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PROJECT RIO BLANCO
FINAL REPORT
DETONATION RELATED ACTIVITIES

June 30, 1975

CER Geonuclear Corporation
Continental Oil Company

MASTER

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PREFACE

This report covers the detonation phase of Project Rio Blanco: its history, execution and results. However, a number of the project programs (e.g., environmental radiological monitoring and long range hydrologic surveillance) are long term and cover both the pre- and postdetonation periods. The final results of those programs will be reported elsewhere when appropriate.

The basic detailed programs for the detonation phase of the project are presented in Volume II of the Project Definition Plan⁽¹⁾ and, for the most part, will not be repeated in this report. Additional information on the entire project is available in Volume I. The reentry and production testing phase is covered in Volume III and will be the subject of a separate final report.

The three nuclear explosives for Project Rio Blanco were detonated at 1000:00.12[±]0.01 second, Mountain Daylight Time, or 1600:00.12[±]0.01 second, Greenwich Mean Time, on May 17, 1973. The three explosions occurred within the Fort Union and Mesaverde formations at depths of 5,838.5 feet; 6,229.7 feet; and 6,689.5 feet. The three explosives were detonated nearly simultaneously as planned and were completely contained. The preliminary indications are that the yields of the three explosives totalled approximately the design yield of 90 kt. The elevation of the ground at the emplacement well, RB-E-01, is 6,629.9 feet above mean sea level. RB-E-01 is located 1,080.50 feet south of the north line and 1,188.49 feet east of the west line in Section 14, Township 3 South, Range 98 West of 6th P.M., Rio Blanco County, Colorado, which corresponds to geodetic coordinates of 108°21'59" west longitude and 39°47'35" north latitude.

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1. INTRODUCTION

1.1 GENERAL

Project Rio Blanco is a Government-Industry experiment in using nuclear explosives to stimulate production of gas from a well completed into thick relatively impermeable gas-bearing sand and shale sequences. The Government was represented by the Atomic Energy Commission (AEC) and CER. Geonuclear Corporation (CER) was the industrial sponsor. It is the third such nuclear stimulation experiment; each being considered as a step toward the commercial use of the technique. The first was Project Gasbuggy in New Mexico (1967), and the second was Project Rulison in Colorado (1969), about 35 miles southeast of the Project Rio Blanco location.

Project Rio Blanco was designed to be the first phase of an experimental program that was expected to lead to the full field development of the Piceance Basin gas field and the addition of this gas to the nation's depleted inventory of energy sources. Subsequent political, and possibly technical, developments have occurred which make it questionable whether nuclear stimulation techniques will be developed as tools in resource exploitation.

The area of the experiment was estimated to contain 74 billion standard cubic feet of natural gas per square mile (640 acres). The predetonation estimated total gas recovery for one nuclearly-stimulated well per square mile of the unit for 25 years was 17.5 billion standard cubic feet. The unit agreement as approved by the United States Geological Survey contains 93,762 acres.

The geology of the Piceance Basin, with the gas being tightly held within the rock, inhibits the usual industrial techniques for gas recovery from being technically and economically feasible. However, the combination of the vast amount of gas locked into the field, the developing shortage of energy sources, and the increasing need for all energy sources indicates that this potential source should be explored with the goal of its being fully utilized.

Besides the actual stimulation of this well and development of the field, the project had a number of more general information goals. Included are:

1. Determining the effectiveness of the nuclear stimulation.
2. The radiochemical composition of the produced gas and how much the tritium release into the biosphere could be reduced.

3. Information on the interaction of three simultaneous explosions and the effect on fracturing, including interchimney communication, effective height and volume of the chimneys, and the effective fracture zone radius.
4. Development of an emplacement and stemming technique allowing rapid reentry to the stimulated interval.
5. The economics of such a project: costs versus the value of the gas returned.
6. How a major project such as this can be conducted with a minimum of dislocation to the people and damage to property.
7. The effects of the project on the environment and how they can be minimized.

Much of this information has already been developed and will be presented in the appropriate sections of this report. The cost data will not be given because its validity is distorted by greatly increased costs caused by political and legal activities and other non-technical delays.

There were a number of technical innovations in Project Rio Blanco. One of the most important was the use of nuclear explosives specifically and wholly designed for stimulating a natural gas well. This enabled a major reduction in the tritium produced from that of prior projects, a desirable factor in the commercial marketing of the gas produced.

Another important "first" was the nearly simultaneous exploding of three nuclear devices in the same wellbore in order to extend vertically the stimulated interval. There was a planned 10-microsecond delay between each explosive to permit acquisition of signals from each explosive prior to destruction of the signal cabling. Although never attempted before, the three detonations took place as planned and the data recorded showed that the yield of the explosions was within the planned limits.

The project was a significant step forward in the assumption by the industrial sponsor of the responsibility for organizing and executing most of the operational, safety and effects programs. It was, furthermore, the first instance in which the industrial sponsor sought and obtained private insurance against claims for bodily injury or property damage due to seismic motion resulting from planned nuclear explosions. Coverage of \$10 million was obtained, with a deductible of \$100,000.

The experiment was effected with minimal disturbance of the local residents, a majority of whom were in favor of the project. A major reason for local acceptance was an extensive public relations and information effort. This included setting up two public information offices, distributing numerous pieces of literature, setting up information displays in surrounding communities, and by repeated public information meetings where the project was fully discussed and questions by the public were openly answered. Individual contact and interaction with project personnel, however, was probably the most productive method of obtaining the approval of the local residents. An observer program was set up for the day of the detonation; several hundred Federal, State, and local Government officials, industrial representatives, members of environmental groups, and local residents attended the event.

The detonation was conducted very smoothly and with complete safety to participants and the general population. Damage to structures from seismic motion was about that predicted. A great deal of technical data has been obtained on nuclear stimulation and its effects on the surrounding area. Worthy of note was the ability of numerous Governmental, industrial, and private organizations to work together in accomplishing a large and complex experiment requiring several years for preparation and execution.

1.2 HISTORY

The possibility of the nuclear stimulation of the gas-bearing sands in the Piceance Creek Drainage Basin in Western Colorado was first explored in the early summer of 1967. This first tentative consideration resulted in the report "Preliminary Evaluation of Equity Oil Company's Nuclear Stimulation Potential in the Piceance Basin".

In August of 1969, at the request of Equity Oil Company, CER Geonuclear Corporation began an in-depth evaluation of the potential for nuclear stimulation of the Piceance Basin gas field and subsequently, the "Project Rio Blanco Feasibility Study" was published⁽²⁾.

The CER Project Rio Blanco Feasibility Study recommended the testing of several sand lenses in the Fort Union and Mesaverde formations to determine their potential for stimulation and gas production. Two wells, Fawn Creek Government Number 1 and Scandard Draw Number 1, were selected for recompletion, testing, and logging to obtain detailed information on the reservoir characteristics.

Surface studies were made of sand outcrops to determine the orientation and extent of sand lenses in the Fort Union and Mesaverde formations. Seismic surveys were also conducted to determine the location of any possible geologic faults in the area of interest.

Both CER and Equity Oil Company became convinced that there was sufficient potential to justify a program (Project Rio Blanco) and on March 24, 1970, the two companies signed a joint-venture agreement. Under this agreement, CER would earn a 50 percent interest in the Equity Oil Company oil and gas leases in the Piceance Basin by the performance of technical services.

In April 1970, CER notified the AEC by letter of its intention to propose Project Rio Blanco. On May 8, 1970, a formal proposal and the Feasibility Study were submitted to the Director of Peaceful Nuclear Explosives, AEC, for consideration as the next step in the Plowshare program for the nuclear stimulation of natural gas production. During the same month, CER began informing Colorado State officials of the concept of Project Rio Blanco and of the proposal to the AEC. CER also began testing selected existing gas wells.

On September 17, 1970, the AEC accepted the Rio Blanco Concept Proposal as a basis for negotiating a project definition agreement. Negotiations were conducted during the fall and were successfully completed with the December 18 signing of a Project Definition Contract, AT(26-1)-521, between CER and the AEC. This allowed work to be started on the Project Definition Plan and other related documents. On December 24, CER notified Equity Oil of its intention to proceed with the project.

Toward the end of the year, the reservoir testing and evaluation program recommended in the Feasibility Study was completed. The more important conclusions documented in the "Reservoir Report"⁽³⁾ were:

1. The permeability to gas was in the range suitable for nuclear stimulation.
2. The water and fault situation did not present problems.
3. The gas-in-place estimates were conservative.
4. The experiment should be conducted in the Fawn Creek area.

On January 6, 1971, the AEC chose Lawrence Livermore Laboratory (LLL) to supply the nuclear explosives and the associated services required for the project. The Nevada Operations Office was designated as the contracting and operation office. The first discussion between LLL and CER on the objectives of the project and the necessary explosive services was held two weeks later.

Because of the nature and extent of Project Rio Blanco, an extensive public relations and information program was undertaken. During January 1971, the first three of a series of public information meetings were held. Similar meetings were held repeatedly during the next 2-1/2 years in nearby towns and cities to ensure that the local residents and interested general public were informed of the scope and progress of the project.

On February 3, CER filed an application for the designation of a Federal Oil and Gas Unit. Also during February, the testing of the selected existing gas wells in the Piceance Basin was completed.

On February 22, a meeting was held with the Colorado Open Space Council. This was the first of numerous meetings with this and other environmental groups in an effort to obtain their opinions of the project and to resolve their objections.

During the first half of 1971, the studies necessary for evaluation of the environmental impact of the project were initiated. These included studies of the geography and demography of the area, the local geology and hydrology, regional seismic activity and others. In particular, it included a study of the climatology, the potential biological/ecological effects and the potential ground motion effects. These studies culminated in the publication of an "Environmental Impact Evaluation"⁽⁴⁾.

In June 1971, Colorado Governor John A. Love appointed a 17-member Special Advisory Committee to inform and advise him on the relation of the State and project. The Committee's first tour of the Rio Blanco site and a briefing on the project took place 7 weeks later on July 27 and 28.

The Miniata test of the "Diamond" low-tritium nuclear explosive was successfully conducted on July 8 at the Nevada Test Site. This type of nuclear explosive was specifically designed for the stimulation of natural gas formations and test results indicated that the device would meet the requirements of the nuclear stimulation project.

The drilling of the EW, RB-E-01, in Section 14, Township 3 South, Range 98 West, Rio Blanco County, began on September 28, 1971, in accordance with a well plan developed by CER, AEC, LLL, and other Government and industrial contractors.

In September and October 1971, the first application was made to the Bureau of Land Management (BLM) for Land Use and Right-of-Way Permits for the project. A great deal of political activity caused substantial delays, and these permits were finally issued on April 12, 1973.

On September 30, approval for the Rio Blanco unit agreement and unit operating agreement was received. The agreement covers an area of 93,762 acres.

On December 13, the Governor's Special Advisory Committee and representatives of several interested oil shale firms toured the Nevada Test Site underground test locations. The next day, the AEC, LLL, and CER briefed the tour members on the compatibility of nuclear gas stimulation and oil shale development in the Piceance Basin.

In January 1972, the AEC published a Draft Environmental Statement in accordance with the National Environmental Policy Act.

The Project Rio Blanco Definition Plan⁽¹⁾ was published and issued March 3, 1972. The associated documents were issued as they were completed. Among these were the Project Rio Blanco Environmental Impact Evaluation⁽⁴⁾, Project Rio Blanco Demonstration Program⁽⁵⁾, Geology of the Piceance Basin, Revision 1⁽⁶⁾, Hydrology of the Piceance Basin⁽⁷⁾, and the LLL Technical Studies⁽⁸⁾. Also during March, public hearings on the Draft Environmental Statement were held in Meeker and Denver, and in April the Final Environmental Statement⁽⁹⁾ was issued.

On April 23, 1972, the EW was completed. During the ensuing eight months, a series of delays were encountered, almost entirely because of political considerations, which exaggerated the costs of the experiment.

On December 13, 1972, negotiations began toward an execution contract for the project. The negotiations were completed with the resulting execution contract being signed by CER and the AEC on April 12, 1973.

On March 17, 1973, the drill rig to be used for the emplacement of the three nuclear explosives was installed at the EW site.

During the first half of April, in addition to signing the execution contract, joint CER/AEC Offices of Information were opened in Grand Junction and Meeker, AEC and LLL personnel became field operational, and representatives of various participating agencies began reporting to the Grand Junction Control Point.

On April 18, 1973, the LLL Operations Director assumed responsibility for industrial and radiological safety at the EW. On the 23rd, the Operations Coordination Center in the Grand Junction Control Point became operational. Security procedures were also initiated during the month, both in Grand Junction and in the field.

On April 25, 1973, the Colorado Oil and Gas Commission approved the detonation but with the stipulation that CER not enter the chimney without first obtaining approval.

On the same day, a suit to stop the Rio Blanco detonation was filed in the Denver District Court. On May 1, 1973, a small group of environmentalists aided by a university law professor requested that District Court Judge Henry Santo postpone the project. He refused to consider the case because the Colorado Water Pollution Control Commission had not issued a permit for the project. The following day, May 2, the Commission did issue the permit. A hearing on the postponement was then scheduled and held on May 9 before Judge Santo. During the hearing, it was also claimed that the permit issued by the Colorado Water Pollution Control Commission was invalid and that it should be returned to the Commission for further hearings. On Monday, May 14, after considering the petition through the weekend, Judge Santo denied the claim that the State Permit for Project Rio Blanco was invalid and also denied the request for an injunction against the detonation. From that point, no further legal difficulties were encountered.

On April 26, 1973, AEC-Headquarters approved the shipment of the three nuclear explosives from the Nevada Test Site (NTS) to the emplacement well site. The shipment convoy left the NTS on April 30, 1973. Because of bad weather, the convoy arrived at the site on the 2nd of May, rather than the 1st as planned.

After testing of the explosive systems, the emplacement of the explosives began on May 3 and was completed on May 6. Stemming operations began on the 9th of May and were completed the following day.

On May 13, the Scientific Advisory Panel met and, after reviewing the project operations and plans for the detonation, recommended that the project proceed through the detonation phase. Detonation authority was received the next day.

That same day, May 14, a full-scale rehearsal was held; and the wellhead was satisfactorily pressure tested.

On May 17, 1973, the three nuclear explosives were successfully and safely detonated.

2. GENERALIZED SITE ACTIVITIES

2.1 SITE PREPARATION

2.1.1 Roads

Road preparation and maintenance was limited to the unpaved access roads to the Entry Control Center (ECC), the EW, the Firing Point Control Point (FPCP), and the adjacent Firing Point Observation Site (FPOS) (Figure 1). Requirements of moving equipment, trailers, and especially the explosives required that some sections of those unimproved roads be widened and graded.

After the roads were initially conditioned, the maintenance requirements were limited except during and immediately after the spring thaw. The combination of an above average winter snow accumulation, a sudden rise in temperature, and the heavy project-related traffic created severe road maintenance problems for several days in April 1973.

2.1.2 Emplacement Well

The EW area was cleared, graded, and compacted to obtain a usable area of approximately 170,000 square feet. An access road was graded up an adjoining slope and a cleared and graded area provided for a weather station and microwave equipment. Figures 2 and 3 illustrate the layout of the area and the placement of equipment for emplacement of the explosives.

To avoid damage from ground motion, all equipment not needed for the actual detonation was removed from the immediate EW area before D-day. The equipment required at the EW to conduct the detonation was tied down and shock mounted.

2.1.3 Entry Control Center

The ECC was located at the junction of Black Sulphur Road and Fawn Creek Road. Equipment stationed at this location (Figure 4) included:

- a. Radiological safety contractor (RSC) trailers
 - 1. Entry Control
 - 2. Laboratory
 - 3. Sample Preparation

Figure 1. Project Rio Blanco site map.

Figure 2. EW area during emplacement.

Figure 3. Placement of equipment at the EW during emplacement.

Figure 4. Layout of Entry Control Center.

b. Meteorological support contractor (MSC) facilities

1. Balloon inflation shelter
2. Shed and trailer* for radar tracking and receiving equipment, Systrac equipment, and storage
3. Helium bottles

c. Security office trailer

2.1.4 Firing Point Control Point

The FPCP facilities (Figures 5 and 6) were located on a cleared, graded area of approximately 100,000 square feet located off Collins Gulch Road. The FPCP was approximately 12 miles from the EW. Located at the FPCP were the LLL firing/hazard control trailer, the CER microwave and communications shed and tower, and the AEC control point trailer. Adjacent to the FPCP was a helicopter landing site with windsock. Adjoining the FPCP was an existing dirt airstrip which served as a parking area for observer automobiles and buses on D-day. The D-day observer area was located at the far end of the airstrip.

2.1.5 Grand Junction Control Point

The Grand Junction Control Point (GJCP) was located in the CER office and warehouse building at 1921 East Main Street, Grand Junction, Colorado (Figure 7). The building housed the CER and AEC offices, Public Information Office, weather center, Operations Coordination Center, and a warehouse.

2.2 ELECTRICAL POWER

2.2.1 Emplacement Well

Completion of the planned three-phase power line to the EW area was deferred until late April 1973 because the BLM deferred issuing a right-of-way permit for use of several thousand feet of BLM land. Pending completion of the power line, electrical power was furnished by a 37.5 KVA diesel generator. Figure 8 shows the distribution of power during the drilling and emplacement.

*An alternate radar trailer was located at the Oldland Ranch - SE 1/4, Sec. 3, T3S, R96W.

Figure 5. Firing Point Control Point.

Figure 6. Layout of facilities at Firing Point Control Point.

TELEPHONES

CIRCUIT	NUMBER TRUNKS	NUMBER INSTRUMENTS
A	1	TWXA
B	1	FAX
C	1	TWXC
E	1	2
F	4	7
G	4	5
H	4	14
I	2	2 CSP
J	1	1 COMMERCIAL RADIO

RADIOS

- △ SECURITY NET
- △ OPERATIONS NET

* FTS LINE BY AEC

Figure 7. Layout of GJCP showing communications circuits.

Figure 8. Electrical Power Distribution at the EW.

2.2.2 Entry Control Center

During the project, power to the Entry Control Center (ECC) was converted from the available single-phase to three-phase. Figure 9 illustrates the electrical power distribution at the ECC. Additionally, the same type of portable light standards were installed as at the EW and Firing Point Control Point.

2.2.3 Firing Point Control Point

Commercial electrical power was not available as had been planned, so electrical power to the Firing Point Control Point (FPCP) was supplied by a diesel generator furnished by LLL. The fuel and lubricant for the generator were supplied by CER. Otherwise the power distribution was as planned.

2.2.4 Grand Junction Control Point

Electrical service to the Grand Junction Control Point (GJCP) was as defined in the Project Definition.

2.3 COMMUNICATIONS

Communications for Project Rio Blanco were approximately as outlined in Volume II of Reference 1. Exceptions were:

1. The FPOS was supplied with a field telephone service.
2. The GJCP ultimately was served by 14 telephone lines (including one AEC - supplied FTS line), 2 TWX and 1 facsimile weather circuit, 2 leased lines to the Colorado State Patrol, and 1 leased line for a commercial radio link.
3. The number of ASP-674, 3-DB gain, mobile radio antennas with magnetic mounts was increased from 11 to 46.

The communications system for the project was composed of a microwave telephone system, radio system (two nets), and commercial telephone (Mountain Bell). The central facilities and the interconnection between the CER telephone system and the Mountain Bell system were located at the Grand Junction Control Point. Various facilities and locations also utilized signal cable where necessary or convenient. Microwave telephone relay stations were located at Lands End and Monument Peak. The radio relay stations were located at Monument Peak. The system was designed to operate on battery power for a minimum of 8 hours in the event of commercial power failure.

NOTE: ELECTRICAL GROUND (#2 BARE COPPER) NOT SHOWN.

Figure 9. Diagram of electrical distribution at the ECC.

One of the radio nets was used for the security contractor, meteorological service contractor, and LLL. The other net was used for operational control. Other operational communications' nets were provided by the Colorado State Patrol, the AEC, and private contractors.

Figures 7, 10, and 11 show the communications setup for the operational locations that differed from the Project Definition.

2.4 INDUSTRIAL HEALTH AND SAFETY

No significant health or safety problems were experienced during the execution of the project. The project was carried out with complete safety to the participants. There were no industrial accidents of significance, but there were four minor vehicle accidents involving project personnel. No personal injuries were experienced.

Figure 10. Communications layout at the EW.

Figure 11. Communications at the ECC.

3. EMPLACEMENT WELL

The EW, RB-E-01 is located in Section 14, Township 3 South, Range 98 West, Rio Blanco County, Colorado (Figure 12). Preparation of the site began on September 20, 1971, and drilling started on September 28, 1971. The well was completed on April 23, 1972. The following summarizes the as-built well completion report. (10)

3.1 DRILLING

A 26-inch hole was drilled to a 15-foot depth and 23-inch OD conductor pipe was set and cemented to the surface. A 14-3/4-inch hole was mud drilled to 850 feet and opened to 22 inches.

Sixteen-inch OD surface casing was run to an 844-foot depth and cemented to the surface. A 9-7/8-inch hole was then drilled from 844 feet to 7,252 feet. Five cores were taken in this interval, the last three at or near the proposed detonation point locations. Geologic and geophysical logging was accomplished in the 9-7/8-inch hole and the hole was then opened to 15 inches to a depth of 6,993 feet. The primary casing (10-3/4-inch OD) was run to 6,990 feet and cemented back in 2 stages. A cement stage collar at 3,428 feet was drilled out and a cement bond log obtained. The log indicated that cementing extended up to no higher than 2,600 feet, instead of to the surface, as planned.

Exploratory drilling was performed by drilling an 8-3/4-inch hole from 7,252 to 7,869 feet. The hole was then plugged back by placing a cement plug from 7,206 to 6,910 feet.

To assure containment of the explosions, additional work was performed to place cement on the outside of the 10-3/4-inch casing from approximately 2,600 to 707 feet. Figure 13 shows the downhole configuration. All depths given are measured from ground level.

3.2 SURFACE EQUIPMENT AND SPECIAL SERVICES

The wellhead used at the time of detonation was an API Series 1500 (5,000-psi working pressure, 10,000-psi test pressure). A multipen recorder was used to record time, footage, weight, torque, and pump pressure. In addition, a mud logging service was used from 844 feet to total depth (TD) in the 9-7/8-inch pilot hole.

3.3 DOWNHOLE EQUIPMENT AND SERVICES

All casing and downhole equipment was measured on the rack before running in the hole. Sixteen-inch OD, H-40, 65-lb/ft casing was set at 844 feet. Thread locking compound was used on the stab-in type shoe. A 1.90-inch OD parasite string was run on the outside of the 16-inch casing to facilitate remov-

Figure 12. Emplacement well location.

Figure 13. RB-E-01 downhole configuration.

al of cement in the 10-3/4-inch by 16-inch annulus above 707 feet. The removal of cement was planned to avoid spall damage to the emplacement casing. The primary casing consisted of 10-3/4-inch OD Range 3 casing.

Centralizers were placed on the surface casing at 830 feet, 760 feet, and then on every third collar to the surface. For the primary casing, centralizers were placed at approximately 120-foot intervals from 6,975 to 1,800 feet, then at every fourth collar to 800 feet, at every other collar to 550 feet, then at every collar to the surface.

The weight and viscosity of the mud used for drilling the surface casing hole were approximately 9.2 lb/gal. and 50 sec/qt, respectively. During the drilling of the 9-7/8-inch and 15-inch holes, no significant lost circulation zones were encountered.

Samples of cuttings at 10-foot intervals were obtained from the surface to TD. Samples have been placed in a commercial library, the American Stratigraphic Company, 6280 East 39th Avenue, Denver, Colorado 80207, for public record.

Five 3-1/2-inch diameter cores were taken in the 9-7/8-inch pilot hole.

Several drill stem tests (DST's) were attempted on a possible water-bearing interval in the Wasatch formation from 4,164 to 4,180 feet. However, hole washout problems above and below the zone of interest made it impossible to get a good packer seat for the test in the 9-7/8-inch hole. Another series of DST's were attempted on the same interval after opening the hole to 15 inches. Again, hole washout caused problems in obtaining a full DST of the interval. However, on two of the tests, open flow periods of 5 to 11 minutes were obtained before packer failure. Between 130 and 475 feet of gas cut drilling mud with no formation water were recovered in the 5-inch drill pipe, indicating the zone was either gas-bearing or nonproductive.

Surveys of hole deviation were run on January 22, 1972. The bottom hole closure between the two surveys was 8.9 feet at 6,993 foot depth. The hole generally trended SSW with the bottom of the hole located approximately 82 feet SSW of the surface location.

3.4 CEMENTING

The surface casing was cemented through the shoe with 1,200 sacks class G "RFC" cement followed with 200 sacks class G cement. Total slurry volume was 2,160 cubic feet which included 44 percent excess over the calculated hole volume. The surface casing was cemented on November 21, 1971

The 10-3/4-inch primary casing was cemented in two stages on January 24-25, 1972. The first stage was comprised of 2,700 sacks of TXI chem-comp cement plus 35 percent D-30 (fine silica sand) plus 0.3 percent D-74 (retarder). The

total slurry volume was 4,500 cubic feet and included 30 percent excess over the hole volume field calculated from caliper logs.

The second stage of the cementing operation was done after waiting 24 hours for the first stage cement to set. The second stage was through the stage collar at 3,428 feet using 1,800 sacks of TXI chem-comp, plus 35 percent D-30 (fine silica sand) and 0.3 percent D-74 (retarder). The total slurry volume pumped was 3,237 cubic feet of slurry which included approximately 35 percent excess volume over the field calculated hole volume.

The cement bond logs run after the primary cementing job was completed indicated that the first stage was cemented from the shoe to the stage collar. The second stage cementing job was not successful in placing cement all the way back to the 16-inch surface pipe. The cement top appeared to be no higher than 2,600 feet.

A drill rig was moved back over the hole on April 2, 1972, and remedial operations carried out from April 2, 1972 to April 23, 1972 to place cement behind the 10-3/4-inch casing in the area where a lack of cement bonding was indicated. Several remedial squeeze operations were performed before the 10-3/4-inch casing was adequately cemented to assure proper containment.

4. EXPLOSIVE SERVICES AND OPERATIONS

The nuclear explosive services and operations were provided to the project by the AEC (LLL). Details on this part of the project can be found in Reference 11.

4.1 EXPLOSIVE SYSTEMS

The "Diamond" explosives used for Project Rio Blanco were designed by LLL specifically for the stimulation of production from tight natural gas reservoirs. Design objectives were:

1. Minimum diameter (final configuration: 7.8 in. OD)
2. Minimum production of tritium
3. Yield range suitable for Rio Blanco formation (30 ± 3 kt each)
4. Minimum cost with no loss of reliability
5. An explosive easily and safely handled by drill rig equipment

Testing of early designs was conducted at the Nevada Test Site with a test of the complete explosive assembly being held on July 8, 1971 (Miniata Event).

The explosive system consisted of the canister, arming and firing system, electronic system, cooling system, and cables. The system was designed to withstand a maximum temperature of 250°F and a maximum pressure of 7,000 psi. The expected maximum temperature and pressure while emplaced for Project Rio Blanco were 215°F and 5,400 psi. The system was also designed to withstand an environment of hydrogen sulfide although none was expected.

The cooling system was designed for simplicity (one moving part) and reliability. It was self-contained and had a lifetime which met the requirements of the emplacement and stemming times and an appropriate contingency period.

4.1.1 Canister

Each explosive was contained in a canister of specially developed steel which was designed to protect the explosive without being excessively expensive. Testing (composition, tensile strength, tear tests, etc.) was conducted on the canister material during various stages of manufacture to ensure that project specifications were met. Test sections were subjected to expected downhole conditions. Finally, a complete canister was tested for project temperature and pressures in a special test facility.

4.1.2 Arming and Firing System

The arming and firing system was designed not only to provide the usual performance and reliability required for LLL applications but also to meet the additional requirement of functioning in as limited an amount of space as possible. One unique component used in the system was the coded switch. This switch separated the arming and firing components from the other canister electronics (timing, control, and monitoring). Its function was to prevent an unplanned detonation of the explosives even when LLL applied electrical power downhole and queried downhole monitors for data during system checks.

4.1.3 Electronic System

This system integrated the timing, control, and monitoring functions. It was capable of operating as many as five explosives in a single well although the Rio Blanco project was to use only three explosive systems. Each electronic system included a power supply, a command decoder, and a monitoring system. The power supply had a 400-Hz, 208-v input and various dc outputs. The monitoring system supplied information on:

1. Functioning of the command decoder
2. Power supply voltage levels
3. Canister integrity
4. Explosive system temperature
5. Cooling system
6. Nuclear explosive performance

The electronic system components were tested and retested as subassemblies for temperature, shock, and vibration.

4.1.4 Cooling System

The system was a single-pass absorption system and was completely self-contained with no connections to the surface when emplaced. It consisted of a temperature controlled expansion valve, water tank, and calcium oxide absorber tanks. It used vacuum vaporization of the water to cool the explosive package with the water vapor being absorbed by the calcium oxide. Therefore, the lifetime of the cooling system was limited by the amount of water and calcium oxide contained in the system.

4.1.5 Cables

There were two coaxial electrical cables going downhole to the explosives. One cable, the armored command and control cable, accommodated the commands, monitors, and power for all three explosives. The other cable was used for the explosive detonation verification and a bottom hole stemming pressure measurement. LLL's specifications for the command and control cable required a single coaxial cable capable of handling the electrical functions for as many as five explosive systems. The final procurement of the cable required an armored, gas-blocked coaxial cable capable of correct operation at 300°F and 10,000 psi with a characteristic impedance of 50 ± 2 ohms. Cable meeting these specifications turned out to be difficult to obtain and only one manufacturer managed it. Even this one cable did not provide complete gas blocking. It was accepted, however, because it could be terminated inside the pressure-tight wellhead.

4.1.6 Testing

Two other tests were run in addition to the component and subsystem tests: the Compatibility and Certification Test, and the Full System Test.

The Compatibility and Certification Tests were a series of combined tests of the electronic and arming and firing systems to ensure that all interface and isolation requirements were being met and that the combined systems functioned correctly under the expected project conditions.

The Full System Test was a test of prototype explosive package and cooling systems at expected project environmental conditions. The testing was done at LLL facilities. The first test was terminated after 12 days because of problems with the cooling systems. A second test, with a modified cooling system, ran for approximately 30 days and results indicated that the unit would be appropriate for the project.

4.1.7 Explosive Assembly

Before assembling the three nuclear explosives, the electronic systems which were to go downhole with the explosives were fully tested with simulated arming and firing components and a test system equivalent to the electronic systems that were to be used for the project. The cooling system evaporators were checked for correct valve functioning. These checks were performed as late as possible before assembly.

After the checkout, the explosives were assembled and stored at the Nevada Test Site until the Rio Blanco site was fully readied for their arrival.

4.2 INTEGRATED CONTROL SYSTEM

The LLL Integrated Control System (ICS) was the command, control, and monitoring system used for the project. The system consisted of Command Trailer 95, ICE Box, power box, microwave receiver/transmitter station, camera, geophones, RAMS, and cabling (Figure 14). The system was used successfully for the Miniata test of the Diamond explosives.

4.2.1 Command Trailer 95

One half of the trailer was used as a control room and contained the command generation system, monitoring and recording systems, microwave communication equipment, and special control unit. The other half of the trailer contained the safety function, display and recording equipment for the remote area monitoring system (RAMS), weather data, and geophones.

4.2.2 ICE Box*

The ICE Box contained the 400-Hz power supply for the downhole systems together with all the interface equipment and explosive verification instrumentation. A separate monitoring system kept the Control Point informed of the internal status of the ICE box.

4.3 DETONATION

4.3.1 Site Preparation and Acceptance

Prior to the actual arrival of the nuclear explosives, all site preparations for their arrival had to be complete. This included installation and check-out of the ICS.

The checkout included installation and alignment of the microwave antennas for the transmitting of commands and command receipt, interpretation, and action. The command timing and encoding was done in Trailer 95. The commands were then transmitted by the microwave link to the receiver/transmitter station, by coaxial cable to the ICE Box, and from the ICE Box to an explosive package simulator by the armored downhole command and control cable. Dry-run explosive monitor information was carried in the reverse direction back to Trailer 95 where it was displayed and recorded.

The ICS also carried data for the safety program. The safety sensors were located in and about the EW area. Signals from the sensors were carried on field wire to the ICE Box where they were interfaced with the ICS.

*Integrated Control Element

Figure 14. Integrated control system.

In addition to verifying the ICE Box readiness as a junction in the command, monitor, and safety data link, the ICE Box checkout included verification of proper operation of the 400-Hz power supply that was the source of the down-hole electrical power, and the oscilloscope camera recording system for the explosive detonation verification measurement.

Finally, a complete electronic systems check was made where all subsystems with an electrical connection to the ICS were put in their detonation-time configuration along with the electrical power, and the entire system was verified to operate compatibly and correctly with a complete system check and countdown dry run.

In addition to the ICS, a checkout of the emplacement equipment and procedures was required. This included a detailed inspection and testing of the emplacement drill rig (especially the running gear) and running a dummy explosive package, including short lengths of the command and control and verification cables, to the depth of the lower explosive, to assure that the total explosive package would pass freely to bottom. There was additional practice by the drill rig crews in picking up the dummy explosive package from the pipe rack and hanging it from the hook on the rig's traveling block. The casing on which the explosive would be lowered had been previously inspected and tested.

4.3.2 Emplacement

After site acceptance and all preparations necessary for their arrival were complete, the explosives were shipped in an AEC van from the Nevada Test Site to the project site. Upon arrival the explosives were checked out and found to be in satisfactory operating condition.

Before the first explosive was removed from the delivery van, a length of 7-inch casing, housing a cylinder of rare gas (krypton), had been positioned in the drill rig. This casing would be directly below the first (bottom) explosive so the krypton gas could serve as a tracer for later determination of chimney interconnection. Below the casing containing the krypton gas tracer bottle was a short aluminum cover providing protection for a pressure transducer being emplaced to obtain data on the pressure history of the stemming. The first explosive was removed from the explosive delivery van and positioned on the rig catwalk. While resting in a wood blockcradle on the catwalk, all joints in the explosive canister were checked for pressure integrity. After pressure testing, each joint was pinned to ensure its integrity.

The explosive was raised into the drill rig using a cable attached between the rig traveling gear and one end of the explosive while the other end of the explosive was attached to a cable from a winch truck. With both the rig and truck working simultaneously, the explosive was first picked straight up to the horizontal, and then gradually maneuvered to a vertical position. Once

Figure 15. Multiple explosive assembly package.

Figure 16. Detail of typical explosive system assembly.

the explosive was in the vertical position and hanging freely from the rig traveling block, it was attached to the casing containing the gas tracer. The assembly was then lowered and fastened at a point where the top of the explosive canister was at a convenient working level above the drill rig floor. The water canister was removed from its van and positioned directly above the explosive canister. The water tank was then lowered to a position where the connections for the cooling system could be made between the top of the explosive canister and the bottom of the water tank. A temporary cable connection between the explosive and the command and control cables permitted monitoring for the correct water pressure when the water valve was opened.

The temporary cable was then disconnected and removed from the rig floor. The makeup joint between the explosive and the water tank was then completed and pressure checked. The total assembly was lowered and fastened so that the top of the water canister was at the working level. The first of three water-vapor-absorption lime tanks was then positioned above the water tank, lowered to a point where the vapor line connection between the water tank and the lime tank could be made up, and the makeup section evacuated. The joint was then made up and pressure checked between the water tank and the first lime tank. This last sequence was repeated twice more for the other two lime tanks in each total explosive assembly (Figures 15 and 16). While the water tank was being attached and the assembly was being lowered below the rig floor, the explosive detonation verification cable was strapped with steel bands at regular intervals to the completed explosive assembly. At the top of the explosive module, the jumper section of the command and control cable between the second and first explosive was attached, and the cable and connector checked for electrical and pressure integrity. As the lowering continued, both the command and control and detonation verification cables were strapped to the assembly at regular intervals. Casing centralizers to keep the 7-inch emplacement casing centered in the 10-3/4-inch hole casing were also installed near each coupling in the explosive assembly and at regular intervals on the spacer casing between the explosives at coupling locations. After the appropriate amount of spacer casing was used, the casing containing the rare-gas tracer bottle for the middle explosive was attached. After the second explosive was attached, it was lowered to a position that permitted connection of the command and control jumper cable to the bottom of the second explosive package. This connection was then pressure checked. The preceding explosive emplacement sequence was then repeated for the second and third explosive. Beginning at the bottom of the second lime tank above the third explosive, a 1/2-inch OD stainless steel gas sampling tube was strapped to the outside of the emplacement string in addition to the two cables.

Since the explosive cooling system was completely self-contained, confirmation of proper cooling system operation was required before stemming could start. After the first explosive system was complete, there were regular pauses in the lowering to allow system connection and utilization of the ICS for monitoring of the explosive system temperature, pressure, and water use rate.

Once the third explosive had been put in the emplacement string, the lowering procedure was continued on a 24-hour basis until the final depth was reached.

4.3.3 Stemming

After the explosives were at total depth and the wellhead pressure checked, tubing was lowered down the bore of the 7-inch emplacement casing and latched into the float collar placed above the third explosive assembly. Cement was then pumped down the tubing through the float collars and out into the annular space between the 10-3/4-inch primary casing and the 7-inch casing, filling the annular space from approximately 5,641 ft below ground to the surface. The command and control cable, the detonation verification cable, and the sampling tube were thus cemented in this annulus. The explosives were in the lower portion of the hole where there was only water in the annular space between the explosives and the primary casing.

The bore of the 7-inch casing was stemmed by filling the lower 500 ft above the top explosive with a gelled fluid, adding 2,400 ft of cement and filling to the surface with water. (It was expected that the viscosity of the gelled fluid would return to that of water in about 10 days.) This assumed that the top of the chimney would be at a level such that the emplacement hardware above the top explosive would break off in a water filled section of the 7-inch casing, with the water then draining into the chimney. Since it was felt that the water-filled section would extend well above the level where any casing might get damaged or pinched by the detonation, it was believed that it would not be necessary to drill through bent or pinched casing for reentry; it would be necessary only to drill out the containment plug to have access to the chimney; and even if there were damage in the water-filled section, there still would be a sufficient opening for the desired gas flow. As will be reported elsewhere, the gelled fluid viscosity remained unexpectedly high and communication with the chimney could be obtained only by whipstocking out of the 7-inch and 10-3/4-inch casings and drilling ahead through the formation.

When the stemming of the emplacement hole was completed, the drill rig was removed. With access gained to the immediate wellhead and cellar, another check of the wellhead for pressure integrity was made.

4.4 SECURITY

The security specifically for the explosives and their support systems was supplied by the AEC. This included physical security for the explosives while they were above ground and protection for the surface end of the command and control cable during emplacement and stemming. Security personnel also assured that personnel were signed-out of the closed area at detonation.

At the EW area, only the ICE Box required a fence around it to control access; the cable and explosive delivery van were simply roped off and direct surveillance maintained. At the FPCP, Trailer 95 was in a fenced enclosure; however, security was required only when the command and control cable was attached to the system.

4.5 SAFETY

Radiological and industrial safety at the EW area was the responsibility of LLL although much of the work was performed through CER by support contractors. Laboratory programs and procedures for implementing this responsibility were set forth in a number of operational safety procedures pertaining to explosive emplacement, detonation day reentry operations, gas sampling, and drillback. The LLL safety recording equipment to be used on Project Rio Blanco was installed in the Hazards Control section of Trailer 95. This equipment consisted of remote area monitors (RAM's) and weather instrument recording for any effluent documentation and geophone recording for chimney collapse data. Detonation time radiological effluent documentation and personnel protection was accomplished with the emplacement of the RAM system, an air sampling array, and a weather station. Nine RAM's were installed: three at the emplacement well, and six spaced in a rough arc approximately 300 ft from the EW. The battery powered particulate air samplers, which included an iodine collecting filter medium, were started when seismically activated switches were closed by detonation-induced ground motion.

Routine dosimetry for personnel was handled by CER's radiological safety contractor while LLL personnel provided the radiological monitoring for the explosive handling. All nuclear operations were conducted without a radiological incident.

The LLL geophone system consisted of three stations installed at 1,000, 4,000, and 7,000 ft from the EW to provide information on cavity collapse and chimney formation. Data from the system were recorded and displayed at Trailer 95. The data were used after detonation to determine when the reentry parties could safely return to the EW area.

5. OPERATIONAL SAFETY

5.1 AREA CONTROL

The objective of the area control program was to ensure the safety of project participants, observers, and local residents. It included traffic control, aerial sweeps and surveillance, and evacuation of residents. Also considered were mines, industrial plants, trains, and the closing of airspace above the detonation area for the detonation.

5.1.1 Traffic Control

Traffic control was accomplished through the establishment of roadblocks at 19 locations. (12) Two kinds of roadblocks were used:

1. Roadblocks isolating fairly long stretches of roads which were considered either highly vulnerable to rockfalls or had low traffic densities. These roadblocks went into effect about 1 hour before detonation time. (Coded "B" in Figure 17.)
2. Shortblocks, i. e., roadblocks covering small road segments of high traffic density locations. These were put into effect 15 minutes before detonation time. (Coded "SB" in Figure 17.)

In addition to the roadblocks, surveillance was maintained at distant rock-fall areas before, during, and after the detonation sequence by roving road patrols. (Coded "S" in Figure 17.) Participating personnel included members of the Colorado State Patrol, the State Highway Department, State Division of Wildlife and the Sheriff and Road Departments of Rio Blanco and Garfield Counties.

5.1.2 Aerial Surveillance

Aerial surveillance was conducted from both chartered and military aircraft during the detonation period to ensure that no one was within the restricted area. The aircraft were also used for emergency standby, road damage survey, documentary photography, radio relay, mapping, and bioenvironmental surveys. The aircraft involved consisted of five helicopters and two fixed wing aircraft. Two additional aircraft were on standby at detonation time.

5.1.3 Resident Safeguards

The safeguard control area extended to a radius of 14.5 miles from the EW, within which peak ground motions of more than 0.1g were predicted. Those

Figure 17. Traffic control stations at detonation time.

residents within a radius of 7.5 miles (0.3g or more) were asked to leave their ranches, while those in the 7.5 to 14.5 mile annulus were asked simply to be outdoors and in a safe place. In practice, all residents in the safeguard control area elected to be at the FPOS observer area at detonation time.

The evacuation was accomplished with the use of Area Control Teams furnished with radio-equipped vehicles. The team members were local residents and each member was responsible for a particular group of residents. The relocating of residents to the observer site was effected without problems. After the detonation, the residents were given preference in leaving the observer site first. Each was contacted soon after arrival home to determine whether emergency repairs were needed; none were.

5.1.4 Railroads

As planned, all trains in the area were scheduled to avoid potentially unsafe locations during the detonation. Immediately after the detonation, six motorized track patrols with radio communication equipment checked the condition of the railroad right-of-way in the areas of interest. They reported that the track was clear and no rockfalls had been observed near the right-of-way, and train traffic was resumed. All internal radio communications were handled over the Denver and Rio Grande Western Railroad radio system. The GJCP was linked with the central railroad dispatch office by telephone.

5.1.5 Mines and Industrial Plants

All active mines within 53 miles of the EW (Figure 18) were evacuated during the detonation. Personnel of industrial plants within 14.5 miles of the EW and the Colony Oil Shale Plant on Parachute Creek were requested to be outside and well away from the plant structures. Verification of response to these recommendations was made by phone at least 1 hour before the detonation. Mine inspectors were stationed at all active mines and inspected them immediately after the detonation. No damage was detected and mining operations resumed.

5.2 STRUCTURAL BRACING PROGRAM

A comprehensive structure inventory was made within a 30-mile radius of the EW. The purposes of the inventory were to identify those structures which might require bracing against possible damage from the detonation-induced ground motion and to facilitate prediction of overall damages. Using this inventory, an extensive structural bracing program was developed. The program enveloped both residential and non-residential structures.

Figure 18. Mines and quarries in the Rio Blanco area.

For its size, the most extensive bracing was applied to the Rock School. A large amount of bracing was also applied to the Bookcliff Bowling Alley and the Colony Development Oil Shale Retort Tower and lesser amounts to numerous other structures. Although no damage was predicted for bridges in the project area, the response of six bridges was documented.

The observed ground motion⁽¹³⁾ was appreciably less than the prediction used to evaluate possible seismic damage, and it is difficult to assess the effectiveness and necessity of the bracing program. In a few cases, however, it was obvious that the bracing was effective in minimizing damage. In other cases and in retrospect, some of the bracing was unnecessary.

6. ENVIRONMENTAL PROTECTION PROGRAM

6.1 RADIOLOGICAL MONITORING PROGRAM

The Radiological Monitoring Program was begun in October 1971 and continued until July 31, 1974. It was suspended temporarily from October 1972 until mid-February 1973 because adequate background data had been obtained and the detonation date was still many months away.

The data obtained by the program have been reported by the Eberline Instrument Corporation in quarterly reports under the basic document number PNE-RB-51.⁽¹⁴⁾ The reports also describe the procedures and equipment used in the program. Appendix A presents the summaries from the four quarterly reports for the year immediately following the detonation. There has been no detectable increase in environmental radiation as a result of the nuclear detonations of Project Rio Blanco.

6.2 HYDROLOGY

As with the Radiological Monitoring Program, the hydrologic testing for Project Rio Blanco was an extensive long-term program. Data were collected and analyzed from time to time and periodically reported. (See references 15 through 19.) The following statements are abstracted from Reference 16.

The sedimentary sequence at the site is approximately 20,000 feet thick. The principal aquifers are at the top of the sedimentary sequence in the Parachute Creek Member of the Green River Formation within 1,500 feet of the surface. The aquifer system consists of 2 aquifers separated by the Mahogany Zone, a kerogen-rich shale about 170 feet thick in the project area. The upper aquifer, or "A" Zone, consists of fractured shale and marlstone overlying the Mahogany Zone, and the lower aquifer, or "B" Zone, consists of fractured shale and marlstone below the Mahogany. Recharge to the system is principally from snowmelt. Generally, water moves through the aquifers from near the basin margins, toward the north-central part of the basin where it is discharged to Piceance Creek. Leaching of the soluble minerals by ground water has increased the dissolved solids concentration of the water in the "B" Zone. The dissolved-solids concentration of water from the "A" Zone is generally less than 2,000 mg/l, while that of water from the "B" Zone may exceed 60,000 mg/l.

Four wells were drilled within 1,300 feet of the EW. Pre- and postdetonation aquifer tests conducted to determine the hydraulic properties of the "A", "B", and Mahogany Zone indicate that the Mahogany Zone was not fractured by the detonation and that the transmissivity of the "A" Zone aquifer has increased by a factor of five.

Seven shallow wells were specially drilled at distances of 3.5 to 12 miles from the EW to investigate possible seismic effects on communication between aquifers along fault planes. These wells were drilled in the alluvium near-known faults. These wells and four existing wells were sampled pre- and post-detonation. No change in water quality was detected.

Eleven wells within 18 miles of the EW were instrumented to detect detonation-induced transient and long-term changes in water levels. With the exception of 2 wells, long-term water-level changes in wells have been less than 6 feet.*

A regional program to monitor changes in spring flow and water quality was also undertaken. Springs were monitored pre- and postdetonation to detect the effects of the nuclear detonation. Increased flows were measured in springs up to 10 miles distant from the EW. Flows increased as much as five-fold in the springs nearest the emplacement well. To date, no change in water quality has been found.

6.3 PROMPT BIOENVIRONMENTAL SURVEY

The prompt bioenvironmental survey was developed to determine the effect of the detonation, particularly from ground motion, on the area's bioecology⁽²⁰⁾. Extensive documentation and evaluation was concentrated within a radius of approximately 1.5 miles of the EW, although some observations were also made outside this area.

Observers were organized into three teams. Team 1 was concerned with the aquatic and riparian environs of Fawn Creek near the EW. Team 2 focused attention on the terrestrial environs in the immediate vicinity of the EW. Team 3, using a helicopter, reconnoitered a 10-mile radius area from the EW to document nesting raptors, livestock and big game concentrations, and their responses to ground motion. All observers looked for wildlife and livestock that might have been injured or killed by the effects of ground motion, e.g., rock falls. No evidence of direct effects of ground motion upon animal life along Fawn Creek was found. However, secondary effects upon animals occurred such as losses of food, cover (habitat), and nests or burrows. Efforts were made both pre- and postdetonation to document existing animal life and carcasses along Fawn Creek. No freshly dead or injured animals (other than birds killed by rockfalls) or fish were found postdetonation. Although not directly observed, one claim was settled with a local rancher for the loss of a lamb killed by a falling rock on the Robinson Ranch on Piceance Road. Cattle within 400 yards of the EW at detonation time showed no effects. Directly observable impacts to vegetation in the terrestrial study areas were the losses of trees, shrubs, grasses, and forbs that were displaced from cliffs, as well as the vegetation buried or broken by the falling debris.

*Both wells, RB-S-03 and RB-D-02, were completed in the "A" Aquifer within 200 feet and 1,400 feet of the EW, respectively.

Within a 1.5-mile radius of the EW, damage to aquatic and riparian habitat along Fawn Creek was severe and common. Severe to moderate effects upon habitat from slides and rockfalls were also common on the steeper, south-facing hillside slopes within this radius. Moderate damage to aquatic and terrestrial habitats in very specific, localized areas was documented in a zone 1.5 to 10 miles in radius from the EW.

As expected, pressure waves from the explosion compressed the groundwater and caused prompt increases in stream and spring flow. The detonation resulted in a substantial prompt increase in the silt load of Fawn Creek and a minor increase in dissolved solids. The spring 1.5 miles above the EW showed an approximate threefold increase in suspended solids but no increase in dissolved solids. Because of heavy snow melt, Fawn Creek was carrying an appreciable sediment load before the detonation and assessment of effects on the aquatic fauna was not possible. The steeper, nonvegetated banks of the Fawn Creek near the EW underwent significant additional sloughage as a result of ground motion.

6.4 DELAYED EFFECTS ON VEGETATION

A postdetonation photographic survey was made to document long-term ecological effects of Project Rio Blanco. The survey, conducted on June 15 and 16, 1974, consisted of repeating the documentary photographs which were taken from 25 marked locations in April 1971 and making notes and observations as a followup to the prompt effects survey in May 1973. The survey will be repeated in the spring of 1975.

Each of the 25 original locations were found and a total of 104 photographs were taken at the same azimuths as in the original set. As expected, there was no obvious evidence of general, long-term detrimental effects on the vegetation of the area from ground motion, although some of the original local damage associated with rockfalls and sloughage was still evident.

Vegetation loss from additional drilling and road-building activities was documented in the new photographic series. Trees and shrubs in general showed apparently normal new growth; apparently ground motion was not sufficient to disrupt root systems or cause a general decline in tree shrub vigor. No signs of general or massive erosion were noticed.

7. SEISMIC EFFECTS AND DAMAGE CLAIMS

7.1 GROUND MOTION

An extensive instrumentation program was undertaken for the Rio Blanco experiment to measure the ground motion at various azimuths and distances from the EW⁽¹³⁾. The objectives of the program were to enhance the predictive capabilities for future experiments in this immediate area and to provide data which would enhance the capabilities of predicting structural damage.

7.1.1 Instrumentation

Thirty-seven locations were instrumented for ground-motion documentation with L-7 velocity systems by the U.S. Geological Survey/Seismic Engineering Branch (USGS/SEB). Two locations were instrumented for ground-motion documentation with strong-motion accelerographs. The Hayden Power Station was instrumented by Kenneth Medearis & Associates (KMA) with an accelerograph. Several strong motion stations were operated by Atlantic Richfield Company, two of which were reported (Arco No. 1 and Arco No. 10). Figure 19 shows the locations of the recording sites.

7.1.2 Data

Where the data were recorded as particle velocity (L-7 stations), the records were digitized and differentiated to obtain accelerations; for those stations where the data were recorded as particle acceleration, the records were digitized and integrated to obtain velocity. Regression analyses were made for the peak horizontal component (PHC) of velocity and the PHC of acceleration. The data were separated as to surface conditions into hard rock, alluvium, or unknowns.

The CER predetonation predictions⁽⁴⁾ were based on the PHC of velocity and acceleration from hard-rock station locations only. The predictions were based on use of two regression lines. One regression line covered the distance from 6 km to 22 km and the second line from 22 km to 300 km.

In the early reporting of the Rio Blanco results, a two-line regression formula was also assumed. Later analysis, however, indicates that all data from stations closer than 10 km are highly questionable because of spall or the ground motion affecting the tape recorder. In this report, a single regression line is assumed from 11 km to 150 km for both hard-rock and unknown station condition analyses. Figures 20 through 23 show the graphical results of this regression analyses.

Figure 19. Ground motion recording sites.

Figure 20. Peak particle velocity (horizontal component) vs slant distance, hard-rock stations.

Figure 21. Peak particle velocity (horizontal component) vs slant distance, alluvium or unknown stations.

Figure 22. Peak particle acceleration (horizontal component) vs slant distance, hard-rock stations.

Figure 23. Peak particle acceleration (horizontal component) vs slant distance, alluvium or unknown stations.

An intensive program was initiated to determine whether or not Project Rio Blanco caused any change in the natural seismicity of the area within 40 km of the EW. (4, 13)

Geologic and seismic surveys showed that there were no surface or subsurface indications of faulting within 9,000 ft of the EW. A seismic station installed on November 20, 1971, about 6 km NNW of the EW, monitored the seismicity of the area within 40 km continuously up to December 17, 1973. In the 18-month predetonation period, only 1 microearthquake was recorded. At detonation time, this station became part of a six-station array deployed to monitor the seismic activity during and after the detonation. This array was discontinued 19 days after the detonation and the single station was returned to its original configuration and continued monitoring the seismicity of the area until December 17, 1973. In the 7-month period starting 19 days postdetonation, only 1 microearthquake was recorded within 40 km of the station.

A 6-instrument array was deployed 17 days before the detonation to record and locate the hypocenters of the subsequent aftershocks. One station was located 900 ft north of the EW and the other five in a circular array at distances ranging from about five to six km. In the period from D-19 days to detonation, no microearthquakes were recorded in the area. From detonation to H+5 minutes, the records were too noisy to permit identification of events. From H+5 minutes to D+8 days, 120 aftershocks were recorded on at least 4 of the 6 seismic stations. No aftershocks were detected after D+8 days. The majority of the aftershocks that occurred in the vicinity of the explosives are chimney related. In no case did an aftershock occur near or in the oil shale horizon, which in this location runs from 400 ft in depth to 2,800 ft in depth.

A second seismic array was fielded by the U.S. Geological Survey/National Center for Earthquake Research (USGS/NCER) to monitor cavity collapse and aftershocks. The USGS/NCER emplaced 33 seismometers within 5.8 km of the EW. Twenty-five stations operated successfully for a period of 24 hours. The depth distribution of hypocenters indicates close agreement with the results reported above.

As a result of the seismicity monitoring program, it is evident that Project Rio Blanco had no long range effect on the natural seismicity of the area, the aftershocks appear to be chimney related, and that no aftershocks occurred in or near the oil shale horizon.

On the basis of data reported by 19 stations of the worldwide network to the National Earthquake Information Center, Project Rio Blanco had an average magnitude of 5.4 m_b .

7.3 MINES AND QUARRIES

A pre- and postdetonation inspection was made of all mines and quarries within 53 miles of the EW. Minor rockfalls from the walls in the Colony Oil Shale Mine were reported. None of the other inspected mines or quarries suffered any damage as a result of the detonation.

7.4 BRIDGES

Although KMA predicted no damage to bridges in the Project Rio Blanco area, the AEC requested that six be documented. KMA inspected these bridges carefully before and after the detonation and found no visible evidence of detonation-related damage.

7.5 OIL AND GAS WELLS

Forty-two oil and gas wells at distances between 1.5 and 7 miles from the EW were inspected and photographed before and after the detonation. No surface damage to any of the wells or ancillary equipment was found. No subsurface damage to those wells was predicted and none has been reported. The casing in Fawn Creek Government No. 1, about 1,300 feet from the explosions, was found to be slightly out of round after the detonation when the well was recompleted. Some soil movement was noted around the well casings in some of the wells within 4 miles of the EW. The inspection was confined to surface facilities.

7.6 WELLS AND SPRINGS

An inventory of wells and springs supplying water for domestic, agricultural, or industrial purposes was made pre- and postdetonation as part of the Rio Blanco seismic effects documentation^(18, 19). Water samples were taken and analysed pre- and postdetonation from all producing wells and springs within 10 miles of the EW. In addition, all the springs within 5 miles and key springs at a distance of from 5 to 10 miles of the EW were equipped with flumes predetonation, and the rates were recorded on a weekly basis and in some cases are continuing to be measured.

Detonation-related well problems were reported for only three of the water wells in the area of interest (A, B, and C on Figure 24). These were all mechanical problems associated with scale being knocked off the casing and cutting or jamming pump cups. The problems were remedied by changing the damaged cups.

The results of these measurements show that the general trend of spring flow rates vs time was an increase in flow rate following detonation with a gradual return toward predetonation rates during the year following detonation. The evaluation is complicated by irrigation water being mixed with the spring water above the flume and being included in the spring flow readings.

Figure 24. Non-project related water wells in Rio Blanco area of interest.

In general, the Rio Blanco detonation appeared to have caused pore pressure fluctuations that in some cases "developed" the existing springs or created new springs. This appears to be a transient phenomena and the spring flows are returning to normal. In other cases, springs have dried up. This appears to be the result of increased flow in other springs discharging the available water. Figure 25 shows the location of the new springs and the dry springs. Figure 26 is a graphic presentation of the capture of water by the increased flow of springs to the north of the White River-Colorado River drainage divide in the Piceance Basin. In this figure, if spring flow on the right or White River side of the drainage divide were to increase due to spring "development", the spring flow on the left or Colorado River side would decrease or cease because of the reduction in the height of the water table (indicated by triangles) and the decreased resistance to flow in the opposite direction.

The results of chemical analyses of water samples from selected springs collected pre- and postdetonation show no significant changes in water quality.

7.7 MICROTREMOR SURVEYS

Microtremor surveys were made in 1970 and 1971 of the towns of Rifle, Grand Valley, Meeker, Rangely, and De Beque. A comparison of the surveys and damage patterns in Rifle and Grand Valley from Project Rulison indicates that for those locations where the ground resonance is less than 12.5 Hz, the damage incidence to residential structures is double that of locations where the ground resonance is above 12.5 Hz^(4, 23).

7.8 DAMAGE CLAIMS

A structural inventory and seismic hazard evaluation was made of the 352 structures located within 30 miles of the EW. Where required, recommendations for bracing were made. The predetonation estimate for seismic damage to low-rise structures was \$51,000 $\pm$ \$13,200⁽²²⁾. The actual adjusted damage to all structures was \$58,922, of which about \$25,000 was related to other than buildings, e. g. , water wells and irrigation ditches. This dollar amount is based on the disposition of 169 complaints. As of March 15, 1975, 115 of these have been settled. Fifty-four were determined to be non-detonation related. Two have been re-opened and are now pending. No more are anticipated. Of those settled, the investigators considered about 14 percent to be at least partially questionable. For these the settlements amounted to less than 10 percent of the total dollar amount. The rationale for settlement in these cases was economic as well as favorable public relations. The distribution of property damage claims is shown in Table 1.

Figure 25. New and dry springs.

Figure 26. Schematic of White River/Colorado River drainage divide and recharge area.

Table 1. Distribution of property damage claims.

<u>Area</u>	<u>Claims</u>	<u>Settled</u>	<u>Amount</u>	<u>NFAC*</u>
Piceance Creek	22	18	\$26,183	4
Roan Creek	5	4	5,533	1
Meeker	56	38	10,948	18
Meeker (Rural)	12	8	7,418	4
Rifle	6	4	612	2
Silt	3	1	150	2
Rifle & Silt (Rural)	10	6	2,939	4
Grand Junction	23	16	1,842	7
Clifton	4	3	320	1
Grand Valley	6	4	318	2
Rangely	6	4	145	2
Other	<u>16</u>	<u>9</u>	<u>2,514</u>	<u>7</u>
TOTALS	169	115	\$58,922	54

*No further action contemplated.

8. ADD-ON PROGRAMS

8.1 GROUND SPALL MEASUREMENT (CER/LLL)

8.1.1 Surface Crack Analysis

Pre- and postdetonation photographs of the Fawn Creek Road surface and well pads were taken in an effort to estimate the lateral extent of spall caused by the detonation. It was expected that visible cracks would develop in the hard-packed surfaced of the road within the spalled region.

Photographs and visual examinations were made predetonation on May 16, 1973 and postdetonation on May 17, 18, 1973 from fixed stations. Figure 27 shows the locations of the fixed photograph stations. Additional photographs were taken of areas of interest.

All detonation-related zones of surface cracks observed along the road and on the well pads were described and located. Representative cracks were also photographed. An intensive search was conducted out to more than 5 km south and more than 8 km north of the EW.

Essentially, all the cracks observed followed preexisting desiccation cracks. As a consequence, crack lines were generally sinuous. No cracks were observed to continue from the road surface or well pads into adjoining rock outcrops or alluvial fill. The locations of the postdetonation surface cracks are shown in Figure 28.

No detonation-related cracks were visible in the photographs taken at the fixed stations. In each postdetonation photograph, the only noticeable detonation effect is fallen rock in the road.

8.1.2 Dynamic Measurements

The purpose of the ground dynamic measurements program was to determine the depth and radial extent of any spall resulting from the detonation of the explosives (23, 24).

There was concern expressed by others not connected with the project that spall might fracture the oil shale sufficiently to make the room and pillar mining technique impossible, or require considerable rock bolting, or that mining would be made impossible or significantly more difficult by the influx of added water from either one of the aquifers above or below the shale zone owing to their being further fractured.

Figure 27. Locations of fixed pre- and postdetonation surface crack photographic stations along Fawn Creek road.

Figure 28. Locations of surface cracks observed on Fawn Creek Road postdetonation.

An instrumentation program was designed to measure the incident and reflected wave at five different ranges from the emplacement well and at various depths. The instrumentation included accelerometers, velocity gages, and *clipers.

The instrumentation was installed in six instrumentation wells and two surface stations. Wells were drilled 280 feet and 650 feet deep, 100 feet northwest of the EW; 280 feet and 430 feet deep, 2,600 feet southwest of the EW; and 680 feet deep, 7,300 feet southwest of the EW. The two surface stations were 12,000 and 23,000 feet northeast of the EW. See Figures 29 through 31 for well installation diagrams.

The accelerometer data indicates that the Rio Blanco spall zone can be described as a broad, shallow dish with a most probable depth of 350 feet or less and a radius of less than 24,000 feet. Acceleration records show that spall occurred above 149 feet at the EW but not below 604 feet. Instruments placed at depths of 350 and 450 feet do not appear to have recorded spall characteristics. The results are in general agreement with predetonation predictions.

8.2 GAS SAMPLING AND CHIMNEY PRESSURE MEASUREMENTS (LLL)

Communication with the chimney was not established immediately postdetonation as originally planned, even though the two diaphragm valves at depths of 3,000 and 4,000 feet in the prompt sample line were ruptured. The gas sampling line was pressurized to 5,000 psi at the wellhead without any real indication of the opening of a flow path to the chimney. Pressures in the sampling tube rose slowly at a rate of about 5 psi per day until the evening of May 31, 1973, when the rate started to increase more rapidly and reached about 150 psi per day.

The pressure in the sampling tube reached a plateau of about 1,600 psi indicating a chimney pressure of about 1,750 psi assuming the chimney top to be at about 5,500 feet and the gas gravity to be 0.65. The sampling tube was pressurized to 4,000 psi with nitrogen on June 28, 1973, and the pressure drop observed. The results indicated a chimney pressure of about 1,800 psi.

Gas samples were obtained on four different days in June 1973. The radioactivity concentrations measured were lower than expected and somewhat anomalous. Likewise the chemical composition of the first gas sample, taken on June 5, did not agree with the predicted chimney gas composition. The data for the June 5 sample are given in Reference 12 with some discussion of the anomalies.

*Acronym - Collapsed Location Indication by Pulsed Electromagnetic Radiation

Figure 29. Spall documentation instrumentation at the EW.

Figure 30. Spall documentation instrumentation, 2,600 feet SW of the EW.

Figure 31. Spall documentation instrumentation,
7,300 feet SW of the EW.

8.3 DETERMINATION OF POSTDETONATION CABLE LENGTH (LLL)

The detonation verification cable was pulsed starting at less than 50 milliseconds postdetonation in an attempt to measure chimney growth⁽¹²⁾. This cable had already been broken by this time at a point 335 ± 5 feet above the top explosive. The firing cable was broken at 152 ± 5 feet above the top explosive. The longer length of this cable is undoubtedly due to its higher tensile strength. These cable lengths were again measured during the week of June 4, 1973, and found to be unchanged.

8.4 CLOSE-IN ACCELERATION MONITORING (LLL)

The vertical component of motions to which the wellhead was subjected were measured by three accelerometers fastened to the wellhead⁽¹²⁾. Data from all instruments have been analyzed. That from one has been reported as follows:

Peak Acceleration	32.5 g
Peak Velocity	3.25 ft/sec
Peak Displacement	2.0 in.

8.5 SUPPLEMENTAL SEISMIC MEASUREMENTS (CER)

Two types of strong motion equipment were set up for the purpose of comparison of data from each with the other and with the data from the L-7 systems.

One SMA-1 and one RFT-250 were deployed beside the L-7 system at the Rock School. The other SMA-1 was deployed at the Cascade Pump Station. The second RFT-250 was deployed at the Shall Plant. Upon the return of the instruments to the manufacturers, it was discovered that neither of the instruments at the Rock School operated properly due to the jamming of the film in the magazine. This instrument failure made it impossible to compare any of the data from the various types of equipment.

The data from the Kinometrics SMA-1 at the Cascade Pump Station have been analyzed visually and given values of acceleration as follows:

Vertical	0.16 g
Radial	0.28 g
Transverse	0.250 g

The PHC, 0.28 g, is 0.6σ of the value calculated from the regression equation (Figure 23) for alluvium or unknown stations.

The data from the strong motion equipment (Geotech RFT-250) at the Shell Plant have been analyzed visually and give values of acceleration as follows:

Vertical	0.23 g
Radial	0.20 g
Transverse	0.15 g

The PHC, 0.20 g, falls halfway between the values calculated from the regression equations (Figures 22, 23) for hardrock and for alluvium or unknown stations.

8.6 EFFECTS MONITORING PROGRAM (EL PASO NATURAL GAS COMPANY)

El Paso Natural Gas has proposed to perform a natural gas experiment utilizing nuclear explosives in the Wyoming area under the code name of Wagon Wheel. This led them to establish a monitoring program on Rio Blanco to gain knowledge of the response of structures and natural features similar to those in the Wagon Wheel site. From the information obtained, they will refine their preliminary conservative evaluations of the ground motion effects on manmade and natural structures.

The data have been collected and compiled in a data report.⁽²⁵⁾ The report does not contain detailed analysis of the results nor any application of the results for effects evaluations for future underground explosions and therefore, is of value only to a qualified investigator.

Specific experimental programs were developed in order to provide information related to several fields of interest in association with a deep underground nuclear detonation. These programs and specific program objectives were as follows:

1. Liquefaction Program: Utilize instrumentation at selected sites to measure the magnitude and the rate of the accumulation and dissipation of pore water pressure in saturated permeable soils to study the liquefaction potential of these soils.
2. Earth Strain Program: Utilize instrumentation at a selected site to measure displacement amplitudes and time rates to study the wave lengths of the ground motion caused by the detonation, and the degree to which differential displacements might be induced in structures 25 feet to a few hundred feet in length.
3. Bridge Program: Utilize instrumentation, photography and surveying techniques at selected sites to measure and observe permanent and transient displacements of small single span bridges typical of those associated with ranching operations and rural transportation, and to use those results to study potential damage characteristics of similar structures.

4. Slope Stability Program: Utilize surveying, photography and various monitoring devices at selected sites to measure and observe displacements and quantities of sloughing soil and rock material to study the potential for and probable magnitudes of sloughing of similar slopes and bluffs.
5. Earth Dam Program: Utilize surveying and photography techniques on selected earth dams to measure and observe permanent displacements to study their damage potential characteristics. Items of particular interest within this program were:
 - a. Indications of overall dam slope stability in relation to embankment settlement and lateral deflection.
 - b. Indications of possible induced soil liquefaction within a dam embankment or supporting soils.
6. Miscellaneous: Utilize before and after surveying and photography techniques to study the damage potential characteristics of:
 - a. Mechanical equipment and structures associated with conventional gas field operations.
 - b. Typical irrigation structures and canals as related to structural damage and settlement and slumping of canal banks.

8.7 PORE PRESSURE ENHANCEMENTS (SANDIA LABORATORIES)⁽²⁶⁾

The objective was to take advantage of the opportunity to study in situ pore pressure changes and liquefaction resulting from the strong seismic motion over a large area. This experiment complemented the EPNG experiment described above and was done in close cooperation with EPNG. The measurement stations were spaced at 2.1, 4, 7, and 10 kilometers from the emplacement well. Two sets of measurements of the pore pressures were made at the inner and outer stations with a single set at the intermediate ranges. Surface accelerations were made at all stations. The stations were placed close to Fawn Creek to assure drilling into saturated medium and the pressure transducers were placed at depths from 2.4 to 6.7 meters. The acceleration and pressure signals were transmitted via FM frequencies to a common recording point where they were recorded on magnetic tape along with calibration signals.

The experiment was reasonably successful. All acceleration measurements were successful, and meaningful pore pressure measurements were obtained except at the four-kilometer station. The dual pressure measurements demonstrated satisfactory consistency.

In general, the sustained pore pressure increases were much lower than would be required to achieve liquefaction. No evidence of liquefaction in undisturbed soils in the postdetonation search was found.

The early transient pore pressure history correlates well with acceleration. This correlation is lost in the later portion of the records. It is suspected that the later pressure fluctuations indicate the action of more oblique seismic waves generating horizontal stresses.

The sustained pressure increases achieved were roughly proportional to both the peak particle velocities and the sum of the individual oscillation peaks of the strongest component of acceleration. There is no physical reason to believe the first correlation is significant, the latter result is consistent with laboratory observations but the sample is rather too small for a final assessment. The soils at stations were deemed of the same general class in the laboratory analysis.

The amplitudes and frequencies of the pore pressure histories suggest the soil permeabilities ranged from millidarcies to darcies. The transient response was less marked in the emplacement holes which dried and required irrigation.

These results seem reasonably consistent with those obtained on the EPNG experiment.

APPENDIX A
SUMMARIES FROM SELECTED
RADIOLOGICAL MONITORING PROGRAM REPORTS

(From Reference 14, PNE-RB-51-6 to -9 inclusive)

1. SUMMARY OF RESULTS FOR MAY 17, 1973 THROUGH JULY 31, 1973

Beta radioactivity in air particulate samples for this quarter remained at very low concentrations, ranging from 0.01 to 0.07 pCi/m³. These values are consistent with values observed and reported by the Environmental Protection Agency (EPA) Air Surveillance Network and are no higher than for previous periods. Gamma scans of the air particulate samples (composite) indicated that the concentration of gamma emitters were below the minimum detectability* of the 4-inch diameter x 4-inch thick NaI(Tl) detector.

TLD data for this period indicated an average background radiation dose rate of 2.8 millirem per week. This is consistent with the dose rate measured in 1972.

Beta radioactivity (other than tritium) in surface water ranged from 0.0 to 8.3 pCi/l. These results were in agreement with other data obtained by Eberline. Tritium concentrations measured by liquid scintillation means were less than 1.0 pCi/ml, concentrations measured by electrolytic enrichment being in the range of 0.1 to 0.6 pCi/l. This tritium is attributable to natural production in the atmosphere and worldwide fallout from atmospheric testing. Gamma scans indicated no detectable activity above background and system sensitivity.

Gamma isotopic (GeLi) analysis of milk indicated no significant concentration of gamma emitters except natural K-40.

*About 0.0007 pCi/m³ referenced to ¹⁰³Ru ¹⁰⁶Ru

2. SUMMARY OF RESULTS FOR AUGUST 1, 1973 THROUGH OCTOBER 31, 1973

Beta radioactivity in air particulate samples for this quarter remained at very low concentrations, ranging from 0.02 to 0.05 pCi/m³. These values are consistent with values observed by Eberline at other sites during this period, at Rio Blanco during previous periods, and with values reported by the Environmental Protection Agency (EPA) Air Surveillance Network. Gamma scans of the air particulate samples (composite) indicated that the concentrations of gamma emitters were below the minimum detectability of the 4-inch diameter x 4-inch thick NaI(Tl) detector.

TLD data for this period indicated an average background radiation dose rate of 2.7 millirem per week. This is consistent with the dose rate measured in 1972.

Beta radioactivity (other than tritium) in surface water ranged from 0.0 to 8.8 pCi/l. These results were in agreement with other data obtained by Eberline. Tritium concentration measured by electrolytic enrichment were in the range of 0.1 to 0.5 pCi/ml. Gamma scans indicated no detectable activity above background and system sensitivity.

Gamma scan analysis of milk indicated no significant concentration of gamma emitters except natural potassium.

The tritium concentration in water recovered by distillation from soil samples was less than 1 pCi/ml as determined by liquid scintillation means. No gamma emitters other than natural thorium, uranium and potassium were detected except for Cs-137, ranging from less than 0.04 to 1.18 pCi/g dry weight, due to worldwide fallout.

The concentration of Sr-90 in vegetation samples ranged from 0.10 to 0.64 pCi/g dry weight. The tritium concentration in water recovered by distillation was less than 1 pCi/g. No gamma emitters were detected other than natural potassium.

Several fish samples were analyzed this quarter. The concentration of Sr-90 ranged from 0.03 to 0.60 pCi/g dry weight of the edible portion of fish. One fish sample was analyzed for tritium. The tritium concentration was less than 1 pCi/g. The gamma analysis of fish indicated no significant concentrations of gamma emitters except natural potassium.

Deer meat samples were analyzed for Sr-89 and Sr-90, tritium and gamma scan. The concentration of Sr-89 and Sr-90 were <0.05 and 0.02 pCi/g dry weight respectively. The tritium concentration in water recovered by distillation was less than 1 pCi/g. No gamma emitters were detected other than natural potassium.

None of the results obtained during this period differed significantly from expected levels above natural background activity.

3. SUMMARY OF RESULTS FOR NOVEMBER 1, 1973 THROUGH FEBRUARY 4, 1974

Beta radioactivity in air particulate samples for this period remained at very low concentrations, ranging from 0.02 to 0.13 pCi/m³. These values are consistent with values observed by Eberline at other sites during this period, at Rio Blanco during previous periods, and with values reported by the Environmental Protection Agency (EPA) Air Surveillance Network. Gamma scans of the air particulate samples (composite) indicated that the concentrations of gamma emitters were below the minimum detectability of the 4-inch diameter x 4-inch thick NaI(Tl) detector.

TLD data for this period indicated an average background radiation dose rate of 2.25 millirem per week. This is consistent with the dose rate measured during the previous winter. Lower dose rates during the winter are attributable to attenuation of radiation from terrestrial sources due to snow cover.

Soil samples collected in November 1973 were analyzed for isotopes of plutonium, uranium and thorium. The concentration of plutonium was within the range of expected values due to worldwide fallout. The concentrations of uranium and thorium were within ranges that occur naturally.

Tritium concentrations in water measured by electrolytic enrichment were in the range of < 0.1 pCi/ml to 0.4 pCi/ml. Other beta activity was in the range of 0.0 to 10.8 pCi/l.

4. SUMMARY OF RESULTS FOR FEBRUARY 4, 1974 THROUGH APRIL 30, 1974

Beta radioactivity in air particulate samples increased in March and April to a peak of 0.47 pCi/m^3 from a mid-winter low of 0.02 pCi/m^3 . A seasonal increase is always noted in the spring, but this increase is more than usual and is attributable to injection of year-old fission products from the upper atmosphere inventory due to spring mixing of the upper and lower atmosphere. The presence of a fission product mixture consistent with the time delay since the June 26, 1973 test by the Peoples Republic of China indicates that this test is responsible for most of the increase in the spring of 1974. The increase is not attributable to Rio Blanco because it was typical of levels measured throughout the United States by Eberline and by the Environmental Protection Agency. For example, gamma isotopic analysis of composite filters from the southeastern United States showed the presence of the same approximately year-old fission product mixture at similar concentrations as measured at Rio Blanco.

Vegetation samples (Goldenrod, Sagebrush, Willow, Greasewood and Milk Cow Feed) were collected on March 29, 1974. Sr-89, tritium, and gamma emitters (other than natural K-40) were not detected in any of the samples. The concentration of Sr-90 ranged from 0.04 to 0.18 pCi/g (dry weight) and is attributable to worldwide fallout.

TLD data for this period indicated an average background dose rate of 3.0 mrem/week. This is higher than the dose rate measured during the winter (2.25 mrem/week) and is attributable to increased dose rate from terrestrial sources due to the melting of the winter snow cover or to the increased worldwide fallout during this period.

Water samples collected during March 1974 did not indicate the presence of any unexpected radioactivity. Gross beta concentrations ranged up to a maximum of $8 \pm 4 \text{ pCi/l}$. Tritium was measured in some of the samples by electrolytic enrichment. Concentrations of tritium ranged from 0.12 ± 0.08 to $0.25 \pm 0.08 \text{ pCi/ml}$.

Gamma emitters, other than natural radioactivity were not detected in samples collected on March 29, 1974.

Cesium-137 was measured in soil samples collected on March 29, 1974 with concentrations ranging from less than 0.09 to 0.9 pCi/g (dry weight). Tritium and gamma emitters (except natural radioactivity) were not detected in any of the samples.

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