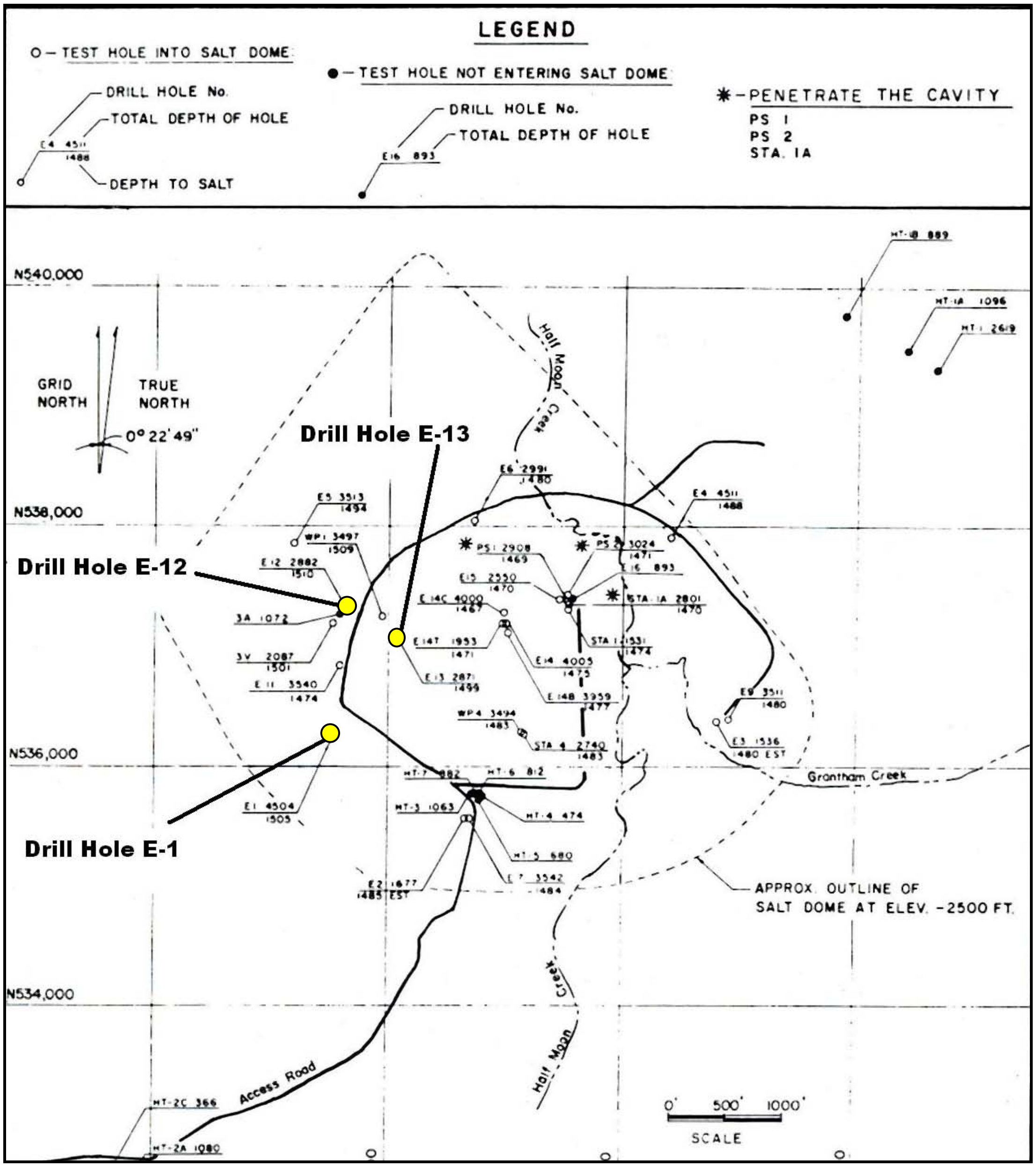


Figure 3.13-3. Map showing the location of drill holes E-1, E-12, and E-13 for Pre-Dribble at the Dribble site (the other drill holes are associated with Dribble) (adapted from Gardner and Downs 1971, Figure 6).

Pre-Dribble was a Level 2 activity. High explosives were used to test for seismic effects. Documentation is not available that shows the precise location for tests conducted in locations off the Tatum Salt Dome.

CHRONOLOGICAL BIBLIOGRAPHY

Mickey, W. V., 1963. Operation Pre-Dribble, Seismic Effects of 1000 L b H-E Detonations in Salt and Sedimentary Deposits. Manuscript, U.S. Department of Commerce, Coast and Geodetic Survey, Washington, D.C., August. On file at: Technical Reports Library, Lawrence Livermore National Laboratory, Livermore, CA.

Fenix & Scisson, Inc., and Petroleum Consultants, 1964. Project Dribble, Critical Hole Summary, Tatum Dome, Lamar County, Mississippi. Report to U.S. Atomic Energy Commission, Nevada Operations Office, from Fenix & Scisson, Inc. and Petroleum Consultants, Tulsa, OK and Houston, TX, January. On file at; Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

U.S. Department of Defense and U.S. Atomic Energy Commission, 1964. Project Dribble. Manuscript, U.S. Department of Defense, Hattiesburg, MS; and U.S. Atomic Energy Commission, Las Vegas, NV, August 1. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas NV; and Technical Reports Library, Lawrence Livermore National Laboratory, Livermore, CA.

U.S. Atomic Energy Commission and U.S. Department of Defense, 1964. Press Release, Subject: Project Dribble, from U.S. Department of Energy and U.S. Department of Defense, September 10.

Gardner, M. C., and C. E. Downs, 1971. Evaluation of the Project Dribble Site, Hattiesburg, Mississippi, for Disposition, Including Identification of Restrictions, Part I. Report to U.S. Atomic Energy Commission, Nevada Operations Office, from Earth Sciences and Engineering, Teledyne Isotopes, Palo Alto, CA, March. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV00067650 and Technical Reports Library, Lawrence Livermore National Laboratory, Livermore, CA.

3.14 PRE-GNOME

Plowshare Program
High Explosives Seismic Experiment
New Mexico

Project Pre-Gnome was a high explosive seismic study conducted prior to Project Gnome, a nuclear experiment designed primarily for studying the feasibility of converting nuclear explosive energy into heat for the production of electrical power. Other objectives for the Gnome nuclear test included investigating the viability of recovering radioisotopes from the underground cavity that could be used for scientific and industrial applications, contributing important data on underground nuclear detonations in a new medium (salt), and making neutron measurements that would contribute to scientific knowledge and the reactor development program. The U.S. Geological Survey conducted the Project Gnome site selection study in the spring and early summer of 1958. Sites in salt beds in the Gulf Coast, Michigan, Colorado, and New Mexico were considered with the final choice in southeastern New Mexico, 25 miles southeast of Carlsbad in Sec. 34, T23S R30E, in Eddy County. The shaft was located at the exact center of Sec. 34.

The U.S. Atomic Energy Commission had a Panel of Consultants whose members were chosen based on the recommendation of the National Academy of Sciences. This panel reviewed the geology, hydrology, seismology, and safety of proposed projects. At a November 19, 1958 Project Gnome meeting in Carlsbad, the panel recommended that an initial study be conducted prior to the Gnome test. At a meeting of the U.S. Atomic Energy Commission and the Potash Industry in Carlsbad on November 21, 1958, the decision was made to perform a series of chemical high explosive tests at the Gnome site (Figure 3.14-1). The purpose was to compare ground motion effects from normal mining activities with the seismic disturbance created by larger detonations in order to scale the magnitude of the nuclear seismic signal at the mines in the area. The high explosive blasts would also provide calibration data for the upcoming Gnome shot. Project Pre-Gnome began in December 1958. The seismic work included the U.S. Coast and Geodetic Survey taking measurements inside three nearby potash mines in order to document the magnitude and characteristics of shock from routine mining operations, such as ore train movements and blasting. The U. S. Geological Survey also monitored six routine mine blasts in the Duval Sulphur and Potash Company mine. The schedule for Pre-Gnome was: 1) December 15, 1958, background seismographs operating in three mines; 2) January 30, 1959, drill hole completed; 3) January 30, 1959, all seismographs in place and working; and 4) February 2, 1959, first detonation of a 0.10-ton high explosive.

Originally, the plan specified the detonation of three charges, starting with a small yield of 0.10 ton of TNT equivalent, increasing to 1 ton, and finally 10 tons. The yield of the final shot, however, was changed to 5 tons TNT equivalent when the Gnome experiment was reduced. Detonation of the Pre-Gnome experiments was planned for a depth of

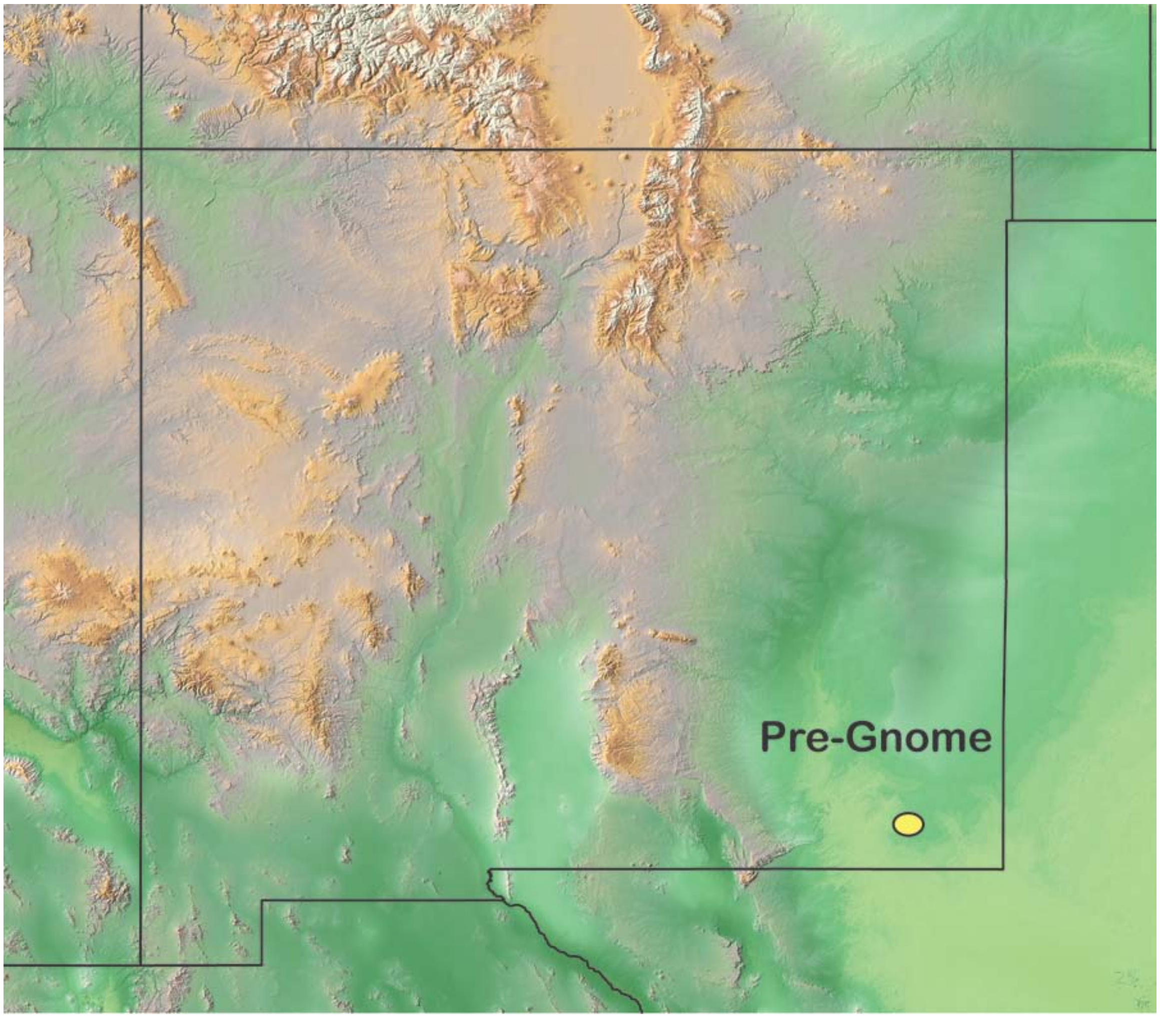


Figure 3.14-1. Location of Project Pre-Gnome in New Mexico (adapted from USA Relief Maps 2004).

1,200 ft (the same depth as Gnome) in a location 502 ft bearing 40.4° from the Gnome shaft. After the Pre-Gnome tests, the high explosives site could be converted to the device room for the Gnome test. The Pre-Gnome emplacement hole was 12 inches in diameter and lined with casing through the upper 20 ft of the salt deposit (Figure 3.14-2). W. D. Brininstool Drilling Company of Carlsbad, New Mexico and Waters Drilling Company of Artesia, New Mexico drilled the shot hole for the Pre-Gnome experiment, completing it on Feb. 7, 1959. The U.S. Army Engineer Waterways Experiment Station stemmed the hole with grout materials. Two types of seismic monitoring equipment were used both at surface stations and at locations in existing area mines. The U.S. Coast and Geodetic Survey and U.S. Geological Survey monitored the seismic stations. The U.S. Bureau of Mines supervised the handling, emplacement, and detonation of the high explosive charges. Edgerton, Germeshausen and Grier, Inc. was in charge of the timing and firing mechanisms for the experiments.

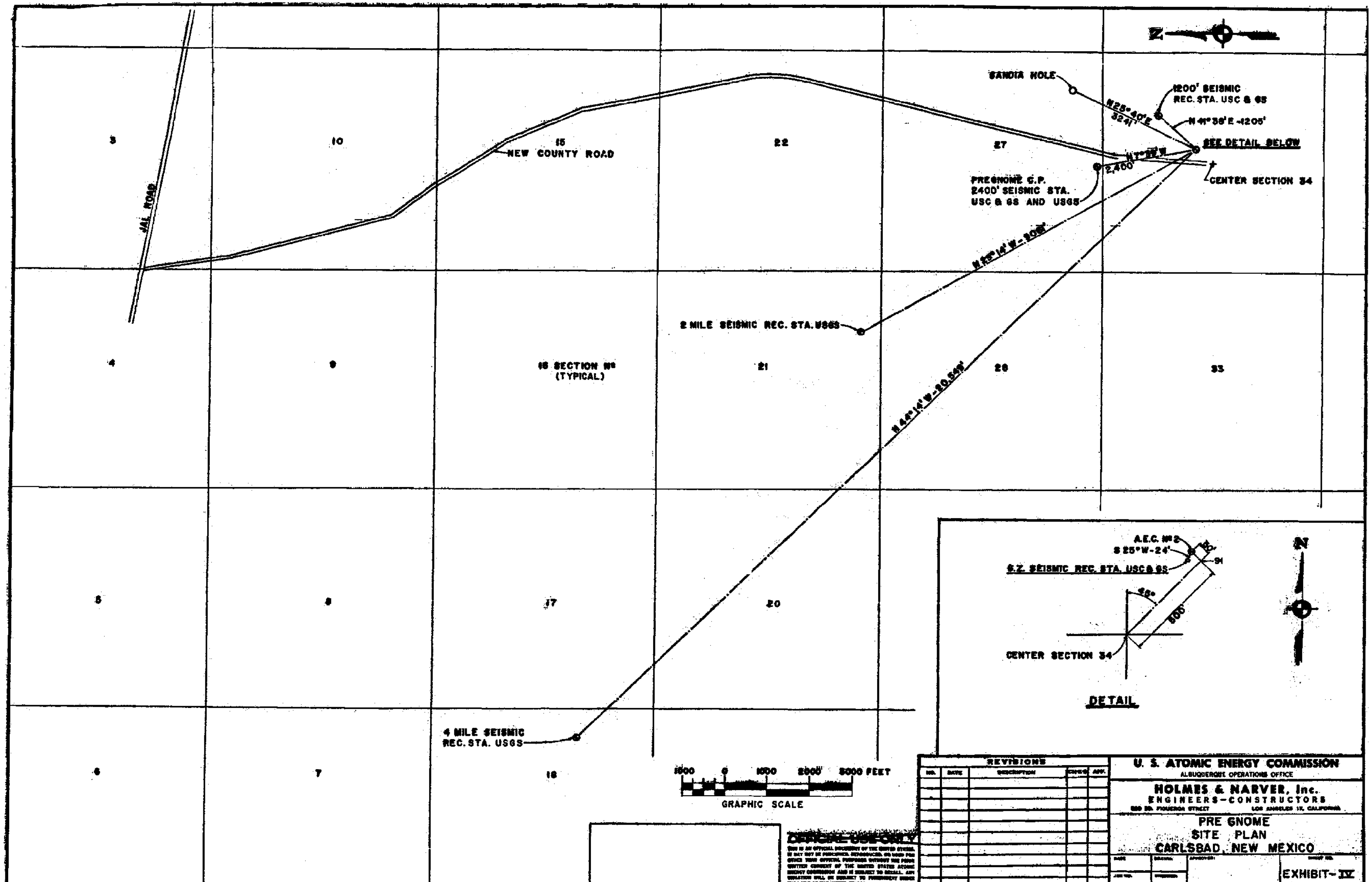


Figure 3.14-2. Location of seismic stations for Project Pre-Gnome (best available copy) (Holmes & Narver, Inc. [1959], no drawing number).

THIS PAGE INTENTIONALLY LEFT BLANK

The Project Pre-Gnome high explosive tests were conducted on February 10, 1959 (180 lbs), February 12, 1959 (750 lbs), and February 16, 1959 (6,260 lbs). All three were Pelletol or pelletized TNT charges, detonated at the bottom of the 1,200-ft hole. After each shot, the cavity was surveyed, washed with saturated brine, and resurveyed. The seismic data from the tests showed that the ground motion of the salt deposits was very different from the ground motion at nuclear explosions in the tuff of the Oak Spring formation at the Nevada Test Site.

Project Pre-Gnome was a Level 2 activity that concluded with high explosive detonations.

CHRONOLOGICAL BIBLIOGRAPHY

Denton, Vern, 1958. Memo with encl. (Pre-Gnome Annex to Gnome Operational Plan, manuscript) from Vern Denton, Lawrence Radiation Laboratory, to Distribution, December 5. On file at: Lawrence Berkeley Laboratory, Berkeley, CA, File 434-900157, 2/18.

Pre-Gnome Operational Plan, 1959. Pre-Gnome Operational Plan. Manuscript, January 23. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0015503.

Roller, J. C., S. W. Stewart, W. H. Jackson, R. E. Warrick, and P. Edward Byerly, 1959. Seismic Measurements by the U.S. Geological Survey during the Pre-Gnome High Explosive Tests: A Preliminary Summary. U.S. Department of the Interior, Geological Survey, Trace Elements Memorandum Report No. 774. Washington, D.C. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0009280 [OUO].

Holmes & Narver, Inc., 1959. "USC&GS and USGS Seismic Stations, Location Plan, Pre-Gnome." Drawing No. C-002-C14, June 19. On file at: Engineering Records Library, Nevada Test Site, Mercury, NV [OUO].

Holmes & Narver, Inc., [1959]. "Pre Gnome Site Plan, Carlsbad, New Mexico." Drawing. On file at: Engineering Records Library, Nevada Test Site, Mercury, NV [OUO].

Byerly, P. Edward, S. W. Stewart, and J. C. Roller, 1960. Seismic Measurements by the U.S. Geological Survey during the Pre-Gnome High Explosive Tests Near Carlsbad, New Mexico: Final Report. U.S. Department of the Interior, Geological Survey, Trace Elements Investigations Report No. 761. Washington, D.C. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

U.S. Atomic Energy Commission. Albuquerque Operations Office, 1961. Background Information on Project Gnome. Pamphlet, Project Gnome Organization, June 1. On file at: Archives and Research Center, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0015450.

Lawrence Radiation Laboratory, 1961. Technical Director's Operation Plan - Project Gnome. Manuscript, Lawrence Radiation Laboratory, July 24. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0015505.

Swift, L. M., 1963. Intermediate Range Earth Motion Measurements, Project Gnome: Final Report. Report to U.S. Atomic Energy Commission, Report PNE 111F, from Stanford Research Institute, Menlo Park, CA, December 10. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Shafer, David S., William. C. Beck, Dwight Treadwell, and Stephen. A. Mellington, 1995. Inventory of Potential Environmental Restoration Liabilities Associated with Plowshare And Vela Uniform Program Sites. Manuscript, U.S. Department of Energy, Office of Environmental Restoration. On file at: Desert Research Institute, Las Vegas, NV.

U.S. Department of Energy. Nevada Operations Office, 1997. Plowshare Program Executive Summary. Report from U.S. Department of Energy, December 22.

3.15 PRE-GONDOLA

Plowshare Program
High Explosives for Waterway Construction
Montana

As conceived and executed, Project Pre-Gondola was a phased series of chemical high explosive single- and row-charge cratering experiments conducted in weak, wet clay-shale. The tests occurred near the edge of the Fort Peck Reservoir in northeastern Montana (Figure 3.15-1). The project was part of the joint U.S. Atomic Energy Commission-U.S. Army Corps of Engineers Plowshare nuclear excavation research program. Designed to investigate the cratering characteristics and behavior associated with large-scale explosions in a various media, the data gathered from these experiments would be used to develop practical construction applications for massive high explosive detonations and eventually nuclear detonations. Possible nuclear applications included waterway and harbor construction as well as reservoir creation. Additionally, Pre-Gondola was to serve as a precursor to the proposed Project Gondola (see Chapter 4.17) nuclear excavation experiment that was planned for a location in eastern Montana, northern Nevada, or South Dakota.

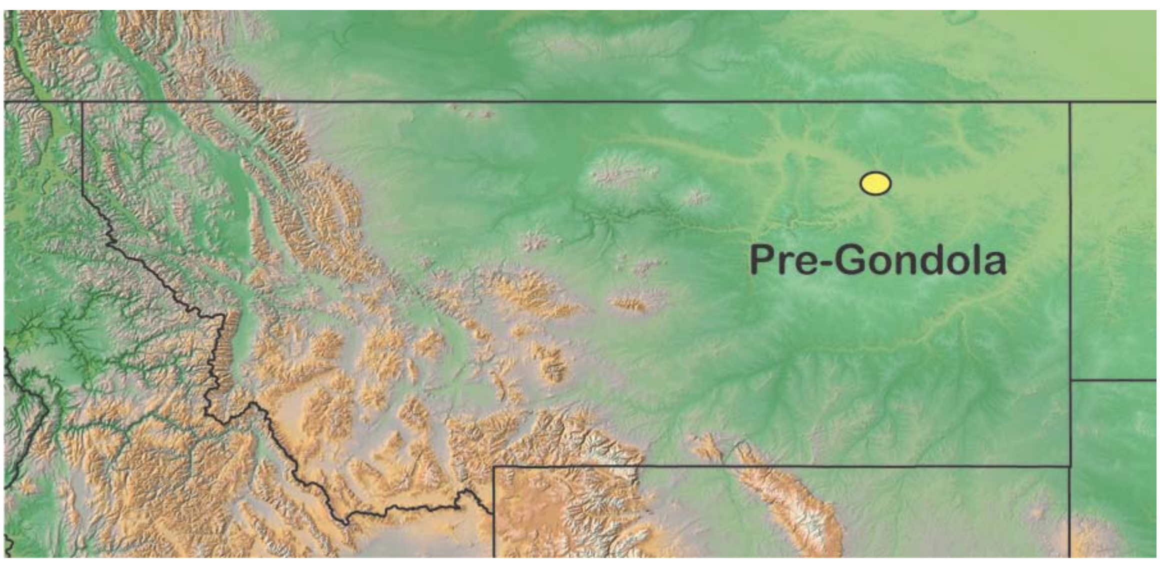


Figure 3.15-1. Location of Project Pre-Gondola in Montana (adapted from USA Relief Maps 2004).

The Pre-Gondola experimental concept focused on acquiring data for a medium likely to be encountered in the actual nuclear excavation of a Trans-Isthmanian Canal. Creation of an alternative to the existing Panama Canal was a presidential priority during the Johnson Administration (1963-1969) and the Plowshare Program earthmoving experiments were crucial to refining the engineering concepts needed for nuclear canal building. The U.S. Atomic Energy Commission was particularly interested in investigating geologic formations similar to the Cucaracha shale of Panama. Numerous delays in the nuclear experimental program made high explosive experiments an attractive and expedient alternative for obtaining the required cratering data and developing appropriate excavation techniques. Both the U.S. Atomic Energy Commission and the U.S. Army Engineer Nuclear Cratering Group already had substantial experience with high explosive cratering experiments having recently completed the Pre-Buggy I, Pre-Schooner I, and Pre-Schooner II projects.

The Nuclear Cratering Group initiated the search for an appropriate test venue in January 1966 beginning with background office research. This involved the review of geologic maps to identify surface outcrops of thick shale formations in the continental U.S. Based on these data, fourteen potential sites were chosen for field investigations consisting of short reconnaissance trips lasting between a few hours to two days. The fourteen identified were:

1) Fort Peck Reservoir, Montana
2) Cedar Ridge, Wyoming
3) Edgemont, South Dakota
4) Powder River, Wyoming
5) Pierre, South Dakota
6) Malta, Montana
7) Sunshine Reservoir, Wyoming
8) Camp Shelby, Mississippi
9) Camp Chaffee, Arkansas
10) Pat Mayes Reservoir, Texas
11) Camp Robinson, Arkansas
12) Grenada Reservoir, Mississippi
13) Camp Gruber, Oklahoma
14) Flaming Gorge, Wyoming

Field visits conducted between February and March 1966 by Nuclear Cratering Group personnel and staff from the U.S. Army Corps of Engineers, Omaha District, resulted in the identification of three potential locations. The primary site selected was along the Missouri River at the Fort Peck Reservoir in Montana. The two alternate sites were Cedar Ridge in Crock County, Wyoming and Edgemont in Fall River County, South Dakota.

The Fort Peck location is on the south fork of Duck Creek Sec. 11, T25N R39E, Valley County, Montana (Figure 3.15-2). This site lies entirely within the land withdrawn for the reservoir and is administered by the U.S. Army Corps of Engineers. The surrounding land is part of the Charles M. Russell National Wildlife Refuge and is managed by the U.S. Department of Fish and Wildlife.

The Cedar Ridge, Wyoming location is in northeastern Wyoming in Crook County, Sec. 20, T56N R67W. With the exception of the privately owned NE1/4NE1/4, Sec. 20, the Cedar Ridge site is on Bureau of Land Management grazing land.

The Edgemont, South Dakota alternate sits along Alkali Creek in southwestern Fall River County and included the N1/2, Sec. 27 and NE1/2, Sec. 28, T11S R1E. Most of the land fell within the Black Hills National Forest administered by the U.S. Forest Service, but there were a few privately owned parcels.

Subsurface explorations occurred at only the primary site and the Edgemont alternative. Six sample bore holes were drilled to a depth of about 100-ft at the

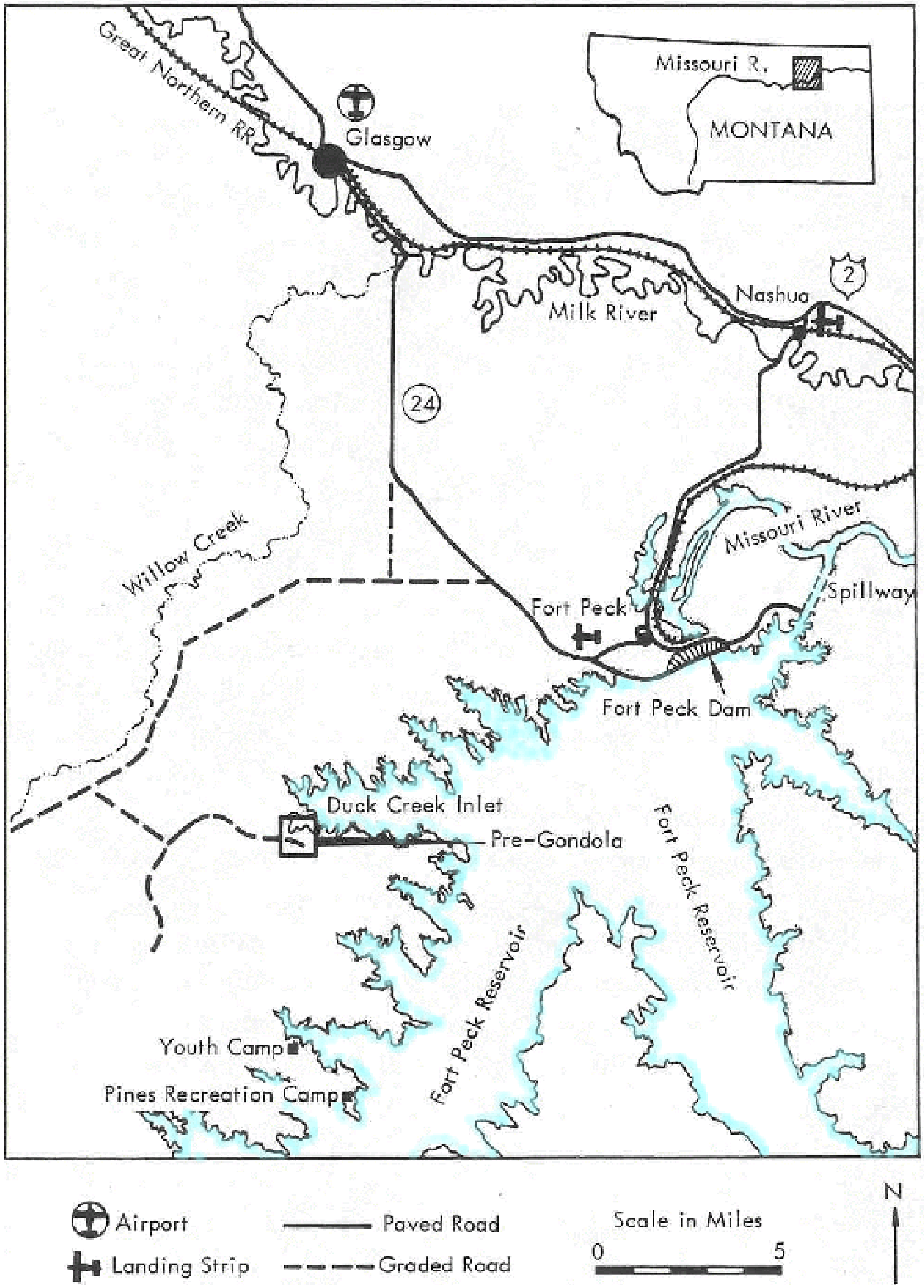


Figure 3.15-2. Access to the Pre-Gondola site (adapted from Kurtz and Redpath 1968, Figure 1).

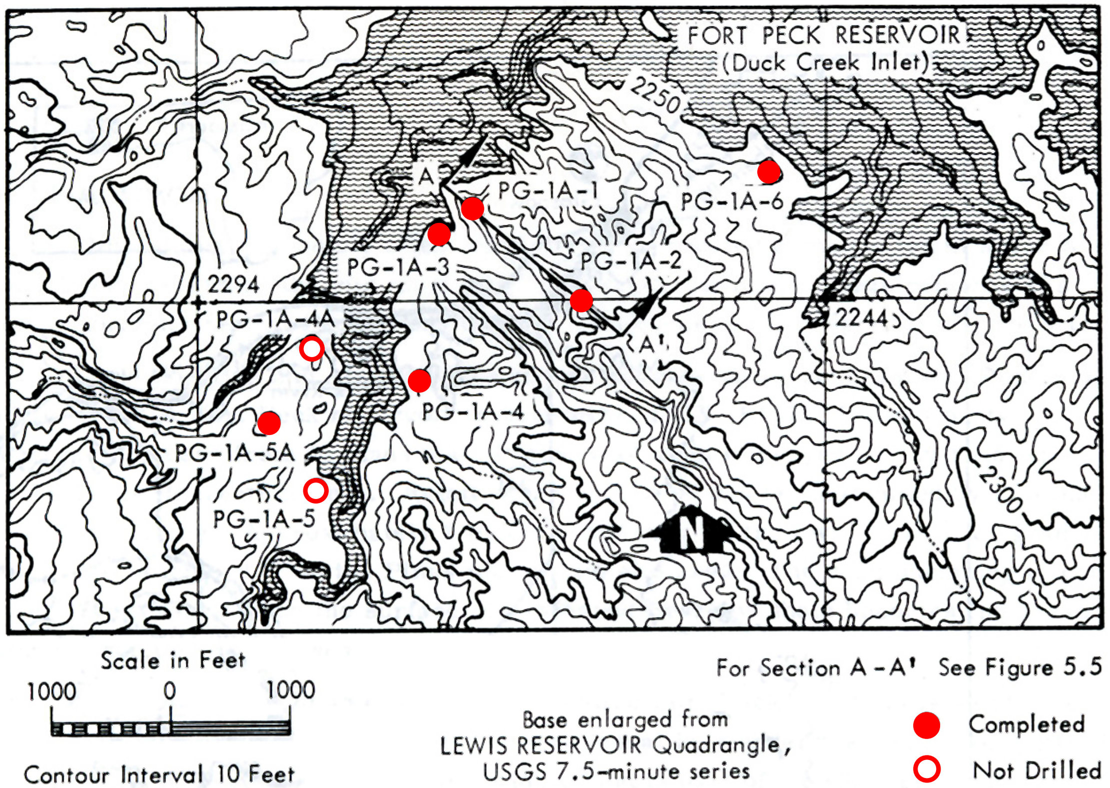


Figure 3.15-3. Locations of the site characterization bore holes at Fort Peck (adapted from Jack and Dudley 1967, Figure 5.2).

Fort Peck site (Figure 3.15-3) and one was drilled at Edgemont. The sampling program took place during April and May, 1966. Based on the results of sample drill holes, the U.S. Army Corps of Engineers concluded that the Fort Peck Reservoir site best satisfied the project requirements. The uncemented, soft compaction Bearpaw shale formation closely resembled the Panamanian Cucaracha shale. A lack of overburden and the saturated condition of the substrate due to its proximity to the reservoir also contributed to the site's suitability. In June 1966, the Corps recommended the Montana location as the preferred area for the Pre-Gondola experiments.

With the final site location identified, planning for Pre-Gondola began. Specific objectives and technical programs for each phase of the experiment were finalized. The Nuclear Cratering Group took primary responsibility for project operations and Lawrence Radiation Laboratory assumed the lead for the technical concept and scientific issues. Edgerton, Germeshausen, and Grier provided scientific and documentary photography. Environmental Science Services Administration contributed the meteorological data. Lawrence Radiation Laboratory also handled explosive assembly, safety, and timing and firing systems. The Nuclear Cratering Group and the U.S. Army Corps of Engineers, Omaha Engineer District provided engineering and construction support as well as site security and public relations.

An extensive series of technical programs was scheduled for the experimental detonations. The Nuclear Cratering Group, the U.S. Army Engineer Waterways Experiment Station, Lawrence Radiation Laboratory, and Montana State University conducted seismic studies, including preshot geophysical measurements, microbarograph measurements, ground motion, and structure response investigations. Sandia Laboratories and the Army Ballistics Research Laboratory provided the expertise for the air-blast investigations. The Stanford Research Institute, Edgerton, Germeshausen, and Grier, and the Nuclear Cratering Group conducted most of the cloud development studies. The Montana Fish and Game Department completed a biological monitoring program. The Nuclear Cratering Group undertook engineering properties and crater studies.

The final design for Project Pre-Gondola was a multiphase experiment consisting of three separate series – Pre-Gondola I, II, and III – with multirow and multilinear detonations. The experiments, using various sizes of high explosive charges, were placed in the wet clay shale from about 15 to 43-ft in depth and produced craters up to 80-ft in diameter and 30-ft deep. In addition to the three named phases, there was a preliminary series of seismic calibration detonations conducted prior to Pre-Gondola I, a decoupling experiment executed between Pre-Gondola I and Pre-Gondola II, and a series of flat-slope array detonations and calibration tests conducted at the start of Pre-Gondola III prior to Phase I (see Table 3.15-1). Table 3.15-1 lists the various Pre-Gondola test series and Figures 3.15-4 and 3.15-5, which are keyed to the far left column of the table, provide the blast locations.

Designed to address safety concerns about the Fort Peck Dam, the Pre-Gondola Seismic Site Calibrations series investigated ground motion effects by detonating four 1,000-lb nitromethane charges at various depths (Figure 3.15-4, nos. 1a-1d). Completed in June 1966, results of these tests provided crater dimension data and enabled predictions of the seismic effects on the Fort Peck Dam so the much larger 20-ton Pre-Gondola I experimental series could take place. The data also helped refine the charge configuration and emplacement design for Pre-Gondola I.

The next stage of the Pre-Gondola experiments, Pre-Gondola I, consisted of four 20-ton chemical cratering experiments conducted between Oct. 25 and Nov. 4, 1966 (Figure 3.15-4, nos. 2a-2d). Designated Alpha, Bravo, Charlie, and Delta, the four shots were spherical charges of liquid nitromethane detonated between 42 and 57-ft below the ground surface in the wet clay-shale Bearpaw Formation. These four detonations were essentially larger scale calibration tests for the upcoming 140-ton Pre-Gondola II row-charge experiment. The results of the tests revealed that detonations in wet shale produced craters much deeper and wider than those created in alluvium or basalt. The charge configuration and depth of emplacement for the upcoming Pre-Gondola II were revised to reflect the Pre-Gondola I data. Technical programs conducted for Pre-Gondola I included crater studies, engineering properties investigations, seismic studies, and cloud development research.

Table 3.15-1. Pre-Gondola Detonations

MAP KEY	EVENT	DATE	YIELD (TONS)	LONGITUDE	LATITUDE
		SEISMIC SITE CALIBRATION SERIES			
1a	SC-1	June 20, 1966	0.5	W 106°38'30.573"	N 47°55'48.383"
1b	SC-2	June 22, 1966	0.5	W 106°38'20.792"	N 47°55'48.181"
1c	SC-3	June 22, 1966	0.5	W 106°38'29.495"	N 47°55'44.579"
1d	SC-4	June 21, 1966	0.5	W 106°38'35.059"	N 47°55'53.380"
		PRE-GONDOLA I SERIES			
2a	Bravo	Oct. 25, 1966	19.36	W 106°38'24.894"	N 47°55'46.154"
2b	Charlie	Oct. 28, 1966	19.62	W 106°38'29.974"	N 47°55'53.294"
2c	Alfa	Nov. 01, 1966	20.35	W 106°38'15.325"	N 47°55'46.570"
2d	Delta	Nov. 04, 1966	20.24	W 106°38'38.134"	N 47°55'48.077"
		SEISMIC DECOUPLING EXPERIMENT			
n/a	SD-1 (coupled)	June 14, 1967	0.5	W 106°37'57.000"	N 47°55'33.000"
n/a	SD-2 (decoupled)	June 14, 1967	0.5	W 106°37'56.000"	N 47°55'36.000"
		PRE-GONDOLA II EXPERIMENT			
3	Single row, 5-charge array, (E, F, G, H, I)	June 28, 1967	~140	W 106°38'31.000"	N 47°55'51.000"
		PRE-GONDOLA III FLAT SLOPE EXPERIMENT,			
4	Array #1:Triple row, two- pass array - outside rows (14 charges), inside row (7 charges)	June 18, 1968 June 20, 1968	21 charges, each charge 64-lbs, 0.67 tons total	no data	
5	Nine Single-charge Calibration Shots (A, B, C, D, E, F, G, H, and I)	Late June 1968	9 individual 64-lb shots, 0.29 tons total	no data	
4	Array #2: Triple row, two- pass array - outside rows (14 charges), inside row (7 charges)	July 01, 1968 July 02, 1968	21 charges, each charge 64-lbs, 0.67 tons total	no data	
4	Array #3: Triple row, two- pass array - outside rows (14 charges), inside row (7 charges)	June 18, 1968 July 22, 1968	21 charges, each charge 64-lbs, 0.67 tons total	no data	
		PRE-GONDOLA III EXPERIMENT, PHASE I			
7	Eight Single-charge Calibration Shots (A, B, C, D, E, F, G, and H)	Sept. 5, 1968	8 charges, 1-ton each, ~8 tons total	see Figure 3.15-5	
6	Phase I, Alpha -triple row, two-pass array - outside rows (14 charges), inside row (7 charges)	Sept. 25, 1968 Oct. 02, 1968	21 charges, 1-ton each, ~21 tons total	see Figure 3.15-5	
		PRE-GONDOLA III EXPERIMENT, PHASE II			
8	Single row, 7-charge array	Oct. 30, 1968	~210	W 106°38'31"	N 47°55'46"
		PRE-GONDOLA III EXPERIMENT, PHASE III			
9	Six single row charge arrays, 5 to 9-charge arrays	August and October 1969	30-54 charges,1-ton each, ~30-54 tons	see Figure 3.15-5	
10	Single row, 5-charge array	Oct. 30, 1969	~70	W 106°38'31"	N 47°55'46"

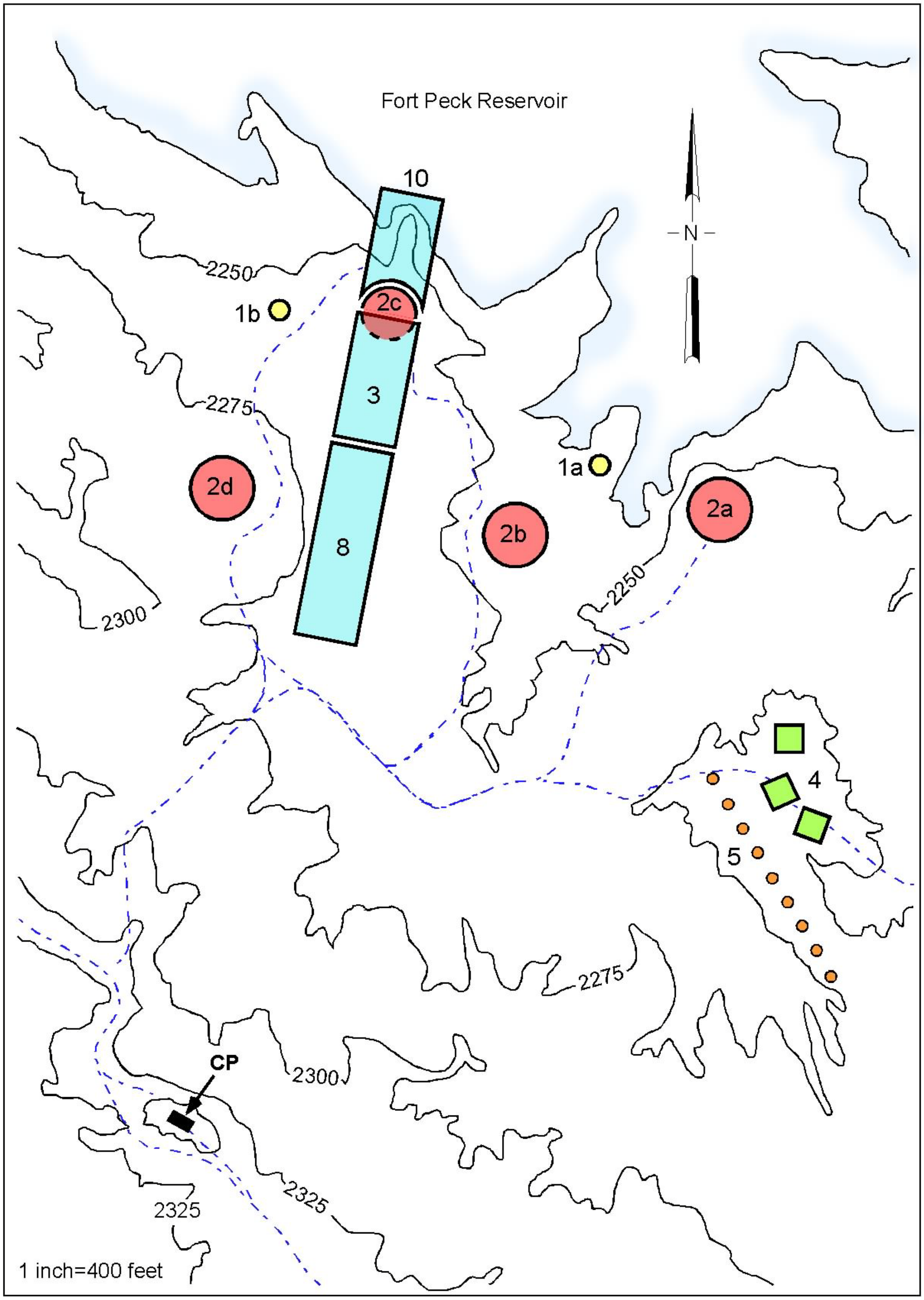


Figure 3.15-4. Layout for the eastern (main) portion of the Project Pre-Gondola experiments conducted at the edge of the Fort Peck Reservoir. See Table 3.15-1 for the key to the experiment locations (adapted from Lawrence Radiation Laboratory. U.S. Army Engineer Nuclear Cratering Group 1969, no figure number).

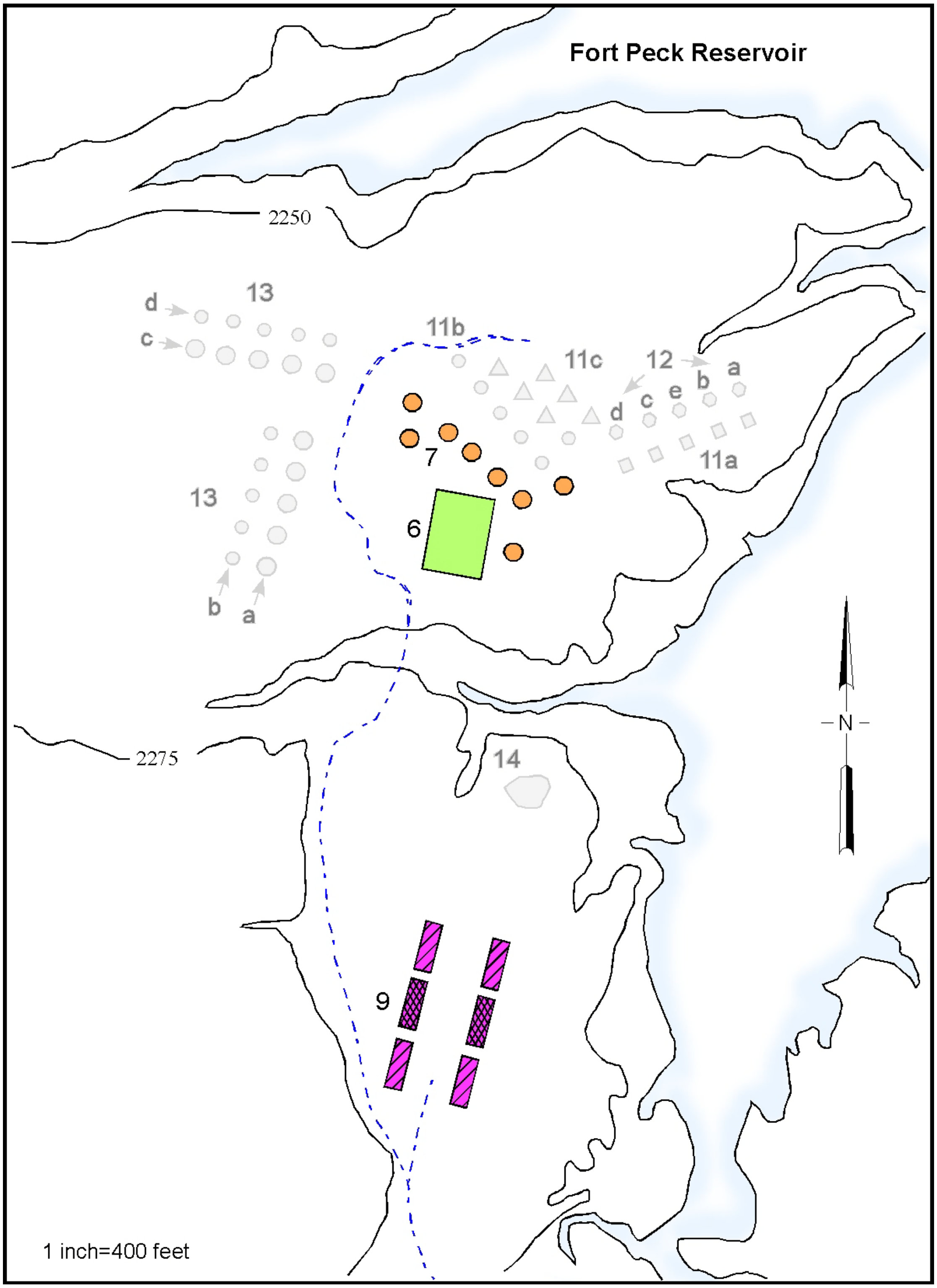


Figure 3.15-5. Layout for the western (secondary) portion of the Project Pre-Gondola experiments conducted at the edge of the Fort Peck Reservoir. The grayed-out shot locations are from Project Trencher (See Chapter 3.22) conducted in August 1969. See Table 3.15-1 for the key to the experiment locations (adapted from Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group 1969, no figure number).

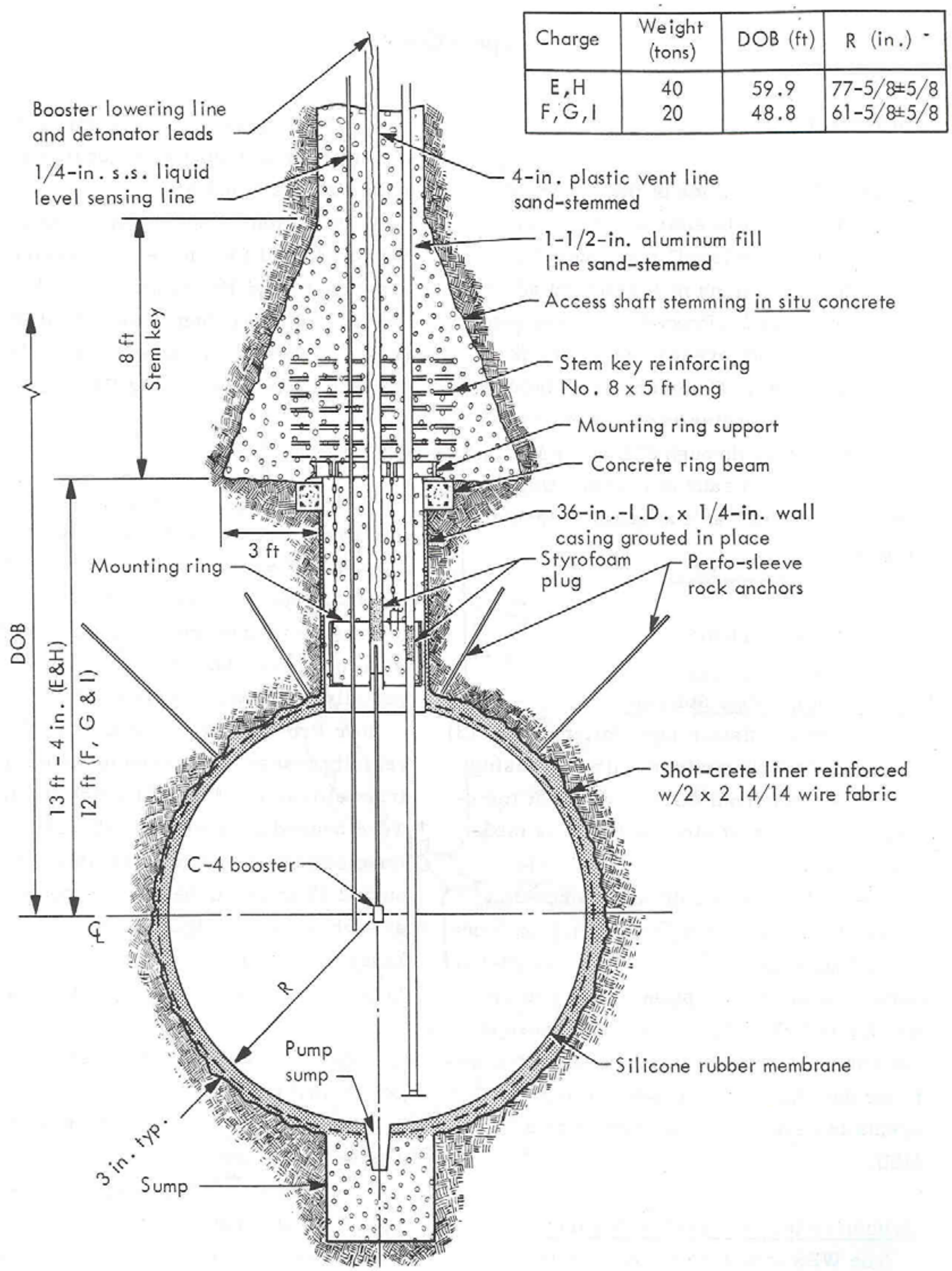
Just prior to Pre-Gondola II, a seismic decoupling experiment took place on June 14, 1967 (Table 3.15-1). Comprised of two 1,000-lb detonations, one coupled and the other decoupled, the test's purpose was to determine if detonating a charge separated or "decoupled" from the surrounding rock could increase crater dimensions. The decoupling experiments were conducted about 1,000 ft southeast of the Pre-Gondola I Alfa shot.

Pre-Gondola II, executed two weeks later on June 28, 1967, was a 140-ton row charge experiment consisting of two 40-ton charges and three 20-ton charges (Figure 3.15-6). The resulting trench connected with the crater produced by the Pre-Gondola I Charlie shot (Figure 3.15-4, no. 3). The specific design objectives for Pre-Gondola II included connection of the row crater to the existing "Charlie" crater and the excavation of a navigable channel 67 ft wide that could be extended through additional high explosive detonations. Researchers were interested in investigating the characteristics of a row charge detonation in the saturated clay-shale medium. They also wanted to examine the effects associated with connecting the row detonation crater with an existing crater. Like the studies conducted for Pre-Gondola I, the Pre-Gondola II technical programs included crater studies, engineering properties investigations, seismic studies, and cloud development research as well as air blast tests and biological monitoring. Investigators also bored a series of 17 pre-shot sample drill holes and 17 post-shot drill holes in order to better characterize the cratering characteristics of the multi-shot event.

The next series, the Flat-Slope experiment, consisted of multiple 64-lb charges and provided data on crater dimension in respect to depth of burst for TNT charges and as a preliminary test for the Pre-Gondola III Phase I Alpha test in clay shale. The Flat-Slope test program consisted of three, triple-row array experiments and one series of nine single-charge calibration shots (Table 3.15-1). The row-charge tests all consisted of 21 charges arranged in three rows of seven charges. These experiments were originally designed solely on the basis of a series of small scale 1-lb single charge detonations, designated Project Zulu. The Zulu studies were conducted in the sand pit facility at the Lawrence Radiation Laboratory's Site 300 in Tracy California. The first field test of the Site 300 data, Array #1, did not produce the flat-sloped linear crater as expected, so a series of nine single charge calibration shots were fired to gather data for redesigning Arrays 2 and 3. Adjustments to the depth of burst, between row spacing, and in-row charge spacing made on the basis of the calibration shot data resulted in a successful outcome for the last two Flat Slope experiments. The exact location of the Flat Slope detonations is unknown, but they were in the Pre-Gondola project area.

Building on the Flat Slope data, another series of eight, much larger, calibration blasts were conducted prior to designing the final shot configuration for the Pre-Gondola, Phase I experiment (Table 3.15-1). The 1-ton calibration shots were detonated between August and September 1968 adjacent to the planned Phase I array site (Figure 3.15-5, no. 7).

The Pre-Gondola III, Phase I Alpha experiment involved the phased detonation of twenty-one 1-ton nitromethane charges (Figure 3.15-5, no.6). The final arrangement consisted of three parallel rows, each comprised of seven charges. The two outside rows were detonated simultaneously on September 25, 1968. Detonation of the center row



Charge	Weight (tons)	DOB (ft)	R (in.)
E,H	40	59.9	77-5/8±5/8
F,G,I	20	48.8	61-5/8±5/8

Figure 3.15-6. Cross section of chemical charge for Project Pre-Gondola (Kurtz and Redpath 1968, Figure 12).

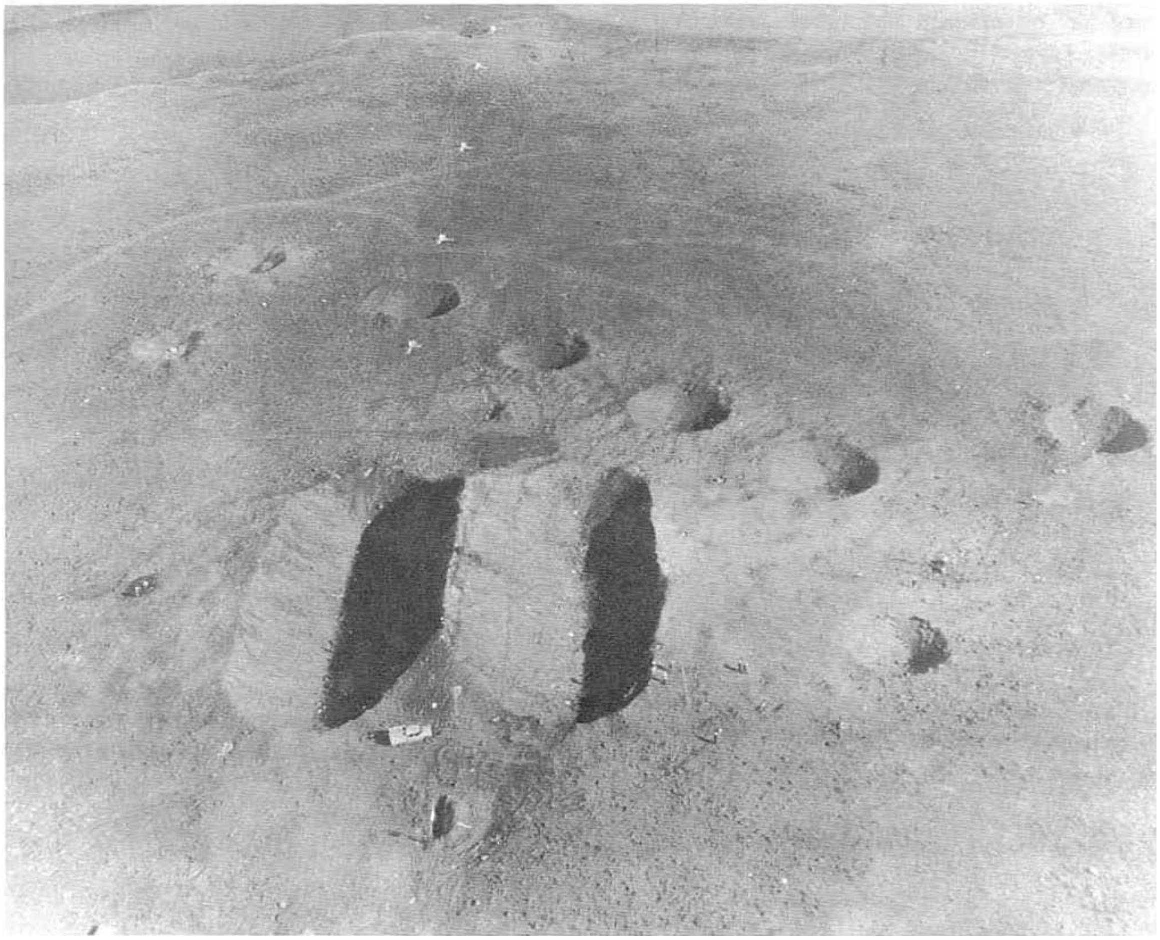


Figure 3.15-7. Aerial view of the Project Pre-Gondola III, Phase I triple-row shot before the detonation of the center row. The surrounding individual craters are from the associated 1-ton calibrations shots (Cress et al. 1970, Figure 7).

occurred a week later on October 2. Unlike the other Pre-Gondola III experiments, the Phase I blast was not intended to connect with another crater. The goal of this experiment was the creation of a linear, flat-sided crater suitable for navigation. It was hoped that these techniques could be applied to nuclear excavation for canal construction. Technical programs included surface motion measurements, cloud development studies and close-in air blast monitoring.

The results of this test revealed that successful excavation of a flat-sided linear crater depended heavily on the configuration and placement of the center row of charges (Figure 3.15-7). The researchers concluded that the center row for this experiment was too shallow. In nuclear excavations, the center row would be emplaced after the two outside rows had been detonated, allowing for adjustments depending on the actual depth of the craters created in the first pass.

Conducted on October 30, 1968, the purpose of the Pre-Gondola III, Phase II experiment was the creation of a linear crater that smoothly connected with the crater excavated by the Pre-Gondola II row charge event (Figure 3.15-4, no.8). This program consisted of a single row of seven 30-ton nitromethane charges spaced at 86 ft intervals at an average depth of 53 ft The resulting blast created a crater 610 ft long with an average width of 191 ft and an average depth of 48 ft. Combined with the pre-existing Pre-Gondola II crater, the total trench length was about 1,100 ft (Figure 3.15-8). Technical programs for Pre-Gondola III, Phase II included crater measurements, surface motion measurements, engineering geology studies, long range air-blast monitoring, seismic measurements, cloud development research, and structure response studies.

Figure 3.15-8. The Pre-Gondola III trench after the detonation of the Phase II row charge. Works crews are shown preparing the emplacement holes for the final explosive series to make the connection to the reservoir c. Sept. 1969 (Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group 1969, no figure number).

The final phase of the Pre-Gondola testing program took place in the late summer and fall of 1969 (Table 3.15-1). The first part of Pre-Gondola III, Phase III consisted of several 1-ton row cratering events conducted on the west side of Duck Creek just south of the Pre-

Gondola III, Phase I triple row experiment (Figure 3.15-5, no. 9). Six separate 5 to 9 nitromethane charge arrays with different charge spacing and burial depths were planned to provide information on row crater enhancement and row crater connections. These detonations were the last opportunity to refine the experiment layout for the upcoming reservoir connection experiment, but only two of the arrays were detonated (Figure 3.15-9).

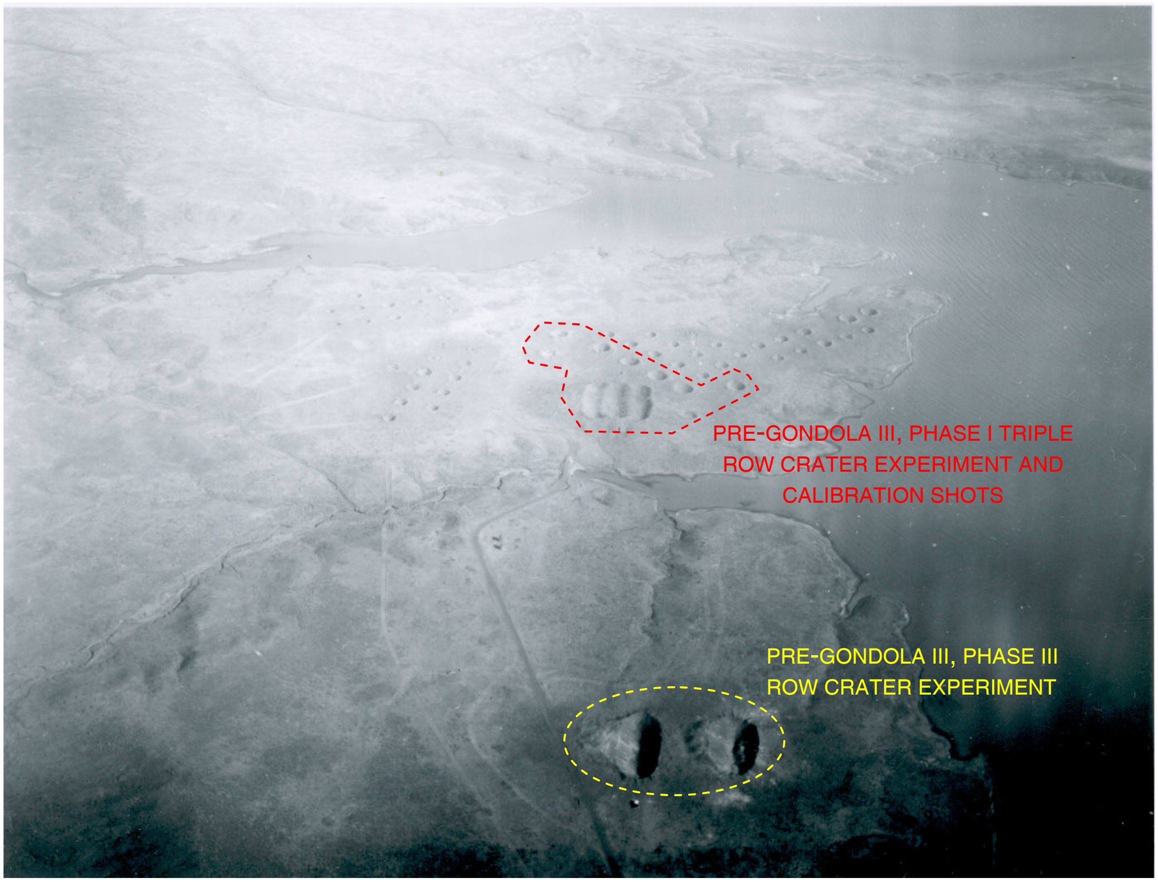


Figure 3.15-9. Aerial view (Nov. 3, 1969) of the Project Pre-Gondola experiments on the west side of Duck Creek. The pair of Pre-Gondola III, Phase III row charge experiments are visible in the center foreground and the Pre-Gondola III, Phase I triple-row charge and eight 1-ton calibration shot craters are visible in the mid-ground center. Additional craters are from Project Trencher (See Chapter 3.22) (adapted from Photo No. CFP70-1269 on file at the U.S. Army Corps of Engineers, Fort Peck Area Office, Montana).

The last experiment of the Pre-Gondola project took place on October 6, 1969. The second part of Pre-Gondola III, Phase III consisted of the row charge detonation designed to link the existing linear crater alignment with the Fort Peck Reservoir (Figure 3.15-4, no. 10). A linear array of five charges totaling 70 tons removed the last earth barrier between the reservoir and existing trench. Much of the mounded material in the barrier had been created by the fall back and ejecta from previous Pre-Gondola detonations. Instead of nitromethane, this experiment used aluminized ammonium nitrate as the blasting agent, which proved to have a cratering effectiveness

Figure 3.15-10. Aerial view of the Pre-Gondola experiment trench, Nov. 3, 1969. The large Pre-Gondola I Alfa, Bravo, and Delta craters are clearly visible. Two of the seismic calibration craters, SC-1 and SC-4 can also be seen (Photo No. CFP70-1272 on file at the U.S. Army Corps of Engineers, Fort Peck Area Office, Montana).

approximately 1.6 times that of TNT. The experiment successfully breached the wall of the reservoir filling the 1,300-ft long crater with water in about 9 minutes (Figure 3.15-10). Once the trench filled, the Corps of Engineers sailed a 42-ft long tugboat into the channel to demonstrate its navigability (Figure 3.15-11).

The documentation that exists concerning the facilities constructed for the Pre-Gondola experiment is primarily in the form of maps and photographs (Figure 3.15-12). The main control point comprised of several structures (portable trailers) was established on a knoll south of the detonation area (Figure 3.15-13). The helicopter pad was directly south of the control point and a contractor's staging area was to the west. Although much of the blast photography was done from a helicopter, at least three ground-based camera stations were built. A mobile camera trailer positioned below (northeast) of the control point supplemented the fixed cameras. A temporary building east of the control point housed the

Figure 3.15-11. U.S. Army Corps of Engineers tugboat “James” navigating the Pre-Gondola channel, Nov. 3, 1969 (Photo No. CFP70-1261 on file at the U.S. Army Corps of Engineers, Fort Peck Area Office, Montana).

meteorological monitoring and weather balloon inflation pad. A fenced enclosure surrounded the nitromethane storage and booster assembly compound which was approximately 2,800 ft south of the control point. The storage compound included separate facilities for chemical explosives and detonators as w ell as an earthen blast berm. Instrument stations were distributed across the landscape. These included a cloud tracking station, air samplers, and wind towers. Temporary ground motion and air overpressure monitoring stations were erected in close proximity to ground zero for each of the detonations. Fifteen intermediate range seismic stations and five structural response instrument stations recorded ground effect and air overpressure data at the Fort Peck Dam complex and in the surrounding area. Most of these instrument stations and the drilling apparatus for the emplacement holes were removed at the conclusion of the project. The large, multi-ton Pre-Gondola detonations took place on the southeast side of the reservoir’s Duck Creek Inlet. The smaller shots took place on the west side of the inlet (Figures 3.15-5 and 3.15-13). A secondary control point was established for these shots.

U.S. Army Corps of Engineers and Lawrence Livermore researchers concluded that the Pre-Gondola series achieved its stated objectives and successfully demonstrated the

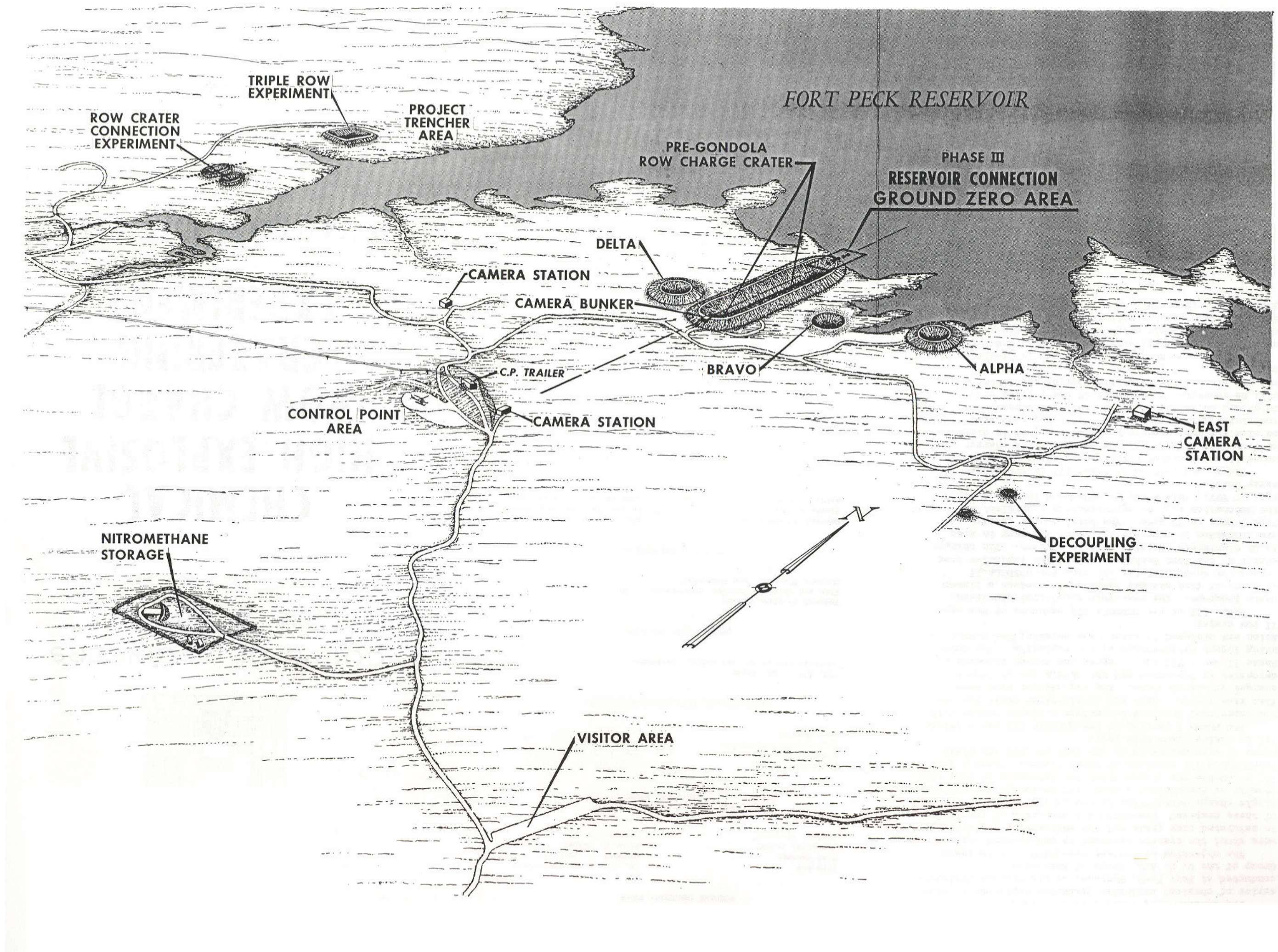


Figure 3.15-12. Layout of the Pre-Gondola site (U.S. Army Corps of Engineers 1969, no figure number).

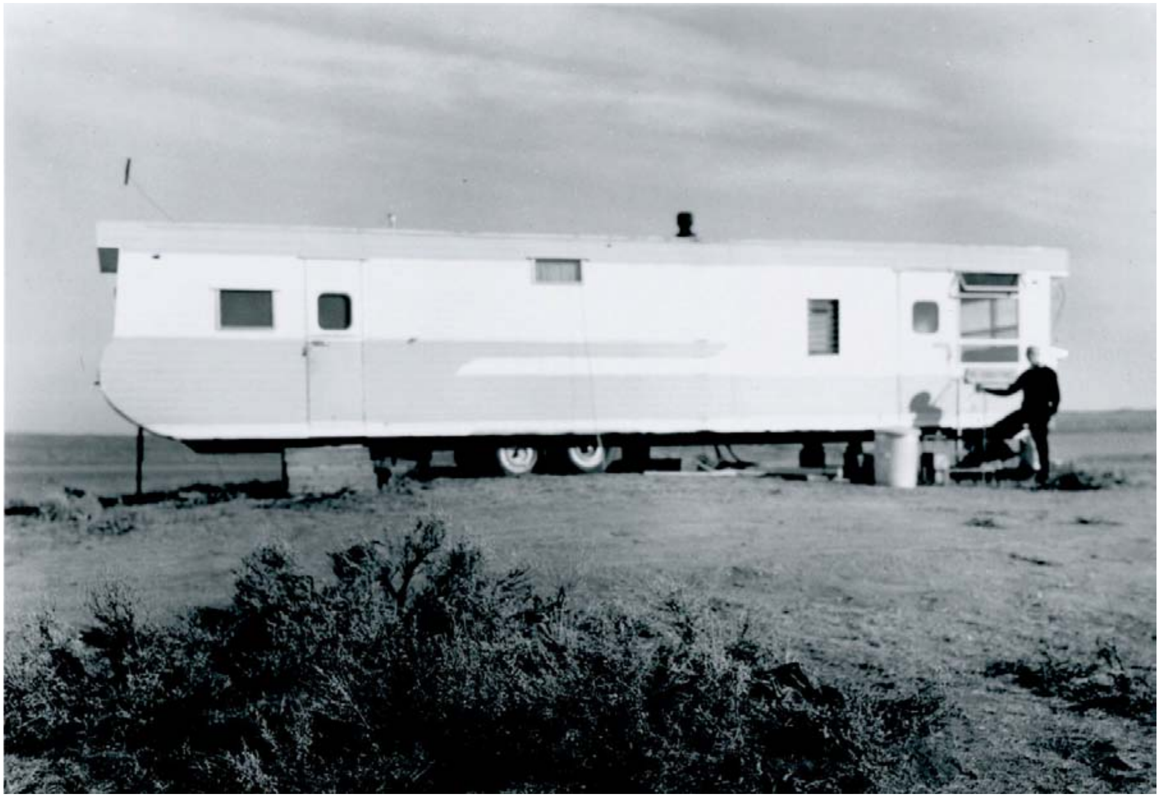


Figure 3.15-13. The U.S. Army Corps of Engineers office trailer at Control Point No.1 for Project Pre-Gondola, Oct. 2, 1968 (Photo No. FP-2916 on file at the U.S. Army Corps of Engineers, Fort Peck Area Office, Montana).

potential application of explosive excavation for waterway construction. The experiments yielded solid data on the cratering characteristic and behavior of high explosive detonations in a saturated medium. The cratering research also furnished valuable models for the configuration of effective explosive arrays in later high explosive trials. Both the Trinidad railway cut excavation in Colorado and the Tugboat small boat harbor project in Kawaihae Bay, Hawaii utilized results from the Pre-Gondola experiments to develop appropriate excavation designs. The data were also used for planning the proposed, but never executed, Gondola nuclear cratering experiment (see Chapter 4.17).

Shortly after the conclusion of the experiment, most of the heavy equipment, scientific instrumentation, and portable trailers were removed from the Pre-Gondola project area. Some of the small storage sheds, however, and many of the instrument station enclosures and stands were left in place. None of the craters were backfilled at this time. The Pre-Gondola and Trencher project areas were eventually remediated during the summer of 1972, when the U.S. Army Corps of Engineers was cleaning up after the conclusion of the nearby Project Diamond Ore experiment, a series of military high explosive cratering tests conducted in 1971 and early 1972. At the request of the U.S. Fish and Wildlife Service and the Charles M. Russell Wildlife Refuge, the Corps removed the remaining structures from the Pre-Gondola site and backfilled the larger craters (Figure 3.15-14).

Project Pre-Gondola was a Level 2 activity. Conventional chemical explosives were used for all of the calibration detonations and explosive excavation experiments. The Pre-Gondola site was visited in FY2004.

Figure 3.15-14. The Pre-Gondola project site after remediation work conducted in the summer of 1972. The Alfa, Bravo, and Delta craters have been backfilled while the small calibration craters SC-2, SC-3, and SC-4 were not filled. Photo taken Sept. 27, 1973 (adapted from Photo No. 904, Box 977 on file at the U.S. Army Corps of Engineers, Fort Peck Area Office, Montana).

FIELD VISIT

The Pre-Gondola location is in a remote part of northeastern Montana, near Fort Peck Reservoir. Five days (June 14-18, 2004) were allocated for travel to and from the area, work at the locations, and research time at the local U.S. Army Corps of Engineers Office. Pre-Gondola was a very large project that involved the detonation of high explosive charges and the creation of a new inlet at Fort Peck Reservoir. The project area encompassed approximately 450 acres. A total of between 138 and 146 charges were detonated there. Twenty-seven were single shots and the remainder were used in row arrays. Most of the Pre-Gondola detonations were conducted north or northeast of the control point and east of Duck Creek. The Pre-Gondola III, Phase I experiments, however, were conducted on the west side of the Duck Creek drainage near the Project Trencher site (see Chapter 3.22). The first experiment in Pre-Gondola III, Phase III was also conducted in this area. The report authors relocated and recorded the current field conditions of the Pre-Gondola activity areas, including the control point and other facility locations. The inlet trench created by the Pre-Gondola II and Pre-Gondola III row charge

Figure 3.15-15. Project Pre-Gondola experimental row-charge trench at Fort Peck Reservoir, Montana. Because of an extended drought and a record-low water level, the 1,100 ft long trench is currently isolated from the reservoir (photo taken June 2004 on file at Desert Research Institute).

arrays dominates the landscape (Figure 3.15-15). At over 1,100 ft long and 200 ft wide, it is surrounded by enormous mounds of ejecta and fallback making it appear even larger. As a result of a severe multi-year drought and falling water levels, the inlet is no longer connected to the reservoir. Water remains trapped within the trench, but is probably no more than 10-12 ft deep at most. Debris from the blasts is scattered across the sides of the trench and includes portions of charge casings, emplacement hole pipe, stemming material, rebar, concrete, wire, conduit, braided steel cable and miscellaneous metal and rubber fragments (Figure 3.15-16). A built-up staging area at the north end of the inlet is once again visible because of the low-water level. Similar debris is strewn across this area. Most of the secondary single-shot craters are still clearly visible at the Pre-Gondola site, too. A few are just wide, shallow, sedge-filled depressions like the Alpha, Bravo, and Delta craters (Figure 3.15-17), but others, like several of the calibration shots, are more than 10 ft deep and steep-sided (Figure 3.15-18). A light background scatter of debris from the detonations covers much of the area, with the heaviest concentrations occurring around the craters (Figure 3.15-19).

Figure 3.15-16. Interior of the Project Pre-Gondola trench. Debris from the detonations is scattered across the sloped walls (photo taken June 2004 on file at Desert Research Institute).

Figure 3.15-17. The Alfa Crater from Pre-Gondola I series of 20-ton cratering experiments (photo taken June 2004 on file at Desert Research Institute).

Figure 3.15-18. One of the seismic calibration craters from Project Pre-Gondola (photo taken June 2004 on file at Desert Research Institute).

Figure 3.15-19. Debris from experiment staging activities and the detonations is scattered across the Project Pre-Gondola site area (photo taken June 2004 on file at Desert Research Institute).

Throughout the project area, rebar and mounting posts remain in place from the numerous ground motion and air overpressure stations erected to monitor the explosions (Figure 3.15-20).

Much of the area between the crater locations has been disturbed (Figure 3.15-21). Numerous dirt roads criss-cross the terrain linking the graded staging areas and camera stations with the shot locations. General construction and industrial debris, such as lumber, corrugated metal, conduit, wire, glass, plywood, and pipe sections are present in the staging areas and surrounding the former control point location. Because of road closures the nitromethane storage area, which appears as a large graded area south of the control point, could only be observed from a distance. Its current condition is unknown, but it is probably much like the rest of the project area.

Access to the site is through land administered by the Charles M. Russell Wildlife Refuge. The roads are poorly maintained, heavily rutted and virtually impassable when wet. The site can only be reached with a four-wheel drive vehicle.

Figure 3.15-20. Many targets from the Project Pre-Gondola ground motion studies remain in place (photo taken June 2004 on file at Desert Research Institute).

Figure 3.15-21. Dirt roads link the numerous staging areas, instrument stations, and shot locations (photo taken June 2004 on file at Desert Research Institute).

CHRONOLOGICAL BIBLIOGRAPHY

Slazak, Walter J., 1965. "Status Report - Nuclear Explosives Studies for Civil Construction (Reports Control Symbol ENGCW-E-9)." Memo with encl. ("Status Report, Effective Date: 31 December 1964 - ENGCE-E-9") from Walter J. Slazak, Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, to Chief of Engineers, Department of the Army, January 15. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029.

U.S. Army Corps of Engineers. Omaha District, 1966. Press Release, Subject: Announcement that Pre-Gondola cratering experiments are scheduled for June; from U.S. Army Corps of Engineers, June 14. On file at: Fort Peck Archives, U.S. Army Corps of Engineers, Fort Peck, MT, Box 917.

Project Pre-Gondola, 1966. Project Pre-Gondola. Manuscript, June 17. On file at: Fort Peck Archives, U.S. Army Corps of Engineers, Fort Peck, MT, Box 917.

U.S. Army Corps of Engineers. Fort Peck, 1966. Pre-Gondola, High Explosive Chemical Calibration Series. Manuscript, Fort Peck, MT, October. On file at: Fort Peck Archives, U.S. Army Corps of Engineers, Fort Peck, MT, Box 935.

Lawrence Radiation Laboratory. U.S. Army Engineer Nuclear Cratering Group, 1966. Technical Director's Operation Plan for 20 Ton Cratering Calibration Series, Project Pre -Gondola I. Manuscript, October 7. On file at: Fort Peck Archives, U.S. Army Corps of Engineers, Fort Peck, MT, Box 935.

Power, Dean V., 1966. Intermediate Range and Special Structures Seismic Measurements: Pre-Gondola Seismic Site Calibration Series. Manuscript, University of California, Lawrence Radiation Laboratory, October 17. On file at: Technical Reports Library, Lawrence Livermore National Laboratory, Livermore, CA (cover page only).

Rabb, David D., 1966. Plowshare Program, July 16, 1966 – October 31, 1966, Vol. II, No. 3. University of California, Lawrence Radiation Laboratory, *Report UCRL-*50008-66-2, October 31. Livermore, CA. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-030.

Pre-Gondola Craters, 1966. Pre-Gondola Craters. Labeled Photo, November 4. On file at: Fort Peck Archives, U.S. Army Corps of Engineers, Fort Peck, MT, Box 935.

U.S. Atomic Energy Commission, 1967. Chapter 11 - Plowshare Program. In *Annual Report to Congress of the Atomic Energy Commission for 1966,* pp. 239-258, January. U.S. Atomic Energy Commission, U.S. Government Printing Office, Washington D.C.

Jack, H. A., and W. W. Dudley, 1967. Project Pre-Gondola, Site-Selection Investigations. Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, *Report PNE* 1101, February. Livermore, CA. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

U.S. Army Corps of Engineers. Omaha District, 1967, "Pre-Gondola II, Control Point Layout Plan , Power and Signal." Drawing No. SS3-30E 5.1, February 23. On file at: Fort Peck Archives, U.S. Army Corps of Engineers, Fort Peck, MT, Box 858.

Rabb, David D., 1967. Plowshare Program February 1, 1967 – April 30, 1967, Vol. II, No. 5. University of California, Lawrence Radiation Laboratory, *Report UCRL-*50008-67-2, April 30. Livermore, CA. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-030.

Kurtz, Maurice K., 1967. "Pre-Gondola Seismic Decoupling Series." Letter with encl. (Technical Director's Operation Plan for Seismic Decoupling Series, Project Pre-Gondola, Manuscript, U.S. Army Engineer Nuclear Cratering Group) from Maurice K. Kurtz, Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, to Distribution, May 8. On file at: Fort Peck Archives, U.S. Army Corps of Engineers, Fort Peck, MT, Box 935.

Lawrence Radiation Laboratory. U.S. Army Engineer Nuclear Cratering Group, 1967. Technical Director's Operation Plan for Project Pre-Gondola II, A Wet Medium 140 Ton Row Charge Cratering Experiment in Varying Terrain. Manuscript, May 17. On file at: Fort Peck Archives, U.S. Army Corps of Engineers, Fort Peck, MT, Box 935.

U.S. Army Corps of Engineers. Fort Peck, 1967. Pre-Gondola II, Chemical High Explosive Row Charge Cratering Experiment. Manuscript, Fort Peck, MT, June. On file at: Fort Peck Archives, U.S. Army Corps of Engineers, Fort Peck, MT, Box 935.

Power, Dean V., 1967. Project Pre-Gondola I, Intermediate Range Ground Motions. Lawrence Radiation Laboratory, Report PNE 1105, July. Livermore, CA. On file at: Technical Reports Library, Lawrence Livermore National Laboratory, Livermore, CA (cover page only).

Stearns, R. T., and J. T. Rambo, 1967. Project Pre-Gondola I, Preshot Geophysical Measurements. Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, Report PNE 1111, July. Livermore, CA. On file at: Technical Reports Library, Lawrence Livermore National Laboratory, Livermore, CA (cover page only).

Ballard, Robert F., 1967. Project Pre-Gondola I, Structures Instrumentation. Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, Report PNE 1106, August. Livermore, CA. On file at: Technical Reports Library, Lawrence Livermore National Laboratory, Livermore, CA (cover page only).

Kurtz, Maurice K, Jr., and Walter Day, 1967. A Report of the Scope and Preliminary Results of Project Pre-Gondola II, Row Charge Cratering Experiment. Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, *NCG Technical Memorandum* No. NCG/TM 67-9, August 14. Livermore, CA. On file at: Fort Peck Archives, U.S. Army Corps of Engineers, Fort Peck, MT, Box 935.

Day, Walter C., and Robert F. Rohrer, 1967. Project Pre-Gondola I, Cloud Development Studies. Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, Report PNE 1108, September. Livermore, CA. On file at: Technical Reports Library, Lawrence Livermore National Laboratory, Livermore, CA (cover page only).

Harlan, R. W., 1967. Project Pre-Gondola I: Crater Studies: Crater Measurements. Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, Report PNE 1107 Part 1, December. Livermore, CA. On file at: Technical Reports Library, Lawrence Livermore National Laboratory, Livermore, CA (cover page only).

U.S. Atomic Energy Commission, 1967. *Plowshare Program During 1966: Based on the Annual Report to Congress for 1966 of the U.S. Atomic Energy Commission.* U.S. Atomic Energy Commission, U.S. Government Printing Office, Washington, D.C. On file at Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029; and Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

U.S. Atomic Energy Commission, 1968. Chapter 11 - The Plowshare Program. In *Annual Report to Congress of the Atomic Energy Commission for 1967,* pp. 199-208, January. U.S. Government Printing Office, Washington, D.C.

Hughes, Bernard C., 1968. "Status Report - Nuclear Explosives Studies for Civil Construction (RCS ENGCW-P-6 (R-1))." Letter with encl. ("Status Report, Effective Date: 31 December 1967") from Bernard C. Hughes, Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, to Chief of Engineers, Department of the Army, January 13. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029.

Kurtz, Maurice, K., Jr., W. G. Christopher, W. C. Day, P. R. Fisher, R. W. Harlan, B. B. Redpath, and J. C. Chandler, 1968. Project Pre-Gondola: Technical Director's Summary Report. Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, Report PNE 1102, May. Livermore, CA. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Kurtz, Maurice K., and Bruce B. Redpath, 1968. Project Pre-Gondola, Seismic Site Calibration. Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, Report PNE 1100, May. Livermore, CA. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV and Defense Threat Reduction Information Center, Albuquerque, NM.

Day, Walter C., 1968. "Preliminary Design and Schedule of Decision Point for Project Pre-Gondola III." Memo from Walter C. Day, Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, to Robert Terhune, May 29. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-026.

Toman, John, 1968. "Technical Concept for Project Pre-Gondola III." Memo from John Toman, Lawrence Radiation Laboratory, to B. C. Hughes, June 6. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-026.

Cress, James P., 1968. Preliminary Report: NCG Pre-Gondola III Sixty-Four Pound TNT Flat-Slope Experiments Conducted at Fort Peck, Montana. Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, *NCG Technical Memorandum* No. D143NCG/TM 68-10, July. Livermore, CA. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Pre-Gondola III, Phase I-II, 1968. Pre-Gondola III, Phase I-II. Notes, July 9. On file at: Fort Peck Archives, U.S. Army Corps of Engineers, Fort Peck, MT, Box 825.

Werth, Glenn C., 1968. "Alternate #1, Tentative Schedule – Plowshare Program – LRL Related." Schedule from Lawrence Radiation Laboratory, September 10. On file at: Archives and Records Office, Lawrence Berkeley National Laboratory, Berkeley, CA, File 434-900205, 28/48.

Werth, Glenn C., 1968. "Alternate #2, Tentative Schedule - Plowshare Program - LRL Related." Schedule from Lawrence Radiation Laboratory, September 10. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-118.

Lawrence Radiation Laboratory. U.S. Army Engineer Nuclear Cratering Group, 1968. Project Operation Plan for Project Pre-Gondola III. Manuscript, September 19. On file at: Archives and Research Center, Lawrence Radiation Laboratory, Livermore, CA, File PLO-026.

Sandia Laboratories, 1968. Plowshare Quarterly Progress Report (Period Ending September 30, 1968) . Report to U.S. Atomic Energy Commission from Sandia Laboratories, Albuquerque, NM, September 30. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

King, Kenneth W., 1968. Pre-Gondola III, Phase II, Operations Report, Fort Peck, Montana. Manuscript, U.S. Department of Commerce, Environmental Science Services Administration, Coast and Geodetic Survey, Rockville, MD. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Hipp, Charles L., 1968. "Pre-Gondola Facilities." Letter from Charles L. Hipp, U.S. Army Corps of Engineers, Omaha District, to Area Engineer, Fort Peck, November 12. On file at: Fort Peck Archives, U.S. Army Corps of Engineers, Fort Peck, MT, Box 859.

Christopher, W. G., and J. E. Lattery, 1969. Project Pre-Gondola I, Crater Studies: Surface Motion. Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, Report PNE 1107 Part II, February. Livermore, CA. On file at: Technical Reports Library, Lawrence Livermore National Laboratory, Livermore, CA (cover page only).

U.S. Atomic Energy Commission, 1969. "United States Atomic Energy Commission, Plowshare Program Statement, JCAE FY 1970 Authorization Hearings." Statement from U.S. Atomic Energy Commission, April 18. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-028.

U.S. Army Corps of Engineers. Fort Peck, 1969, Pre-Gondola III, Phase III, Chemical High Explosive Row Charge Cratering Experiment in Saturated Clay. Manuscript, Fort Peck, MT, October. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-026.

Lawrence Radiation Laboratory. U.S. Army Engineer Nuclear Cratering Group, 1969. Summary and Location of Major Cratering Experiments at Fort Peck. Manuscript, Livermore, CA, October 1. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-091.

Hipp, Charles L., 1969. "Wrap-Up Activities, Project Pre-Gondola III, Phase III." Letter from Charles L. Hipp, U.S. Army Corps of Engineers, Omaha District, to Area Engineer, Fort Peck, November 3. On file at: Fort Peck Archives, U.S. Army Corps of Engineers, Fort Peck, MT, Box 859.

Vandenberg, William E., 1969. Letter from William E. Vandenberg, U.S. Army Engineer Nuclear Cratering Group, Lawrence Radiation Laboratory, to Donald C. Beckman, November 11. On file at: Fort Peck Archives, U.S. Army Corps of Engineers, Fort Peck, MT, Box 860.

Day, Walter C., 1969. The Corps of Engineers Nuclear Construction Research Program. *Nuclear Applications and Technology,* Vol. 7, No. 3, pp: 253-268.

U.S. Atomic Energy Commission. Division of Technical Information, 1969. Status of Nuclear Test Reports. U.S. Atomic Energy Commission, Report TID-9533. Washington, D.C. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0105641.

Toman, John, 1970. Summary of Nuclear-Excavation Applications. Paper prepared for Proceedings of the ANS Topical Meeting, Engineering with Nuclear Explosives, Las Vegas, Nevada, January 14-16, 1970. University of California, Lawrence Radiation Laboratory, *Preprint UCRL*-72220, January 29. Livermore, CA. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-104.

Beckman, D. C., 1970. "Inspector's Diary - Survival Hole Work - Pre-Gondola II, Fort Peck, Montana." Transmittal with encl. from R G. Burnett, Area Engineer, Fort Peck Area, to Engineering Division, Omaha District, March 12. On file at: Fort Peck Archives, U.S. Army Corps of Engineers, Fort Peck, MT, Box 825.

Cress, J. P., J. E. Lattery, J. B. Andrews, F. F. Warden, and L. J. Vortman, 1970. Project Pre-Gondola III, Phase I, Summary Report. Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, Report PNE 1114, April. Livermore, CA. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Toman, John, 1970. Summary of Nuclear-Excavation Applications. In *Symposium on Engineering with Nuclear Explosives: Proceedings,* Report CONF-700101, Vol. 1, pp. 245-279, May. American Nuclear Society, Hinsdale, IL.

Vandenberg, William E., and Walter C. Day, 1970. Excavation Research with Chemical Explosives. In *Symposium on Engineering with Nuclear Explosives: Proceedings*, Report CONF-700101, Vol. 1, pp. 360-373, May. American Nuclear Society, Hinsdale, IL.

Bulletin of the Atomic Scientists, 1970. *Bulletin of the Atomic Scientists*, pp. 88-91, June. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029.

Reed, Jack W., 1971. Project Pre-Gondola III Phase III, Connection of a Row Crater to a Reservoir. Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, Report PNE 1120, January. Livermore, CA.

Day, Walter C., editor, 1971. Project Pre-Gondola II Summary Report. Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, Report PNE 1112, February. Livermore, CA. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Lattery, J. E., editor, 1971. Project Pre-Gondola III, Phase II, Summary Report: Connecting Row-Crater Experiment. Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, Report PNE 1117, March. Livermore, CA. On file at: Technical Library, National Nuclear Security Administration, Las Vegas, NV.

Reed, Jack W., 1971. Project Pre-Gondola III, Phase II, Microbarograph Measurements. Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, Report PNE 1118, June. Livermore, CA. On file at: Technical Reports Library, Lawrence Livermore National Laboratory, Livermore, CA (cover page and references only).

LaFrenz, Robert L., 1971. "Status Report - Rapid Excavation with Explosives." Letter with encl. ("Status Report, Effective Date: 30 September 1971") from Robert L. LaFrenz, Explosive Excavation Research Office, Corps of Engineers, to Director, U.S. Army Engineer Waterways Experiment Station, October 29. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-108.

LaFrenze, Robert L., and Walter C. Day, 1972. Explosive Excavation Development for Construction and Combat Applications. U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Office, AD750344. Livermore, CA.

Redpath, Bruce B., 1972. Project Pre-Gondola III, Phase III: Connection of a Row Crater to a Reservoir. U.S. Army Nuclear Cratering Group, Report PNE 1120, January. Livermore, CA. On file at: Technical Reports Library, Lawrence Livermore National Laboratory, Livermore, CA; and Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Laboratory, 1972. "Listing and Publication Schedule of EERO Reports." Schedule from Explosive Excavation Research Laboratory, Livermore, CA, March 31. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-108.

U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Laboratory, 1972. "Technical Reports Published and Distributed During First Three Quarters FY72." Table from Explosive Excavation Research Laboratory, Livermore, CA, March 31. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-108.

Gates, Richard H., 1972. "Site Improvement." Letter from Richard H. Gates, U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Laboratory, to D. Beckman, Area Manager, Fort Peck Lake Area, July 10. On file at: Fort Peck Archives, U.S. Army Corps of Engineers, Fort Peck, MT, Box 858.

Rooke, A. D., Jr., B. L. Carnes, and L. K. Davis, 1974. Cratering by Explosions: A Compendium and an Analysis. U.S. Army Engineer Waterways Experiment Station, Technical Report N-74-1, January. Vicksburg, MS. On file at: Defense Threat Reduction Information Analysis Center, Albuquerque, NM.

McGlaun, J. Michael, 1980. C omputer Modeling of the Pre-Gondola Cratering Experiments. Sandia National Laboratories, Report No. SAND80-1695, September. Albuquerque, NM.

Shafer, David S., William. C. Beck, Dwight Treadwell, and Stephen. A. Mellington, 1995. Inventory of Potential Environmental Restoration Liabilities Associated with Plowshare And Vela Uniform Program Sites. Manuscript, U.S. Department of Energy, Office of Environmental Restoration. On file at: Desert Research Institute, Las Vegas, NV.

U.S. Department of Energy. Nevada Operations Office, 1997. P lowshare Program Executive Summary. Report from U.S. Department of Energy, December 22.

Chandler, James C., [1966]. Proposed Biological Monitoring of the Second Series of Blast at Pre-Gondola I Site, Fort Peck Reservoir, Montana. Manuscript. On file at: Fort Peck Archives, U.S. Army Corps of Engineers, Fort Peck, MT, Box 917.

Lawrence Radiation Laboratory. U.S. Army Engineer Nuclear Cratering Group, [1966]. "Cloud Sampling Station, Pre-Gondola II." Drawing No. SK-NCG-PG-34. On file at: Fort Peck Archives, U.S. Army Corps of Engineers, Fort Peck, MT, Box 858.

Lawrence Radiation Laboratory. U.S. Army Engineer Nuclear Cratering Group, [1966]. "Ground Surface Motion Photo Targets, Pre-Gondola III." Drawing No. SK-NCG-PG-29.1. On file at: Fort Peck Archives, U.S. Army Corps of Engineers, Fort Peck, MT, Box 858.

VIP Visitors - Pre-Gondola II, [1966]. "VIP Visitors - Pre-Gondola II." Table. On file at: Fort Peck Archives, U.S. Army Corps of Engineers, Fort Peck, MT, Box 935.

Lawrence Livermore National Laboratory, n.d. Pre-Gondola photo pg_9. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

U.S. Department of Energy. Nevada Operations Office, n.d. The Plowshare Program (Draft). Report from U.S. Department of Energy.

U.S. Department of the Interior. Bureau of Land Management, n.d. "Status of Public Domain Land and Mineral Titles and Acquired Lands, Mt. Plat, Township 26 North Range 39 East of the Principal Meridian, Montana." Drawings and table pp. 1-5, 8. On file at: U.S. Department of the Interior, Bureau of Land Management, Montana State Office, Billings, MT.

U.S. Department of the Interior. Bureau of Land Management, n.d. "Status of Public Domain Land and Mineral Titles and Acquired Lands, Mt. Plat, Township 25N Range 39E, East of the Principal Meridian, Montana." Tables, pp. 2-3, 5, 7, 9. On file at: U.S. Department of the Interior, Bureau of Land Management, Montana State Office, Billings, MT.

3.16 PRE-SCHOONER II

Plowshare Program
High Explosive Cratering Experiment
Idaho

Initially, Project Schooner was a proposed 100-kt nuclear cratering experiment to be conducted in a hard rock environment off the Nevada Test Site. At some time in the early 1960s, the Bruneau River area in Owyhee County, Idaho was identified as a prospective location. In 1963, the U. S. Geological Survey in Denver conducted fieldwork to study the geological suitability of this area for the test. They looked at several areas previously identified as possible locations between the Bruneau River and its forks covering a total of 720 square miles (T11S R7E, T12S R8E, and T10-13S R7E) in southwestern Idaho. The evaluation was based on five criteria for site selection issued by the project Technical Director on May 3, 1963. Data from at least two drill holes, Bruneau 1 and Bruneau 2, and nearby exploratory probes were used to understand the geology and identify a site location. Bruneau 1 was 4,343 ft deep and Bruneau 2 was 4,475 ft deep. The U.S. Geological Survey concluded that the site area was acceptable but some aspects of the criteria could not be met, e.g., a Control Point with line of sight capabilities.

Pre-Schooner tests were needed to obtain data regarding cratering characteristics in hard rock. Previous detonations in similar media showed significant variability in crater dimensions. Pre-Schooner I was conducted at the Nevada Test Site in February of 1964. The Director of the U.S. Army Engineer Nuclear Cratering Group wrote the manager of the U.S. Atomic Energy Commission on January 26, 1965, to explain that the Group wanted to conduct a high explosives experiment near the proposed Schooner site on the Bruneau Plateau in May or June 1965 (Figure 3.16-1). The letter provided descriptions of the purpose of the detonation, the associated technical programs, support requirements of the Nevada Operations Office, fiscal issues, and the schedule. This marked the inception of Project Pre-Schooner II. Subsequent correspondence between the Nuclear Cratering Group and the U.S. Atomic Energy Commission resulted in the Nuclear Cratering Group submitting a formal project proposal on April 12, 1965. An agreement between the two agencies establishing the field schedule and operational organization was finalized in July. Funding for the experiment came from the U.S. Army Corps of Engineers civil works appropriations.

Pre-Schooner II was considered part of the joint Atomic Energy Commission – Corps of Engineers nuclear excavation research program. The purpose of Pre-Schooner II was to help eliminate some of the uncertainty associated with crater dimension predictions in a hard, dry rock medium. In addition, Pre-Schooner II was a correlation shot for the proposed Schooner test. The objectives were: 1) improve knowledge of cratering in a hard, dry rock and to provide information for the emplacement design and operational safety for the Schooner event; 2) provide data on cratering physics that could be used in theoretical calculations programs; 3) give agencies an opportunity to test new scientific

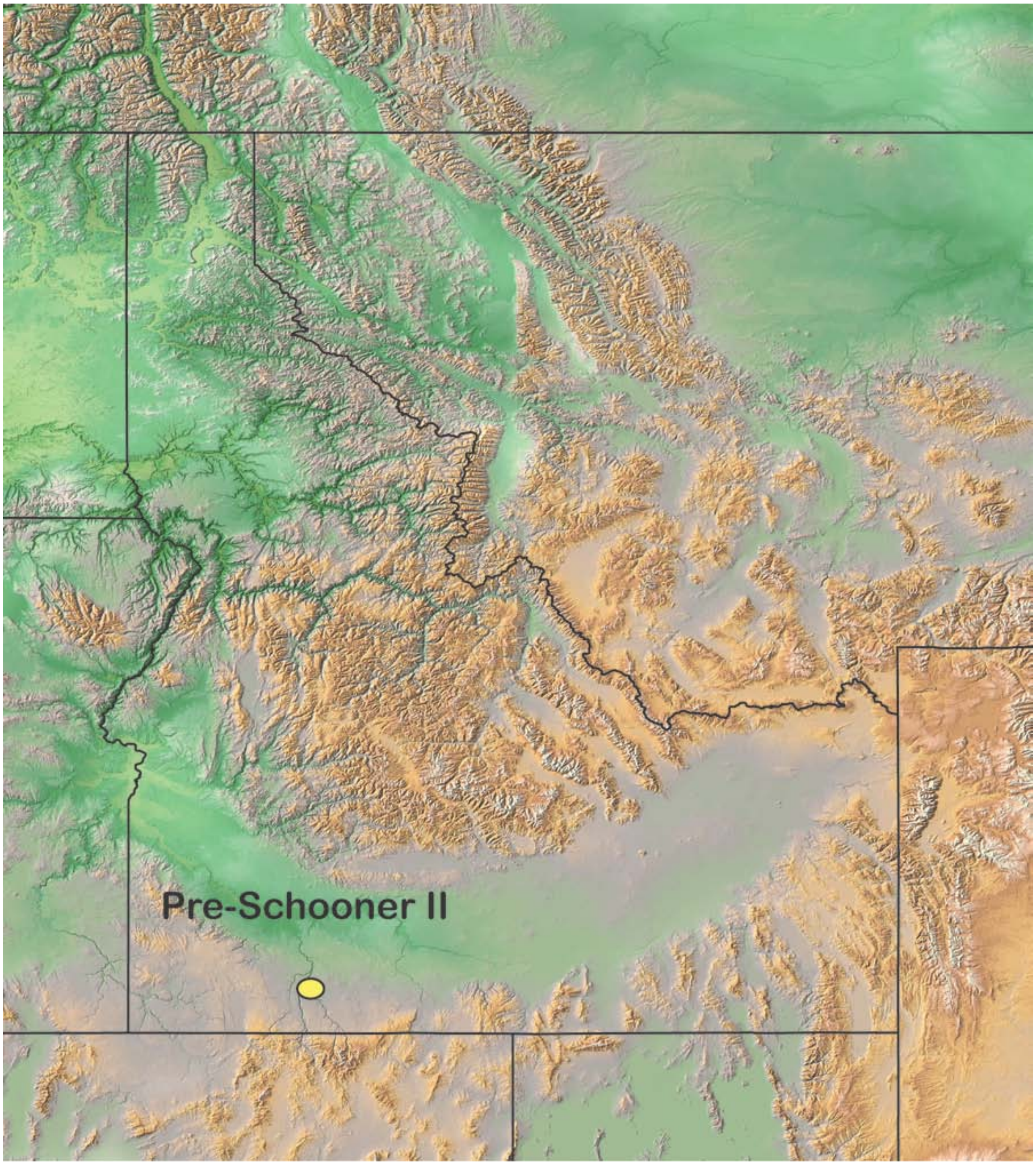


Figure 3.16-1. Location of Project Pre-Schooner II in Idaho (adapted from USA Relief Maps 2004).

instrumentation and techniques to evaluate their suitability for nuclear cratering tests; and 4) provide data on the engineering properties of the crater for studies regarding the engineering usefulness of explosion-produced craters.

The U.S. Army Engineer Nuclear Cratering Group identified five potential Pre-Schooner II locations after review of published data and a February 1965 field reconnaissance (Figure 3.16-2). All five met the site selection criteria: 1) proximity to the Schooner site;

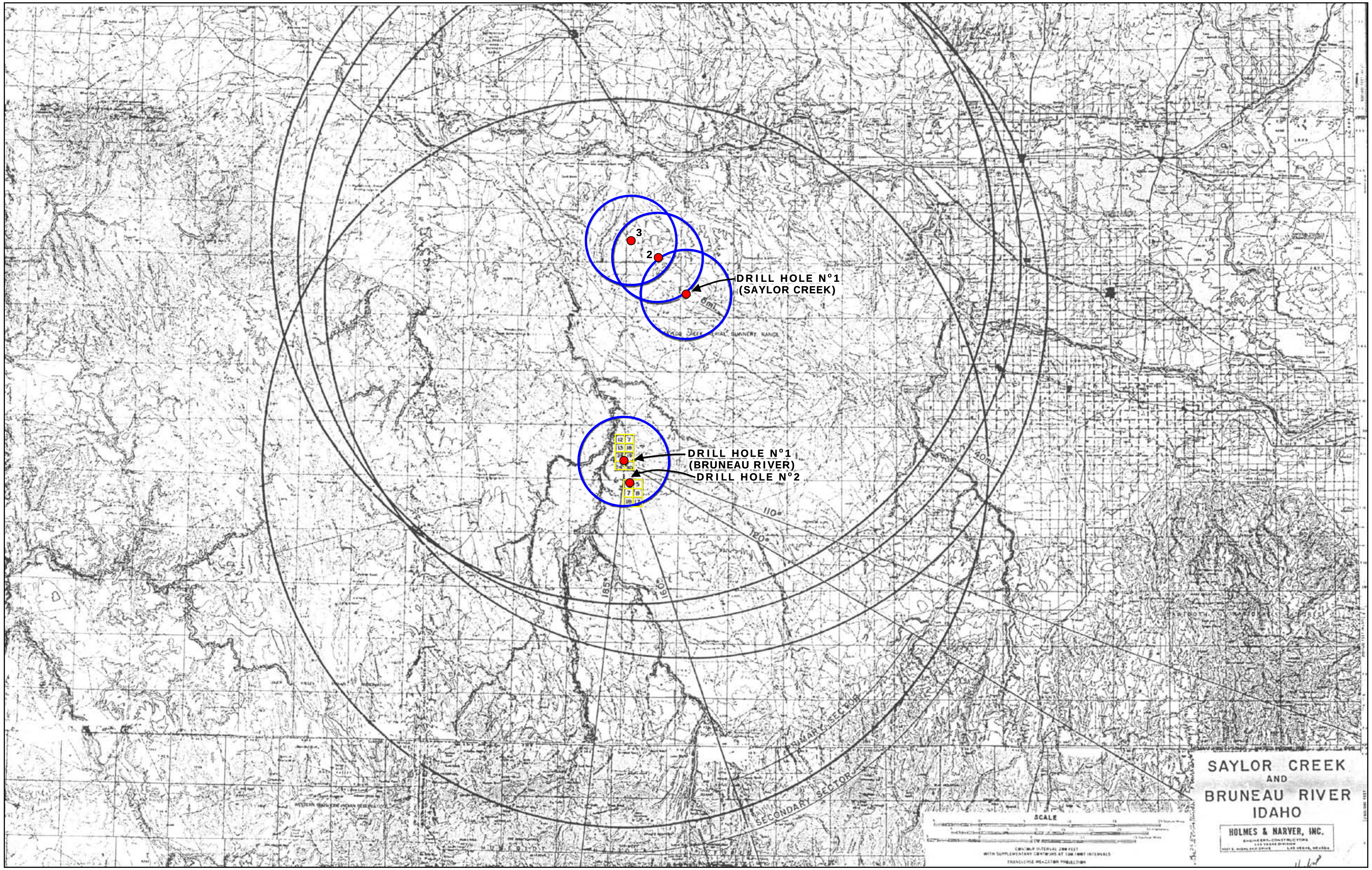


Figure 3.16-2. Some of site selection drill hole locations for the Pre-Schooner II experiment (adapted from Holmes & Narver, Inc. [1965b], no drawing number).

THIS PAGE INTENTIONALLY LEFT BLANK

2) rock similar to the Schooner site, 3) minimum overburden; 4) flat topography; and 5) topography favorable for photography. Field studies to select the test location were carried out in March 1965. The U. S. Army Engineer Waterways Experiment Station and the Nuclear Cratering Group conducted geologic mapping, seismic traversing, and core drilling programs. At least thirteen core holes were drilled and the data analyzed. Because Pre-Schooner II was conceived as a correlation detonation for the proposed Schooner event, site selection involved searching for a geologic analog. On the basis of the results from this field effort, the Nuclear Cratering Group chose one of the five for Pre-Schooner II. The Pre-Schooner II location was on the Bruneau Plateau, 40 miles southwest of Bruneau, Idaho, approximately 7,600 ft southwest of the proposed Schooner location on land administered by the Bureau of Land Management (Figure 3.16-3). The Pre-Schooner II emplacement hole was located at coordinates longitude W115°34'25.203", latitude N42°24'02.943" (N267,639.53 and E547,783.11, modified Idaho State Coordinate System).

Preparatory fieldwork for the Pre-Schooner II experiment began early in the summer of 1965. The test was designed as a high explosive cratering experiment using a 100-ton liquid explosive nitromethane charge in a spherical cavity. A 1,000 ft diameter work area around ground zero was cleared and leveled for drilling a 36-inch diameter access hole through the hard rock formation. The drill hole extended to a depth of approximately 80 feet below the ground surface. A spherical cavity with a radius of 8.76 ft was excavated at the bottom of the access hole for emplacement of the chemical explosive (Figure 3.16-4). The cavity was lined with a liquid plastic, gunite coated with Adiprene, to prevent leakage of the liquid explosive. Support facilities built for the project included a control point, a camera station, and a helipad located approximately 3,400 ft northwest of ground zero. Several mobile trailers, a chemical toilet, and an equipment storage area were setup at the control point. A second bunker-type camera station was established 1,128 ft southwest of the emplacement hole while a third ground camera station was 15,500 ft to the northwest adjacent to the laser station. A nitromethane storage area and a detonator storage bunker were constructed about 4,000 ft to the southwest near an existing stone cabin. A 19 ft x 40 ft trailer for temporary housing and a chemical toilet were situated about 3,400 ft northwest of ground zero adjacent to the balloon inflation pad. Various instrumentation stations were set up radially from ground zero and included three microbarograph towers, two seismic stations, multiple wooden targets, smokeless flare targets, and eight instrument gauge stations for subsurface effects measurements. The instrument gauge stations consisted of 10-inch diameter cased and grouted drill holes of varying depths dispersed at distances of 10 ft to 4,000 ft from ground zero. Multiple survey control points and five balloon anchoring blocks were also constructed. A network of graded dirt roads linking the support facilities and instrument stations was completed. Finally, a contractor's storage yard was bladed along the road between the control point and ground zero and a fuel tank and large water tower were erected on a knoll southeast of ground zero. Figure 3.16-5 shows the proposed site layout for the Pre-Schooner II experiment.

Originally planned for execution between 10:00 am and 2:00 pm Mountain Standard Time on September 30, 1965, the Pre-Schooner II experiment was delayed several hours.

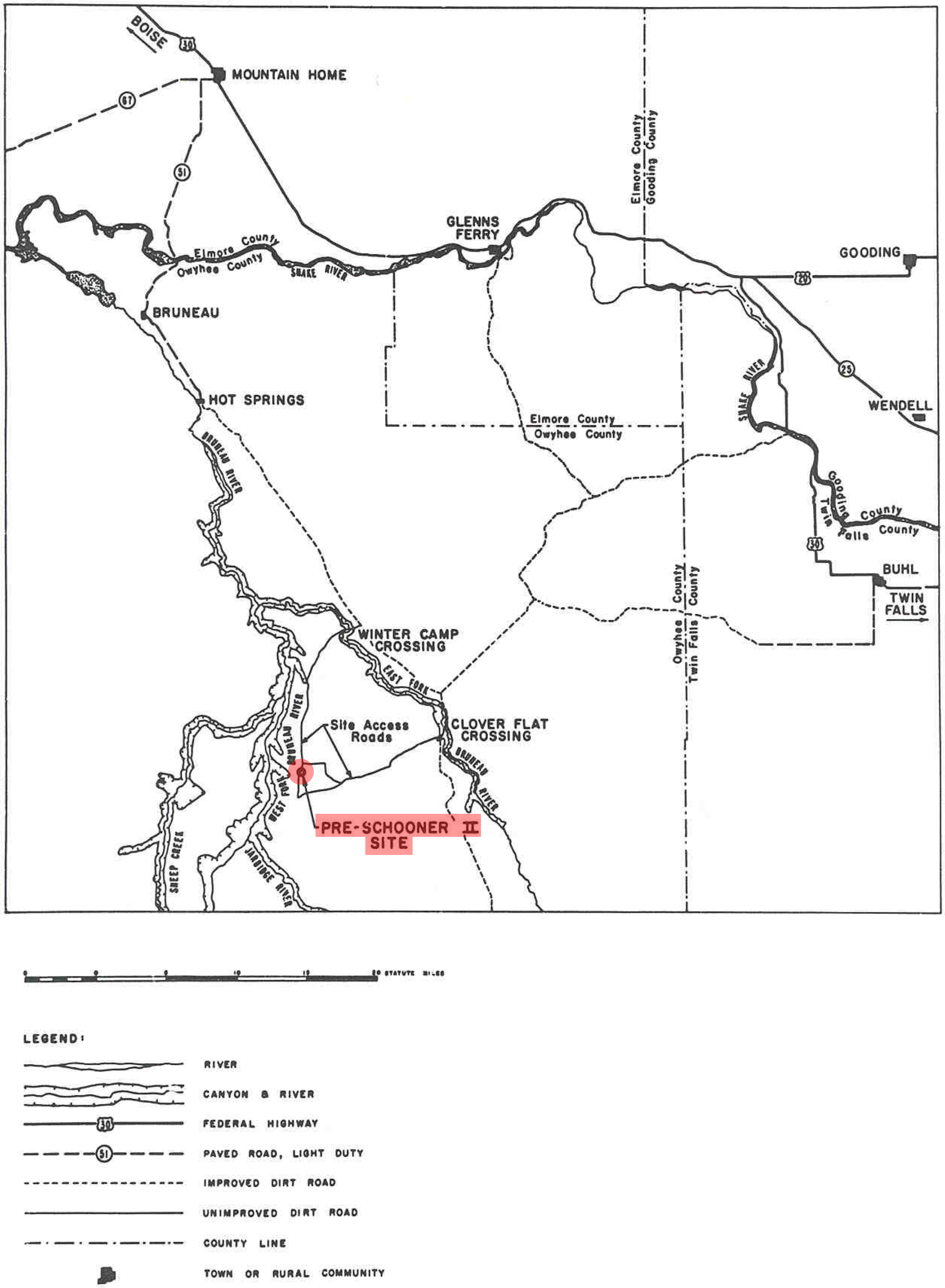


Figure 3.16-3. Project Pre-Schooner II site access map (adapted from Frandsen 1967, Figure 1.1).

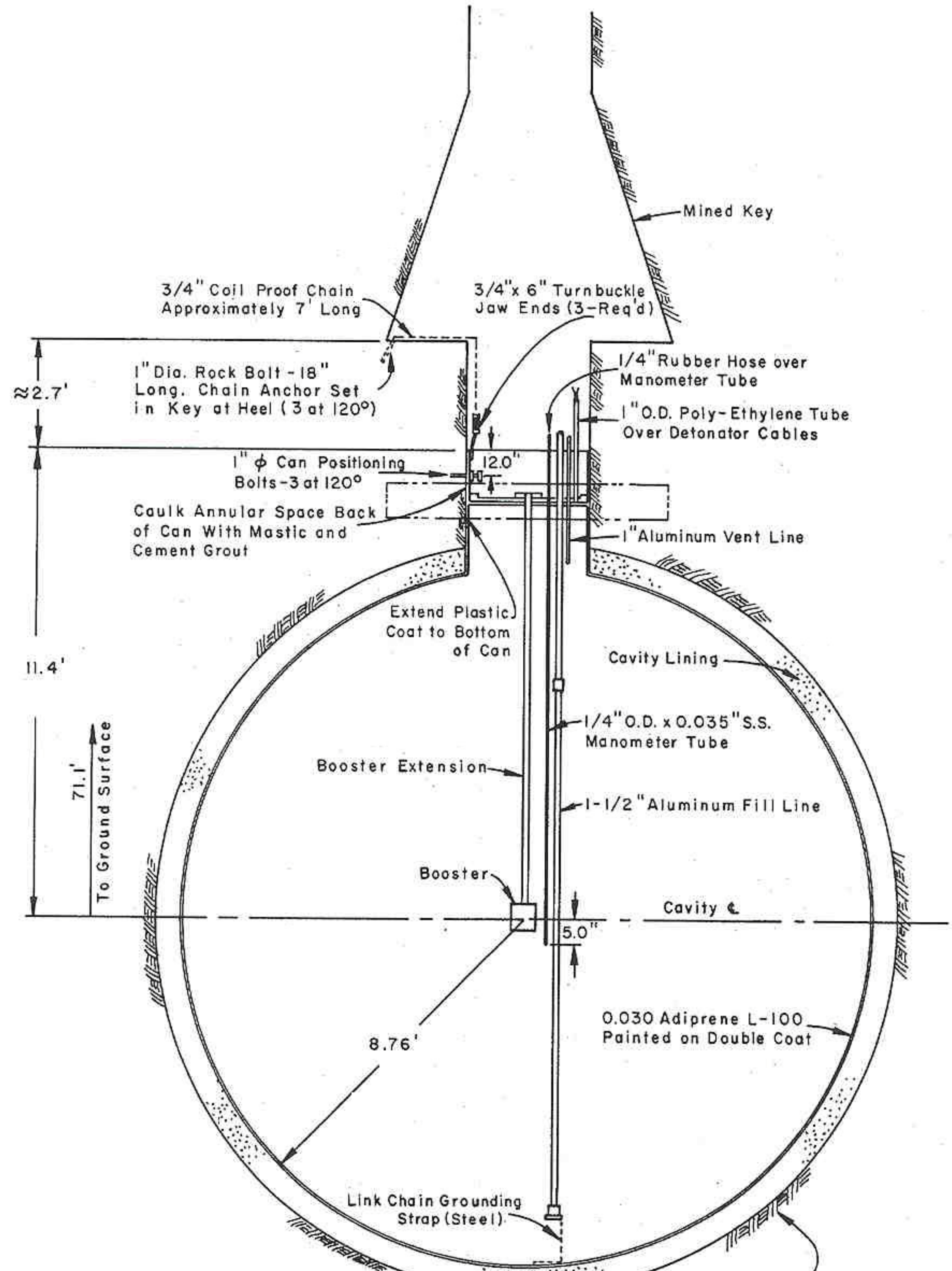
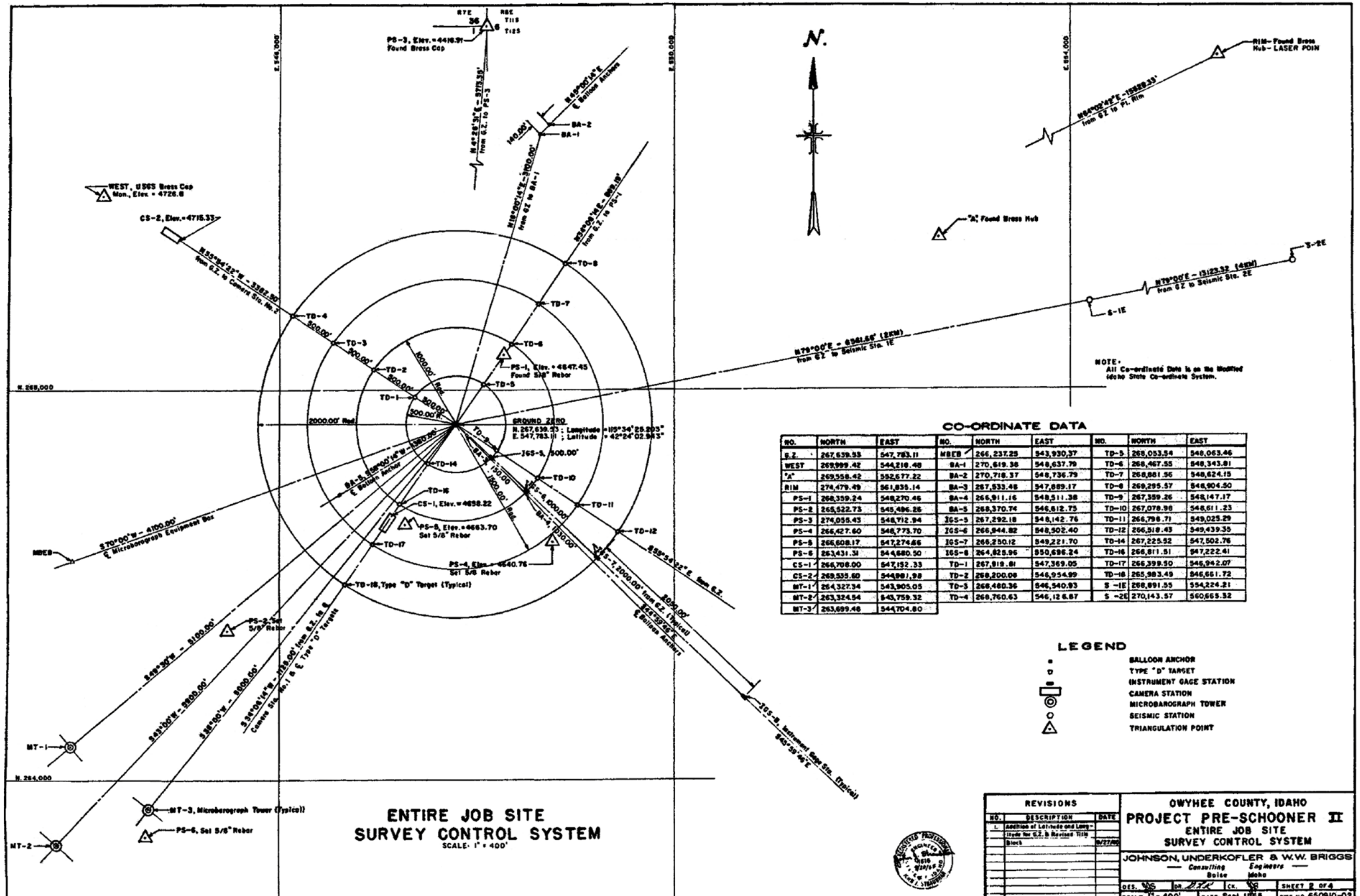


Figure 3.16-4. Schematic of the lower portion of the Pre-Schooner II emplacement hole, and explosive charge cavity (Hughes 1966, Figure 2.6).

THIS PAGE INTENTIONALLY LEFT BLANK



CO-ORDINATE DATA

NO.	NORTH	EAST	NO.	NORTH	EAST	NO.	NORTH	EAST
G.Z.	267,639.53	547,783.11	MBEB	266,237.25	543,930.37	TD-5	268,053.54	548,063.46
WEST	269,999.42	544,210.48	BA-1	270,619.38	548,637.79	TD-6	268,467.55	548,343.81
"A"	269,558.42	552,677.22	BA-2	270,718.37	548,736.79	TD-7	268,881.56	548,624.15
RIM	274,479.49	561,835.14	BA-3	267,533.48	547,889.17	TD-8	269,295.57	548,904.50
PS-1	268,359.24	548,270.46	BA-4	266,911.16	548,511.38	TD-9	267,359.26	548,147.17
PS-2	265,522.73	545,496.26	BA-5	268,370.74	546,612.75	TD-10	267,078.98	548,611.23
PS-3	274,055.43	548,712.94	IGS-5	267,292.18	548,142.76	TD-11	266,798.71	549,025.29
PS-4	266,427.60	548,773.70	IGS-6	266,944.82	548,502.40	TD-12	266,518.43	549,439.35
PS-5	266,608.17	547,274.66	IGS-7	266,250.12	549,221.70	TD-14	267,225.52	547,502.76
PS-6	263,431.31	544,680.50	IGS-8	264,825.96	550,696.24	TD-16	266,811.51	547,222.41
CS-1	266,708.00	547,152.33	TD-1	267,919.81	547,369.05	TD-17	266,399.50	546,942.07
CS-2	269,535.60	544,981.98	TD-2	268,200.08	546,954.99	TD-18	265,983.49	546,661.72
MT-1	264,327.34	543,905.05	TD-3	268,480.36	546,540.93	S-1E	268,891.55	554,224.21
MT-2	263,324.54	543,759.32	TD-4	268,760.63	546,126.87	S-2E	270,143.57	560,665.32
MT-3	263,699.48	544,704.80						

Figure 3.16-5. Site layout for Project Pre-Schooner II (Johnson, Underkofler & W.W. Briggs 1965, Drawing No. 650910-02).

THIS PAGE INTENTIONALLY LEFT BLANK

Problems with chemical explosive leaking from the charge cavity and an unsuccessful attempt to get more nitromethane delivered from Las Vegas combined with the failure of some of the smokeless flares used for the high-speed photography to postpone the blast until 5:10 pm Mountain Standard Time. Two 1.2-ton above-ground calibration shots were detonated two minutes prior to the main blast alerting the distant seismic recording stations in Idaho, Utah, and Nevada of the impending experiment. Intended as a 100-ton detonation, the actual yield for Pre-Schooner II was only 85.5 tons due to the cavity wall leak. Even with the lower yield, the blast was impressive (Figure 3.16-6). Ejecta from the detonation reached a height of over 3,000 ft and the resulting crater had an apparent crater size that was approximately 190 ft across and 61 ft deep. Volume of the apparent crater was 24,780 cubic yards and the average lip crest height was 17.2 ft.

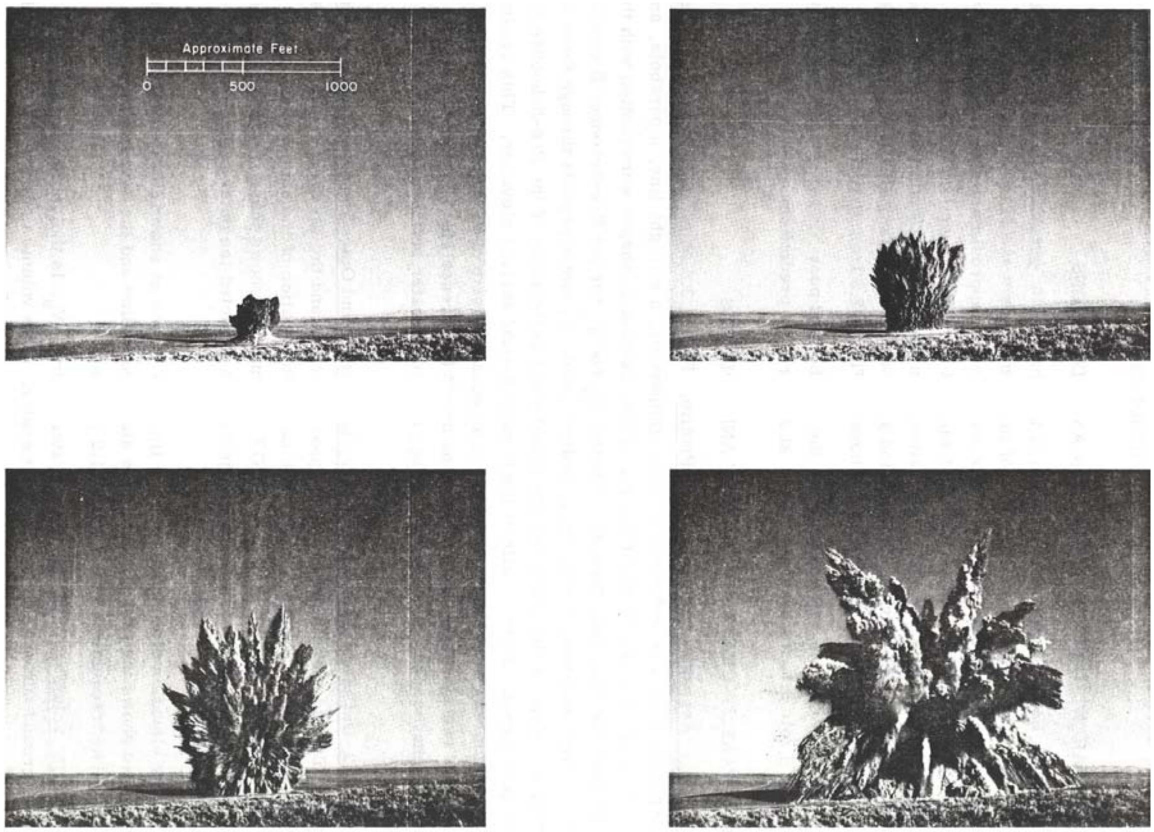


Figure 3.16-6. Project Pre-Schooner II crater detonation sequence (Benfer 1967, Figures 3.1 – 3.4).

Observed cloud dimensions were the following: crosswind base surge radius of 2,100 feet, base surge height of 1,060 ft, main cloud radius of 875 ft, and main cloud height of 1,400 ft. Ejecta from the detonation were recorded as far as 2,320 ft from the surface ground zero point. Technical studies associated with Pre-Schooner II included surface motion investigations, crater measurement studies, ground shock measurements, subsurface effects, cloud development studies, and close-in air blast monitoring. Three camera stations were used for the project, with one being positioned in an overhead helicopter. The other two were at the control point (Camera Station No.2) and at the laser station (Camera Station No. 3) (Figure 3.16-5). For the Pre-Schooner II detonation, Lawrence Radiation Laboratory provided the technical expertise for the laser-radar experiment and the fluorescent particle tracer technique. The results indicated that the laser-radar system was useful for cloud studies, but the method of dispersion chosen for the particle tracer technique was not successful. Edgerton, Germeshausen, and Grier, Inc. was responsible for the cloud photography along with most of the other scientific and documentary photography. Aerial Mapping Co. from Boise provided some of the aerial photography support. The U.S. Weather Bureau Research Station collected the meteorological data. Sandia Corporation analyzed the air-blast data gathered from the pressure gauge equipped balloon and the microbarograph towers. The ground motion recordings produced by the high-speed photography of the various wooden target arrays were analyzed by the U.S. Coast and Geodetic Survey.

Post-shot geological cratering studies were conducted for the Pre-Schooner II project (Figure 3.16-7). Western Construction Company out of Boise Idaho was awarded the excavation contract. The engineering firm of Johnson, Underkofler and W.W. Briggs assisted. The technical study compared pre-shot and post-shot geology by excavating a series of three radial trenches through the lip of the crater. Two of the trenches were extended farther away from the crater lip into the fallback material ejected from the blast. The trenches exposed profiles on the upthrust ground surface, ejecta, the rupture zone, and the fallback material in the crater. This allowed the measurement of the true crater radius, which averaged 100 ft and the average lip upthrust of 11 ft. These studies found the true crater radius was much smaller than the apparent crater radius.

The detonation produced a symmetrical, smooth crater that was approximately 27 percent wider and 53 percent deeper than would have been predicted using the then current cratering curves based on experience in basalt (Figure 3.16-8). The large difference indicated the rhyolite at the Pre-Schooner site had cratering characteristics significantly different from basalt; important information if Project Schooner was to be conducted in the same medium.

The Pre-Schooner II event was well-covered by the Idaho state newspapers, which touted the importance of the experiment for future nuclear civil works excavation projects. The experiment also garnered a great deal of attention from Washington D.C. officials. Brigadier General Harry G. Woodbury, Jr. Deputy Director of Civil Works with the Chief Engineers Office, U.S. Army Corps of Engineers and a member of the Atlantic-Pacific Interoceanic Canal Study Commission observed the shot. Both General Woodbury and Major Bernard Hughes, the project's technical director and a member of the Nuclear Cratering Group, were very pleased with the outcome of the experiment and felt the data would be instrumental to the successful planning of the proposed 100-kt nuclear test "Schooner."

As of October 1965, the Schooner experiment was tentatively scheduled for execution during the winter of 1967 near the Pre-Schooner II site. A technical director and deputy director were appointed for the project along with preliminary plans and field assessments. However, the Schooner nuclear cratering experiment was never conducted

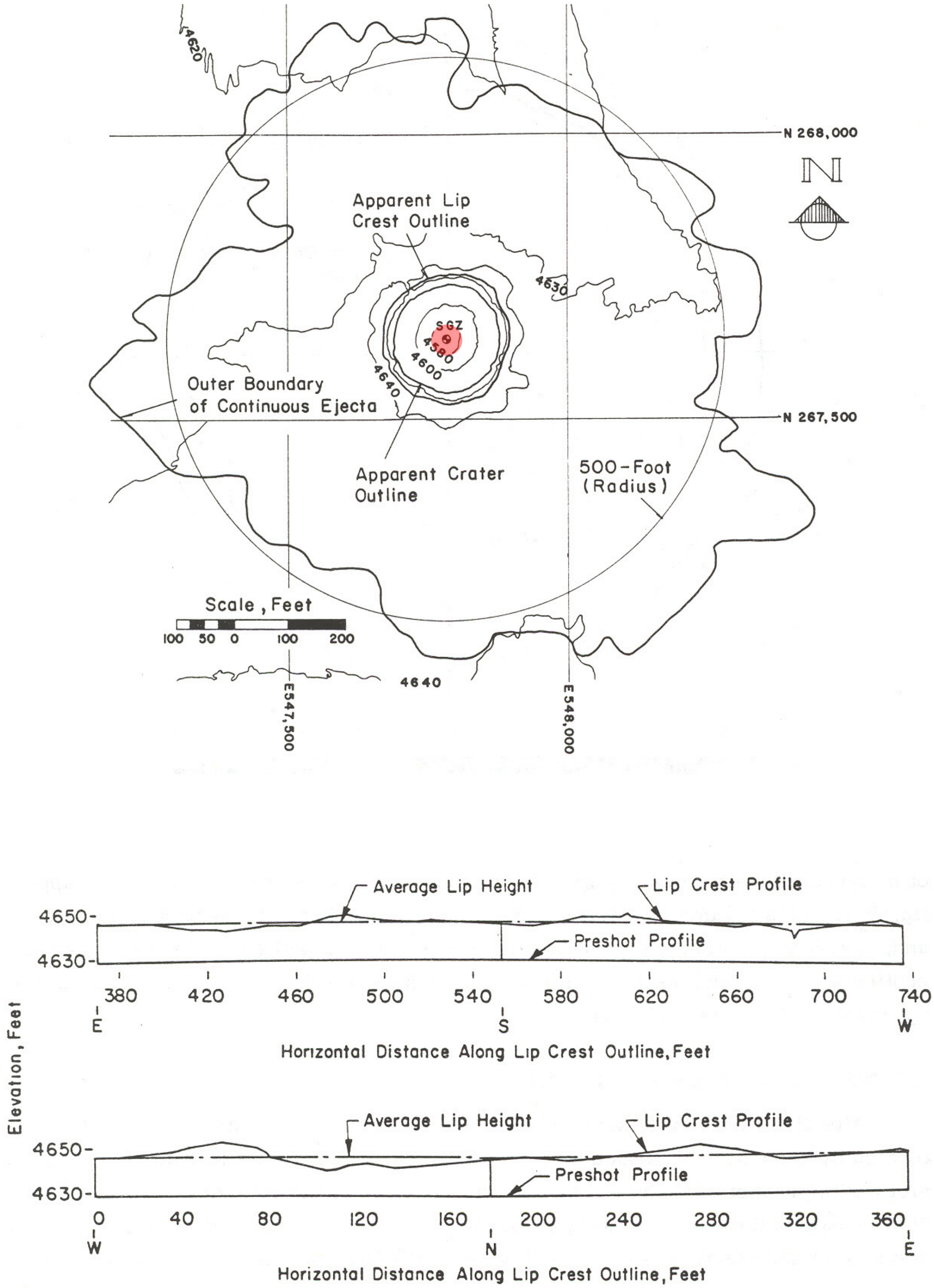


Figure 3.16-7. Crater lip outline and profiles (adapted from Benfer 1967, Figures 3.8 and 3.9).

Figure 3.16-8. Post-shot aerial of the Project Pre-Schooner II crater (Benfer 1967, no figure number).

on the Bruneau Plateau. The Schooner experiment was downsized and moved to the Nevada Test Site eventually carried out on December 8, 1968 with a yield of 30 kt.

Project Pre-Schooner II was a Level 2 activity with fieldwork consisting of various drill holes and the chemical explosive detonations. The Pre-Schooner II site was visited in FY 2004.

FIELD VISIT

DRI researchers Beck and Edwards conducted a thorough field reconnaissance of the Pre-Schooner II site, spending three days (June 29-July 1, 2004) recording the physical remains of this Plowshare high explosive crater experiment conducted in 1965. Located on the Bruneau Plateau in southwestern Idaho on land administered by the Bureau of Land Management, the crater is now encompassed by a four-strand barbed-wire fence for safety reasons (Figures 3.16-9 and 3.16-10). The most distinguishing feature of the site is the crater itself. Over 190 ft in diameter and 61 ft deep, the Pre-Schooner II crater is surrounded by a large, mounded berm surrounding the crater lip (Figure 3.16-11). Three deep trenches cutting through the crater lip reflect post-shot scientific studies conducted to investigate overall crater morphology as well as crater lip formation processes,

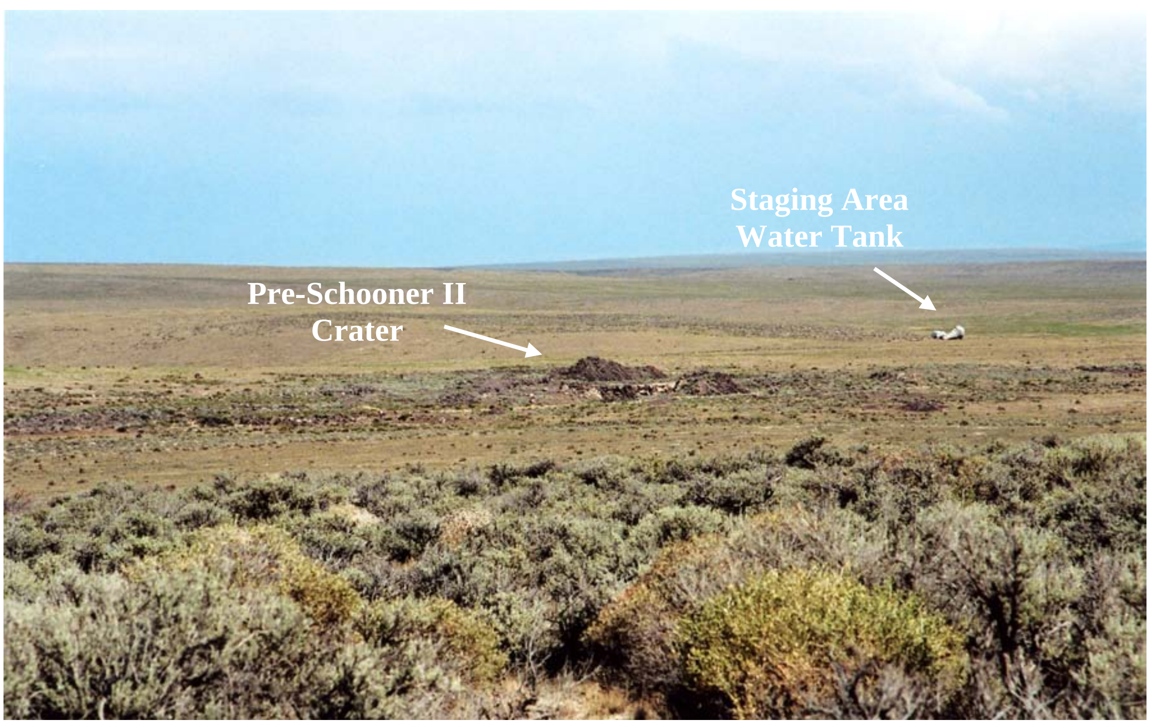


Figure 3.16-9. Overview of the Project Pre-Schooner II site shows the crater in the photo center and the collapsed water tower at one of the staging areas on the right (photo taken from the old control point in June 2004 on file at Desert Research Institute).

Figure 3.16-10. Located on l and administered by the Bureau of Land Management, the Project Pre-Schooner II crater is now surrounded by a barbed wire fence for safety reasons (photo taken June 2004 on file at Desert Research Institute).

Figure 3.16-11. A large, mounded berm of ejecta and fallback surrounds the Pre-Schooner II c rater (photo taken July 2004 on file at Desert Research Institute).

apparent crater radius, and ejecta composition At least ten targets used in surface motion studies are scattered around the crater. The targets are composed of 8-inch diameter iron drill pipe with concrete-filled culvert collars (Figures 3.16-12 and 3.16-13). Other than the large motion study targets, there is very little debris immediately surrounding the Pre-Schooner II crater. Most of the explosive charge casing, drill pipe, stemming, and down-hole instrumentation have been blown from several hundred to nearly 2,000 ft from ground zero (Figure 3.16-14).

Several staging areas are also associated with the Pre-Schooner II project site. These include the experiment control point located approximately 0.6 m i west-northwest of ground zero, another staging area located 0.4 mi southeast of the crater, and a camera station .25 mi to the southwest. The control point is visible as a large graded area with general industrial and domestic debris concentrated near the former locations of office trailers, a camera station, and perhaps some temporary portable housing (Figure 3.16-15). Food and beverage containers are intermingled with cable spools, wood, wiring, metal strapping, conduit, wood, solvent and oilcans, nails, and broken glass (Figure 3.16-16). Several potential privy areas were also identified (Figure 3.16-17). None of the trailers or structures remain.

There are several standing structures at the staging area on the knoll to the southeast of ground zero (Figure 3.16-18). These include a large cylindrical fuel oil tank, a collapsed water tank, and a small bunker. Within the larger graded area, there are also several low earthen berms, a trash pit, a trash burning area, and miscellaneous industrial debris such as iron pipe, wood, steel cable, and drill casing.

Figure 3.16-12. Target stands used in surface motion studies for the Pre-Schooner II detonation (photo taken July 2004 on file at Desert Research Institute).

Figure 3.16-13. The surface motion targets are made of 8-inch diameter pipe with concrete-filled culvert collars. The targets were placed radially at varying distances from ground zero and recorded with motion picture cameras (photo taken July 2004 on file at Desert Research Institute).

Figure 3.16-14. The 100-ton detonation blew debris as far as 2,000 ft away from ground zero (photo taken July 2004 on file at Desert Research Institute).

Figure 3.16-15. Graded areas are part of the Pre-Schooner II control point complex consisting of office trailers, a camera station, a helipad, and possibly some portable housing (photo taken June 2004 on file at Desert Research Institute).

Figure 3.16-16. Debris is a mixture of general industrial and domestic trash and includes food and beverage containers, cable spools, lumber, wiring, conduit, nails, and broken glass (photo taken June 2004 on file at Desert Research Institute).

Figure 3.16-17. Possible privy location at the Project Pre-Schooner II control point complex (photo taken June 2004 on file at Desert Research Institute).

Figure 3.16-18. A fuel oil tank and collapsed water tank are located at the staging area southeast of the Pre-Schooner II ground zero (photo taken July 2004 on file at Desert Research Institute).

Figure 3.16-19. Debris surrounding the location of the old camera station. The station has been removed (photo taken July 2004 on file at Desert Research Institute).

The Camera Station No. 2 bunker to the southwest of ground zero has been removed, but debris is strewn around the location (Figure 3.16-19). Materials observed included sheet metal target fragments, drill casing, and unidentifiable metal fragments. The detonator bunker and nitromethane storage structure have also been removed.

Dirt roads link the various staging areas, control point, and ground zero. Although graded at one time, these roads are now badly rutted and rock strewn, making vehicle access to the site somewhat difficult. The Pre-Schooner II project site encompasses approximately 320 acres and is approximately 6.5 mi from the closest graded road.

Land status research was conducted at the Idaho State Office of the Bureau of Land Management, U.S. Department of the Interior in Boise in conjunction with the FY 2004 field visit. A review of the agency's realty records indicates the U.S. Atomic Energy Commission obtained a special use permit from the Bureau of Land Management for the area surrounding the Pre-Schooner II site and the proposed Schooner site in 1965. The permit was allowed to expire in 1968 and the land reverted to the legal jurisdiction of the Bureau of Land Management. There are no outstanding land status issues for the Pre-Schooner II experiment site or the proposed Schooner experiment site.

CHRONOLOGICAL BIBLIOGRAPHY

Gard, L. M., and J. W. Hasler, 1963. Geology of Proposed Schooner Site, Bruneau River Area, Owyhee County, Idaho (A Preliminary Investigation), Technical Letter: Schooner-3. Report to U.S. Atomic Energy Commission, Las Vegas, NV, from U.S. Department of the Interior Geological Survey, Denver, CO, September 25. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0172861.

Lawrence Livermore National Laboratory, 1964. Status of Plowshare Field Programs. Report from Lawrence Livermore National Laboratory, May 6. On file at: Technical Reports Library, Lawrence Livermore National Laboratory, Livermore, CA.

Slazak, Walter J., 1965. Letter from Walter J. Slazak, Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, to James E. Reeves, January 26. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-054.

Johnson, Gerald W., 1965. "The Schooner Excavation Test." Telex from Gerald W. Johnson, Lawrence Radiation Laboratory, to James E. Reeves, April 1. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-054.

Hughes, Bernard C., 1965. "Status Report - Nuclear Explosives Studies for Civil Construction (Reports Control Symbol ENGCW-E-9)." Letter with encl. ("Status Report, Effective Date: 31 March 1965 - ENCGW-P-6(R1)") from Bernard C. Hughes, U.S. Army Engineer Cratering Group, to Chief for Engineers, Department of the Army, April 13. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029.

Holmes & Narver, Inc., 1965. "Owyhee County Idaho, Project Pre-Schooner II, General - Location Map." Drawing No. J-094-C51.2, July 1. On file at: Engineering Records Library, Nevada Test Site, Mercury, NV.

Holmes & Narver, Inc., 1965. "Owyhee County, Idaho, Project Pre-Schooner II, Ground Zero, Site Plan." Drawing No. J-094-C52, July 1. On file at: Engineering Records Library, Nevada Test Site, Mercury, NV.

Holmes & Narver, Inc., 1965. "Owyhee County, Idaho, Project Pre-Schooner II, Photography Targets, Plot Plan." Drawing No. J-094-C53.2, July 1. On file at: Engineering Records Library, Nevada Test Site, Mercury, NV.

Holmes & Narver, Inc., 1965. "Owyhee County, Idaho, Project Pre-Schooner II, Base Surge Photo Targets, Plan & Details." Drawing No. J-094-C55-2, July 1. On file at: Engineering Records Library, Nevada Test Site, Mercury, NV.

Reeves, James E., 1965. "Planning Directive (PL-15-6-65) Project Pre-Schooner II." Memo from James E. Reeves, U.S. Atomic Energy Commission, Nevada Operations Office, to Those Listed Below, July 7. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-054.

Johnson, Underkofler & W. W. Briggs, 1965. "Owyhee County, Idaho, Project Pre-Schooner II, Ground Profile - Target Holes." Drawing No. 650816-01 from Johnson, Underkofler & W.W. Briggs, Boise, ID, August. On file at: Engineering Records Library, Nevada Test Site, Mercury, NV.

Johnson, Underkofler & W. W. Briggs, 1965. "Owyhee County, Idaho, Project Pre-Schooner II, Ground Zero Area, Survey Control System." Drawing No. 650910-01 from Johnson, Underkofler & W. W. Briggs, Boise, ID, September. On file at: Engineering Records Library, Nevada Test Site, Mercury, NV.

Johnson, Underkofler & W. W. Briggs, 1965. "Owyhee County, Idaho, Project Pre-Schooner II, Entire Job Site Survey Control System." Drawing No. 650910-02 from Johnson, Underkofler & W.W. Briggs, Boise, ID, September. On file at: Engineering Records Library, Nevada Test Site, Mercury, NV.

Johnson, Underkofler & W. W. Briggs, 1965. "Owyhee County, Idaho, Project Pre-Schooner II, Pre-Shot Topographic Map, Aerial Control and Sheet Index Diagram." Drawing No. D650910-05 from Johnson, Underkofler & W.W. Briggs, Boise, ID, September. On file at: Engineering Records Library, Nevada Test Site, Las Vegas, NV.

Lorimer, Bob, 1965. AEC Chemical Blast Gouges Huge Hole in Idaho Desert. *The Idaho Daily Statesman*, October 1. Boise, Idaho. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-054.

Lorimer, Bob, 1965. Pre-Schooner Blast Data Compiled in Preparation for Engineering Project. *The Idaho Daily Statesman,* October 3. Boise, Idaho. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-054.

Hughes, Bernard C., 1965. "Pre-Schooner II Interim Data Technical Report." Memo from Bernard C. Hughes, Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, to Distribution, October 12. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-054.

Beers, Roland F., Inc., 1965. Pre-Schooner II, Interim Report. Report to U.S. Atomic Energy Commission, Nevada Site Office, Report NVO-1163-63, from Beers, Inc., Alexandria, VA. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Plowshare Advisory Committee, 1965. Plowshare Advisory Committee, Report on Fourteenth Meeting. Meeting held at Lawrence Radiation Laboratory, Livermore, CA, November 9-10. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029 [OUO].

Heusinkveld, Myron, 1965. Accident Report from Myron Heusinkveld, December 2. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, Box 422, File 4073.

Nuclear Cratering, 1965. Nuclear Cratering: Experience, Problems, Programs. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0184661.

Holmes & Narver, Inc., [1965a]. "Saylor Creek - Bruneau River Area." Topographic Map. On file at: Engineering Records Library, Nevada Test Site, Mercury, NV.

Holmes & Narver, Inc., [1965b]. "Saylor Creek and Bruneau River Idaho." Drawing showing drill holes. On file at: Engineering and Records Library, Nevada Test Site, Mercury, NV.

Johnson, Underkofler & W. W. Briggs, [1965]. "Owyhee County, Idaho, Project Pre-Schooner II, Pre-Shot Topographic Map." Drawing from Johnson, Underkofler & W. W. Briggs, Boise, ID. On file at: Engineering Records Library, Nevada Test Site, Mercury, NV.

U.S. Atomic Energy Commission, 1966. Chapter 12 - The Plowshare Program. In *Annual Report to Congress of the Atomic Energy Commission for 1965*, pp. 191 -209, January. U.S. Atomic Energy Commission, U.S. Government Printing Office, Washington D.C.

U.S. Atomic Energy Commission. Nevada Operations Office, 1966. Press Release, Subject: Post-shot excavation in and around the Pre-Schooner II crater, from U.S. Atomic Energy Commission, NV-66-11, February 10.

Day, Walter C., and Robert F. Rohrer, 1966. Project Pre-Schooner II: Cloud Development Studies. Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, Report PNE 511, June. Livermore, CA. On file at: Nuclear Testing Archives, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0017206.

Heusinkveld, M. and R. E. Marks, 1966. Project Pre-Schooner II: Subsurface Effects Measurements. Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, Report PNE 515, June. Livermore, CA. On file at: Technical Reports Library, Lawrence Livermore National Laboratory, Livermore, CA (cover page only).

Rabb, David D., 1966. Plowshare Program, October 1, 1965 – July 15, 1966, Vol. II, No. 2. University of California, Lawrence Radiation Laboratory, *Report UCRL*-50008-66-1, July 15. Livermore, CA. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-030.

Hughes, Bernard C., 1966. Project Pre-Schooner II: Technical Director's Summary Report. Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, Report PNE 507, October. Livermore, CA. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0015368.

Davis, L. L., 1966. Project Pre-Schooner II: Ground Shock Measurement. Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, Report PNE-514, November. Livermore, CA. On file at: Technical Reports Library - Microfiche, Lawrence Livermore National Laboratory, Livermore, CA (partial copy).

Werth, Glenn C., 1967. Program Activities for Plowshare. University of California, Lawrence Livermore National Laboratory, *Report UCRL*-124785, February 3. Livermore, CA. On file at: Technical Reports Library, Lawrence Livermore National Laboratory, Livermore, CA.

Lawrence Radiation Laboratory. U.S. Army Engineer Nuclear Cratering Group, 1967, Summary of Long Range Programming for Nuclear Excavation Research and Development. Manuscript, April 5. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029.

U.S. Atomic Energy Commission, 1967. "Statement on the Civilian Applications of Nuclear Explosives (Plowshare) Program, U.S. Atomic Energy Commission FY 1968 Authorization Hearings Before the Joint Committee on Atomic Energy." Statement from U.S. Atomic Energy Commission, April 17. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-028.

Benfer, R. H., 1967. Project Pre-Schooner II: Apparent-Crater Studies. Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, Report PNE 508, May. Livermore, CA.

Saucier, Kenneth L., and F. S. Stewart, 1967. Project Pre-Schooner II: Design, Construction, and Postshot Evaluation of Concrete Stem for Access Hole. Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, Report PNE 510F, August. Livermore, CA. On file at: Technical Reports Library, Lawrence Livermore National Laboratory, Livermore, CA.

Frandsen, A. D., 1967. Project Pre-Schooner II: Postshot Geologic and Engineering Properties Investigations. Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, Report PNE 516, November. Livermore, CA. On file at: Technical Reports Library, Microfiche, Lawrence Livermore National Laboratory, Livermore, CA.

Jackson, Melvin W., 1967. Ten Years of Plowshare. *Civil Engineering*, December. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029.

Lutton, R. J., F. E. Girucky, R. W. Hunt, and J. R. Curro, Jr., 1967. Project Pre-Schooner II: Preshot Geologic and Engineering Properties Investigations. Lawrence Radiation Laboratory, Report PNE 509, D ecember. Livermore, CA. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Hughes, Bernard C., 1968. "Status Report - Nuclear Explosives Studies for Civil Construction (RCS ENGCW-P-6 (R-1))." Letter with encl. ("Status Report, Effective Date: 31 December 1967") from Bernard C. Hughes, Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, to Chief of Engineers, Department of the Army, January 13. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029.

Christopher, W. G., and K. L. Larner, 1968. Project Pre-Schooner II: Surface Motion Measurements. Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, Report PNE 513, October. On file at: Nuclear Testing Archives, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0330837.

Day, Walter C., 1969. The Corps of Engineers Nuclear Construction Research Program. *Nuclear Applications and Technology,* Vol. 7, No. 3, pp: 253-268.

3.17 R. D. BAILEY

Plowshare Program
High Explosive Experiment for Dam Spillway Excavation
West Virginia

Project R. D. Bailey was an experimental high explosives excavation that was designed as a pilot study for construction of the spillway for the R. D. Bailey Lake Project (Figure 3.17-1). The R. D. Bailey Lake Project, located in the Appalachian Mountains of West Virginia, was authorized by Congress in the Federal Flood Control Act of 1962 to reduce flood damage along the Guyandotte and Ohio Rivers. In the early 1970s, the U.S. Army Corps of Engineers Explosive Excavation Research Laboratory identified R. D. Bailey as a suitable civil works project for an explosive excavation project.

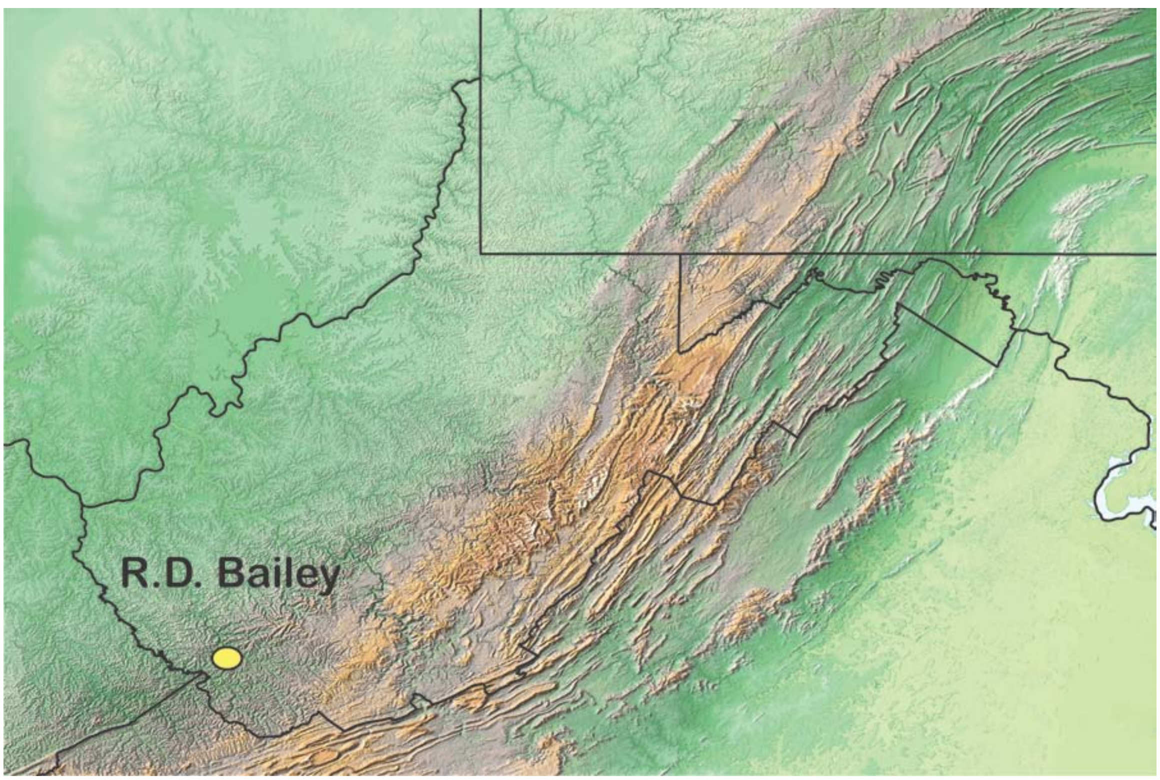


Figure 3.17-1. Location of the R. D. Bailey Project in southwestern West Virginia (adapted from USA Relief Maps 2004).

A status report from the Explosive Excavation Research Laboratory indicates that planning for the project was underway by September 1972. The primary objective of the experimental excavation was to obtain technical information about large charges of bulk explosives, in conjunction with larger than normal blast holes, to use in developing specifications for construction of the spillway at R. D. Bailey. Another objective was to determine if explosive excavation would reduce costs of drilling and blasting in the spillway. In addition, the experiment was designed to provide scientific data on blasting techniques and effects for future explosive excavation projects.

The technical plan for the explosive experiment needed to address a number of design problems specific to the R. D. Bailey project. The plan called for using rock excavated from the spillway to construct the dam embankment, therefore, the rock fragments needed to meet specified size requirements. The use of controlled blasting techniques would be necessary to protect the spillway walls from damage due to production blasts. Another concern was that a 300-ft water intake structure, located 2,000 ft from the spillway area, would be under construction during the explosive experiment. Blasting needed to be designed so that the spillway structure would not be damaged by blast-induced ground motion. Finally, ground motion and air blast would need to be minimized to prevent damage to the nearby town of Justice. By November 1972, the technical concept for the program was sent to the Huntington District, and the operational plan was completed in February 1973. The contract for the support work for the experimental excavation was issued to the Dow Chemical Corporation and the experiment was carried out from February to August 1973.

The pilot spillway excavation, located on the Guyandotte River in Mingo County, near Justice, West Virginia (Figure 3.17-2), was conducted jointly with the U.S. Army Corps of

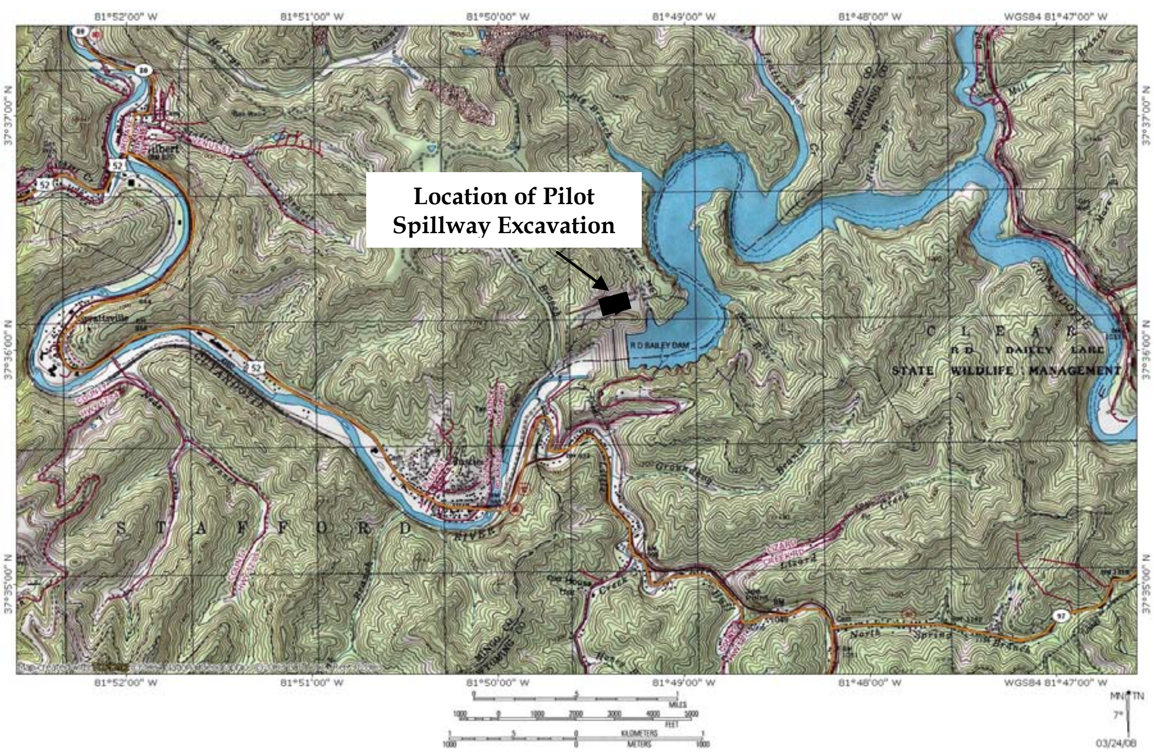


Figure 3.17-2. Location of the dam and spillway for the R. D. Bailey Lake Project, showing the location of the pilot experimental excavation (adapted from National Geographic Topographic Maps 2006).

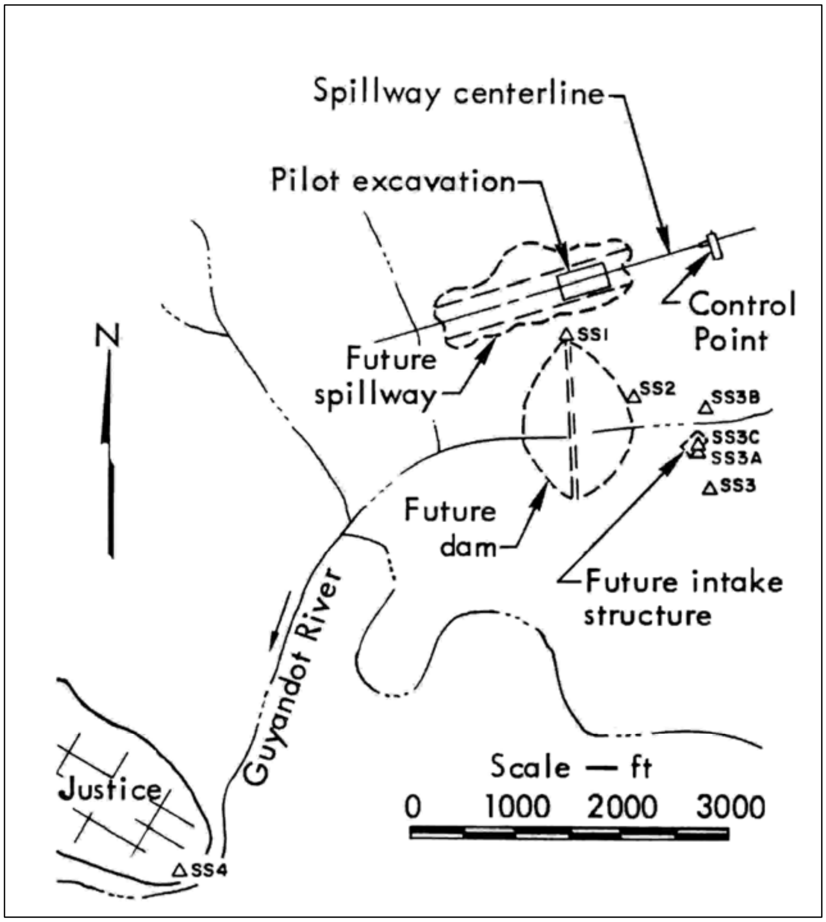


Figure 3.17-3. Location of the pilot excavation in relation to the proposed spillway and dam for R. D. Bailey (Bechtell 1975, Figure 69).

Engineers, Huntington District. High explosive blasts were executed in a pilot excavation area on the upstream edge of the proposed spillway (Figure 3.17-3). There were fifteen blasts in all including nine primary blasts (PB-1 through PB-5, PB-6a and 6b, PB-7, and PB-8). The blasts were conducted in five levels (Figure 3.17-4) and each level had a blast design to investigate various configurations of blast hole diameter and depth, spacing, delays, and explosive type. For some levels overburden was removed after the blast with a D-8 bulldozer, while in other cases ripping was used in conjunction with blasting. A discussion of the blast design and results for each of the primary blasts is summarized in the final technical report. Explosive excavation through the level PB-4 was predominantly in shale and the levels including blasts PB-5, 6, 7 and 8 were in sandstone with shale at the base of the excavation. ANFO and aluminized ammonium nitrate slurry were the two types of explosive used in the high explosive program. Table 3.17-1 provides a summary of blast data for R. D. Bailey. The result of the explosive series was a cut 300 ft long and 175 ft deep (Figure 3.17-5). Approximately 152,000 cubic yards of rock were removed from the cut.

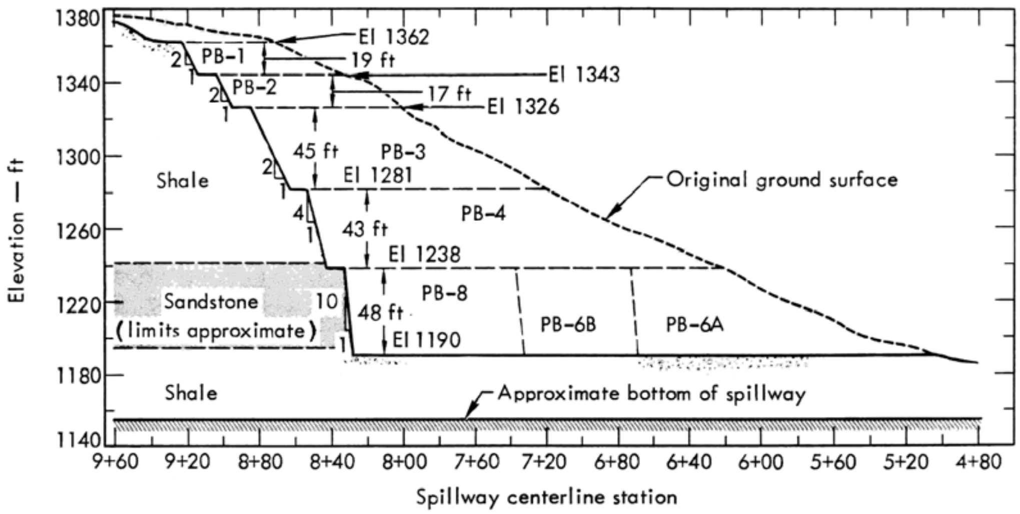


Figure 3.17-4. Profile of the pilot excavation showing major blast groups in relation to the five levels (Bechtell 1975, Figure 7).

Table 3.17-1. Experimental Excavation Summary (Bechtell 1975, Table 1 and Text)

Test Blast	Date (1973)	Material	Explosive (lb)	Blast hole Diameter (in)	Average Depth (ft)
PB-1	6 April	Weathered shale	ANFO (1150)	3	17
PB-2	no data	no data	no data	no data	no data
PB-3	7 May	Weathered shale	ANFO (3300)	6-3/4	15
PB-4	19 May	Weathered shale, coal, and sandstone	ANFO	3	6
PB-4A	7 June	Sandstone and shale	ANFO (803)	3	6
PB-4B	7 June	Sandstone and shale	ANFO (3128)	3	9
PB-4C	7 June	Sandstone and shale	ANFO (1683)	3	9
PB-4D	9 June	Sandstone and shale	ANFO (1581)	3	6
PB-5	9 June	Weathered sandstone	ANFO (1188)	3	15
PB-6A	18 June	Sandstone	ANFO (15,350)	6-1/4	45
PB-4E	22 June	Sandstone	MS-80-25 slurry (550)	3	6
PB-6B	23 June	Sandstone	MS-80-25 slurry (8600)	6-1/4	49
PB-7	30 June	Sandstone	MS-80-25 slurry (19,950)	9	55
PB-6C	5 July	Sandstone	MS-80-25 slurry (1960)	6-3/4	27
PB-8	12 July	Sandstone	MS-80-25 slurry (32,100)	12-1/4	50

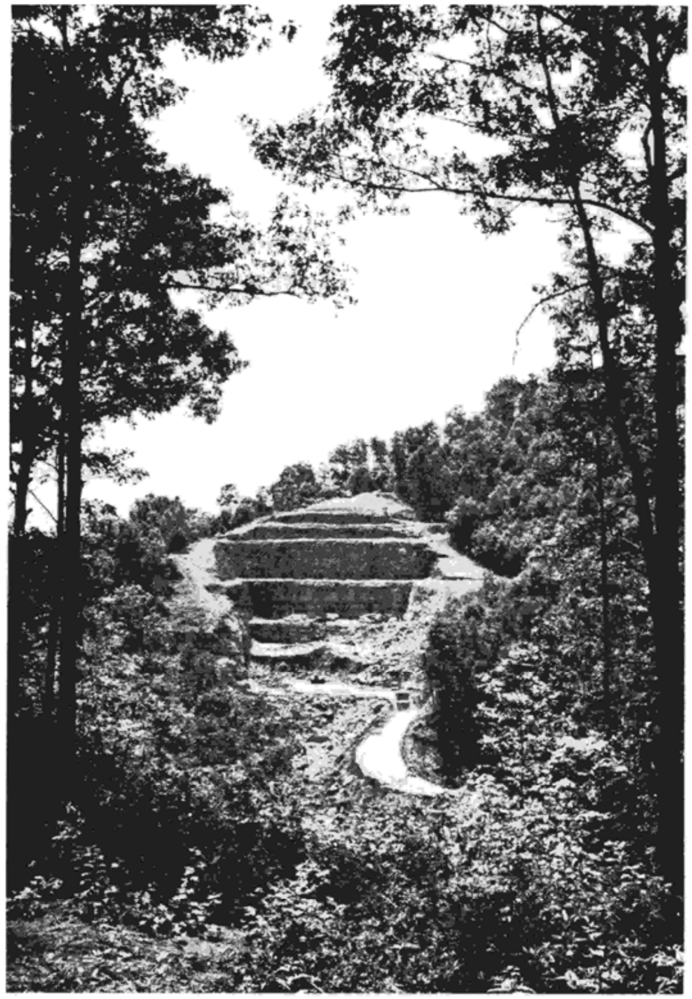


Figure 3.17-5. View north of the experimental excavation for the spillway, R. D. Bailey Lake Project (photo taken on July 5, 1973, Bechtell 1975).

A final technical report issued in June 1975 summarizes a number of technical programs carried out in conjunction with the pilot blasts. These were studies of rock fragmentation, measurements of seismic motion, collection of close-in subsurface ground shock data, airblast overpressure measurements, and photography. The airblast overpressure measurements provided data to estimate the airblast that would result in future detonations at R. D. Bailey and input for prediction method studies. A discussion of the airblast program along with a presentation and analysis of the results were included in a report issued during February 1975. Following completion of the test blasts, a report was made available to potential contractors to assist in formulating bids for construction of the dam. The Explosive Excavation Research Laboratory also prepared blasting guidelines for the resident engineer of the R. D. Bailey project to assist in evaluating blasting procedures proposed for construction of the spillway. An analysis of drilling and blasting costs as a function of the diameter of the blast hole found a favorable reduction in cost with increased blast hole diameter.

R. D. Bailey is a unit in the U.S. Army Corps of Engineers Ohio River Basin Flood Control System. Construction of the rock-fill dam began in 1974 and was completed in 1980. The dam is 310 ft in height with a top length of 1,370 ft and has a layer of steel reinforced concrete on the upstream face. R. D. Bailey is under the administration of the U.S. Army Corps of Engineers, Huntington District (Figure 3.17-6).

High explosives were used in the experimental pilot excavation making this project a Level 2 activity.

Figure 3.17-6. View of the upstream concrete face of the dam for the R. D. Bailey Lake Project. The spillway is located on the northern (far) side of the dam (<http://en.wikipedia.org/wiki/R._D._Bailey_Lake>, last accessed August 2008).

CHRONOLOGICAL BIBLIOGRPAHY

Mills, Robert R., Jr., 1972. "Status Report - Rapid Excavation with Explosives." Letter with encl. ("Status Report, Effective Date: 30 September 1972") from Robert R. Mills, Jr., U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Laboratory, Corps of Engineers, to Director, U.S. Army Engineer Waterways Experiment Station, October 10. On file at Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-108.

Hoeft, Michael J., 1975. Results of Airblast Overpressure Measurement Program at Project F. D. Bailey. U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Laboratory, Miscellaneous Paper No. E-75-4, February. Livermore, CA. On file at: Technical Reports Library, Lawrence Livermore National Laboratory, Livermore, CA.

Bechtell, William R., 1975. Project R. D. Bailey Experimental Program. U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Laboratory, Technical Report E-75-2, June. Livermore, CA. On file at: Technical Reports Library, Lawrence Livermore National Laboratory, Livermore, CA.

THIS PAGE INTENTIONALLY LEFT BLANK

3.18 RUFUS

Vela Uniform Program
Surface Detonation of Nuclear Explosives
Alaska

The main purpose of Rufus was to select and evaluate one or more sites suitable for the surface detonation of nuclear explosives of at least one megaton or greater. Other considerations were to be able to test the effects of a nuclear explosion on a Minuteman Missile System, to record electromagnetic and seismic effects, conduct effects tests of nuclear explosions, device testing, and Plowshare experiments. The Plowshare experiments were not described in the documents and were not the focus of the Rufus project. Suitable sites for evaluation were limited to the continental United States, its possessions, and areas under its control (Figure 3.18-1). Certain foreign areas were identified, but were not seriously considered within the scope of this project.

In the fall of 1962, the Defense Atomic Support Agency made a request to the U.S. Atomic Energy Commission, Nevada Operations Office for the study. The U.S. Atomic Energy Commission Nevada Operations Office accepted the responsibility to conduct the study and by January of 1963, funds were appropriated for the project. Meanwhile, project members were selected (see below) and organizational meetings were held in Denver, Colorado and Las Vegas, Nevada during November of 1962. Two steps to site selection were agreed upon: 1) rejecting sites according to six criteria, and 2) critical analysis and further evaluation of those sites not rejected. The six criteria were: 1) population density, 2) accessibility and logistics, 3) economic, industrial, and military considerations, 4) political and public relations factors, 5) topographic conditions, and 6) geologic considerations. The process of elimination or acceptance was to apply the criteria in order from 1 to 6 and if a site did not meet any one of the criteria then it was dismissed. Information about the sites evaluated during steps 1 and 2 was obtained from available literature, such as census data.

The ideal situation was an area with a low-density population; ability to have control of population movement within a 40 mile radius; federal lands or government control or purchase of the lands available; no cities greater than a population of 10,000 on a east-west sector within 150 miles; at least one downwind fallout sector not less than 100 miles away; access by sea or air for at least six months of the year; enough space for a 5,000-ft runway; a relatively flat area within a one mile radius surrounding the facility; no disruptment of industry, agriculture, transportation systems, defense installations, public works, wildlife, or fisheries; and bedrock should be homogeneous and sedimentary, and the seismic velocity and electrical resistivity of the bedrock should fall within specified ranges.

The large area east of the Mississippi River was rejected because of high population densities, lack of control of population movement, and proximity to large population centers. West of the Mississippi river, six locales were considered potential candidates based on low population: 1) the Las Vegas Bombing and Gunnery Range, including the Nevada Test Site, 2) northwest Nevada, 3) central Nevada, 4) southeast Utah, 5) McCone County, Montana, and 6) southwest Texas. After further consideration of the remaining criteria, the site in southwest Texas was the only one eliminated, mostly because of political reasons associated with its proximity to Mexico. The remaining sites were recommended for further study to be conducted in step 2 of the project.

Areas in Alaska considered were the southeast panhandle, the railbelt and road net area, Kodiak Island, St. Lawrence Island, Pribilof Islands, Brooks Range and northern Alaska, lower Kuskokwim and lower Yukon area, the Alaska Range Area, Chirikof Island, Yukon River, Koyukuk River, and Upper Kuskokwim River area, and the Aleutian Islands of the Alaska Peninsula. Four sites were determined eligible for further study. These included the northern foothills of the Brooks Range, the upper Holitna River area of the lower Kuskokwim and lower Yukon area, Chirikof Island, and the Aleutian Islands (Figure 3.18-1).

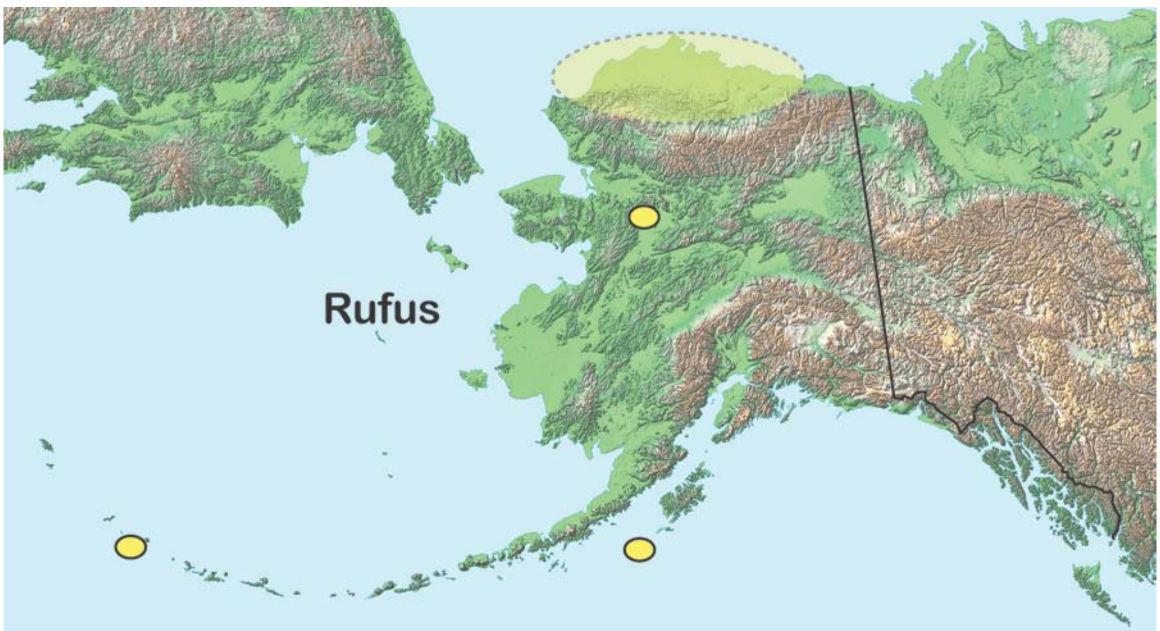


Figure 3.18-1. Four proposed locations for Project Rufus in Alaska (adapted from USA Relief Maps 2004).

All of the lands in the American-Caribbean area were rejected because of high population density, lack of uninhabited areas, and proximity to high population centers. In the Pacific Ocean area, small coral atolls and islands were automatically rejected because of size. Large American-owned or controlled islands considered in the study were the Carolines (Ponape, Truk, Yap, Kusaie, Palau Babelthaup group), the Marianas (Guam, Saipan, Tinian, Anatahan, Rota, Agrihan, Pagan), the Samoa-American (Tutuila, Tau, Ofu, and Olosega of the Manua group), the Bonins and Volcano (Chichi Jima Retto, Haha Jima Retto, Iwo Jima), the Daito (Kita Daito Jima, Minami Daito Jima), and the Hawaiian Islands (Niihau, Kauai, Oahu, Molokai, Lanai, Kahoolawe, Maui, Hawaii). Pagan Island was the only one in the Pacific selected for further consideration and evaluation. Foreign areas mentioned as possible locales, but disregarded, were northwestern Alberta and northern Ontario of Canada, Grand Cayman and Caicos of the Caribbean, Baja California of Mexico, all foreign islands in the Pacific, Australia, and Kerguelen Island in the Indian Ocean.

In summary, in Step 1 ten locales were selected for further study and evaluation in Step 2. Four were in the western United States, four were in Alaska, and one was in the Pacific Ocean. Accordingly, these nine locales, plus the Nevada Test Site, were subjected to more in depth scrutiny of site specifics for comparison and ranking. Three of the sites, southeast Utah, northwest Nevada, and McCone County in Montana, were eliminated from further consideration for various reasons. Leading the list for acceptable sites in the conterminous United States was the Nevada Test Site, followed by central Nevada. In those areas outside the conterminous United States and in decreasing priority were Chirikof Island, the northern foothills of the Brooks Range, the western Aleutian Islands, and the upper Holitna River in Alaska, and finally, Pagan Island in the Pacific Ocean. In Step 2 of the Rufus project, seven sites or locales were able to satisfy a more intense application of the six criteria and recommended for additional studies and evaluation.

In the spring of 1963, project personnel conducted an aerial reconnaissance of the four sites in Alaska. The focus of the aerial reconnaissance was the potential ground zero for each of the sites with a circle having a 50-mile radius, and 150-mile arcs for potential fallout sectors was established around each of the ground zeroes. Villages, cabins, towns, canneries, military establishments, and areas of biological interest(s) within these delineated zones were photographed during the flights. These data were then incorporated with literature research that included potential effects from nuclear explosions on marine and land biota, upon people and their activities, and structures and buildings, the access routes and estimated costs for facility construction, and the geology in terms of topography, lithology, water table, bedrock, and electrical resistivity and seismic velocity. An overall comparative evaluation was conducted of the four Alaskan sites and further studies recommended. The upper Holitna River area was exempted from further consideration because of existing population, potential forest fires, economic interests in the area, a limited fallout sector, and marginal topographic and geologic features. Chirikof Island was deemed least desirable of the other three sites because of a fishing industry around the island, including canneries and villages, a grazing lease for cattle, and its relatively small size. The other two sites, the northern foothills of the Brooks Range and Amchitka Island, were recommended for further advanced studies. These studies included detailed topographic maps, resistivity and seismic measurements, chemical and physical properties of soil and rock samples, operational cost and construction estimates, establishment of meteorological and seismic stations, human population movements and activities, the human-caribou food chain, cesium content of the environment, property rights, fishing practices, wildlife, including migratory birds and marine animals, and archaeology.

After the study and elimination of a number of locations, the Larkspur study was initiated to conduct further evaluations of three sites in Alaska, Chirikof Island, the northern foothills of the Brooks Range, and Amchitka Island. It was decided to hold Chirikof Island in reserve and not proceed with more work there. Before the field investigations started in late summer of 1963 on the Brooks Range and Amchitka Island, the Test Ban Treaty was signed by the United States on August 5, 1963 and the field operations were canceled. The treaty went into force on October 11, 1963. The treaty was of unlimited duration and prohibited nuclear weapons tests "or any other nuclear explosion" in the atmosphere, in outer space, and underwater. While not banning tests underground, the treaty prohibited them if they cause "radioactive debris to be present outside the territorial limits of the State under whose jurisdiction or control" the explosions were conducted. In the summer of 1964, field investigations were undertaken on Amchitka Island for another project, Long Shot, and provided the opportunity to complete the Amchitka portion of Larkspur. The field investigations focused on four areas on the island and included drill holes and testing activities.

The activity level for Project Rufus was a Level 3 because the field activities involved drilling test holes and conducting other test activities.

CHRONOLOGICAL BIBLIOGRAPHY

Hancock, John H., William S. Twenhofel, and Jules D. Friedman, 1963. Project Rufus Site Selection: Part I Rejection and Preliminary Selection of Areas. Manuscript, U.S. Atomic Energy Commission, Nevada Operations Office, Las Vegas, NV, February. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Twenhofel, William S., Jules D. Friedman, and John H. Hancock, 1963. Project Rufus Site Selection: Part II Preliminary Description of Areas. Manuscript, Atomic Energy Commission, Nevada Operations Office, Las Vegas, NV, February.

Black, Rudolph A., Garth B. Harlan, Kermit H. Larson, Robert E. Lyle, William S. Twenhofel, and Luke J. Vortman, 1963. Project Rufus Site Selection: Reconnaissance Report – Alaska. Manuscript, Atomic Energy Commission, Nevada Operations Office, Las Vegas, NV, May. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

U.S. Army Corps of Engineers. North Pacific Division, 1965. Project Larkspur, Amchitka Island, Alaska: Investigations of Areas 1, 2, 3 and 4. Manuscript, U.S. Army Engineer District, Alaska, March. On file at: Defense Threat Reduction Information Analysis Center, Albuquerque, NM.

3.19 SERGIUS NARROWS

Plowshare Program
Explosive Studies for Channel Improvement
Alaska

During the 1960s, the U.S. Army Corps of Engineers, Alaska District, studied making improvements to the channel through Sergius Narrows. Sergius Narrows is in the northern Alexander Archipelago, southeastern Alaska, approximately 30 miles north of Sitka, Alaska (Figure 3.19-1). The channel is between the Baranof Islands and Chichagof Island and provides small boat access between the Inside Passage and Sitka. Sergius Narrows was formed by a glacial valley that terminates at tide water with steep side slopes and exposed bedrock in places. Rapid and shifting tidal flows, rip tides, and rock formations make travel through the channel hazardous. The Alaska District studied a number of alternate alignments of the channel and recommended removing a section of the Wayanda Ledge to widen the channel from 285 to 450 feet. The plan also called for removal of West Francis Rock to provide sufficient area for a vessel to maneuver a course change (Figure 3.19-2).

Figure 3.19-1. Location of proposed Sergius Narrows project in southeastern Alaska (adapted from USA Relief Maps 2004).

The concept for the Sergius Narrows project developed from the Alaska District study and had a number of components. First, in 1968, the U.S. Army Engineer Nuclear

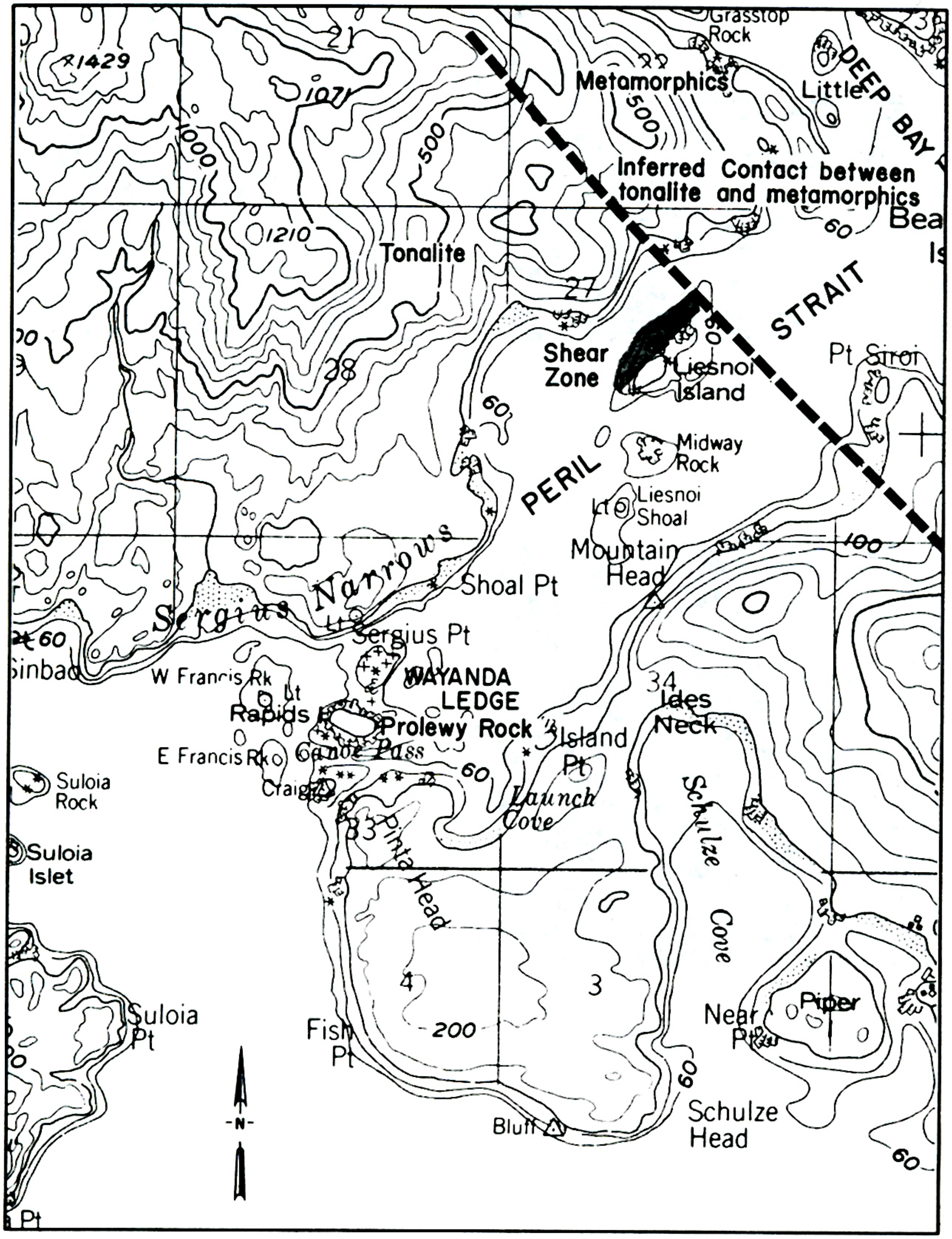


Figure 3.19-2. Map showing the location of Wayanda Ledge and West Francis Rock in Sergius Narrows, and the location of Liesnoi Island where high explosive tests were conducted (Gillespie 1971, Figure 3).

Cratering Group completed a feasibility study for using nuclear excavation to make channel improvements. Later, in 1970, the U.S. Army Engineer Explosive Excavation Research Office (successor to the Nuclear Cratering Group) conducted a series of high explosive experiments on Liesnoi Island at the northern end of the channel, to investigate cratering criteria for the high-strength rock characteristic of rock in Sergius Narrows. This was followed by a study of emplacement construction techniques for excavation at Sergius Narrows, with a final report issued in 1971. Finally, underwater explosive excavation modeling tests were conducted to verify the design concept for Sergius Narrows, and the results were summarized in a report issued in January 1972.

In November 1968, the feasibility study for making channel improvements at Sergius Narrows using nuclear excavation techniques was distributed. The study favored the alignment that incorporated the existing navigation channel as recommended by the previous Alaska District study (Figure 3.19-3). The plan called for a row-shot with five 1 kt explosive charges at Wayanda Ledge and two 10 kt explosives to remove West Francis Rock. The project would require construction of three or possibly four offshore drilling platforms to sink the emplacement holes and to set casings. Post-shot dredging of the channel would be necessary to remove debris resulting from the nuclear detonation. Insufficient information was available about the channel bottom to make a cost estimate for dredging, but the cost was considered significant. The study concluded that while the project was technically feasible it was not economical compared to conventional methods. This was, in part, due to the relatively small amount of rock that needed to be excavated, as well as costs incurred by having to remove ejected material from the channel.

Following the 1968 study, emphasis shifted from nuclear excavation to investigation of the use of chemical explosives for removing a portion of the Wayanda Ledge. In 1970, a series of high explosive cratering experiments were conducted on Liesnoi Island (Figure 3.19-2), with the final report completed in November 1971. The high explosive tests were a continuation of the hole springing work done at the Buchanan Dam site in California in a granitic medium (see Travois - Chapter 3.21). Hole springing is a blasting method in which successive detonations of small charges are fired in a drill hole to enlarge the bottom. Objectives of this segment of Project Sergius Narrows included: 1) determining the effectiveness of hole springing detonations for emplacement hole construction in an intermediate to high-strength medium, 2) gathering data on cratering characteristics in a submerged rock medium, and 3) developing design criteria for parallel row charge arrays for directional blasting applications. Construction techniques based on the results from the high explosive experiments were to be applied to Sergius Narrows.

The high explosive tests at Liesnoi Island were made up of five series of detonations (Figure 3.19-4). Series I consisted of hole-springing two 5 ¾ -inch diameter by 60 ft deep drill holes. Series II consisted of two individual 2-ton shots, one on dry land and one underwater. Series III employed three separate 2-ton charges detonated on sloping terrain, under water, and at different depths of burst. Series IV was a double row array with three 2 ton charges per row detonated simultaneously underwater. Finally, Series V

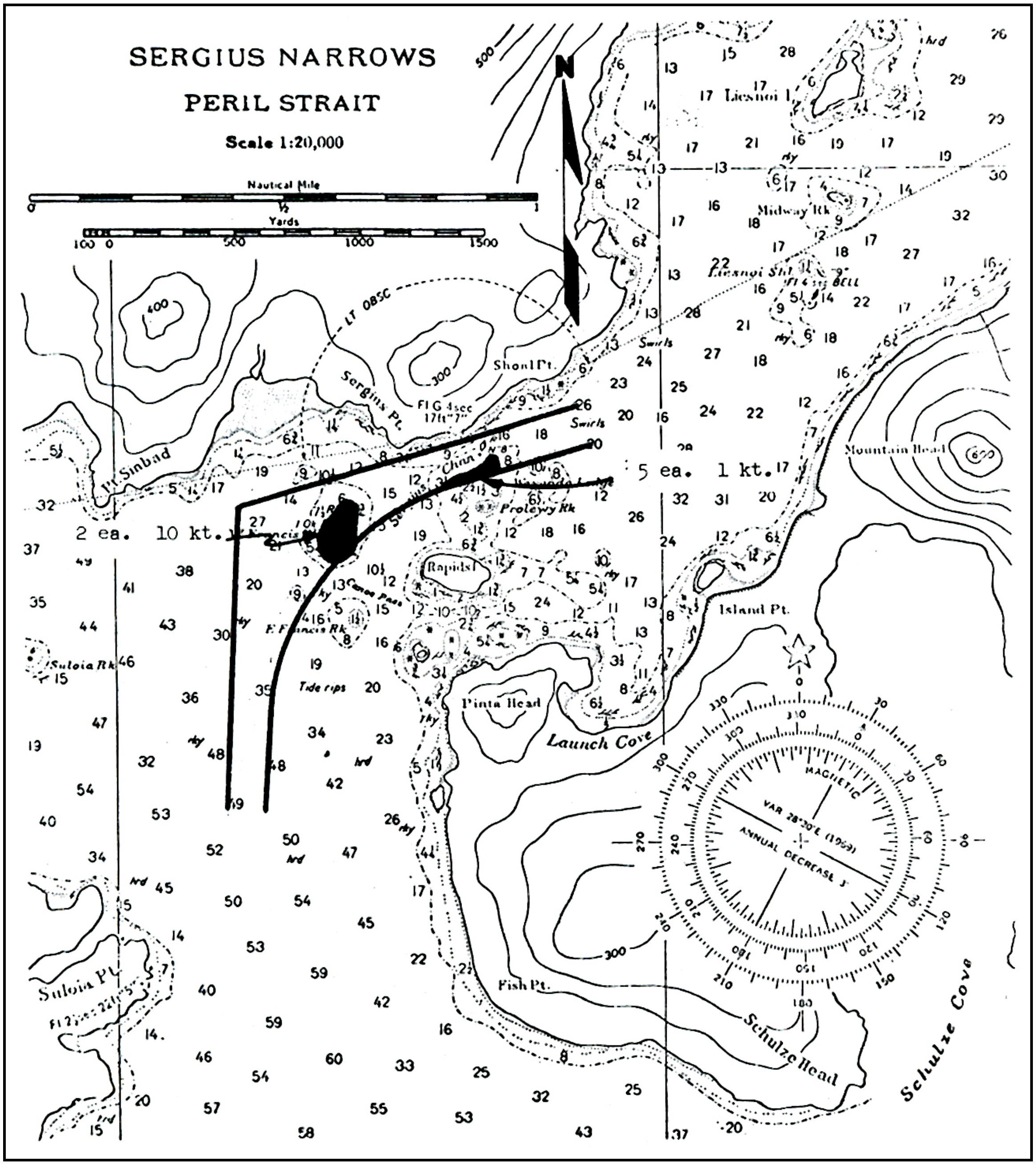


Figure 3.19-3. Location of the alignment proposed for using nuclear explosives to make channel improvements at Sergius Narrows (Mattes 1968, Figure 4).

repeated the double row three charge array with different spacing and depth of burst and a slight firing stagger between the rows. For all the detonations, the charge cavities were enlarged with four springing detonations. Additional drill holes were needed due to failure of the holes after some of the springing passes. In total, 57 holes were drilled on

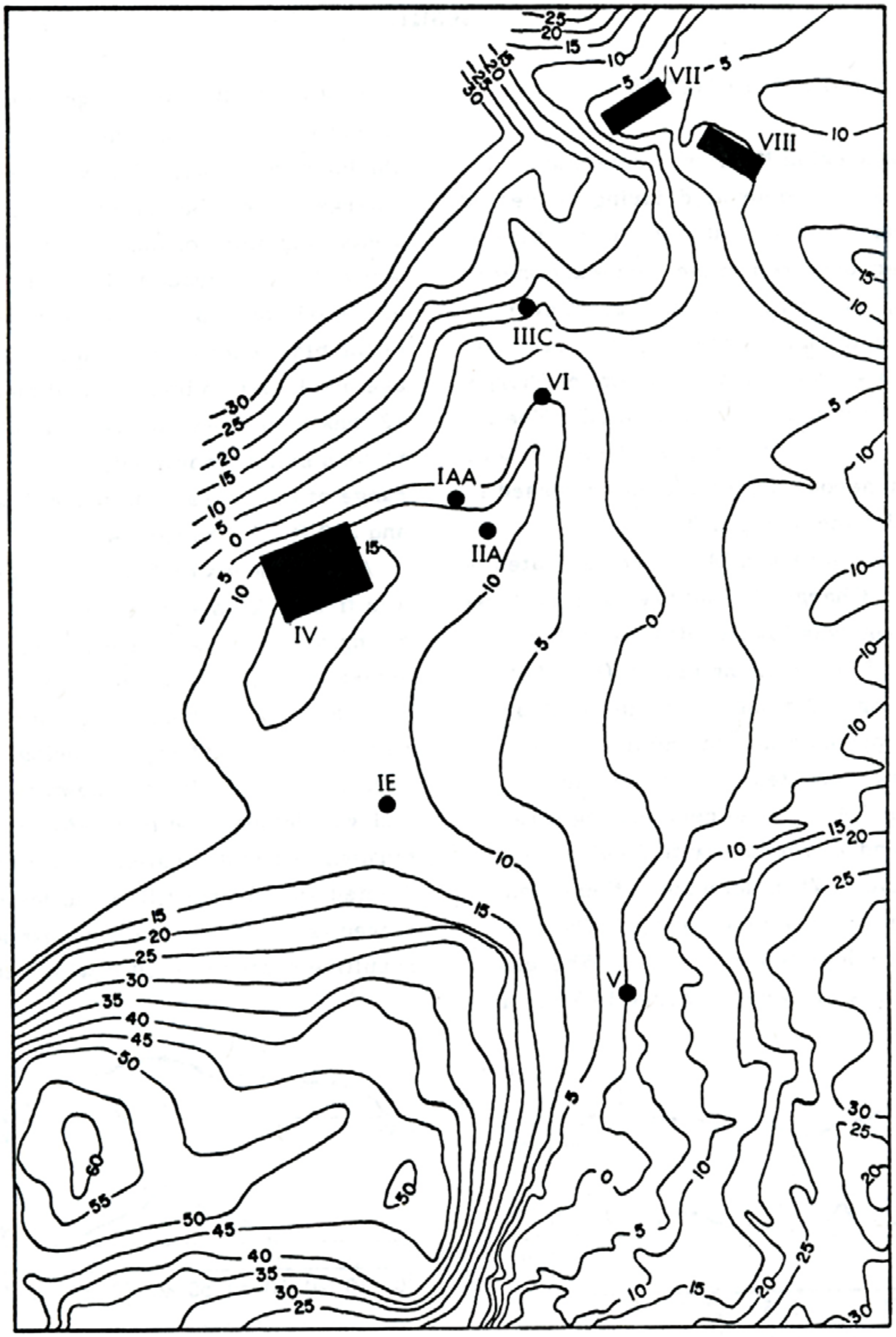


Figure 3.19-4. Map showing distribution of charge locations for the high explosive tests on Liesnoi Island (note: the map is not tied to a defined grid location) (Gillespie 1971, Figure 19).

the island, and the charges were detonated from July 2 through July 8, 1970. The experiments demonstrated that hole springing is not economical in intermediate- or high-strength rock due to a high failure rate. The cratering data was less conclusive since only two of the six single-charge detonations produced craters, although the report concluded that the granite medium at Sergius Narrows appeared to follow the criteria for cratering in high strength rock studied elsewhere.

A report on emplacement construction techniques for the excavation of Sergius Narrows was also completed in 1971, but a copy of this document is not available. However, the channel improvements at Sergius Narrows were part of an authorized project of the U.S. Army Corps of Engineers, Alaska District. A status report from the Explosive Excavation Research Office, effective September 30, 1971, mentioned that the explosive excavation design for Sergius Narrows was up for bid with the contract being awarded to the low bid for the explosive excavation.

In January 1972 a report entitled “Underwater Explosive Excavation Modeling Tests” was issued. The laboratory-scale tests were conducted to investigate directed blasting underwater to verify the design concept for the Sergius Narrows project. A secondary objective of the modeling tests was to provide data for underwater explosive excavation projects in general. The modeling tests consisted of a series of seventeen detonations of spherical 1 lb charges of Composition C-4; 7 charges in concrete without water overburden and 10 charges in concrete with water overburden. The former were to calibrate the cratering characteristics of concrete and the latter to investigate the effect of water on mound velocities and crater dimensions. The modeling tests suggested that crater dimensions in a cohesive medium are independent of water overburden and confirmed that directed blasting could be applied to underwater rock excavation. The location and precise dates of the modeling tests are not specified in the document.

Final documentation for Project Sergius Narrows occurs in a status report from the Explosive Excavation Research Office for the period ending March 31, 1972. The report states that the progress of conventional excavation operations at Sergius Narrows was monitored to evaluate the cost effectiveness of explosive excavation in underwater rock excavation projects. The Sergius Narrows site was visited in February 1972, and it was determined that drilling operations could be accomplished using an anchored barge except during periods of extreme tidal flow. Information on drilling and dredging operations were to be included in a report entitled “Sergius Narrows – Lessons Learned” scheduled to be issued in June 1972. It appears, however, that the final report was not completed, and no draft copies have been located. There is no documentation available about Project Sergius Narrows after the March 1972 status report.

The Sergius Narrows project had a number of components. In Sergius Narrows the project was a Level 5 activity. On Liesnoi Island the project was a Level 2 activity because high explosive tests were conducted. The precise location of the tests on the island is not known.

CHRONOLOGICAL BIBLIOGRAPHY

Mattes, Richard W., 1968. Analysis of the Feasibility of Channel Improvement by Nuclear Excavation at Sergius and Whitestone Narrows, Alaska. U.S. Army Engineer Nuclear Cratering Group, *Technical Memorandum* No. NCG/TM 68-13, November. Livermore, CA. On file at: Technical Information Center, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

LaFrenz, Robert L., 1971, "Status Report - Rapid Excavation with Explosives." Letter with encl. ("Status Report, Effective Date: 30 September 1971") from Robert L. LaFrenz, Explosive Excavation Research Office, Corps of Engineers, to Director, U.S. Army Engineer Waterways Experiment Station, October 29. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-108.

Gillespie, Richard H., 1971. Project Sergius Narrows - Summary of Tests on Liesnoi Island, Alaska, 1970. U.S. Army Engineer Explosive Excavation Research Office, Technical Report No. 33, November. Livermore, CA. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-092.

Kleist, E. H., and M. R. Florey, 1972. Underwater Explosive Excavation Modeling Tests. Lawrence Radiation Laboratory, U.S. Army Engineer Explosive Excavation Research Office, *EERO Technical Memorandum* No. EERO/TM 71-9, January. Livermore, CA.

LaFrenz, Robert L., 1972. "Status Report - Rapid Excavation with Explosives." Letter with encl. ("Status Report, Effective Date: 31 March 1972") from Robert L. LaFrenz, Explosive Excavation Research Office, Corps of Engineers, to Director, U.S. Army Engineer Waterways Experiment Station, April 10. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-108.

THIS PAGE INTENTIONALLY LEFT BLANK

3.20 THUNDERBIRD

Plowshare Program
Nuclear Explosives for Coal Extraction
Wyoming

In 1966 or 1967, a group of coal engineers contacted the U.S. Atomic Energy Commission, U.S. Bureau of Mines and the U.S. Geological Survey regarding the prospect of conducting an experimental in situ coal-energy program in northeastern Wyoming (Figure 3.20-1). Remarks made by Glenn T. Seaborg, Chairman of the U.S. Atomic Energy Commission, at the Governor's Industrial Safety Conference on February 7, 1968, discussed this potential project, by then named Project Thunderbird, as an example of a proposed plan to use nuclear explosions to increase energy production. He remarked that the coal engineers estimated that a successful use of nuclear technology could produce more than twice the energy in the United States oil reserves through the gasification of a large coal deposit in Wyoming. Coal gasification is a process for converting coal to combustible gases such as carbon monoxide, carbon dioxide, hydrogen, methane, and nitrogen. After purification, these gases can be used as fuels. This project was a logical extension of other proposed nuclear experiments in the Plowshare Program that were addressing the stimulation of oil and gas reserves. Thunderbird was the first project to focus on coal reserves.

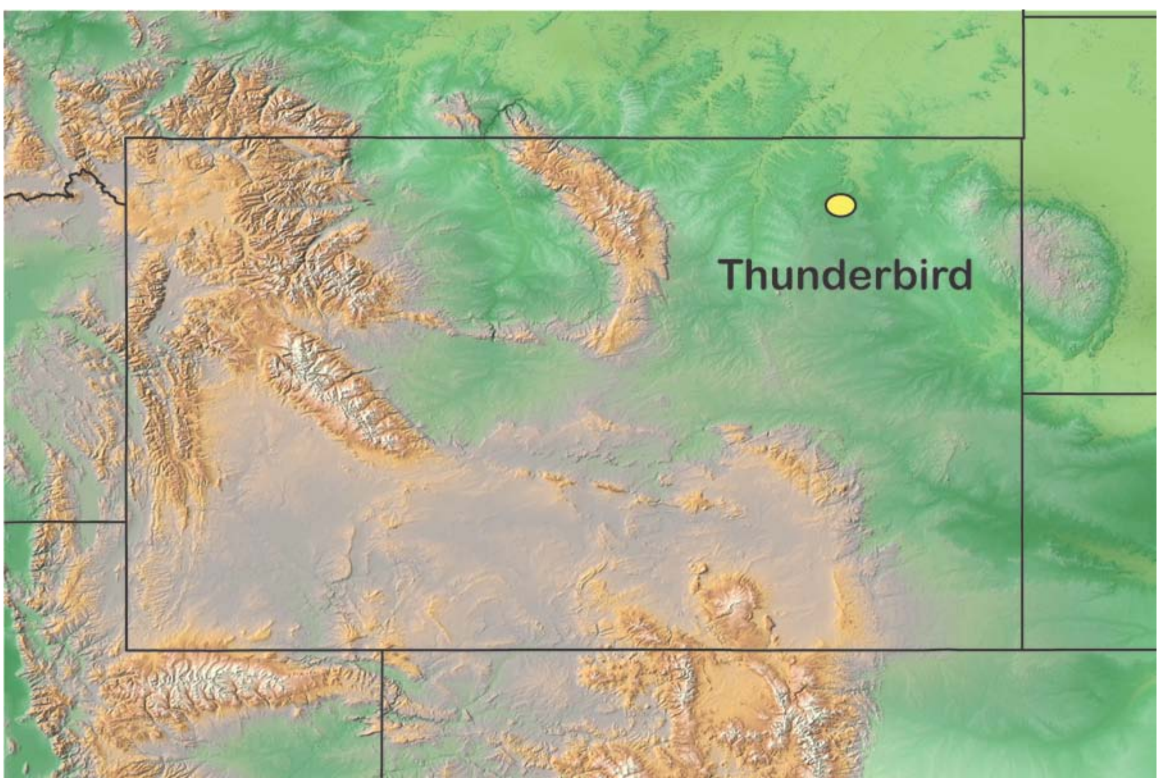


Figure 3.20-1. Location of Project Thunderbird in Wyoming (adapted from USA Relief Maps 2004).

The research potential of Project Thunderbird included in situ gasification of individual coal beds, hydraulic coal mining, solution mining, conventional underground mining, and creation of a nuclear chimney with in situ gasification. Although numerous coal and oil companies showed an interest in the Plowshare Program, the Casper, Wyoming firm of Wold and Jenkins was the primary proponent from the private sector pushing for the nuclear stimulation of coal reserves. Working in conjunction with scientists from Lawrence Radiation Laboratory, the engineers believed that a nuclear detonation could open multiple seams of coal and solve some problems encountered during other attempts at underground gasification. There was great interest in the potential to create a rubble chimney with void space that could be burned under controlled conditions (Figure 3.20-2). By injecting oxygen and, if needed, steam into the chimney and surrounding fracture zone, Btu gas and associated products could be extracted from the burning coal.

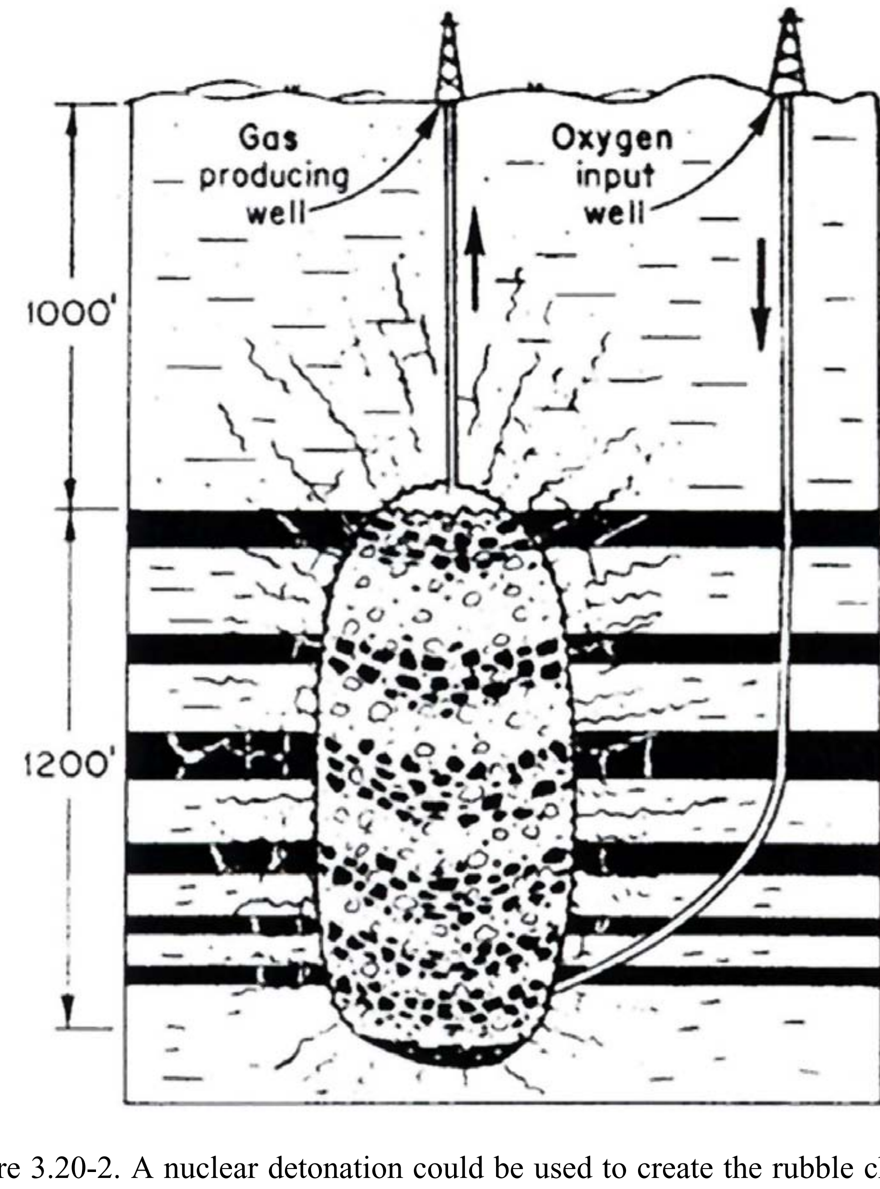


Figure 3.20-2. A nuclear detonation could be used to create the rubble chimney for in situ coal gasification (Wold and Woodward 1967, Fig. 2).

Project Thunderbird was located in the Tertiary Fort Union-Wasatch Formation in the central Powder River Basin. It consisted of a 100 sq mi area with an estimated 20 billion tons of subsurface coal (Figure 3.20-3). The Tongue River member of this formation was estimated to contain the thickest sequence of coal beds in North America and possibly the Western Hemisphere. Just 25 mi east of the Thunderbird project area, the most famous of these coal beds, the more than 150-ft thick Roland bed, was being strip-mined in a 90-ft surface exposure in the Wyodak Mine (Figure 3.20-4). In the Project Thunderbird region, the Roland bed occurs below 1,000 ft rather than at the surface.

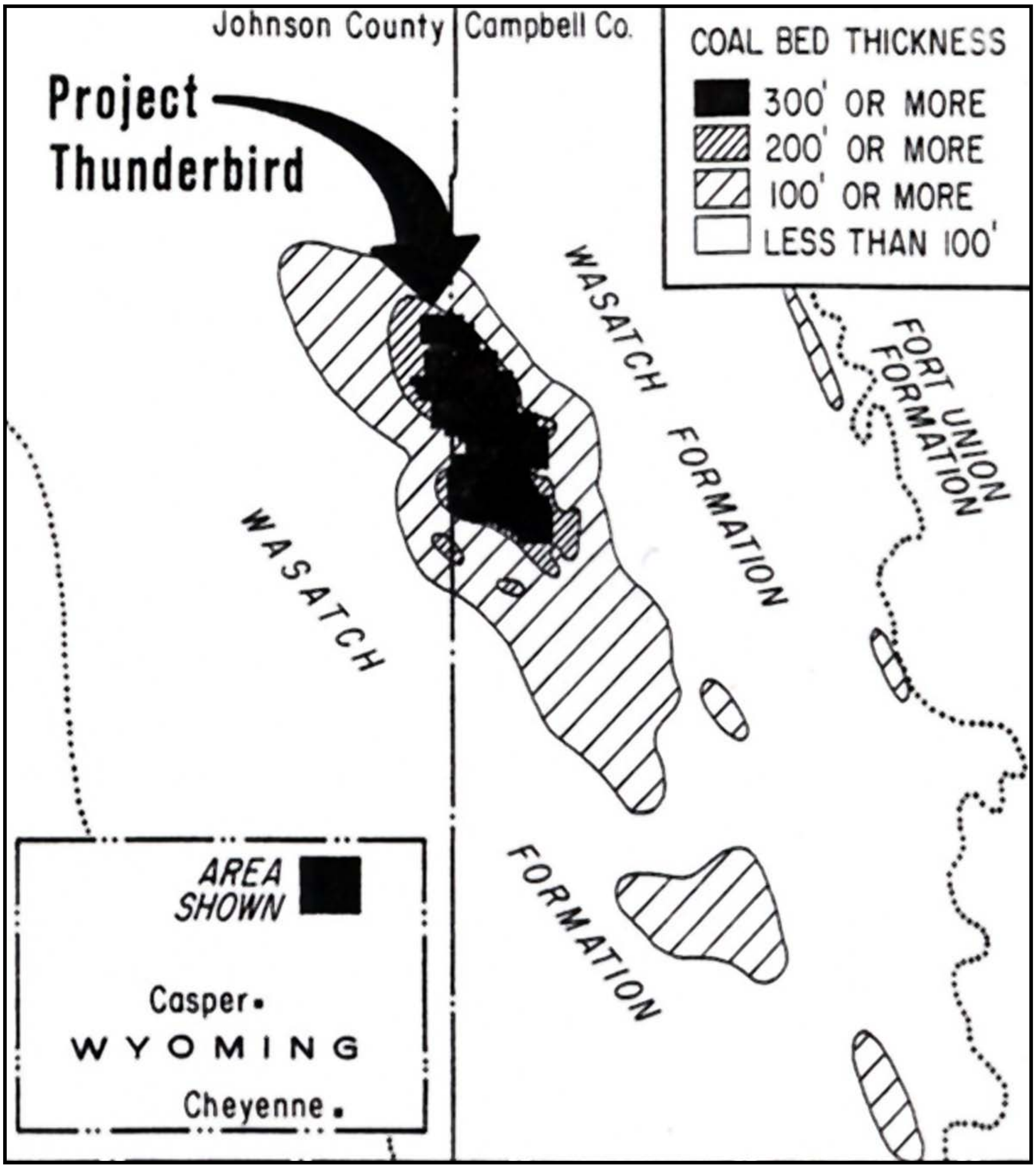


Figure 3.20-3. The primary coal deposits in the central Powder River Basin (Wold and Woodward 1968a:111).

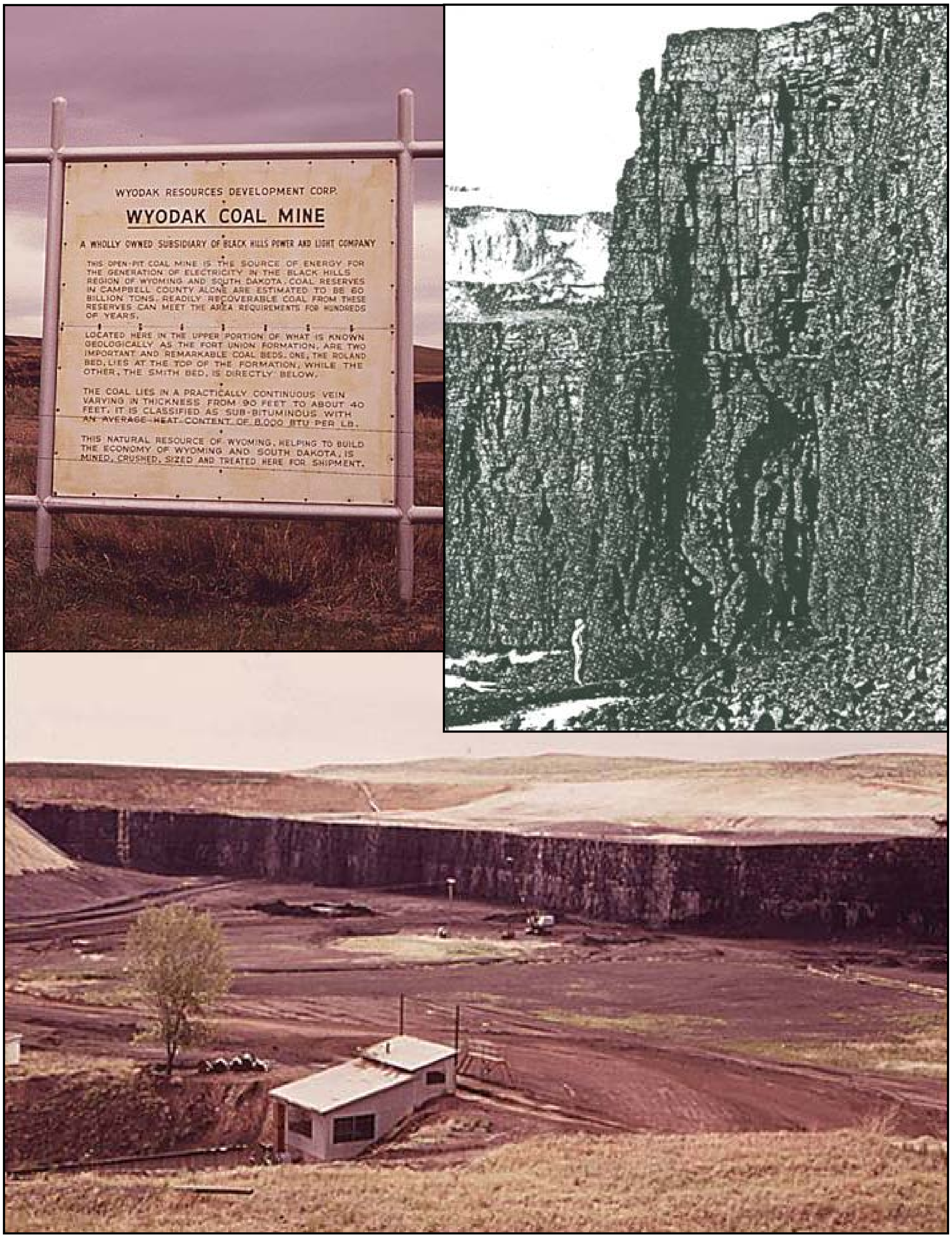


Figure 3.20-4. Although the massive Roland coal bed appears at the surface near Wyodak, Wyoming, it occurs at depths below 1,000 ft in the Project Thunderbird area just 25 mi to the west. (Clockwise from upper left) The photos show the entrance to the Wyodak Mine, a 1960s-era photo of the coal bed with a man at the lower left for scale (Wold and Woodward 1968, Fig. 3), and a more recent overview of the still-active mine.

The project site was 20 miles west of Gillette, Wyoming on Interstate Highway 90 in Campbell and Johnson Counties. The location covered parts of Township 51 North, Ranges 76 and 77 West; Township 50 North, Ranges 75, 76, and 77 West; Township 49 North, Ranges 75 and 76 West; and Township 48 North, Ranges 75 and 76 West. The richest coal beds occur at depths from 1,000 to 2,200 feet with 18 to 30 percent coal at this depth. The Project Thunderbird area encompassed the best coal section in the basin with the coal beds averaging 220 ft thick and ranging from 50 to almost 400 ft in thickness. Additionally, the sandstone formations containing the coal beds were highly lenticular and local in extent indicating that in-situ extraction should not be plagued by excessive ground water flows. This geological characterization for the project was obtained from analyses of data from 151 holes that were drilled for oil in the area. The oil drill hole locations appear as small crosses and dots on the map in Figure 3.20-5.

Coal Gasification

In 1968, there were two nuclear experiment proposals under consideration for Project Thunderbird. The first was a nuclear detonation with a yield of 50 kt at the base of the coal bearing beds. Focusing on the technical feasibility of a nuclear gasification experiment, CER Geonuclear Corporation calculated that a 50 kt explosion would produce a rubble chimney with a radius of 127 ft and a height of 635 ft with fractures extending into the surrounding formation for a radius of 300 ft. Twenty-five percent of the two million tons of broken rock would be coal and would have a Btu equivalency of 1.5 million barrels of oil. Oxygen injected into the chimney would be required for the ignition of the fracture zone and extraction of the low Btu gas. Excessive groundwater would not be a concern in the project area and a reliable surface source of processing water could be obtained from the nearby Powder River.

The second proposal considered the use of a 1,000 kt detonation. A professor at the University of Wyoming's Natural Resources Institute produced a preliminary feasibility study of this larger project. Both technical and economic viability were evaluated. It was estimated that this explosion would produce a chimney 1,200 ft in height with a radius of 310 ft and a volume of 25 to 30 percent coal. This larger blast would produce about 3.32 million tons of fragmented coal – nearly 7 times the amount of the 50 kt explosion. In theory, the 1,000 kt experiment would also greatly expand the surrounding fracture zone thereby increasing the combustible coal by as much as 10 to 50 percent. Although the cost of the nuclear device and required emplacement hole would cost more, the potential return on investment would be significantly higher than the smaller yield experiment. This made the larger detonation more economically attractive to the engineers from Wold and Jenkins.

Burning of the coal in either case would create an enormous, subterranean coke oven. According to the conceptual design, the nuclear detonation would create the "reaction zone" where the coal burning takes place. The gas would be collected and upgraded at the surface. Above-ground processing of the synthetic gas would be accomplished using a Fischer-Tropsch type plant. Ancillary holes would have to be drilled including one used to pump oxygen into the chimney. Water for processing could come from either surface

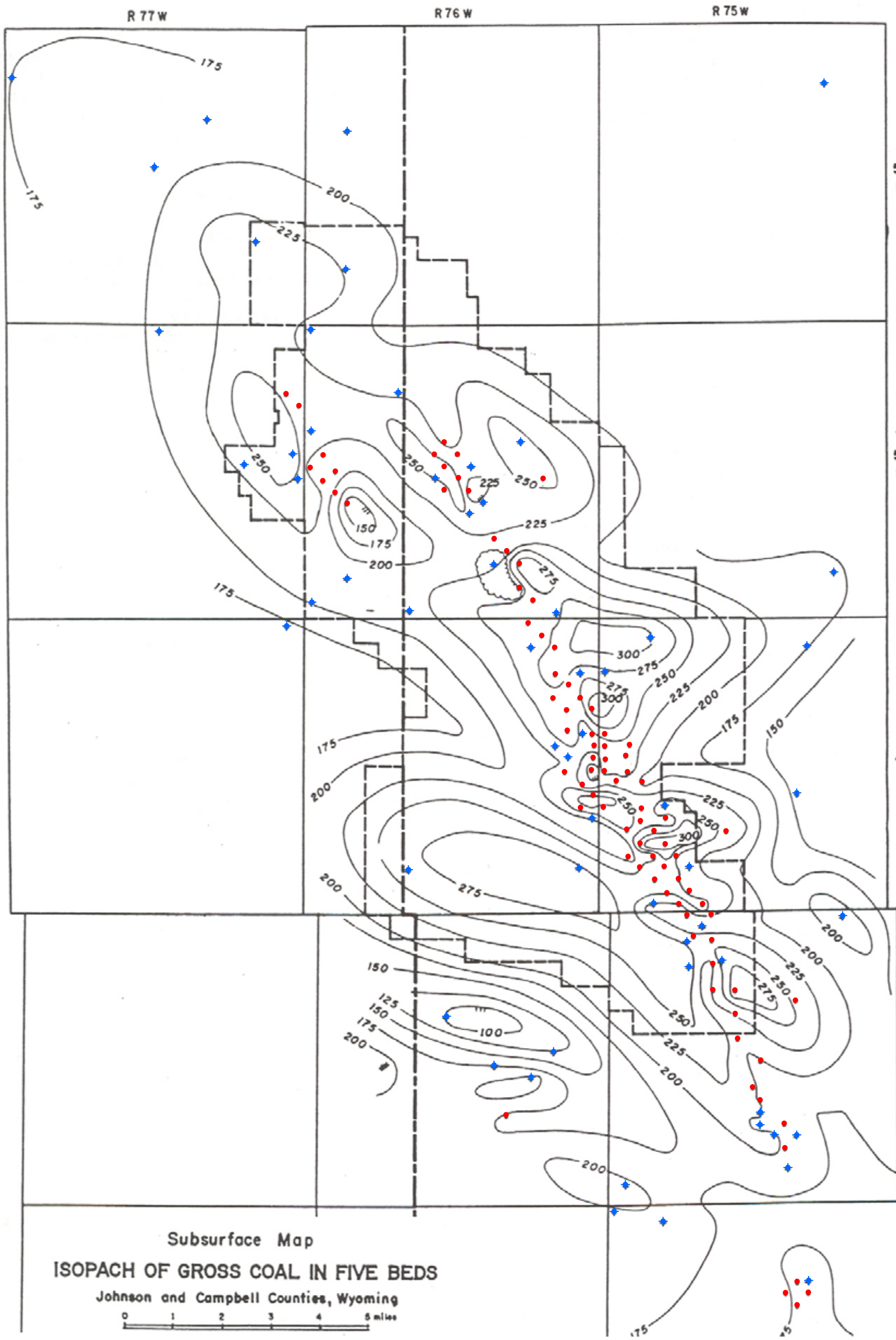


Figure 3.20-5. Coal bed thicknesses in the Project Thunderbird area. The colored crosses and dots represent wells drilled for oil and coal exploration (adapted from Wold and Woodward 1968b, Fig. 5).

or groundwater. Existing pipelines could move the gas and liquid commercial products to market.

Between April and June of 1969, 14 holes were drilled at the Project Thunderbird site on selected Wold and Jenkins leases to obtain additional information on the coal reserves in places where there was minimal to no primary data on the coal deposits (Figure 3.20-6). In addition, the drilling produced information to meet the validation requirements for the coal permits issued by the U.S. Geological Survey. Materi Exploration drilled the holes with two rigs. Coring of each of the five major coal beds revealed the heat content of the deposits ranged from 9,100 to 10,400 Btu per pound. Because of this effort, the reserve estimate of coal was increased from 20,000 million tons to 22,000 million tons. It also was suggested that the Project Thunderbird location was appropriate for studying the processing of synthetic crude oil too.

Based on the drilling results, the Wold and Jenkins engineers appeared cautiously optimistic that nuclear coal gasification was a viable extraction technology for the Powder River Basin project area. However, an analysis by an independent engineering firm came to a different conclusion. In July 1969, Gibbs & Hill, Inc. issued a report to Lawrence Radiation Laboratory after examining the Thunderbird project as proposed by Wold and Woodward. Their conclusion was that the numbers in terms of production potential and development and operations costs were incorrect making the project technically and economically unfeasible. A response by the Laboratory's Director, Dr. Michael May, the following month indicated scientists at Lawrence Radiation Laboratory concurred with the conclusions reached by the Gibb and Hill engineers. No later documentation has been identified by the current research effort suggesting that the negative engineering review effectively ended the proposed nuclear gasification experiment component of Project Thunderbird.

Project participants were fairly limited for the nuclear component of Project Thunderbird. They included the U.S. Atomic Energy Commission; U.S. Bureau of Mines; U.S. Geological Survey; Lawrence Radiation Laboratory; CER Geonuclear Corporation; Wold & Jenkins; University of Wyoming, Natural Resources Institute; Materi Exploration; Gibbs and Hill, Inc.; and a few independent consulting geologists/engineers.

Development work for Project Thunderbird was limited to utilizing geochemical data obtained from 151 existing oil wells and the drilling of 14 new coal bed characterization exploratory holes in the project area. Beyond the drill holes, there is no indication that any permanent surface facilities were built in support of the Thunderbird field activities.

A review of the realty records at the Bureau of Land Management Wyoming State Office in Cheyenne revealed that all 14 of the coal bed characterization drill hole locations were on leases held by the firm of Wold and Jenkins at the time of the project in the late 1960s. All the leases, however, were allowed to lapse in the 1970s reverting to the Bureau of Land Management. New leases have been issued to other oil and gas development companies for some of the locations while other locations remain unleased. The records

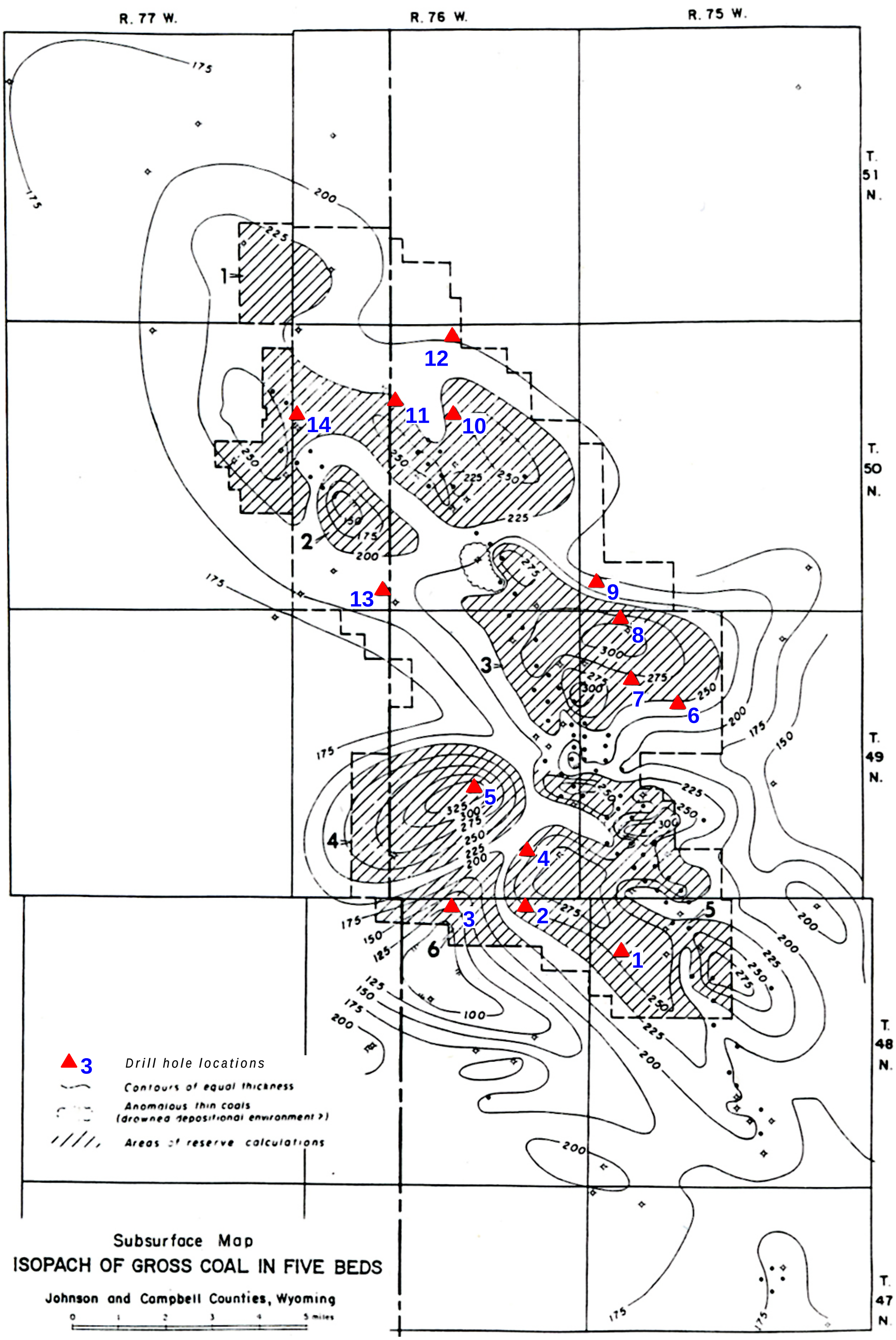


Figure 3.20-6. Locations of the 14 Project Thunderbird coal bed characterization drill holes completed between April and June, 1969 (adapted from Hicks and Woodward 1969, Fig. 2).

were administered by the U.S. Atomic Energy Commission either through a withdrawal, transfer, or special use permit.

Project Thunderbird was a Level 3 activity with field work limited to use of existing wells and the drilling of 14 new characterization wells. The location was visited in FY 2006.

FIELD VISIT

Desert Research Institute investigators, Beck and Edwards visited the Thunderbird project area during the summer of 2006 with the goal of photodocumenting the current condition of the 14 coal bed characterization holes drilled between April and June 1969 (See Figure 3.20-6). Prior to start of the field work the locations of the drill holes were plotted on USGS 7.5 minute quadrangle maps of the region and tentative UTM coordinates calculated. The drill hole locations are provided in Table 3.20-1. The numeric drill hole designations 1 through 14 were randomly assigned during the current research project. Original names or numeric designations of the drill holes are unknown.

Starting on July 10, 2006, the researchers attempted to relocate the drill hole sites. Like much of the western U.S., however, this portion of Wyoming is experiencing a boom in oil, gas, and coal exploration and development. While the Wold and Jenkins coal exploration firm no longer exists, Wold Oil Properties still has extensive holdings in the region (Figure 3.20-7) and is currently engaged in oil and gas development in the region. However, none of the old coal bed characterization drill holes are located on Wold Oil holdings. Devon Energy and Williams Companies, Inc., both natural gas production companies, hold most of the current leases at or near the old Thunderbird locations (Figure 3.20-8).

The Powder River Basin is covered with hundreds of old capped drill holes and new active wells. The region is a maze of newly graded roads with constant heavy equipment activity. Many old roads leading to the Thunderbird drill hole locations have been blocked or modified. Other drill hole sites sit surrounded by active mineral leases or private property with limited or no access. Only a few of the Thunderbird sites could be reached for direct evaluation (Figure 3.20-9), however a number of old locations could be viewed from a distance using a telephoto lens and binoculars (Figure 3.20-10 and 3.20-11).

With the exception of the well heads, no surface facilities associated with the Thunderbird project drill holes remain. The recording/telemetry sheds and fencing surrounding the drill hole locations with active wells post-date the Project Thunderbird activities. The 2006 field reconnaissance completed the on-site recordation and land status assessment for Project Thunderbird.

Table 3.20-1. Project Thunderbird Coal Bed Characterization Drill Hole Locations

DRILL HOLE DESIGNATION	LOCATION DESCRIPTION
1	just northwest of the junction of Bridge Draw and Dead Horse Creek in the NW1/4NE1/4, Sec. 7, T48N R75W, Campbell County, WY.
2	about 1.25 mi southwest of the junction of Pearson Draw and Dead Horse Creek in the center of the N1/2NE1/4, Sec. 2, T48N R76W, Campbell County, WY.
3	between Morgan Draw and Government Draw in the W1/2NW1/4, Sec. 3, T48N R76W, Campbell County, WY.
4	about 0.5 mi southwest of Dead Horse Creek and 0.75 mi east of Morgan Draw in the NE1/4NE1/4NE1/4, Sec. 35, T 49N R76W, Campbell County, WY.
5	just north of Dead Horse Creek on the south side of Interstate Highway 90 in the N1/2SE1/4, Sec. 22, T49N R76W, Campbell County, WY.
6	about 1.5 mi east of the South Prong channel of Barber Creek in the SW1/4SW1/4SW1/4, Sec. 9 T49N R75W, Campbell County, WY.
7	about 1 mi east of the South Prong channel of Barber Creek in the SW1/4NW1/4, Sec. 8, T49N R75W, Campbell County, WY.
8	along a wash between Barber Creek and the South Prong drainage channel in the NE1/4NE1/4, Sec. 6, T49N R75W, Campbell County, WY.
9	head of the wash between Barber Creek and the South Prong drainage channel in the SE1/4NE1/4, Sec. 31, T50N R75W, Campbell County, WY.
10	Maycock Draw north of Barber Creek and west of the Kinney Divide in the SE1/4SW1/4, Sec. 10, T50N R76W, Campbell County, WY.
11	0.75 mi north of Barber Creek and west of Maycock Draw in the W1/2SW1/4, Sec. 9, T50N R76W, Campbell County, WY.
12	north end of Maycock Draw in the NE1/4NW1/4, Sec. 3, T50N R76W, Campbell County, WY.
13	about 3 miles north of the junction of Interstate Highway 90 and Laskie Draw in the NE1/4SE1/4, Sec. 32, T50N R76W, Johnson County, WY.
14	on Barber Creek in either the SW1/4SW1/4SW1/4, Sec. 7 or the NW1/4NW1/4NW1/4, Sec. 18, T50N R76W, Johnson County, WY.

Figure 3.20-7. Wold Oil Properties, the parent company of the now defunct Wold and Jenkins coal exploration firm, is still active in the Powder River Basin (photo taken July 2006 on file at Desert Research Institute).

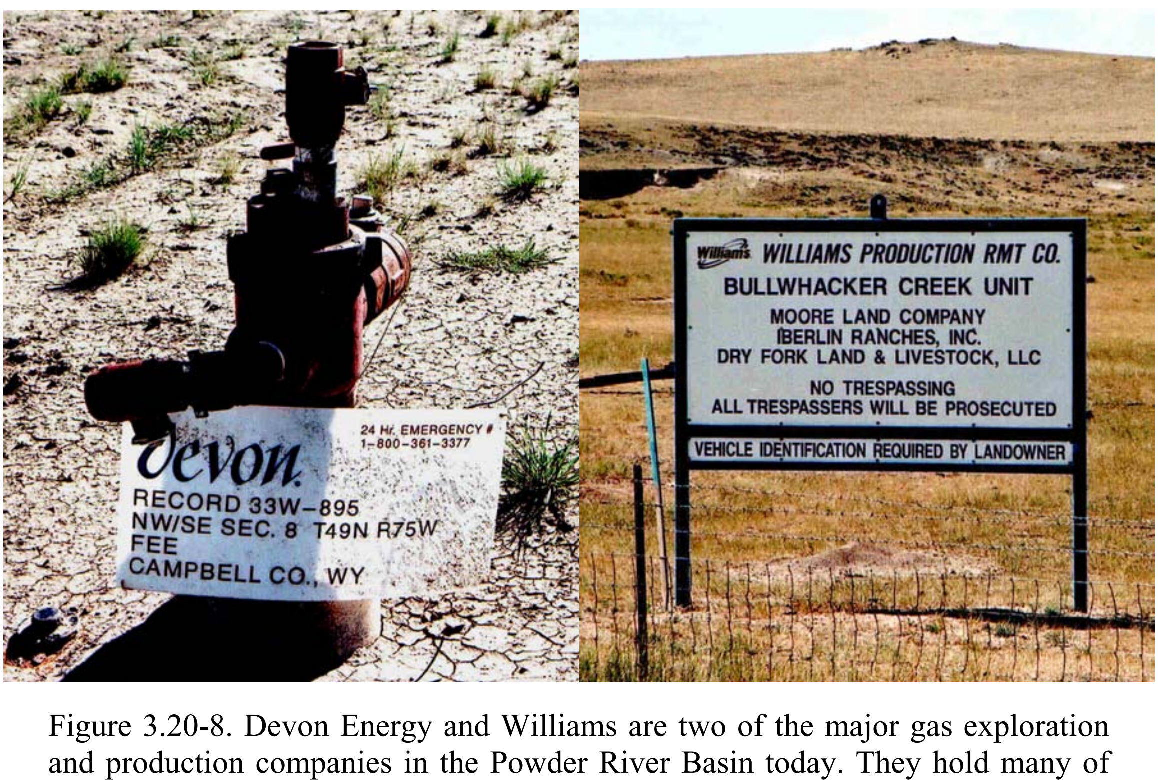


Figure 3.20-8. Devon Energy and Williams are two of the major gas exploration and production companies in the Powder River Basin today. They hold many of the leases at or near the Project Thunderbird drill holes (photos taken July 2006 on file at Desert Research Institute).

Figure 3.20-9. Devon Energy holds the current lease on the location of the Project Thunderbird coal bed characterization drill hole No. 8 located along a wash between Barber Creek and the South Prong drainage channel in theNE1/4NE1/4, Sec. 6, T49N R75W, Campbell County (photos taken July 2006 on file at Desert Research Institute).

Figure 3.20-10. Drill Hole No. 5 located just north of Dead Horse Creek on the south side of Interstate Highway 90 in the N1/2SE1/4, Sec. 22, T49N R76W, Campbell County. The old drill hole is the site of an active gas well and telemetry shed surrounded by the fenced pasture of a local rancher (photo taken July 2006 on file at Desert Research Institute).

Figure 3.20-11. Drill Hole No. 4 is located about 0.5 mi southwest of Dead Horse Creek and 0.75 mi east of Morgan Draw in the NE1/4NE1/4NE1/4, Sec. 35, T49N R76W, Campbell County. An active gas well and telemetry shed are located at the site of the old drill hole. The road into the site was blocked (photo taken July 2006 on file at Desert Research Institute).

CHRONOLOGICAL BIBLIOGRAPHY

Coal Age, 1967. Project Thunderbird Nuclear Trigger for Coal Gasification. *Coal Age*, pp. 64-68, September.

Seaborg, Glenn T., 1968. The Progress of the Peaceful Atom. Paper presented at the Governor's Industrial Safety Conference, February 7, 1968, San Francisco, California. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Las Vegas, NV, Accession No. NV0148558.

Wold, John S., and Thomas C. Woodward, 1968a. Coal Makes Bid to Join Plowshare Nuclear Program. *World Oil*, pp. 111-120, May.

Wold, John S., and Thomas C. Woodward, 1968b. Project Thunderbird. *Wyoming Geological Association Guidebook,* Twentieth Annual Field Conference, pp. 147-153.

Gambs, Gerard C., 1969. "Analysis of Project Thunderbird - In Situ Coal-Nuclear Experimental Program." Memo from G. C. Gambs, Gibbs & Hills, Inc., New York, NY, to Plowshare File, July 28.

Gambs, Gerard C., 1969. Letter from Gerard C. Gambs, Gibbs & Hill, Inc., New York, NY, to Michael M. May, July 29.

May, Michael M., 1969. Letter from Michael M. May, Lawrence Radiation Laboratory, to Gerard C. Gambs, August 11.

Hicks, Merle E., and Thomas C. Woodward, 1969. Project Thunderbird: A Progress Report. *Wyoming Geological Association Guidebook*, Twenty-First Annual Field Conference, pp. 161-163.

Shafer, David S., William. C. Beck, Dwight Treadwell, and Stephen. A. Mellington, 1995. Inventory of Potential Environmental Restoration Liabilities Associated with Plowshare And Vela Uniform Program Sites. Manuscript, U.S. Department of Energy, Office of Environmental Restoration. On file at: Desert Research Institute, Las Vegas, NV.

U.S. Department of Energy. Nevada Operations Office, 1997. Plowshare Program Executive Summary. Report from U.S. Department of Energy, December 22.

Woodward, Thomas C., [1968]. Project Thunderbird: An In-Situ Coal Extraction Research Program. Abstract, Association Round Table (publication unknown), pp.214-215.

U.S. Department of Energy. Nevada Operations Office, n.d. The Plowshare Program (Draft). Report from U.S. Department of Energy.

3.21 TRAVOIS

Plowshare Program
Nuclear Quarrying for Dam Construction
California, Idaho, and Oregon

In 1966, the U.S. Army Engineer Nuclear Cratering Group was looking for demonstration projects to explore two different methods of nuclear dam construction. The first method involved the detonation of a nuclear explosive to create a landslide dam across a river canyon. The second method focused on using nuclear explosives to quarry rock aggregate for the construction of a rockfill dam. Research for a location in the western United States initially identified three possible places for this project: 1) the Buchanan Dam, California, 2) the Twin Springs Dam, Idaho and (3) the Cochiti Dam, New Mexico (an Oregon location was considered much later- see pg. 3.21-11). The Buchanan damsite was on the Chowchilla River, in Madera County, 17 miles northeast of Chowchilla, 26 miles east of Merced, and 35 miles northwest of Fresno. A potential nuclear quarry site was 2.25 miles north of the damsite in Mariposa County. The Twin Springs site was on the Boise River, 28 miles east of Boise and about 14 miles upstream from Arrowrock Dam in the Sawtooth Mountains area of the Boise National Forest. Cochiti Dam, about 40 miles north of Albuquerque, New Mexico, on the Rio Grande, was under construction. The proposed nuclear quarry for the Cochiti dam was about three miles northeast. The U.S. Atomic Energy Commission Nevada Operations Office requested the U.S. Geological Survey to prepare a statement on the hydrologic safety problems associated with the use of a nuclear device for excavation at each site, to estimate the cost of a hydrologic safety evaluation for each site, and to identify apparent favorable and unfavorable conditions at each site. The U.S. Geological Survey concluded that from a hydrologic safety viewpoint, each of the sites had about equal advantages and disadvantages with the Cochiti Dam Site having a slight advantage with a deeper water table. The Buchanan Dam Site, however, was the one initially chosen and this effort to create rockfill for a dam with nuclear detonations was named, Project Travois (Figures 3.21-1 and 3.21-2).

By May 1967, planning for Project Travois was underway with the initial concept centered on using a 10 kt nuclear explosion in a granite knoll. Field characterizations studies utilized pre-existing geological and hydrological drill holes and data from earlier geological studies conducted for a conventionally constructed dam. The results of a preliminary seismic safety study were reported in August 1967 and evaluated the number and distribution of potential complaints resulting from damage from the seismic wave. The report expected 571 complaints but noted that this number probably was high. Yosemite National Park, 35 miles east of ground zero was not expected to experience significant damage. Preliminary safety studies were also conducted for radioactivity and air blast. The 10 kt device was predicted to produce 2 million cubic yards of aggregate for dam construction. In December, the U.S. Atomic Energy Commission Nevada Operations Office provided preliminary cost estimates for field construction, technical support, and logistical support to the U.S. Army Engineer Nuclear Cratering Group. The following month, the Nuclear Cratering Group expressed concern over the high cost of

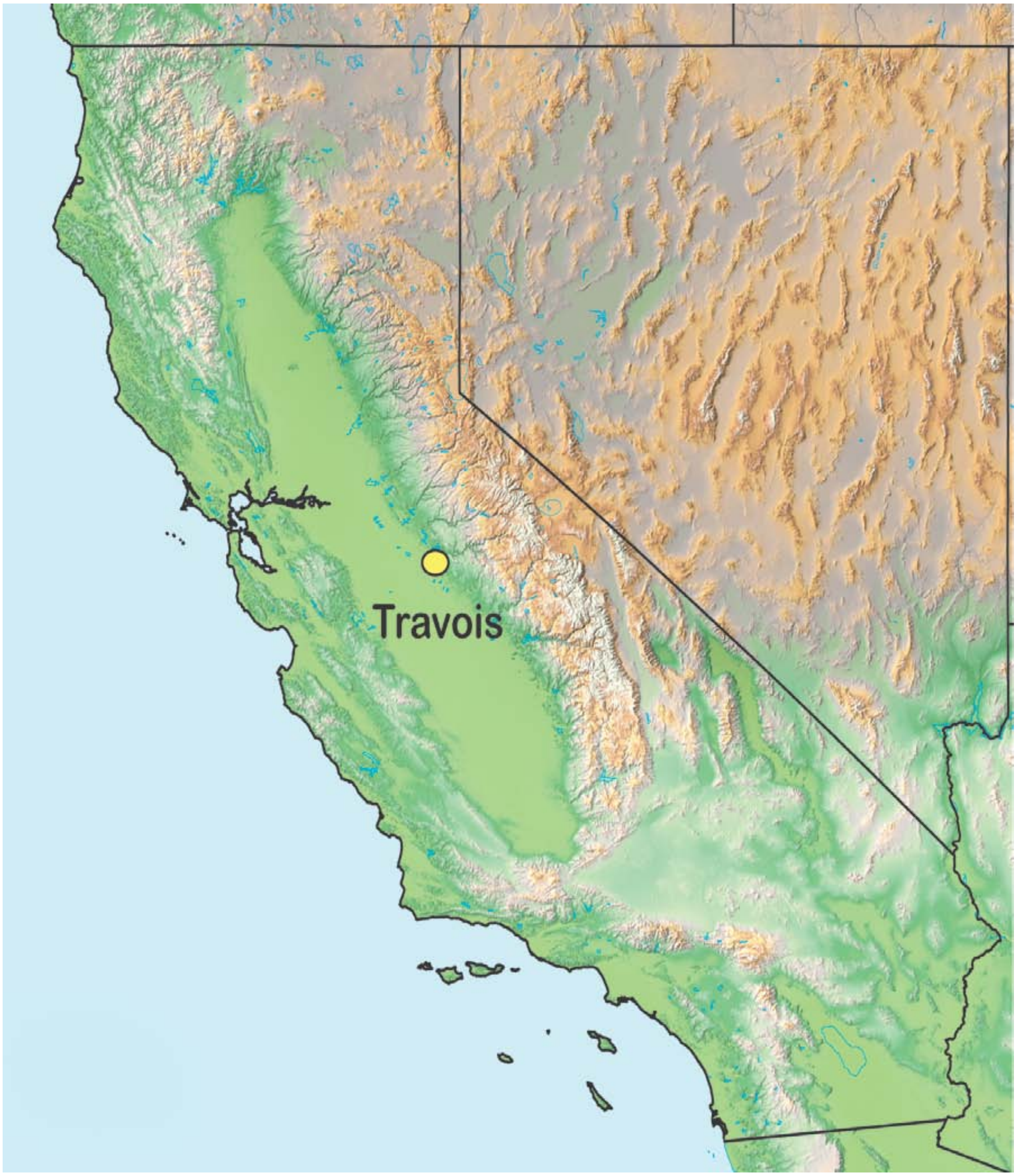


Figure 3.21-1. Proposed location for Project Travois near Merced, California at the Buchanan Dam Site (adapted from USA Relief Maps 2004).

the estimate. The Group stated that one of the goals of the project could be to identify minimum scope and cost for safety with nuclear detonations to achieve overall economy in construction because the current level of costs would not make most applications of Plowshare technology economically feasible. Around the same time, the schedule for execution of Travois was changed to a later date, the second quarter of FY 1970. The original date for the experiment is unknown.

In a February 2, 1968, letter to Lawrence Radiation Laboratory, the director of the Nuclear Cratering Group discussed the need to proceed with Project Angledozer, a high explosive calibration series for Project Travois. Angledozer (later renamed Excavator) would provide data on the seismic characteristics of the area, most importantly if seismic effects would move toward major population areas. Angledozer would consist of three high explosive detonations on sloped topography and one detonation on level terrain for correlation (Figure 3.21-3). The director requested that Lawrence Radiation Laboratory inform him if the scientists thought there was any seismic risk and invited them to participate in the calibration tests. Before the calibration tests could be conducted, however, concerns over the relatively large population centers near the Buchanan Dam and possible seismic and radiological safety impacts created some misgivings and lead to a reassessment of the location. Shortly thereafter, the Buchanan Dam Site was determined unsuitable for Project Travois. By this time, the Cochiti Dam project in New Mexico was already moving forward using conventional construction methods, so Project Travois was moved to the Twin Springs, Idaho location (Figure 3.21-4).

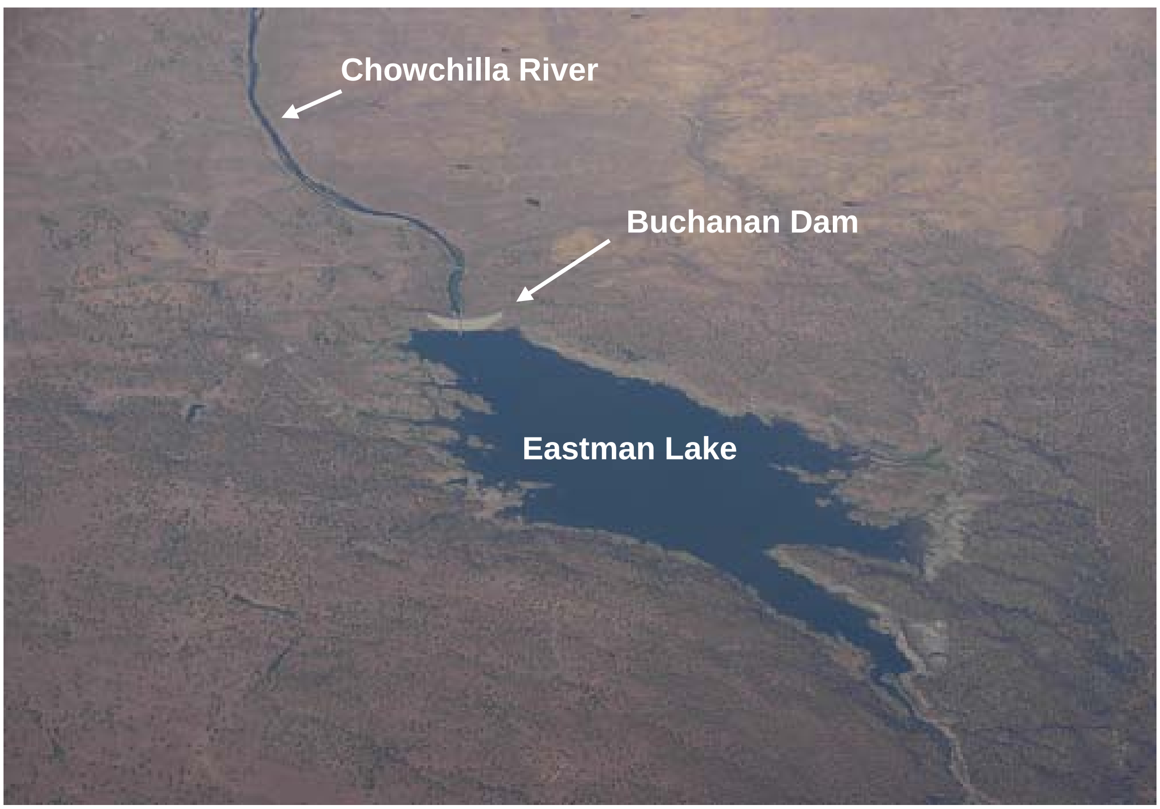
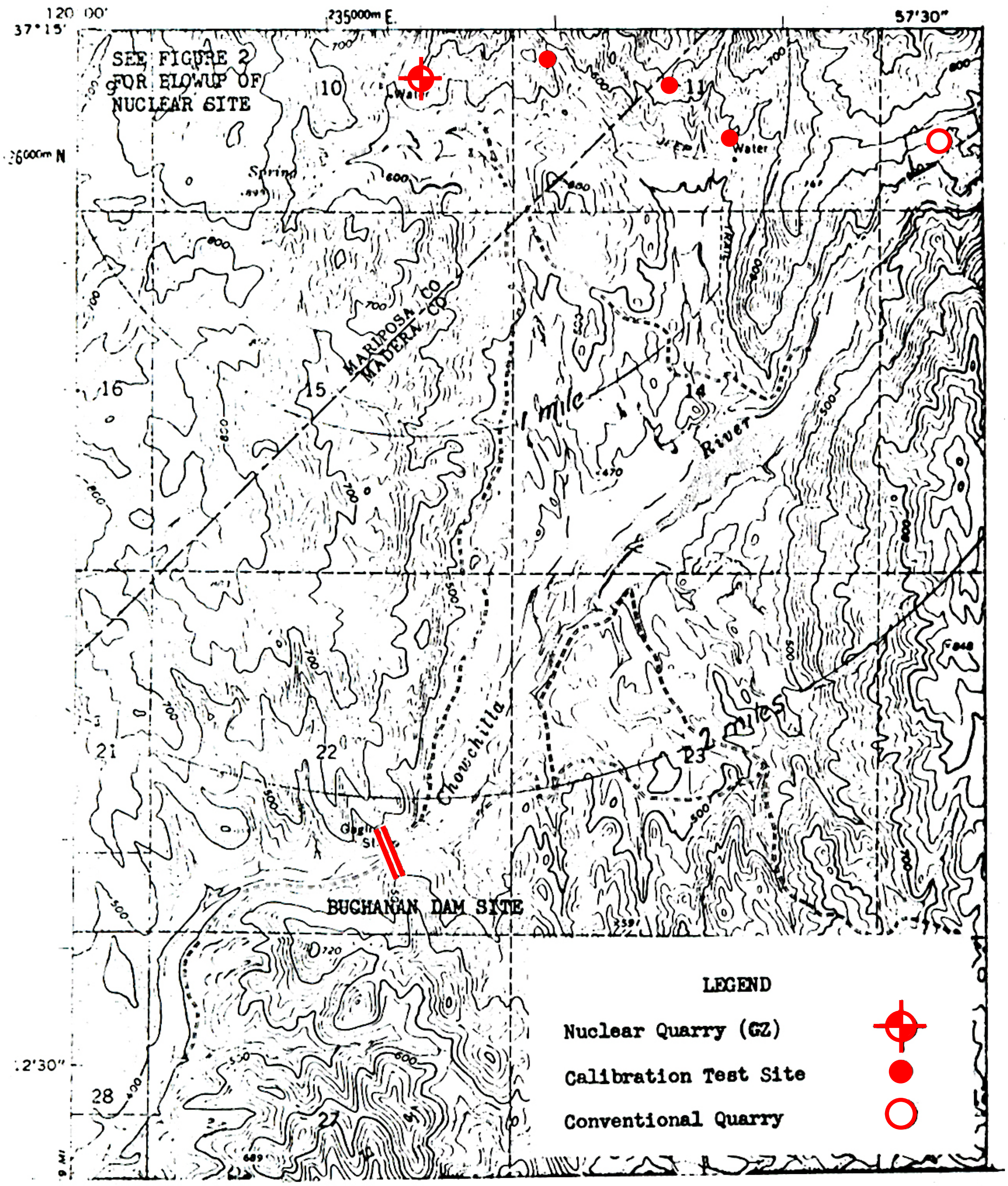


Figure 3.21-2. Aerial view of Buchanan Dam and the Eastman Lake Reservoir. After Project Travois relocated to Idaho, a dam and reservoir were eventually completed at the original site using conventional construction methods in 1975 (adapted from http://www.flickr.com/photos/brewbooks/972673287/in/set-72157600795607331/, last accessed September 2008).



TOPOGRAPHIC MAP
(From Raymond Quadrangle)
Scale 1:24000
Contour Interval 20'

Figure 3.21-3. The Buchanan dam site, the proposed nuclear quarry ground zero, the conventional quarry, and three of the proposed high explosive calibration shot locations are shown on this map (adapted from Hoggan and Nordyke 1968, Figure 2).

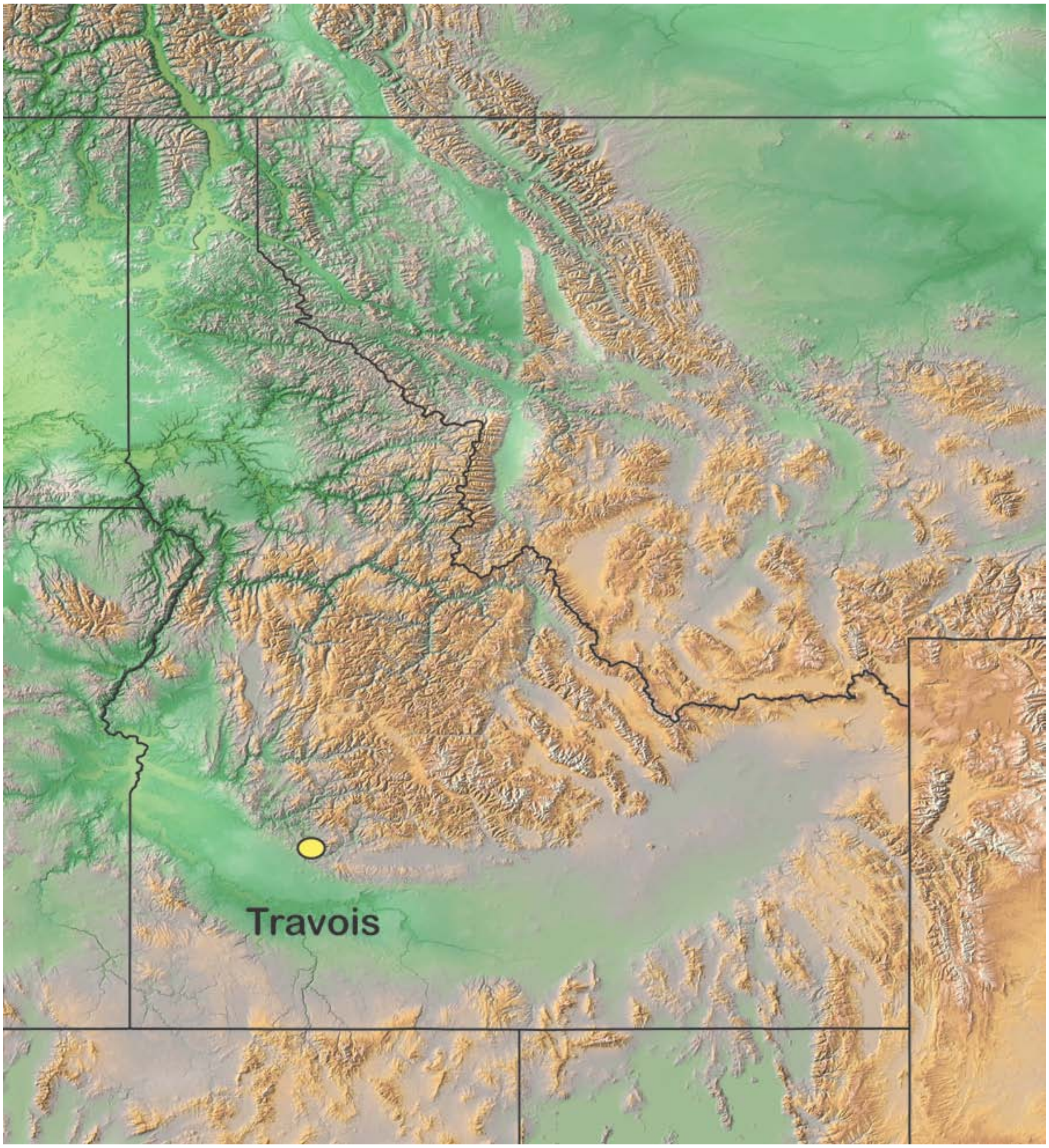


Figure 3.21-4. Proposed location of Project Travois at Twin Springs, Idaho. (adapted from USA Relief Maps).

The Twin Springs Dam site was in the SW1/4, Sec. 12, T 4N R7E, Boise Principal Meridian. It could be reached by a series of state, county, and Forest Service roads. The U.S. Bureau of Reclamation had been investigating this location as a potential dam site for more than 50 years. Purposes for the dam were water quality control, flood control, power generation, and flow regulation for a proposed Lucky Peak power generation facility about 35 miles downstream. As conceived, the project consisted of an embankment dam, a gated spillway, a concrete and steel-lined tunnel, an indoor powerhouse, and re-routing of an existing access road along the river. Construction of the dam required a quarry capable of producing approximately 7,000,000 cubic yards of rockfill to create a 1,390 ft long embankment to a height of 470 ft. The quarry area selected for conventional excavation methods was on the south side of the river just above the dam, but was deemed too close to the canyon walls for nuclear excavation. An alternate site was chosen approximately 1 mile to the northwest. It was in the S1/2NW1/4, Sec. 12, T4S R6E on a 30 percent slope at 4,200 ft elevation (Figures 3.21-5 and 3.21-6). The U.S. Forest Service administered the land for the proposed quarrying operation.

Preliminary safety evaluations were conducted for the Twin Springs Dam with the preliminary seismic safety report delivered on April 1, 1968. The schedule called for Project Excavator, a series of high explosive calibration tests, to be conducted in FY 1969 before the Twin Springs nuclear detonation. The nuclear excavation was slated for FY 1971. On April 18, 1968, the Nuclear Cratering Group formally requested Lawrence Radiation Laboratory develop a technical concept for both the original nuclear quarry experiment (Alternative #1) and a nuclear ejecta dam experiment (Alternative #2) at the Twin Springs site (Figures 3.21-7 and 3.21-8). Concurrently, planning was also underway for Project Excavator at this location. It would consist of three 40-ton chemical high explosive calibration shots. By June, a 40 kt thermonuclear explosive was proposed for the Twin Springs site with evaluations showing that potential problems were reservoir contamination and a high number of seismic damage complaints. It was determined that multiple, lower yield detonations would not alleviate these problems. A decision was made to proceed with data collection under Phases I and II, site exploration and high explosive calibrations. The U.S. Atomic Energy Commission approved the Travois concept in late July and the project was presented at a public hearing in Boise on August 2, 1968. Objections raised to the project were the loss of stream fishing and wildlife habitat in the reservoir area and low recreational appeal of the reservoir.

An estimated cost comparison of the quarrying operation using conventional methods versus nuclear procedures suggested the nuclear methods provided a savings of approximately 10 percent. However, the cost estimates did not include nuclear operations and public safety activities conducted by the U.S. Atomic Energy Commission. The proposed schedule for the nuclear quarrying technique also compared favorably with the timetable for conventional excavation methods.

Discussions regarding the division of responsibilities between the various entities continued into September. The Travois pre-shot site preparation was scheduled for the fourth quarter of 1970 with execution slated for the third quarter of FY 1971.

Exactly why the Idaho location fell out of favor is unclear. It may have been because a dam at this location could have proved problematic for native fish in the Boise River Sub-basin. The proposed site on the Middle Fork Boise River would have completely blocked the migratory corridor for redband trout and bull trout seeking to access spawning and rearing areas in both the North and Middle Fork drainages. Additionally, there were already two other dams, the Lucky Peak Dam and the Arrow Rock Dam just a

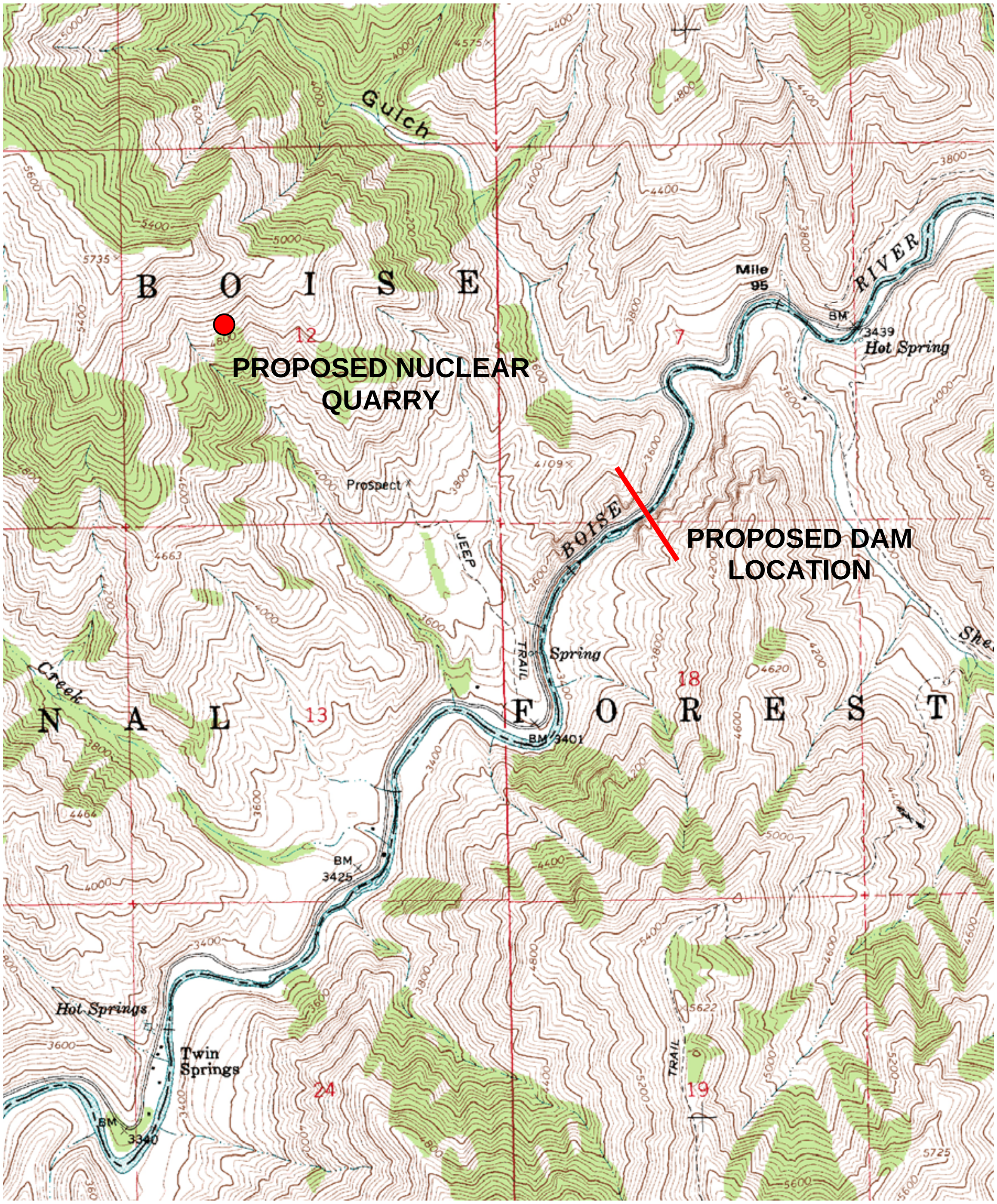


Figure 3.21-5. Both the Twin Springs, Idaho proposed dam and the proposed nuclear quarry are shown on this map (adapted from National Geographic Topographic Maps 2006).

THIS PAGE INTENTIONALLY LEFT BLANK

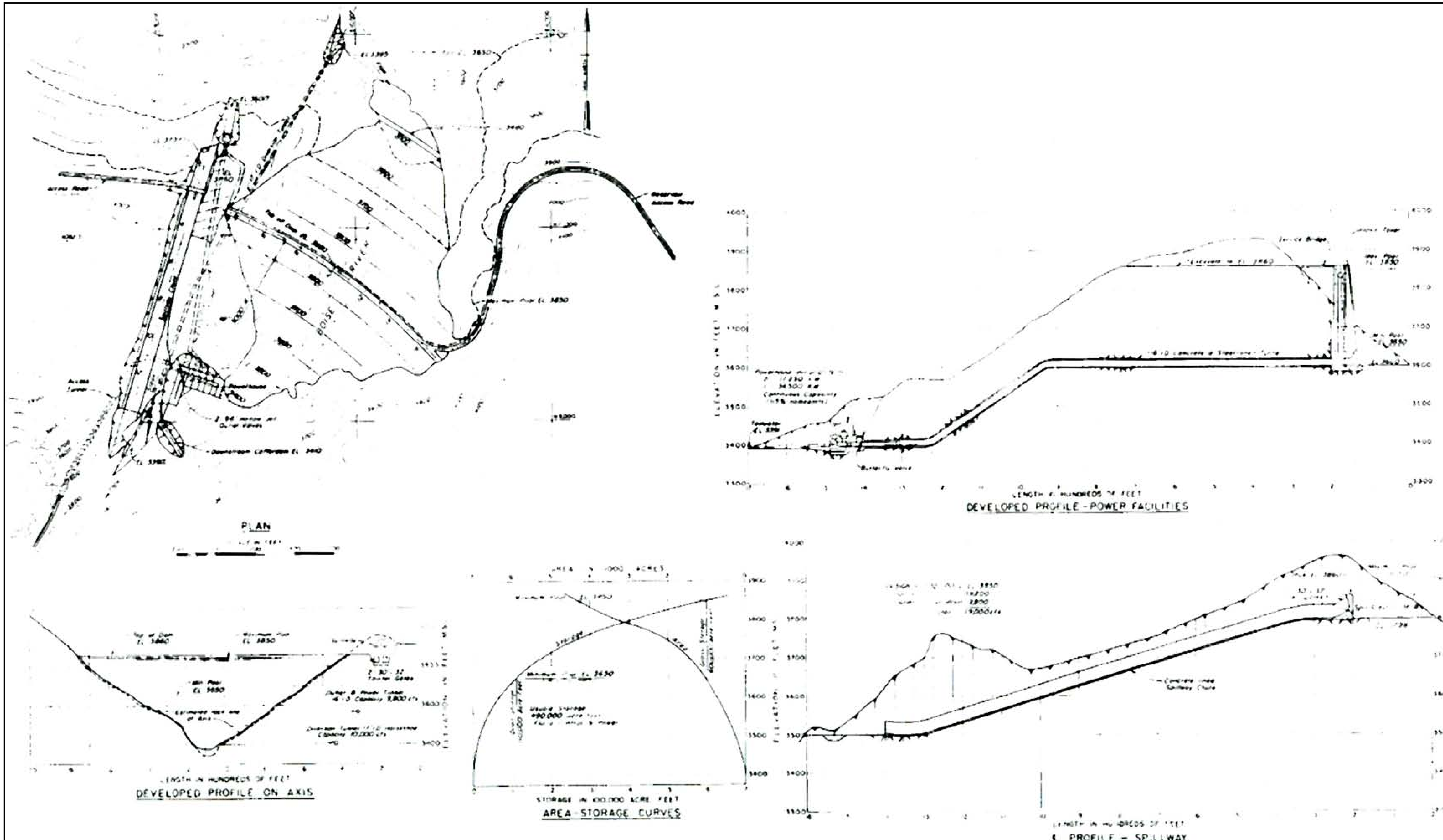


Figure 3.21-6. Plan and profile view [best copy available] (U.S. Army Corps of Engineers. Walla Walla District 1966, Plate 2).

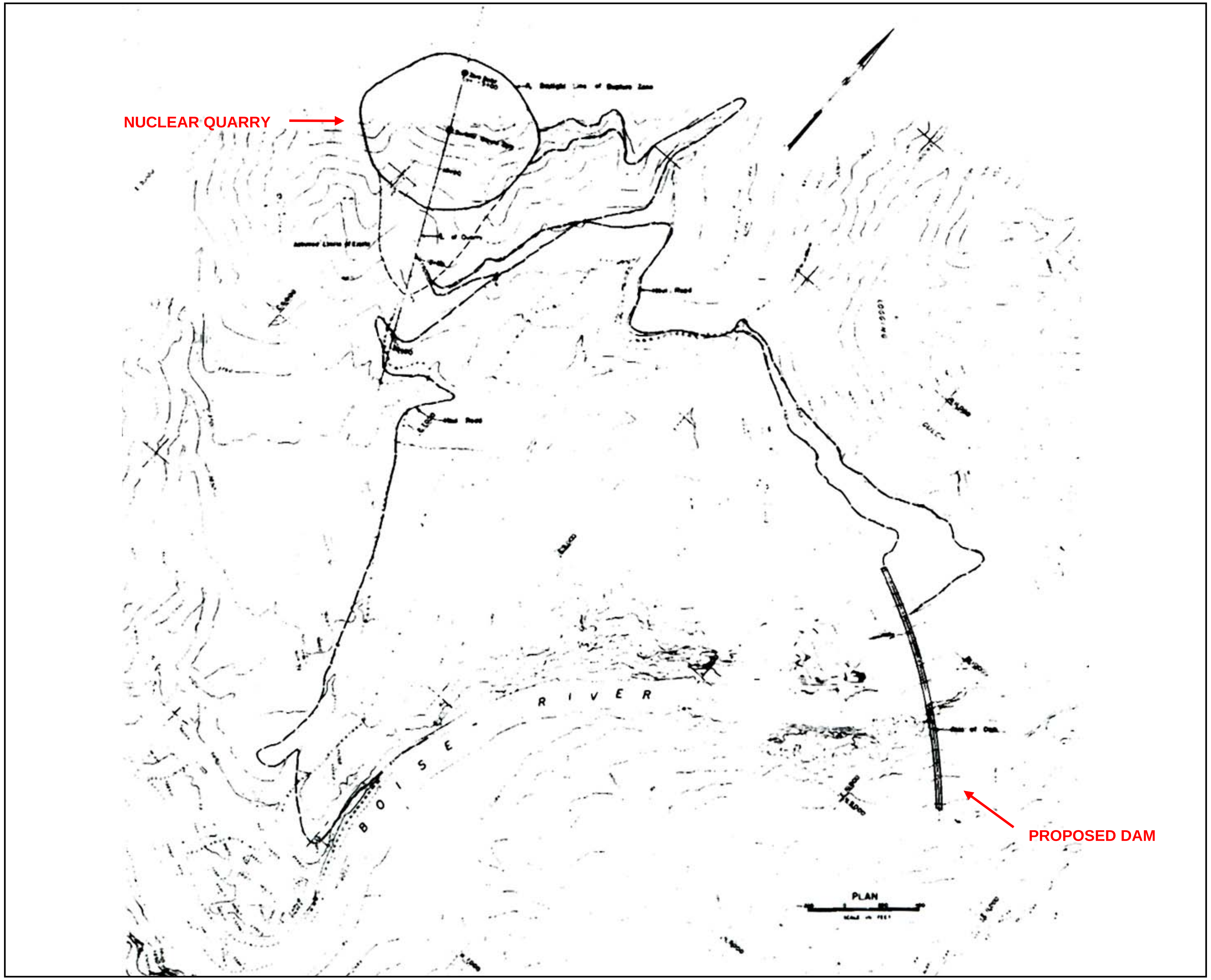


Figure 3.21-7. Plan view of the nuclear quarry site [best copy available] (adapted from U.S. Army Corps of Engineers. Walla Walla District 1966, Plate 4).

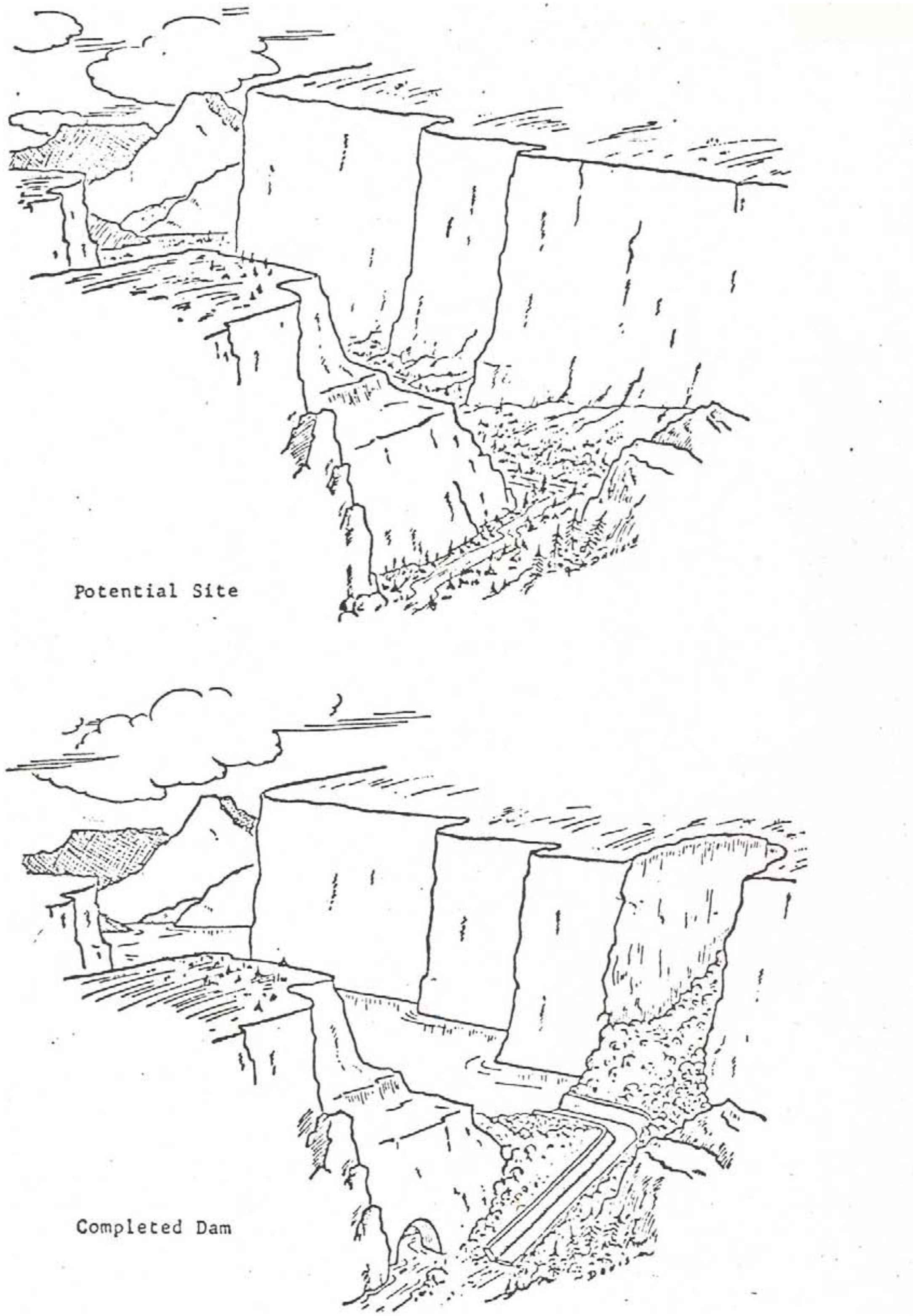


Figure 3.21-8. Schematic drawing for the Alternate #2 c oncept of a nuclear ejecta embankment dam (Kleist 1967, Figure 3).

few miles downstream from the Twin Springs project. Some of the preliminary seismic studies raised concerns about the ground shock effect of the proposed 40 kt blast on the structure of the Arrow Rock Dam. Whatever the reason, sometime in either late September or early October 1968, the Nuclear Cratering Group decided that the Twin Springs site was unsuitable for both Project Travois and the associated Project Excavator high explosive calibration shots. The U.S. Corps of Engineers notified the U.S. Atomic Energy Commission that they were in the process of finding a new site. The Nuclear Cratering Group began discussions with the U.S. Army Corps of Engineers North Pacific Division about an alternate site. Within just a few weeks, they settled on the proposed Catherine Creek damsite located on a tributary of the Grande Ronde River in northeastern Oregon (Figure 3.21-9). Like the Twin Springs site, this prospective site fell within the Walla Walla Engineer District. The proposed nuclear quarry was 25 miles northeast of Baker City and 8 miles southeast of the town of Union near the Oregon, Idaho, and Washington border (Figure 3.21-10). Anxious to proceed with the experiment, the Nuclear Cratering Group immediately initiated a feasibility study and requested that the U.S. Atomic Energy Commission conduct a cursory safety feasibility inspection of the project area

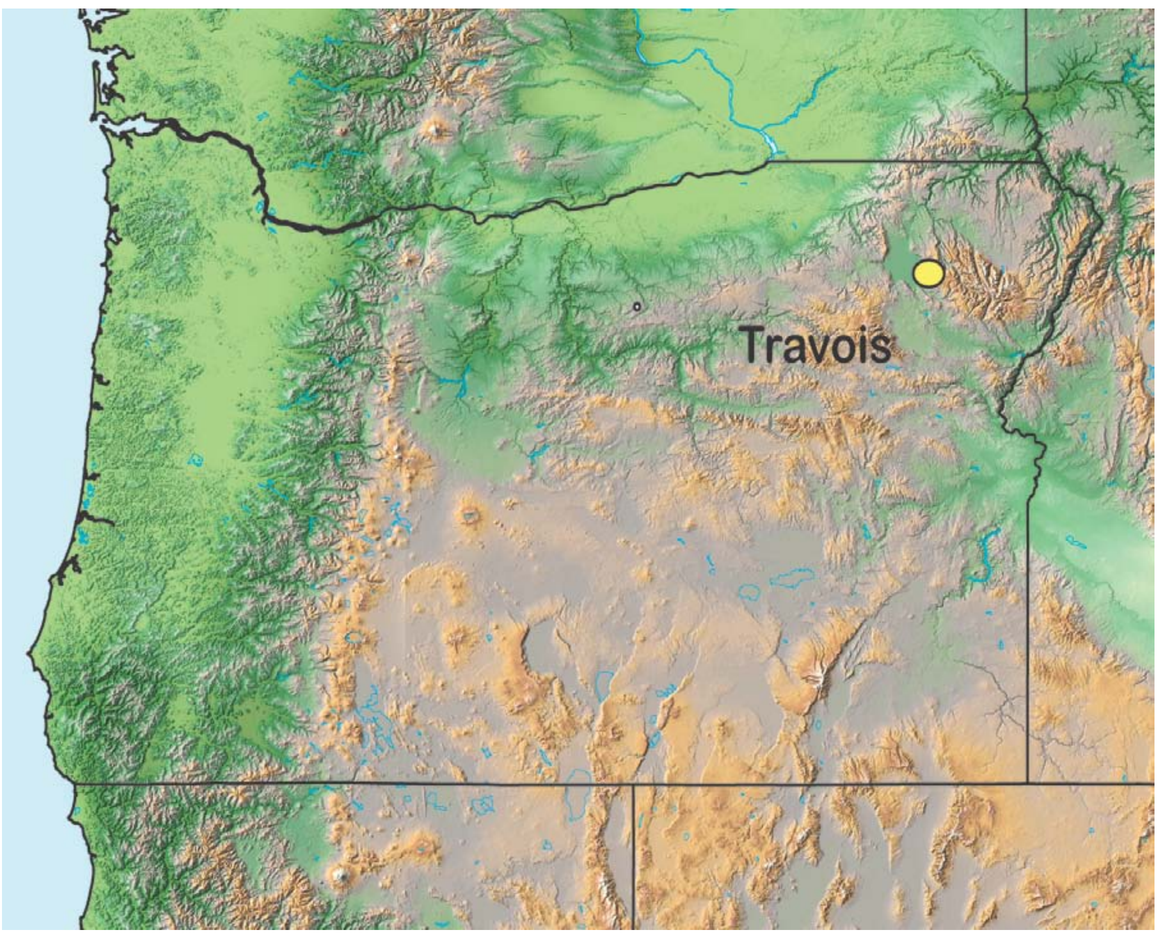


Figure 3.21-9. Proposed location for Project Travois at the Catherine Creek dam site near Union, Oregon. (adapted from USA Relief Maps 2004).

(Figures 3.21-11 and 3.21-12). The plan was to conduct the Project Excavator high explosive calibrations shots at the site to provide data for the nuclear quarry experiment. The high explosive shots were tentatively scheduled for the second and third quarters of FY 1970 and the nuclear detonation for the second or third quarter of FY 1972. Hoping to accelerate the schedule, the Nuclear Cratering Group urged the U.S. Atomic Energy Commission to brief Oregon's congressional delegation as soon as t he new congress convened in January 1969. Plans were also made to hold discussions with Oregon's governor and selected officials from the neighboring states of Washington and Idaho.

It is unclear if any of these meetings ever took place. No additional correspondence concerning the Project Travois nuclear quarrying experiment has been located that post-dates December 1968. However, the Walla Walla Engineer District did move forward with its original plans for an earth embankment dam using conventional quarrying methods (Figure 3.21-13) eventually completing an environmental impact statement for the Catherine Creek Dam project in 1974. Ultimately, even the conventional project was sidetracked because of legal challenges brought by the Confederated Tribes of the Umatilla Indian Reservation and strong public opposition generated by a local organization, *The Committee for Catherine Creek*. Fiscal Year 1976 was the last year with any recorded U.S. Army Corps of Engineers activity for the project. The conventional dam was placed in "deferred" status in January 1981 and finally "de-authorized" in 1990.

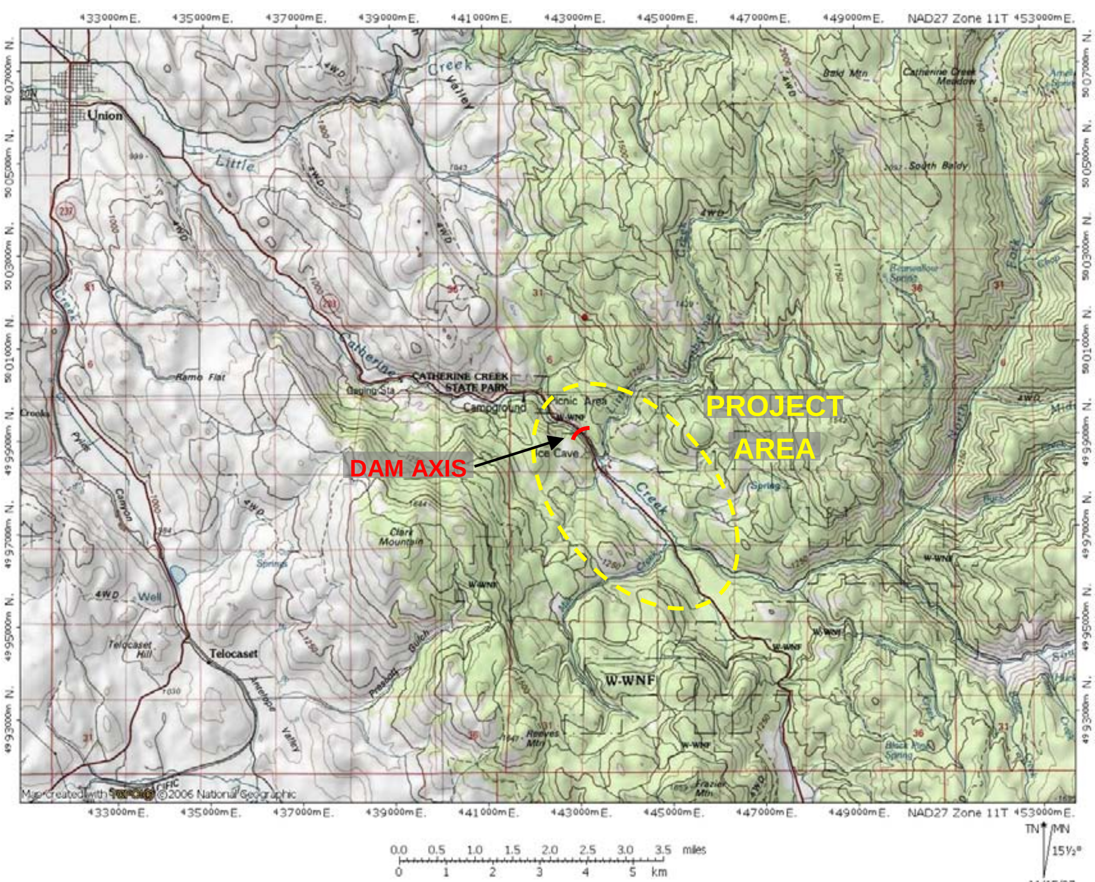


Figure 3.21-10. The Catherine Creek location for Project Travois. The town of Union, Oregon is in the upper left corner (adapted from National Geographic Maps 2006).

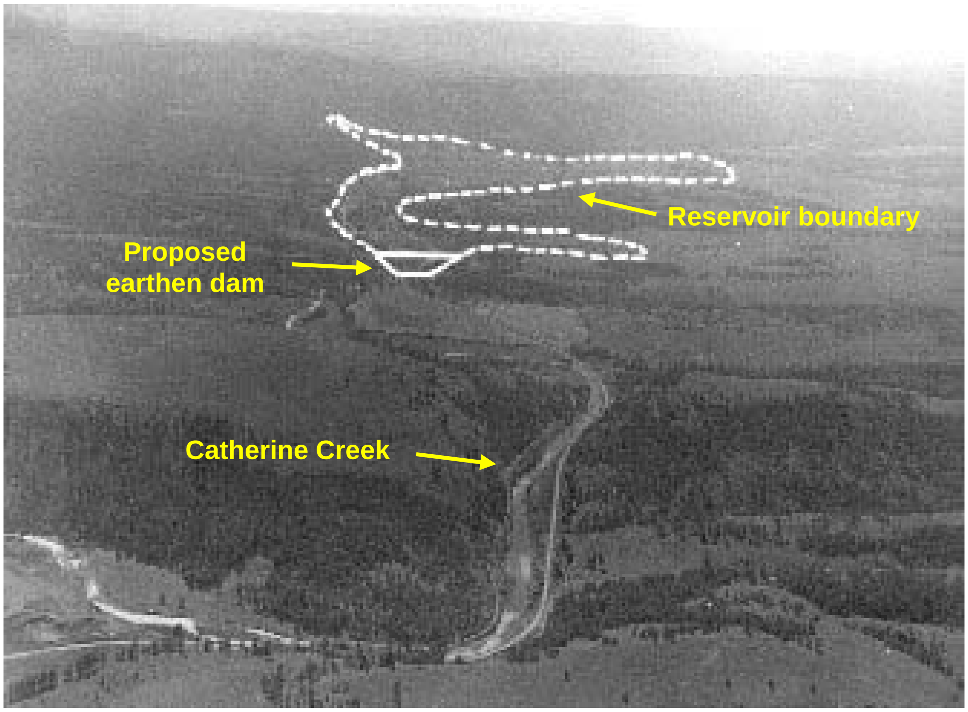


Figure 3.21-11. Conceptual drawing of the Catherine Creek dam site and reservoir, 1968 (adapted from U.S. Army Corps of Engineers, Walla Walla District website 2007, http://www.nww.usace.army.mil/dpn/f609a.htm, last accessed September 2008).

Figure 3.21-12. Catherine Creek dam site, 08 June 1971 (U.S. Army Corps of Engineers, Walla Walla District website 2007, http://www.nww.usace.army.mil/dpn/f609c.htm, last accessed September 2008).

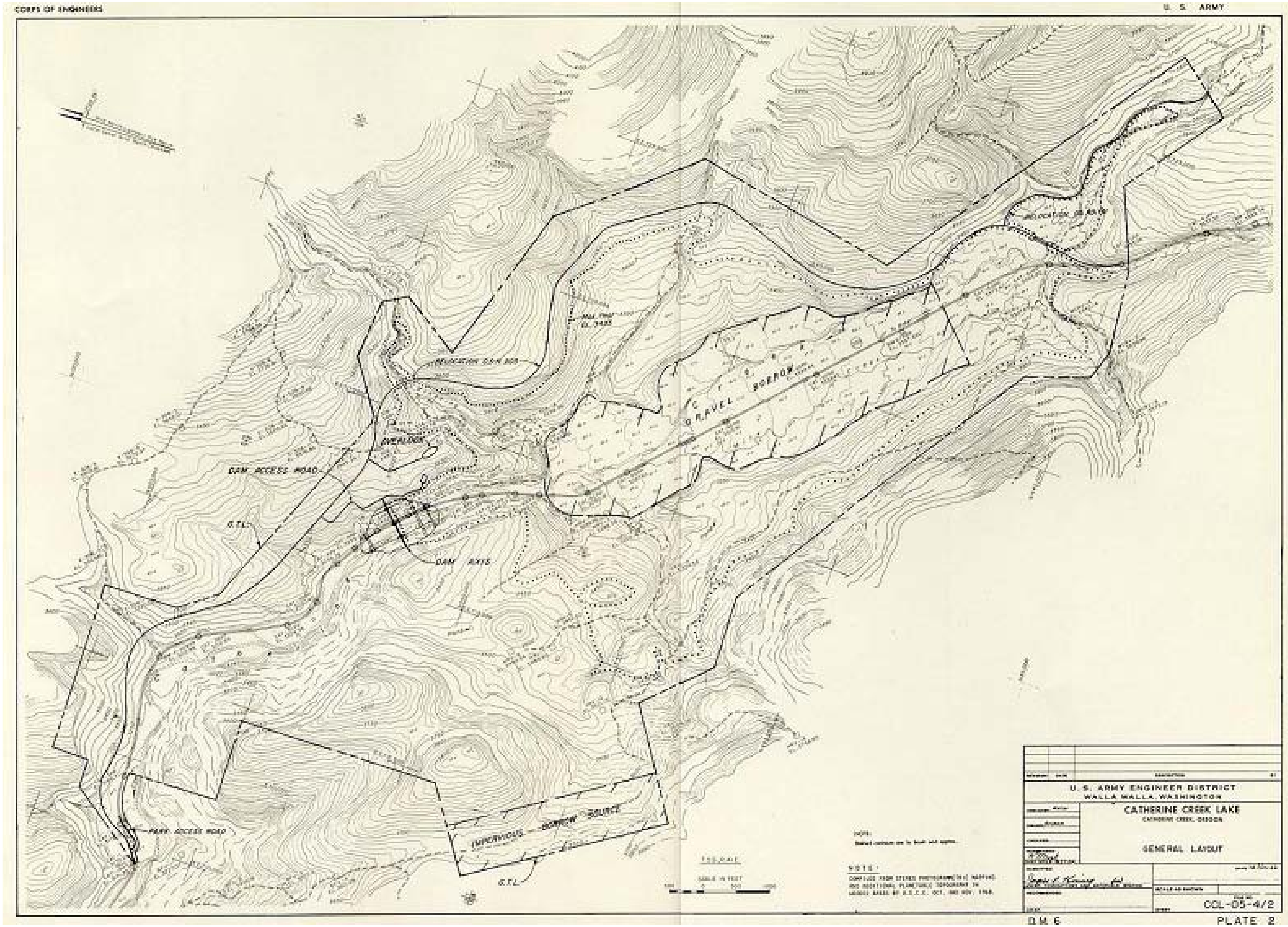


Figure 3.21-13. General layout for the Catherine Creek Dam Project c. 1966 prior to its selection as a nuclear quarrying experiment (adapted from U.S. Army Corps of Engineers, Walla Walla District website 2007, Plate 2, http://www.nww.usace.army.mil/dpn/nwwf6091.htm, last accessed September 2008).

THIS PAGE INTENTIONALLY LEFT BLANK

FIELD VISIT

Because the U.S. Army Corps of Engineers and the Nuclear Cratering Group spent the most time and energy evaluating the Idaho location for the nuclear quarrying experiment, the decision was made to concentrate field visit efforts at the Twin Springs project area. Both the Project Travois and Project Excavator sites are located on the Boise River near the small community of Twin Springs. The Travois project site can be accessed by following Forest Service Road #268, a graded but narrow dirt road that follows the north bank of the Boise River. Situated approximately 2.2 mi northeast of Twin Springs, the proposed Project Travois dam location is in a narrow portion of the steep-walled river canyon (Figures 3.21-14 and 3.21-15). On June 27, 28 and July 2, 2004, Beck and Edwards conducted a visual inspection of the north side of the canyon beginning approximately 0.2 mi upstream of the proposed dam site and continuing downstream for 2.2 miles, searching for evidence of any drill holes or sampling locations related to Project Excavator or Project Travois, as well as the jeep trail leading to the proposed quarry site situated 1 mi northwest of the dam site. Approximately 0.7 mi south of the dam site, the researchers located an old jeep trail leading up to the proposed quarry area adjacent to a rocky outcrop that may have been the location of the geological characterization drill hole mentioned in the project documentation (Figure 3.21-16). The weathered granite outcrop, its crest and slopes covered with broken rock, is surrounded by an old, partially collapsed barbed-wire fence. Pull-tab beverage containers (1964-1972 vintage), bailing wire, insulated electrical wire, metal fragments, several rusted food tins, and broken glass litter the base of the outcrop. The datable material in the trash scatter is consistent with the time-period for the Plowshare projects, but the scatter could also simply be related to recreational use of the Forest Service road and the Boise River. No drill hole or drilling equipment was found. The steep jeep trail has been blocked with a 3-ft high earth and rock berm making it impassable. A 1/3 mi hike up the road beyond the berm was enough to confirm that the road was in extremely poor condition. While additional attempts to reach the quarry location were abandoned because of time constraints, the researchers were able to examine the proposed quarry location from a distance by using telephoto lenses (Figure 3.21-17). The quarry site, clearly visible from the outcrop and the Forest Service road below, showed no obvious signs of disturbance. Continued visual inspection of the north side of the river canyon to a point just downstream from the community of Twin Springs revealed no other indication of Project Travois site characterization activities.

From the documentation, it does not appear that any more than a single bore hole was drilled for site characterization studies in support of Project Travois. It appears that the project was shelved before drilling for the high explosive calibration shots could be completed (Project Excavator). The only other activity that may have taken place was the grading of an access road to the proposed quarry location. The field visit conducted in FY 2004 completed the field activity evaluations for Project Travois.

During FY 2004, a review of the land status records on file at the Idaho State Office of the Bureau of Land Management in Boise revealed that the Project Travois project area fell within lands administered by the U.S. Forest Service as part of the Boise National Forest. That agency continues to administer the land today.

Figure 3.21-14. Overview of the proposed Project Travois dam site looking southwest (photo taken July 2004 on file at Desert Research Institute).

Figure 3.21-15. Overview of the proposed Project Travois dam site looking northeast. Dam was situated in the narrowest portion of the granitic canyon (photo taken July 2004 on file at Desert Research Institute).

Figure 3.21-16. Bedrock outcrop that may have been the site of geological characterization activities for Project Travois (photo taken July 2004 on file at Desert Research Institute).

Figure 3.21-17. The Project Travois quarry site was located at an elevation of 4,200 ft approximately one mile northwest of the dam site (photo taken July 2004 on file at Desert Research Institute).

CHRONOLOGICAL BIBLIOGRAPHY

U.S. Army Engineer Nuclear Cratering Group, 1966. Plan for Accomplishment of a Demonstration of the Application of Nuclear Excavation in Civil Works Projects. Manuscript, August 27. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-100.

Slazak, Walter J., 1966. Letter with encl. ("Summary of Possible Quarrying Projects") from Walter J. Slazak, Lt. Colonel, Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, to Michael M. May, September 20. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029.

U.S. Army Corps of Engineers. Walla Walla District, 1966. Nuclear Quarrying Feasibility Study: Twin Springs Dam and Reservoir, Boise River, Idaho. Report to U.S. Army Engineer Nuclear Cratering Group, Livermore, CA, from Walla Walla District, Walla Walla, WA, November. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0330824.

Lawrence Radiation Laboratory. U.S. Army Engineer Nuclear Cratering Group, [1966]. Demonstration Project Summary. Manuscript. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-103 [OUO].

U.S. Department of the Interior. Geological Survey, [1966]. Summary of Water Conditions and Suggested Programs for Evaluation of Hydrological Safety of Nuclear Excavation at Three Proposed Dam Sites: Buchanan Damsite, California; Twin Springs Damsite, Idaho; and Cochiti Damsite, New Mexico. Report to U.S. Atomic Energy Commission from Geological Survey. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV [OUO].

U.S. Public Health Service. Department of Health, Education and Welfare, [1966]. PHS Off-Site Evaluation of Twin Springs Dam and Reservoir Project, Twin Springs, Idaho. Manuscript, Las Vegas, NV. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Werth, Glenn C., [between 1966 and 1973]. Handwritten notes on Plowshare program meetings from Glenn C. Werth, U.S. Atomic Energy Commission, Division of Peaceful Nuclear Explosives, 1966-1973. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-118.

Nordyke, Milo D., 1967. “Status Review of Field Project Studies.” Memo from Milo Nordyke, Lawrence Radiation Laboratory, to G. Higgins, April 14. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore CA, File PLO-026.

Rabb, David D., 1967. Plowshare Program May 1, 1967 – July 31, 1967, Vol. II, No. 6. University of California, Lawrence Radiation Laboratory, *Report UCRL*-50008-67-3, July 31. Livermore, CA. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-030.

Kurtz, Maurice K., 1967. Letter from Maurice K. Kurtz, Jr., Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, to Glenn Werth, August 2. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029 [OUO].

Kleist, Erwin H. (editor), 1967. Nuclear Excavation Feasibility Study Construction of Rockfill Embankment for a Dam. Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, *NCG Technical Memorandum* No. NGG/TM 67-16, September 28. Livermore, CA. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Reeves, James E., 1967. "Unclassified Reference: Letter, Miller, NVOO, to Kurtz, NCG, May 10, 1967." Telex from James E. Reeves, U.S. Atomic Energy Commission, Nevada Operations Office, to John S. Kelly, December 19. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

Miller, Robert E., 1967. "Budgetary Estimates for Travois." Telex from Robert E. Miller, U.S. Atomic Energy Commission, Nevada Operations Office, to Lt Col M. K. Kurtz, December 26. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

Kurtz, Maurice K., 1967. Letter with encls. (Project Travois Preliminary Cost Estimates and Resume of Responsibility for Budgeting and Estimating Project Travois) from Maurice K. Kurtz, U.S. Army Engineer Nuclear Cratering Group, to Robert E Miller, December 29. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065 [OUO].

Hoggan, Daniel H., and M. Nordyke, 1968. "Project Travois: Preliminary Safety, Evaluation – Buchanan Dam Site." Memo with encls. ("Project Travois - Air Blast," memo from D. N. Montan to D. H Hoggan, August 25; and "Project Safety: Project Travois, Buchanan Dam," memo from Daniel H. Hoggan to Distribution, August 14) from Daniel H. Hoggan and M. Nordyke, Lawrence Radiation Laboratory, January 9. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

Hughes, Bernard C., 1968. "Status Report - Nuclear Explosives Studies for Civil Construction (RCS ENGCW-P-6 (R-1))." Letter with encl. ("Status Report, Effective Date: 31 December 1967") from Bernard C. Hughes, Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, to Chief of Engineers, Department of the Army, January 13. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029.

Hughes, Bernard C., 1968. Letter from Bernard C. Hughes, Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, to Glenn C. Werth, February 2. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

U.S. Army Engineer Nuclear Cratering Group, 1968. Engineering Applications of Nuclear Explosives, Bi-Monthly Statistics of NCG Technical Reports, Memoranda, and Studies. Manuscript, February 15. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Nadolski, Michael E., 1968. "Seismic Safety: Project Travois – Twin Springs Dam." Memo from Michael E. Nadolski, Lawrence Radiation Laboratory, to Distribution, April 1. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

Noble, Charles C., 1968. Letter from Charles C. Noble, Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, to John S. Kelly, April 9. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

Hughes, Bernard C., 1968. Letter from Bernard C. Hughes, Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, to Glenn C. Werth, April 18. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065 [OUO].

Kelly, John S., 1968. Letter with encl. ("U.S. Atomic Energy Commission Plowshare Program Projections – Estimated Cost in Thousands and Number of Nuclear Detonations") from John S. Kelly, U.S. Atomic Energy Commission, Division of Peaceful Nuclear Explosives, to Charles C. Noble, April. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

Hughes, Bernard C., 1968. "Discussions between Manager, NVOO, and Director, NCG, on 22 May 1968." Memo with encls. (Kelly, 4/29/68 and Hughes 4/18/68) from Bernard C. Hughes, Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, to Record, May 23. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065 [OUO].

Toman, John, 1968. "Selection of Dob's for Project Excavator." Memo from John Toman, Lawrence Radiation Laboratory, to Bernard C. Hughes, May 28. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

Reeves, James E., 1968. Letter from James E. Reeves, U.S. Atomic Energy Commission, Nevada Operations Office to Lt. Col B. C. Hughes, May 31. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

Lawrence Radiation Laboratory, 1968. Technical Concept, Project Travois Aggregate Production Experiment. Manuscript, June 6. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065 [OUO].

Hughes, Bernard C., 1968. "Meeting with Director of Idaho Water Resource Board." Memo from Bernard C. Hughes, Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, to Record, June 11. On file at: Archives and Research, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029 [OUO].

Reynolds, Harry L., 1968. "TRAVOIS - Comments on SDK 68-24." Memo from Harry L. Reynolds, Lawrence Radiation Laboratory, to Glenn Werth, June 26. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

Lawrence Radiation Laboratory, 1968. "Background Discussion Paper for 27 June 1968 Travois Meeting." Manuscript, Lawrence Radiation Laboratory, June 27. Livermore, CA. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065 [OUO].

Lawrence Radiation Laboratory, 1968. "Proposed Agenda Topics – Travois Meeting, 27 June 1968, Summary of Scientific and Technical Programs and Time Estimates for Project Travois." Agenda for Travois Meeting, Nevada Operations Office, June 27. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

Werth, Glenn C., 1968. Letter from Glenn C. Werth, Lawrence Radiation Laboratory, to John S. Kelly, July 9. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

Lee, Robert R., 1968. "Lucky Peak Power Plant-Twin Springs Dam and Reservoir Hearings." Memo from Robert R. Lee, State of Idaho, Idaho Water Resource Board, to All Interested Parties, July 10. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

Knox, J. B., 1968. Water Quality Considerations - Project Travois. University of California, Lawrence Radiation Laboratory, *Report UCRL*-124984, July 16. Livermore, CA.

Harris, John A., 1968. "August 2 Hearing in Boise on Twin Springs Dam Project." Telex from John A. Harris, U.S. Atomic Energy Commission, to List, July 26. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, PLO-065.

Rabb, David D., 1968. Plowshare Program, May 1, 1968 – July 31, 1968, Vol. II, No. 1. University of California, Lawrence Radiation Laboratory, *Report UCRL*-50008-68-3, July 31. Livermore, CA. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-030 [OUO].

Day, Walter C., 1968. "Trip Report, Idaho Water Resources Board Public Hearing on Lucky Peak Power House and Town Springs Dam Project." Memo with encls. (Lee 7/10/68; "Statement to Be Made by Col Giesen of the Corps of Engineers, Walla Walla District, at a public hearing in Boise, Idaho; and "Statement Provided for the Minutes of the Hearing for Release to Interested Persons following the Hearing") from Walter C. Day, Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, to Record, August 6. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

Kelly, John S., 1968. "AEC-Corps of Engineers Functions - Project Travois." Letter from John S. Kelly, U.S. Atomic Energy Commission, to James E. Reeves, September 3. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

Kelly, John S., 1968. Letter from John S. Kelly, U.S. Atomic Energy Commission, to Glenn C. Werth, September 3. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

Werth, Glenn C., 1968. "Alternate #1, Tentative Schedule – Plowshare Program – LRL Related." Schedule from Lawrence Radiation Laboratory, September 10. On file at: Archives and Records Office, Lawrence Berkeley National Laboratory, Berkeley, CA, File 434-900205, 28/48.

Werth, Glenn C., 1968. "Alternate #2, Tentative Schedule - Plowshare Program - LRL Related." Schedule from Lawrence Radiation Laboratory, September 10. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-118.

Kelly, John S., 1968. Letter from John S. Kelly, U.S. Atomic Energy Commission, Division of Peaceful Nuclear Explosives, to Glenn C. Werth, October 14. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

Nelson, Thomas W., 1968. "Catherine Creek Project." Memo from Thomas W. Nelson, U.S. Atomic Energy Commission, Division of Peaceful Nuclear Explosives, to Thomas McCarvill, October 24 [OUO].

McCarvill, Thomas J., 1968. "Proposed Alternate Site for Project Travois--Catherine Creek, Oregon." Letter with encl. ("Catherine Creek Project," Memo from Thomas W. Nelson, Department of the Army, to Thomas McCarvill, October 24 [OUO]) from Thomas J. McCarvill, U.S. Atomic Energy Commission, Division of Peaceful Nuclear Explosives, October 31. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

Ide, Roger H., 1968. Letter from Roger H. Ide, Lawrence Radiation Laboratory, to W. R. Cooper, November 25. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession Nos. NV0308620 and NV0309997.

Connell, Richard P., 1968. Letter with encl. ("U.S. Atomic Energy Commission, Fiscal Year 1969 Midyear Review, Schedule A, Plowshare Program") from Richard P. Connell, Lawrence Radiation Laboratory, to John S. Kelly, December 19. On file at: Lawrence Berkeley National Laboratory, University of California, Berkeley, CA, File 434-900205, 28/48.

Vortman, L. J., 1969. Nuclear Excavation. Report, SC-DC-69-1716, Underground Physics Division, Sandia Laboratories, Albuquerque, NM, March. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-104.

Toman, John, 1970. Summary of Nuclear-Excavation Applications. Paper prepared for Proceedings of the ANS Topical Meeting, Engineering with Nuclear Explosives, Las Vegas, Nevada, January 14-16, 1970. University of California, Lawrence Radiation Laboratory, *Preprint UCRL*-72220, January 29. Livermore, CA. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-104.

Toman, John, 1970. Summary of Nuclear-Excavation Applications. In *Symposium on Engineering with Nuclear Explosives: Proceedings,* Report CONF-700101, Vol. 1, pp. 245-279, May. American Nuclear Society, Hinsdale, IL.

Shafer, David S., William. C. Beck, Dwight Treadwell, and Stephen. A. Mellington, 1995. Inventory of Potential Environmental Restoration Liabilities Associated with Plowshare And Vela Uniform Program Sites. Manuscript, U.S. Department of Energy, Office of Environmental Restoration. On file at: Desert Research Institute, Las Vegas, NV.

U.S. Department of Energy. Nevada Operations Office, 1997. Plowshare Program Executive Summary. Report from U.S. Department of Energy, December 22.

U.S. Department of Energy. Nevada Operations Office, n.d. The Plowshare Program (Draft). Report from U.S. Department of Energy.

California Statistical Abstract, 1999. Major Dams and Reservoirs of California, Table G-3. *California Statistical Abstracts*, Section G.

3.22 TRENCHER

Plowshare Program
High Explosive Excavation Experiment
Montana

Project Trencher was an explosive evaluation experiment conducted in clay shale to determine the single-charge cratering performance of two different aluminized slurry explosives. The concept for Project Trencher was proposed by the U.S. Army Engineer Nuclear Cratering Group in early 1969. A test site at the Fort Peck Reservoir in northeastern Montana (Figure 3.22-1) was selected because the Trencher experiments would test one of the explosives being considered for the Pre-Gondola III, Phase III experiments (see Chapter 3.15) that were already underway. The 175 acre project area was located on Duck Creek Inlet approximately 1 mile west of the Pre-Gondola project site (Figure 3.22-2). The geology of the area consisted of varying thicknesses (2 ft – 10 ft) of glacial till overlying a layer of weathered shale that graded into the unweathered Bearpaw shale formation.

The experimental design for Trencher was an extension of earlier laboratory-scale tests conducted at Lawrence Radiation Laboratory's Explosive Test Facility, Site 300 located in Tracy, California. The Trencher field testing program focused on obtaining data on explosive excavation methodology using substantially larger (500-lb vs. 8-lb) chemical charges. The planned series of detonations would provide comparative data for even larger chemical excavation experiments in major civil works projects.

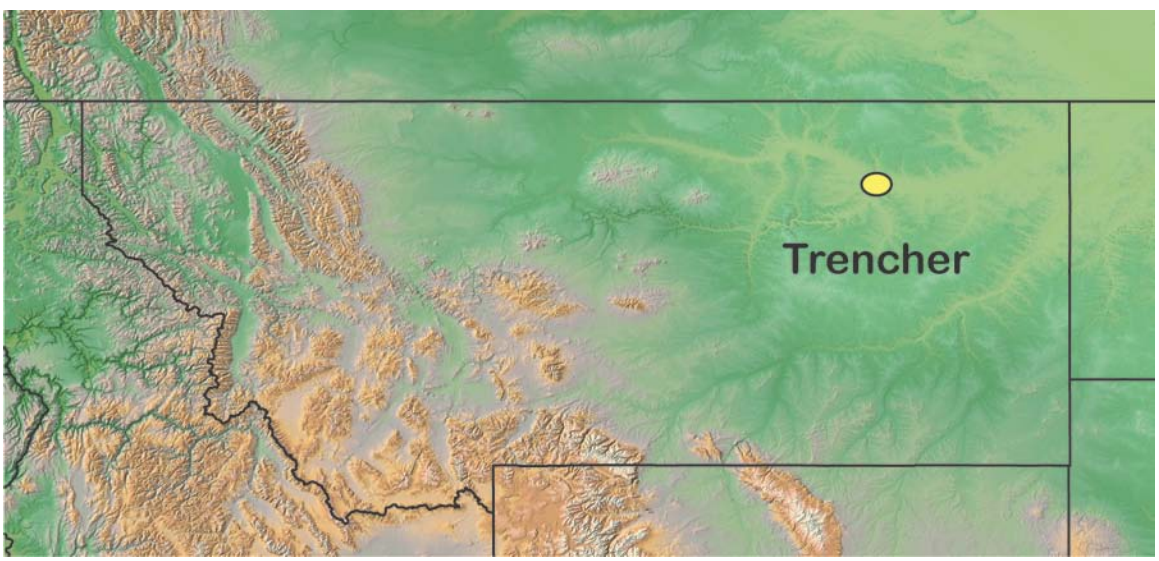


Figure 3.22-1. Location of Project Trencher in Montana (adapted from USA Relief Maps 2004).

The Site 300 tests had focused primarily on comparing the performance of various commercially available chemical explosives, but because the Fort Peck location offered.

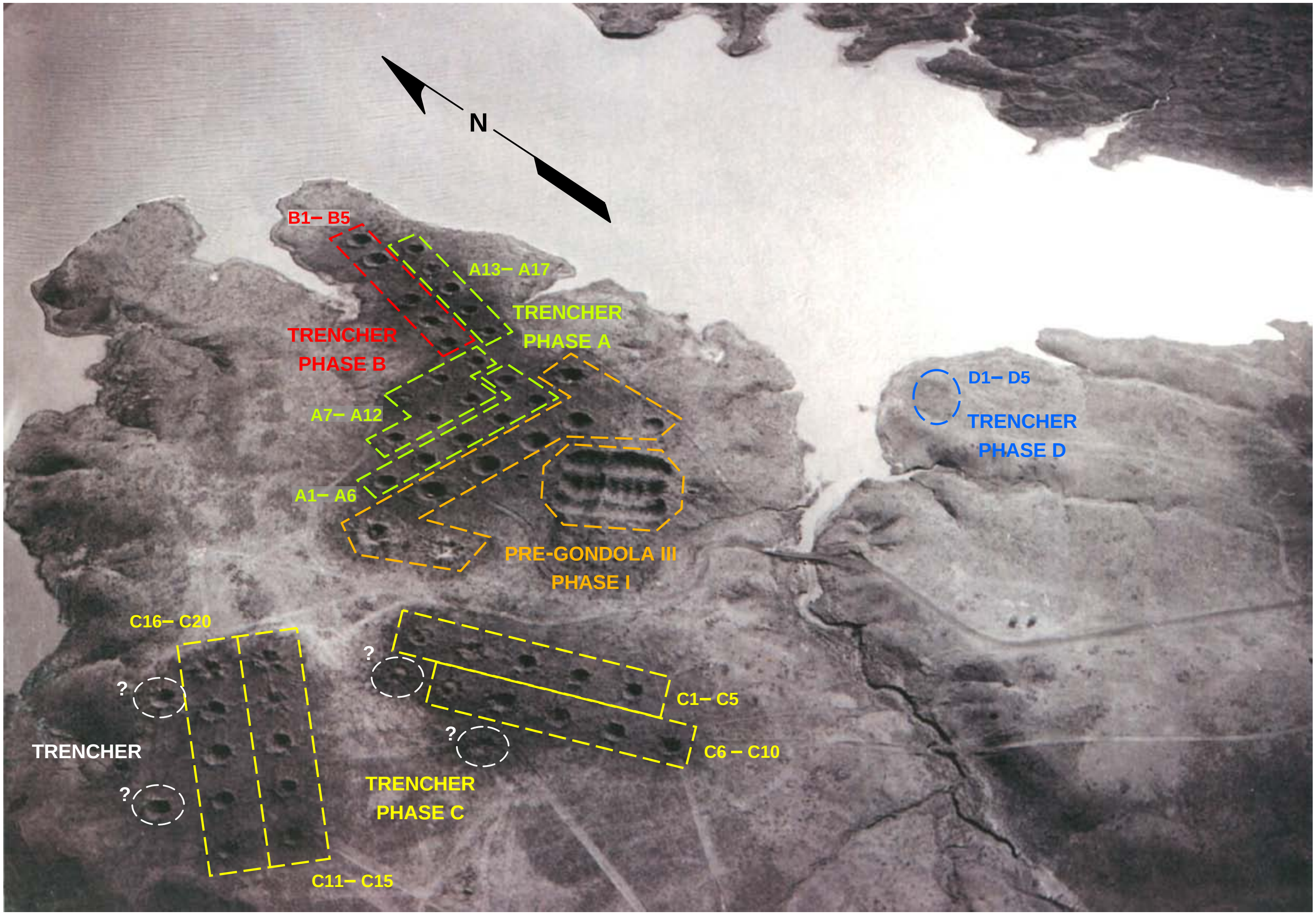


Figure 3.22-2. Craters produced by the Project Trencher detonations. The Project Pre-Gondola III, Phase I triple row charge experiment and eight calibration shots also appear on the aerial photo, c. Sept. 1969 (adapted from Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group 1969).

an extensive experimentation area, Project Trencher's test program was expanded. As described by the final technical plan, Trencher had four main objectives: 1) to determine the single-charge cratering performance in clay shale of two different aluminized slurry explosives; 2) to determine the effects of different stemming materials on craters formation; 3) to determine the effects of different cylindrical charge geometries on crater formation; and 4) to determine the feasibility of springing holes in clay shale. More than 45 separate detonations were planned to accomplish these goals.

Project Trencher consisted of four phases designated Phases A through D. Each phase had specific methodologies and test objectives. Specific dates and times for each of the experimental detonations were unavailable, but they all occurred during August 1969 as noted in Table 3.22-1. Although situated alongside the Fort Peck Reservoir, none of the experimental craters penetrated the water table.

Table 3.22-1. Trencher Detonations

MAP KEY	SHOT	DATE	STEMMING	YIELD
		PHASE A – EXPLOSIVE EVALUATION SERIES		
11a	A13 – A17	August 1969	sand and water	5 individual nitromethane charges, 500-lb each, 2.5 tons total
11b	A1 – A6	August 1969	sand and water	7 individual IRECO DBA-22M explosive charges, 500-lb each, 3.0 tons total
11c	A7 – A12	August 1969	sand and water	5 individual Dow MS80 explosive charges, 500-lb each, 3.0 tons total
		PHASE B – STEMMING STUDIES SERIES		
12a	B5	August 1969	crushed rock	500-lb IRECO DBA-22M explosive
12b	B4	August 1969	concrete	500-lb IRECO DBA-22M explosive
12c	B2	August 1969	none	500-lb IRECO DBA-22M explosive
12d	B1	August 1969	sand and water	500-lb IRECO DBA-22M explosive
12e	B3	August 1969	water	500-lb IRECO DBA-22M explosive
		PHASE C – CHARGE GEOMETRY SERIES		
13a	C1 – C5	August 1969	sand and water	500-lb IRECO DBA-22M explosive
13b	C6 – C10	August 1969	sand and water	500-lb IRECO DBA-22M explosive
13c	C11- C15	August 1969	sand and water	500-lb IRECO DBA-22M explosive
13d	C16 – C20	August 1969	sand and water	500-lb IRECO DBA-22M explosive
		PHASE D – HOLE SPRINGING SERIES		
14	D1 – D3	August 1969	sand	10-lbs IRECO DBA-22M explosive
14	D4	August 1969	sand and water	5-lbs IRECO DBA-22M explosive
14	D5	August 1969	sand	5-lbs IRECO DBA-22M explosive

Designed to investigate two research questions, the Phase A series consisted of 17 test detonations of 500-lb charges in 55-gal drums. Designated Shots A1 – A17, these charges were placed near the edge of the reservoir just northeast of the previously executed Pre-

Gondola III, Phase I triple row experiment and associated 1-ton calibration shots (Figures 3.22-2 and 3.22-3). The primary purpose of these blasts was to compare the effectiveness of two different types of metallized slurry explosives against the standard nitromethane explosive. The second objective of this series was to determine if the lower yield test results from Livermore's Site 300 experiments could be scaled up to model the expected results from the 500-lb tests.

Five of the Phase A cratering shots used nithromethane for the explosive charge, seven employed IRECO DBA-22M, and the final five used Dow MS80-20. The drum charges were buried in 30-in diameter bore holes at varying depths from approximately 8 ft to 20 ft below the surface. Each charge emplacement was stemmed (filled) with a sand and water mixture to the top of the hole.

Situated in the middle of the Phase A craters (Figures 3.22-2 and 3.22-3), the purpose of the Phase B series was to study the effect of different types of stemming on crater morphology. The DBA-22M slurry explosive was used for the five test detonations – Shots B1 – B5. Each charge, comprised of a 55-gal drum filled with 500-lbs of explosive, was buried at approximately the same depth of 13.6 ft, but employed different stemming materials. The control (Shot B-3) used no s temming, one used water only, another employed a mixture of sand and water, one used gravel, and the last was stemmed with concrete.

Located farther from the reservoir than the Phase A and B areas, the Phase C terrain was characterized by much greater variability in the depth of overburden (Figures 3.22-2 and 3.22-3). This experimental series focused on investigating the effects of charge geometry on cratering size and shape. Phase C was comprised of 20 test detonations (Shots C1 – C20) of 500-lb charges place in cylindrical corrugated metal containers of different lengths and diameters. Four different ratios of container length to container diameter (1/d) were used -1/3.0, 1/4.5, 1/6.0, and 1/9.0. Like Phases A and B, Phase C employed 30-inch diameter boreholes of varying depths for the emplacement of the charges. The depth of burial ranged from 7.4 ft to 21 ft and the holes were stemmed with a sand and water mixture. Five identical charges for each 1/d ratio were placed at several burial depths.

Phase D, the hole springing test series, was south of the main Project Trencher test area (Figures 3.22-2 and 3.22-3). The objective of these shots (D1 – D5) was to determine if small charges could "spring" out a volume of earth thereby creating a cavity capable of accommodating a l arger cratering charge. The experiment consisted of five test detonations utilizing 5- to 10-lb charges placed 10 to 20 ft deep in 1-ft diameter boreholes. Dry sand or water stemming was used for these relatively shallow detonations.

Post-shot activities for all four of the test phases involved crater analyses including volume, depth, lip radius, and fallback and ejecta characterization. These data were used to evaluate the performance of the various types of chemical explosive used as well as the effectiveness of different stemming materials. The field analysis was completed by the end of the year with the final report issued in November 1970.

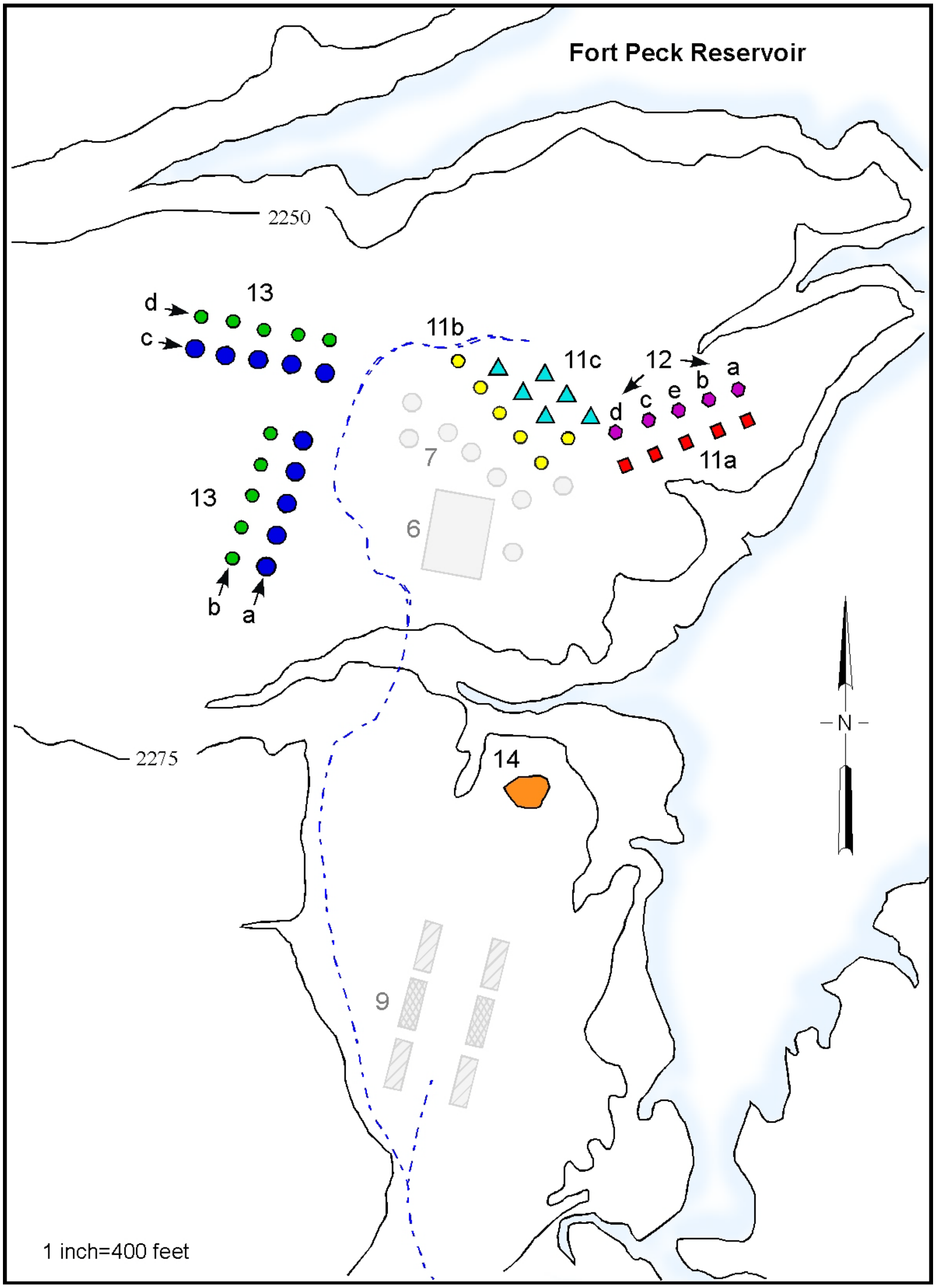


Figure 3.22-3. Layout for the Project Trencher experiments conducted at the edge of the Fort Peck Reservoir. The grayed-out shot locations are from Project Pre-Gondola III, Phases I and III (See Chapter 3.15). See Table 3.22-1 for the key to the map shot locations (adapted from Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group 1969).

Results from the Trencher project were mixed. Phases A, B, and C provided some useful data that minimally confirmed expectations, but more experiments were recommended. There had been some problems with incomplete detonations. This might explain the appearance of several extra craters in the Phase C test area (Figure 3.22-4) although the documentation does not mention any extra shots. The Phase D hole springing tests revealed that the current methodology could not produce usable charge emplacement holes and no further tests were recommended. It does not appear that the Trencher data were very useful for refining the final Pre-Gondola III, Phase III design. The costs and benefits of the additional experiments recommended by Corps of Engineers personnel were considered for several months after the conclusion of the Trencher and Pre-Gondola projects. Plans for a follow-on experiment for Trencher were finally shelved. Final clean up of the equipment, instrumentation, and temporary structures and backfilling of some of the craters took place in the summer of 1972 (Figure 3.22-5).

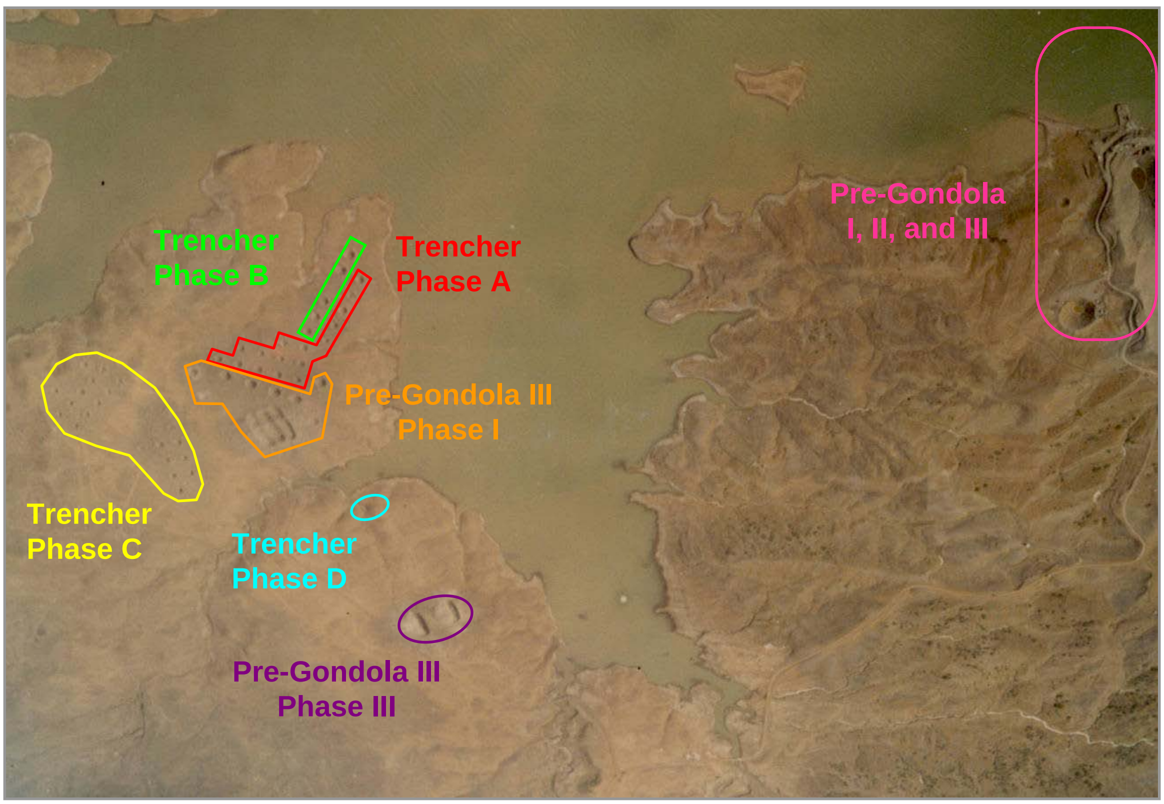


Figure 3.22-4. Aerial photograph of Project Trencher near the Pre-Gondola project along the shore of Duck Creek Inlet, Fort Peck Reservoir, Montana (adapted from photo by U.S. Army Corps of Engineers, Omaha District on file at the U.S. Army Corps of Engineers, Fort Peck Area Office, Montana).

U.S. Army Corps of Engineers is the agency responsible for the lake and the land up to the "take line" along the shore line. The Charles M. Russell National Wildlife Refuge, U.S. Fish and Wildlife Service was and is responsible for the surrounding land.

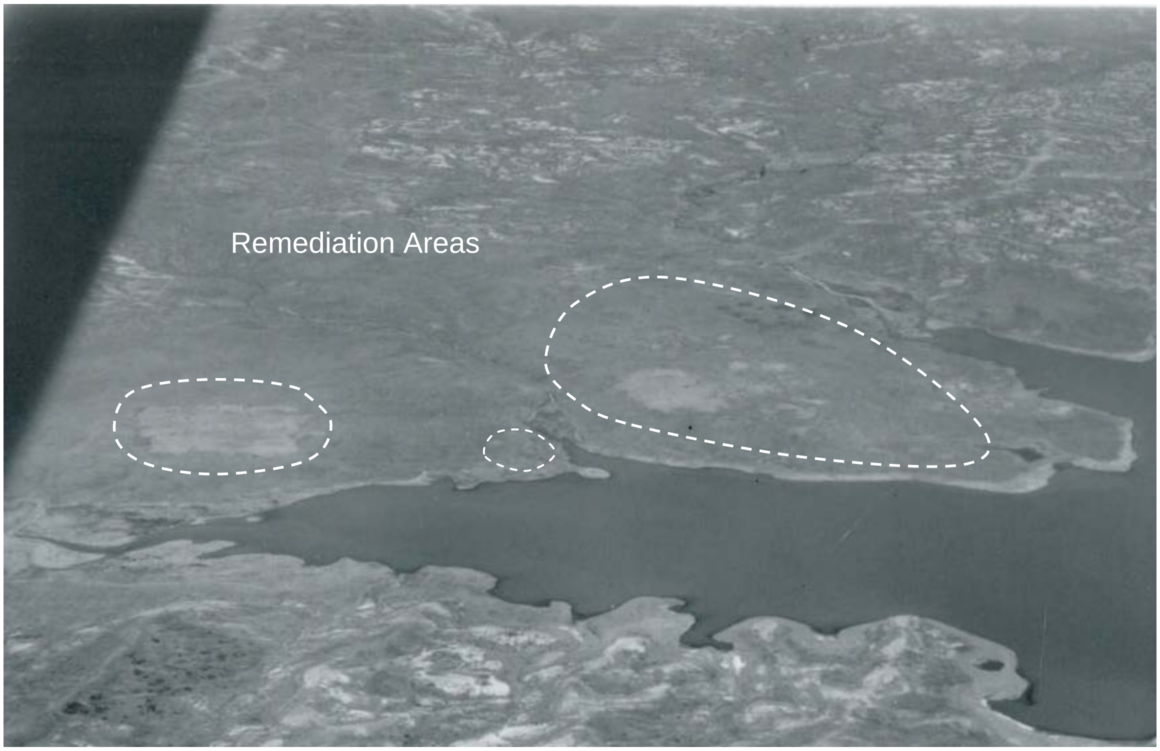


Figure 3.22-5. Aerial view of the Trencher project site in July 1973 showing the remediation of the Trencher craters and the Pre-Gondola III, Phase I triple row charge crater and the Pre-Gondola III, Phase III row crater experiment (adapted from Photo No. 976, Box 977 on file at the U.S. Army Corps of Engineers, Fort Peck Area Office, Montana).

Project Trencher was a Level 2 activity with fieldwork consisting of the drilling of numerous emplacement holes and chemical explosive detonations.

FIELD VISIT

The execution of Project Trencher was verified by the May 2004 and May 2005 field visits to the location, and historic aerial photographs showing the Trencher project craters and ground disturbance. Desert Research Institute personnel conducted a pedestrian survey of much of the project area and were able to document the majority of the Trencher blast locations during 2004. The researchers recorded 32 of the 47 Project Trencher craters. These included all of the Phase A (n=17), Phase B (n=5), and Phase D (n=5) detonations, and 5 of the 20 Phase C craters (Figure 3.22-6). Eight craters identified on a schematic of the area as 1-ton nitromethane calibration tests were also documented, as well as and a large bladed and deflated area, which was the site of a triple row-charge experiment (Figure 3.22-7). Both the calibration tests and triple row detonations were conducted as part of the Pre-Gondola III, Phase I experiment.

Figure 3.22-6. One of the craters from the Project Trencher, Phase B series detonations. This series investigated the characteristics of different stemming materials using 500-lb chemical explosive charges (photo taken June 2004 on file at Desert Research Institute).

Figure 3.22-7. This large bladed area, surrounded by the Project Trencher blast craters, is the site of the Project Pre-Gondola III, Phase I triple row charge experiment. The huge trench created by the multiple detonations crater was backfilled after the experiment (photo taken June 2004 on file at Desert Research Institute).

The site of the triple row shots has been backfilled and leveled, although some settling has occurred. Small pieces of debris, including fragments of the aluminum charge casing, wire, steel conduit, coaxial cable, plywood target fragments, and miscellaneous pieces of metal, covered the row-shot area. In most cases, the single-charge crater locations were easily identified. Most were shallow, circular depressions approximately 20-30 ft in diameter. Typically, the depressions were filled with a few inches of water and lush vegetation consisting of grass and sedges (Figure 3.22-8). The debris scatter around the single-charge craters, while similar in composition, was much lighter than in the triple row charge location.

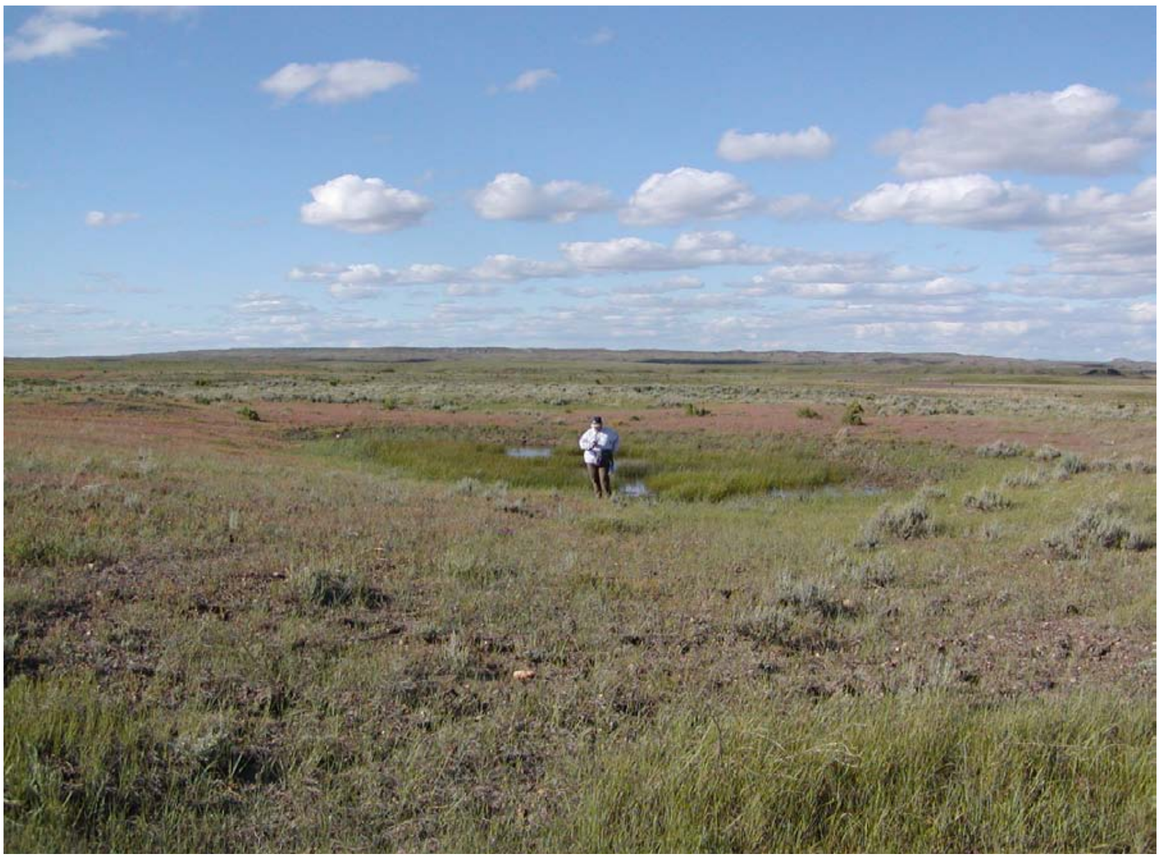


Figure 3.22-8. One of the Project Trencher, Phase A craters (photo taken June 2004 on file at Desert Research Institute).

Fieldwork at the Trencher site and the associated archival research could not be completed during the FY 2004 site visit. The Trencher project area (including the Pre-Gondola III, Phase I detonations) encompassed about 175 acres. Fifteen of the Trencher Phase C crater experiments remained unrecorded along with the associated staging areas and camera stations. As with the Pre-Gondola project location, access was through the Charles M. Russell Wildlife Refuge. Because of extensive channel cutting and erosion, the primary roads used to reach the site were no longer passable even with four-wheel drive. Secondary roads were used to reach a point approximately 3/4 mile south of the

Trencher project location and the remainder of the journey was made on foot. The difficult access shortened on-site recording time. In addition, research pertinent to various Plowshare projects in the Fort Peck Lake Office archives had to be postponed until FY2005 because of time constraints and inclement weather.

Investigators Edwards and Beck returned to the Trencher project area in May 2005 to complete recording the 20 "Phase C" craters (Figures 3.22-3 and 3.22-4). The Phase C experiments were designed to investigate charge geometry and consisted of 500-lb charges placed in cylindrical containers of different lengths and diameters. Most of the Phase C detonations produced very shallow craters because they were located in areas where bedrock was at or near the surface (Figure 3.22-9).

During the reconnaissance of the Trencher project area, the DRI researchers identified the Control Point II area for the Pre-Gondola III Phase I row-charge experiment that was situated in the middle of the Trencher project area (see Figures 3.22-3 and 3.22-4). The control point consisted of a trailer (now removed) positioned on a bladed and level area about 50 ft (N/S) by 30 ft (E/W) (Figure 3.22-10). The concrete and braided steel cables that anchored the trailer remain in place. Debris scattered across the area includes lumber, wooden stakes, nails, metal washers, pipe connectors, metal banding, stainless steel alligator clamps, rubber gaskets, paint brushes, Coca Cola bottle glass, and rubber hose sections. A 6 ft diameter by 2 ft deep depression is located at the west edge of the trailer pad and may have been the site of a privy.

The researchers also identified the location of the Pre-Gondola III, Phase III row crater experiment. Although six row charge arrays were planned only two were executed. The pair of linear craters were found approximately 500 ft southeast of the Trencher Phase D series craters (see Figures 3.22-3 and 3.22-4). Records research in the Fort Peck Field Office archives (Figure 3.22-11) located several aerial photographs of the Trencher project area. Documentation also indicates that the Trencher craters and at least some of the Pre-Gondola craters were back-filled during the Project Diamond Ore reclamation efforts. Site facilities, instrumentation, and most of the large debris piles were also removed.

As with Project Pre-Gondola, the land status records indicate that the Fort Peck Reservoir is administered by the U.S. Army Corps of Engineers, while the refuge is managed by the U.S. Fish and Wildlife Service. Project Trencher's proximity to the reservoir's shoreline confirms that the U.S. Army Corps of Engineers, Omaha District had jurisdiction over the entire project area. No special use permits or temporary withdrawals for the project were found during records research at the Bureau of Land Management, Montana State Office in Billings. However, the State of Montana did issue a permit for a gravel pit on state lands in support of the Trencher and Pre-Gondola projects.

Field reconnaissance in 2005 completes the on-site recordation and land status assessment for Project Trencher.

Figure 3.22-9. Project Trencher Phase C crater. View is to the southeast (photo taken May 2005 on file at Desert Research Institute).

Figure 3.22-10. Overview of Control Point II trailer pad (photo taken May 2005 on file at Desert Research Institute).

Figure 3.22-11. Archives in the basement of the U.S. Army Corps of Engineers, Fort Peck Area Office (photo taken May 2005 on file at Desert Research Institute).

CHRONOLOGICAL BIBLIOGRAPHY

Lawrence Radiation Laboratory. U.S. Army Engineer Nuclear Cratering Group, 1969. Summary and Location of Major Cratering Experiments at Fort Peck. Manuscript, Livermore, CA, October 1. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-091.

Hipp, Charles L., 1969. "Wrap-Up Activities, Project Pre-Gondola III, Phase III." Letter from Charles L. Hipp, U.S. Army Corps of Engineers, Omaha District, to Area Engineer, Fort Peck, November 3. On file at: Fort Peck Archives, U.S. Army Corps of Engineers, Fort Peck, MT, Box 859.

Bourque, Robert F., 1970. Project Trencher: Evaluation of Aluminized Blasting Agents for Cratering and Hole Springing. U.S. Army Engineer Nuclear Cratering Group, *NCG Technical Report* No. 28, November. Livermore, CA. On file at: Technical Reports Library, Lawrence Livermore National Laboratory, Livermore, CA.

LaFrenz, Robert L., 1972. "Status Report - Rapid Excavation with Explosives." Letter with encl. ("Status Report, Effective Date: 31 March 1972") from Robert L. LaFrenz, Explosive Excavation Research Office, Corps of Engineers, to Director, U.S. Army Engineer Waterways Experiment Station, April 10. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-108.

Gates, Richard H., 1972. "Site Improvement." Letter from Richard H. Gates, U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Laboratory, to D. Beckman, Area Manager, Fort Peck Lake Area, July 10. On file at: Fort Peck Archives, U.S. Army Corps of Engineers, Fort Peck, MT, Box 858.

Lawrence Livermore National Laboratory, n.d. Trencher photo pg_b. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

Lawrence Livermore National Laboratory, n.d. Trencher photo pg_c. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

Lawrence Livermore National Laboratory, n.d. Trencher photo pg_d. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

Lawrence Livermore National Laboratory, n.d. Trencher photo pg_e. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

THIS PAGE INTENTIONALLY LEFT BLANK

3.23 - TRINIDAD

Plowshare Program
High Explosives for Railroad Construction
Colorado

Project Trinidad consisted of multiple explosive excavation experiments using high explosive single- and row-charges to create large craters. The detonations occurred in the interbedded sandstone and shale formations near Trinidad in Las Animas County, Colorado just north of the Colorado/New Mexico border during 1970 and 1971 (Figures 3.23-1 and 3.23-2). Technical programs associated with the tests included seismic effect investigations, air blast monitoring, and engineering property studies.

Sponsored by t he U.S. Army Engineer Waterways Experiment Station, Explosive Excavation Research Laboratory, most of Project Trinidad's funding came from the U.S. Army Corps of Engineers, Directorate of Civil Works. The U.S. Atomic Energy Commission and Lawrence Livermore Laboratory also participated in the project. This followed the policy established in 1962 with the Atomic Energy Commission and the Corps of Engineers jointly pursuing a Plowshare program exploring the potential of nuclear excavation techniques for large civil works projects. While all early cratering

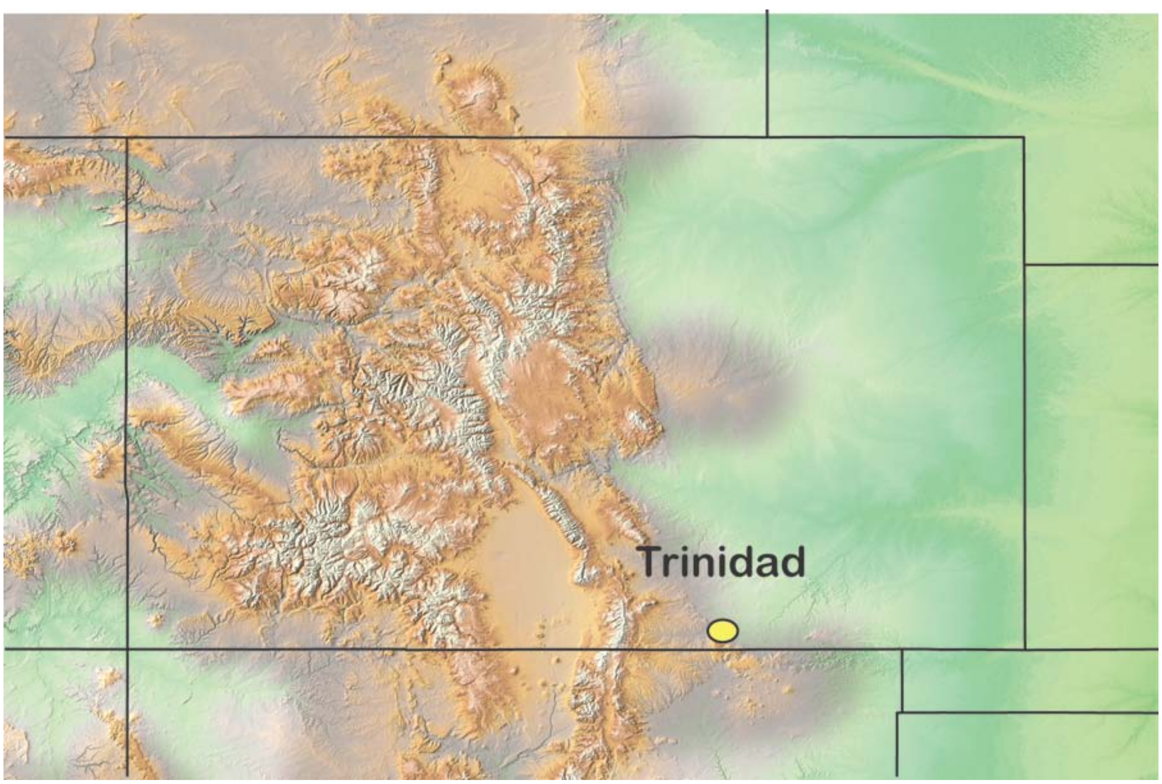


Figure 3.23-1. Location of Project Trinidad in Colorado (adapted from USA Relief Maps 2004).

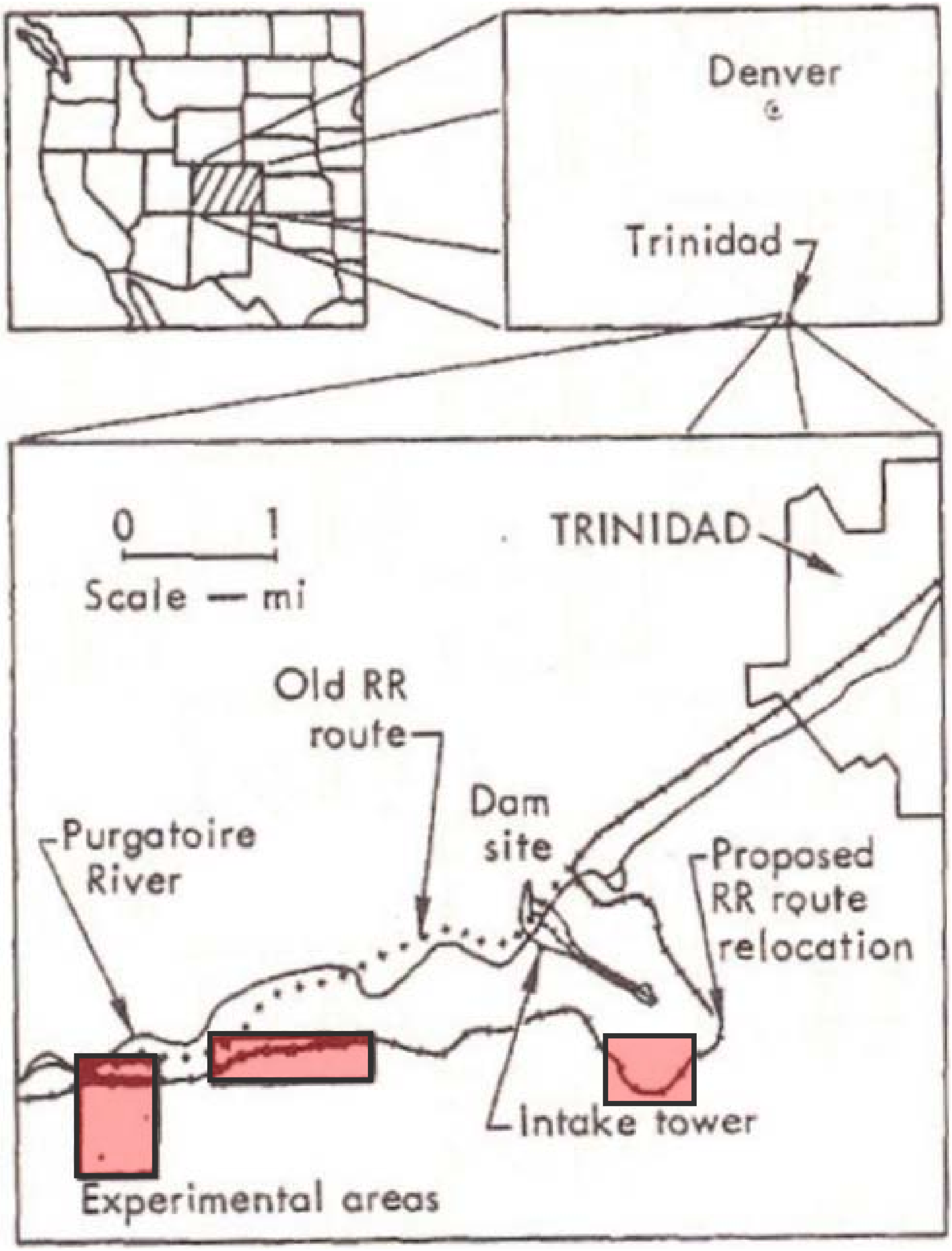


Figure 3.23-2. Proposed experiment locations for Project Trinidad (adapted from Redpath 1972, Figure 2).

experiments were designed as chemical-explosive models of nuclear experiments, the emphasis gradually shifted as time passed. Later experiments, such as Trinidad, re-focused on t he use of more economical chemical explosives, although they still incorporated scientific studies for possible nuclear applications. Structured to investigate cratering behavior in sandstone and shale, the experiments also examined the economics of explosive excavation. The Trinidad project involved an extensive series of cratering tests and technical programs culminating in the excavation of several railroad cuts for the realignment of a rail line.

Site selection for these high explosive cratering experiments followed the Corps of Engineers' policy of conducting research activities in conjunction with actual civil works projects whenever practical. The construction of an earthfill dam across the Purgatoire River near Trinidad, Colorado provided a venue for Project Trinidad. Construction of the dam and adjacent reservoir would inundate the existing Colorado and Wyoming Railroad tracks making relocation a necessity. The required through-cuts for the realignment afforded the opportunity for a practical application of cratering excavation.

The Trinidad Dam and Lake Project had been under consideration for several years as a means of revitalizing the Trinidad area by making it a recreational and agricultural center for southern Colorado. Once a prosperous coal producing region, Trinidad's economy and population had gradually declined as a devastating series of labor strikes and fires closed most of the mines. Only a single coal mine remained active by the time the site, located six miles west of the town of Trinidad, was selected for the cratering experiments.

The entire experimental explosive test site fell within the Trinidad Lake Project boundaries on lands administered by the Corps of Engineers, Albuquerque District. The Government had already acquired all of the structures in the small community of Sopris destined for submersion once the reservoir filled.

The Corps of Engineers specified a wide range of objectives for Trinidad. Designed to provide information on explosive cratering in a previously untried geologic medium, the experiments also explored a method for expanding an explosive device emplacement cavity. In addition, the technical programs included the investigation of row crater formation; determination of the effects of time delays between detonations; and identification of techniques for crater excavation in uneven terrain.

Conducted between July and December 1970, t he original phase of Project Trinidad consisted of four independent cratering experiments detonated in interbedded shales and sandstone. The experiment series were designated A, B, C, and D (Figure 3.23-3). Two later railway through-cuts conducted in 1971 were labeled RR#2 and RR#3 (see Table 35-1). In addition to the original Trinidad program and the follow up c uts, a series of supplemental experiments also designed to investigate explosive crating parameters, were conducted. These included Middle Course I, Middle Course II, and Project Mini Mound I and II.

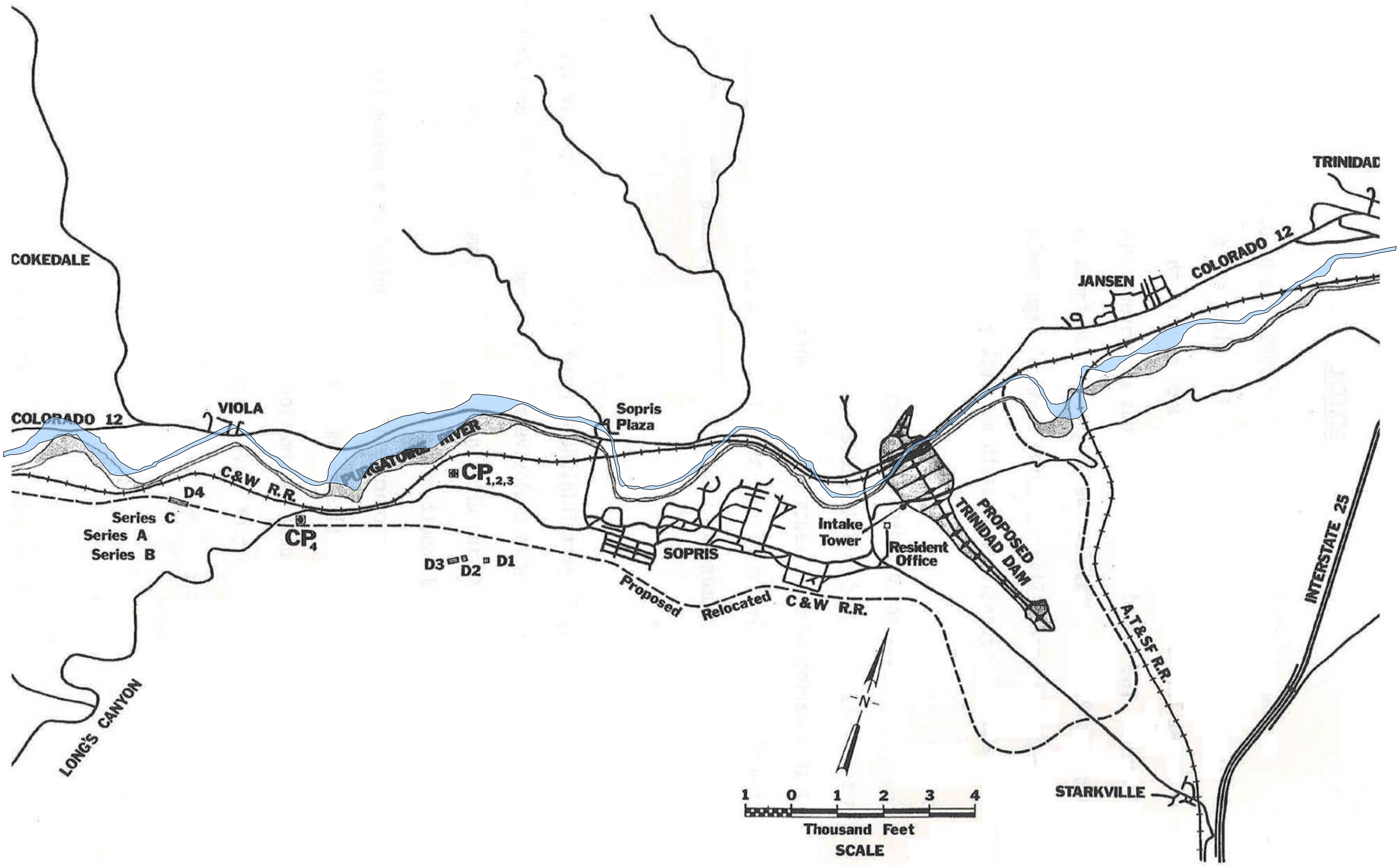


Figure 3.23-3. Location of Project Trinidad, Experimental Series A, B, C, and D near Sopris, Colorado. Locations for two of the Control Points (CP) are also shown (adapted from U.S. Army Engineer Nuclear Cratering Group 1970, Figure 1).

Table 3.23-1. Project Trinidad Experiments

SERIES	NUMBER	DESCRIPTION	DATE
A	-	Hole springing experiments conducted intermittently throughout the project	July – December 1970
B	B1 – B3 B4 – B8 B9	Three 1-ton single charge craters using ANFO Five 1-ton single charge craters using aluminized slurry Canceled	July and August 1970
Middle Course I	B10 – B13 B14 – B15	DASA sponsored Middle Course I – surface detonations DASA sponsored Middle Course I – subsurface detonations	October 1970
C	C1 – C3 C4 – C5 C6	Three row-charge craters, five to seven 1-ton charges, aluminized slurry, simultaneous detonation Two row-charge craters, five 1-ton charges, aluminized slurry, delayed detonations Two parallel row-craters, five 1-ton charges, aluminized slurry, simultaneous detonation	September and October 1970
D	D1 D2 D3 D4	Row-charge crater through a ridge, nine charges, 200 lb to 1-ton, ANFO Row-charge crater along sidehill, five 1-ton charges, aluminized slurry Double row-charge crater along sidehill, six 1-ton and six 2-ton charges, aluminized slurry Double row-charge railway cut, twenty 1-ton and twelve 2-ton charges, aluminized slurry, delayed detonation	November 1970 December 1970
Mini Mound I	A1 – A7 B1 – B7	Two rows (A and B) of seven 200-pound charges detonated in weak shale	April/May 1971
Middle Course II	M1 – M2 M3 – M16	DASA sponsored Middle Course II – two detonations near the Trinidad B series in Long Canyon DASA sponsored Middle Course II – 14 detonations in Frisco Canyon	Spring 1971
Mini Mound II	C1 – C7 D1 – D7	Two rows (C and D) of seven 200-pound charges detonated in a massive sandstone	September 1971
-	RR#2	Double row-charge railway cut, Thirty-five 400 to 800 lb charges, ANFO, simultaneous detonation	September 1971
-	RR#3	Four row-charge railway cut, forty-six 0.5 to 4-ton charges, ANFO, delayed detonation	September 1971

DASA = Defense Atomic Support Agency; ANFO = Ammonium nitrate fuel oil.

Three different methods were used for creating the emplacement holes for the Project Trinidad charges. Some were drilled using an "underreamer," which involved boring small pilot holes and then using a special tool to expand the bottom half of the hole to the required diameter. The second method employed a conventional bucket auger. For surface shots, the emplacement holes were hand dug.

The Trinidad A Series (Figure 3.23-4), conducted intermittently throughout the project, was designed to test the possibility of creating explosive emplacement cavities using small detonations or "hole springing" rather than relying on fullbore drilling. The series detonated charges of up to 200 lbs in access h oles of varying diameter to create these cavities.

Eight 1-ton blasts utilizing two different chemical explosives made up the first part of the B Series (Figure 3.23-4). Nine detonations were planned, but the last was cancelled.

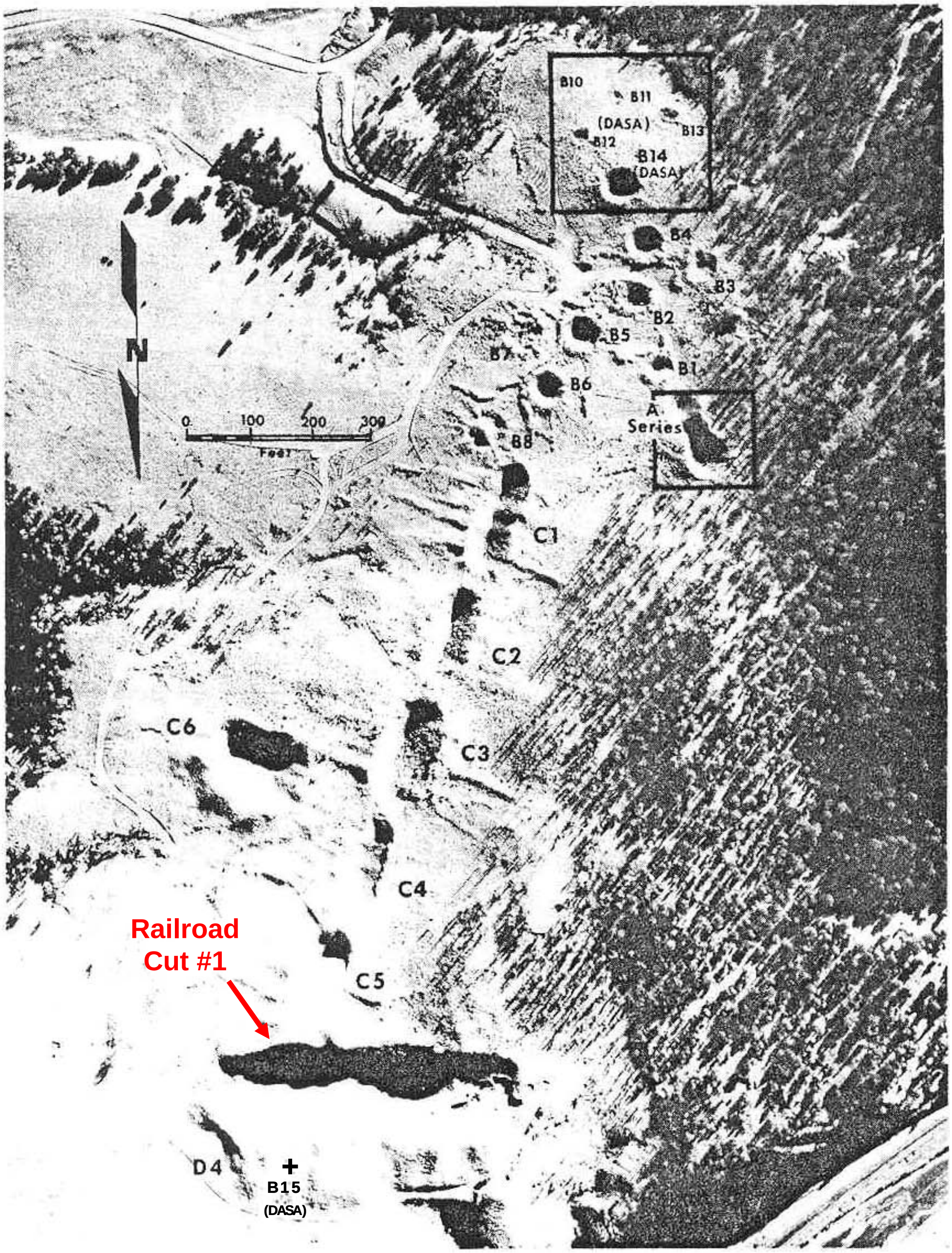


Figure 3.23-4. Aerial view of Project Trinidad test sites c. 1972. The D4 row charge detonation is Railroad Cut #1. Middle Course I tests B10 – B14 are shown at the top of the photo and B15 is at the bottom. Note that north is toward the bottom of this photo (adapted from Redpath 1972, Figure 5).

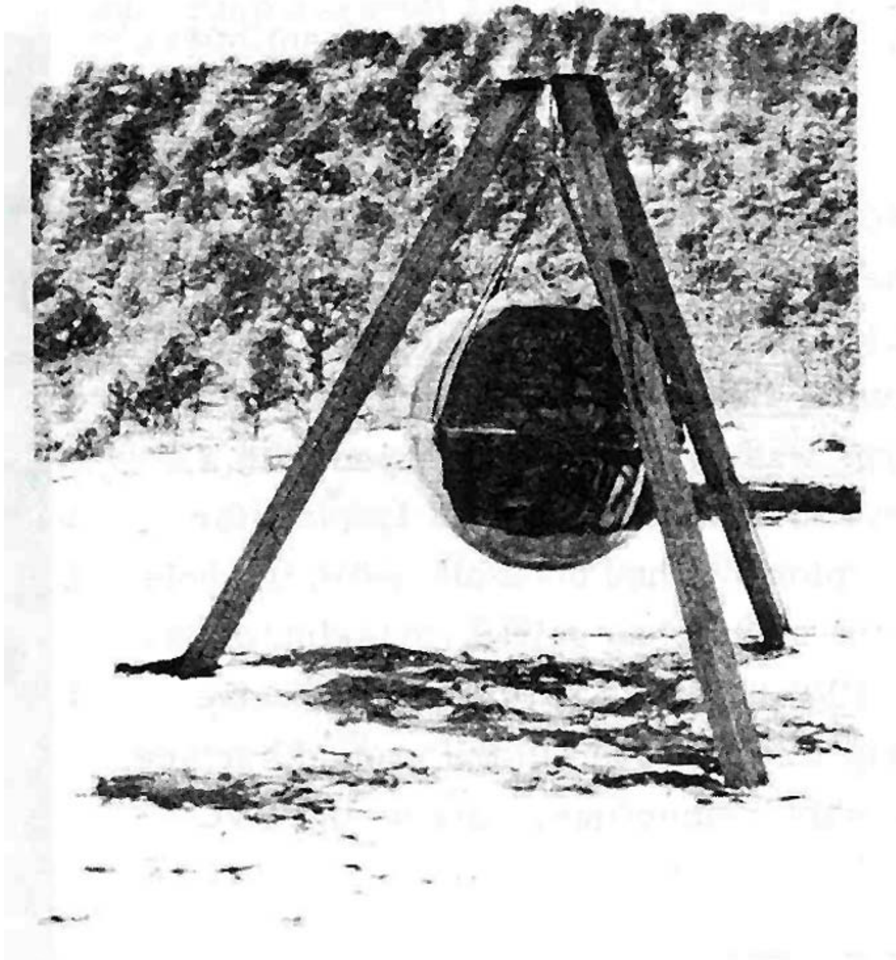


Figure 3.23-5. Suspended charge for Charge B10, Middle Course I (Fitchett 1971, Figure 7).

Detonated at various depths, these tests compared the effectiveness of ammonium nitrate fuel oil with that of aluminized ammonium nitrate slurry. Conducted during July and August 1970, t hey were also designed to determine the cratering characteristics of sandstone and shale. Data obtained through these experiments would be employed to develop cratering curves for these media.

The Defense Atomic Support Agency sponsored the second portion of the "B" series. Designated Middle Course I, the shots consisted of six one-ton experiments conducted between October 5-9, 1970 (Figure 3.23-4). Four of the blasts were surface detonations (Tests B10 – B13) and two of the shots occurred at depth in drill holes (Tests B14 – B15) (Figure 3.23-5). The purpose of these was two-fold. First, the detonations were structured to expand the data set for military applications of cratering by providing information on the performance of surface and subsurface blasts in sandstone. Secondly, the Middle

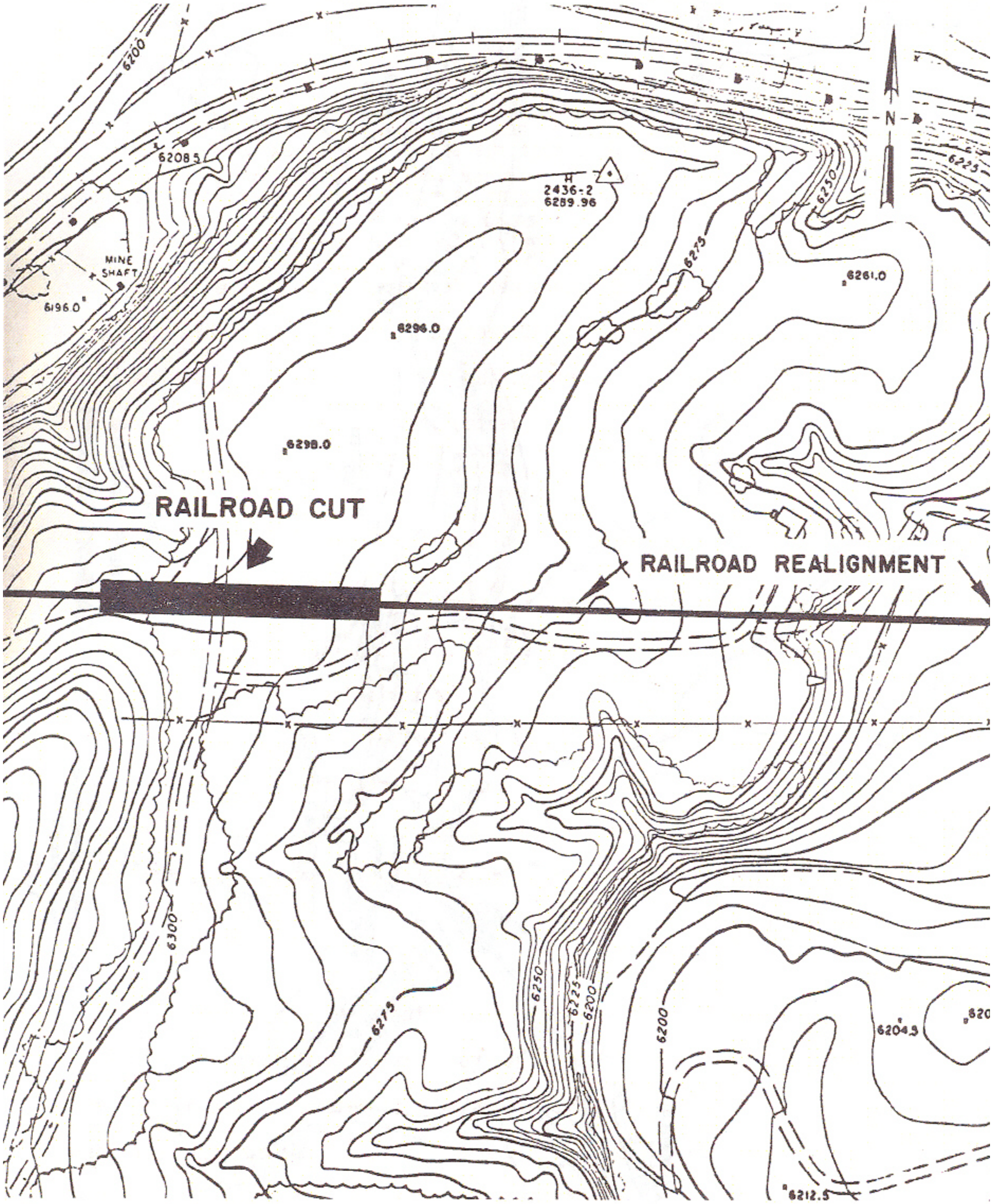
Course I te sts were meant to supplement the rest of the Project Trinidad data by contributing to the development of scaled cratering curves for sandstone.

Comprised of six row charge detonations using 1-ton charges filled with aluminized ammonium nitrate slurry as the explosive, the C Series took place in September and October, 1970. Five were single row charges. Detonations C1, C2, C4, and C5 consisted of five separate charges while detonation C3 used seven charges. The final blast in the series, C6, was a double row experiment with 10 separate charges (Figure 3.23-4). The C series investigated the effects of simultaneous detonations as well as sequential detonations. The effects of differential spacing and depth of blast were also explored.

Series D consisted of four experiments. The control point for the first three "D" experiments was located approximately 2,000 ft north of the blast area, while the control point for the D4 shot was situated approximately 2,600 ft east of the row charge experiment. Shots D1 and D2 took place on November 17 and 18, 1970, respectively. Both were single row detonations with yields of five tons each. Detonation D1 was a single row array distributed across varying terrain. The D2 experiment was also a single row detonation situated on a sidehill utilizing pre-splitting charges. The D3 shot, conducted on November 19, 1970, consisted of a two-row configuration, one with six tons of explosive and the other with 12 tons. D3 incorporated delayed timing between the double rows of pre-splitting charges laid out over an uphill slope. The D4 detonation (aka. Railroad Relocation Cut #1 – RR#1) took place Dec. 16, 1970 (Figure 3.23-6). The double row blast in varying terrain consisted of 44 tons of explosive in 32 separate charges. It created a 400 ft long railroad cut for the relocation of the Colorado and Wyoming Railroad (Figures 3.23-4 and 3.23-6).

The success of the D4 row-charge excavation led to a follow up project. Performed as the final phase of Project Trinidad, the U.S. Army Corps of Engineers, Waterways Experiment Station conducted two additional explosive excavations in September 1971 (Figure 3.23-7). Because these were essentially practical applications of the techniques developed and tested in the first four series of Project Trinidad, Railroad Relocation Cuts #2 and #3 (RR#2 and RR#3) had only minimal instrumentation for ground motion and air blast measurements. Instead, the primary technical objective of these experiments was to test the performance of specific charge arrays. Both experiments used a mixture of prilled ammonium nitrate and fuel oil for the explosive charges. The first experiment, RR#2, used a mounding charge array which is very similar to conventional blasting except that its design facilitates breaking a horizontal surface rather than a bench or rock face. The design of the second experiment, RR#3, focused on testing a charge array that would produce a crater that required little mechanical excavation because the fractured material would have been thrown out by the blasting.

The two experiment sites were selected from the 23 through-cuts required for the relocation of the 9-mile long Colorado and Wyoming Railroad (Figure 3.23-7). The location for RR #2 was chosen because of its slight slope and relatively uniform depth of cut. It consisted of a 35-charge, double-row explosive array intended to fracture rock within the cut area in preparation for removal by mechanical equipment. The 10.4-ton "mounding" blast, used



CONTOUR INTERVAL: 5 FEET
SCALE: 1" = 200 FEET

Figure 3.23-6. Location of Railroad Cut RR#1 (aka. D4) in Long Canyon (U.S. Army Engineer Nuclear Cratering Group 1970, Figure 2).

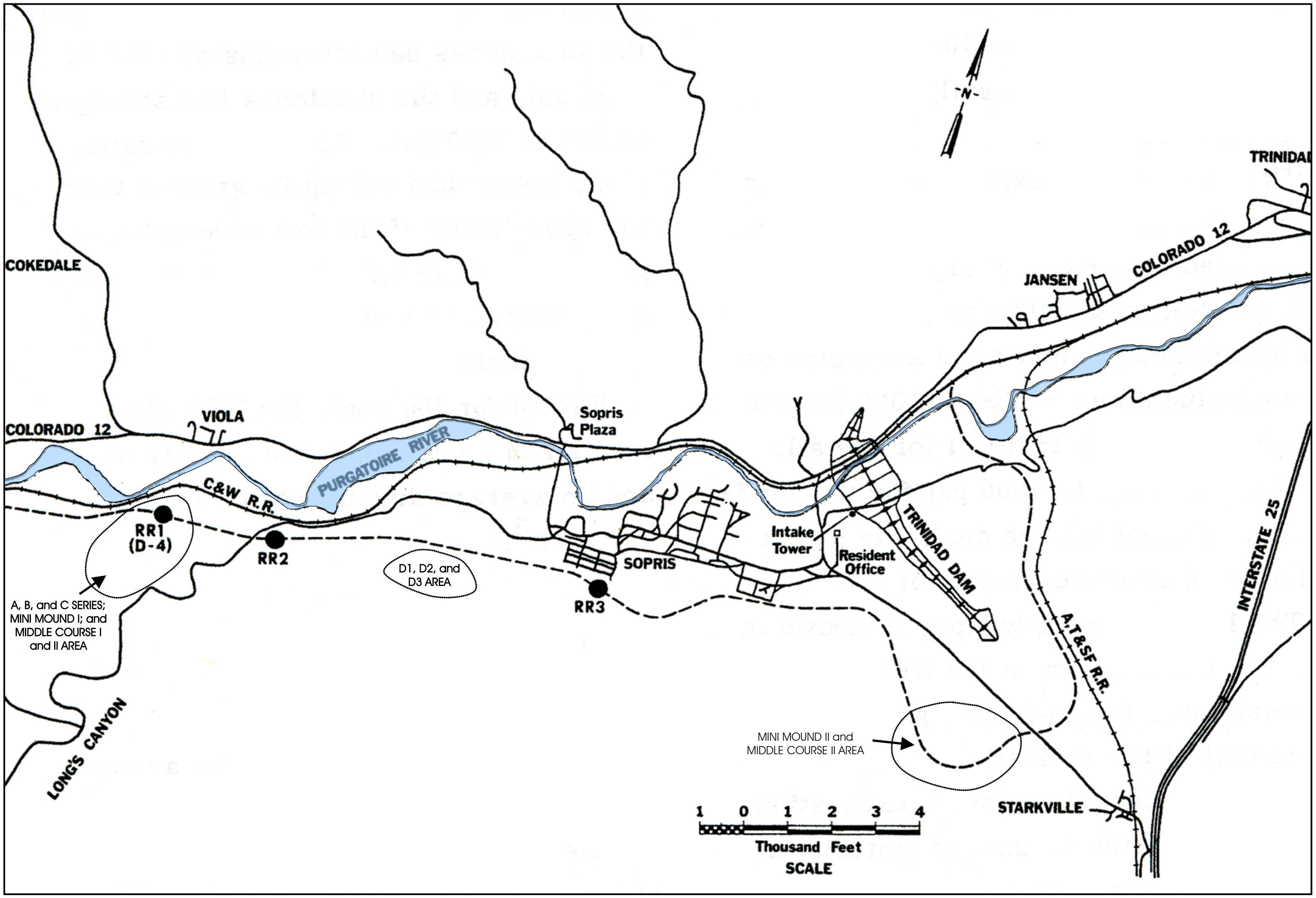


Figure 3.23-7. Location of the three Project Trinidad railroad cuts, the Trinidad explosive series A, B, C, and D, the Mini Mound and the Middle Course series (adapted from Lattery 1974, Figure 1).

for breaking horizontal surfaces, resulted in a 520 ft long cut that averaged 28 ft deep (Figure 3.23-8). The detonation took place on September 18, 1971.

Railroad Cut RR#3 consisted of 48 charges arranged in a four-row configuration with a total yield of 68.5-tons. This experiment, located on a steep side slope and requiring a deep cut, produced a crater 520 ft long by 42 ft deep (Figure 3.23-9). The charge array incorporated varying charge weights and spacing, and delayed detonation between the first row and the other three rows to accomplish directional throwout cratering. The experiment took place on September 23, 1971.

The other supplemental experimental series at the Trinidad project site began in spring 1971. Project Mini Mound was a small-scale row-charge mounding experiment conducted by the U.S. Army Engineer Explosive Excavation Research Office (formerly the Nuclear Cratering Group). Mini Mound was a follow on field experiment for a model controlled blasting study conducted at the Lawrence Radiation Laboratory's Site 300 test facility in Livermore California. Its objectives were to provide depth, spacing, and shape crater data for use in designing larger scale project applications where throwout cratering techniques were prohibited by yield and safety concerns or where cut and fill excavation was a more economical design solution. The experiment was accomplished in two phases, Mini Mound I and Mini Mound II. Mini Mound I took place in Long Canyon adjacent to the Trinidad A, B, and C series and the Middle Course I blasts (Figure 3.23-7). It was conducted in April and May 1971 and consisted of two 105 ft long rows (1A and 1B) of seven 200-pound charges each. Detonated at mounding depth in a weak shale medium, the charges were spaced at varied intervals to investigate the effects of spacing on fragmentation and true crater dimensions. The main charge emplacement holes were 12 inches in diameter and were stemmed with gravel. Controlled blasting techniques, including presplitting and cushion blasting were incorporated into the experiment. The pre-splitting and cushioning charges consisted of 2.5-inch diameter holes drilled 10-15 feet deep. The pre-splitting holes were loaded with between 0.25 to 0.5-pounds of Trimtex explosive per foot of depth while the cushioning holes contained 1.5-pounds of dynamite per foot of depth.

Because the detonations in the interbedded weak shale/sandstone deposits of Long Canyon produced inconclusive results, the second phase, Mini Mound II, was executed in a sandstone formation in Frisco Canyon approximately three miles east near the town of Starkville (Figure 3.23-7). Two rows of charges (2A and 2B) were detonated in September 1971. Row 2A was 105 ft long and was comprised of seven 200-pound aluminized ammonium nitrate slurry charges, while Row 2B was 54 ft long and consisted of four charges. Presplitting and cushioning charges were also used in this phase.

A variety of technical programs such as high-speed photography, true crater measurements, rubble studies, and surface and subsurface motion measurements were associated with the Mini Mound experiment. Camera stations, pressure gauges, seismic and other recording instruments surrounded each test area. The follow up characterization studies for both phases of the Mini Mound experiment included post-detonation ground

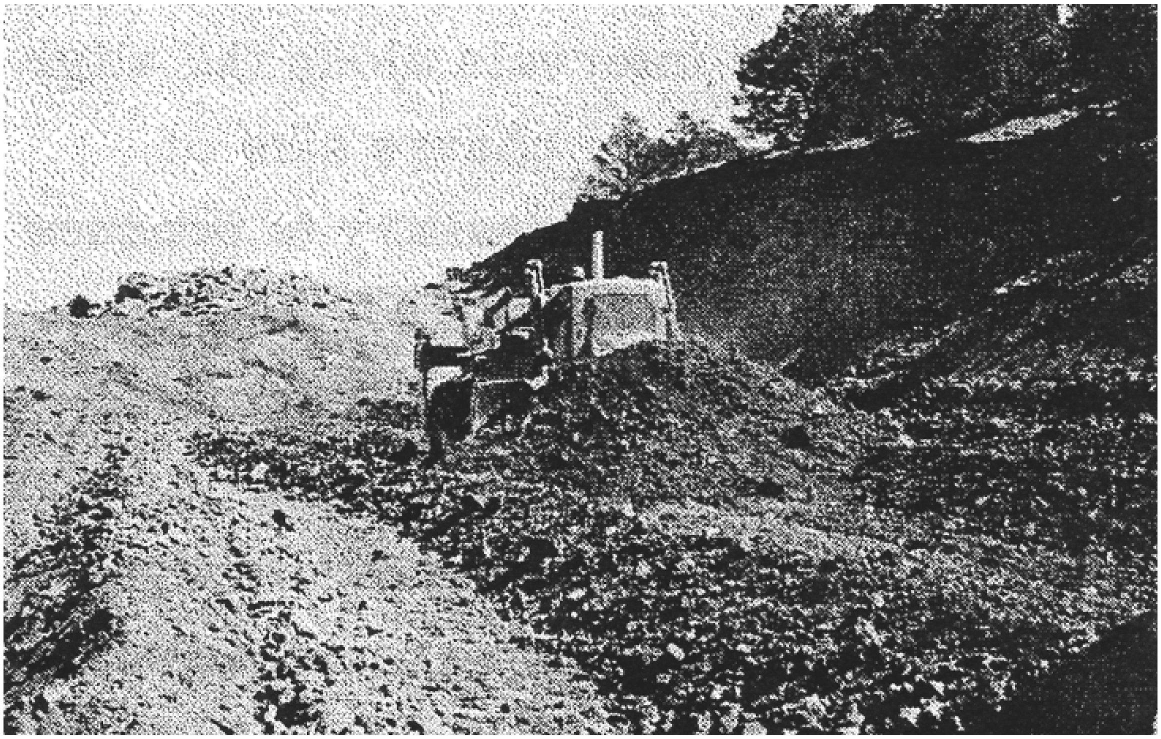


Figure 3.23-8. Railroad Relocation Cut #2 being excavated after the double row-charge detonation (from Lattery 1974, Figure 7a).

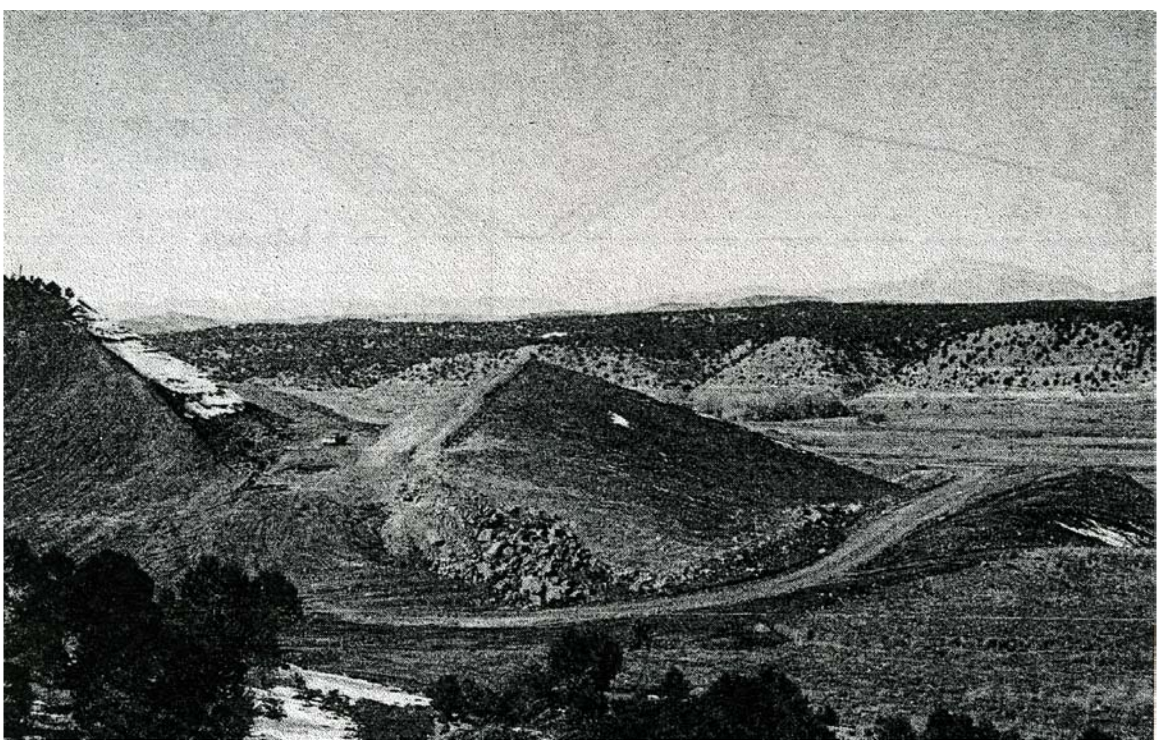


Figure 3.23-9. Completed Railroad Relocation Cut#3 (from Lattery 1974, Figure 18).

surveys, rubble gradation studies, analysis of the ground motion data, and crater excavation. The post-shot field investigations concluded in October 1971.

Middle Course II began in the spring of 1971. A follow up to the previous Middle Course tests sponsored by the Defense Atomic Support Agency, this series of experiments was conducted to fill in data gaps. Twenty-eight 1-ton explosions over a range of burial depths were originally planned, but this number was reduced to 16. The first two Middle Course II detonations, M-1 and M-2, were conducted in Long Canyon near the Middle Course I craters for comparative purposes (Figure 3.23-7). Another 14 blasts were conducted in the sandstone deposits of Frisco Canyon (Figure 3.23-10). The geology of the two canyons was similar, but not identical. The Frisco Canyon shots included seven shots detonated in 36-inch diameter open holes, one shot in a 4-inch diameter hole, five shots with water stemming, and one shot with gravel stemming.

Most of the technical programs associated with Middle Course II were similar to the Project Trinidad, Middle Course I and Mini Mound experiments and included crater and ejecta studies, seismic motion measurements, surface mound growth measurements, air overpressure measurements, and cloud studies. Middle Course II also included a fallout simulation program. The objective of this program was to test a fallout simulation technique for a future test series called Project Diamond Ore, a military high explosive cratering experiment planned for late 1971. The Middle Course II detonations, while not designed to simulate nuclear detonations, provided an opportunity to test a new fallout simulation technique using a tracer material comprised of neutron-activable iridium-coated quartz particles. Four of the Middle Course II charges, M-4, M-9, M-13, and M16, each contained 200 pounds of iridium-tagged particles mixed with the 1-ton explosive charge. Between 200 and 300 sample collection trays were arrayed around each ground zero. After the blasts, the trays were collected and analyzed. Small one–gram samples from each tray were irradiated with thermal neutrons in the laboratory and the iridium content of each collection tray was determined. The utility of this simulation methodology was that all irradiated material was confined to the laboratory.

The U.S. Army Engineer Waterways Experiment Station, Explosive Excavation Research Laboratory and Lawrence Livermore Laboratory developed the technical concepts and provided technical support for Project Trinidad as well as the other supplemental experiment programs (Middle Course and Mini Mound). Lawrence Livermore also supervised the explosive assembly, arming, timing, firing, and safety, while the Explosive Excavation Research Laboratory provided key supervisory personnel and assumed responsibility for documentary photography and the hole-springing technical programs. The U.S. Army Corps of Engineers, Albuquerque Engineer District, provided all engineering, construction, and operational support. Mile High Drilling Company was contracted for emplacement hole drilling and IRECO Chemical furnished the explosives. The National Oceanic and Atmospheric Administration and the U.S. Army Engineer Waterways Experiment Station investigated ground motion and seismic effects, while Limbaugh Engineers gathered crater measurements. Sandia Laboratory and Dunegan Research Corporation also conducted some of the ground motion and air blast measurements.

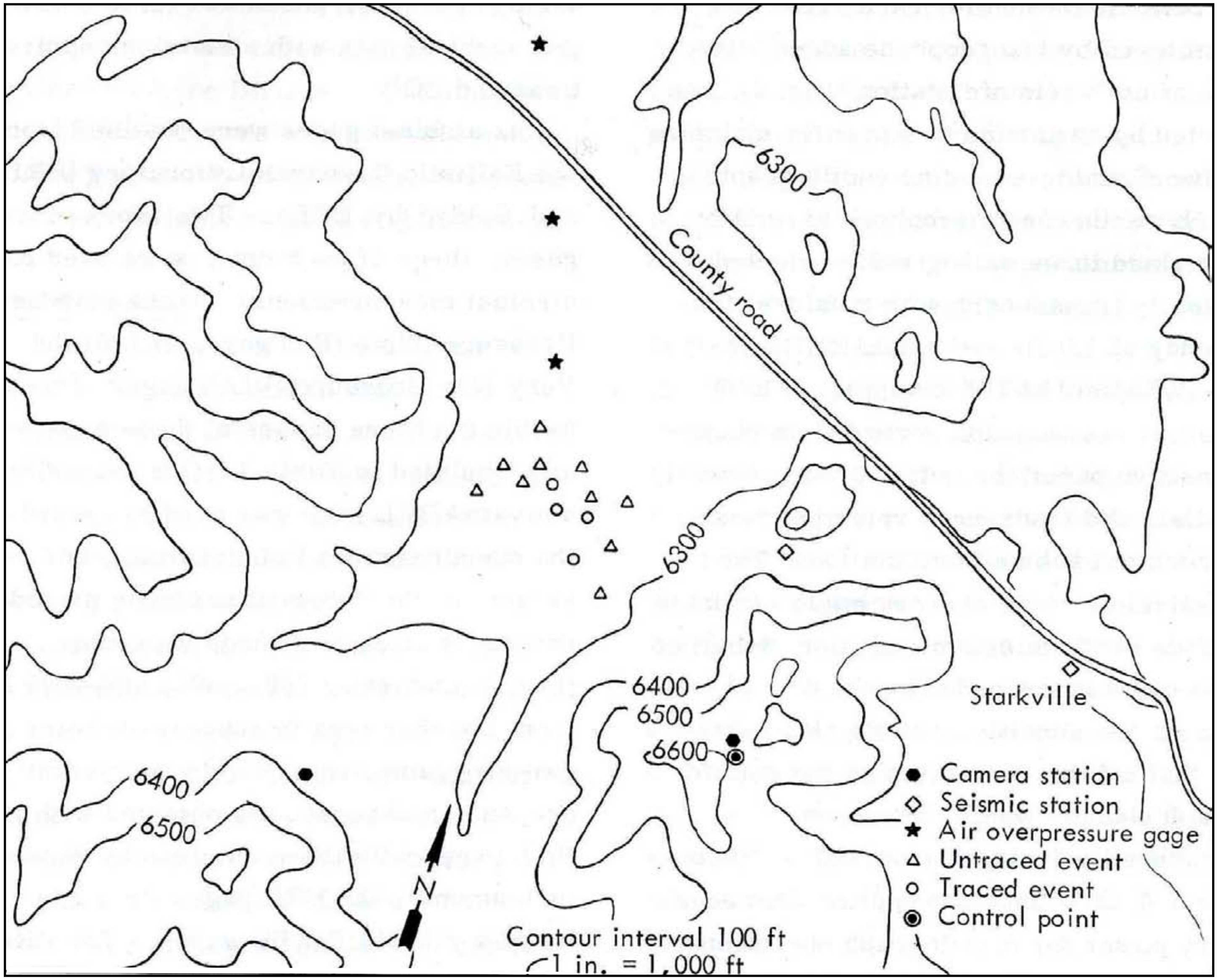


Figure 3.23-10. Locations of the Middle Course II shots M-3 through M-16 in Frisco Canyon (Sprague 1973, Figure 5).

The U.S. Atomic Energy Commission, Nevada Operations Office contracted John A. Blume & Associates, Engineers for a structural response study to investigate the effects of dynamic ground motion on a variety of structures to aid in the development of predictive models. Done in conjunction with cratering experiments, the study acquired data by monitoring ground motion in residential buildings in the nearby town of Sopris, Colorado during the "D" series of detonations. The study found a good correlation between the recorded building motions and the predicted response.

Facilities constructed for the Trinidad experiments were limited. Apparently, several different control points were set up for the detonations, but documentation only provided control point locations for the D Series and Middle Course II Frisco Canyon detonations (see Figures 3.23-3 and 3.23-10). Temporary ground motion and air overpressure monitoring stations, as well as camera stations, were established in close proximity to ground zero for each of the detonations. The communities of Sopris, Piedmont, Jansen, Trinidad, and Starkville also housed seismic and air blast instrumentation for the blasts. These instrument stations and the drilling apparatus for the emplacement holes were removed at the conclusion of the project. While few, if any, structures associated with the Trinidad experiment remain, the three railroad cuts, as well as some of the 40+ craters created by the various excavation experiments, are still visible (Figures 3.23-4 and 3.23-7). Most of the cratering experiment ground zeros were located south of the Colorado and Wyoming Railroad realignment and were not flooded by the completed reservoir.

The U.S. Army Corps of Engineers considered Project Trinidad a complete success with results from the original four series of experiments effectively applied to the excavation of two additional railway cuts. The cratering tests also demonstrated that using fewer but larger drill holes and larger charges resulted in significant economic advantages over conventional blasting methods. In addition, the results of seismic and air overpressure measurements along with the fallout simulation studies contributed much needed data making it much easier to predict the effects of future detonations.

Project Trinidad and the associated Middle Course and Mini Mound series were a Level 2 activity where conventional explosives were used for excavating the three railroad relocation cuts and the various cratering experiments. The Trinidad project site was inspected in FY 2003.

FIELD VISIT

Desert Research Institute personnel visited the Project Trinidad high explosive experiment site on August 15, 2003 to obtain information on land status and the condition of the site. The main experimental test area for the Trinidad project is located approximately five miles southwest of the town of Trinidad, Colorado in the S1/2, Sec. 31, T33S R64W, Animas County. Situated on the west side of Long Canyon just south of Trinidad Lake, this area is the site of the A, B, and C series of chemical explosive detonations, the D4 row charge blast that created Railroad Relocation Cut #1, the six craters from the Middle Course I series, and detonations M1 and M2 of the Middle Course II series. Railroad Relocation Cuts #2 and #3 are located in the NW1/4, Sec. 32, and the NW1/4, Sec. 33, T33S R64W, respectively (Figures 3.23-4 and 3.23-7).

Field visits to Railroad Relocation Cut #3, the D1-3, and the Middle Course II and Mini Mound II craters were not possible because the road leading to these locations passed through a gated private residential community. However access to the main Trinidad project site is possible via public roads. Beginning from the junction of Interstate 25 and State Route 12 near the south end of the town of Trinidad, travel west on State Route 12 for about 8.1 miles past the community of Cokedale. Turn left (south) onto the 18.3 Road, which immediately crosses over the Purgatoire River curving back towards the east. Continue along this winding road for about 3.2 miles until reaching Long Canyon. Turn left (north) following the signs for the Trinidad Lake State Park wildlife viewing area. Proceed on foot 0.5 mi to the railroad tracks and the Project Trinidad site. The test area falls within the Trinidad State Recreation Area, which was created when the U.S. Army Corps of Engineers completed the dam across the Purgatoire River. The only visible remains from the project are the railroad cuts (Figures 3.23-11, 3.23-12, and 3.23-13) and some very shallow (>15-inch deep) and gently sloped depressions from the high explosive detonations (Figures 3.23-14 and 3.23-15). The depressions are approximately 20 ft in diameter. Most appear to have been backfilled. Faint traces of dirt access roads to the blast area remain, but these are badly eroded and overgrown with vegetation.

The D4 row charge detonation formed the railroad relocation cut RR#1. The C series depressions are on the south side of the railroad tracks, and extend in a roughly south-southwesterly direction (Figure 3.23-13). The locations of the A and B series detonations, as well as the Middle Course I and Mini Mound I sites, are on the west side of a gated barbed wire fence line. The gate is locked and there was no access to this area. Another fence line is 150+ m to the west of the first fence and this marks the boundary of the recreation area – private land is on the other side of this fence line. The fences and depressions are all on the west side of Long Canyon. A brass survey cap is located at the juncture of the angled barbed wire fence line and the north-south barbed wire fence line with the locked gate. This juncture is on the embankment above the railroad cut. The brass cap reads: "CORPS OF ENGINEERS US ARMY SURVEY MARK/$250 FINE OR IMPRISONMENT FOR DISTURBING THIS MARK/BY CORPS US ALBUQUERQUE DISTRICT/ AGENCY STATION DESIGNATION LS 7969 YEAR 1974". The words are inscribed in a circular pattern following the shape of the cap. Railroad Relocation Cut #2 is located on the east side of Long Canyon (Figure 3.23-12)

The area is virtually free of debris. Nothing indicating a staging area could be found although the marshes surrounding the reservoir created by the dam might be covering past activity areas. The staging area may also have been located on the other side of the fence line.

A visit to the U.S. Army Corps of Engineers office located at the Trinidad Dam verified that the Corps operates the dam and support facilities. The area surrounding the reservoir is part of the *Trinidad Lake State Park* and the state of Colorado has legal jurisdiction for land within the park boundaries including the location of the Project Trinidad experiment. Desert Research Institute personnel interviewed two individuals who were both long-time employees at the Corps of Engineers Trinidad Dam Office. Joseph L. Torres (1972-present) and Richard Falduto (born and raised in Sopris) have worked at the dam since its beginning. According to Torres and Falduto, the railroad along the south side of the reservoir is no longer used and is scheduled for demolition. Actually the dismantling had been delayed several months and should already have been completed. They expected the track removal to start the week of August 18 or 26th 2003.

Figure 3.23-11. Overview of railroad cut RR#1 created by the D4 series of high explosive detonations. View is to the west (photo taken August 15, 2003 on file at Desert Research Institute).

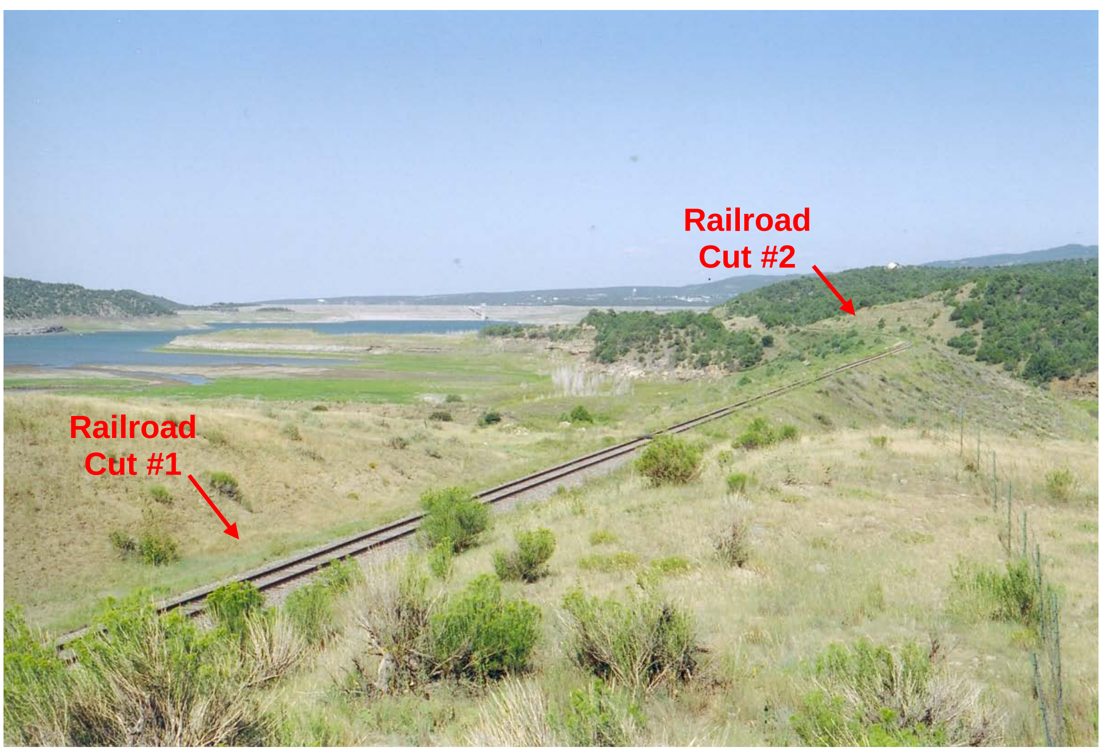


Figure 3.23-12 Abandoned Colorado and Wyoming Railroad scheduled for demolition fall 2003. View is to the northeast (photo taken August 15, 2003 on file at Desert Research Institute).

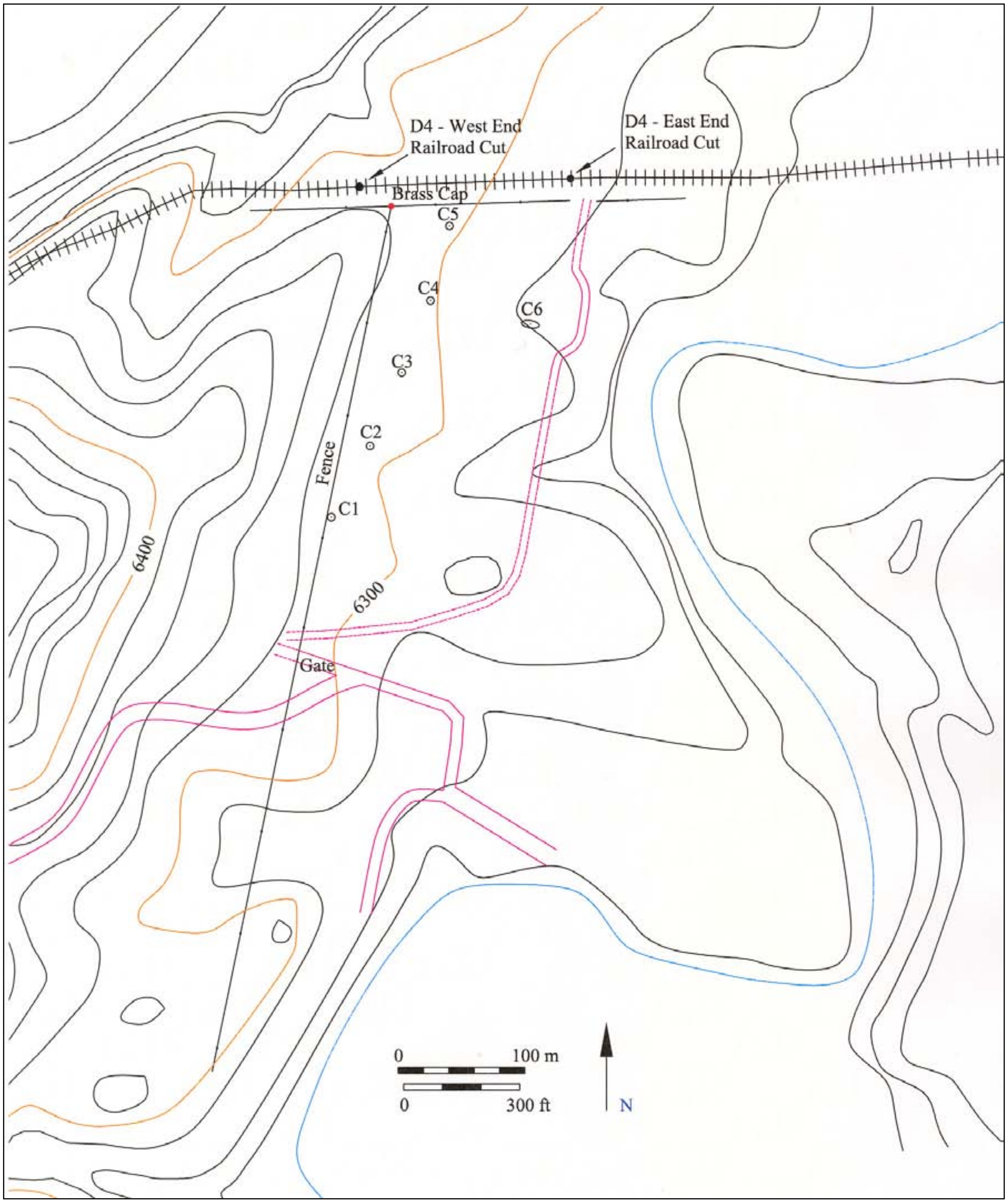


Figure 3.23-13. Plan view of the current Project Trinidad site based on observations made on August 15, 2003.

Figure 3.23-14. Overview of shallow depression from the “C5” detonation. Faint depressions from the other “C” series high explosive detonations are visible in the background. View is to the south-southwest (photo taken August 15, 2003 on file at Desert Research Institute).

Figure 3.23-15. Overview of shallow depression from the “C5” detonation. Several boulders mark the edge of the depression. View is to the southeast (photo taken August 15, 2003 on file at Desert Research Institute).

CHRONOLOGICAL BIBLIOGRAPHY

Vandenberg, William E., 1970. Letter with encls. ("Project Trinidad Test Program; form for attendance at railroad cut detonation of Project Trinidad; Visitor's Schedule, Project Trinidad - railroad cut detonation; "Project Trinidad, D Series, Chemical Explosive Cratering Experiment in Weak Rock," manuscript, U.S. Army Corps of Engineers, Nov. - Dec. 1970) from William E. Vandenberg, Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group, to Glenn Werth, November 6. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029.

U.S. Army Corps of Engineers Nuclear Cratering Group, 1970. Project Trinidad. Manuscript, December. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

King, Kenneth W., 1970. Project Trinidad: Delta Series Numbers 1, 2, and 3, Sopris, Colorado. Report to U.S. Atomic Energy Commission, Nevada Operations Office, from U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Survey, December 18. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Fitchett, Donald J., 1971. Middle Course I Cratering Series. U.S. Army Engineer Nuclear Cratering Group, *NCG Technical Report* No. 35, June. Livermore, CA. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV and Defense Threat Reduction Information Analysis Center, Albuquerque, NM.

Vortman, L. J., 1971. Airblast from Project Trinidad Detonations. Sandia Laboratories, Report No. SC–RR-71-0056, June. Albuquerque, NM. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

LaFrenz, Robert L., 1971. "Status Report - Rapid Excavation with Explosives." Letter with Encl. ("Status Report, Effective Date: 30 September 1971") from Robert L. LaFrenz, Explosive Excavation Research Office, Corps of Engineers, to Director, U.S. Army Engineer Waterways Experiment Station, October 29. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-108.

LaFrenze, Robert L., and Walter C. Day, 1972. Explosive Excavation Development for Construction and Combat Applications. U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Office, AD750344. Livermore, CA.

Shackelford, Terry J., 1972. Project Mini-Mound. U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Laboratory, Technical Memorandum EERO TM/71-10, March. On file at: Technical Information Center, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MI.

U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Laboratory , 1972. " Listing and Publication Schedule of EERO Reports." Schedule from Explosive Excavation Research Laboratory, Livermore, CA, March 31. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-108.

U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Laboratory, 1972, "Technical Reports Published and Distributed During First Three Quarters FY72." Table from Explosive Excavation Research Laboratory, Livermore, CA, March 31. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-108.

LaFrenz, Robert L., 1972. "Status Report - Rapid Excavation with Explosives." Letter with encl. ("Status Report, Effective Date: 31 March 1972") from Robert L. LaFrenz, Explosive Excavation Research Office, Corps of Engineers, to Director, U.S. Army Engineer Waterways Experiment Station, April 10. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-108.

Scholl, R. E., and I. Farhoomand, 1972. Observed Dynamic Response Characteristics of Residential Structures: Project Trinidad. John A. Blume & Associates Research Division, Report No. JAB-99-89, May. San Francisco, CA. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

LaFrenze, Robert L., and Walter C. Day, 1972. Explosive Excavation Research: Projects Tugboat and Trinidad. *Nuclear Technology,* Vol. 15, pp. 75-84, July.

Redpath, Bruce B., 1972. Project Trinidad: Explosive Excavation Tests in Sandstone and Shale. U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Laboratory, Technical Report No. E-73-1 (Revised), July. Livermore, CA. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0330826.

U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Laboratory, 1972. "Listing and Publication Schedule of EERL Reports." Schedule from Explosive Excavation Research Laboratory, Livermore, CA, September. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-108.

Mills, Robert R., Jr., 1972. " Status Report - Rapid Excavation with Explosives." Letter with encl. ("Status Report, Effective Date: 30 September 1972") from Robert R. Mills, Jr., U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Laboratory, Corps of Engineers, to Director, U.S. Army Engineer Waterways Experiment Station, October 10. On file at Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-108.

Vortman, L. J., 1972. Project Middle Course II Airblast and Surface Motion. Sandia Laboratories, Report No. SC-RR-72-0342, December. Albuquerque, NM. On file at: Archives and Research Center, Lawrence Livermore National Laboratories, Livermore, CA, File PLO-092.

Ellett, D. M., 1973. Comparison of Post-Shot Prediction and Recorded Response to an Airblast. Sandia Laboratories, Technical Memorandum No. SLA-73-0337, June. Albuquerque, NM.

Sprague, Kenneth A., 1973. Middle Course II Cratering Series. U.S. Army Engineer Waterways Experiment Station, Explosive Research Laboratory, Technical Report No. E-73-3, July. Livermore, CA. On file at: U.S. Army Corps of Engineers Technical Library, Jacksonville, FL.

Lattery, J. E., 1974. Project Trinidad: Explosive Excavation of Railroad Cuts 2 and 3 by Mounding and Directed Blasting. U.S. Army Engineer Waterways Experiment Station, Explosive Excavation Research Laboratory, Technical Report No. E-74-1, January. Livermore, CA. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Reed, John W., 1974. Dynamic Response Reconciliation of Residential Structures: Project Trinidad. John A. Blume & Associates, Engineers, Report No. JAB-99-110, October 1974, San Francisco, CA. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Shafer, David S., William. C. Beck, Dwight Treadwell, and Stephen. A. Mellington, 1995. Inventory of Potential Environmental Restoration Liabilities Associated with Plowshare And Vela Uniform Program Sites. Manuscript, U.S. Department of Energy, Office of Environmental Restoration. On file at: Desert Research Institute, Las Vegas, NV.

U.S. Department of Energy. Nevada Operations Office, 1997. Plowshare Program Executive Summary. Report from U.S. Department of Energy, December 22.

U.S. Department of Energy. Nevada Operations Office, n.d. The Plowshare Program (Draft). Report from U.S. Department of Energy.

3.24 - TUGBOAT

Plowshare Program
High Explosive Excavation for Harbor Construction
Hawaii

The U.S. Atomic Energy Commission and the U.S. Army Engineer Nuclear Cratering Group considered large-scale high explosives experiments a major stepping-stone in the eventual acceptance of using nuclear explosive in massive civil works projects. The ultimate goal was the development of explosive excavation techniques that were economically competitive with conventional methods and could serve as models for future nuclear excavation projects. Project Tugboat, a high explosive excavation of a small boat harbor in Kawaihae Bay, Hawaii (Figures 3.24-1 and 3.24-2) provides an example of just such a "demonstration" experiment. Designed to take advantage of a planned U.S. Army Corps of Engineers civil works project, the Tugboat concept was jointly developed by the U.S. Army Engineer Nuclear Cratering Group and Lawrence Livermore Laboratory in 1969. The Kawaihae Harbor project had been previously authorized during the 89th Congress, 1st Session, under Section 301 of the Rivers and Harbors Act of

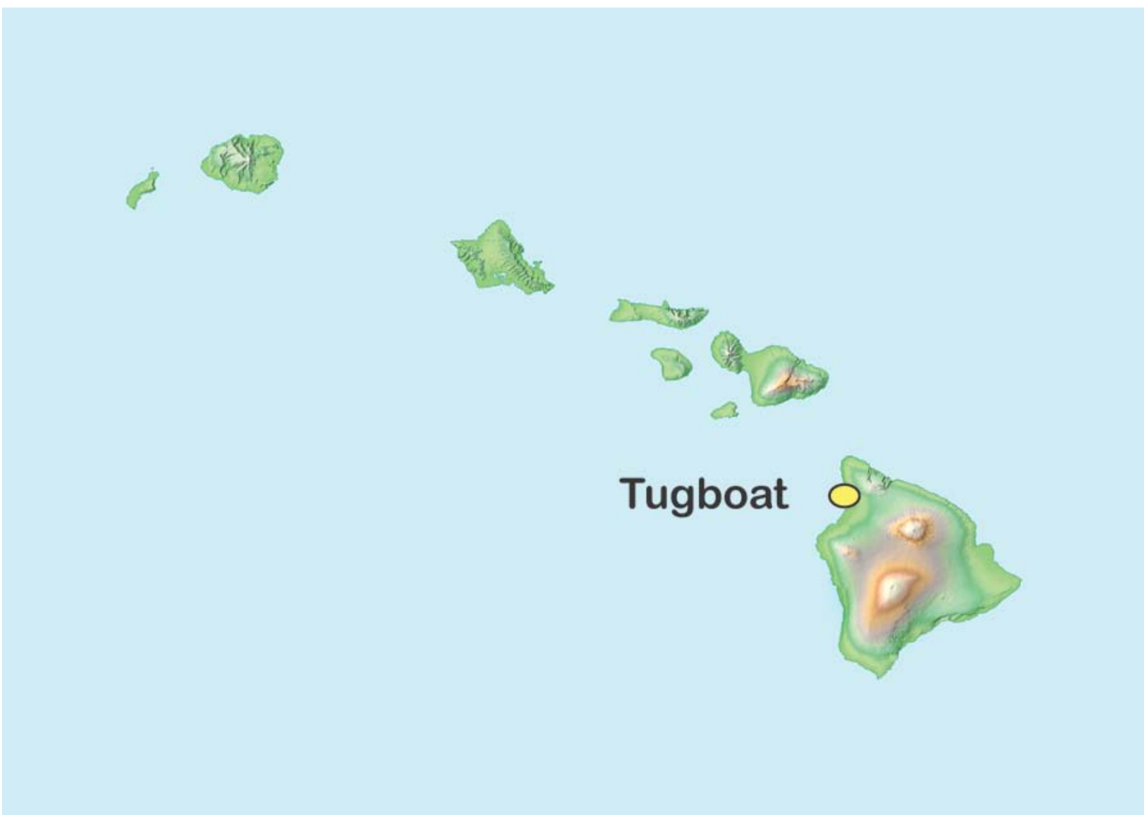


Figure 3.24-1. Location of Project Tugboat in Hawaii (adapted from USA Relief Maps 2004).

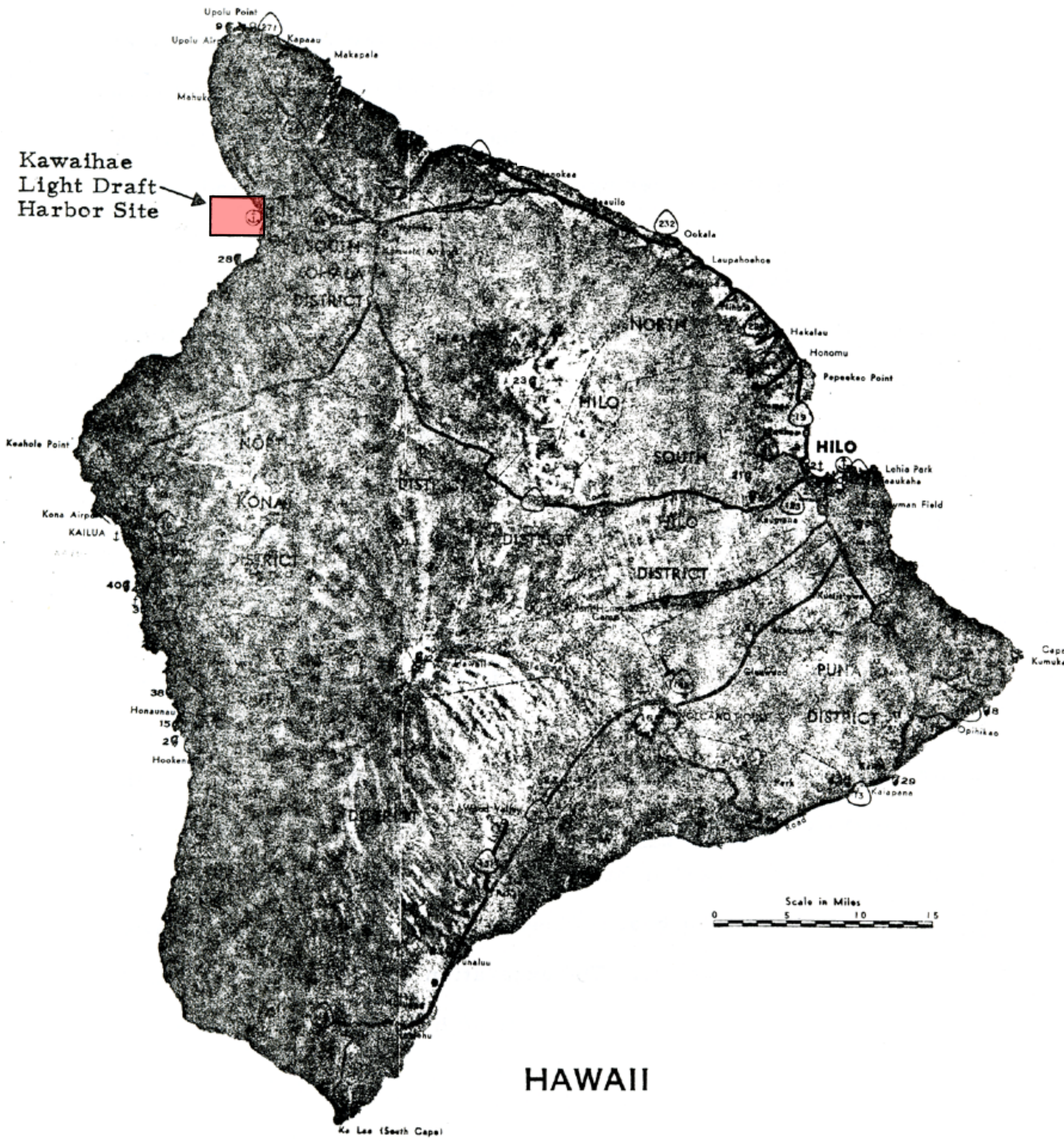


Figure 3.24-2. Location of Project Tugboat in Kawaihae Bay, island of Hawaii (adapted from Lawrence Radiation Laboratory. U.S. Army Engineer Nuclear Cratering Group 1969, Figure 1).

October 18, 1965. Planned as a jointly-funded federal and state project, the facility would become part of the statewide system of small-boat harbors.

The original location selected for the light draft boat harbor was in Kawaihae Bay on the northwest coast of the island of Hawaii (Figure 3.24-3). Initially proposed by the U.S. Army Corps of Engineer's Honolulu District in March 1968, this site proved unworkable

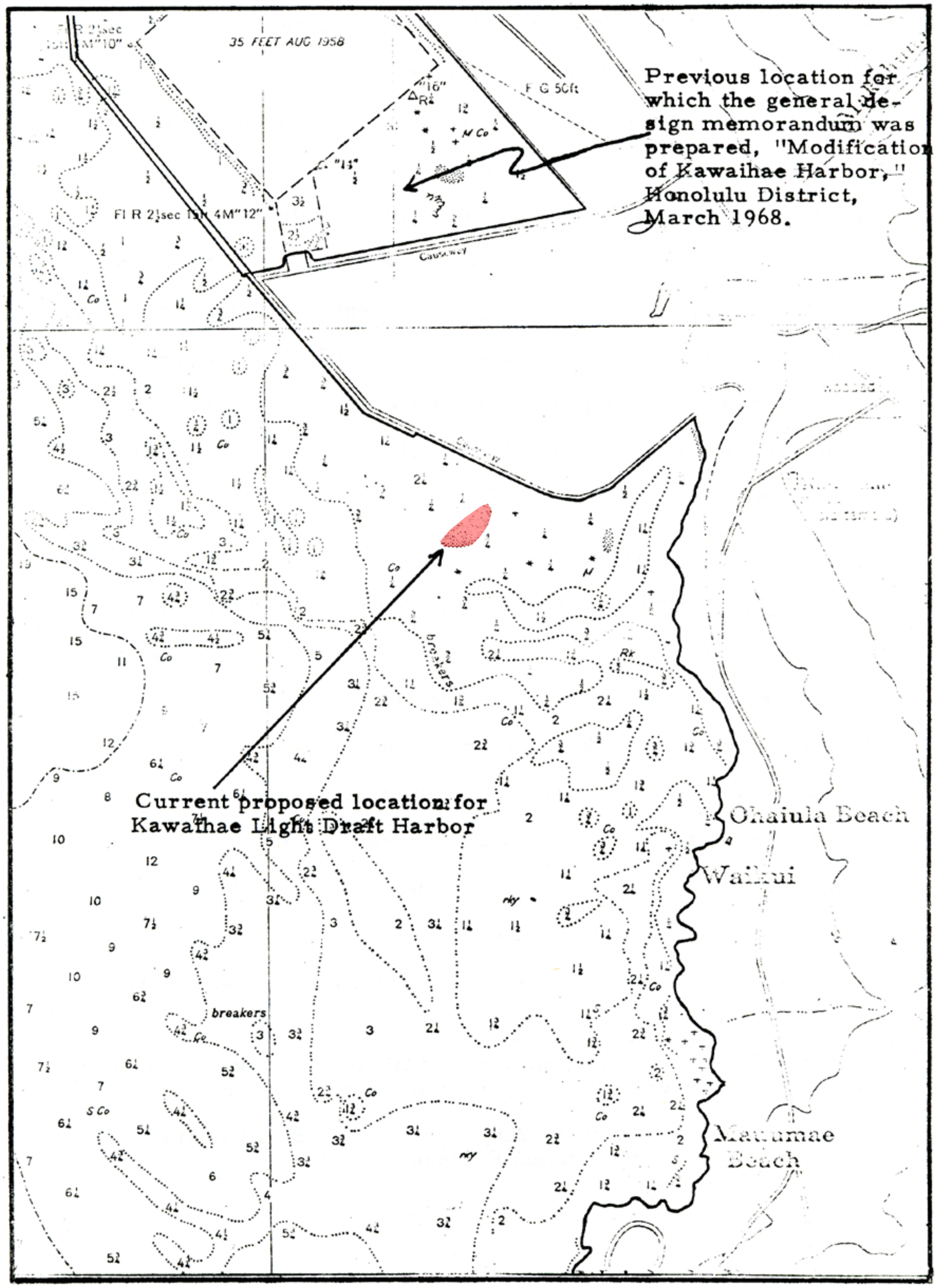


Figure 3.24-3. Original and final location chosen for the Project Tugboat light-draft harbor (adapted from Lawrence Radiation Laboratory. U.S. Army Engineer Nuclear Cratering Group 1969, Figure 2).

when additional studies revealed potential traffic problems with larger vessels. A decision in May 1969 moving the proposed light draft harbor a mile south to shallower water outside the existing deep-draft harbor, solved the traffic conflict.

With the site location finalized, Lawrence Livermore Laboratory's (formerly Lawrence Radiation Laboratory) K-Division began development of the technical concept including the objectives, scope, site plan, technical programs, and tentative schedule of activities. Tugboat's primary objective was the creation of a usable light-draft boat harbor that was part of a larger U.S. Army Corps of Engineers Civil Works construction project at Kawaihae Bay. Additionally, the Tugboat experiment would test the applicability of high explosive cratering methods for harbor construction and provide technical data useful for the design of nuclear harbor excavation experiments.

The Lawrence Livermore Laboratory's report, completed in June 1969, proposed a three-phase project with the Honolulu Engineer District providing the engineering, construction, operational, and logistical support. Phase I involved the detonation of a series of several low-yield safety calibration shots to gather ground motion and air blast data as well as information on the cratering characteristics of the coral. This data would be used to refine the design of subsequent phases. Phase II plans specified the row charge excavation of the entrance channel using 100 tons of chemical high explosives, while the Phase III design called for a 100-ton multi-charge array for excavation of the berthing basin.

The technical concept also specified various pre- and post-shot site investigations. These included geophysical surveys, hydrographic and topographic mapping, meteorological studies, geological characterization drilling, structural engineering surveys, and biological and cultural resources studies. Because the project was viewed as a model for both future high explosive and possible nuclear explosive civil works projects, Tugboat had an ambitious technical program. These scientific investigations, conducted concurrently with the detonations, involved crater and wave measurements, seismic motion and air blast overpressure monitoring, surface water measurements, aerial photography, and structural response investigations. The tentative schedule anticipated site investigations between June and July 1969, followed by the execution of Phase I in October 1969, Phase II in February 1970, and Phase III in May 1970.

Initial on-site investigations, including drilling fifteen sampling holes in the coral formation, occurred during the summer of 1969. In November of the same year, Phase I consisting of a series of five calibration charges ranging in size from 1 ton to 10 tons, was conducted. Following evaluation of the calibration data, the explosive agent requirements and number of charges were scaled back for the actual explosive excavation. Cratering data from the Pre-Gondola tests at Fort Peck, Montana, had served as the model for the preliminary Project Tugboat design concept. The coral formation, however, yielded more readily than the wet clay shale at Fort Peck making the original design yields excessive.

Initially planned as two separate phases, the harbor detonations took place in April and May 1970 with both the channel and berthing basin construction combined into Phase II. Execution of the explosive excavation design involved four series of multiple charge detonations (Figure 3.24-4). Eight charges produced the entrance channel and four created the berthing basin. All of the charges contained aluminized ammonium nitrate slurry. Incomplete detonation of two of the charges for the entrance channel required a remedial excavation program consisting of 16 small detonations in December 1970. The subsequent post-shot technical investigations concluded in early 1971. The detonation date and yield for each Tugboat explosion appear in Table 36-1 below.

Table 3.24-1. Project Tugboat Detonations

CHARGE DESIGNATION	YIELD (LB)	DATE OF DETONATION	REMARKS
PHASE I – SAFETY CALIBRATION			
1a (Alpha)	2,000	Nov. 06, 1969	-
1b (Bravo)	2,000	Nov. 06, 1969	-
1c (Charlie)	1,975	Nov. 04, 1969	-
1d (Delta)	1,950	Nov. 05, 1969	-
1e (Echo)	20,200	Nov. 07, 1969	-
PHASE II - EXCAVATION			
II – ABCD	52,000	Apr. 23, 1970	incomplete yield - charges C and D
II – EF	40,000	Apr. 28, 1970	-
II – IJKL	80,000	May 01, 1970	-
II – GH	20,000	May 08, 1970	charge G deflagrated
REMEDIAL DETONATIONS – CHANNEL CLEARING			
A1, C1 to C13, G1, G2	14,800	Dec. 08, 1970	16 small yield charges

Facilities built specifically for executing Project Tugboat were minimal (Figure 3.24-5). The expanse of coral fill between the existing Kawaihae harbor and the experiment site was used as a staging area. Approximately 0.5 miles east of the experiment site, a Control Point with a few temporary trailers was established on the bluff just south of Pu’ukohola Heiau, a Hawaiian cultural heritage site. An explosive storage bunker was erected on the coral fill area about 1,000 ft north of the blast area. Two visitor observation areas were established. The primary observer area was off the Akoni Pule Highway (aka. Kawaihae-Waimea Road or State Route 270) approximately 1 mile northwest of the experiment site. The second visitor area was about 1.1 miles southeast of the blast area along the Queen Ka’ahumanu Highway (State Route 19). A number of existing seismic stations and ten temporary seismic stations were setup for the experiment. Camera stations included at least two land-based locations with one erected on the coral fill area near the explosive storage bunker. A helicopter was used for the aerial photography. The drill holes for the pre-shot site investigations and Phase I were accomplished using a temporary causeway that was later removed by dragline. A drill rig anchored to a floating platform bored the Phase II emplacement holes (Figure 3.24-6). During the summer of 1970, a contractor built a permanent breakwater to protect the newly excavated berthing basin.

Various agencies and contractors took part in the Tugboat experiment. Lawrence Livermore Laboratory, K-Division developed the technical concept, the explosive safety program, and handled the emplacement, arming and firing of the charges. The U.S. Army Corps of Engineers’ Honolulu Engineer District provided the engineering, construction,

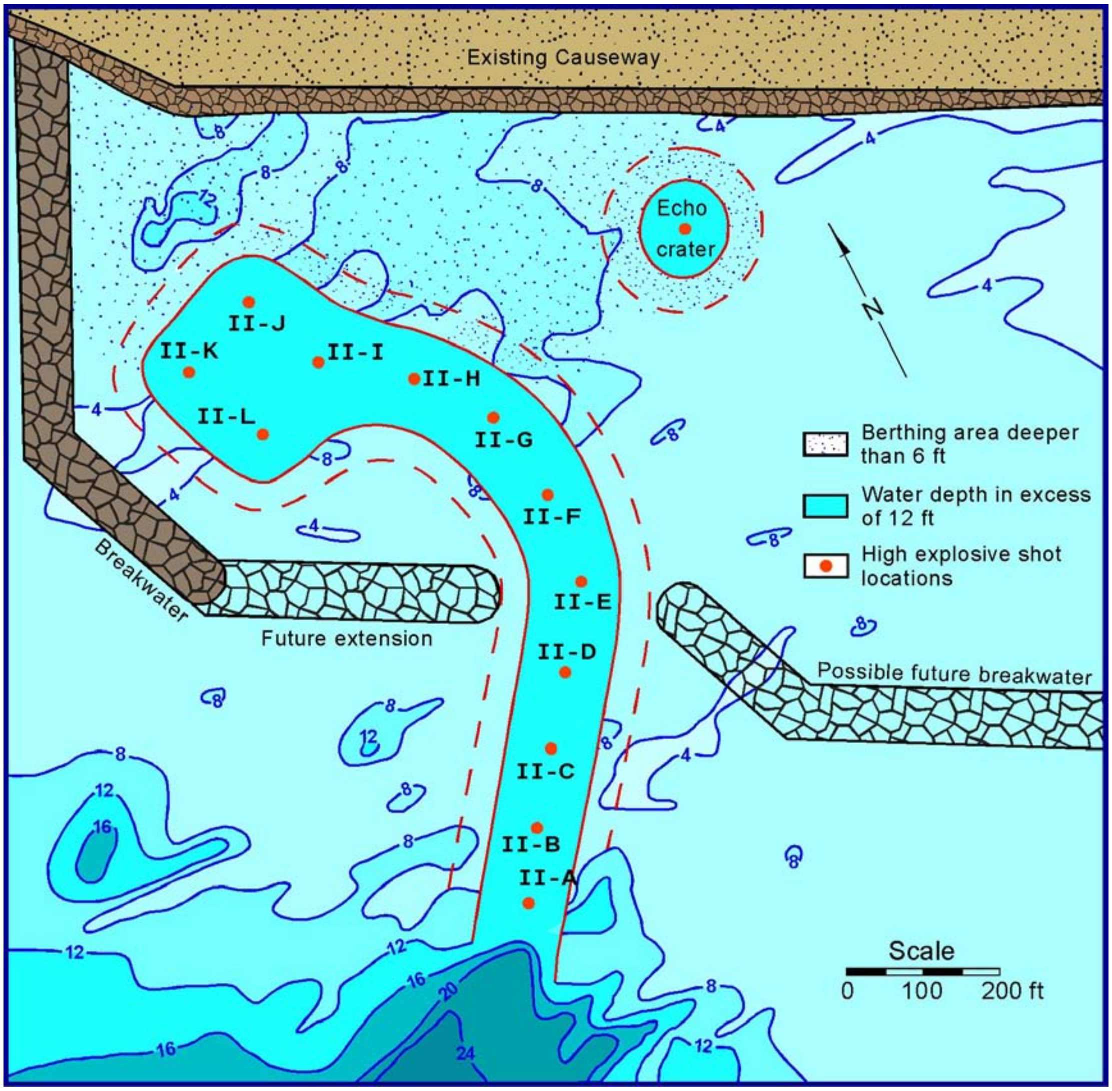


Figure 3.24-4. Plan view of the Phase II charge locations and the Phase I Echo calibration detonation (adapted from Day 1972, Figure 15).

and operational support. The Los Angeles Engineer District provided photo documentation of all the Tugboat activities. Dow Chemical Company was the explosive contractor, while Mile High Drilling of Boulder, Colorado drilled the charge emplacement holes and built the breakwater.

Many groups conducted scientific studies. Sandia Laboratory (formerly Sandia Corporation) directed the air-overpressure investigations in both Phase I and Phase II, while the University of Hawaii attempted a series of intermediate range seismic measurements utilizing existing seismic monitoring stations located on other islands in the Hawaiian chain. Air-overpressure effects were measured for each of these detonations by monitoring ten separate instrument stations located along the coast both north and south of the harbor site. No airblast damage resulted from any of the detonations.

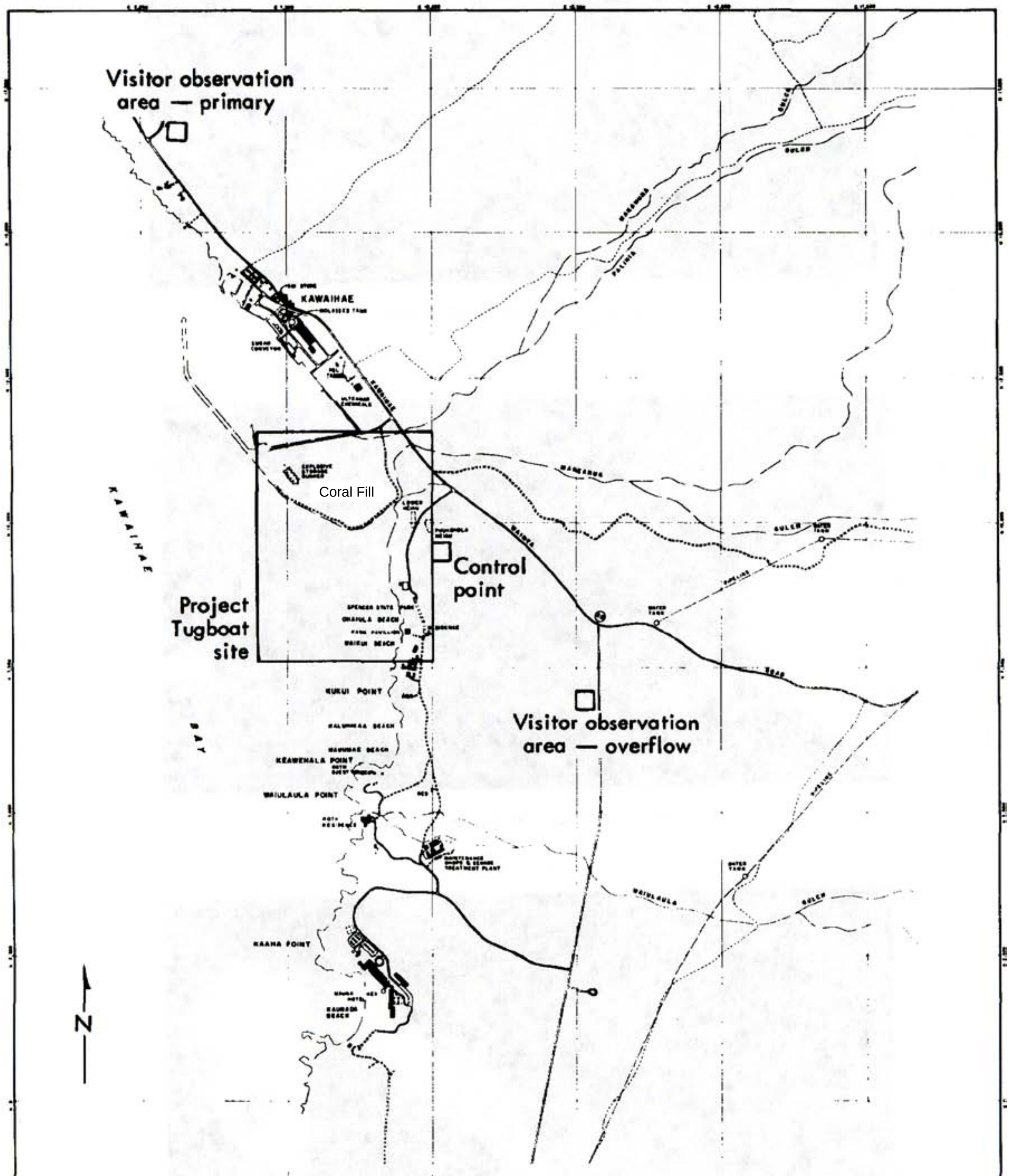


Figure 3.24-5. Area plan for Project Tugboat (Day 1972, Figure 3).

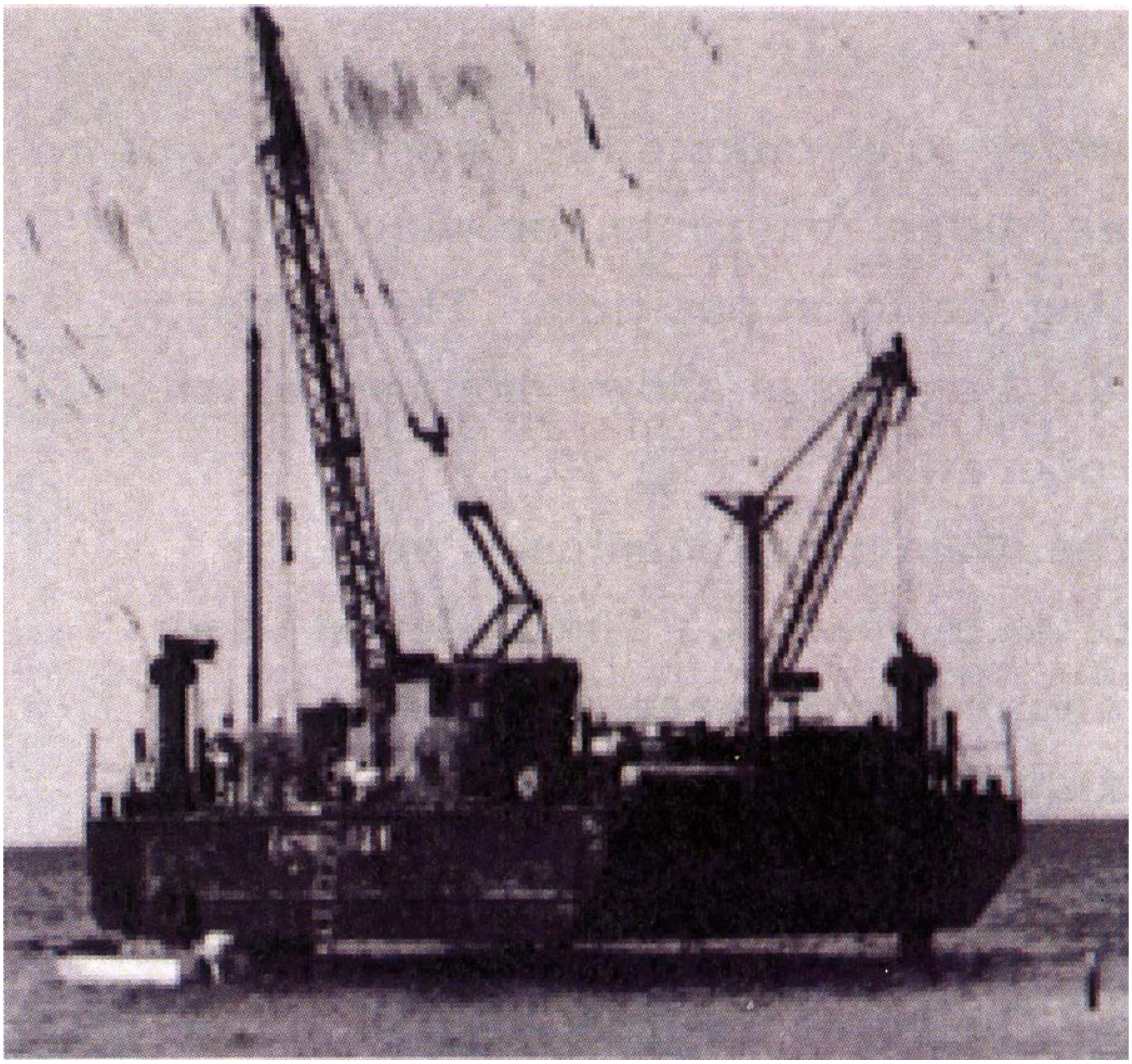


Figure 3.24-6. The drilling platform used for construction of the Tugboat Phase II emplacement holes (Day 1972, Figure 20).

ESSO Production Research sponsored aerial photography for Phases I and II and a wave measurement program in Phase I (Figure 3.24-7). The U.S. Army Corps of Engineer's Coastal Engineering Research Center supplied the wave measurement program for Phase II. John A. Blume & Associates was the principle consultant for evaluating Tugboat's seismic motion effects on structures. Blume & Associates accomplished this through a series of pre-shot structural surveys, ground motion monitoring and data collection during Phase I, development of predictive models and recommendations for the Phase II detonations, and then the subsequent structural resurvey following the conclusion of the experiment. Their Phase I studies, along with Sandia's over-pressure results, were used to determine the maximum safe yield for the subsequent Phase II harbor excavation detonations.

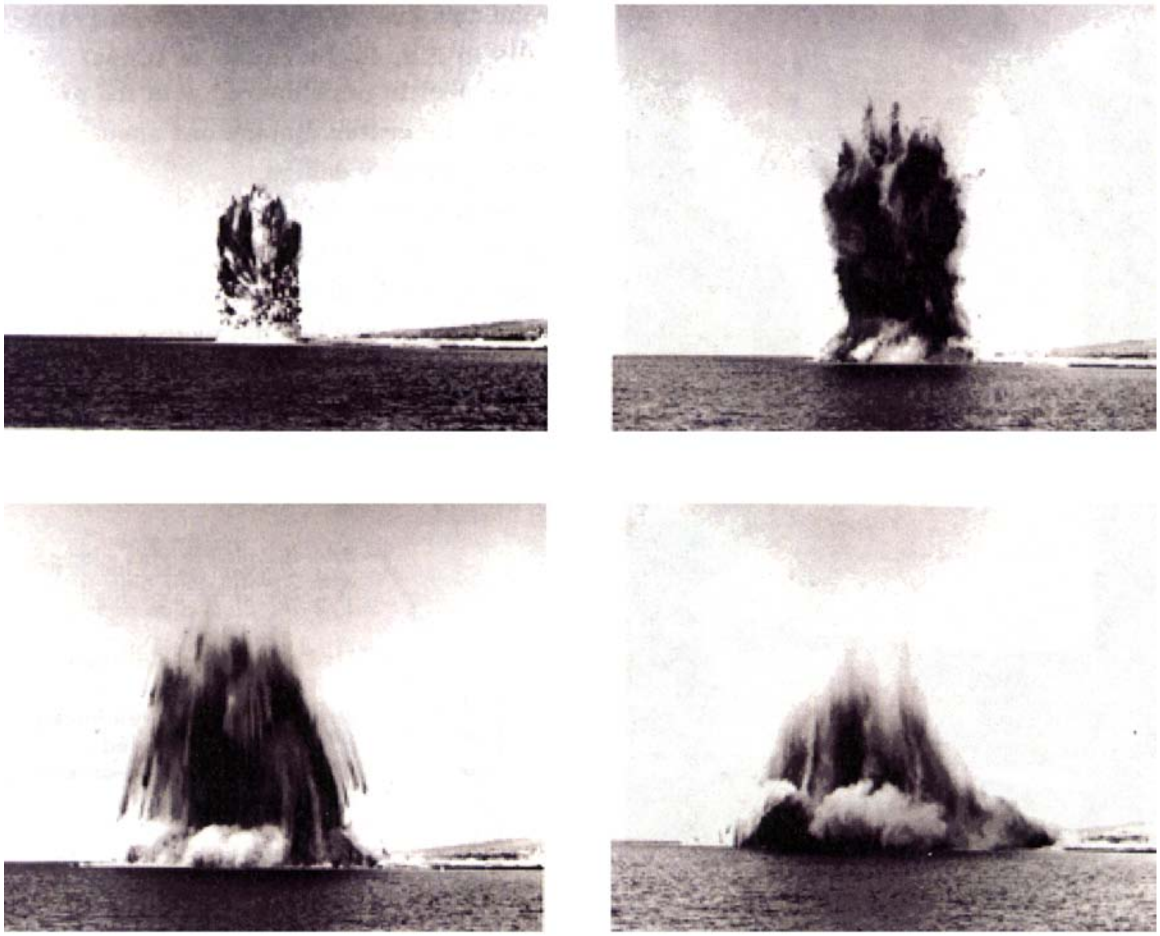


Figure 3.24-7. Sequential photos of Project Tugboat Phase I "Echo" calibration 10-ton detonation (Day 1972, Figure 36).

Lawrence Livermore carried out an investigation of the blasts' effects on the surface water layer (Figures 3.24-8 and 3.24-9). Scientific instrumentation measured key attributes including shock pressure, wave acceleration, and velocity for five of the Phase II 10-ton charges. The primary purpose of their studies was the development of instrumentation and methodology appropriate for surface water environments.

Charged with conducting the environmental resource studies for the project, the State of Hawaii, Division of Fish and Game made both pre- and post-detonation fish counts. The agency concluded the effects to local marine life were minimal beyond the initial fish deaths from the shock wave.

By all accounts, Tugboat was a success with the final harbor configuration exceeding the original design requirements. The explosive excavation program created a channel ranging in width from 150 to 260 ft at a minimum depth of 12 ft. The adjoining berthing basin was approximately 400 x 400 ft square. Although the craters produced were much broader and shallower than predicted, the wide, flat cross-section actually proved more desirable for a light-draft harbor. In addition, the technical programs generated data

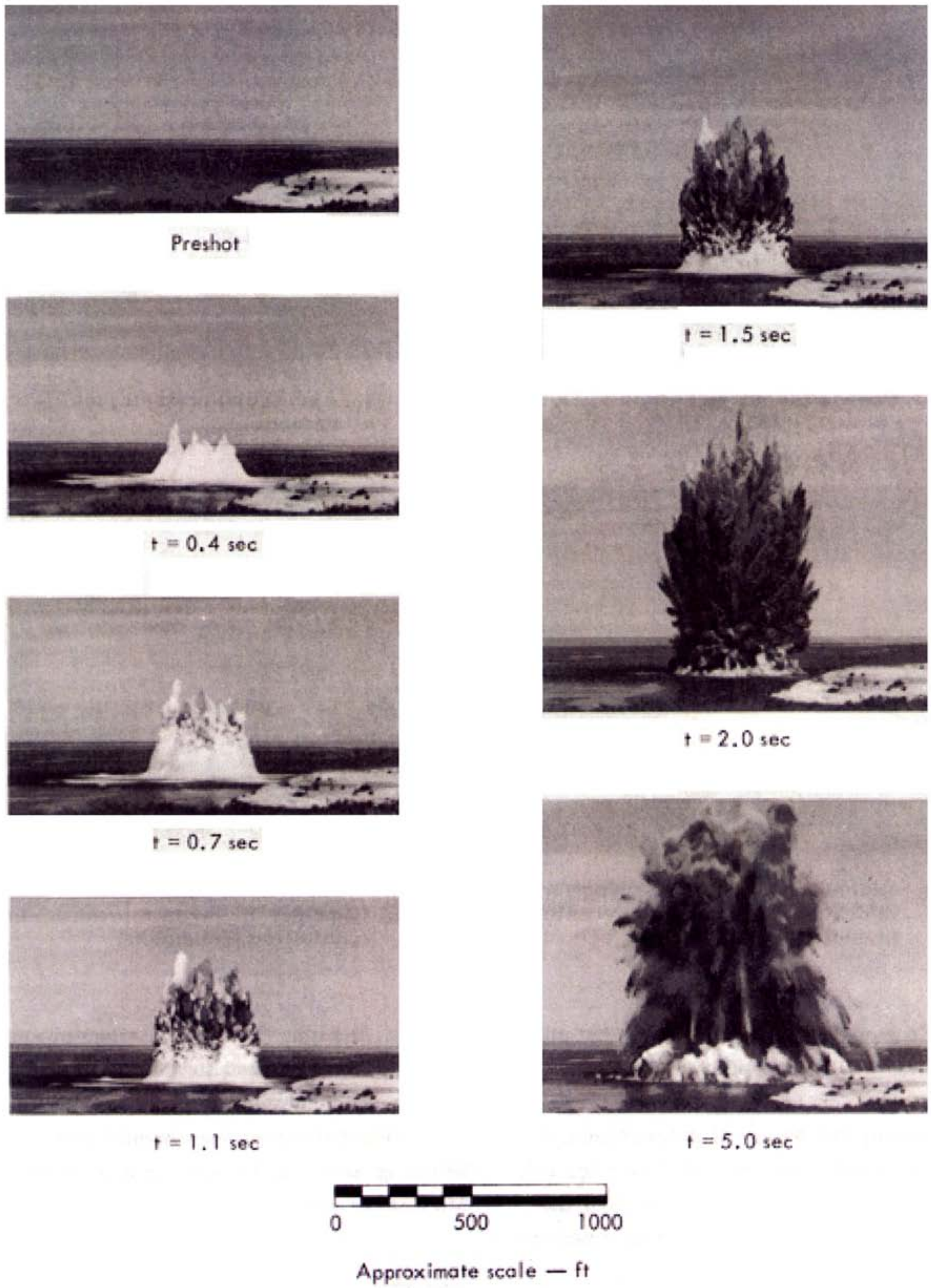


Figure 3.24-8. Project Tugboat Phase II detonations. Sequential photos of the four simultaneous blasts that created the berthing basin. Total yield was 40 tons (Day 1972, Figure 41).

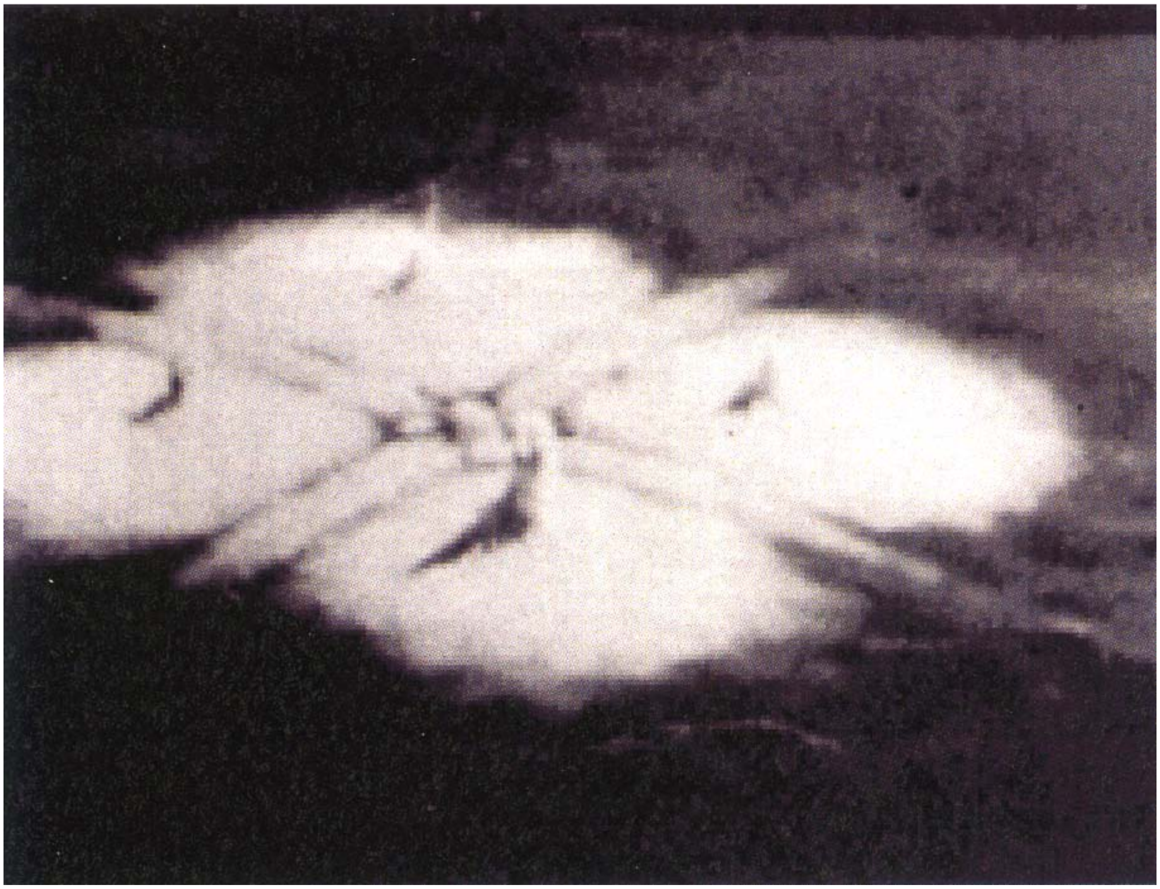


Figure 3.24-9. Detonations for the berthing basin showing the shock interaction and cavitation phenomenon of the four simultaneous blasts (Day 1972, Figure 45).

useful for developing future explosive excavation applications and refining cratering prediction calculations.

From its initial planning through the conclusion of the post-shot technical studies, Project Tugboat lasted approximately 2 years. The objectives of the project were accomplished and another test project was under consideration in order to investigate harbor construction in a stronger or different medium. The State of Hawaii maintains the light-draft harbor created by Project Tugboat. Small craft use the harbor's fueling station and access is unrestricted. Shafer et al. (1995) confirmed this information with the Coast Guard in June 1994.

Project Tugboat was a Level 2 activity where conventional explosives were used for excavating a harbor. The Tugboat harbor was inspected in FY 2003.

FIELD VISIT

On June 9 and 10, 2003, Desert Research Institute personnel made a field visit to the Tugboat project location in Kawaihae, Hawaii. To access the site, travel north from the Kailua-Kona International Airport along the coast on State Route 19 (Queen Kaahumanu Highway) for 25 miles until reaching the junction of State Route 19 and State Route 270, Head northwest (left) on State Route 270 (Akoni Pule Highway) for another 0.7 miles. Turn west (left) onto the road leading to the U.S Army Kawaihae Military Reservation and the south mooring area for the original Kawaihae boat harbor (approximately 0.3 miles) to reach the Project Tugboat breakwater and berthing area.

The original breakwater and berthing area constructed during the Tugboat project remain in place as shown in the pre-1990 photo below (Figure 3.24-10). The planned marina with dock facilities, restaurants, and slips for over two hundred recreational craft never materialized (Figures 3.24-11 and 3.24-12). At the time of the field visit, only four vessels were anchored in the light-draft harbor and no evidence remained of the temporary causeway, explosive storage bunker, or drilling equipment used for the Tugboat project. However, some additional development did occur after the early 1990s (Figure 3.24-13). A small YMCA training and storage facility for kayaks and racing sculls has been built along the shore. Another breakwater was added to partially enclose the south end of the berthing area (Figure 3.24-14). In 1998, the “Pua ka ‘ilima O Kawaihae Cultural Surf Park” was established at the berthing basin created by Project Tugboat. The Surf Park is named after a now-submerged archaeological feature consisting of a rock monument (heiau) to a Hawaiian Shark God. The location of the monument is noted on Figures 3.24-11 and 3.24-13. The former Control Point location is within the boundaries of the Puukohola Heiau National Historic Site and any evidence of its existence has been obliterated by the construction of the monuments visitor’s center, park and walking trails. The two Project Tugboat visitor observer areas have also been obscured by subsequent commercial development along the highways.

The U.S. Coast Guard currently operates the Kawaihae small boat harbor including the berthing basin created by Project Tugboat. The entire harbor facility is administered as part of Hawaii’s state-wide system of small boat harbors which provide support for light-draft commercial vessels, fishing boats, and recreational craft.

Figure 3.24-10. Aerial view of Kawaihae Harbor prior to 1990. Deep-draft harbor is in the upper left and the Project Tugboat light-draft harbor and breakwater are in the foreground. View is to the northeast (U.S. Army Corps of Engineers, Honolulu District).

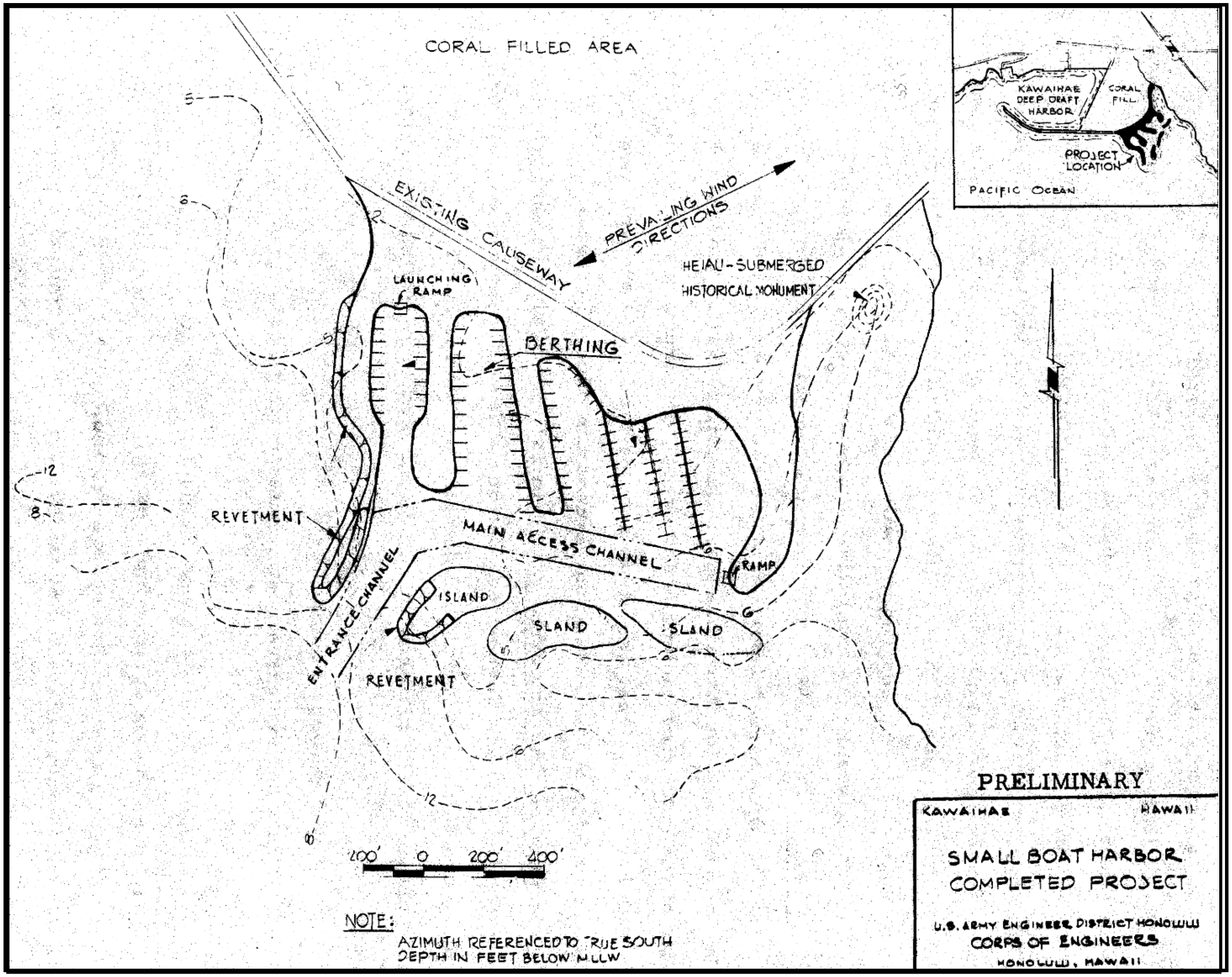


Figure 3.24-11. Conceptual model of Project Tugboat (Lawrence Radiation Laboratory, U.S. Army Engineer Nuclear Cratering Group 1969).

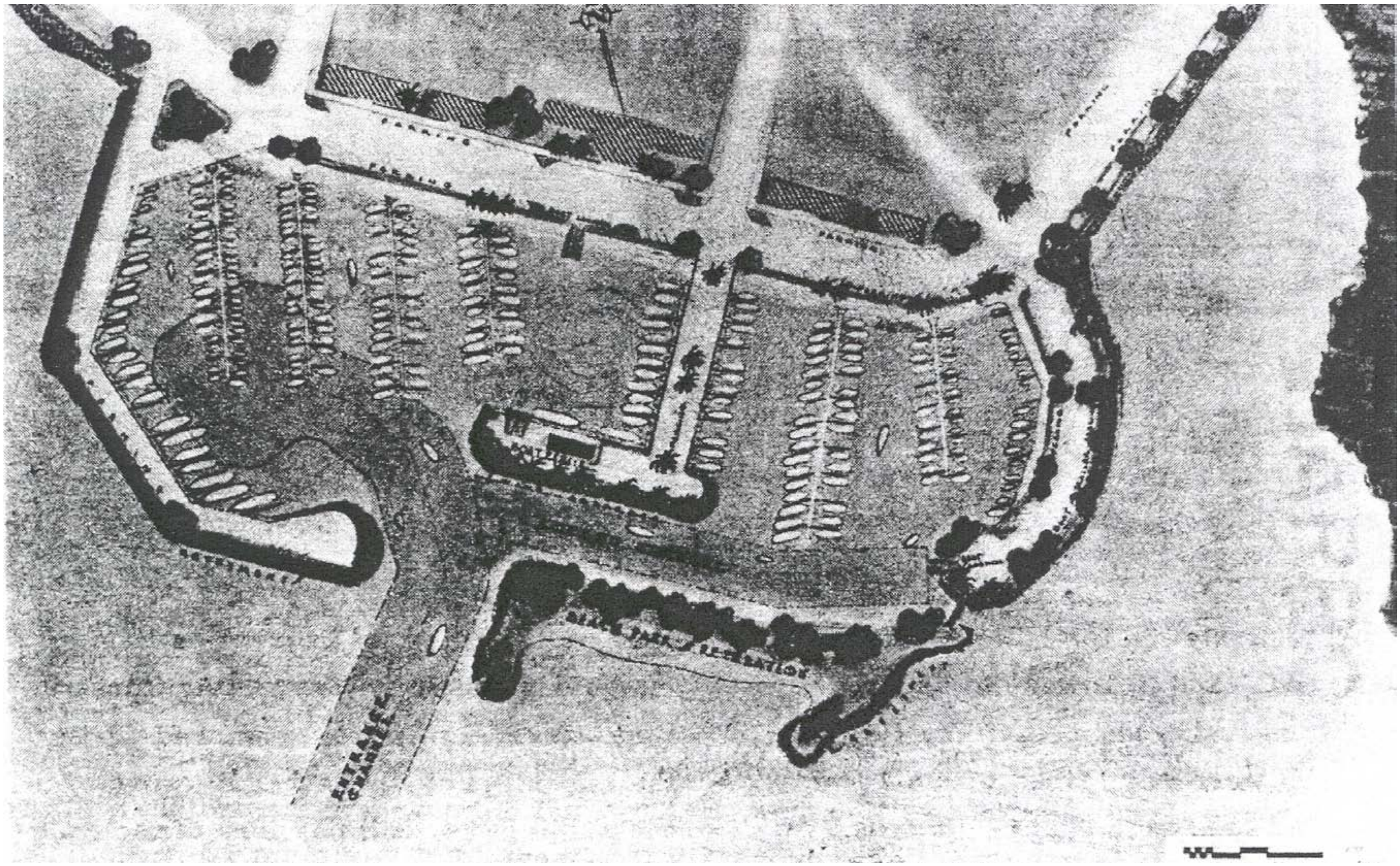


Figure 3.24-12. Another conceptual model and potential development of the Project Tugboat harbor. This version includes over 250 boat slips, a beach park, a boat fueling/service area and extensive parking areas (Day 1972, Figure 16).

Figure 3.24-13. Overview of Project Tugboat small-boat berthing area and breakwater. The red “X” marks the location of a submerged historical monument. View is to the west (photo taken June 10, 2003 on file at Desert Research Institute).

Figure 3.24-14. Project Tugboat harbor looking towards the west. Breakwater in the center added after 1994 (photo taken June 10, 2003 on file at Desert Research Institute).

CHRONOLOGICAL BIBLIOGRAPHY

Lawrence Radiation Laboratory. U.S. Army Engineer Nuclear Cratering Group, 1969. Technical Concept for Project Tugboat: Explosive Excavation of Kawaihae Light Draft Boat Harbor. Manuscript, Livermore, CA, June. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Hughes, Bernard C., 1969. "Technical Concept for Project TUGBOAT." Memo from Bernard C. Hughes, Lawrence Radiation Laboratory, Corps of Engineers, Nuclear Cratering Group, to Distribution, June 5. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

Toman, John, 1970. Summary of Nuclear-Excavation Applications. Paper prepared for Proceedings of the ANS Topical Meeting, Engineering with Nuclear Explosives, Las Vegas, Nevada, January 14-16, 1970. University of California, Lawrence Radiation Laboratory, *Preprint UCRL*-72220, January 29. Livermore, CA. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-104.

Toman, John, 1970. Summary of Nuclear-Excavation Applications. In *Symposium on Engineering with Nuclear Explosives: Proceedings,* Report CONF-700101, Vol. 1, pp. 245-279, May. American Nuclear Society, Hinsdale, IL.

Garcia, W. J., Jr., 1970. Water Waves Produced by Cratering Explosions in Shallow Water. University of California, Lawrence Livermore National Laboratory, *Report UCRL*-50940, October 20. Livermore, CA. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-036.

Vortman, L. J., 1970. Airblast from Project Tugboat Detonations. Sandia Laboratories, Report No. SC–RR-70-541, November. Albuquerque, NM. Note: Document location?

LaFrenz, Robert L., 1971. "Status Report - Rapid Excavation with Explosives." Letter with encl. ("Status Report, Effective Date: 30 September 1971") from Robert L. LaFrenz, Explosive Excavation Research Office, Corps of Engineers, to Director, U.S. Army Engineer Waterways Experiment Station, October 29. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-108.

LaFrenze, Robert L., and Walter C. Day, 1972. Explosive Excavation Development for Construction and Combat Applications. U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Office, AD750344. Livermore, CA.

Day, Walter C., 1972. Project Tugboat: Explosive Excavation of a Harbor in Coral. U.S. Army Engineer Waterways Experiment Station, Explosive Research Laboratory, Technical Report No. E-72-23, February. Livermore, CA. On file at: Nuclear Testing Archives, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0330828 and Defense Threat Reduction Information Analysis Center, Albuquerque, NM.

Snell, Charles M., 1972. Shock Wave Interaction and Near-Surface Cavitation, Project Tugboat. U.S. Army Engineer Waterways Experiment Station, Explosive Excavation Research Laboratory, Technical Memorandum, No. EERL/TM 71-17, April. Livermore, CA.

LaFrenz, Robert L., 1972. "Status Report - Rapid Excavation with Explosives." Letter with encl. ("Status Report, Effective Date: 31 March 1972") from Robert L. LaFrenz, Explosive Excavation Research Office, Corps of Engineers, to Director, U.S. Army Engineer Waterways Experiment Station, April 10. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-108.

LaFrenze, Robert L., and Walter C. Day, 1972. Explosive Excavation Research: Projects Tugboat and Trinidad. *Nuclear Technology,* Vol. 15, pp. 75-84, July.

Mills, Robert R., Jr., 1972. "Status Report - Rapid Excavation with Explosives." Letter with encl. ("Status Report, Effective Date: 30 September 1972") from Robert R. Mills, Jr., U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Laboratory, Corps of Engineers, to Director, U.S. Army Engineer Waterways Experiment Station, October 10. On file at Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-108.

Day, Walter C., 1974. Project Tugboat: Explosive Excavation of a Harbor in Coral. In *Proceedings of the First Conference on the Environmental Effects of Explosives and Explosions (May 30-31, 1973)*, George A. Young, compiler, pp. 138-147, June. Naval Ordnance Laboratory, White Oak, Silver Spring, MD.

LaFrenze, R. L., 1980. Coral Cratering Phenomenology. Report to the Defense Nuclear Agency, Report No. 5813T, Washington, D. C., from Systems, Science and Software, Inc., La Jolla, CA, October 31. On file at: Defense Threat Reduction Information Analysis Center, Albuquerque, NM.

Shafer, David S., William. C. Beck, Dwight Treadwell, and Stephen. A. Mellington, 1995. Inventory of Potential Environmental Restoration Liabilities Associated with Plowshare And Vela Uniform Program Sites. Manuscript, U.S. Department of Energy, Office of Environmental Restoration. On file at: Desert Research Institute, Las Vegas, NV.

U.S. Department of Energy. Nevada Operations Office, 1997. Plowshare Program Executive Summary. Report from U.S. Department of Energy, December 22.

Naval Studies Board, 2001. Appendix C: Breaching by Line Charge Analogue. In Naval Mine Warfare: Operational and Technical Challenges for Naval Forces, Naval Studies Board, National Research Council, pp. 161-163. National Academy Press, Washington, D.C. <http://www.nap.edu/openbook/0309075785/html/R1.html>.

U.S. Department of Energy. Nevada Operations Office, n.d. The Plowshare Program (Draft). Report from U.S. Department of Energy.

THIS PAGE INTENTIONALLY LEFT BLANK

3.25 UTAH

Plowshare Program
Nuclear Explosives to Fracture Oil Shale for Underground Retorting
Utah

By the 1960s, there were concerns regarding the nation's long-term energy supplies and oil companies were interested in more effective methods for obtaining this resource. With an estimated production potential of 480 billion barrels, the Green River Formation in Colorado, Utah, and Wyoming was of great interest to the oil industry. Oil and gas companies were actively researching several new types of retorting techniques in an attempt to reduce the cost of obtaining petroleum from oil shale. Because the mining, transporting, crushing, and disposal of spent shale was the most expensive component of extracting oil from these deposits, in place processing offered the greatest cost savings. One method under consideration involved nuclear fracturing of an oil shale deposit and the in situ retorting of the broken rock.

Project Pinot (see Chapter 3.11) was the first experimental foray into this area. The 1961 high explosive fracturing test in Colorado provided some information on the feasibility of this recovery technique, but more studies were needed. In early 1962, J.H. Morgan of Utah Resources International, Inc., an oil company out of Salt Lake City, expressed interest in participating in a nuclear fracturing experiment for oil shale deposits in eastern Utah, either on State of Utah leases or the Utah Naval Oil Shale Reserve No.2. However, a similar experiment in Colorado's Piceance Creek Basin, Project Bronco (see Chapter 3.1), received more initial interest than the Utah proposal. Feasibility and site characterization studies for the Bronco experiment moved forward, while the Utah oil shale deposits investigations were temporarily sidetracked.

Interest revived in a Utah-based experiment when the Western Oil Shale Corporation and CER Geonuclear Corporation approached the U.S. Atomic Energy Commission in 1968 or early 1969 regarding the possibility of conducting an experiment for using a nuclear explosive to fracture rich oil shale deposits in the central part of the Uintah Basin, part of the Green River Formation (Figures 3.25-1 and 3.25-2). Originally the experiment was designated WOSCO (Western Oil Shale Corporation) because the experiment was to take place on one of the company's oil leases, but was renamed Project Utah in late 1969. The overall purpose of the project was to determine the feasibility of conducting in situ retorting of the shale for more efficient oil production by creating permeability with a nuclear explosion. The fracturing had to produce a sufficient quantity of rubblized shale to make oil recovery commercially viable. Concurrently, the U.S. Bureau of Mines, Laramie Petroleum Research Center in Wyoming was studying oil shale properties and retorting characteristics of broken and unbroken shale and in situ retorting at their facility in Rock Springs. The intent was to apply this information to the development of techniques for in situ retorting for proposed nuclear projects. The Laramie Research Center was especially interested in the oil recovery potential of "lean" (i.e., 12-16 gallon per ton) shale like those in eastern Utah, western Colorado, and southern Wyoming.

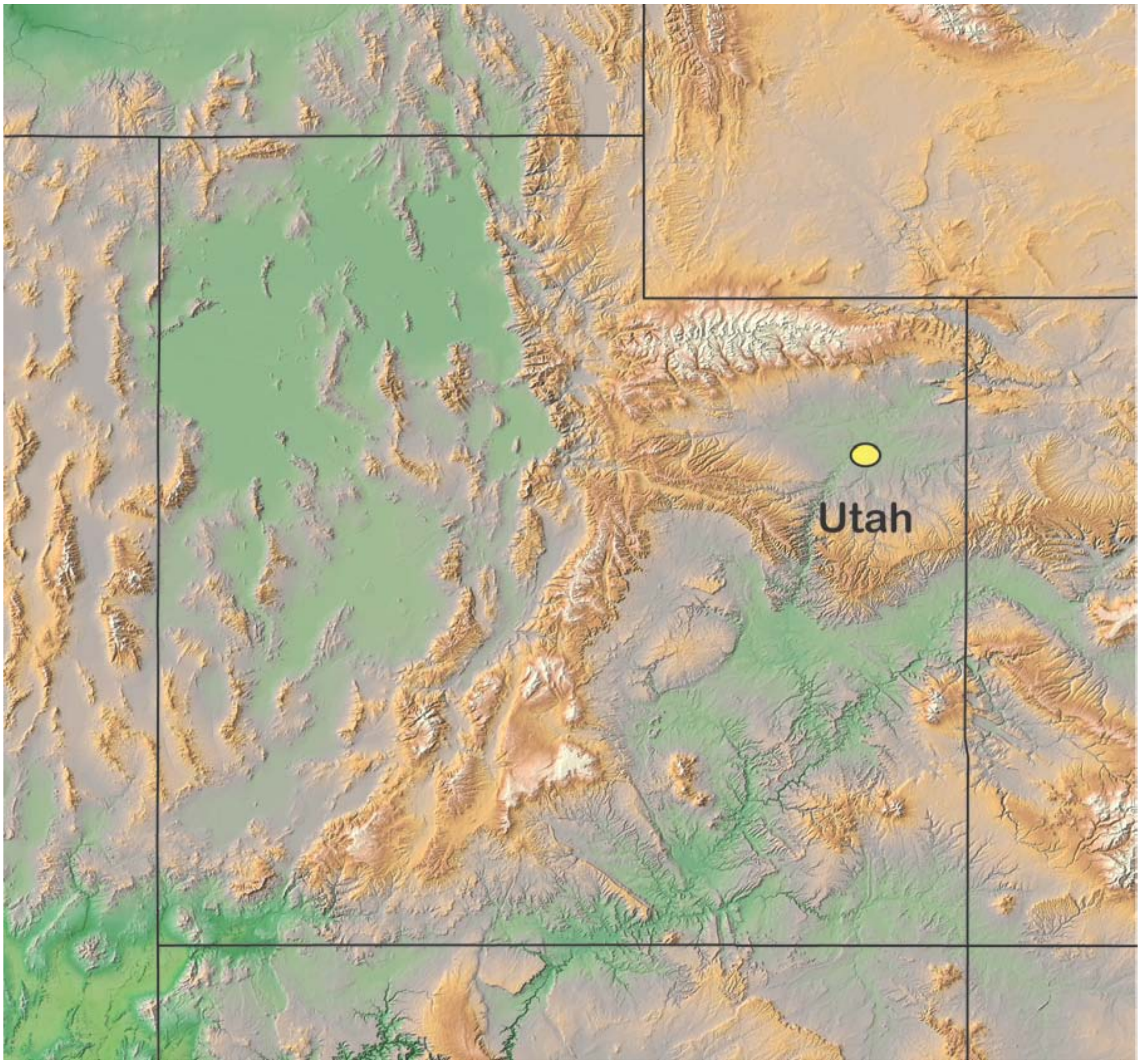


Figure 3.25-1. Location of Project Utah (adapted from USA Relief Maps 2004).

The study site for Project Utah was in Uintah County in northeastern Utah about 8 miles southeast of the town of Ouray and approximately 40 miles from Vernal, Utah (Figure 3.25-3). CER Geonuclear Corporation submitted a preliminary study for Western Oil Shale Corporation on April 3, 1969. This study recommended that an exploratory hole, EX-1, be drilled to obtain more data on the geology and hydrology of the area and to evaluate the location's suitability for a nuclear experiment. The research focused on the fracturing properties of the "Mahogany Ledge," a sufficiently rich layer of oil-bearing shale.

CER Geonuclear supervised the drilling in July and August of 1969. The U.S. Bureau of Mines assisted with the coring, and the U.S. Geological Survey with the hydrologic testing. Well EX-1 was drilled at 504 ft from the south line, 1,844 ft from the east line, in the SW1/4SE1/4SE1/4, Sec. 36, T9N R20E, Salt Lake Base Meridian. The Laramie Petroleum Research Center conducted the assay work on the core from this hole (Figure 3.25-4).

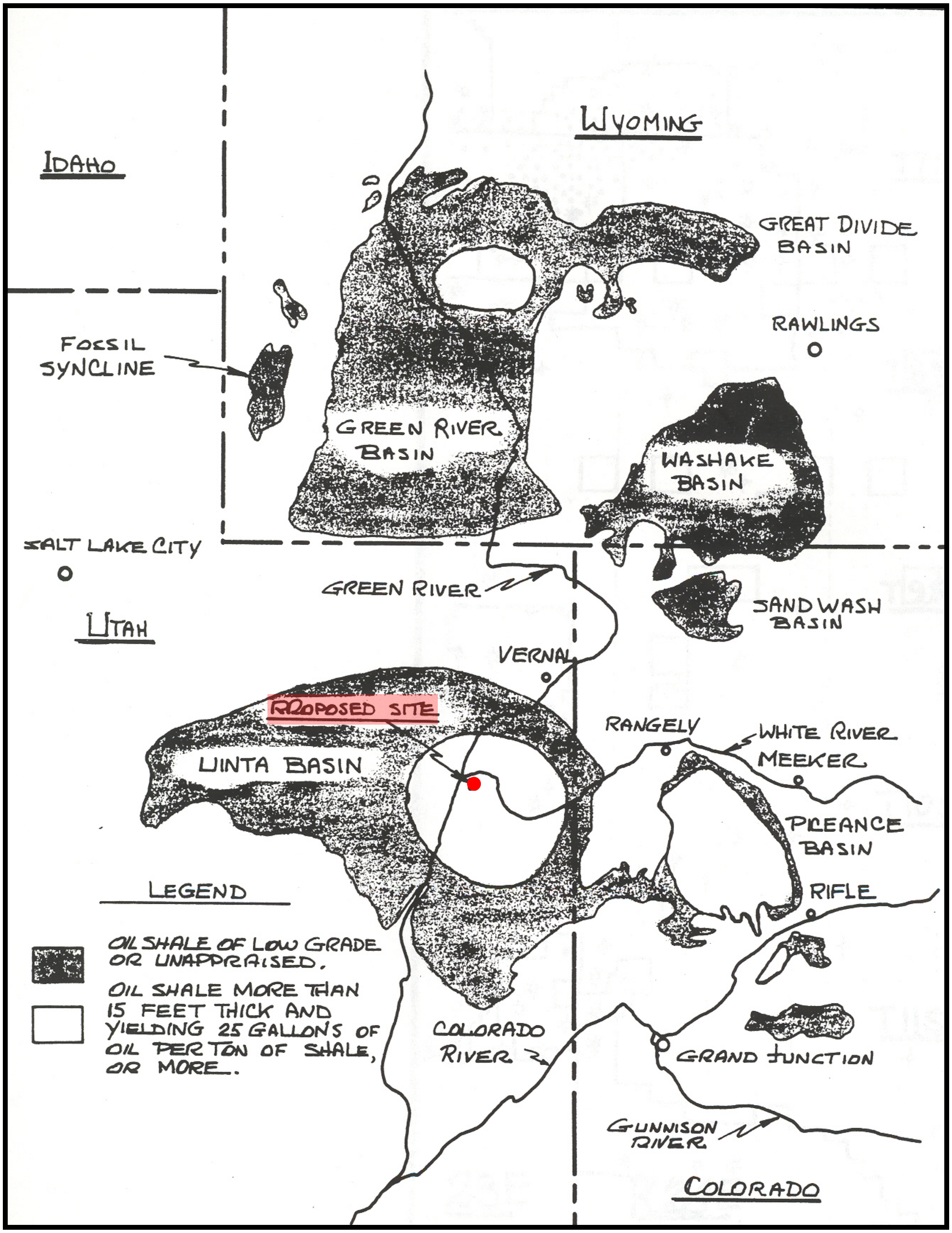


Figure 3.25-2. Oil shale deposits that comprised the Green River Formation (adapted from CER Geonuclear Corporation [1970], Figure 4).

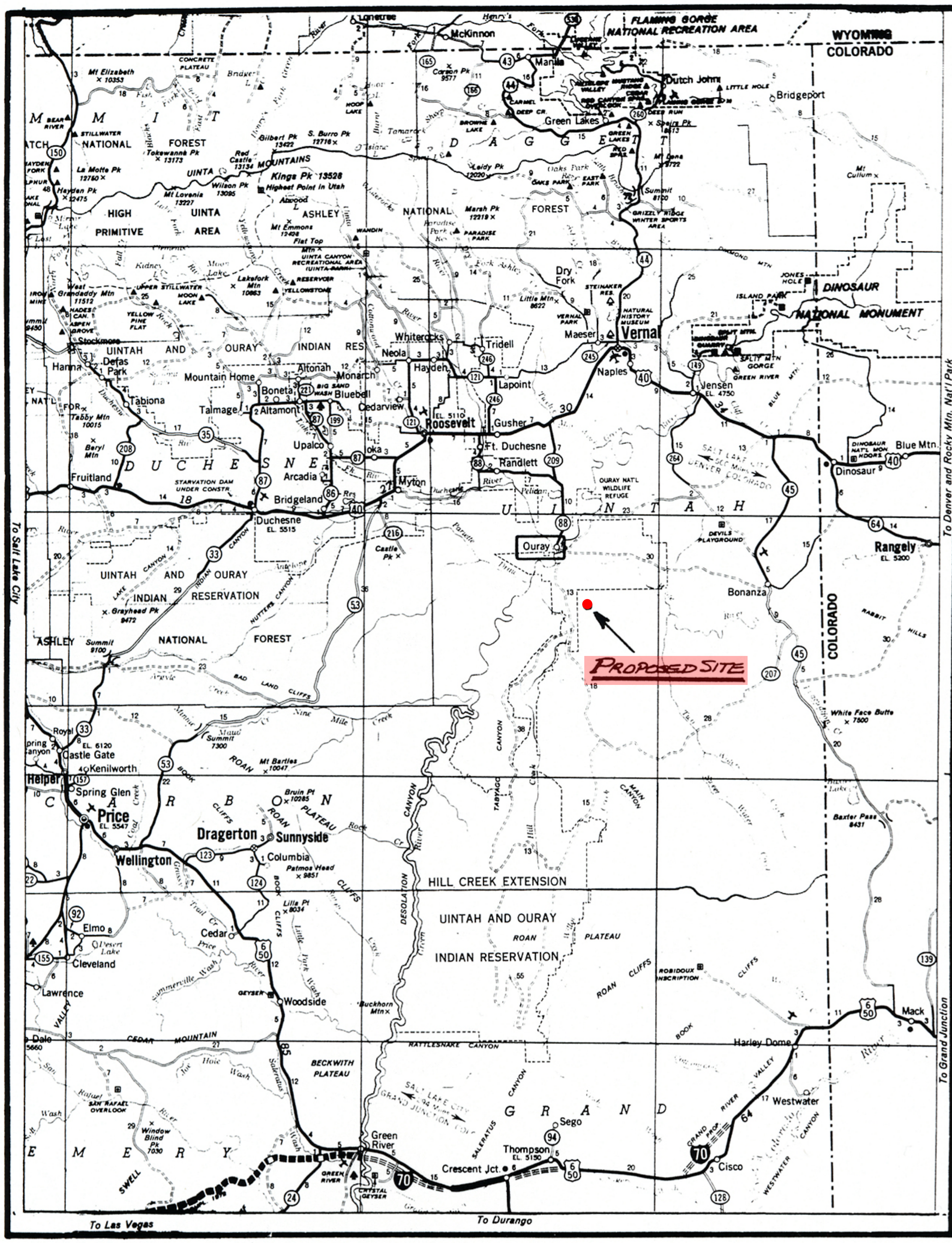


Figure 3.25-3. Site for the proposed Project Utah (adapted from CER Geonuclear Corporation [1970], Figure 1).

Figure 3.25-4. An experimental above ground retort for the Plowshare Program (Lawrence Livermore National Laboratory n.d., Negative No. GLB-666-4764).

The geohydraulic information gathered from Well EX-1 provided sufficient data to characterize the subsurface regime. Calculations showed that after a nuclear device of appropriate magnitude was detonated at this location to form a rubble chimney at a depth of 2,369 ft, the richest oil shale would fracture sufficiently for an in situ retorting experiment (Figure 3.25-5). At the same time, it was predicted that only a few minor fractures would reach the water-bearing rock that was 361 ft below the predicted chimney.

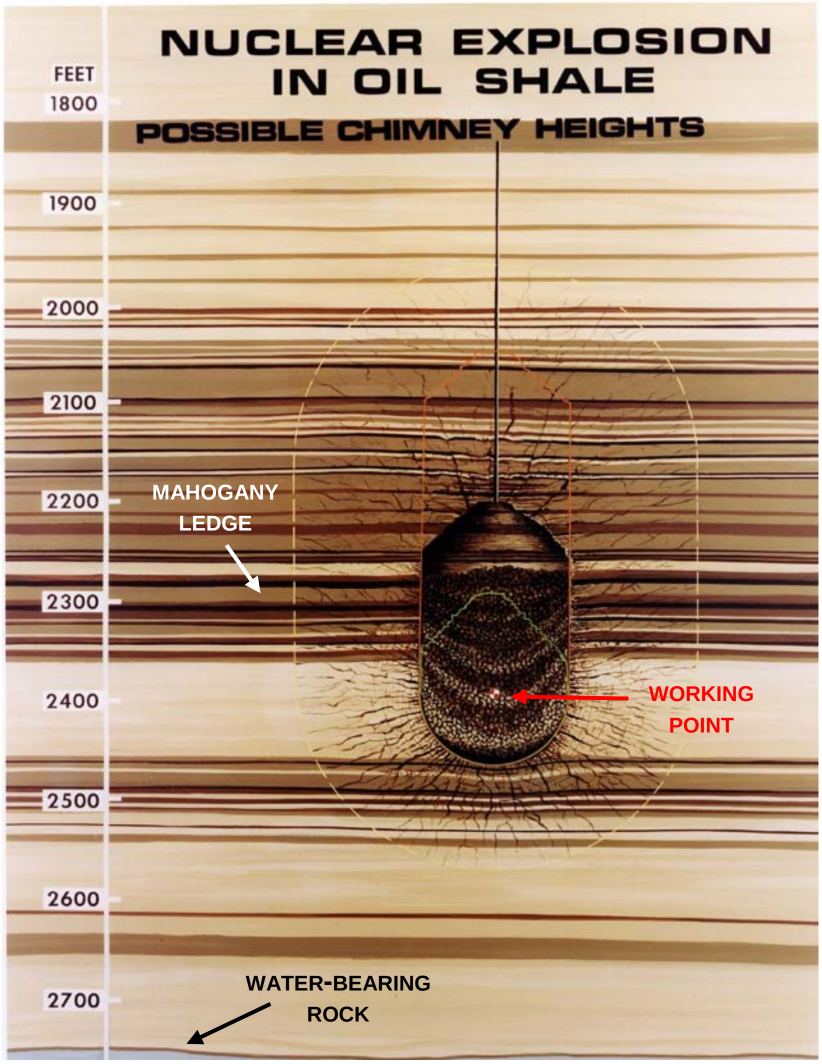


Figure 3.25-5. Concept drawing of the rubble chimney that would be created by a nuclear detonation in the barren zone just below the Mahogany Ledge oil shale deposit (adapted from Lawrence Livermore National Laboratory n.d., Negative No. GLC712-871A).

The 1970 draft preliminary feasibility study contained the EX-1 well data and basic environmental information for the area. This study concluded that the EX-1 site appeared to be acceptable from a ground motion, structural response, public health, and hydrologic standpoint. It recommended that Project Utah be conducted to evaluate the feasibility of in situ oil recovery and ways to increase the recovery rate through the retorting of the wall rock. In addition, it stated that the project design should evaluate the parameters for commercial development of Western Oil Shale Corporation's holdings.

CER Geonuclear determined that a low yield nuclear device was preferable to the high yield option discussed in the preliminary study the previous year. Although a low-yield explosion in the 5 to 10 kt range would produce a smaller amount of oil, it would provide the opportunity to determine if low-yield devices would create enough fractured wall rock for retorting (Figure 3.25-6). In addition, the idea was proposed to enhance the results of the low-yield device with small post-shot chemical explosions, possibly precluding the need for high-yield nuclear detonations. One concept for commercial production advocated using an array of smaller yield nuclear explosions to rubblize a series of rock chimneys and create a continuous zone of fractured rock for oil recovery (Figure 3.25-7).

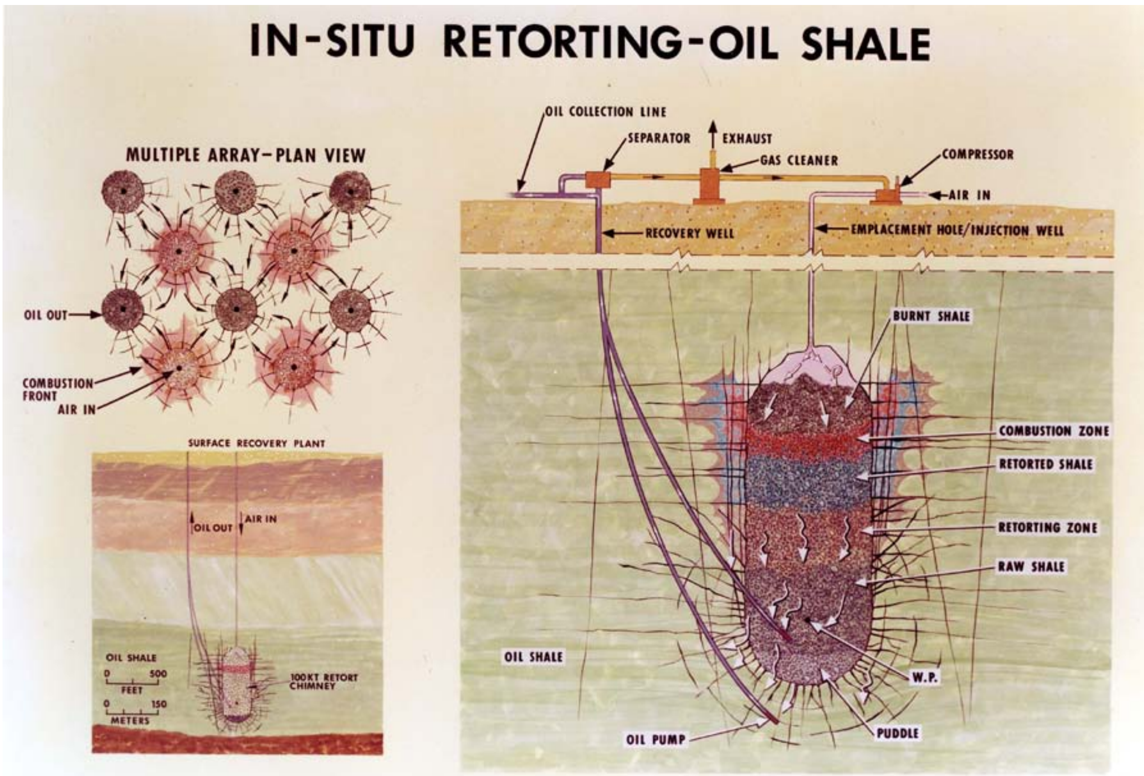


Figure 3.25- 6. Model for in situ retorting process using nuclear explosives to rubblize the oil shale deposit (Lawrence Livermore National Laboratory n.d., Negative No. GLC665-3753).

CER Geonuclear was in discussions with more than 30 energy companies, mostly oil and gas related, as potential investors in Project Utah. Information provided them detailed interests and royalty agreements should a company agree to be an investor. In May 1970, focus for the experiment moved to the creation and analysis of a nuclear chimney and analysis of associated fracturing, a less complex and more quickly accomplished endeavor. Plans were presented for field operations that included one more pre-shot well and three post- shot wells and the process for approvals, agreements and operational

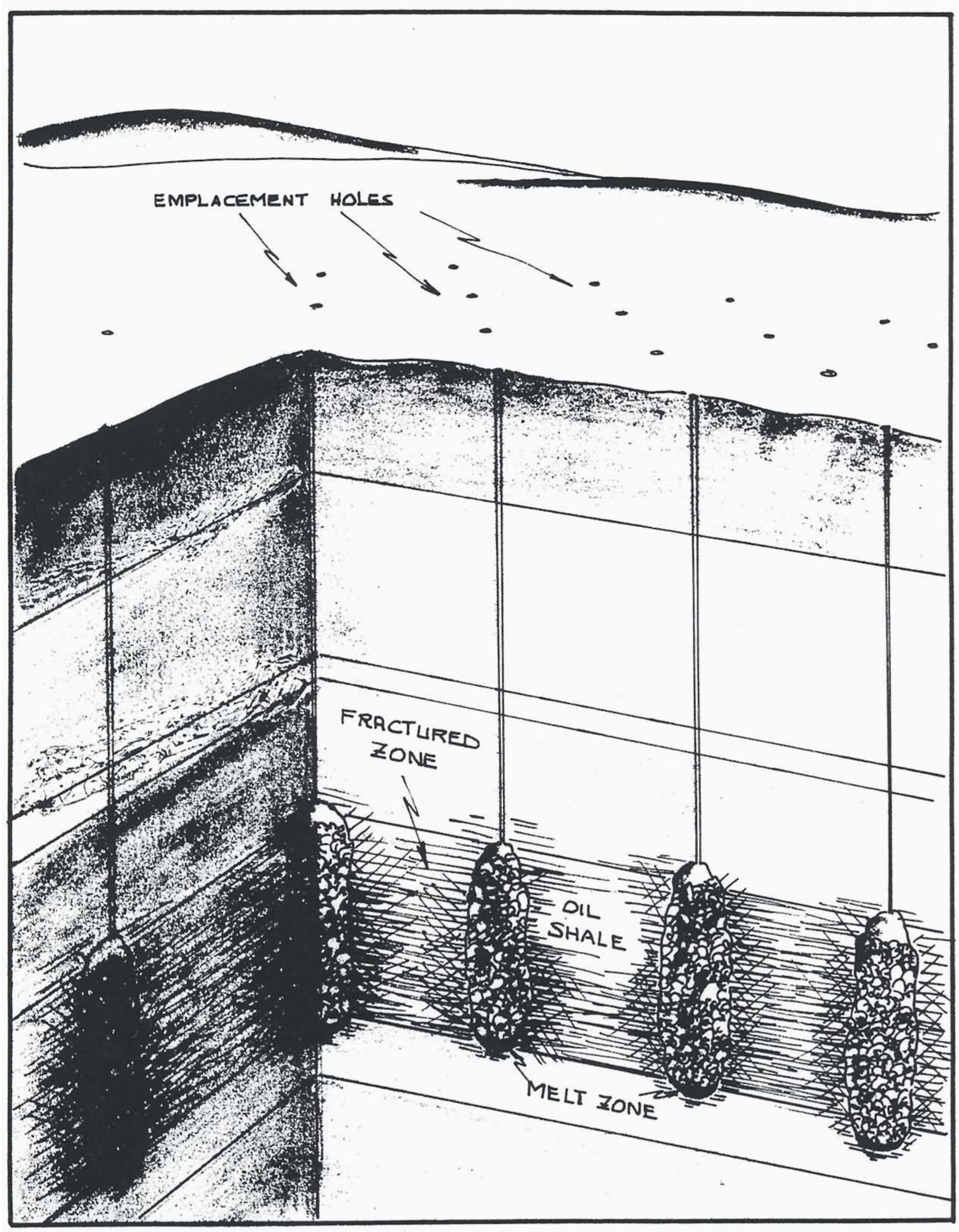


Figure 3.25-7. Concept drawing depicting a commercial oil shale production field with a multiple-shot array and a continuous zone of fractured rock (CER Geonuclear Corporation [1970], Figure 9).

plans, including public hearings. The investors' cost for this reduced scope for Project Utah was estimated at five million dollars. In October 1970, the U.S. Bureau of Mines in

Laramie began retort runs on Utah oil shale to determine potential oil yields. These results were critical information to companies that were considering investing in Project Utah. The runs produced excellent yields of oil from oil shale considered a lower grade than the shale in the Project Utah area.

A meeting of the project participants and interested parties was held in Laramie on February 17-18, 1971. Attendees included representatives from Western Oil Shale Corporation, Marathon Oil Company, Ashland Oil Company, Union Oil Company, Shell Oil Company, American Oil Company, The Oil Shale Corporation, U.S. Bureau of Mines, Minerals Exploration Company, El Paso Natural Gas Company, Champlin Petroleum Company, Continental Oil Company, Equity Oil Company, Sohio Petroleum Company, Cleveland-Cliffs Iron Company, Texaco, Panhandle Eastern Pipe Line Company, Amerada-Hess Corporation, Sun Oil Company, Cameron Engineers-Resource Associates, Cities Service Oil Company, Magellan Petroleum Corporation, Superior Oil Company, Getty Oil Company, Mobil Research and Development Corporation, BP North America, Coastal States Gas Production Company, Garrett Research and Development Corporation, Atlantic Richfield Company, Cities Service Oil Company, Husky Oil, Phillips Petroleum Company, American Petrofina Company, Anadarko Production Company, CER Geonuclear Corporation, University of Wyoming, Wyoming Department of Economic Planning and Development, Utah Governor's Office, Utah Department of Natural Resources, Utah Division of State Lands, Representative of Wyoming Senator, Lawrence Radiation Laboratory, U.S. Geological Survey, and the U.S. Atomic Energy Commission Headquarters in Washington, D.C. and the Nevada Operations Office. This symposium on oil shale retorting and Project Utah presented technical data on the proposed experiment and results of retorting studies. By this meeting, the projected date for execution of Project Utah was 1973. No documentation has been found that discusses Project Utah activities after this symposium.

Project participants were the Western Oil Shale Corporation, U.S. Atomic Energy Commission Headquarters, Washington D.C. and the Nevada Operations Office; U.S. Bureau of Mines, Laramie Petroleum Research Center; U.S. Geological Survey; CER Geonuclear Corporation; Lawrence Radiation Laboratory; and Oak Ridge National Laboratory. Other possible participants are the attendees at the Laramie Meeting listed above.

Project Utah was a Level 3 activity which corresponds to fieldwork limited to drilling the EX-1 test hole and grading several access roads. Geological, geophysical and hydrological characterizations of the geological formations were made using the cores and measurements from the test hole as well as using data from the pre-existing wells in the surrounding area. The Project Utah site was visited in FY2005.

FIELD VISIT

The experimental well currently sits on land leased to the Westport Oil and Gas Company and is surrounded by land belonging to the Uintah and Ouray Indian Reservation. To access the site, travel to Ouray, Utah on County Road 88 and cross the Green River. From the Green River crossing proceed 5.5 miles south on CR 88 until reaching a graded gravel and dirt road on the left (east) side of the paved highway. Proceed east-southeast along this unpaved road for approximately 3.5 miles. Turn right (southwest) onto the dirt road that leads to a large bladed area with a water holding pond and spoil pile. The experimental drill hole is located less than 150 ft southeast of the bladed area just beyond the junction of two surface gas pipelines.

On August 2, 2005, Edwards and Beck conducted a visual inspection of the Project Utah experimental well site (Figure 3.25-8). The WOSCO EX-1 drill hole utilized for the experiment is not currently in use although many active oil and gas wells are located in the surrounding area. Looking much as it did in 1969 (Figure 3.25-9), the 10 ¾-inch well casing is capped with a "Rector" well head with a wheeled valve closure (Figure 3.25-10). The valve assembly also has two pressure relief valves and two 3-inch diameter vent pipes that are capped. The whole assembly stands approximately 4 ft 6 inches high. The wheeled valve is chained and padlocked. Four galvanized steel eyebolt anchors that stabilized the drill rig remain embedded in the ground approximately 40 ft from the well head.

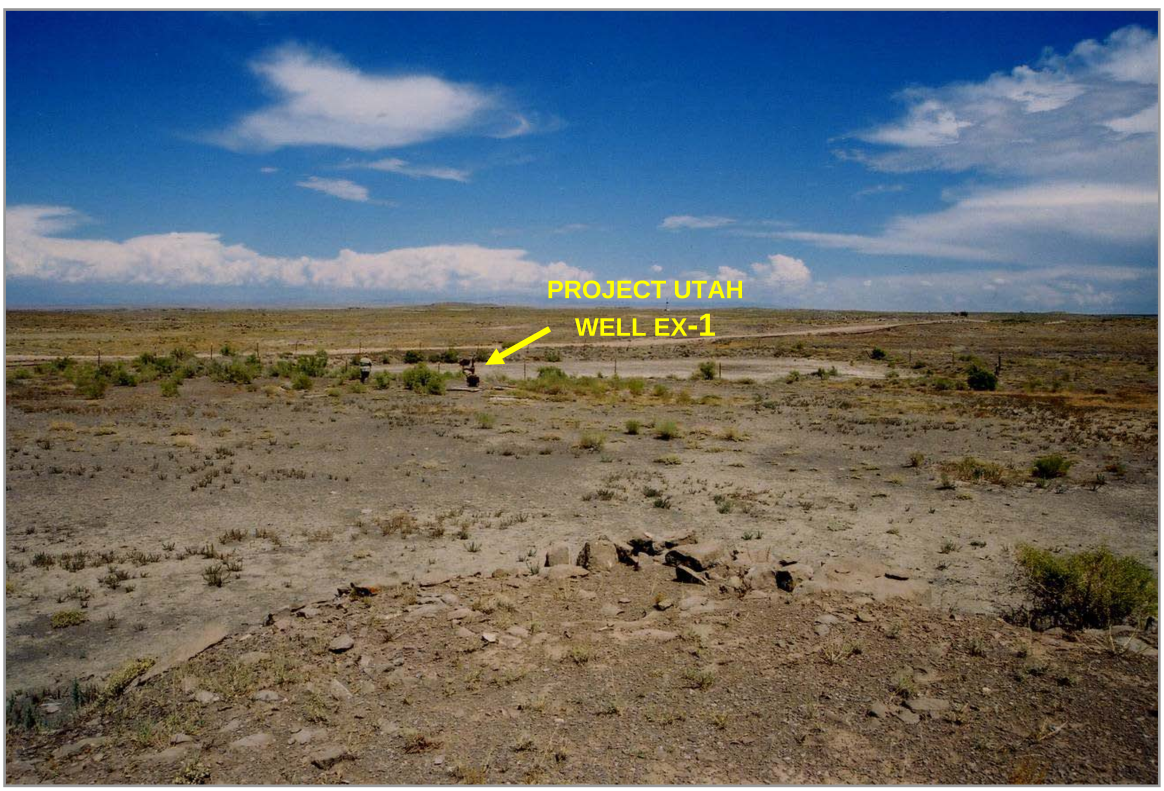


Figure 3.25-8. Overview of the Project Utah site. Taken from the low knoll overlooking the well, the view is towards the northeast (photo taken August 2005 on file at Desert Research Institute).

Debris scattered around the well head includes 4 wood panels approximately 4 ft 6 inches high x 5 ft wide. These panels probably formed a box that enclosed the wellhead at one time. Other debris includes miscellaneous pieces of lumber, metal strapping, metal bottle caps (crown cap closures), clear glass fragments, and a clear glass jar.

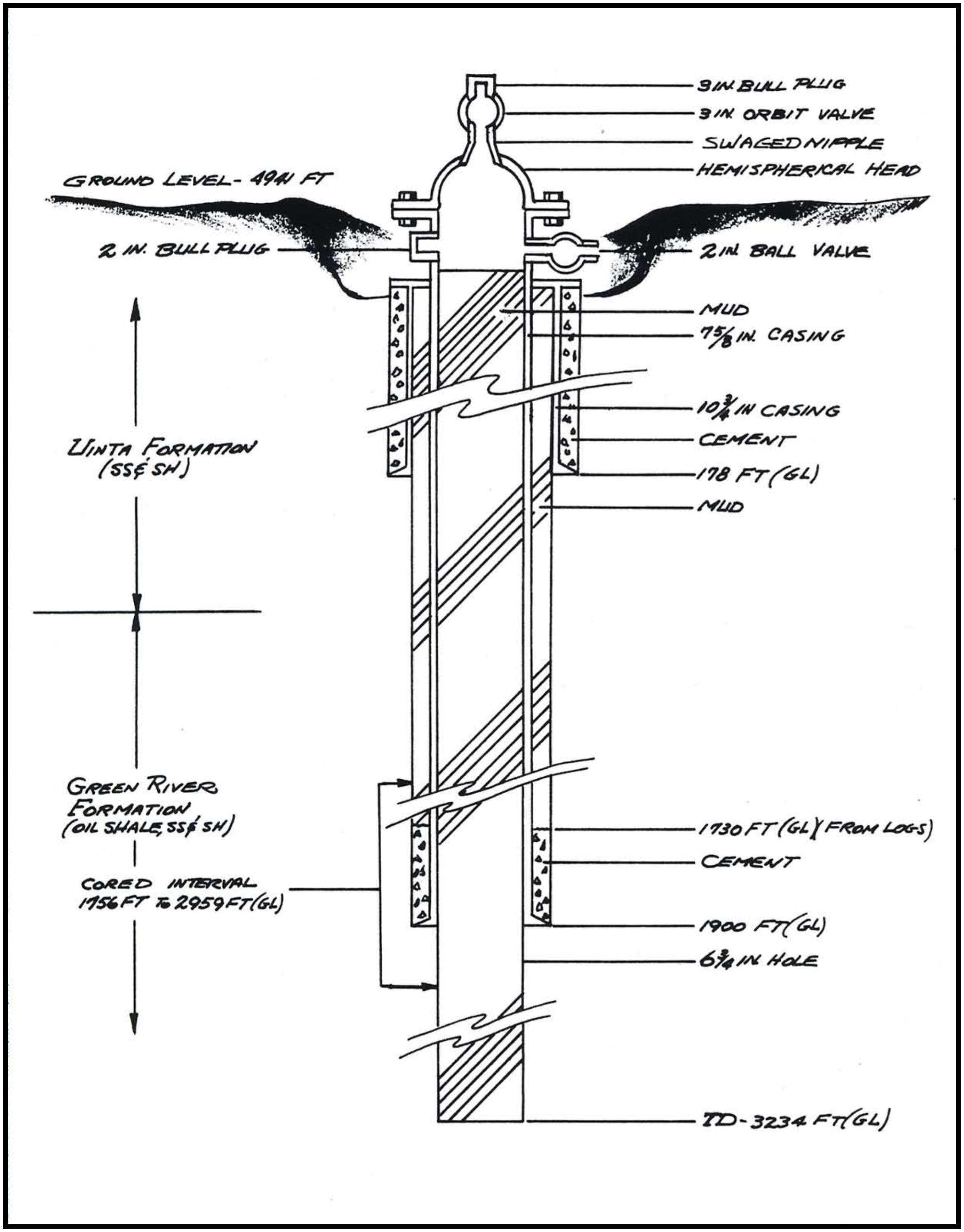


Figure 3.25-9. Schematic drawing of the WOSCO EX-1 drill hole (CER Geonuclear Corporation [1970], Figure 13).

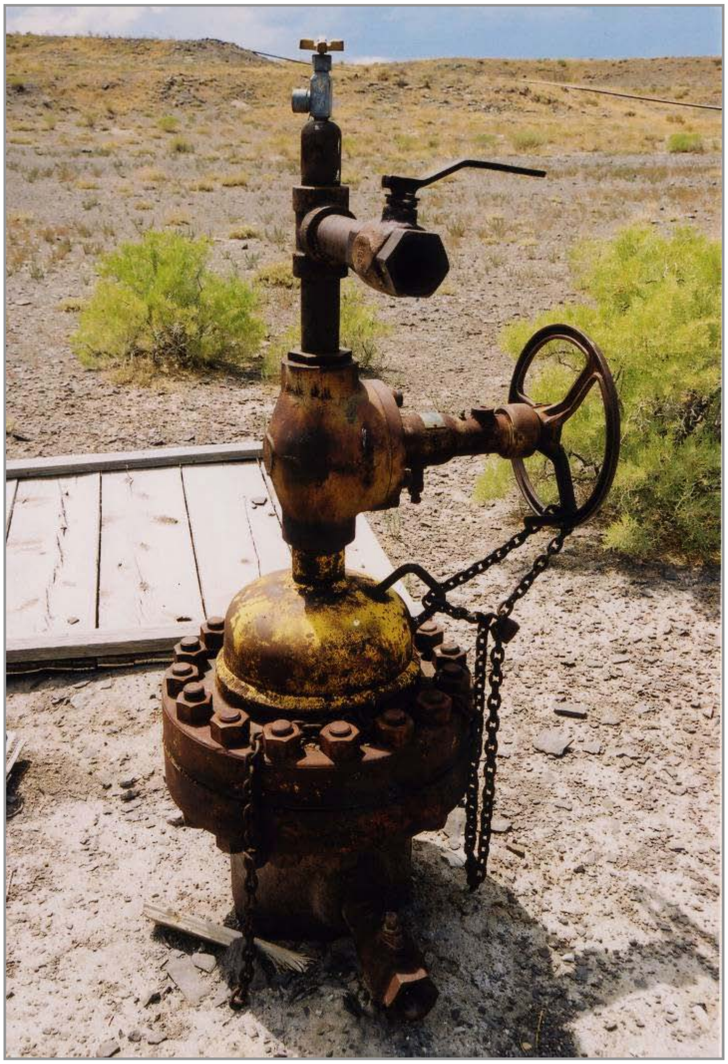


Figure 3.25-10. Close-up of the Project Utah EX-1 well head (photo taken August 2005 on file at Desert Research Institute).

A large drilling mud pit is located about 30 ft NNE of the wellhead (Figure 3.25-11). The pond is surrounded by a 4 ft - 5 ft high by 10 ft - 12 ft wide earth berm on three sides. The fourth side is level with the ground surface at the well head. A metal T-post and 6-in x 6-in wire mesh fence surrounds the entire pit. A single strand of barbed wire stretches above the wire mesh on the east side of the enclosure. All four corner posts of the enclosure are anchored with rebar and barbed wire guy wires. The pit has been used for disposal of trash. Industrial debris within the pit includes two empty 55-gallon drums, several empty 1 gallon and 5 gallon paint cans, a tire, several heavy equipment air filters, well casing and drill pipe segments, black rubber hose, 1-inch diameter braided wire cable, welding rods, threaded bolts, metal flanges, rubber gaskets and O-rings, more than 20 one-quart motor oil cans (SAE 20/20), and miscellaneous metal and wood fragments. Personal gear or consumables discarded in the mud pit include pull tab aluminum cans, pull tab soft-top steel cans, discarded Pepsi Cola and Coca Cola bottles, assorted green,

Figure 3.25-11. Drilling mud pit behind the Project Utah well head (photo taken August 2005 on file at Desert Research Institute).

amber, and clear glass fragments, sanitary-type fruit and vegetable cans, cotton work gloves, and a rubber boot heel.

There are several other debris concentrations surrounding the well head and mud pit. Items noted in these areas include food and beverage cans, bottle glass, lumber, bailing wire, and miscellaneous metal fragments (Figure 3.25-12). A low knoll located approximately 100 ft southwest of the EX-1 well head, had been bladed and leveled. The knoll probably was the location of a small office or equipment shed as indicated by the plywood, lumber, and metal scattered across the area.

During May 2006, a review of the land status records on file at the Bureau of Land Management, Utah State Office in Salt Lake City verified that the Project Utah experiment area and Well EX-1 sit on land belonging to the State of Utah. The 640 acre Project Utah study area (Sec. 36, T9S R20E) is mostly surrounded by lands administered by the U.S. Department of Interior, Bureau of Land Management. A small strip of State land lies to the east and the Ouray and Uintah Indian Reservation is to the west. The Western Oil Shale Company lease on the parcel has lapsed. Currently, the Westport Oil and Gas Company of Denver, Colorado has an authorized oil and gas agreement on file with the Utah Bureau of Land Management and the State of Utah.

Figure 3.25-12. One of the numerous debris scatters surrounding the Project Utah well head (photo taken August 2005 Desert Research Institute).

CHRONOLOGICAL BIBLIOGRAPHY

Kelly, John S., 1962. Letter with encls. (letter from Frank E. Moss, U.S. Senator, to Richard X. Donovan, March 12; and letter from John H. Morgan, et al., to Frank E. Moss, February 23) from John S. Kelly, U.S. Atomic Energy Commission, Division of Peaceful Nuclear Explosives, to Frank E. Moss, Senator, U.S. Senate, March 28. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105.

Thorne, H. M., 1964. An In-Situ Oil-Shale Process Development Proposal. Proposal, Laramie Petroleum Research Center, Laramie, WY, May. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-105.

U.S. Department of the Interior. Bureau of Mines, 1968. Prospects for Oil Shale Development, Colorado, Utah, and Wyoming. Manuscript, May. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Plowshare Advisory Committee, 1969. Plowshare Advisory Committee, Report on Nineteenth Meeting. Meeting held at Lawrence Radiation Laboratory, Livermore, CA, November 4-5. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029 [OUO].

U.S. Atomic Energy Commission, 1970. *Plowshare Program During 1969: Based on the Annual Report to Congress for 1969 of the U.S. Atomic Energy Commission.* U.S. Atomic Energy Commission, U.S. Government Printing Office, Washington, D.C. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

U.S. Atomic Energy Commission, 1970. Chapter 11 - Peaceful Nuclear Explosives. In *Annual Report to Congress of the Atomic Energy Commission for 1969,* pp. 195-203, January. U.S. Government Printing Office, Washington D.C.

Carpenter, H. C., H. W. Sohns, and G. U. Dinneen, 1970. Oil Shale Research Related to Proposed Nuclear Projects, In *Symposium on Engineering with Nuclear Explosives: Proceedings,* Report CONF-700101, Vol. 2, pp. 1364 -1375., May. American Nuclear Society, Hinsdale, IL.

Evans, Roy B., and David E. Bernhardt, 1970. "Probable Scheduling of Plowshare Events." Memo from Roy B. Evans and David E. Bernhardt, U.S. Department of Health, Education, and Welfare, Southwestern Radiological Health Laboratory, to Francis N. Buck, May 8. On file at Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0173142 [OUO].

Coffer, Henry F., 1970. "Project Utah." Letter from Henry F. Coffer, CER Geonuclear Corporation, Las Vegas, NV, to Distribution, October 23. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, PLO-065.

Coffer, Henry F., 1970. "Project Utah." Letter from Henry F. Coffer, CER Geonuclear Corporation, Las Vegas, NV, to Distribution, December 23. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

Coffer, Henry F., 1970. Letter from H. F. Coffer, CER Geonuclear Corporation, Las Vegas, NV, to Distribution, December 29. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, PLO-065.

Coffer, Henry F., 1970. Letter with encl. (Project Utah Proposal, manuscript) from Henry F. Coffer, CER Geonuclear Corporation, to Glenn C. Werth, December 30. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, PLO-065.

CER Geonuclear Corporation, [1970]. Preliminary Feasibility Study for a Nuclear In Situ Oil Shale Experiment in the Area of the WOSCO EX-1 Well, Uintah County, Utah (Draft). Manuscript, Las Vegas, NV. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-065.

U.S. Atomic Energy Commission, 1971. Chapter 9 - Peaceful Nuclear Explosives. In *Annual Report to Congress of the Atomic Energy Commission for 1970,* pp. 195-202, January. U.S. Government Printing Office, Washington D.C.

Coffer, Henry F., 1971. "Project Utah." Letter from Henry F. Coffer, CER Geonuclear Corporation, Las Vegas, NV, to Glenn C. Werth, January 27. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, PLO-065.

Bray, Bruce G., 1971. Project Utah Concept. In *Symposium on Oil Shale Retorting and Project Utah,* pp. 129-131, Western Oil Shale Corporation, February 17. Laramie, WY. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Bray, Bruce G., 1971. Resource Potential for Project Utah. In *Symposium on Oil Shale Retorting and Project Utah,* pp. 135-140, Western Oil Shale Corporation, February 17. Laramie, WY. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Carpenter, N. C., 1971. Rock Springs In Situ Work. In *Symposium on Oil Shale Retorting and Project Utah,* pp. 20-40, Western Oil Shale Corporation, Laramie, WY., February 17. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Coffer, Henry F., 1971. Introduction. In *Symposium on Oil Shale Retorting and Project Utah*, p. 1, Western Oil Shale Corporation, February 17. Laramie, WY. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Cook, G. L., 1971. Properties of Oil Shale. In *Symposium on Oil Shale Retorting and Project Utah,* pp. 5-19, Western Oil Shale Corporation, February 17. Laramie, WY. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Dinneen, G. U., 1971. Bumines Oil Shale Program. In *Symposium on Oil Shale Retorting and Project Utah,* pp. 2-4, Western Oil Shale Corporation, February 17. Laramie, WY. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Harak, A. E., 1971. Retort Studies (Including Results of Retorting Utah Shale). In *Symposium on Oil Shale Retorting and Project Utah,* pp. 49-81, Western Oil Shale Corporation, February 17. Laramie, WY. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Kelly, John S., G. U. Dinneen, and H. F. Coffer, 1971. Comments and Wrap-Up. In *Symposium on Oil Shale Retorting and Project Utah,* pp. 132-134, Western Oil Shale Corporation, Februrary 17. Laramie, WY. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Knutson, C. F., 1971. Project Utah Geology and Feasibility Study. In *Symposium on Oil Shale Retorting and Project Utah*, pp. 82 -94, Western Oil Shale Corporation, February 17. Laramie, WY. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Sohns, H. W., 1971. Retorting Studies. In *Symposium on Oil Shale Retorting and Project Utah,* pp. 41-48, Western Oil Shale Corporation, February 17. Laramie, WY. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Werth, Glenn C., 1971. Effect of Nuclear Explosive in Oil Shale. In *Symposium on Oil Shale Retorting and Project Utah,* pp. 95-128, Western Oil Shale Corporation, February 17. Laramie, WY. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Western Oil Shale Corporation, 1971. *Symposium on Oil Shale Retorting and Project Utah.* Western Oil Shale Corporation, February 17. Laramie, WY. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Werth, Glenn C., 1971. Status of Contained Nuclear Explosive Applications. University of California, Lawrence Radiation Laboratory, *Report UCRL*-51074, June 21. Livermore, CA. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-103.

Shafer, David S., William. C. Beck, Dwight Treadwell, and Stephen. A. Mellington, 1995. Inventory of Potential Environmental Restoration Liabilities Associated with Plowshare And Vela Uniform Program Sites. Manuscript, U.S. Department of Energy, Office of Environmental Restoration. On file at: Desert Research Institute, Las Vegas, NV.

U.S. Department of Energy. Nevada Operations Office, 1997. Plowshare Program Executive Summary. Report from U.S. Department of Energy, December 22.

DOE Techline, 2000. Richardson Announces Plans for Historic Return of Land to Native Americans. *DOE Techlines*, January 14. U.S. Department of Energy. http://www.fossil.energy.gov/news/techlines/2000/tl_nosr2ute.html.

Lawrence Livermore National Laboratory, n.d. "In-Situ Retorting-Oil Shale." Oil shale drawing, retort_b. Negative No. GLC-665-3753. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

Lawrence Livermore National Laboratory, n.d. "Nuclear Explosion in Oil Shale." Oil shale chimneys drawing, oshale_a. Negative No. GLC-712-871A. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

Lawrence Livermore National Laboratory, n.d. Retort_a photo. Negative No. GLB-666-4764. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

U.S. Department of Energy. Nevada Operations Office, n.d. The Plowshare Program (Draft). Report from U.S. Department of Energy.

3.26 WAGON WHEEL

Plowshare Program
Nuclear Explosives for Stimulation of Underground Natural Gas Reservoirs
Wyoming

Project Wagon Wheel was a joint Plowshare effort between industry and the federal government to further develop the use of underground nuclear explosions to stimulate low permeability natural gas reservoirs. The driver behind the Wagon Wheel project was a perceived natural gas shortage in the United States and a desire to derive more gas from the underground gas-bearing geologic formations. It was the fourth such experiment, following the Gasbuggy, Rulison, and Rio Blanco projects. El Paso Natural Gas Company was the industrial sponsor of the project. Cooperating entities were the U.S. Atomic Energy Commission and the U.S. Department of Interior as specified in Contract No. AT(26-1)-422 between the United States and the gas company dated December 24, 1968.

The project was located in the Pinedale Unit natural gas field, Sublette County, Wyoming (Figures 3.26-1 and 3.26-2). The unit consisted of 90,000 acres of federal, State of Wyoming, and fee oil and gas leases held since 1954 by El Paso Natural Gas Company, Mountain Fuel Supply Company, and Hondo Oil and Gas Company. El Paso Natural Gas Company

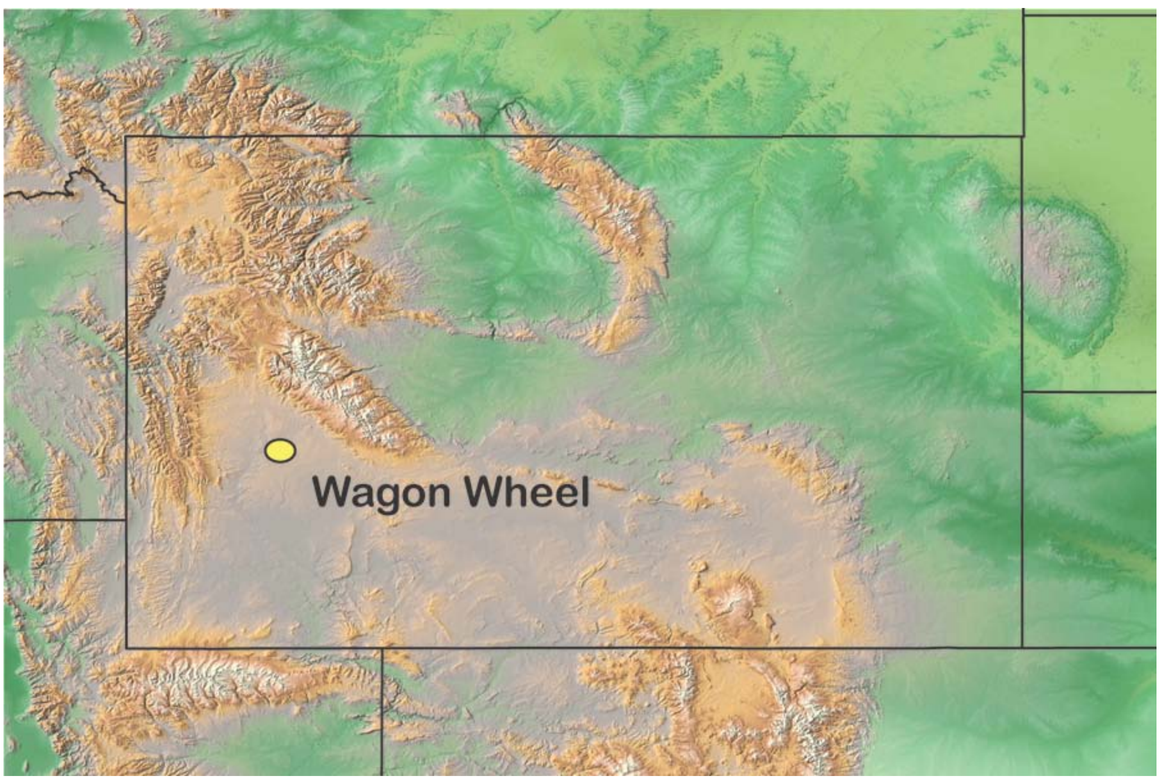


Figure 3.26-1. Location of Project Wagon Wheel in Sublette County, Wyoming (adapted from USA Relief Maps 2004).

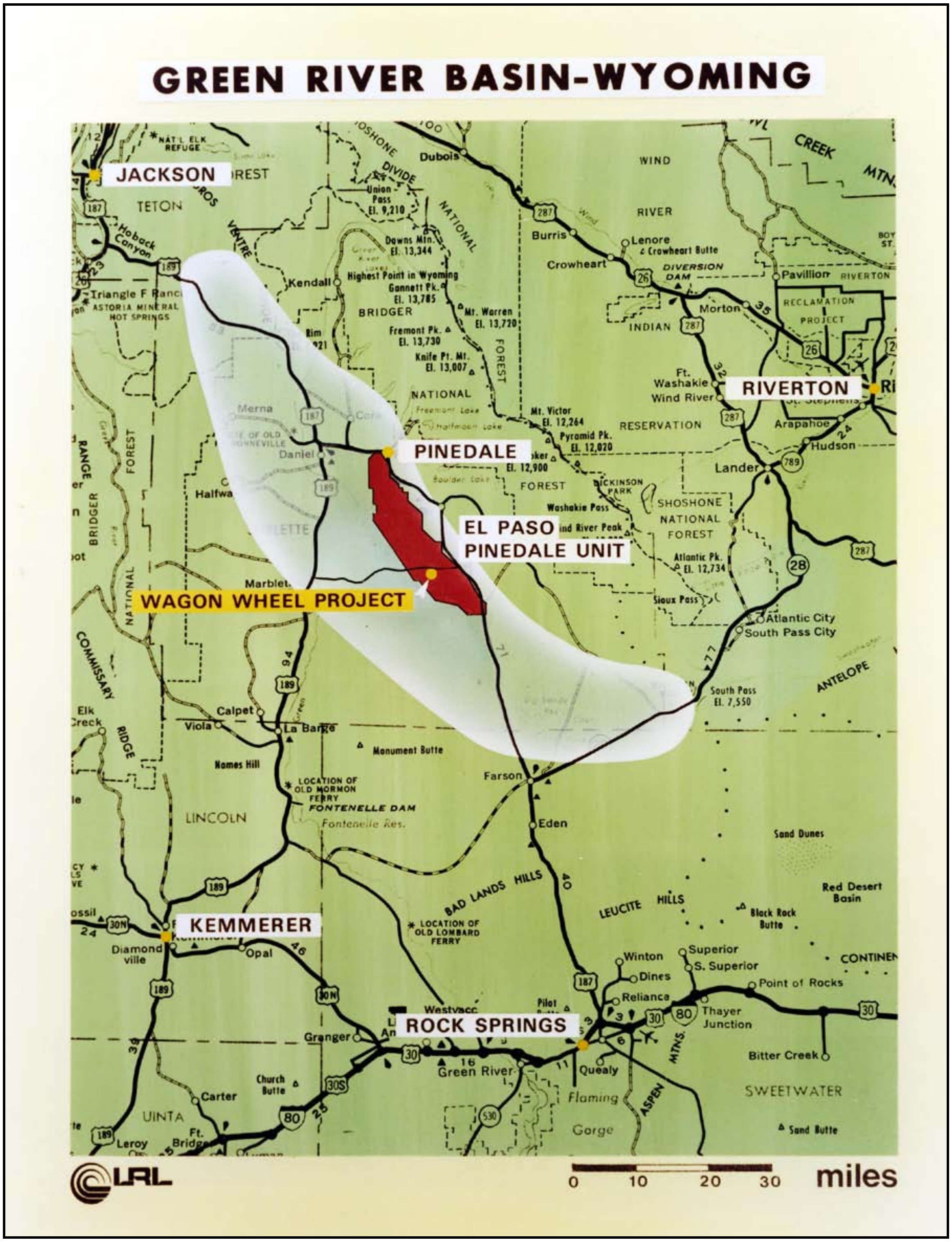


Figure 3.26-2. The Wagon Wheel Project location is shown within the Pinedale Unit natural gas field (Lawrence Livermore National Laboratory n.d.).

was the unit operator for the group. Eight wells had been drilled in the Pinedale Unit since 1954 and low permeability natural gas deposits from 7,500 and 10,700 ft below surface had been identified. After these initial explorations, it was determined that conventional production methods would not be economic to justify developing the unit and that massive fracturing of the underground formations bearing the natural gas would be required. In contrast to conventional methods, such as high explosive or hydraulic, nuclear explosions produce substantially greater amounts of rock fracturing.

In 1958, the El Paso Natural Gas Company approached the U.S. Atomic Energy Commission with the possibility of using nuclear explosions to stimulate the gas-bearing formations in the unit, but the nuclear explosive technology at this time was not advanced enough to undertake the task. Later in 1963, the gas company, the U.S. Department of the Interior, U.S. Atomic Energy Commission, and the Lawrence Radiation Laboratory studied the feasibility of this method and concluded an experiment was deemed essential to develop techniques and the engineering for using nuclear explosives to fracture the underground formations. The gas company then joined with the U.S. Atomic Energy Commission and the U.S. Bureau of Mines to conduct the feasibility study for such a project. However, the first nuclear stimulation test, Gasbuggy, was conducted in 1967 in northwestern New Mexico. Following this, Project Wagon Wheel was proposed and a contract between the gas company and the government was signed in 1968 in order to define the study and cover all processes through to project design. A second contract was to be negotiated before the actual test was conducted. Lawrence Radiation Laboratory was selected to provide principal technical assistance and the nuclear device. In contrast to the earlier experiments, Wagon Wheel was designed to provide information on whether stimulation by nuclear explosion was a practical means for the commercial production of natural gas in the Pinedale Unit.

The director of the Department of Peaceful Nuclear Explosives authorized the U.S. Atomic Energy Commission, Nevada Operations Office manager in December 1968 to conduct preliminary field studies for the Wagon Wheel project. Located about 20 miles south of the town of Pinedale and 20 miles east of the town of Big Piney and just off state Highway 351, the project was in the northern portion of the Green River Basin, Sublette County, Wyoming, in the NW1/4 Sec. 5, T30N R108W (Figure 3.26-3). Preliminary studies to evaluate the site began in June and July 1969, and included geology, ground water, ground motion, ecology, climate, and radioactivity. In August of the same year, these studies were completed and indicated the site was satisfactory for the proposed project, but several issues were still to be worked out. A water well was also drilled at the site to retrieve hydrologic data and to supply water for drilling an exploratory hole. The exploratory hole was started in October 1969 and completed in November 1970. Reaching a depth of 19,000 ft, it was cased with various size liners (Figure 3.26-4). A plug was set at a depth of 11,700 ft. Participants for this particular operation were EL Paso Natural Gas Company, the Water Resources Division of the U.S. Geological Survey, Lawrence Radiation Laboratory, and Teledyne Isotopes. Samples and measurements were obtained on the geology, reservoir fluids, pressure, and temperatures, and it was determined there was no connection between water aquifers and the underlying gas reservoirs. The gas reservoirs were detected below the 7,972 ft mark. Also, because of the relatively larger size of the exploratory hole

THIS PAGE INTENTIONALLY LEFT BLANK

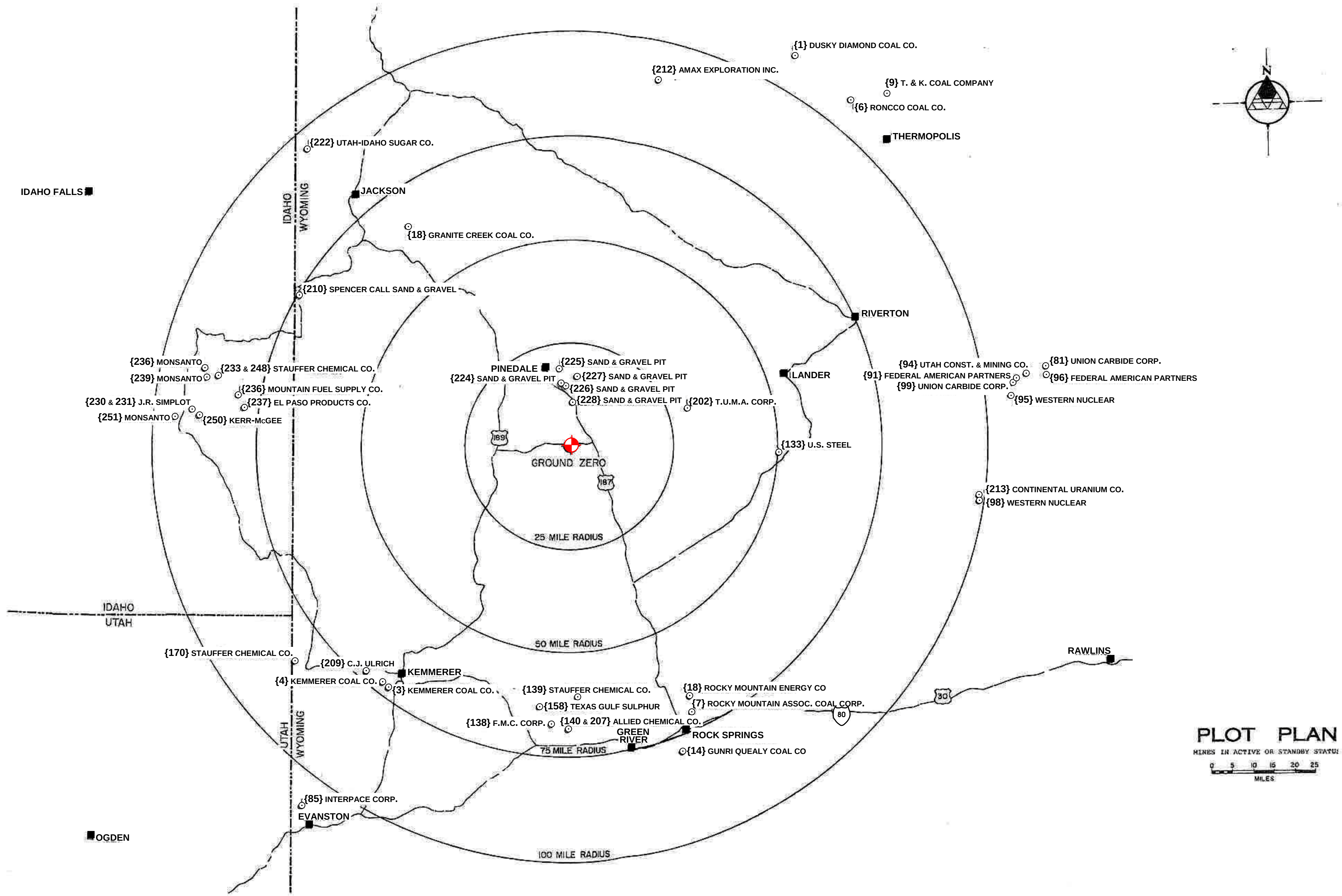


Figure 3.26-3. Plot plan of Project Wagon Wheel showing existing mines and larger communities (adapted from Dames & Moore 1972, Figure XIV-3).

THIS PAGE INTENTIONALLY LEFT BLANK

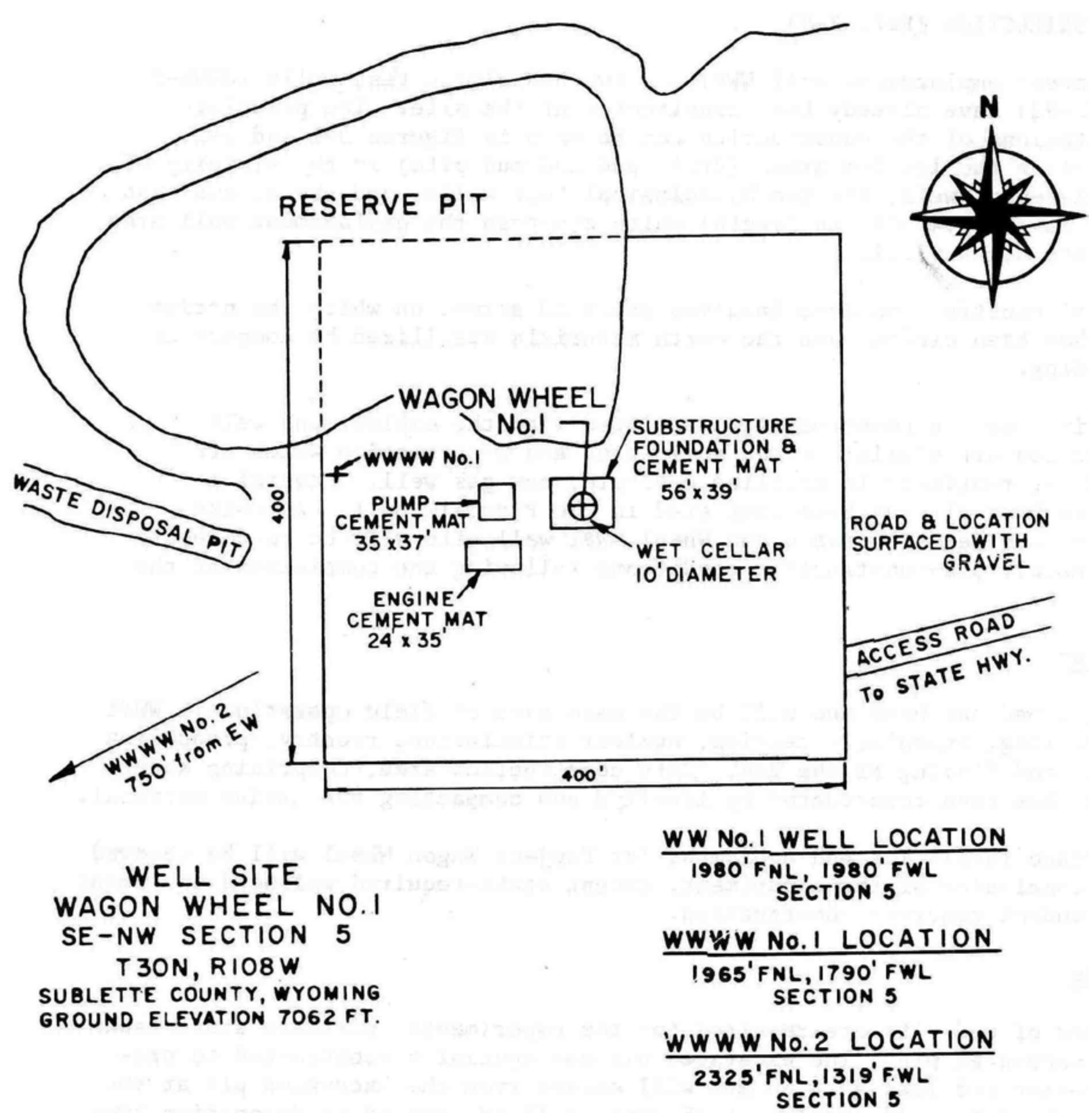


Figure 3.26-4. Project Wagon Wheel site plan (U.S. Atomic Energy Commission 1972, Figure 3-1).

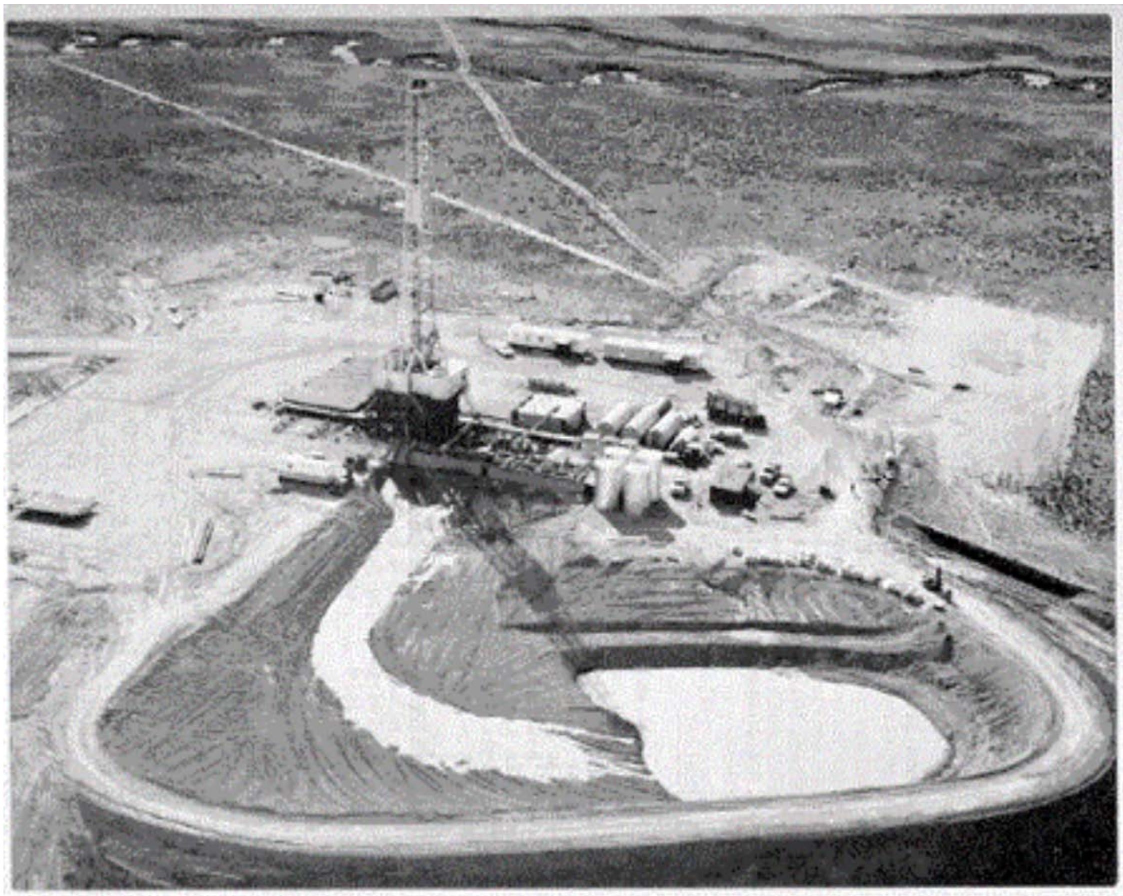


Figure 3.26-5. Drilling at Project Wagon Wheel in 1970. View is to the south-southeast (U.S. Atomic Energy Commission 1972, Figure 3-2).

due to its depth, it was intended to be the emplacement hole for the nuclear explosives (Figure 3.26-5).

The design concept for the Wagon Wheel project was adopted in 1971 and the actual experiment was guided by a maximum limit of a single 200-kt explosion in order to prevent excessive damage in the surrounding area by ground motion. The solution was to have a series of five 100-kt nuclear explosions detonated in vertical sequence in the same drill hole, starting at the bottom and with a time interval of five minutes between them (Figure 3.26-6). The time lapse allowed ground motion to subside before the next explosion. The nuclear devices would be arranged in depth from 9,220 and 11,570 ft below the surface (Figure 3.26-7). Because of the close proximity of the explosions to one another, a 'ruggedized' nuclear device was being developed by the U.S. Atomic Energy Commission and was to be tested during the Yacht series at the Nevada Test Site before being employed at Wagon Wheel. Chimneys created by the explosions were expected to join, establishing one continuous chimney of about 2,700 ft in length from which to draw the gas. Once the nuclear devices were emplaced, the control point for the firing would be in the town of Pinedale and the signals relayed via a repeater facility on a microwave system. A project geologist stated that the energy generated from the explosions was

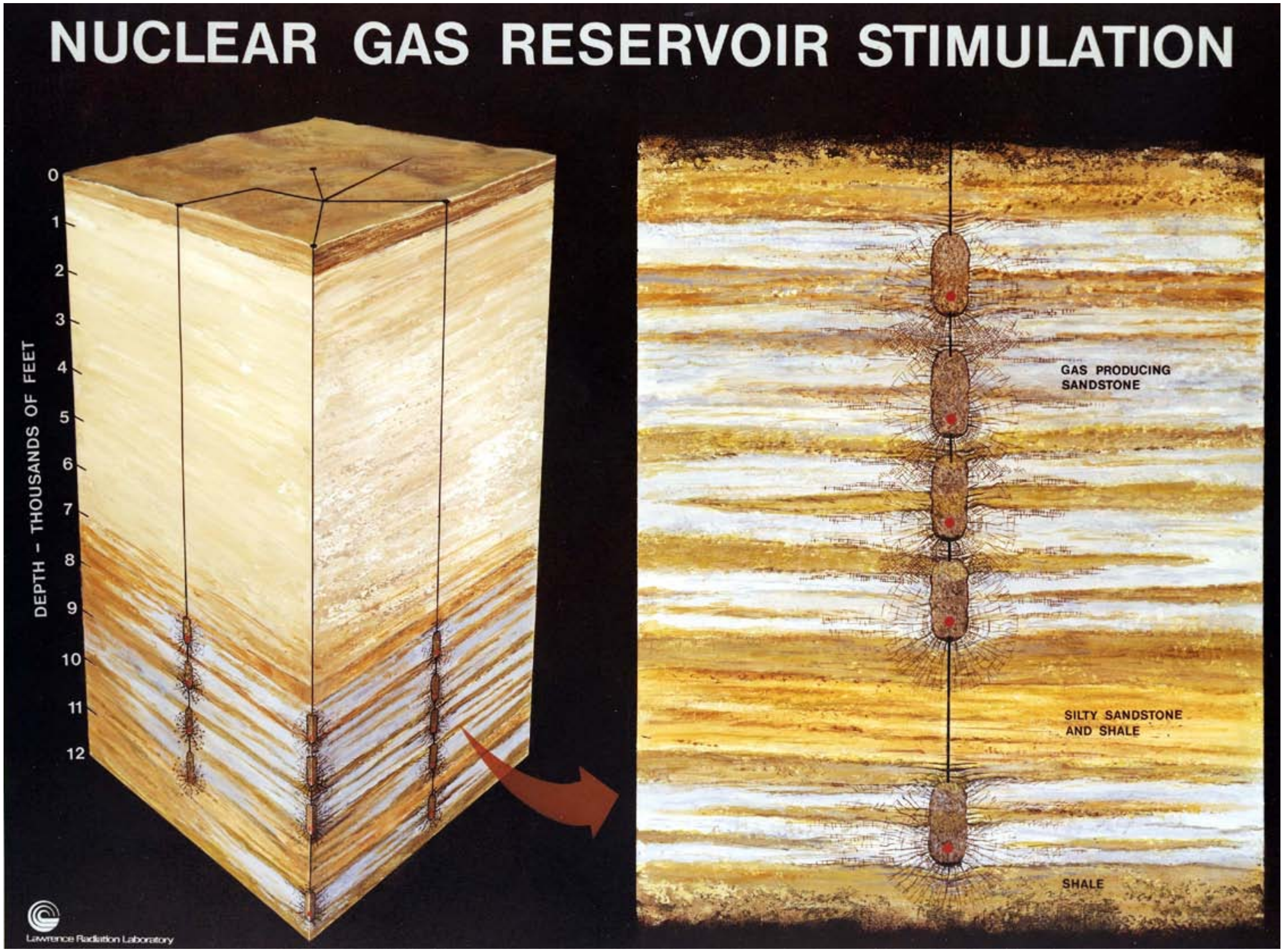


Figure 3.26-6. Schematic drawing of multi-shot models for nuclear gas reservoir stimulation experiments. The underground cross-section of the five 100-kt sequential shot Project Wagon Wheel experiment is shown on the right. The cutaway on the left depicts Wagon Wheel as part of a field of nuclear stimulated gas wells (Lawrence Livermore National Laboratory n.d.).

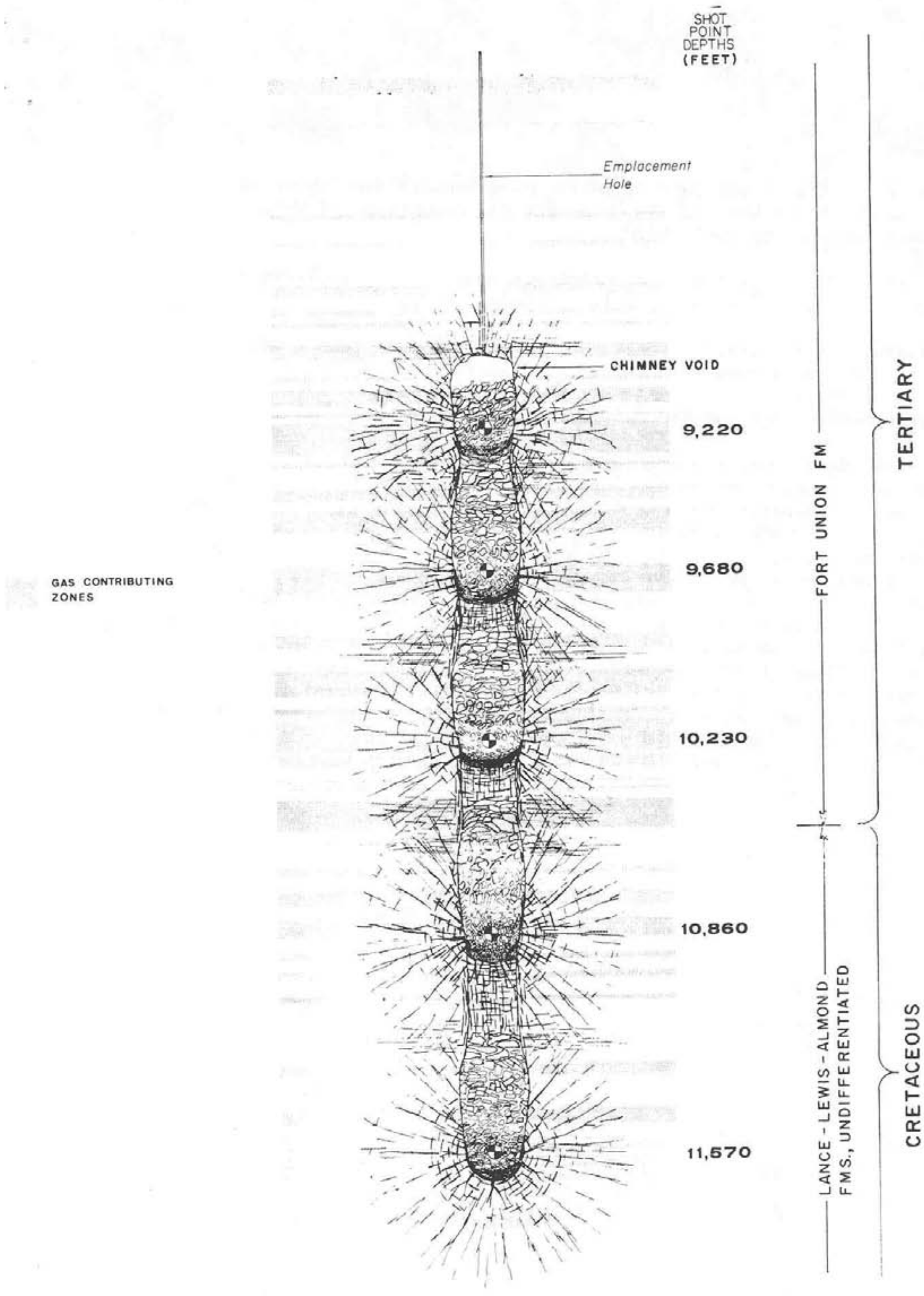


Figure 3.26-7. Project Wagon Wheel chimney region showing the proposed spacing of the explosive charges (U.S. Atomic Energy Commission 1972, Figure 2-3).

about 35 times that of the gas to be extracted from the well. After a wait of four to six months, reentry into the top of the chimney would occur through the emplacement hole casing and eventually gas would be produced from this opening as well. Upon reentry, tests would be conducted to determine the extent the well had been stimulated by the nuclear explosions. If the experiment was successful, full development of the gas field was planned (Figure 3.26-6). Ten stimulation wells of similar design were planned for 1977, 20 in 1978, 30 in 1979, 40 in 1980, and 50 in 1981 and for several years after. Associated facilities to be constructed included gathering systems, processing plants, and pipelines.

Once the design of the experiment was established, additional and more detailed studies were called for and included a second water well southwest of the exploratory hole. Objectives of the second water well were to evaluate the aquifers situated between 4,937 and 5,108 ft and between 2,312 and 2,427 ft and to supplement the hydrologic data from the first water well. The second well was capped and never used as a source for water. Earlier project studies were based on the concept of using only one explosion for the experiment rather than a sequence. Sequential nuclear explosions with considerable yield had not yet been undertaken and the problems and methods still needed to be worked out. Studies were performed by the Lawrence Radiation Laboratory to predict chimney size and the effects of shock waves, and the U.S. Atomic Energy Commission was working on the 'ruggedizing' of the devices so they could survive the blast effects of previously fired explosions. In addition, Applied Nuclear Company studied the thermodynamics; Dames & Moore Corporation and principal subcontractor H.J. Degenkolb & Associates, Engineers, examined the effects of seismic motion on area structures; and Eberline Instrument Corporation measured background radioactivity. The University of Wyoming Water Resources Research Institute was engaged for the location and quality of water wells and springs, H.G. Fisser of the University of Wyoming for the area ecology, Terra Tek, Inc. the rock mechanics, and Core Labs, Inc. for reservoir properties. The U.S. Atomic Energy Commission also conducted studies of rock mechanics, mineralogical and chemical analyses, permeability, and with the Lawrence Radiation Laboratory, computer simulations. The U.S. Atomic Energy Commission also hired John A. Blume and Company, the Environmental Research Corporation, the Battelle Memorial Institute, and Holmes & Narver Company to conduct preliminary site evaluations. Other government agencies involved were the U.S. Public Health Service, U.S. Bureau of Mines, U.S. Geological Survey, and the Environmental Science Services Administration.

Impact on the environment was judged to be minimal, being mainly restricted to the construction site. Two water wells and one exploratory/emplacement well were constructed, involving a pad of about 10 acres where native growth was cleared and the land compacted and graded. An access road, about 0.4 miles in length, was constructed from Highway 351 to the drill pad, and a temporary buried gas line 0.5 mile in length from an existing gas well was established to supply fuel to the project area. Statistics on the two water wells are provided below.

Wagon Wheel Water Well #1; Pinedale Unit; Sublette County, Wyoming, 1,980 ft from the north line, 1,880 ft from the west line of Sec. 5, T 30N R108W;

7,072 ft ground elevation; Contractors: Walton Dry Hole Digger, Roden Drilling Company, and Evitt Drilling Company; Completed drilling July 27, 1969; Completed operations August 15, 1969; Total depth 2,501 ft (Driller), 2,502 ft (Schlumberger); Casing: 10 3/4 inch to 22 ft; Production: 1,600 barrels per day with pump.

Wagon Wheel Water Well #2; Pinedale Unit; Sublette County, Wyoming, 2,325 ft from the north line, 1,319 ft from the west line of Sec. 5, T30N R108W; 7,062 ft ground elevation; Contractors: Roden Drilling Company, Evitt Drilling Company; Completed drilling May 5, 1971; Completed operations May 22, 1971; Total depth 5,200 ft (Driller), 5,212 ft (Schlumberger); Casing: 10 3/4 inch to 102 ft.

Anticipated adverse and unavoidable effects from the Wagon Wheel project were from well construction, architectural damages from seismic motions, released radioactivity during production testing, and the presence of radioactivity in the chimney. However, it was determined neither seismic motion nor radioactivity released during post-testing of the well would affect the environment. Cultural and natural structures within a hundred mile radius did not present any major limiting restrictions on the project, but some areas were noted where precautions needed to be taken to protect people. Based on population dynamics it was recommended that the experiment be conducted between October and April when there were fewer people in the area and that people nearest the site, within seven miles, should be requested to leave the immediate area until after the test. The surface of the site was to be restored to a condition similar to the surrounding land after completion of the experiment. Damage to structures from the detonations was estimated at about $65,000 and there might be minor damage to some of the dams, irrigation canals, water wells, bridges, towers, and mines in the area.

A concern was venting of radioactive material after detonation. A radiological monitoring program was established in May 1971 to monitor background radiation and was to continue until the end of the project. The only planned or expected release of radioactivity from Wagon Wheel was during the flaring of gas and steaming of water during testing of the well. These tests were considered necessary to determine the extent the well had been stimulated by the nuclear explosions. Tritium, Krypton-85, and Argon-37 were to be released into the air, rising in a plume and dispersed. Predictions on dose concentrations for the surrounding population indicated the highest doses would occur about two miles from the wellhead where there was no population at that time. However, dose rates from the Wagon Wheel experiment were to be of such low amounts compared to those already released into the environment from previous nuclear testing and from natural conditions to make them negligible as health problems.

In reviewing the environmental statement for the Wagon Wheel project the U.S. Environmental Protection Agency had several key comments. The first comment was that additional information was needed for assessing the predictive models used for the seepage and dispersion of radioactive gas. The second comment was that the statement did not provide any criteria by which to determine the success or failure of the experiment. A third comment was on the appropriateness of the alternatives provided in the statement. These alternatives referred only to other kinds of national energy sources rather than alternatives to Project Wagon Wheel. A fourth concern was that the statement should have expanded the discussion on the quality of gas in reference to the risk-benefit of nuclear stimulation and the ability to sell gas exposed to radiation. Also noted was that the land ownership of the specific location for the project was not provided, only that the gas company was the main manager for the entire Pinedale Unit composed of federal, state, and fee leases.

The local populace was also able to review the environmental statement for the Wagon Wheel Project and opposition soon arose and escalated over time. The Wagon Wheel Information Committee was formed and became the nucleus for local opposition. Many agreed, including congressmen, that the environmental statement was not adequate and more work should be done. Local populace became aware of potential dangers, such as damage to structures and homes, rockslides, and mine collapses. The El Paso Natural Gas Company and the U.S. Atomic Energy Commission also appeared cavalier to the local people by basing their judgments of damage solely on what they considered a fair assessment and did not take into consideration any of the economic or social aspects of the local area, causing mistrust with the local populace. It was also realized if Wagon Wheel was a success, then more wells would be established. There could be up to 370 nuclear explosions per year in the Upper Colorado River Basin if taken together with other planned projects in Colorado. A local straw poll conducted during an election showed overwhelming opposition to the project. Comments by the Wagon Wheel Information Committee were published in the local Pinedale Roundup newspaper and included in a letter to the chairman of the U.S. Atomic Energy Commission. At one time he stated the project would not occur if the people of Sublette County do not want it. Members of the Wagon Wheel Information Committee traveled to Washington, D.C. to seek support and to ask the U.S. Atomic Energy Commission and others to cancel the project, and one member appeared on national television debating the issue. Consequently, Wyoming congressmen became involved at the federal level and funds were cut from the Plowshare Program to where Wagon Wheel experiments slated for the Nevada Test Site involving sequential nuclear firing tests could not be conducted. This action delayed the Wagon Wheel project until at least 1977.

Lederer in his 1998 thesis provided a social and political context for the nuclear stimulation experiments in the Plowshare program. Gasbuggy, the first stimulation experiment, located in New Mexico, was well received by the public, especially the local people and state congressmen. In contrast, Rulison, the second experiment, located in Colorado, had a great deal of opposition. Rulison had to overcome a grass roots environmental movement and a lawsuit. Some Colorado politicians were ousted in the next elections because of their support for the project. Rio Blanco, also in Colorado, was the third experiment and faced relatively less opposition because of local support and because the national focus was on President Nixon and Watergate. Wagon Wheel was to be the fourth such experiment, but was never conducted.

The exact date for termination of the Wagon Wheel project has not been firmly established. The federal budget in 1974 did not include funding for tests in the Plowshare Program and this has often been cited as the leading cause for the projects demise. The Plowshare Program itself ended in 1975. In 1974 and 1975, the El Paso Natural Gas Company used the well drilled for the nuclear stimulation experiment to conduct massive hydraulic fracturing tests. These tests determined that this hydraulic technique was not economically feasible.

Project Wagon Wheel was a Level 3 activity which corresponds to fieldwork including drilling the emplacement hole and two water wells and constructing support facilities. Geological, geophysical and hydrological characterizations of the geological formations were made using the cores and measurements from the exploratory hole and water wells, as well as using data from the pre-existing wells in the surrounding area. The Wagon Wheel site was visited in FY2003.

FIELD VISIT

On August 10, 2003, Desert Research Institute personnel inspected the Project Wagon Wheel site (Figures 3.26-8 and 3.26-9). Beginning at Rock Springs, Wyoming, the site can be reached by traveling north on U.S. Route 191 approximately 85 miles to the junction of Highway 191 and State Route 351. Turn left (west) onto State Route 351 and proceed 5.6 miles. From the paved highway, turn left (south) onto a graded dirt road flanked by two white steel posts. Follow this road as it curves to the west for about 0.3 miles to the fenced Wagon Wheel compound. A 6-x-6 inch wire mesh and metal pole fence capped by three strands of barbed wire surrounds the main compound. Entry is through a double gate with a metal cattle guard. A sign mounted on the gate reads: "THIS RIGHT OF WAY CONTAINS HIGH PRESSURE NATURAL GAS FACILITIES. ALL UNAUTHORIZED PERSONS KEEP OFF! EL PASO NATURAL GAS COMPANY." At the time of the field visit, the gate was wide open.

The principal feature in the compound is the Project Wagon Wheel emplacement hole. Today, a 4 1/2-inch diameter pipe that extends 6 ft above the ground surface marks the location of the 19,000 ft deep well (Figures 3.26-10 and 3.26-11). The upper end of the pipe is pinched and welded shut. It is labeled with the following information:

"WAGON WHEEL #1
NW SEC. T30N R108W
SUBLETTE COUNTY. WYOMING
EL PASO EXPLORATION COMPANY
FED. LEASE # WYW06933"

Concrete pads surround the well (Figure 3.26-12). Water Well #1 is located south of the Wagon Wheel emplacement hole. The water well is still active. The top of the well casing is locked down with a plate and a padlock. A flexible pipe extends from the well to a pair of holding tanks along the south boundary fence. This well is surrounded by a small (6-x-6 ft) wire fence enclosure (Figure 3.26-13).

A pair of 8-ft diameter tanks rests on a raised earthen pad along the south fence line (Figure 3.26-14). One tank is 20 ft long and the other is about 12 ft long. They are connected

Figure 3.26-8. Overview of Project Wagon Wheel Site. View is towards the south (photo taken August 10, 2003 on file at Desert Research Institute).

Figure 3.26-9. Entry gate to Wagon Wheel compound. View is to the west (photo taken August 10, 2003 on file at Desert Research Institute).

Figure 3.26-10. The Wagon Wheel #1 emplacement hole (photo taken August 10, 2003 on file at Desert Research Institute).

to each other and are seated in cradles that elevate them above the earth pad. Water flows from the well into the northern tank, which then flows into the south tank. A line leads from the bottom of the south tank to the troughs just outside the fenced compound. The "Loomix" trough consists of three 8 ft long x 4 ft wide x 2.5 ft deep water-filled troughs connected to each other with pipes. They are sitting on railroad ties and are partially covered by a wooden frame made of poles and 2x4s. The trough nearest the holding tanks has a ball/float valve to regulate water flow. A second trough consisting of a pair of split 16 inch diameter iron pipes is just west of the Loomix trough. The pipes are welded together and sit on an A-frame support that raises them about 18 inches off the ground. There is a ball/float valve at the northeast end of each trough. Just west of the troughs, in an area labeled as "flare pit" by the Ultra Resources Surveyors, is a horizontal, twin tank dehydrator and flow regulator.

Another well, possibly Water Well #2, is located near the dehydrator and the watering troughs. It consists of a 6 1/2-inch diameter pipe that extends approximately 28 inches above the ground surface. The well is uncapped and does not appear to be active (Figure 3.26-15).

Figure 3.26-11. Close-up of welding on emplacement hole casing (photo taken August 10, 2003 on file at Desert Research Institute).

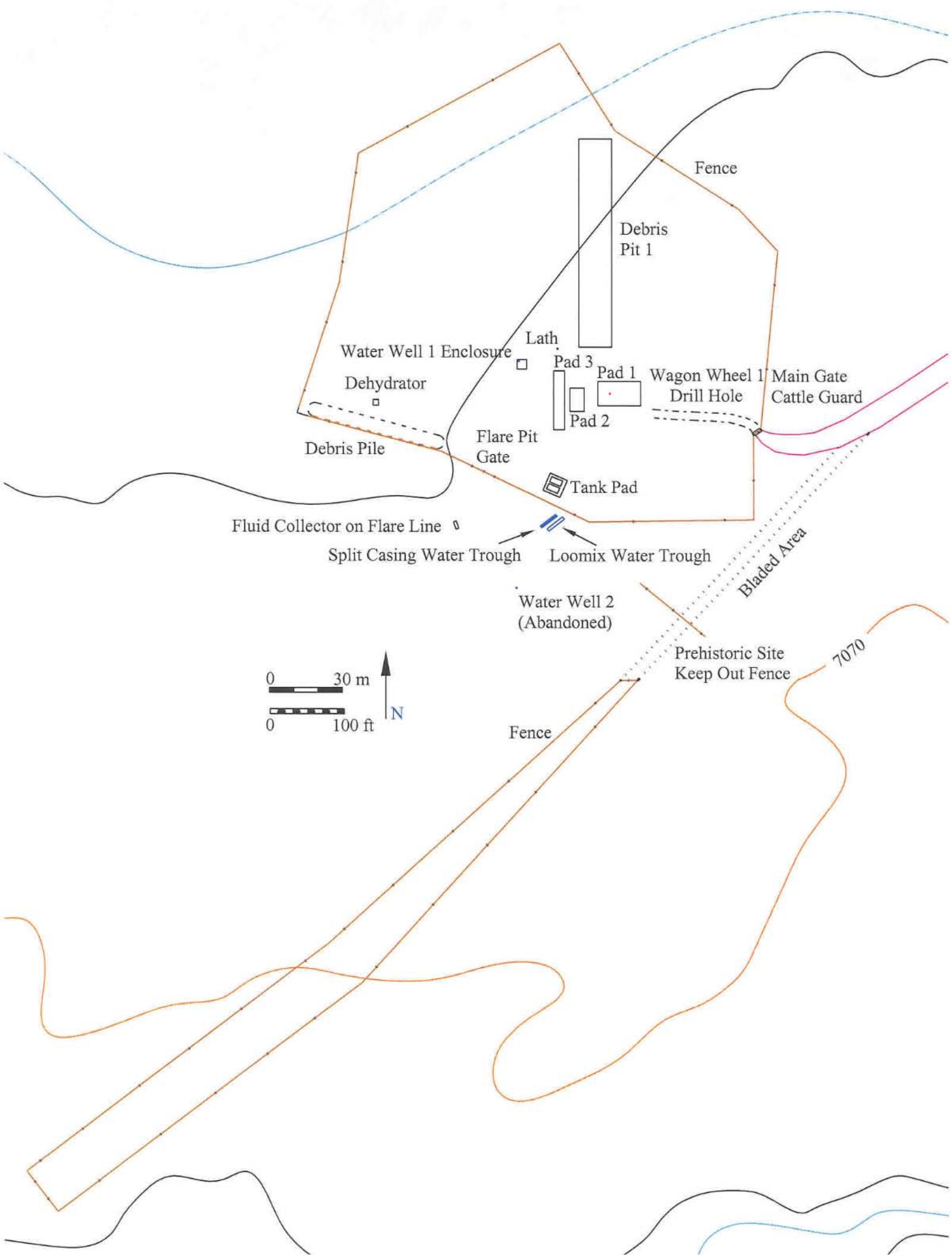


Figure 3.26-12. Plot plan of Project Wagon Wheel Site from FY 2003 field visit.

Figure 3.26-13. Water Well No. 1 is still active (photo taken August 10, 2003 on file at Desert Research Institute).

Figure 3.26-14. Tanks from the Wagon Wheel Project reused as w ater tanks (photo taken August 10, 2003 on file at Desert Research Institute).

Figure 3.26-15. Water Well No. 2 is in the foreground. The watering troughs and water tanks are in the background. View is to the northwest (photo taken August 10, 2003 on file at Desert Research Institute).

A long fenced enclosure comprised of posts and four strands of barbed wire is located south of the Wagon Wheel compound. Unrelated to the Plowshare project, the enclosure surrounds a shallow depression lined its entire length with black poly-tarp weighted down by river cobbles and sand.

In addition to the structural remains and features, discarded drilling equipment, construction material, and miscellaneous debris are piled along the south fence line and in the large debris pit north of Wagon Wheel #1 (Figure 3.26-16). The debris includes black PVC pipe, metal hose clamps, railroad ties and lumber of various sizes, wooden lath, plywood sheets, galvanized pipe, metal hose/pipe couplers, threaded pipe couplings, threaded pipe caps, iron pipe in various lengths and diameters, metal fence posts, galvanized corrugated pipe sections, empty 5-gallon gas cans, dehydrators, flow regulators, cardboard boxes, D-cell batteries, soda cans, solder cans, empty motor oil cans and paint cans, several empty 55-gallon drums, galvanized culvert, wooden pallets, and various components of flow regulators (Figure 3.26-17). With the exception of the recent activity of the Ultra Resources survey crew; the site looks probably much as it did when the Wagon Wheel project was abandoned in 1975.

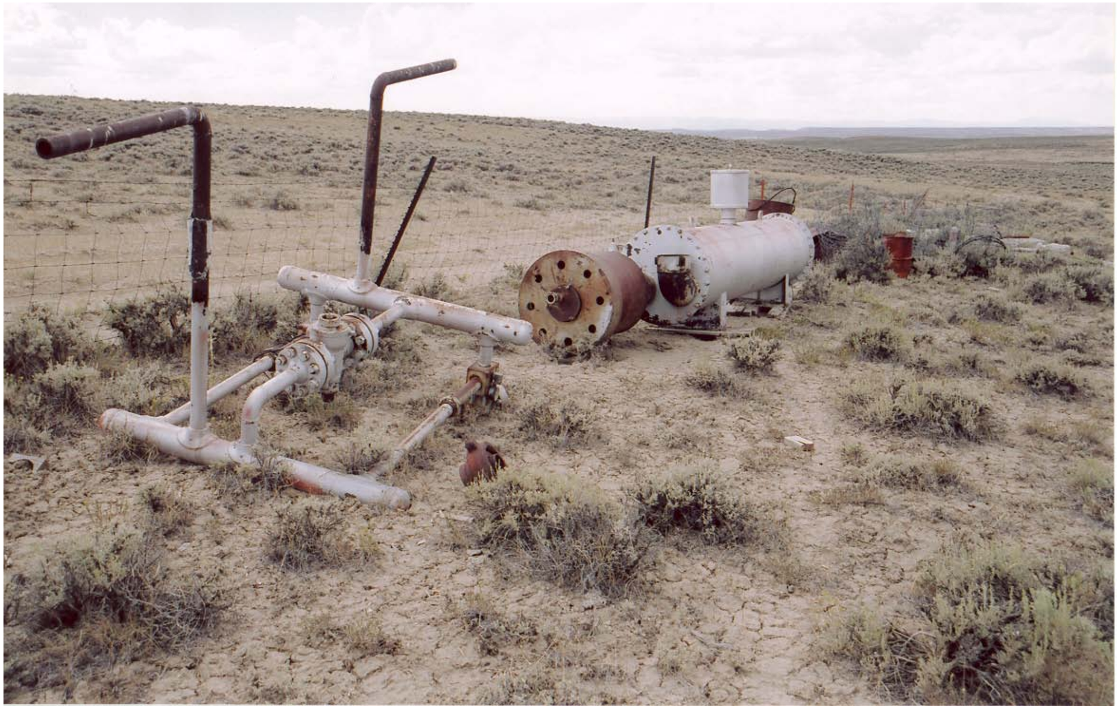


Figure 3.26-16. Discarded equipment along the south fence line (photo taken August 10, 2003 on file at Desert Research Institute).

Figure 3.26-17. Construction debris in pit north of the Wagon Wheel No. 1 emplacement hole (photo taken August 10, 2003 on file at Desert Research Institute).

A visit to the Bureau of Land Management, Pinedale Resource Area Office provided some data concerning the land status of the Wagon Wheel project area. According to the agency's oil and gas leasing specialist, the Bureau of Land Management has legal jurisdiction over the former project site. Currently several companies are interested in re-developing the old Wagon Wheel lease although not the actual well. Ultra Resources plans on drilling at least three, and possibly more, new wells in and around the Wagon Wheel #1 location within the next year. Shell Oil Company is looking at developing a leasehold just south of the Wagon Wheel compound. At the present time, it is unclear how extensively these projects will impact the site. Local Bureau of Land Management personnel were convinced that the historic well head marking the Wagon Wheel #1 drill hole would be removed during the new gas exploration/development activities.

CHRONOLOGICAL BIBLIOGRAPHY

Werth, Glenn C., [between 1966 and 1973]. Handwritten notes on Plowshare program meetings from Glenn C. Werth, U.S. Atomic Energy Commission, Division of Peaceful Nuclear Explosives, 1966-1973. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-118.

Rawson, Don, 1967. "Preliminary Information on Pinedale from EPNG Geologists." Memo from Don Rawson, Lawrence Radiation Laboratory, to Distribution, July 31. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-067.

Smith, Sam, 1967. Letter from Sam Smith, El Paso Natural Gas Company, El Paso, TX, to John F. Philip, September 1. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-067.

Kelly, John S., 1967. "Redirection of Plowshare Industrial Effort." Memo from John S. Kelly through General Manager, U.S. Atomic Energy Commission, to Seaborg et al., November 21. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-027.

Holzer, Fred, 1968. "EPNG Time Table for Pinedale." Memo from F. Holzer, Lawrence Radiation Laboratory, to G. Werth, March 21. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-032.

Smith, Sam, 1968. Letter from Sam Smith, El Paso Natural Gas Company, El Paso, TX, to John F. Philip, April 2. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-032.

McCool, W. B., 1968. “Atomic Energy Commission Status of Plowshare Industrial Projects." Memo with encl. ("Status of Plowshare Industrial Projects," memo from John S. Kelly, U.S. Atomic Energy Commission, Division of Peaceful Nuclear Explosives, to List) from W. B. McCool, U.S. Atomic Energy Commission to Distribution, April 26. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029 [OUO].

Kelly, John S., 1968. Letter from John S. Kelly, U.S. Atomic Energy Commission, to Samuel Smith, September 30. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-032.

Kelly, John S., 1968. "Proceed to the Project Definition Phase on Project Pinedale." Telex from John S. Kelly, Lawrence Radiation Laboratory, to James Reeves, December 10. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-032.

Cooper, William R., 1969. Letter with encl. (Pinedale Agreement, Contract No. AT(26-1)-422) from William R. Cooper, U.S. Atomic Energy Commission, Nevada Operations Office, to W. E.. Ogle, G. C. Werth, and C.D. Broyles, January 2. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-032.

Serocki, Stan T., 1969. "Pinedale - Programs and Costs Estimates for Possible Emplacement Holes." Memo from Stan T. Serocki to James L. Cramer, January 8. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-032.

Werth, Glenn C., 1969. Letter (draft) from Glenn C. Werth (prepared by Gary H. Higgins) to William R. Cooper, January 17. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-032.

Blankenship, T. H., 1969. "Initial Meeting of the Pinedale Joint Project Definition Group." Telex from T. H. Blankenship, U.S. Atomic Energy Commission, Nevada Operations Office, to L. Randolph et al., February 14. O n file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-032.

Sterrett, T. S., 1969. "Maximum Formational Temperatures and Pressures Encountered at the Pinedale and WASP Project Areas." Memo from T. S. Sterrett, Lawrence Radiation Laboratory, to M. D. Nordyke, March 10. O n file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-061.

Kelly, John S., 1969. Letter from John S. Kelly, U.S. Atomic Energy Commission, to Norris E. Bradbury, March 12. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-032.

Reservoir Engineering Department, 1969. A Reservoir Analysis and Gas in Place Study Concerning the Possible Use of Nuclear Stimulation of the Fort Union Formation; Pinedale Field Sublette County, Wyoming. Manuscript, March 18. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-032.

Power, Dean V., 1969. Preliminary "Pinedale" Seismic Safety Evaluation. Manuscript, El Paso Natural Gas Company Nuclear Group, El Paso, TX, April 8. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-032.

Werth, Glenn C., 1969. Planned Applications of Peaceful Nuclear Explosives. University of California, Lawrence Radiation Laboratory, *Report UCRL*-71901, August 13. Livermore, CA. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-037.

Shaughnessy, Jack, 1969. Completion Report, Wagon Wheel Water Well No. 1. Manuscript (PNE-WW-18), El Paso Natural Gas Company, Farmington, NM, September. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

El Paso Natural Gas Company, 1969. "Pinedale, Well No. Pinedale Unit #5." Drawings/Graphs of static surveys and temperature surveys, October 2.

King, Kenneth W., 1969. Preliminary WASP/Wagon Wheel Seismic Evaluation. U.S. Department of Commerce, Environmental Science Services Administration, *Coast and Geodetic Survey, Report,* No. CGS-746-1, October 30. Rockville, MD. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Gardner, M. C., P. R. Fenske, and C. E. Downs, 1969. Effects Evaluation for Ground Water Project Wagon Wheel. Report to U.S. Atomic Energy Commission, Nevada Operations Office (NVO-1229-120), from Isotopes, Palo Alto Laboratories, Palo Alto, CA, November. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Plowshare Advisory Committee, 1969. Plowshare Advisory Committee, Report on Nineteenth Meeting. Meeting held at Lawrence Radiation Laboratory, Livermore, CA, November 4-5. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029 [OUO].

Holzer, Fred, 1969. "Summary of the AIF Workshop on Industrial Plowshare Program - November 17 to 19, 1969." Memo from Fred Holzer, Lawrence Radiation Laboratory, to M. M. May, November 20. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-100.

McAnally, H. E., 1969. "Bottom Hole Pressure for the Hydrological Test Run on Wagon Wheel No. 1." Memo from H. E. McAnally, El Paso Natural Gas Company, Farmington, NM, to C. E. Matthews, December 1.

U.S. Atomic Energy Commission, 1970. Chapter 11 - Peaceful Nuclear Explosives. In *Annual Report to Congress of the Atomic Energy Commission for 1969,* pp. 195-203, January. U.S. Government Printing Office, Washington D.C.

U.S. Atomic Energy Commission. Nevada Operations Office, 1970. Project Wagon Wheel: Preliminary Site Evaluation Report. U.S. Atomic Energy Commission, Nevada Operations Office, Report No. NVO-55, March. Las Vegas, NV. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Miller, Robert E., 1970. "Amendment No. 1 - DPNE (Plowshare) Work Authorization 70-6, Wasp/Wagon Wheel - Field Planning and Support." Memo from Robert E. Miller, U.S. Atomic Energy Commission, Nevada Operations Office, to R. H. Thalgott, et al., March 4. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0173145.

U.S. Atomic Energy Commission, 1970. "Plowshare Program Statement, JCSE FY 1971 Authorization Hearings." Statement from U.S. Atomic Energy Commission, March 5. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-028.

Shaughnessy, Jack, and R. H. Butcher, 1970. Project Wagon Wheel: Interim Report of Wagon Wheel No. 1 at Casing Point Depth of 12,106 Feet. Report PNE-WW-15, El Paso Natural Gas Company Northwest Region, April. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Evans, Roy B., and David E. Bernhardt, 1970. “Probable Scheduling of Plowshare Events.” Memo from Roy B. Evans and David E. Bernhardt, U.S. Department of Health, Education, and Welfare, Southwestern Radiological Health Laboratory, to Francis N. Buck, May 8. On file at Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0173142 [OUO].

West, Chris L., 1970. “Answer to Inquiry Status of Bronco, WASP, and Wagon Wheel.” Letter from Chris L. West, U.S. Atomic Energy Commission, Nevada Operations Office, to Files, October 7. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0325747.

U.S. Atomic Energy Commission, 1970. *Plowshare Program During 1969: Based on the Annual Report to Congress for 1969 of the U.S. Atomic Energy Commission.* U.S. Atomic Energy Commission, U.S. Government Printing Office, Washington, D.C. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

U.S. Atomic Energy Commission. Nevada Operations Office, [1970?]. Project Wagon Wheel Site Evaluation Report. Manuscript, Las Vegas, NV, no da te. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

U.S. Atomic Energy Commission, 1971. Chapter 9 - Peaceful Nuclear Explosives. In *Annual Report to Congress of the Atomic Energy Commission for 1970,* pp. 195-202, January. U.S. Government Printing Office, Washington D.C.

U.S. Atomic Energy Commission, 1971. S.958 AEC Authorization Bill for Fiscal Year 1972 (Nuclear Waste Disposal). Hearings Before the Joint Committee on Atomic Energy, Congress of the United States, Washington, D.C., March 23. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-028.

Plowshare Advisory Committee, 1971. Plowshare Advisory Committee, Report on Twenty-First Meeting. Meeting held at U.S. Atomic Energy Commission Offices, Washington, D.C., April 28-29. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029 [OUO].

Werth, Glenn C., 1971. Status of Contained Nuclear Explosive Applications. University of California, Lawrence Radiation Laboratory, *Report UCRL*-51074, June 21. Livermore, CA. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-103.

Shaughnessy, Jack, 1971. Completion Report: Wagon Wheel Water Well No. 2. Report PNE-WW-16, El Paso Natural Gas Company, Farmington, NM, July 21. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0068490.

Werth, Glenn C., 1971. "Results of the Poll of the Technically Most Innovative Developments in 1971." Memo from Glenn C. Werth, Lawrence Radiation Laboratory, to Management Group, August 26. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-027.

Terhune, Robert W., 1971. Prediction of Underground Nuclear Explosion Effects in Wagon Wheel Sandstone. University of California, Lawrence Radiation Laboratory, *Report UCRL*-50993, Revision 1, September 13. Livermore, CA. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV; and Archive and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

Werth, Glenn C., 1971. Letter from Glenn C. Werth, Lawrence Radiation Laboratory, to John S. Kelly, December 3.

Borg, I. Y., 1971. Microscopic Examinations of Undeformed and Laboratory Deformed Wagon Wheel Rocks. In Project Wagon Wheel: Technical Studies Report, El Paso Natural Gas Company, editor, pp. 187-202. El Paso Natural Gas Company, Report PNE-WW-1, December 31. El Paso, TX. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Butcher, R. H., 1971. Modal Analysis of Petrographic Study. In Project Wagon Wheel: Technical Studies Report, El Paso Natural Gas Company, editor, pp. 203-206. El Paso Natural Gas Company, Report PNE-WW-1, December 31. El Paso, TX. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Cutler, W. G., 1971. Drilling Program. In Project Wagon Wheel: Technical Studies Report, El Paso Natural Gas Company, editor, pp. 17-29. El Paso Natural Gas Company, Report PNE-WW-1, December 31. El Paso, TX. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

El Paso Natural Gas Company, 1971. Project Wagon Wheel: Technical Studies Report. El Paso Natural Gas Company, editor, Report PNE-WW-1, December 31. El Paso, TX. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Green, S. J., R. M. Griffin, and H. R. Pratt, 1971. Material Properties of Wagon Wheel Shale for Shock Calculations. In Project Wagon Wheel: Technical Studies Report, El Paso Natural Gas Company, editor, pp. 101-124. El Paso Natural Gas Company, Report PNE-WW-1, December 31. El Paso, TX. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Habbit, R. D., H. J. Patel, and R. F. Lemon, 1971. Reservoir and Recoverable Gas Analysis. In Project Wagon Wheel: Technical Studies Report, El Paso Natural Gas Company, editor, pp. 153-178. El Paso Natural Gas Company, Report PNE-WW-1, December 31. El Paso, TX. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Lessler, R., and J. Green, 1971. Radioactivity. In Project Wagon Wheel, Technical Studies Report, El Paso Natural Gas Company, editor, pp. 207-210. El Paso Natural Gas Company, Report PNE-WW-1, December 31. El Paso, TX. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Montan, D. N., 1971. Wagon Wheel Production Calculations. In Project Wagon Wheel: Technical Studies Report, El Paso Natural Gas Company, editor, pp. 179-181. El Paso Natural Gas Company, Report PNE-WW-1, December 31. El Paso, TX. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Power, Dean V., 1971. Ground Motion Predictions. In Project Wagon Wheel: Technical Studies Report, El Paso Natural Gas Company, editor, pp. 217-237. El Paso Natural Gas Company, Report PNE-WW-1, December 31. El Paso, TX. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Pratt, H. R., R. M. Griffin, and A. D. Black, 1971. Rock Mechanics on Wagon Wheel Sandstone. In Project Wagon Wheel: Technical Studies Report, El Paso Natural Gas Company, editor, pp. 79-100. El Paso Natural Gas Company, Report PNE-WW-1, December 31. El Paso, TX. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Quong, R., and W. J. LaGuardia, 1971. Permeability of Gas Reservoir Specimens. In Project Wagon Wheel: Technical Studies Report, El Paso Natural Gas Company, editor, pp. 125-126. El Paso Natural Gas Company, Report PNE-WW-1, December 31. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Rogers, Leo A., and R. W. Terhune, 1971. Interpretive Summary. In Project Wagon Wheel: Technical Studies Report, El Paso Natural Gas Company, editor, pp. 1-5. El Paso Natural Gas Company, Report PNE-WW-1, December 31. El Paso, TX. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Schock, R. N., H. C. Heard, and D. R. Stephens, 1971. High-Pressure Mechanical Properties of Rocks from Wagon Wheel No. 1 Well. In Project Wagon Wheel: Technical Studies Report, El Paso Natural Gas Company, editor, pp. 65-77. El Paso Natural Gas Company, Report PNE-WW-1, December 31. El Paso, TX. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Shaughnessy, Jack, and R. H. Butcher, 1971. Geological Report. In Project Wagon Wheel: Technical Studies Report, El Paso Natural Gas Company, editor, pp 7-16. El Paso Natural Gas Company, Report PNE-WW-1, December 31. El Paso, TX. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Shaughnessy, Jack, R. H. Butcher, and T. S. Sterrett, 1971. Hydrological Evaluation. In Project Wagon Wheel: Technical Studies Report, El Paso Natural Gas Company, editor, pp. 31-46. El Paso Natural Gas Company, Report PNE-WW-1, December 31. El Paso, TX. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Sterrett, T. S., 1971. Areal Extent of Wagon Wheel Gas-Bearing Sandstone Units. In Project Wagon Wheel: Technical Studies Report, El Paso Natural Gas Company, editor, pp. 183-185. El Paso Natural Gas Company, Report PNE-WW-1, December 31. El Paso, TX. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Terhune, Robert W., 1971. Prediction of Underground Nuclear Explosion Effects. In Project Wagon Wheel: Technical Studies Report, El Paso Natural Gas Company, editor, pp. 47-64. El Paso Natural Gas Company, Report PNE-WW-1, December 31. El Paso, TX. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Tewes, H., and R. Taylor, 1971. Gas Quality at Wellhead: Predictions for Project Wagon Wheel. In Project Wagon Wheel: Technical Studies Report, El Paso Natural Gas Company, editor, pp. 239-248. El Paso Natural Gas Company, Report PNE-WW-1, December 31. El Paso, TX. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Hill, John H., 1971. Chemical Analysis of Samples from Wagon Wheel No. 1. In Project Wagon Wheel: Technical Studies Report, El Paso Natural Gas Company, editor, pp. 211-215. El Paso Natural Gas Company, Report PNE-WW-1, December 31. El Paso, TX. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Keelan, Dare K., 1971. Special Core Analysis Study. In Project Wagon Wheel: Technical Studies Report, El Paso Natural Gas Company, editor, pp. 127-152. El Paso Natural Gas Company, Report PNE-WW-1, December 31. El Paso, TX. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

U.S. Atomic Energy Commission, 1972. Plowshare Program. In *Annual Report to Congress of the Atomic Energy Commission for 1971,* pp. 139-142, January. U.S. Government Printing Office, Washington D.C.

Flaherty, J. J., and J. S. Kelly, 1972. "General Advisory Committee Briefing on Plowshare Program." Agenda, January 31. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-028.

Rogers, Leo A., 1972. Project Wagon Wheel: Nuclear Explosive Stimulation of a Natural Gas Well. Paper (El Paso Natural Gas Company, Report PNE-WW-7), presented at the National Meeting of the American Institute of Chemical Engineers, Dallas, Texas, February 22-23.

Werth, Glenn C., 1972. Letter from Glenn C. Werth, Lawrence Livermore Laboratory, to John S. Kelly, March 3.

Dames & Moore, 1972. Project Wagon Wheel: Structural Response and Environmental Impact Evaluation, Phase 1. Report PNE-WW-11 to El Paso Natural Gas Company from Dames & Moore, March 20. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Werth, Glenn C., 1972. Unclassified Portion of Gas Stimulation Briefing. Presentation to General Advisory Committee, March 20, 1972. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-028.

U.S. Atomic Energy Commission, 1972. Wagon Wheel Gas Stimulation Project, Sublette County, Wyoming, Environmental Statement. U.S. Atomic Energy Commission, Report Nos. WASH-1524 and PNE-WW-5, April. Washington, D.C. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Steele, Mary Ann, 1972. Letter from Mary Ann Steele, Wagon Wheel Information Committee, to James R. Schlesinger, April 11. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0076279.

Shaughnessy, Jack, and R. H. Butcher, 1972. Geology of Project Wagon Wheel Nuclear Stimulation Project. Paper (PNE-WW-14) presented at the National Convention of the American Association of Petroleum Geologists, Denver, CO, April 17-19. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

El Paso Natural Gas Company, 1972. Project Wagon Wheel. Report PNE-WW-8 prepared for distribution at Annual Meeting of the Green River Valley Cattlemen's Association, April 29. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

U.S. Atomic Energy Commission. Nevada Operations Office, 1972. Reports Available in Plowshare Open File. Report, NVO-D171886 (Rev. 1) UC-35, May. On file at: Defense Threat Reduction Information Analysis Center, Albuquerque, NM.

Vesper, Howard G., 1972. Letter with encl. (Report on the Ad Hoc Plowshare Review Committee) from Howard G. Vesper, General Advisory Committee, U.S. Atomic Energy Commission, to James R. Schlesinger, May 22. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-028 [OUO].

Werth, Glenn C., 1972. Memo from Glenn C. Werth, Lawrence Livermore Laboratory, to Roger E. Batzel, June 7. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-028.

Lawson, Herbert G., 1972. Plowshare Payoff? The Nuclear Blasting of Gas Wells Appears Near Commercial Use, Contract to Serve 18 Towns in Colorado is Discussed, Seen as a Regulatory Test. *Wall Street Journal*, June 8. On file at: Archives an Research Center, Lawrence Livermore National Laboratories, Livermore, CA, File PLO-029.

Dolenc, Max R., Dean V. Power, C. T. Hamlett, and H. Samaniego, 1972. Cultural and Environmental Survey Studies – 1971. Manuscript (PNE-WW-19), El Paso Natural Gas Company, El Paso, TX, August 25. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Eberline Instrument Corporation, 1972. Radiation in the Wagon Wheel Environment, In Project Wagon Wheel: Technical Studies Report Number Two, Leo A Rogers, editor, pp. C1-C24. El Paso Natural Gas Company, Report PNE-WW-13, October 1. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Fisser, H. G., 1972. An Ecological Description of Biotic Communities of the Wagon Wheel Environs. In Project Wagon Wheel: Technical Studies Report Number Two, Leo A Rogers, editor, pp. I1-I48. El Paso Natural Gas Company, Report PNE-WW-13, October 1. El Paso, TX. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Parks, Donald E., and Leo A. Rogers, 1972. Preliminary Predictions of Wagon Wheel Chimney Temperature. In Project Wagon Wheel: Technical Studies Report Number Two, Leo A. Rogers, editor, pp. E 1-E35. El Paso Natural Gas Company, Report PNE-WW-13, October 1. El Paso, TX. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Power, Dean V., 1972. Predicted Effects of Ground Motion: Project Wagon Wheel. In Project Wagon Wheel: Technical Studies Report Number Two, Leo A. Rogers, editor, pp. B1-B7. El Paso Natural Gas Company, Report PNE-WW-13, October 1. El Paso, TX. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Power, Dean V., 1972. Predicted Ground Motions: Project Wagon Wheel, In Project Wagon Wheel: Technical Studies Report Number Two, Leo A. Rogers, editor, pp. A1-A15. El Paso Natural Gas Company, Report PNE-WW-13, October 1. El Paso, TX. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Rogers, Leo A., 1972. Estimate of In-Situ Stress at Project Wagon Wheel. In Project Wagon Wheel, Technical Studies Report Number Two, Leo A Rogers, editor, pp. H1-H4. El Paso Natural Gas Company, Report PNE-WW-13, October 1. E1 Paso, TX. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Rogers, Leo A. (editor), 1972. Project Wagon Wheel: Technical Studies Report Number Two. El Paso Natural Gas Company, Report PNE-WW-13, October 1. El Paso, TX. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Schalit, L. M., and D. H. Laird, 1972. Predictions of Initial Gas Composition for Project Wagon Wheel, In Project Wagon Wheel: Technical Studies Report Number Two, Leo A Rogers, editor, pp. F1-F18. El Paso Natural Gas Company, Report PNE-WW-13, October 1. El Paso, TX. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Sterrett, T. S., 1972. Off-Site Water Well and Natural Spring Documentation. In Project Wagon Wheel: Technical Studies Report Number Two, Leo A. Rogers, editor, pp. D1-D35. El Paso Natural Gas Company, Report PNE-WW-13, October 1. El Paso, TX. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Chew, Eddie W., 1972. Release of Radioactivity from Wagon Wheel, In Project Wagon Wheel: Technical Studies Report Number Two, edited by Leo A Rogers, pp. G1-G16, Report PNE-WW-13.

Draft Environmental Statement Project Wagon Wheel, [1972?]. Draft Environmental Statement Project Wagon Wheel. Manuscript, no date. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0018063.

U.S. Environmental Protection Agency, [1972?]. Comments on Draft Environmental Statement for Wagon Wheel Gas Stimulation Project, Wyoming, (AEC Document WASH-1524). Manuscript, no date. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0076274.

Bell, Paul A., and Glenn A. Whan, 1973. Plowshare Technology Assessment: Material Resources Analysis. Paper presented at the 1972 Winter Meeting of the American Nuclear Society, Washington, D. C., January. Report to Western Interstate Nuclear Board from University of Mexico. On file at: Defense Threat Reduction Information Analysis Center, Albuquerque, NM.

Taylor, R. W., 1973. "Trip Report - French Model for Cavity History: A Comparison to Chapin's Model and an Application to Wagon Wheel." Memo from R. W. Taylor, Lawrence Livermore Laboratory, to Distribution, January 12. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-108.

Star-Tribune, 1973. Economy Cuts Wagon Wheel. *Star-Tribune*, January 30. Casper, WY. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0189017.

Daily Rocket-Miner, 1973. Wagon Wheel Delayed Until 1977: Hansen. *Daily Rocket-Miner*, February 3. Rock Springs, WY. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0189011.

Star-Tribune, 1973. Nixon Budget Delays Wagon Wheel Plans. *Star-Tribune*, February 3. Casper, WY. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0189012.

Laramie Daily Boomerang, 1973. Budget Cuts Halt Wagon Wheel. *Laramie Daily Boomerang*, February 4. Laramie, WY. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0189058.

Wyoming Eagle, 1973. Wagon Wheel Group Head on 'Today' Show Today. *Wyoming Eagle,* February 6. Cheyenne, WY. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0189053.

Jackson Hole Guide, 1973. What Will Become of the Wagon Wheel Project? *Jackson Hole Guide*, February 22. Jackson Hole, WY. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0189025.

Whan, Glenn A., 1973. Plowshare Technology Assessment, Final Report, Implications to State Governments. Report to the Western Interstate Nuclear Board, Lakewood, CO, from Glenn A. Whan, Chemical and Engineering Department, University of New Mexico. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Roncalio, Teno, 1974. Stop Waste Now. Congressional Record - House. Statement (including paper prepared for the Tri-State Energy Conference, Denver, Co, February 1) by Hon. Teno Roncalio, February 25. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029.

Denver Post, 1974. N-Blast Gas Stimulation May Be Subsiding. *Denver Post*, March 14. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029.

Shaughnessy, Jack, and R. H. Butcher, 1974. Geology of Wagon Wheel Nuclear Stimulation Project, Pinedale Field, Wyoming. The American Association of Petroleum Geologists, Vol. 58, No. 11, pp. 2250-2259, November.

Crump, Joseph R., 1975. PNE (Peaceful Nuclear Explosion) Activity Projections for Arms Control Planning, Vol. I. Report to the U.S. Arms Control and Disarmament Agency, Contract No. ACDE/PAB-253, from Gulf Universities Research Consortium, Galveston, TX, April 10.

Whicker, F. Ward, A. William Alldredge, Herbert G. Fisser, and George Post, 1975. Ecological Considerations for Project Wagon Wheel and Hydraulic Fracturing Activities: Phase II (a), Annual Summary for 1974. Report (PNE-WW-40) to El Paso Natural Gas Company, August. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Whicker, F. Ward, A. William Alldredge, Herbert G. Fisser, Wayne C. Hanson, and George Post, 1976. Ecological Considerations for Project Wagon Wheel and Hydraulic Fracturing Activities: Phase II (b), Annual Summary for 1975 and Project Completion Report. Report (PNE-WW-41) to El Paso Natural Gas Company, July. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Shafer, David S., William. C. Beck, Dwight Treadwell, and Stephen. A. Mellington, 1995. Inventory of Potential Environmental Restoration Liabilities Associated with Plowshare And Vela Uniform Program Sites. Manuscript, U.S. Department of Energy, Office of Environmental Restoration. On file at: Desert Research Institute, Las Vegas, NV.

Lederer, Adam M., 1998. Using Public Policy Models to Evaluate Nuclear Stimulation Projects: Wagon Wheel in Wyoming. Masters thesis, Department of Political Science, University of Wyoming, May. Laramie, WY.

Lederer, Adam M., 2002. Project Wagon Wheel: A Nuclear Plowshare for Wyoming. <http://www.elmada.com/wagon/WWS000Plow.html>, last accessed October 22, 2002.

Lawrence Livermore National Laboratory, n.d. "Green River Basin-Wyoming." Green River basin map_05_a. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

Lawrence Livermore National Laboratory, n.d. "Nuclear Gas Reservoir Stimulation." Nuclear gas reservoir drawing, gas_b. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA.

Map of Project Wagon Wheel Site , n.d. Map of Project Wagon Wheel Site. Map showing site of blast. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0189042.

WASP and Wagon Wheel: Area Map Projects, n.d. "Area Map Projects WASP and Wagon Wheel." Map (JAB-99-68). On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Wasp Area - Large Scale Map, n.d. "WASP Area - Large Scale Map." On file at: Engineering Records Library, Nevada Test Site, Mercury, NV.

Wasp Area - Large Scale Map (Merna Site), n.d."WASP Area - Large Scale Map (Merna Site)." On file at: Engineering Records Library, Nevada Test Site, Mercury, NV.

THIS PAGE INTENTIONALLY LEFT BLANK

3.27 WASP

Plowshare Program
Nuclear Explosives for Stimulation of Underground Natural Gas Reservoirs
Wyoming

Following the development of the Wagon Wheel Project, a second Plowshare project was proposed for the Green River Basin of southwestern Wyoming by a group of six independent oil companies with International Nuclear Corporation acting as the main operator (Figures 3.27-1 and 3.27-2). The group was formed in 1967 to develop and exploit natural gas resources on lands held under lease by the group including Burnham and Company of New York City, CRA, Inc. of Kansas City, Waymon G. Peavy of Dallas, International Nuclear Corporation of Denver, Oil and Gas Futures, Inc. of Bellaire, Texas, Petroleum Resources Company of Cushing, Oklahoma, and Planet Oil and Mineral Corporation of Dallas. Designated WASP for Wyoming Atomic Stimulation Project, it was another industry-sponsored natural gas stimulation project using nuclear explosives to fracture low-permeability and high-pressure gas bearing sandstone reservoirs. Furthermore, because of the similarities between Wagon Wheel and WASP, the same project evaluation panel established for Wagon Wheel was responsible for the WASP project.

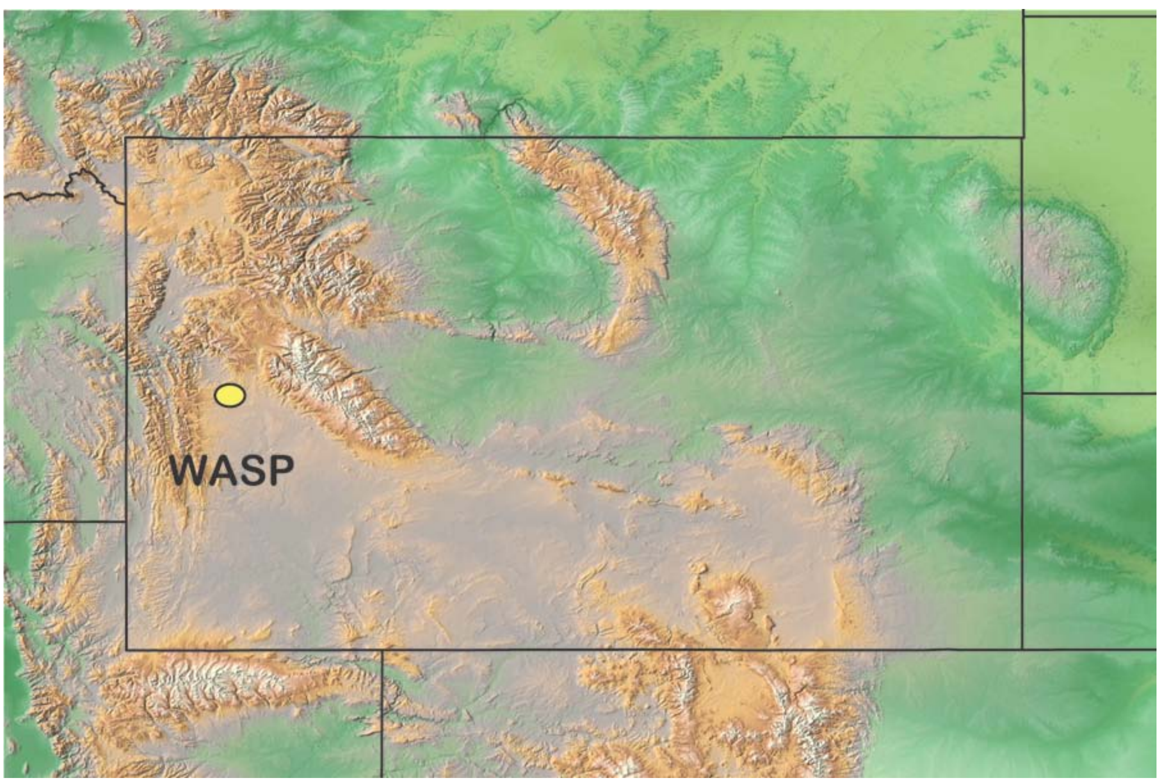


Figure 3.27-1. Location of Project WASP in Wyoming (adapted from USA Relief Maps 2004).

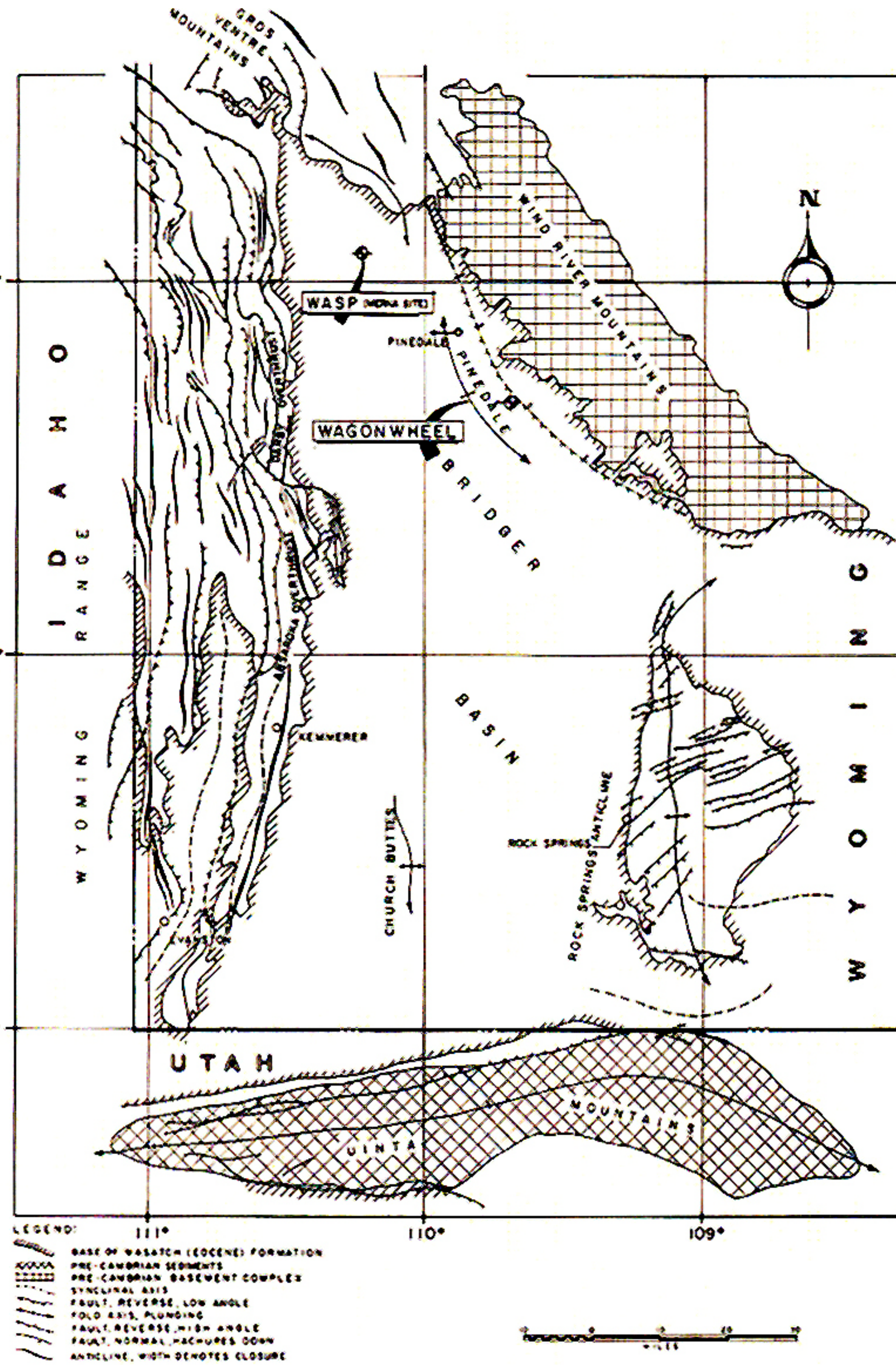


Figure 3.27-2. General area for Project WASP near Pinedale, Wyoming showing tectonic features of the Green River Basin (U.S. Atomic Energy Commission, Nevada Operations Office 1970, Figure 3).

Initial research efforts for the WASP project began in early 1967 and consisted of compiling and evaluating all published material on underground nuclear detonations and their potential for gas stimulation. The industrial group promoting the project completed a preliminary feasibility study in mid-1967 which led to the purchase and consolidation of oil and gas leases in the Pinedale region. The WASP partners held leases on approximately 285,000 acres in this area.

Originally, the WASP group chose the site location, known as the Merna site, to be in SW1/4, 1,320 ft from south line and 1,320 ft from west line of Sec. 28, T36N R112W, and toward the northern end of the Green River Valley, Sublette County, Wyoming (Figures 3.27-3 and 3.27-4). Elevation was 7,775 ft. It was bounded on three sides by high mountain ranges: the Wyoming Range, the Gros Ventre Range, and the Wind River Range. Surrounding the project area were cattle ranches and portions of the Bridger

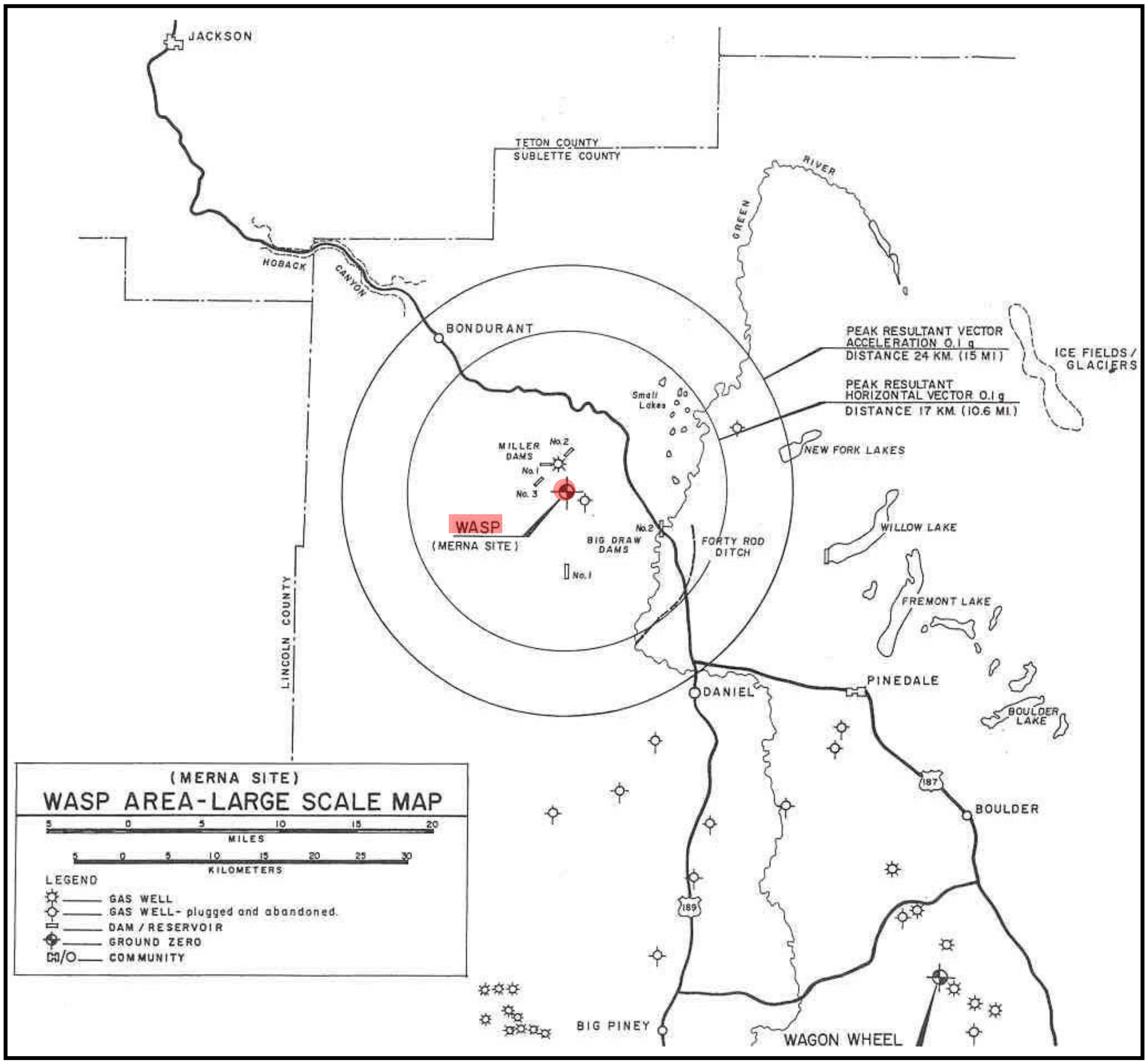


Figure 3.27-3. Location of Project WASP at the Merna Site (adapted from U.S. Atomic Energy Commission, Nevada Operations Office 1970, Figure 1).

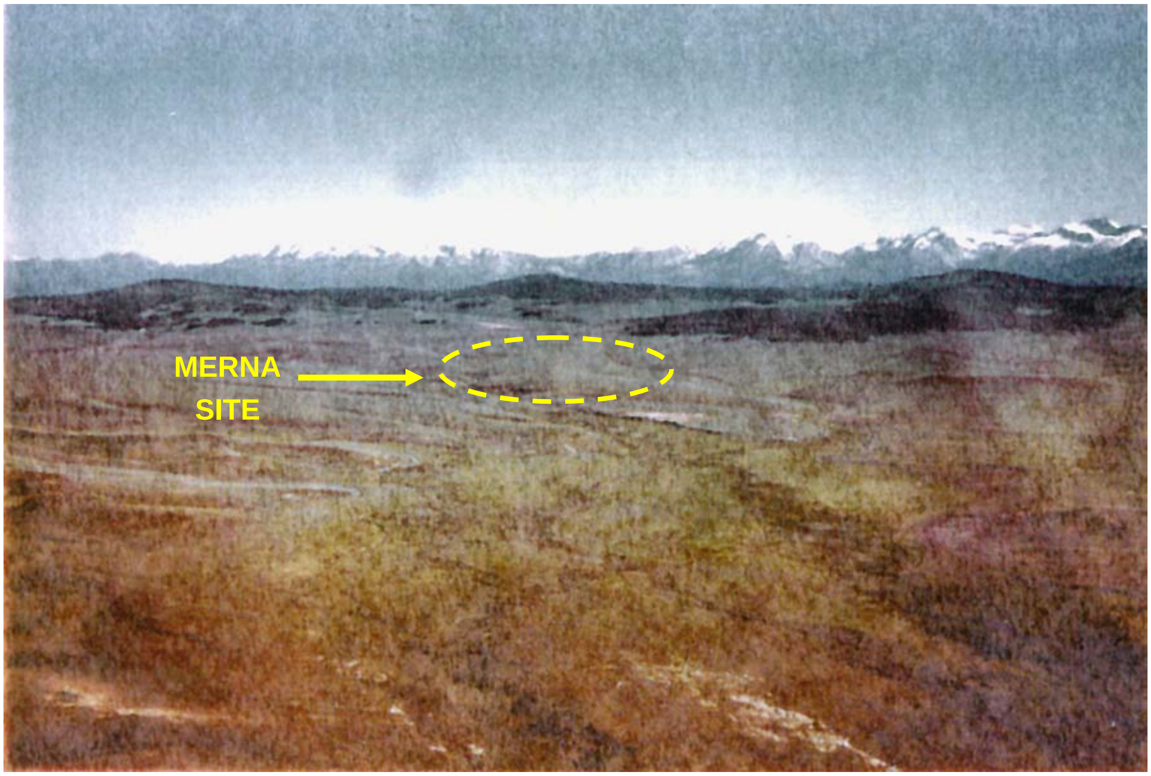


Figure 3.27-4. Overview of the Merna Site, Sublette County Wyoming. The proposed emplacement hole is located between two existing gas wells that appear as bare spots in the center of the 1969 photograph. View is to the northeast [best copy available] (adapted from International Nuclear Corporation 1969, Figure 4).

and Teton national forests. Nearest inhabitants were about four miles away and the nearest populated center between 10 and 15 miles. Field headquarters for the project was at Pinedale, Wyoming. A second and alternative site, called the Daniel site, was also proposed for the same general area as the primary site and located in the center of S1/2, Sec. 32, T34N R111W (Figure 3.27-5).

In March 1969, the Governor of Wyoming was briefed on the proposed experiment by U.S. Atomic Energy Commission and U.S. Bureau of Mines staff. Two months later, the WASP project partners gave representatives of other Wyoming state organizations a technical briefing on the gas stimulation experiment. Shortly thereafter, the WASP group signed a project definition agreement with the government. At least two drill holes were planned, an evaluation hole and an emplacement hole. The emplacement hole was proposed for early 1970, with the test in mid-1970, and post-shot investigations carried out in late 1970 and 1971. Cooperating entities in this effort included the WASP Group, U.S. Department of the Interior, and the U.S. Atomic Energy Commission and its contractors. Objectives of the first phase were to gather data determining the quality of the gas sands to support additional expenses of emplacing and detonating a nuclear device for stimulation of the gas. The director of the Division of Peaceful Nuclear Explosives authorized the U.S. Atomic Energy Commission, Nevada Operations Office

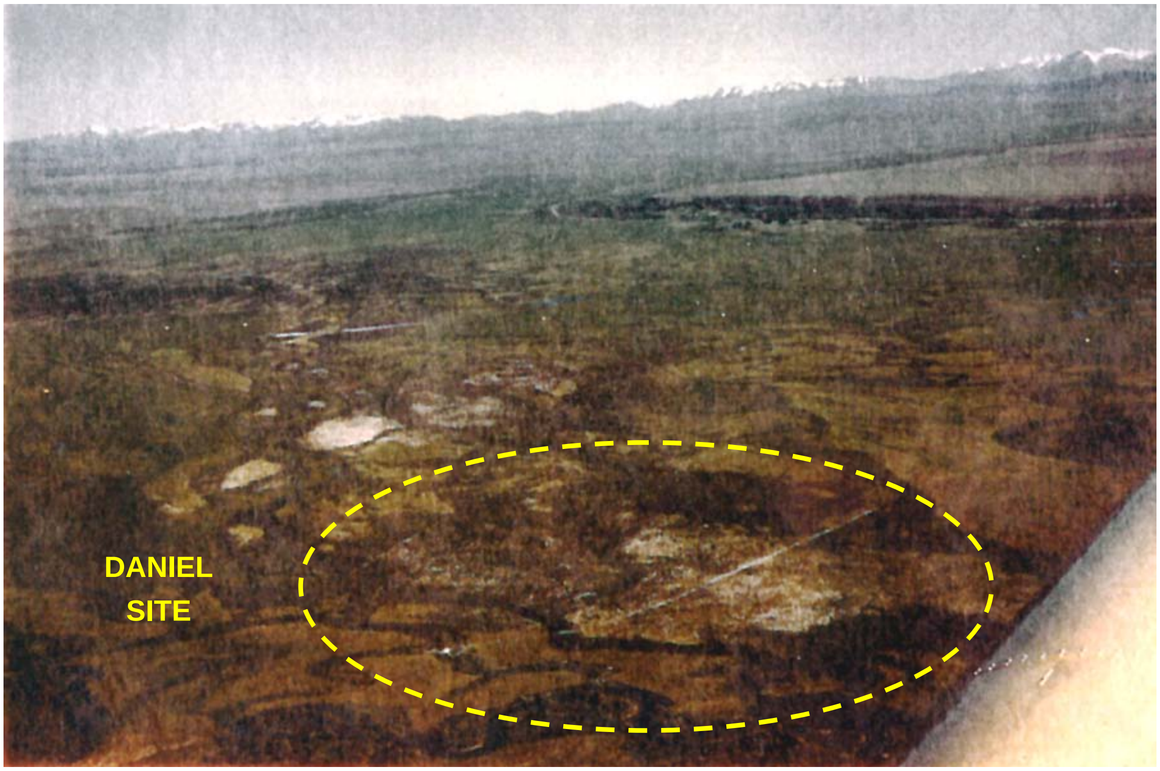


Figure 3.27-5. Overview of the Daniel Site, Sublette County Wyoming. The proposed alternate Daniel site is on the higher dry unirrigated area in the foreground of this 1969 photograph. View is to the north [best copy available] (adapted from International Nuclear Corporation 1969, Figure 7).

manager to conduct the preliminary field investigations for project planning and safety issues. Primary considerations were project development and design, project objectives, site evaluation, geology, containment, ground motion, area structural and feature evaluations, hydrology, ecology, population and cow count, meteorology and fallout, project technical feasibility, public relations, and estimated cost summary.

Field evaluation studies started in 1969 and were based on the assumption that the nuclear stimulation experiment would be a single 50-kt explosive detonated at a depth of 11,500 ft. The drilling plan for the Merna evaluation hole Wasp 1-A was prepared with the assistance of the U.S. Atomic Energy Commission, Nevada Operation Office; U.S. Bureau of Mines; and the U.S. Geological Survey. By the time the WASP Group actually began drilling the exploratory hole in late May 1969, the location had been shifted about 1/2 mile to the northwest in the NE1/4, NW1/4, 2,303 ft from the south line and 1,532 ft from the west line of Sec. 28, T 36N R112W. Brinkerhoff Drilling Corporation was responsible for drilling the hole while the U.S. Atomic Energy Commission contractors conducted on-site investigations in June and July. Drilling was completed on November 7, 1969 with the hole reaching a depth of 14,363 ft penetrating the Lance and Mesa Verde Sandstone Formations (Figure 3.27-6).

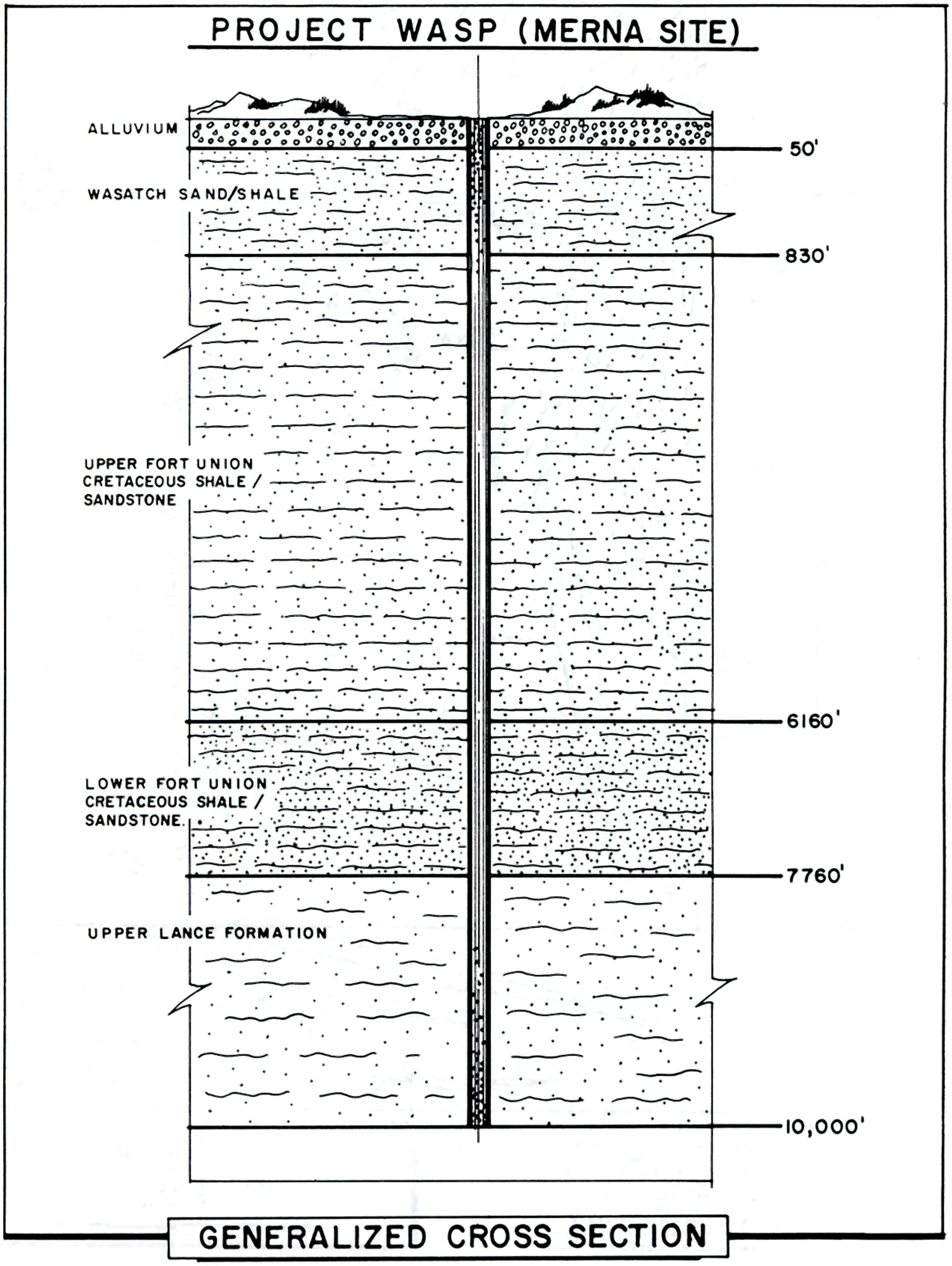


Figure 3.27-6. Generalized Cross Section the stratigraphy of Project WASP at the Merna Site (U.S. Atomic Energy Commission. Nevada Operations Office 1970, Figure 4).

A population study around the project area to a distance of 20 miles from ground zero identified the number of people, family milk cows, dairies, water supplies, and land use. No major problems were indicated for off-site safety issues associated with conducting the underground nuclear detonation. Recommendations were that a detailed inventory of structures be conducted and that particular areas be abandoned during the test. A seismic refraction study of the project areas was also recommended. Meteorological concerns were focused on an inadvertent release of radioactive gas. Consequently, the preliminary meteorological requirements were mostly for data on various atmospheric parameters to design and position on-site facilities and structures and for setting up working conditions to protect personnel and equipment. Ideally, structures and personnel would be stationed upwind from ground zero and no nuclear material would be handled in times of adverse climatic conditions.

The results from the Merna site proved disappointing. The WASP group management determined the primary site was not acceptable based on testing and samples from the WASP A-1 drill hole. Gas returns were considered unsatisfactory with permeability and porosity too low for further investment. The hole was plugged and the group began a search for a more favorable area for exploration and testing in the Green River Basin.

At a November 20, 1969 Atomic Industrial Forum-American Nuclear Society workshop on Plowshare Program industrial applications, WASP personnel announced plans to move its operations to an existing well located approximately 45 miles southeast of the Merna site. The existing well had been previously drilled to a depth of 11,000 ft and plans were to deepen it by coring to 14,000 ft. Instead of being discouraged by the Merna exploratory test well, the group was actually in the process of acquiring additional leases in the area and was prepared to drill as many as 4 to 6 wells if necessary.

Apparently, the planned use of the existing gas well described above was abandoned in early 1970. Documents dated between March and May 1970 indicate that although the project had been delayed, the WASP group was still looking for a site for a second exploratory hole. A July 1970 report suggests that the WASP experimental concept was undergoing revisions. Instead of focusing on a single 50-ft blast, the WASP engineers were examining the possibility of using two explosives with a yield between 50 and 120 kt. Identifying a specific site for the experiment, however, remained elusive. The last mention of Project WASP indicated that the experiment had been delayed until at least FY 1973 or FY 1974. The experiment was eventually abandoned.

Project participants included the U.S. Atomic Energy Commission, San Francisco and Nevada Operations Offices; Wyoming Atomic Stimulation Project group; International Nuclear Corporation; Oil & Gas Futures, Inc.; Burnham & Company; CRA, Inc.; Waymon G. Peavy; Petroleum Resources Company; Planet Oil & Mineral Corporation; U.S. Bureau of Mines, Bartlesville Petroleum Research Center; U.S. Geological Survey; Lawrence Radiation Laboratory; Los Alamos Scientific Laboratory; Sandia Laboratories; John A. Blume & Associates, Research Division; Battelle Memorial Institute, Columbus Laboratories; Environmental Research Corporation; Environmental Science Services Administration, Air Resources Laboratory; U.S. Public Health Service, Southwestern

Radiological Health Laboratory; Holmes & Narver, Inc.; ATCOR Laboratories, Inc.; National Lead Company, Baroid Division; Halliburton Company; Dow Chemical Company, Dowell Division; and Brinkerhoff Drilling Corporation.

Project WASP was a Level 3 activity which corresponds to fieldwork limited to drilling the WASP 1-A test hole and re-grading the access road. Geological, geophysical and hydrological characterizations of the geological formations were made using the cores and measurements from the test hole as well as using data from the pre-existing wells in the surrounding area. An unsuccessful attempt to visit the Project WASP Merna site was made in FY 2003.

FIELD VISIT

On August 10, 2003, the Desert Research Institute attempted to visit the Merna site by traveling west from Pinedale to Daniel Junction via U.S. Route 191. Turning north (right) at Daniel Junction, U.S. Route 191/189 continues up through the Green River Valley towards Jackson Hole. Approximately 7 miles north of Daniel Junction, a series of graded dirt roads head west from the paved highway leading to the confluence of the Beaver Creek and Crooked Creek drainages where the Merna site is situated. However, all these roads into the WASP project area had seriously worded and lengthy “Keep Out” signs. During discussions at the Pinedale District Bureau of Land Management Office the following day, the Desert Research Institute personnel explained the situation and were told that the Merna site was located in an area of “split estate” mineral rights meaning the land had private surface and federal subsurface mineral rights. Access to the site would have to be arranged through the landowner. The time investment of another day or two to gain access could not be accommodated by the field visit schedule. However, it is clear from the documentation that at the time of the Project WASP experiment, the group of industrial investors had purchased the oil and gas leases for both the Merna and alternate Daniel sites along with approximately 285,000 acres of additional leases in the Pinedale area.

CHRONOLOGICAL BIBLIOGRAPHY

Werth, Glenn C., [between 1966 and 1973]. Handwritten notes on Plowshare program meetings from Glenn C. Werth, U.S. Atomic Energy Commission, Division of Peaceful Nuclear Explosives, 1966-1973. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-118.

U.S. Atomic Energy Commission, 1967. *Plowshare Program During 1966: Based on the Annual Report to Congress for 1966 of the U.S. Atomic Energy Commission.* U.S. Atomic Energy Commission, U.S. Government Printing Office, Washington, D.C. On file at Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029; and Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

McCool, W. B., 1968. " Atomic Energy Commission Status of Plowshare Industrial Projects." Memo with encl. ("Status of Plowshare Industrial Projects," memo from John S. Kelly, U.S. Atomic Energy Commission, Division of Peaceful Nuclear Explosives, to List) from W. B. McCool, U.S. Atomic Energy Commission to Distribution, April 26. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029 [OUO].

Carter, Melvin W., 1969. Letter from Melvin W. Carter, Public Health Service, Southwest Radiological Health Laboratory, to Richard A. Johnson. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0134180.

U.S. Atomic Energy Commission, 1969. Chapter 11 - Peaceful Nuclear Explosions. In *Annual Report to Congress of the Atomic Energy Commission for 1968,* pp.195-202, January. U.S. Government Printing Office, Washington, D.C.

International Nuclear Corporation, 1969. Feasibility Study, Wyoming Atomic Stimulation Project. Manuscript, Denver, CO, January 21. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Sterrett, T. S., 1969. "Maximum Formational Temperatures and Pressures Encountered at the Pinedale and WASP Project Areas." Memo from T. S. Sterrett, Lawrence Radiation Laboratory, to M. D. Nordyke, March 10. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-061.

Kelly, John S., 1969. Letter from John S. Kelly, U.S. Atomic Energy Commission, to Norris E. Bradbury, March 12. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-032.

International Nuclear Corporation, 1969. Evaluation Hole, Wyoming Atomic Stimulation Project. Manuscript, Denver, CO, March 17. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

International Nuclear Corporation, 1969. Evaluation Hole, Wyoming Atomic Stimulation Project, Sublette County, Wyoming. Paper for presentation at Technical Evaluation Panel, U.S. Atomic Energy Commission, Nevada Operations Office, Meeting March 24, Las Vegas, NV, March 19. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Nordyke, Milo D., 1969. Underground Engineering Applications. Paper prepared for The Symposium on Public Health Aspects of Peaceful Uses of Nuclear Explosives, Las Vegas, April. University of California, Lawrence Radiation Laboratory, *Preprint UCRL*-71453, April. Livermore, CA. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-103.

Holmes & Narver, Inc., 1969. Reconnaissance Report on Logistics and Supporting Services for Project Wasp. Report to U.S. Atomic Energy Commission, Nevada Operations Office, from Holmes & Narver, Inc., On-Continent Test Division, Las Vegas, NV, June. On file at: Technical Library, National Nuclear Security, Administration, Nevada Site Office, Las Vegas, NV.

Atcor Laboratories Inc., 1969. Field Operations Manual: Wyoming Atomic Stimulation Project. Manual for Wyoming Atomic Stimulation Project from Atcor Laboratories, Inc., Elmsford, NY, June 26.

U.S. Department of Health, Education, and Welfare. Southwestern Radiological Health Laboratory, 1969. Preliminary Off-Site Area Survey - Wasp: Off-Site Radiological Safety Aspects. Report to U.S. Atomic Energy Commission from Southwestern Radiological Health Laboratory, July 31. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0134181.

Werth, Glenn C., 1969. Planned Applications of Peaceful Nuclear Explosives. University of California, Lawrence Radiation Laboratory, *Report UCRL*-71901, August 13. Livermore, CA. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-037.

Atcor Laboratories Inc., 1969. Project WASP: Ecological Medium Tests and Radiological Surveillance Programs, Section 1: Operational Plans. Manuscript, Columbia, MO, September 9. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

King, Kenneth W., 1969. Preliminary WASP/Wagon Wheel Seismic Evaluation. U.S. Department of Commerce, Environmental Science Services Administration, *Coast and Geodetic Survey, Report,* No. CGS-746-1, October 30. Rockville, MD. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Blume, John A., and Associates, 1969. Preliminary Structural Evaluation: WASP. John A. Blume and Associates Research Division, Report (draft) No. JAB-99-68, San Francisco, CA, November. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Environmental Science Services Administration, 1969. Preliminary Meteorological Effects Evaluation: Project WASP. Report to U.S. Atomic Energy Commission, Nevada Operations Office, from Air Resources Laboratory, Las Vegas, NV, November. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0134178.

Johnson, Richard A., 1969. "USPHS Preliminary WASP Report." Letter from Richard A. Johnson, U.S. Atomic Energy Commission, Nevada Operations Office, to F. W. Stead, et al., November. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0134179.

Plowshare Advisory Committee, 1969. Plowshare Advisory Committee, Report on Nineteenth Meeting. Meeting held at Lawrence Radiation Laboratory, Livermore, CA, November 4-5. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-029 [OUO].

Holzer, Fred, 1969. "Summary of the AIF Workshop on Industrial Plowshare Program - November 17 to 19, 1969." Memo from Fred Holzer, Lawrence Radiation Laboratory, to M. M. May, November 20. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-100.

U.S. Atomic Energy Commission. Nevada Operations Office, 1970. Project WASP Site Evaluation Report. Manuscript, Las Vegas, NV. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

U.S. Atomic Energy Commission, 1971. Chapter 9 - Peaceful Nuclear Explosives. In *Annual Report to Congress of the Atomic Energy Commission for 1970,* pp. 195-202, January. U.S. Government Printing Office, Washington D.C.

U.S. Atomic Energy Commission, 1970. Chapter 11 - Peaceful Nuclear Explosives. In *Annual Report to Congress of the Atomic Energy Commission for 1969,* pp. 195-203, January. U.S. Government Printing Office, Washington D.C.

U.S. Atomic Energy Commission. Nevada Operations Office, 1970. Project Wagon Wheel: Preliminary Site Evaluation Report. U.S. Atomic Energy Commission, Nevada Operations Office, Report No. NVO-55, March. Las Vegas, NV. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Miller, Robert E., 1970. "Amendment No. 1 - DPNE (Plowshare) Work Authorization 70-6, Wasp/Wagon Wheel - Field Planning and Support." Memo from Robert E. Miller, U.S. Atomic Energy Commission, Nevada Operations Office, to R. H. Thalgott, et al., March 4. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0173145.

U.S. Atomic Energy Commission, 1970. "Plowshare Program Statement, JCSE FY 1971 Authorization Hearings." Statement from U.S. Atomic Energy Commission, March 5. On file at: Archives and Research Center, Lawrence Livermore National Laboratory, Livermore, CA, File PLO-028.

Evans, Roy B., and David E. Bernhardt, 1970. "Probable Scheduling of Plowshare Events." Memo from Roy B. Evans and David E. Bernhardt, U.S. Department of Health, Education, and Welfare, Southwestern Radiological Health Laboratory, to Francis N. Buck, May 8. On file at Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0173142 [OUO].

U.S. Atomic Energy Commission. Nevada Operations Office, 1970. Project WASP: Preliminary Site Evaluation Report, Merna Site. U.S. Atomic Energy Commission, Nevada Operations Office, Report No. NVO-54, July. Las Vegas, NV. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

West, Chris L., 1970. "Answer to Inquiry Status of Bronco, WASP, and Wagon Wheel." Letter from Chris L. West, U.S. Atomic Energy Commission, Nevada Operations Office, to Files, October 7. On file at: Nuclear Testing Archive, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV, Accession No. NV0325747.

U.S. Atomic Energy Commission, 1970. *Plowshare Program During 1969: Based on the Annual Report to Congress for 1969 of the U.S. Atomic Energy Commission.* U.S. Atomic Energy Commission, U.S. Government Printing Office, Washington, D.C. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Whan, Glenn A., 1973. Plowshare Technology Assessment, Final Report, Implications to State Governments. Report to the Western Interstate Nuclear Board, Lakewood, CO, from Glenn A. Whan, Chemical and Engineering Department, University of New Mexico. On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Crump, Joseph R., 1975. PNE (Peaceful Nuclear Explosion) Activity Projections for Arms Control Planning, Vol. I. Report to the U.S. Arms Control and Disarmament Agency, Contract No. ACDE/PAB-253, from Gulf Universities Research Consortium, Galveston, TX, April 10.

Shafer, David S., William. C. Beck, Dwight Treadwell, and Stephen. A. Mellington, 1995. Inventory of Potential Environmental Restoration Liabilities Associated with Plowshare And Vela Uniform Program Sites. Manuscript, U.S. Department of Energy, Office of Environmental Restoration. On file at: Desert Research Institute, Las Vegas, NV.

Lederer, Adam M., 1998. Using Public Policy Models to Evaluate Nuclear Stimulation Projects: Wagon Wheel in Wyoming. Masters thesis, Department of Political Science, University of Wyoming, May. Laramie, WY.

WASP and Wagon Wheel: Area Map Projects, n.d. "Area Map Projects WASP and Wagon Wheel." Map (JAB-99-68). On file at: Technical Library, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV.

Wasp Area - Large Scale Map, n.d. "WASP Area - Large Scale Map." On file at: Engineering Records Library, Nevada Test Site, Mercury, NV.

Wasp Area - Large Scale Map (Merna Site), n.d. "WASP Area - Large Scale Map (Merna Site)." On file at: Engineering Records Library, Nevada Test Site, Mercury, NV.

THIS PAGE INTENTIONALLY LEFT BLANK