RIO BLANCO DEMONSTRATION PROGRAM

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CER GEONUCLEAR CORPORATION

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I. INTRODUCTION

During late 1969 and early 1970, CER Geonuclear Corporation undertook to evaluate the prospects for nuclear stimulation of natural gas production on Equity Oil Company properties in the Piceance Basin, Colorado. A result of the study was the report "Project Rio Blanco, Feasibility Study, Piceance Basin, Colorado," dated April 16, 1970. This study convinced CER of the potential of nuclear stimulation technology for recovery of otherwise unavailable natural gas reserves. A joint venture agreement between Equity Oil and CER Geonuclear to carry out a single experiment was executed and a formal proposal was made to the Atomic Energy Commission.

During this time, however, it became increasingly apparent that single research experiments of possible applications would not allow a timely development of the available technology. What was needed was an accelerated rate of technological development to demonstrate the economic feasibility of this method of augmenting the Nation's gas reserves. Therefore, in December 1970, CER proposed an agreement with the Government to undertake jointly a demonstration program in three phases:

<u>Phase I</u>: Designed to simultaneously detonate three nuclear explosives in a single well.

<u>Phase II</u>: The sequential detonation of multiple explosives in four to six wells.

<u>Phase III</u>: The sequential detonation of multiple explosives in 20 to 60 wells.

CER, encouraged by the replies and the results from additional reservoir testing, proceeded with the design of Phase I as contemplated in a December 1970, Project Definition Contract with the Government.

In September 1971, the Rio Blanco Unit was formed covering 93,762 acres. Based on geological and geophysical log analysis of wells in the area, the gas in place in this area is estimated to be 10 to 12 trillion standard cubic feet in the Fort Union Formation and the upper 1,200 feet of the Mesaverde Formation.

If all of the acreage in the unit area proves commercial, it is estimated that 35% of the gas in place (3.5 to 4.2 trillion standard cubic feet) can be recovered in the first 25 years, assuming 1 stimulated well per 640 acres. If the field is developed with more than 1 well per 640 acres or if the gas is produced for more than 25 years, the percentage of gas and total recovery would be substantially increased.

II. PHASE I

Phase I, the initial program experiment, is designed to simultaneously detonate three nuclear explosives in a single wellbore and will provide the baseline information necessary to proceed to the next step in the demonstration program. Phase I is planned to take place in the NW/4, NW/4 of Sec 14, T3S, R98W, Rio Blanco County, Colorado. The 3 explosives will be spaced about 450 feet apart in order to fracture a 1,350-foot section of rock containing about 370 feet of net pay sand between 5,550 and 6,900 feet of the Fort Union and upper Mesaverde formations (Figure 1).

The zone selected for the first stimulation contains approximately 76 billion standard cubic feet of natural gas per section. Reservoir calculations based on the permeability, porosity, and sand thickness measured at Rio Blanco indicate that the reentry well, following the nuclear stimulation, could produce natural gas at a rate of 8 million standard cubic feet per day (MMSCFD) for 1.2 years, and then start to decline (Figure 2). After 25 years, the well could still produce gas at the rate of 2 MMSCFD. The cumulative gas recovery from a single nuclear-stimulated well per 640 acres is also shown in Figure 2. The expected recovery over the 25-year period is calculated to be 26 BSCF of gas.

After detonation and about a 3-month waiting period, the chimney area will be reentered and production testing to evaluate the effectiveness of the stimulation will begin.

The gas produced from the chimney during testing will be flared. The water, separated as a liquid, will either be disposed of as water vapor into the atmosphere or, preferably, reinjected deep underground in suitable disposal strata.

Phase I will provide some of the data needed to evaluate the economic parameters of a single-well, multiple-explosion, gas stimulation technique. Specific information to be developed in Phase I which will contribute to the design of Phase II consists of:

1. Evaluation, based on production test data, of the:

    a. Long-term potential productivity and deliverability of the multiple-explosive stimulated well.

    b. Amenability of the Fort Union and upper-Mesaverde reservoirs to nuclear explosion stimulation for gas production.

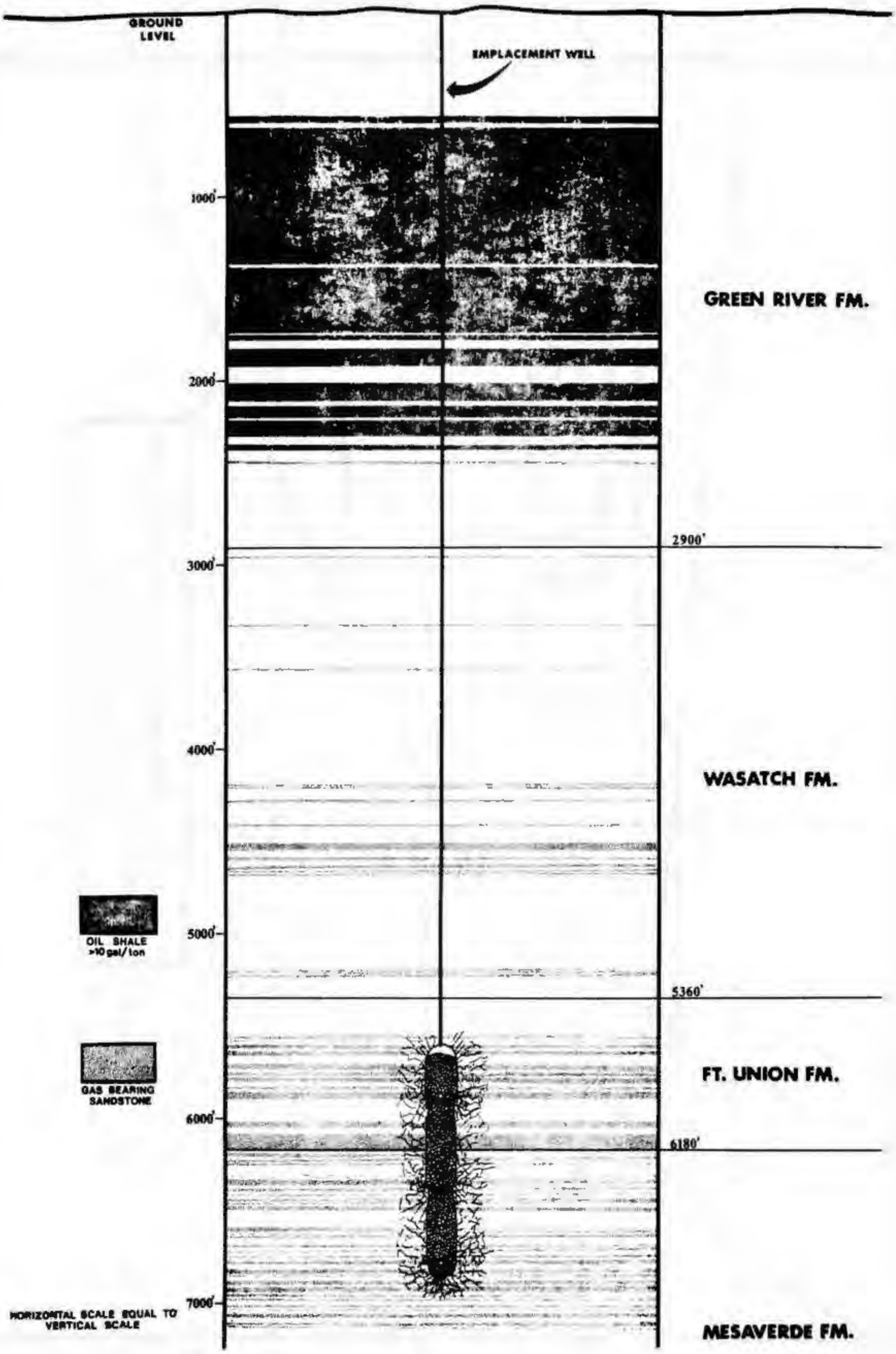

Figure 1. Postdetonation configuration.

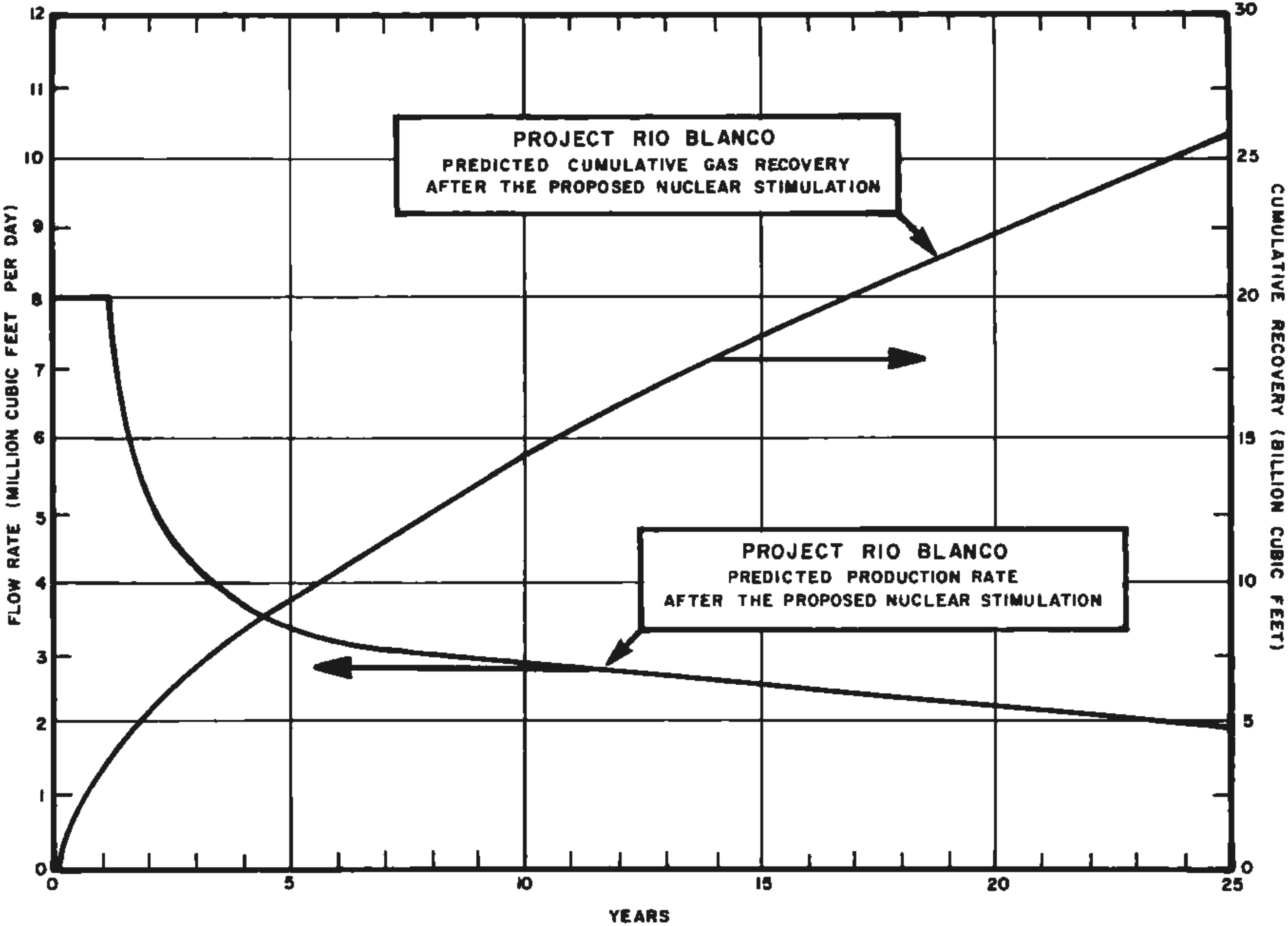

Figure 2. Potential gas production rate and recovery for the Project Rio Blanco stimulated well.

c. Adequacy of the interchimney connection for gas flow.

d. Effective in-situ permeability.

2. Evaluation of produced trace amounts of radionuclides and non-hydrocarbon gaseous compounds and the collection of data for use in establishing procedures for the following operations:

   a. Determination of ^{85}Kr and ^{3}H concentrations in gas at reentry and during production testing to assist in the development of regulations for sale of the produced gas.

   b. Determination of ^{3}H concentration in produced water to evaluate alternative techniques for water disposal.

   c. Determination of CO_2 concentrations during production testing and the evaluation of possible removal techniques.

3. Evaluation of measures to assure public safety during the nuclear operations.

   a. Adequacy of containment model.

   b. Correlation of seismic effects data, structural response, and ground motion predictions.

4. Evaluation of operational techniques and procedures for use in follow-on activities.

   a. Explosive, packaging, and handling designs for use in gas reservoirs.

   b. Emplacement, stemming, and reentry techniques.

   c. Explosive command, control, and monitoring systems and procedures.

   d. Waste water disposal technique.

5. Evaluation of administrative procedures and practices.

   a. Effect on operations of environmental policy and law.

   b. Analysis of insurance and indemnification programs.

   c. Analysis of Government and industry project administration and management procedures.

Phase I is tentatively scheduled to begin in the third quarter of 1972 with completion of all tests and evaluation occurring in 1973.

If possible, arrangements will be made to allow pipeline production from the Phase I well at the end of the final buildup test. This is desirable even if the allowable rate is low to provide a basis for subsequent discussions on: 1) the associated problems and capabilities for continuous on-line monitoring and regulation of gas streams from stimulated wells, and 2) monitoring and documentation of variations in radioactivity in the pipeline system downstream of the stimulated gas well and upstream from the first use point.

Successful completion of Phase I will provide the impetus to the operational activities on Phase II. Detailed planning for Phase II will begin immediately following the explosive operations in Phase I.

III. PHASE II

Phase II will consist of a sufficient number of stimulations to provide the experimental, reservoir, and operational data needed prior to the large investment required in Phase III. The current plan anticipates four to six well stimulations to be conducted on a single day. Between 1,500 and 2,500 vertical feet of rock will be broken in each well, requiring the employment of 3 to 5 explosives per well for a total of 12 to 30 explosives.

Detonation point depths could be as deep as 9,500 feet. These stimulations will be designed to further develop the operational systems, techniques, and ideas originating during Phase I and to gain further reservoir information related to the broader question of field development.

Sequential firing will be considered for Phase II but will depend upon the explosive development program undertaken by the Government. Sequential firing should produce enhanced fracturing and allow increased yield per single explosive without increasing the ground motion effects associated with simultaneous detonations.

Phase II will develop the additional information about nuclear explosion engineering, economics of nuclear explosion stimulation, sequential firing, and optimum fielding techniques. It will also assist in the development of guidelines for the sale and use of material gas containing trace amounts of radionuclides, the establishment of the mechanism for the production of the required number of nuclear explosives, and the initiation of administrative procedures scaled to effectively manage a large number of stimulations per year.

Evaluation of the stimulated wells could be accomplished by either monitoring initial pressure buildup in the chimney following the pressure decrease in the cavity resulting from the explosion or possibly by producing the gas into one of the pipelines presently in the area. (Minimal flaring may be necessary for evaluation purposes.) A more comprehensive on-line pipeline monitoring and radiation control program will be incorporated into the Phase II testing.

Disposal of the produced tritiated water in Phase II could be accomplished by injection into appropriate disposal wells.

The explosive services to be provided by the Government during Phase III and the later commercial development need to be defined and development started during Phase II.

A test of the firing system to be used in Phase III needs to be conducted. If the Nuclear Explosion Services (NES) study or some other such proposal is to be instituted, assurances as to the explosion services compatibility and suitability are needed.

An industry and Government decision must be made at the end of Phase II to make a significant investment if a substantial amount of gas is to flow to market before the end of this decade. Thus, information about the market for the gas, the pipeline route, and the number of wells required to serve the pipeline should be determined concurrently with or at the end of Phase II.

Phase II is probably the most critical in the Rio Blanco Demonstration Program and must be designed to provide the basic data necessary for Government and industry to make the major decisions regarding continuation of the program.

Information desired from Phase II includes:

1. An evaluation of Government and industry administrative procedures.

2. Data required by insurance pools to provide a reasonable basis for determining rate structures.

3. Optimum horizontal and vertical spacing of the explosives.

4. Reliability of sequential detonations in a single well (provided a sequential capability can be developed).

5. Optimum reentry technique.

6. Evaluation of test run of NES system.

7. Data to allow the design of a commercial mode of field operations.

8. Data to allow the design of an optimum safety program.

9. Evaluation of the effects and costs of any required documentation program.

10. Data necessary to allow industry to make the decision to commit funds for pipeline design, right-of-way, and construction.

11. Data necessary for the Government to establish prices and commit funds for fabrication of explosives and to provide staff and administrative procedures for the semi-fullscale fielding program which constitutes Phase III.

12. Data to provide refinements to unit wide prediction of ground motion. The multiple energy sources, differing locations and depths of burial, and the fixed stations offer a unique opportunity to collect ground motion data.

The Phase II detonations may be scheduled for 1974 with completion of all tests and evaluations occurring in 1975 or early 1976. It is assumed that following the completion of the gas production program for Phase II, the wells would be connected to a pipeline to further verify the adequacy of the on-line monitoring and control capabilities.

The Phase III Project Definition and environmental impact reviews should have been completed at the end of Phase II. In addition, the studies of pipeline size and right-of-way, end-point use, and markets should have been completed. If both industry and Government choose to proceed, Phase III could be initiated in 1976.

IV. PHASE III

Phase III is the last or pilot plant step in demonstrating that natural gas can be commercially produced by nuclear stimulation. Phase III would consist of the stimulation of enough gas-producing wells, perhaps 20 to 60, to justify the construction of a major pipeline. It would combine the developments of the previous phases with solutions of the delivery problems to demonstrate the practicality of nuclear stimulation technology.

The end use study and preliminary pipeline design would have been completed prior to the major decision point and the required number of wells would be known. Concurrent with the execution of Phase III, the pipeline and gas collection facilities would be constructed.

Many of the Phase III wells would be grouped around those of Phase II. The rock intervals to be stimulated would depend upon the results of Phase II but would probably range between 1,500 to 2,500 feet. CO_2 removal systems for the gas may be desirable at this point. Water disposal systems would have been evaluated in prior stages, and full-scale operations for "minimum as practicable" radioactivity would be employed.

Figure 3 identifies sections representing a best guess of those which might be selected for well sites in Phases I, II, and III.

A possible schedule for the conduct of all three phases is shown as Figure 4.

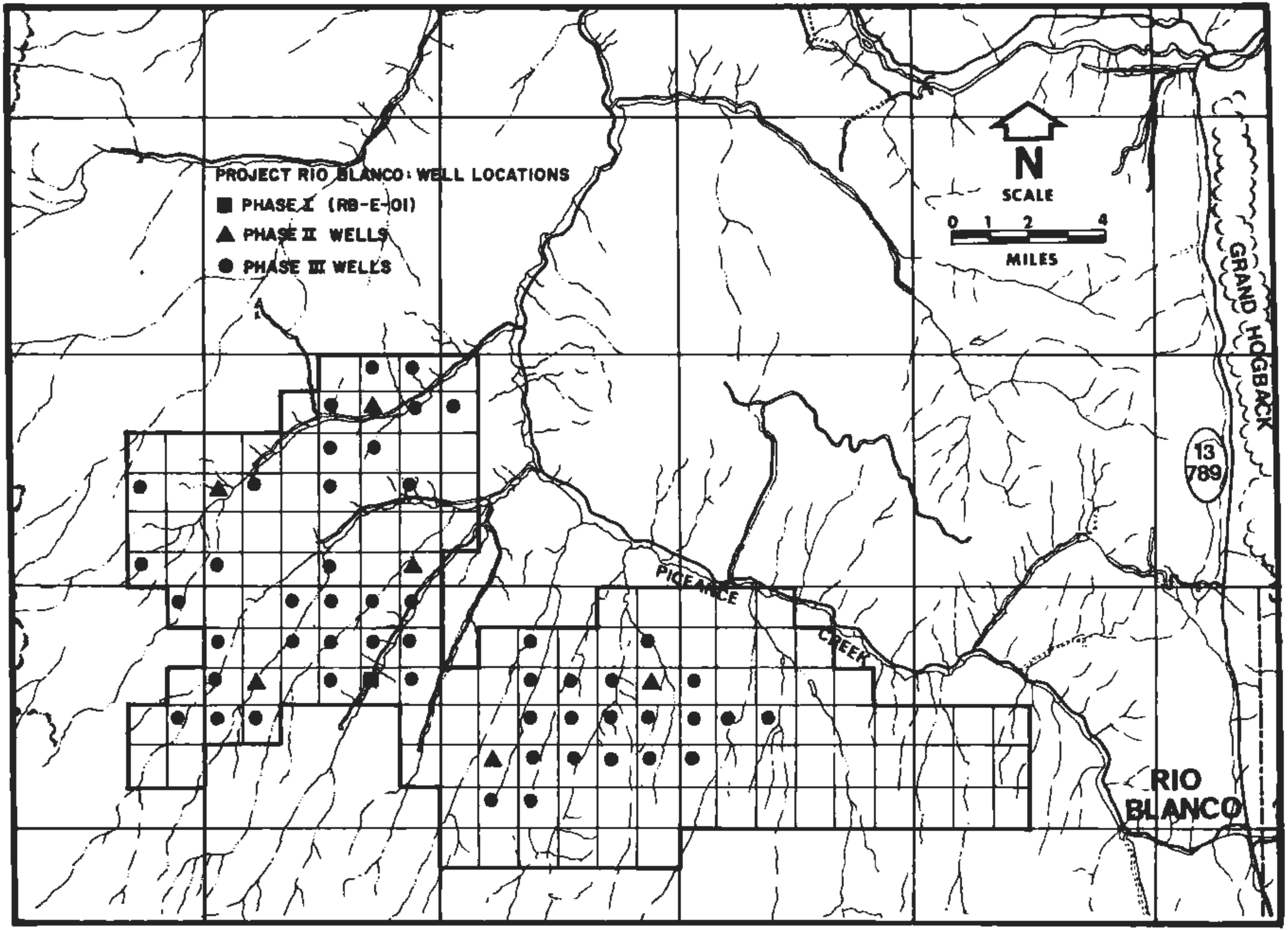

Figure 3. Rio Blanco Unit Area showing possible well locations.

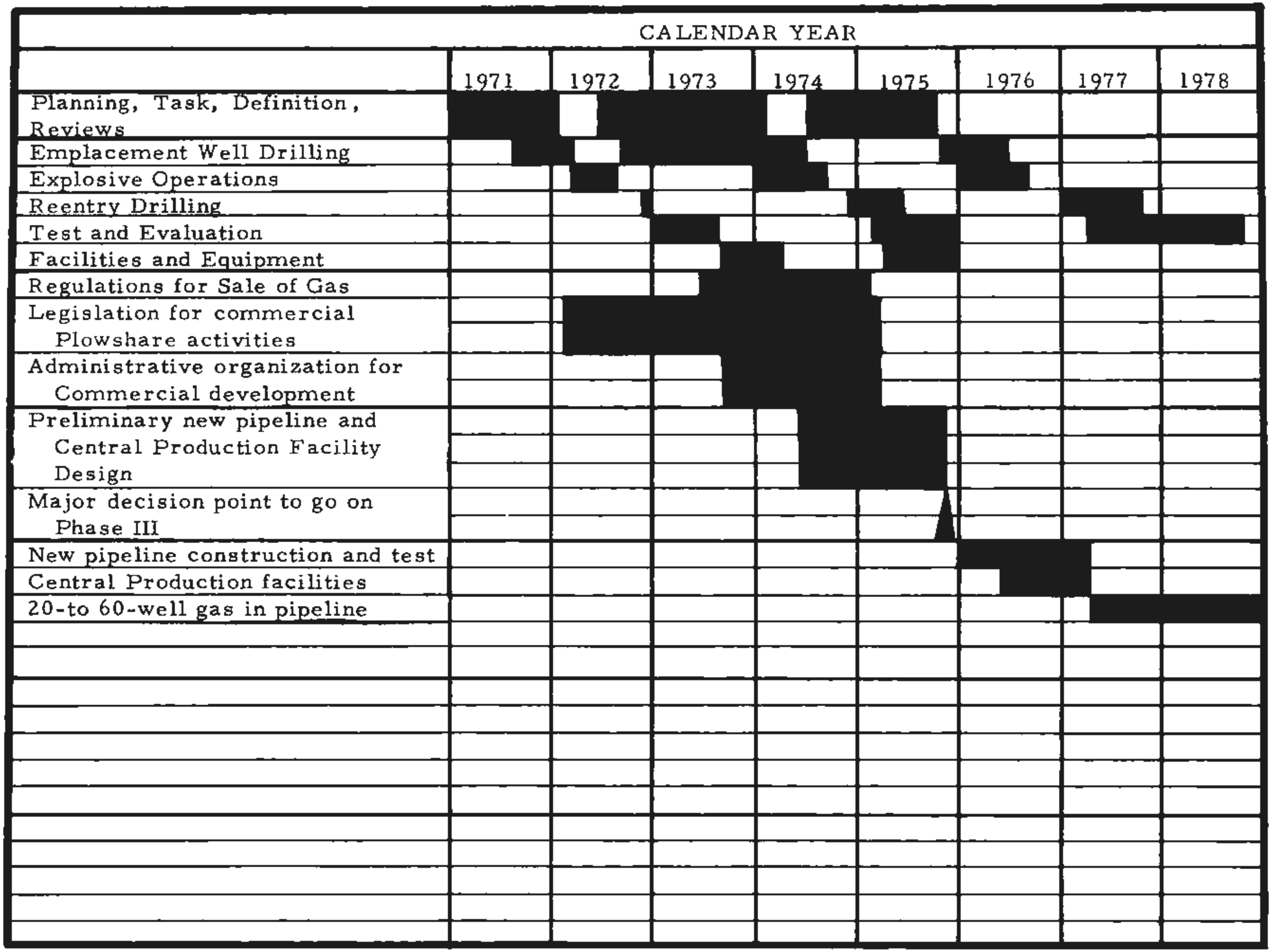

Figure 4. Rio Blanco Demonstration Program schedule.

V. COMMERCIAL FIELD DEVELOPMENT

The conclusion of the Rio Blanco Demonstration Program would result in gas flowing from the field to the end-use area in a pipeline. Enough wells would have been developed in Phase III to supply the pipeline. However, the deliverability of gas from the wells decreases with time, and additional wells would be required to supply the market.

A hypothetical case involving maintaining a pipeline at capacity for 25 years will be used to discuss some of the ramifications of a field development program. If, for instance, a constant pipeline capacity of 350 MMSCFD is selected for the model, then a 58-well program is sufficient to provide the capacity and keep the line loaded for approximately 3 years. At the end of 3 years, additional wells would have to come on-stream to keep the line at capacity.

If only efficiency and economic factors are considered, the number of wells stimulated in this step would depend upon equating the economics of multiple well stimulation against the cost of capital to develop capacity that could not be used immediately. Thus, a 25-year field development program would be carried out in a number of steps in which the time between steps and number of wells involved in each step would be optimized on an economic basis (Figure 5).

External considerations could completely change the economics of the optimized field development program. For example, if oil shale development were started in the next few years and a multiple resource development program required nuclear stimulation activities to be completed in 10 years, an intensive nuclear stimulation program would be required. This would adversely affect the economic return from nuclear stimulation but would be an alternative under the multiple resource conditions. This case is also shown in Figure 5.

Other external factors, such as unit requirements that are not compatible with optimum nuclear stimulation procedures (e.g., a requirement to drill "x" number of wells per year) could produce a different field development pattern (dashed lines on Figure 5). This becomes further complicated by the fact that 320 rather than 640 acre spacing could look increasingly attractive.

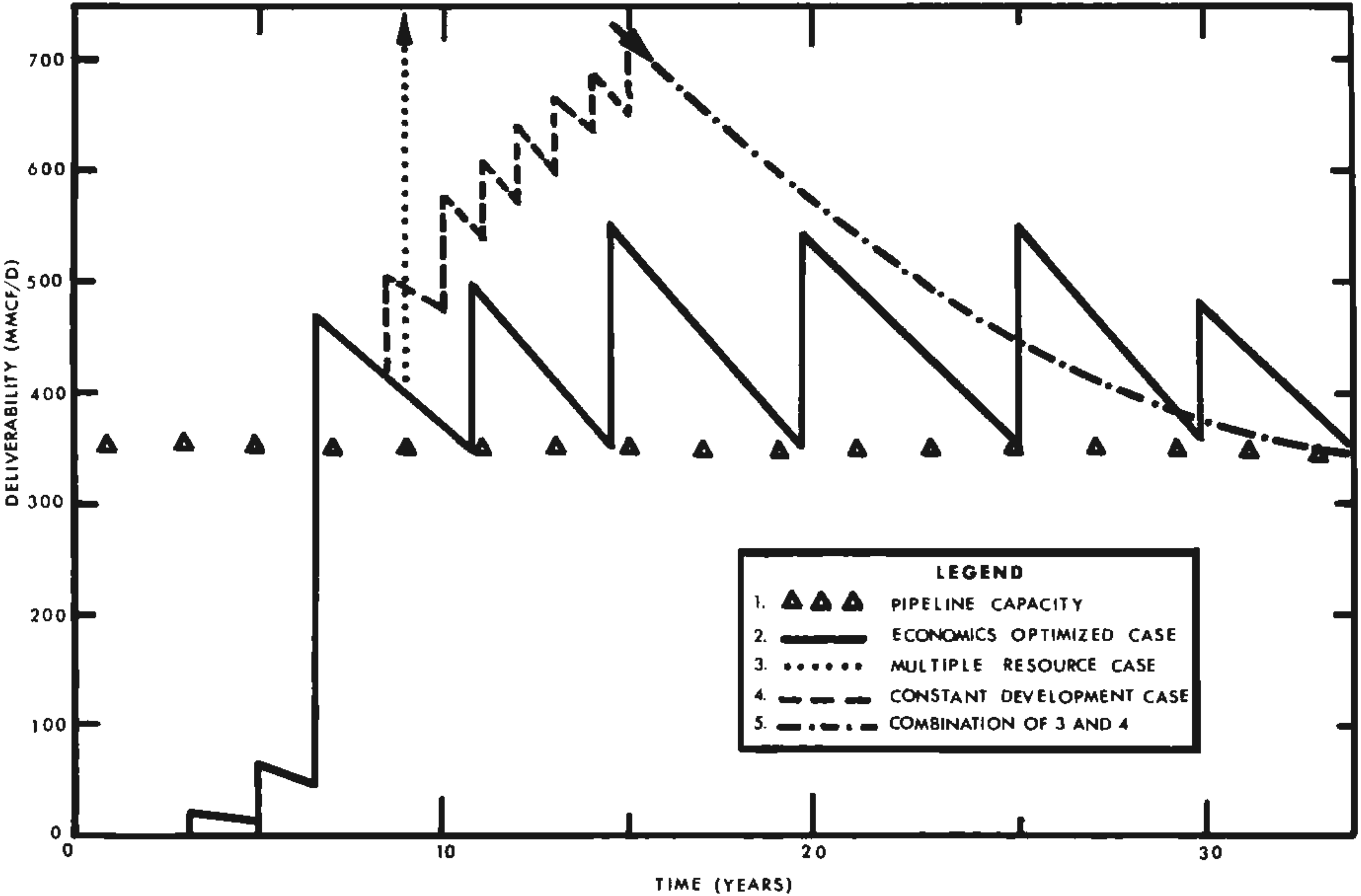

Figure 5. Hypothetical deliverability as a function of time for three types of field development programs.

VI. POSSIBLE DIVISION OF RESPONSIBILITIES

To carry out the Rio Blanco Demonstration Program, Government and Industry must work together if nuclear explosive stimulation is to become a viable application of Plowshare technology. Any such program must include provision for full cost recovery on the part of Government.

A proposed assignment of responsibilities is as follows:

Government

1. Develop administrative procedures in a timely manner for Plowshare applications, to include generation of criteria, provision for necessary reviews, and regulations and procedures for the sale of gas.
2. Develop a ruggedized nuclear explosive system for gas stimulation and the associated downhole hardware for sequentially detonating multiple explosives in a single well.
3. Improve predictive capabilities of the mechanism of fracturing, chimney gas chemistry, and effects of differing rock characteristics, and develop appropriate containment models.
4. Institute explosive production capability and provide nuclear explosive services for each phase leading to a definition of the commercial explosive services.
5. Institute administrative procedures recognizing the differences between conventional resource development and Plowshare technology; i.e., Unit Agreements, land use, leases, etc.

Industry

1. Develop basic project plans for commercial gas production, provide project management for nuclear operations, and develop private contractors for related services.
2. Provide acreage suitable for a nuclear stimulation field development program.
3. Vigorously pursue and provide, when available, a private insurance program.
4. Provide environmental impact information and a monitoring and protection program coupled with a public affairs program tailored to local and state needs.
5. Provide data required by Government for development of standards for sale of gas from nuclear-stimulated wells.
6. Develop predictive techniques of nuclear effects related to safety and assume operational responsibility for personnel safety.