Acknowledgements

The U.S. Department of Energy, Nevada Operations Office, Office of Public Affairs and Information, acknowledges the contribution of Dr. William C. Beck, Belfort Engineering & Environmental Services, Incorporated, for providing historical information for this publication; Patricia Nolan Bodin, Janine M. Ford, Sandra A. Smith and Warren S. Udy, U.S. Department of Energy, Nevada Operations Office, Office of Public Affairs and Information; Beverly A. Bull, Lawrence Livermore National Laboratory; Richard Reed, Remote Sensing Laboratory (operated by Bechtel Nevada); Carole Schoengold, Martha DeMarre**,** Coordination and Information Center (operated by Bechtel Nevada); Loretta Bush, Technical Information Resource Center (operated by Bechtel Nevada).

Executive Summary

Plowshare Program

Introduction

The United States Atomic Energy Commission (AEC), now the Department of Energy (DOE), established the Plowshare Program as a research and development activity to explore the technical and economic feasibility of using nuclear explosives for industrial applications. The reasoning was that the relatively inexpensive energy available from nuclear explosions could prove useful for a wide variety of peaceful purposes. The Plowshare Program began in 1958 and continued through 1975. Between December 1961 and May 1973, the United States conducted 27 Plowshare nuclear explosive tests comprising 35 individual detonations.

Conceptually, industrial applications resulting from the use of nuclear explosives could be divided into two broad categories: 1) large-scale excavation and quarrying, where the energy from the explosion was used to break up and/or move rock; and 2) underground engineering, where the energy released from deeply buried nuclear explosives increased the permeability and porosity of the rock by massive breaking and fracturing.

Possible excavation applications included: canals, harbors, highway and railroad cuts through mountains, open pit mining, construction of dams, and other quarry and construction-related projects. Underground nuclear explosion applications included: stimulation of natural gas production, preparation of leachable ore bodies for in situ leaching, creation of underground zones of fractured oil shale for in situ retorting, and formation of underground natural gas and petroleum storage reservoirs.

Historical Development

The concept of using nuclear explosives for peaceful purposes was first discussed early in the nuclear weapons development program even before the first successful nuclear detonation. In the 1950s, while the U.S. was developing nuclear weapons during the Cold War for defense purposes, some scientists and government-agency personnel were anxious to pursue a program that would use the power of nuclear explosives for peaceful purposes. Lewis L. Strauss, Chairman of the AEC from 1953-1958, expressed some interest in this idea. However, it was not until November 1956 that Herbert York, then the

director of Lawrence Radiation Laboratory - Livermore (LRL-L), now part of Lawrence Livermore National Laboratory, proposed that scientists from LRL-L, along with those from Los Alamos and Sandia laboratories, now Los Alamos National Laboratory and Sandia National Laboratories, respectively, held a classified conference to discuss the possibilities of using energy unleashed by nuclear explosions to produce power, dig excavations, and produce isotopes. The AEC approved this conference that was held at Livermore in February 1957 where discussions ensued on using clean nuclear explosive devices for industrial uses. The AEC foresaw some problems with this program because weapons design characteristics for peaceful-use devices and those for weapons use were very similar, and declassification of this information was not possible. Since the nuclear devices developed for industrial uses would eventually have to be made available to civilian industry, it was decided, in order to control access to classified design information, that the whole program would be conducted at the Secret level. With AEC approval, the Plowshare Program was established in the Division of Military Application (DMA) in June. By July 1957, LRL-L had formally established the Plowshare Project to investigate nonmilitary applications of nuclear devices, and LRL-L scientists, most notably Dr. Edward Teller, were advocating expansion of the project with proposed increased budgets for 1958 through 1960.

The successful execution of the RAINIER test on September 19, 1957, the first U.S. nuclear detonation to be contained underground, provided data on possible underground engineering applications of nuclear explosions. This test, by providing the first information concerning the possible use of underground nuclear explosions for nonmilitary purposes, was an impetus for LRL-L scientists to press for expansion of the Plowshare Project for 1958 and beyond. The AEC's interest in Plowshare increased, and subsequently, the program scope and budget were also increased.

On June 6, 1958, the Atomic Energy Commission publicly announced the establishment of the Plowshare Program, named for the biblical injunction to ensure peace by beating swords into plowshares.

> "And they shall beat their swords into plowshares, and their spears into pruning hooks; nation shall not lift up sword against nation, neither shall they learn war any more."

The Program objective was to use nuclear explosives for civilian as opposed to military purposes. The AEC San Francisco Operations Office (SAN) Special Projects Group provided the oversight management for Plowshare with support efforts from the AEC

Albuquerque and Oak Ridge Offices, Sandia, the U.S. Geological Survey, and the U.S. Bureau of Mines. On October 31, 1958, the U.S. and the Soviet Union entered into a nuclear weapons testing moratorium. No nuclear tests were conducted for almost three years. During that time, Plowshare planning studies and high explosive tests would be conducted to evaluate excavation techniques.

By the end of 1958, DMA had established the Peaceful Nuclear Explosives (PNE) Branch to manage the Plowshare Program. Dr. Edward Teller, then the director of the Livermore Laboratory, had outlined an ambitious Plowshare Program for fiscal years (FY) 1959-60 in his October 7, 1958, letter to Dr. H. Fiedler, AEC/SAN. The LRL-L program proposed studies in these areas: for FY 1959 - constructing a channel through the reef at Kapingamarangi in the Marshall Islands; harbors at both Cape Thompson and Katalla, Alaska; a canal across the Alaskan peninsula at Port Moller; oil extraction from tar sands and from oil shale; creating artificial aquifers; and mining by leaching; for FY 1960 - in addition to continuing the above-mentioned projects, testing a new nuclear explosive design, and using a nuclear detonation for physics experiments.

By mid-1959, plans and preparations were well under way for several Plowshare projects with significant emphasis on: 1) Project Chariot, a five-detonation experiment first proposed as one 100-kiloton yield, 700-foot deep cratering detonation to produce a harbor at Cape Thompson, Alaska, and an additional four 20-kiloton yield detonations to produce a channel connecting the harbor to the ocean (in November 1960, the plan was modified to use one 200-kiloton yield and four 20-kiloton yield detonations); 2) Project Gnome, a proposed 10-kiloton yield device, to be fired in a salt dome to study isotope and energy production; and 3) Project Ditchdigger, a test of a clean weapon device to enhance the feasibility of building sea level canals. Project proposals made by LRL-L personnel were presented to DMA, however the program could not proceed without clarification on the testing moratorium or whether a to-be-negotiated treaty would have a provision allowing underground testing. These uncertainties, along with fears that Congress might reduce the Plowshare budget, were concerns that had to be addressed by the end of 1959.

In early 1960, Plowshare program proponents continued to develop projects approved by the AEC and supported by the newly formed Plowshare Advisory Committee. The prospect of conducting actual detonations was not likely as the voluntary moratorium continued, and budget problems were a reality because of the needs of other projects. The AEC authorized an ecological survey and developmental studies for Ditchdigger (at LRL) as long as there was no other shot preparation, and they also authorized continuing bioenvironmental studies at the Chariot site in Alaska. The target date for firing Chariot

was moved forward to spring of 1962. This removed the need for any construction work in the summer of 1960. Also during the summer and early autumn of 1960, Sandia conducted Plowshare high-explosive cratering experiments at the Nevada Test Site (NTS) to determine scaling data in different rock and soil media. Projects Buckboard, Toboggan, and Scooter (high explosive tests) were successfully conducted during that time.

Information from both high-explosive Plowshare and Vela Uniform (Seismic Detection Program) tests provided data for studies that continued in 1961. Work continued on the bioenvironmental studies and safety aspects of Project Chariot, and plans for Project Gnome progressed. By July 1961, newspapers were reporting on plans for the U.S. resumption of underground testing as preparations for the GNOME event became known. In August, the AEC moved the Plowshare program from DMA to the newly established Division of Peaceful Nuclear Explosives (DPNE) to administer the expanding program.

Testing Period

When the moratorium ended on September 1, 1961, with a Russian nuclear explosion, the U.S. nuclear testing program resumed on September 15, 1961. The Plowshare testing program commenced with the first of 27 nuclear tests, starting in December 1961 with GNOME, a 3-kiloton multipurpose test conducted in an underground salt bed deposit near Carlsbad, New Mexico. The program concluded in May 1973 with RIO BLANCO, a three (33-kiloton each) nuclear explosive test as part of a joint government-industry natural gas stimulation experiment, near Rifle, Colorado. In the intervening 12 years between GNOME and RIO BLANCO, the U.S conducted 23 tests at the NTS and two gas stimulation tests, GASBUGGY in December 1967 in Farmington, New Mexico, and RULISON in September 1969 in Grand Valley, Colorado. Table I summarizes the nuclear tests chronologically. Figure 1 shows the states and general locations where Plowshare nuclear tests were conducted, and Figure 2 shows area locations of the tests on the NTS.

During the years of Plowshare nuclear testing, high-explosive experiments continued in order to provide essential information on cratering, excavation, fracturing, in situ leaching, isotope production, and gas stimulation. Some of these experiments were specifically conducted as a pretest for an upcoming nuclear test, and some were multipurpose experiments. A chronological listing of Plowshare non-nuclear, high-explosive tests conducted on and off the NTS is given in Table II. Figure 3 shows the general locations where these projects were conducted. Those projects that were planned, but where little or no work or where no actual field testing occurred, are listed in Table III.

When testing began, most Plowshare information was publicly available. Health and safety issues were always a foremost consideration of the program planners. Radioactive releases from the tests, whether the tests were conducted on or away from the NTS, were always carefully monitored and data concerning the releases were made publicly available. Some of the projects that were never executed had the potential for unacceptable levels of radioactive fallout. The planned and actual yields of all the Plowshare tests, except for some of the device development tests, were publicly announced in advance of the tests. These latter test yields have now been announced by the Department of Energy.

Plowshare Termination

Plowshare was a program that started with great expectations and high hopes. Many engineering projects did not progress beyond their planning phase and construction was not started. In general, planners were confident that the projects could be completed safely, at least within the guidelines at the times. There was less confidence that they could be completed cheaper than by conventional means and most importantly, there was insufficient public or Congressional support for the projects. Projects Chariot and Coach were two examples where environmental concerns and technical problems prompted further feasibility studies and, after several years of continuous field work and numerous delays, each project was eventually canceled. In addition, throughout the course of the Plowshare Program citizen groups voiced concerns and opposition to some of the tests. Concerns that the blast effects from the SCHOONER explosion could dry up active wells or trigger an earthquake were raised. Opposition to both RULISON and RIO BLANCO were also voiced because of the possibility of radioactive gas flaring operations and other environmental hazards.

In the end, although less dramatic than nuclear excavation, the most promising use for nuclear explosions proved to be for stimulation of natural gas production. This technology development had industry support from the beginning of the Plowshare Program. Industrial participants included the El Paso Natural Gas Company for the GASBUGGY test; Austral Oil Company and CER Geonuclear Corporation for the RULISON test; and CER Geonuclear Corporation for the RIO BLANCO test. Although the technology was demonstrated to be technically feasible, it could not be proved that national energy needs justified the elaborate procedures that would be required. Concerns about the potential of the tritium contamination of the gas that would result from nuclear explosive stimulation were raised by Colorado and western alliance agencies. These concerns and the lack of

public support for the program made it unlikely that Congress would ever approve a commercial joint government-industry venture.

By 1974, approximately 82 million dollars had been invested in the nuclear gas stimulation technology program (i.e., nuclear tests GASBUGGY, RULISON, and RIO BLANCO). It was estimated that even after 25 years of gas production of all the natural gas deemed recoverable, that only 15 to 40 percent of the investment could be recovered. At the same time, alternative, non-nuclear technologies were being developed, such as hydrofracturing. Consequently, under the pressure of economic and environmental concerns, the Plowshare Program was discontinued at the end of FY 1975.

A chronology of Plowshare Program milestones, including tests and projects conducted, is included the appendix.

Table I. PLOWSHARE NUCLEAR TESTS

Name	Date	Location	Type/Yield	Purpose
GNOME	12/10/61	Carlsbad, NM (25 miles SE)	Shaft/3 kt	A multipurpose experiment designed to provide data concerning: (1) heat generated from a nuclear explosion; (2) isotopes production; (3) neutron physics; (4) seismic measurements in a salt medium; and (5) design data for developing nuclear devices specifically for peaceful uses.
SEDAN	07/06/62	Nevada Test Site	Crater/104 kt	A excavation experiment in alluvium to determine feasibility of using nuclear explosions for large excavation projects, such as harbors and canals; provide data on crater size, radiological safety, seismic effects, and air blast.
ANACOSTIA	11/27/62	Nevada Test Site	Shaft/5.2 kt	A device-development experiment to produce heavy elements and provide radiochemical analysis data for the planned Coach Project.
KAWEAH	02/21/63	Nevada Test Site	Shaft/3 kt	A device-development experiment to produce heavy elements and provide technical data for the planned Coach Project.
TORNILLO	10/11/63	Nevada Test Site	Shaft/0.38 kt	A device-development experiment to produce a clean nuclear explosive for excavation applications.
KLICKITAT	02/20/64	Nevada Test Site	Shaft/70 kt	A device-development experiment to produce an improved nuclear explosive for excavation applications.
ACE	06/11/64	Nevada Test Site	Shaft/3 kt	A device-development experiment to produce an improved nuclear explosive for excavation applications.
DUB	06/30/64	Nevada Test Site	Shaft/11.7 kt	A device-development experiment to study emplacement techniques.

Table I. PLOWSHARE NUCLEAR TESTS (continued)

Name	Date	Location	Type/Yield	Purpose
PAR	10/09/64	Nevada Test Site	Shaft/38 kt	A device-development experiment designed to increase the neutron flux needed for the creation of heavy elements.
HANDCAR	11/05/64	Nevada Test Site	Shaft/12 kt	An emplacement experiment to study the effects of nuclear explosions in carbonate rock.
SULKY	12/18/64	Nevada Test Site	Shaft/92 tons	An excavation experiment to explore cratering mechanics in hard, dry rock and study dispersion patterns of airborne radionuclides released under these conditions.
PALANQUIN	04/14/65	Nevada Test Site	Crater/4.3 kt	An excavation experiment in hard, dry rock to study dispersion patterns of airborne radionuclides released under these conditions.
TEMPLAR	03/24/66	Nevada Test Site	Shaft/0.37 kt	A device-development experiment to improve nuclear explosives for excavation applications.
VULCAN	06/25/66	Nevada Test Site	Shaft/25 kt	A device-development experiment.
SAXON	07/28/66	Nevada Test Site	Shaft/1.2 kt	A device-development experiment to improve nuclear explosives for excavation applications.
SIMMS	11/05/66	Nevada Test Site	Shaft/2.3 kt	A device-development experiment to evaluate clean nuclear explosives for excavation applications.
SWITCH	06/22/67	Nevada Test Site	Shaft/3.1 kt	A device-development experiment to evaluate clean nuclear explosives for excavation applications.
MARVEL	09/21/67	Nevada Test Site	Shaft/2.2 kt	An emplacement experiment to investigate underground phenomenology related to emplacement techniques.
GASBUGGY	12/10/67	Farmington, NM (55 miles E)	Shaft/29 kt	A gas stimulation experiment to investigate the feasibility of using nuclear explosives to stimulate a low-permeability gas field; first Plowshare joint government-industry nuclear experiment to evaluate an industrial application.

Table I. PLOWSHARE NUCLEAR TESTS (continued)

Name	Date	Location	Type/Yield	Purpose
CABRIOLET	01/26/68	Nevada Test Site	Crater/2.3 kt	An excavation experiment to explore cratering mechanics in hard, dry rock and study dispersion patterns of airborne radionuclides released under these conditions.
*BUGGY-A BUGGY-B BUGGY-C BUGGY-D BUGGY-E (simultaneous, separate holes)	03/12/68	Nevada Test Site	Crater/1.08 kt Crater/1.08 kt Crater/1.08 kt Crater/1.08 kt Crater/1.08 kt	A five-detonation excavation experiment to study the effects and phenomenology of nuclear row-charge excavation detonations.
STODDARD	09/17/68	Nevada Test Site	Shaft/31 kt	A device-development experiment to develop clean nuclear explosives for excavation applications.
SCHOONER	12/08/68	Nevada Test Site	Crater/30 kt	An excavation experiment to study the effects and phenomenology of cratering detonations in hard rock.
RULISON	09/10/69	Grand Valley, CO (45 miles NE of Grand Junction)	Shaft/40 kt	A gas stimulation experiment to investigate the feasibility of using nuclear explosives to stimulate a low-permeability gas field; provide engineering data on the use of nuclear explosions for gas stimulation; on changes in gas production and recovery rates; and on techniques to reduce the radioactive contamination to the gas.
*FLASK-GREEN FLASK-YELLOW FLASK-RED (simultaneous, separate holes)	05/26/70	Nevada Test Site	Shaft/105 kt Shaft/90 tons Shaft/40 tons	A three-detonation device development experiment to develop improved nuclear explosives for excavation applications.
MINIATA	07/08/71	Nevada Test Site	Shaft/83 kt	A device-development experiment.

Table I. PLOWSHARE NUCLEAR TESTS (continued)

Name	Date	Location	Type/Yield	Purpose
*RIO BLANCO-1 RIO BLANCO-2 RIO BLANCO-3 (simultaneous, same hole)	05/17/73	Rifle, CO (50 miles N of Grand Junction)	Shaft/33 kt Shaft/33 kt Shaft/33 kt	A gas stimulation experiment to investigate the feasibility of using nuclear explosives to stimulate a low-permeability gas field; develop technology for recovering natural gas from reservoirs with very low permeability.

* Test is comprised of simultaneous detonations. (A test is defined in the Threshold Test Ban Treaty as either a single underground nuclear explosion conducted at a test site, or two or more underground nuclear explosions conducted within an area delineated by a circle having a diameter of two kilometers and conducted within a total period of time not to exceed 0.1 second.)

Table II. PLOWSHARE NON-NUCLEAR EXPERIMENTS

Name	Date	Location	Type	Purpose
*CHARIOT Site	1958-62	NW Alaskan Coast Cape Thompson	N/A	A nuclear cratering (harboring) test was proposed for this site but not executed; tracer tests and numerous bioenvironmental studies were conducted at the site from 1959-62.
Pre-GNOME	02/10-16/59	Carlsbad, NM	High explosive	Three high explosive seismic experiments to predict ground shock for the planned GNOME nuclear test.
TOBOGGAN	11-12/59 & 04-06/60	Nevada Test Site	High explosive TNT	A total of 122 detonations of linear and point high explosive charges to study ditching characteristics for nuclear row-charge experiments.
HOBO	02-04/60	Nevada Test Site	High explosive TNT	Three tests to study fracturing and related phenomena and provide seismic data for future projects.
STAGECOACH	03/60	Nevada Test Site	High explosive TNT	A three-detonation excavation experiment to study blast, seismic effects, and throw out characteristics for nuclear cratering experiments.
PLOWBOY	03-07/60	Winnfield, LA	N/A	A mining operation into a cavity produced by an high explosive experiment inducing fracturing of salt.
BUCKBOARD	07-09/60	Nevada Test Site	High explosive TNT	A 14-detonation excavation experiment to study depth of burst curves for underground explosives in a hard rock medium.
PINOT	08/02/60	Rifle, CO	High explosive nitromethane	A high explosive tracer test in oil shale.
SCOOTER	10/60	Nevada Test Site	High explosive TNT	An excavation experiment to study crater dimensions, throw out characteristics, ground motion, dust cloud growth, and long-range air blast.
ROWBOAT	06/61	Nevada Test Site	High explosive TNT	An eight-detonation row charge experiment to study the effects of depth of burial and charge separation on crater dimensions.

Table II. PLOWSHARE NON-NUCLEAR EXPERIMENTS (continued)

Name	Date	Location	Type	Purpose
YO-YO	Summer 1961	Site 300 at LRL (near Tracy, CA)	High explosive	A simulated nuclear excavation experiment to develop quantitative atmospheric radiation release data from cratering detonations.
Pre-BUGGY I	11/62-02/63	Nevada Test Site	High explosive nitromethane	A 26-detonation (single and multiple charges) row-charge experiment to study phenomenology and effects for nuclear row charge experiments.
Pre-BUGGY II	06-08/63	Nevada Test Site	High explosive nitromethane	A five-row (of five) row charge experiment to study phenomenology and effects for nuclear row-charge experiments.
Pre-SCHOONER I	02/64	Nevada Test Site	High explosive nitromethane	Four detonations to study basic cratering phenomenology for nuclear cratering experiments.
DUGOUT	06/24/64	Nevada Test Site	High explosive nitromethane	A row charge experiment to study the processes involved in row-charge excavation in dense, hard rock.
Pre-SCHOONER II	09/30/65	Owyhee County, (SW Idaho)	High explosive nitromethane	A cratering experiment to obtain cavity growth, seismic effects, and air blast data for the SCHOONER nuclear cratering test.
Pre-GONDOLA	10/66-10/69	near Ft. Peck Reservoir, Valley, County, MT	High explosive nitromethane	A multiphase experiment (seismic calibration test; Pre-Gondola I, II, and III) consisting of multirow and multilinear detonations to provide cratering characteristics in weak, saturated, Bearpaw Shale to demonstrate the potential application for explosive excavation for large construction projects.
TUGBOAT	11/69-12/70	Kawaihae Bay, HI	High explosive TNT	A two-phase, multidetonation excavation experiment; study to excavate a small boat harbor in a weak coral medium, with a 4-8-foot water overburden.
TRINIDAD	07-12/70	Trinidad, CO (6 miles W)	High explosive	Four series of detonations to study excavation designs in a sandstone/shale medium using row-charge detonations.

Table II. PLOWSHARE NON-NUCLEAR EXPERIMENTS (continued)

Name	Date	Location	Type	Purpose
OLD RELIABLE	08/71-03/72	Galiuro Mtns. (44 miles NE of Tucson, AZ)	High explosive ammonium nitrate	An experiment to promote fracturing and in situ leaching of copper ore.

* No high-explosive tests were conducted.

Table III. PROPOSED PLOWSHARE PROJECTS

(Not Executed)

Name	Date	Location	Type	Purpose
OXCART	1959	Nevada Test Site	Nuclear explosive	Investigate excavation efficiency as a function of yield and depth in planning for Project Chariot.
OILSANDS	1959	Athabasca, Canada	Nuclear explosive	Study the feasibility of oil recovery using a nuclear explosive detonation in the Athabascan tar sands.
OIL SHALE	1959	Not determined	Nuclear explosive	Study a nuclear detonation to shatter an oil shale formation to extract oil.
DITCHDIGGER	1961	Not determined	Nuclear explosive	A deeply buried clean nuclear explosive detonation excavation experiment
COACH	1963	Carlsbad, NM (GNOME site)	Nuclear explosive	Produce neutron-rich isotopes of known trans-plutonium elements.
PHAETON	1963	Not determined	Nuclear explosive	Scaling experiment.
CARRYALL	November 1963	Bristol Mountains Mojave Desert, CA	Nuclear explosive	Row-charge excavation experiment to cut through the Bristol Mountains for realignment of the Santa Fe railroad and a new highway I-40.
DOGSLED	1964	Colorado Plateau CO or AZ	Nuclear explosive	Study cratering characteristics in dry sandstone; study ground shock and air blast intensities.
TENNESSEE/ TOMBIGEE WATERWAY	1964	Northeast Mississippi	Nuclear explosive	Excavation of three miles of a divide cut through low hills; connect Tennessee and Tombigee rivers; dig 250-mile long canal.

Table III. PROPOSED PLOWSHARE PROJECTS (continued)

(Not Executed)

Name	Date	Location	Type	Purpose
INTEROCEANIC SEA-LEVEL CANAL STUDY	1965-70	Pan-American Isthmus (Central America)	Nuclear explosive	Commission appointed in 1965 to conduct feasibility studies of several sea-level routes for an Atlantic-Pacific interoceanic canal. Two routes were in Panama and one in northwestern Colombia. The 1970 final report recommended, in part, that no current U.S. canal policy should be made on the basis that nuclear excavation technology will be available for canal construction. AEC deferred in making any decision.
FLIVVER	03/66	Nevada Test Site	Nuclear explosive	A low-yield cratering detonation to study basic cratering phenomenology.
DRAGON TRAIL	12/66	Rio Blanco County, CO	Nuclear explosive	Natural gas stimulation experiment; different geological characteristics than either GASBUGGY or RULISON; geological study completed.
KETCH	08/67	Renovo, PA (12 miles SW)	Nuclear explosive	Create a large chimney of broken rock with void space to store natural gas under high pressure.
BRONCO	10/67	Rio Blanco County, CO	Nuclear explosive	Break oil shale deposits for in situ retorting; exploratory core holes drilled.
SLOOP	10/67-68	Stafford, AZ (11 miles NE)	Nuclear explosive	Fracturing copper ore; extract copper by in situ leaching methods; feasibility study completed.
THUNDERBIRD	1967	Buffalo, WY (35 miles E)	Nuclear explosive	Coal gasification; fracture rock-containing coal and in situ combustion of the coal would produce low-Btu gas and other products.
GALLEY	1967-68	Not determined	Nuclear explosive	A high-yield row charge in hard rock under terrain of varying elevations.
AQUARIUS	1968-70	Clear Creek or San Simon, AZ	Nuclear explosive	Water resource management; dam construction, subsurface storage, purification; aquifer modification.

Table III. PROPOSED PLOWSHARE PROJECTS (continued)

(Not Executed)

Name	Date	Location	Type	Purpose
WAGON WHEEL	01/68-74	Pinedale, WY (19 miles S)	Nuclear explosive	Natural gas stimulation; study stimulation at various depths; an exploratory hole and two hydrological wells were drilled.
WASP	07/69-74	Pinedale, WY (24 miles NW)	Nuclear explosive	Natural gas stimulation; meteorological observations taken.
UTAH	1969	near Ouray, UT	Nuclear explosive	Oil shale maturation; exploratory hole drilled.
STURTEVANT	1969	Nevada Test Site	Nuclear explosive	Cratering experiment to extend excavation information on yields and rock types relevant to the trans-Isthmian canal.
Australian Harbor Project	1969	Cape Keraudren (NW coast of Australia)	Nuclear explosive	First discussed with U.S. officials in 1962, the U.S. formally agreed to participate in a joint feasibility study with the Australian government in early 1969 for using nuclear explosives to construct a harbor. The project was stopped in March 1969 when it was determined that there was an insufficient economic basis to proceed.
YAWL	1969-70	Nevada Test Site	Nuclear explosive	Cratering experiment to extend excavation information on yields and rock types relevant to the trans-Isthmian canal.
Geothermal Power Plant	1971	Not determined	Nuclear explosive	Geothermal resource experiment; fracturing would allow fluids circulated in fracture zones to be converted to steam to generate electricity.

Figure 1. Plowshare Nuclear Test Locations.

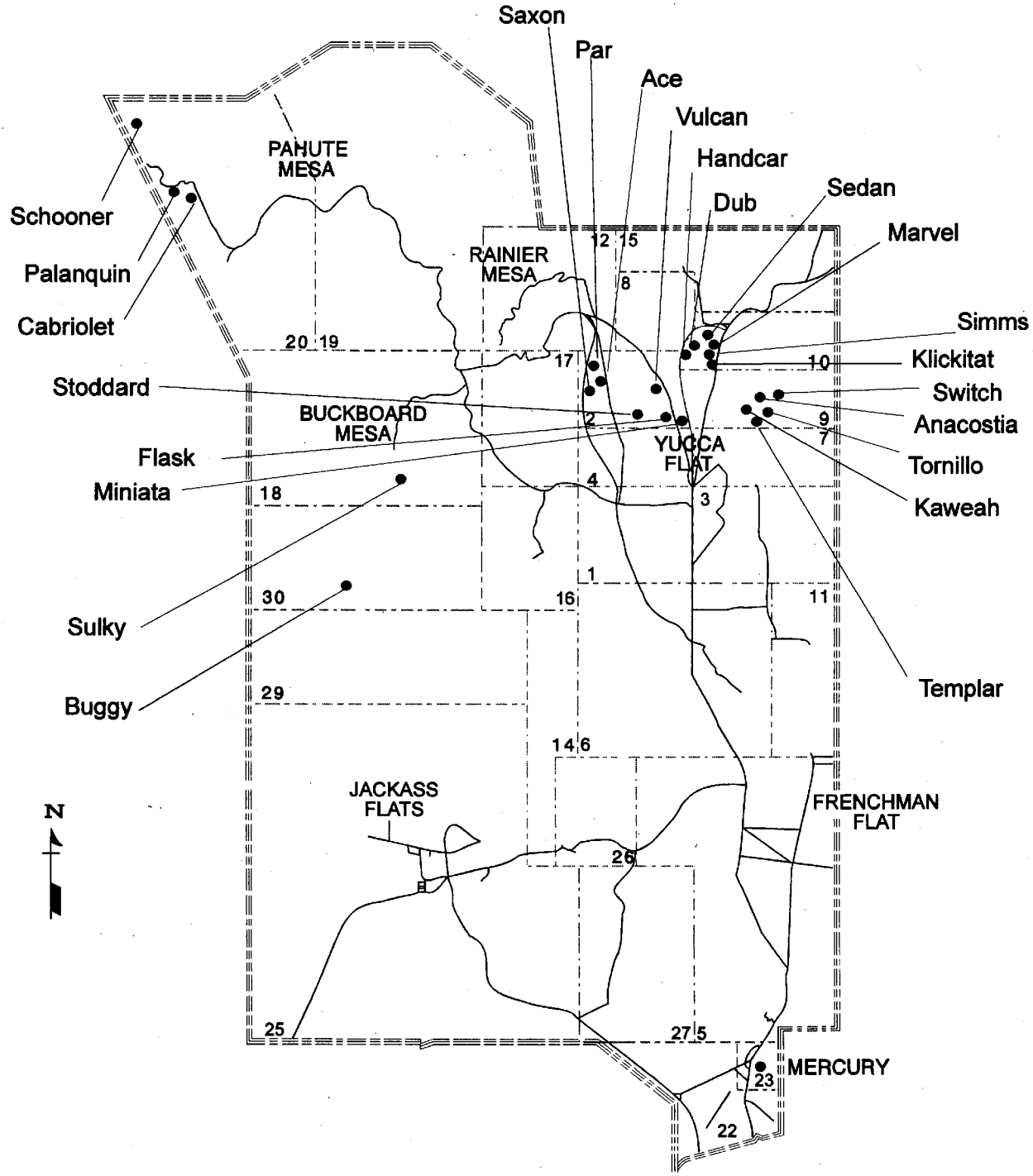

Figure 2. Nevada Test Site Plowshare Nuclear Test Locations.

Figure 3. Plowshare Non-Nuclear Experiment Locations.

APPENDIX

PLOWSHARE CHRONOLOGY

Date	A. Program Milestones
November 26, 1956	Commission approved in-house conference on peaceful uses of nuclear explosives. Lawrence Radiation Laboratory, Livermore (LRL-L), had been informally studying the question during previous years. (Staff Paper 811/4)
February 1957	First Plowshare Symposium held at LRL to discuss “Industrial Uses of Nuclear Explosives.”
June 27, 1957	Commission approved the establishment of a program in the Division of Military Application to investigate nonmilitary uses of nuclear explosives. (Staff Paper 811/6, dated June 13, 1957)
July 1957	LRL-L formally established Project Plowshare to investigate the nonmilitary applications of nuclear weapons.
September 1957	Project Rainier, the first U.S. underground detonation of a nuclear explosive. A chimney of fractured rock was formed which provided data on possible underground engineering applications of nuclear explosions.
October 1957	The U.S. Corps of Engineers agreed to supply support services for the Plowshare Program.
December 10, 1957	General Advisory Committee to AEC recommended that a study group be formed to investigate peaceful uses of nuclear explosives for the production of isotopes and for large earth-moving projects.
March 31, 1958	Responsibilities for operations and industrial contacts delegated to San Francisco Operations Office (SAN). SAN established Special Projects Group to oversee program.

July 1, 1958	Plowshare support efforts established at Albuquerque Operations Office (ALOO) and Oak Ridge Operations Office (OROO).
August 15, 1958	U.S. Geological Survey agreed to conduct support studies for Plowshare Program.
September 9, 1958	U.S. Bureau of Mines agreed to cooperate on Plowshare Program.
October 1958	U.S. began voluntary moratorium on all nuclear testing.
December 15, 1958	Formation of Peaceful Nuclear Explosives Branch in DMA to supervise Plowshare Program.
January 1959	Joint AEC/Bureau of Mines Oil Shale Symposium at Dallas, Texas. Presented material on use of nuclear explosions to recover oil from oil shale.
May 13-15, 1959	The Second Symposium on the Plowshare Program was held in San Francisco, California, with 495 attendees. The symposium was open to the public including international participation.
November 1959	Sandia Laboratories Plowshare research and development effort established.
January 1960	In 1960 the Panama Canal Company reviewed and updated the 1947 studies in collaboration with the AEC.
August 1961	The Plowshare Program was removed from DMA and the Division of Peaceful Nuclear Explosives established to administer the program.
September 1961	The U.S. voluntary test moratorium of two years and 11 months duration was ended.
December 10, 1961	Project Gnome, the first Plowshare experiment was conducted December 10, 1961, near Carlsbad, New Mexico. The explosive yield of this multipurpose experiment was 3 kt.

1962	U.S. Corps of Engineers established Nuclear Cratering Group at LRL to cooperate with AEC on (1) projects concerning collateral high explosive experiments, (2) the development of engineering concepts relating to construction in fracture zones, and (3) studies of slope stability and related engineering considerations.
April 1962	The President requested the AEC and Corps of Engineers to jointly assess the feasibility of using nuclear excavation for canal construction. This led to 1964 canal studies.
July 1962	Savannah River Operations Office initiated support studies for Plowshare Program.
September-October 1963	Team of Australian scientists visited U.S. to review Plowshare program and study the scientific, engineering and safety aspects of nuclear explosives.
October 1963	The Limited Test Ban Treaty was ratified by the President, with consent of the Senate. The treaty prohibits nuclear explosions in the atmosphere, the oceans, and space. It also prohibits any underground explosion "which causes radioactive debris to be present outside the territorial limits of the state under whose jurisdiction or control the explosion is conducted."
April 21-23, 1964	The Third Plowshare Symposium, "Engineering with Nuclear Explosives," was held at the University of California, Davis, California. Several hundred visitors including representatives from the United Kingdom, France, Australia, Canada, Mexico, Switzerland, South Africa, Israel and the International Atomic Energy Agency (IAEA) attended.
May 1964	The U.S. Atomic Energy Commission released a policy statement and projected charges for Plowshare thermonuclear explosives for use by industry in conducting studies of economic and technical feasibility: 10 Kilotons - $350,000 2 Megatons - $600,000

September 22, 1964	Public Law 88-609 was signed by the President “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,” and authorized establishment of a Commission to carry out provisions of the Act. The Atlantic-Pacific Interoceanic Canal Study Commission was established on April 18, 1965, to study sites for construction of a sea-level Isthmian canal connecting the Atlantic and Pacific Oceans, and methods of construction. Studies included the feasibility of excavating a sea-level canal with nuclear explosives.
February 14, 1967	Treaty for the prohibition of nuclear weapons in Latin America was signed in Mexico City. The treaty establishes Latin America as an area in which the participating nations will not manufacture or otherwise acquire nuclear weapons (explosives), but permits these nations to collaborate with third parties such as the U.S. for the purpose of carrying out nuclear explosions for peaceful purposes.
December 10, 1967	Project Gasbuggy, the first cooperative industry-government experiment, was conducted on December 10, to investigate the use of a nuclear explosion to stimulate a low permeability gas field. The nuclear explosion of 29 kt, that occurred 4,240 feet (1,292 meters) beneath the earth’s surface, created a chimney about 335 feet (102 meters) high and 160 feet (49 meters) in diameter.
March 8, 1968	The Commission assigned the technical direction for Project Rulison to Los Alamos Scientific Laboratory.
March 12, 1968	Project Buggy, the first nuclear row charge experiment. The explosion, which involved the simultaneous detonation of five explosives (each detonation yielded 1.08 kt) placed 150 feet (45.7 meters) apart at a depth of 135 feet (41.1 meters), created a ditch 855 feet (261 meters) long, 254 feet (77.4 meters) wide, and 65 feet (19.8 meters) deep.

April 14-16, 1969	The first of a series of U.S./U.S.S.R. bilateral technical talks took place in Vienna, Austria, on “Peaceful Applications of Nuclear Explosions.”
January 14-16, 1970	An “Engineering with Nuclear Explosives” symposium sponsored by the American Nuclear Society was held in Las Vegas, Nevada. Sixteen foreign countries participated or attended. France, for the first time, presented technical data on their “Plowshare” Program.
February 11-17, 1970	The second U.S./U.S.S.R. bilateral technical talks took place in Moscow on “Peaceful Uses of Nuclear Explosions.” The talks, just as those in April 1969, were restricted to technical aspects.
March 5, 1970	Ratification of the Treaty for the Nonproliferation of Nuclear Weapons by the U.S. was put into force. Article V of the Treaty pertains to making available to non-nuclear-weapons states any benefits from peaceful uses of nuclear explosions.
March 2-6, 1970	An IAEA panel meeting on the peaceful uses of nuclear explosives was held in Vienna, Austria. The participants included France, Japan, Sweden, Australia, India, USSR, United Kingdom, and the U.S. At this meeting the Soviets, for the first time in public, discussed the U.S.S.R. “Plowshare” program entitled, “Nuclear Explosives for the National Economy.”
March 16, 1970	The Rulison Court decision by the U.S. District Court for the District of Colorado (Judge Alfred A. Arraj) ruled that: ” the flaring phase of Project Rulison does not present a threat to public health and safety; the AEC has planned its activities and is carrying them out with all due regard for health and safety; and radiation dose from flaring will be within radiation standards.”
December 1, 1970	The Atlantic-Pacific Interoceanic Canal Study Commission transmitted to the President its final report on December 1, 1970, and stated: “...although we are confident that someday nuclear explosions will be used in a wide variety of massive

	earth-moving projects, no current decision on U.S. canal policy should be made in the expectation that nuclear excavation technology will be available for canal construction...” It was recommended that “...the U.S. pursue development of the nuclear excavation technology, but not postpone Isthmian Canal policy decisions because of the possible establishment of feasibility of nuclear excavation at some later date.”
June 30, 1975	The Plowshare Program was terminated.
May 28, 1976	The Treaty on Underground Nuclear Explosives for Peaceful Purposes was signed by the U.S. and the Soviet Union.

Date	B. Nuclear Tests and Non-Nuclear Experiments
September 19, 1957	**RAINIER** nuclear test Type - Tunnel Yield - 1.7 kt Depth of Burial - 900 ft (274.3 m) Medium - Tuff rock Site - Nevada Test Site Plowshare Interest -The first U.S. underground detonation of a nuclear explosive. This weapons test formed a chimney of broken rock which provided data on possible underground engineering applications of nuclear explosives.
1958-62	**Chariot** project experiments Site - Northwest Alaskan coast, Cape Thompson Objective - Studies undertaken to provide environmental data to aid in determining feasibility of conducting Plowshare excavation experiments; tracers tests were also conducted. Final report issued January 1966.
February 10-16, 1959	**Pre-Gnome** seismic experiment Type - High explosive Yield - 3.65 tons Depth of Burial - 1,200 ft (365.8 m), each Medium - Bedded salt Site - Southeast of Carlsbad, New Mexico Objective - Three seismic experiments to measure ground shock for the planned GNOME nuclear test.
November- December 1959 & April-June 1960	**Toboggan** ditching experiment Type - High explosive, TNT Yield - Series of 122 detonations of both linear and point HE charges Depth of Burial Range - 3 to 20 ft (1 to 6.1 m) Medium - Playa (combination of silt and clay) Site - Nevada Test Site Objective - Study ditching characteristics of both-end detonated and multidetonated HE explosives in preparation for nuclear row charge experiments.

February-
April 1960

Hobo seismic experiment
Type - High explosive, TNT
Yield - Three explosions, varying from 500 to 1,000 lb. charges each
Medium - Tuff
Site - Nevada Test Site
Objective - To study rock fracturing and related phenomena produced by contained explosions.

March 1960

Stagecoach excavation experiment
Type - High explosive, TNT
Yield - Three 40,000 lb. charges
Depth of Burial - Shot 1 - 80 ft (24.4 m); Shot 2 - 17.1 ft (5.2 m); Shot 3 - 34.2 ft (10.4 m)
Medium - Alluvium
Site - Nevada Test Site
Crater Dimensions - Diameter; Depth; Volume
Shot 1 114 ft (34.7 m); 7 ft (2.1 m); 49,000 ft^3 (1,390 m^3)
Shot 2 101.0 ft (30.8 m); 23.6 ft (7.2 m); 8,370 ft^3 (237 m^3)
Shot 3 116.2 ft (35.4 m); 28.2 ft (8.6 m); 145,000 ft^3 (4,100 m^3)
Objective - Examine blast, seismic effects and throw out characteristics in preparation for nuclear cratering experiments.

March-July 1960

Plowboy experiment
Site - Winnfield, Louisiana
Objective - Mining operation to examine high explosive-induced fracturing of salt.

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July-September 1960

Buckboard excavation experiment
Type - High explosive, TNT
Yield - Three 40,000 lb. charges and ten 1,000 lb. charges
Depth of Burial Range - 5 to 59.85 ft (1.5 to 18.24 m)
Medium - Basalt
Site - Nevada Test Site
Crater Dimension Ranges - Diameter, 9.26 to 114 ft (2.8 to 34.7 m); Depth, 1.40 to 34.70 ft (0.43 to 10.58 m); Volume, 44.9 to 135,000 ft^3 (1.27 to 3.82 m^3)

Objective - Establish depth of burst curves for underground explosives in a hard rock medium.

August 2, 1960

Pinot tracer experiment
Type - High explosive, nitromethane
Depth of Burial - 610 ft (185.9 m)
Medium - Oil shale
Site - Rifle, Colorado
Objective - To determine how gases in a confined underground explosion migrate.

October 1960

Scooter excavation experiment
Type - High explosive, TNT
Yield - 500 ton charges
Depth of Burial - 125 ft (38.1 m)
Medium - Alluvium
Crater Dimensions - Diameter, 307 ft (93.6 m); Depth, 75 ft (22.8 m); Volume, 100,000 yds^3 (76,000 m^3)
Site - Nevada Test Site
Objective - To study crater dimension, throw out material distribution, ground motion, dust cloud growth, and long-range air blast.

June 1961

Rowboat row-charge experiment
Type - High explosive, TNT
Yield - 8 detonations of series of four 278 lb. charges
Depth of Burial - Varied
Medium - Alluvium
Site - Nevada Test Site
Objective - To study the effects of depth of burial and charge separation on crater dimensions.

Summer 1961

Yo-Yo simulated excavation experiment
Type - High explosive
Yield - 100 gm charges
Depth of Burial - Varied
Medium - Oil-sand mixture
Site - At LRL, near Tracy, California

Objective - To develop estimates for the quantities of radiation released to the atmosphere by a cratering detonation.

December 10, 1961

GNOME nuclear test
Type - Shaft
Yield - 3 kt
Depth of Burial - 1,185 ft (361 m)
Medium - Salt
Cavity Dimensions - Diameter, 160 to 170 ft (48.8 to 51.8 m); Height, 60 to 80 ft (18.3 to 24.4 m)
Site - near Carlsbad, New Mexico
Objectives - Isotope recovery; neutron physics experiment; examination of heat recovery; seismic measurements; and explosive development

July 6, 1962

SEDAN nuclear test
Type - Crater
Yield - 104 kt
Depth of Burial - 635 ft (194 m)
Medium - Alluvium
Crater Dimensions - Diameter, 1280 ft (390 m); Depth, 320 ft (97.5 m); Volume, 7,500,00 yds^3 (5,700,000 m^3)
Site - Nevada Test Site
Objective - Study effects and phenomenology of excavation detonations.

November 1962-
February 1963

Pre-Buggy I row-charge experiment
Type - High explosive, nitromethane
Yield - Six single-charge detonations, four multiple-charge detonations of five charges each
Depth of Burial - 15 to 21.4 ft (4.57 to 6.52 m) for single-charge detonations; all row-charge detonations at 19.8 ft (6.04 m)
Medium - Alluvium
Site - Nevada Test Site
Objective - U.S. Army Engineer Cratering Group Study of row-charge phenomenology and effects in preparation for nuclear row-charge tests.

November 27, 1962 **ANACOSTIA** nuclear test
Type - Shaft
Yield - 5.2 kt
Depth of Burial - 747 ft (227.7 m)
Medium - Tuff
Site - Nevada Test Site
Objective - A device-development test to produce heavy elements and provide radiochemical analysis data for future projects.

February 21, 1963 **KAWEAH** nuclear test
Type - Shaft
Yield - 3 kt
Depth of Burial - 745 ft (227.1 m)
Medium - Alluvium
Site - Nevada Test Site
Objective - A device-development test to produce heavy elements and provide radiochemical analysis data for future projects.

June-August 1963 **Pre-Buggy II** row-charge experiment
Type - High explosive, nitromethane
Yield - Five rows of five 1,000 lb. charges
Depth of Burial - 18.5 to 23 ft (5.64 to 7.0 m)
Medium - Alluvium
Site - Nevada Test Site
Objective - U.S. Army Corps of Engineers study of row-charge phenomenology and effects in preparation for a nuclear row-charge experiment.

October 11, 1963 **TORNILLO** nuclear test
Type - Shaft
Yield - 0.38 kt
Depth of Burial - 489 ft (149 m)
Medium - Alluvium
Site - Nevada Test Site
Objective - Develop a clean nuclear explosive for excavation applications.

February 1964

Pre-Schooner I cratering experiment
Type - High explosive, nitromethane
Yield - Four 40,000 lb. spherical charges
Depth of Burial - 42 to 66 ft (18.3 to 20.1 m)
Medium - Basalt
Site - Nevada Test Site
Crater Dimensions - Diameter; Depth; Volume
Shot 1, 100.6 ft (30.6 m); 22.9 ft (6.98 m); 75,926 ft^3 (2,150 m^3)
Shot 2, 98 ft (29.8 m); 22.5 ft (6.86 m); 73,804 ft^3 (2,090 m^3)
Shot 3, mound 1.3 ft (78.0 m) high
Shot 4, 92.2 ft (28.2 m); 25.6 ft (7.8 m); 64,625 ft^3 (1,830 m^3)
Objective - U.S. Army Engineer Nuclear Cratering Group study of basic cratering phenomenology in preparation for nuclear cratering experiments.

February 20, 1964

KLICKITAT nuclear test
Type - Shaft
Yield - 70 kt
Depth of Burial - 1,616 ft (492.6 m)
Medium - Tuff
Site - Nevada Test Site
Objective - Develop a clean nuclear explosive for excavation applications.

June 11, 1964

ACE nuclear test
Type - Shaft
Depth of Burial - 862 ft (262.7 m)
Yield - 3 kt
Medium - Alluvium
Site - Nevada Test Site
Objective - Develop an improved clean nuclear explosive for excavation applications.

June 24, 1964

Dugout row charge experiment
Type - High explosive, nitromethane
Yield - simultaneous detonation of a row of five 20 ton charges placed 45 feet (13.7 m) apart (1 crater radius)
Depth of Burial - 59 ft (18.0 m)
Medium - Basalt

Site - Nevada Test Site
Objective - Study fundamental processes involved in row charge excavating dense, hard rock.

June 30, 1964 — **DUB** nuclear test
Type - Shaft
Yield - 11.7 kt
Depth of Burial - 848 ft (258.5 m)
Medium - Alluvium
Site - Nevada Test Site
Objective - A device-development test to study emplacement techniques.

October 9, 1964 — **PAR** nuclear test
Type - Shaft
Yield - 38 kt
Depth of Burial - 1,325 ft (403.9 m)
Medium - Alluvium
Site - Nevada Test Site
Objective - A device-development test designed to increase neutron flux needed for creation of heavy elements.

November 5, 1964 — **HANDCAR** nuclear test
Type - Shaft
Yield - 12 kt
Depth of Burial - 1,332 ft (406 m)
Medium - Dolomite (carbonate rock)
Site - Nevada Test Site
Chimney dimensions - Diameter, 138 ft (42 m); Height, 233 ft (71 m)
Objective - An emplacement test to study effects of nuclear explosions in carbonate rock.

December 18, 1964 — **SULKY** nuclear test
Type - Shaft
Yield - 92 tons
Depth of Burial - 90 ft (27.4 m)
Medium - Basalt
Site - Nevada Test Site

Crater Formation - Mound Height 21 ft (6.4 m); Diameter, 80 ft (24.4 m)
Objective - An excavation test to explore cratering mechanics in hard, dry rock and study dispersion pattern of airborne radionuclides released under these conditions.

April 14, 1965

PALANQUIN nuclear test
Type - Crater
Yield - 4.3 kt
Depth of Burial - 280 ft (85.3 m)
Medium - Rhyolite
Site - Nevada Test Site
Crater Dimensions - Diameter, 238 ft (72.5 m); Depth 79 ft (24.1 m)
Objective - Excavation test to investigate cratering mechanics in hard, dry rock and study dispersion pattern of airborne radionuclides released under these conditions.

September 30, 1965

Pre-Schooner II cratering experiment
Type - high explosive, nitromethane
Yield - 85 ton charge
Depth of Burial - 71 ft (21.6 m)
Medium - Rhyolite
Site - Owyhee County, southwestern Idaho
Crater Dimensions - Diameter, 190.4 ft (58.0 m); Depth 60.7 ft (18.5 m); Volume, 24,780 cu ft (18,950 m^3)
Objective - Obtain data for proposed Schooner nuclear cratering test, particularly cavity growth, seismic effects, and air blast.

March 24, 1966

TEMPLAR nuclear test
Type - Shaft
Yield - 0.37 kt
Depth of Burial - 495 ft (150.9 m)
Medium - Tuff
Site - Nevada Test Site
Objective - To develop an improved nuclear explosive for excavation applications.

June 25, 1966

VULCAN nuclear test
Type - Shaft
Yield - 25 kt
Depth of Burial - 1,057 ft (322.2 m)
Medium - Alluvium
Site - Nevada Test Site
Objective - A heavy element device-development test to evaluate neutron flux performance.

July 28, 1966

SAXON nuclear test
Type - 1.2 kt
Yield - Less than 20 kt
Depth of Burial - 502 ft (153 m)
Medium - Tuff
Site - Nevada Test Site
Objective - To develop an improved nuclear explosive for excavation applications.

October 1966 - October 1969

Pre-Gondola I, II, III excavation experiments
Type - High explosive, nitromethane
Yield - Pre-Gondola I, four 20-ton charges; Pre-Gondola II, row of five charges totaling 140 tons; Pre-Gondola III, Phase I, three rows of seven one-ton charges; Phase II, one row of seven 30-ton charges; Phase III, one row of five charges varying from five to 35 tons and totaling 70 tons
Depth of Burial - Varied
Medium - Saturated Bearclaw shale
Site - Near Fort Peck Reservoir, Valley County, Montana
Objective - U.S. Army Corps of Engineers project to provide seismic calibration test data and cratering characteristics for excavation projects.

November 5, 1966

SIMMS nuclear test
Type - Shaft
Yield - 2.3 kt
Depth of Burial - 650 ft (198.1 m)
Medium - Alluvium
Site - Nevada Test Site

Objective - To develop a clean nuclear explosive for excavation applications.

June 22, 1967

SWITCH nuclear test
Type - Shaft
Yield - 3.1 kt
Depth of Burial - 990 ft (301.8 m)
Medium - Tuff
Site - Nevada Test Site
Objective - To develop a clean nuclear explosive for excavation applications.

September 21, 1967

MARVEL nuclear test
Type - Shaft
Yield - 2.2 kt
Depth of Burial - 572 ft (174.3 m)
Medium - Alluvium
Site - Nevada Test Site
Objective - To investigate underground phenomenology related to emplacement techniques.

December 10, 1967

GASBUGGY nuclear test
Type - Shaft
Yield - 29 kt
Depth of Burial - 4,240 ft (1,292 m).
Medium - Sandstone, gas bearing formation
Site - San Juan Basin, 55 miles east of Farmington, New Mexico
Chimney Dimensions - Diameter, 160 ft (48.8 m); Height 335 ft (102 m)
Objective - To investigate the feasibility of using nuclear explosives to stimulate a low-permeability gas field; the first Plowshare joint government-industry nuclear experiment to test an industrial application.

January 26, 1968

CABRIOLET nuclear test
Type - Crater
Yield - 2.3 kt
Depth of Burial - 170 ft (51.8 m)

Medium - Rhyolite
Site - Nevada Test Site
Crater Dimensions - Diameter, 360 ft (110 m); Depth 120 ft (36.6 m)
Objective - An excavation test to study the effects and the phenomenology of creating detonations in hard, dry rock.

March 12, 1968 — **BUGGY -A, -B, -C, -D, -E,** nuclear test (simultaneous, separate holes)
Type - Crater
Yield - 1.08 kt each; charges spaced 150 ft (45.7 m) apart
Depth of Burial - 135 ft (41.1 m)
Medium - Basalt
Site - Nevada Test Site
Crater Dimensions - Length, 855 ft (261 m); Width 254 ft (77.4 m); Depth 65 ft (19.8 m)
Objective - To study the effects and phenomenology of nuclear row-charge excavation detonations.

September 17, 1968 — **STODDARD** nuclear test
Type - Shaft
Yield - 31 kt
Depth of Burial - 1,535 ft (467.9 m)
Medium - Tuff
Site - Nevada Test Site
Objective - To develop a clean nuclear explosive for excavation applications.

December 8, 1968 — **SCHOONER** nuclear test
Type - Crater
Yield - 30 kt
Depth of Burial - 365 ft (111.3 m)
Medium - Tuff
Site - Nevada Test Site
Crater Dimensions - Diameter, 852 ft (259.7 m), Depth, 208 ft (63.4 m)
Objective - To study the effects and phenomenology of cratering detonations in hard rock.

September 10, 1969

RULISON nuclear test
Type - Shaft
Yield - 40 kt
Depth of Burial - 8,425 ft (2,567.9 m)
Medium - Sandstone
Site - Grand Valley, Garfield County, Colorado
Chimney Dimensions - Diameter, 140 ft (42.6 m); Height, 270 ft (82.3 m)
Objective - A joint government-industry gas stimulation experiment to investigate the feasibility of using nuclear explosives to stimulate a low-permeability gas field.

November 1969-
December 1970

Tugboat excavation experiment
Type - High explosive, TNT
Depth of Burial - 4-8 ft (1.2-2.4 m) water
Site - Kawaihae Bay, Hawaii
Objective - To study excavation of a small boat harbor in a weak coral medium.

May 26, 1970

FLASK -GREEN, -YELLOW, -RED nuclear test (simultaneous, separate holes)
Type - Shaft
Yield - GREEN, 105 kt; YELLOW, 90 tons; RED, 40 tons
Depth of Burial - GREEN, 1736 ft (529.2 m); YELLOW, 1,099 ft (335 m); RED, 499 ft (152.1 m)
Medium - GREEN, Tuff; YELLOW and RED, Alluvium
Site - Nevada Test Site
Objective - To develop improved nuclear explosives for excavation applications.

July-December 1970

Trinidad excavation experiment
Type - High explosive
Medium - Sandstone/shale
Site - Trinidad, Colorado (six miles west)
Objective - Four series of row-charge detonations to study excavation designs.

July 8, 1971

MINIATA nuclear test
Type - Shaft
Yield - 83 kt
Depth of burial - 1,735 ft (528.8 m)
Medium - Tuff
Site - Nevada Test Site
Objective - To develop a clean nuclear explosive for excavation applications.

August 1971-
March 1972

Old Reliable fracturing experiment
Type - High explosive, ammonium nitrate
Yield - 2,002 tons
Site - Galiuro Mountains, 44 miles northeast Tucson, Arizona
Objective - To promote fracturing and in situ leaching of copper ore.

May 17, 1973

RIO BLANCO -1, -2, -3 nuclear test (simultaneous, same hole)
Type - Shaft
Yield - 33 kt (each)
Depth of Burial - 5,840 ft (1,780 m); 6,230 ft (1,898.9 m); 6,690 ft (2,039.1 m)
Medium - Sandstone, gas-bearing formation
Site - Rifle, Colorado
Objective - A gas stimulation experiment to investigate the feasibility of using nuclear explosives to stimulate a low-producing gas field.

Date	C. **Proposed Projects** (little work or field testing conducted)
November 1963	**Project Carryall** - A joint feasibility study conducted by the Atkinson, Topeka and Santa Fe Railroad, the California Division of Highways and the U.S. AEC to evaluate the excavation by nuclear explosives of a mountain pass through the Bristol Mountains in Southern California (near Amboy) for a new interstate highway and main line railroad.
December 1966	**Project Dragon Trail Study** - A joint natural gas stimulation experiment proposed by Continental Oil Company and CER Geonuclear Corporation. In May of 1969, Continental advised the AEC that they did not plan to move forward in this project because of the added expense of drilling to greater depths than they planned. Also they felt the information from Gasbuggy and Rulison would answer many of their questions.
August 1967	**Project Ketch Study** - A joint feasibility study begun in 1965 was completed by the Columbia Gas System Service Corporation, U.S. Bureau of Mines, Lawrence Radiation Laboratory, and the San Francisco Operations Office - AEC to study uses of nuclear explosives to create underground natural gas storage reservoirs. The study was followed by a proposal from Columbia Gas to the AEC to conduct a joint experiment to further investigate this application. However, in 1968 Columbia withdrew the request for state land in Pennsylvania to look for other sites.
October 24, 1967	**Project Bronco Study** - A joint feasibility study begun in 1966 was completed by CER Geonuclear Corporation, representing some 20 oil companies, the Lawrence Radiation Laboratory, the U.S. Bureau of Mines, and the San Francisco Operations Office to study the use of nuclear explosions to fracture oil shale for subsequent recovery of the oil by an in situ retorting process. The study resulted in a proposal from CER on behalf of the oil companies to conduct a joint experiment to test this concept. Although a contract was negotiated in 1968, it was not accepted by the oil companies.

October 25, 1967	**Project Sloop** - A joint feasibility study begun in 1965 by the Kennecott Copper Corporation, U.S. Bureau of Mines, Lawrence Radiation Laboratory, and the San Francisco Operations Office - AEC to consider the overall feasibility of using nuclear explosives for fracturing low-grade copper ore bodies for subsequent recovery of copper by conventional in situ leaching methods was completed. Upon completion of the study, Kennecott Copper Corporation proposed a joint experiment to the AEC to test this concept. The company re-evaluated the project with regard to the price of copper versus the lack of available funds in both government and industry.
January 24, 1968	**Project Wagon Wheel** - This was a Plowshare gas stimulation project in the Pinedale area of Wyoming to demonstrate stimulation of formations at depths of 10,000 to 18,000 feet (about 3,000 to 5,500 meters). The industrial sponsor, El Paso Natural Gas Company, completed the project definition stage. Execution was planned in late 1972 or early 1973.
July 30, 1969	**Project WASP** - A joint venture of companies and individuals interested in a Plowshare gas stimulation project in the Pinedale area of Wyoming. Oil and Gas Futures, Incorporated, Bellaire, Texas, was the operating company for this group. The project was in the project definition stage. The project execution date was not expected before 1973 or 1974.