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REPORT TO THE CONGRESS

Progress And Problems In Developing Nuclear And Other Experimental Techniques For Recovering Natural Gas In The Rocky Mountain Area

B-164105

Atomic Energy Commission
Department of the Interior
Federal Power Commission

BY THE COMPTROLLER GENERAL OF THE UNITED STATES

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APRIL 2, 1974

COMPTROLLER GENERAL OF THE UNITED STATES
WASHINGTON, D.C. 20548

B-164105

To the President of the Senate and the
Speaker of the House of Representatives

This is our report on the progress and problems in developing nuclear and other experimental techniques for recovering natural gas in the Rocky Mountain area.

We made our review pursuant to the Budget and Accounting Act, 1921 (31 U.S.C. 53), and the Accounting and Auditing Act of 1950 (31 U.S.C. 67).

We are sending copies of this report to the Director, Office of Management and Budget; the Administrator, Federal Energy Office; the Chairman, Atomic Energy Commission; the Secretary of the Interior; and the Chairman, Federal Power Commission.

Comptroller General
of the United States

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ABBREVIATIONS

AEC	Atomic Energy Commission
FPC	Federal Power Commission
GAO	General Accounting Office

COMPTROLLER GENERAL'S REPORT TO THE CONGRESS

PROGRESS AND PROBLEMS IN DEVELOPING NUCLEAR AND OTHER EXPERIMENTAL TECHNIQUES FOR RECOVERING NATURAL GAS IN THE ROCKY MOUNTAIN AREA
Atomic Energy Commission
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D I G E S T

WHY THE REVIEW WAS MADE

Senator Gale W. McGee requested information on the Government's efforts to develop various experimental techniques for recovering natural gas in the tight geological formations in the Rocky Mountain area.

Information presented covers economic, technical, and environmental aspects of nuclear stimulation, massive hydraulic, and chemical explosive techniques.

FINDINGS AND CONCLUSIONS

The amount of natural gas available and expected to be available is not sufficient to meet current and anticipated demands within the United States through 1990. Large amounts of gas are located in low-permeability, or tight, geological formations in the Rocky Mountain area in three basins: Green River Basin, Wyoming; Piceance Basin, Colorado; and Uinta Basin, Utah. (See pp. 7 and 11.)

This gas is not considered part of the U.S. reserves because it cannot be recovered economically with conventional techniques. (See p. 11.)

A task force sponsored by the Federal Power Commission estimated, in its April 1973 report, that up to 300 trillion cubic feet of this gas could be recovered with either of two techniques--nuclear stimulation or massive hydraulic fracturing--currently under study. This is more than 12 times the 1972 domestic gas recovery and more than the current reserves. (See pp. 8 and 11.)

Nuclear stimulation involves detonating nuclear explosives in a wellbore to greatly enlarge its effective diameter and cause more gas to flow.

The Atomic Energy Commission (AEC), in cooperation with private firms and with technical advice and assistance of the Department of the Interior, has funded development of the nuclear stimulation technique for about 10 years. (See pp. 14 and 19.)

Through fiscal year 1973, more than $33 million of Federal funds have been spent to develop this technique, which included funds for three field experiments in the Rocky Mountain area. (See p. 14.)

Massive hydraulic facturing involves injecting fluid under pressure to produce cracks or fractures in the surrounding geological formation and thereby increase gas flow from tight gas-bearing formations. No Federal funds were spent on this technique before fiscal year

1974. (See pp. 15 and 32.)

Chemical explosive fracturing involves detonating chemical explosives in wellbores to enlarge existing fractures in the earth's subsurface so more natural gas can flow into the wellbore. The Department of the Interior has been developing this technique for about 10 years. Between fiscal years 1968 and 1973, about $380,000 was spent to develop this technique. (See pp. 16 and 35.)

Private firms have been involved in developing all three of these techniques. (See pp. 12 to 16.)

Development status of experimental techniques

Nuclear stimulation field experiments--involving single explosives--indicate that, in similar geological formations, several times more gas can be recovered over a well's life using nuclear-stimulation than can be recovered using conventional techniques. (See pp. 18 to 23.)

AEC and private firms participating in such experiments believe this technique, by sequentially detonating several explosives in one wellbore, can recover even more gas than demonstrated by past experiments. (See pp. 24 and 25.)

Technology to demonstrate this increased potential has not yet been developed. AEC said that it had not decided whether to request funds to conduct experiments for developing this technology. (See p. 25.)

Experiments using the massive hydraulic fracturing technique have not been conducted in the Rocky Mountain formations. Federal and industry officials are not sure whether this technique can be applied there successfully.

Although experiments using this technique were not funded previously by the Government, AEC and Interior budgets for fiscal year 1974 include about $1.2 million which could be used in developing this technique. Interior's fiscal year 1975 budget estimates include about $1 million for further development of this technique. (See p. 32.)

Field experiments with chemical explosive fracturing have not been successful. Two attempts by private firms have resulted in premature detonations and fatal accidents. (See p. 35.)

Industry and Federal officials said development of this technique was significantly behind that of both massive hydraulic fracturing and nuclear stimulation. (See p. 37.)

Factors affecting estimated wellhead cost of recovering gas in tight formations

The task force report contains estimates indicating that massive hydraulic fracturing generally could recover gas at a lower cost than could nuclear stimulation.

The report pointed out, however, that there was a significant amount of uncertainty in these estimates and that therefore both techniques need to be thoroughly tested and evaluated. (See pp. 39 and 40.)

It is possible that fractures created with nuclear explosives might close. If fractures close, the wellhead cost of gas increases significantly, depending on how quickly they close. AEC and Interior officials do not agree on whether fractures created on two nuclear field experiments have started closing.

More should be done to minimize the uncertainty as to whether fractures created by nuclear stimulation close and the rate of such closure before nuclear stimulation can be considered economically acceptable. (See p. 44.)

AEC said that additional tests, although very costly, could be made that would provide better data on this problem. (See p. 44.)

Factors which could affect commercial development of gas

The task force report estimated that, to recover 40 to 50 percent of the gas in the tight Rocky Mountain area formations, it would be necessary to have commercial development programs of the following magnitude.

--For nuclear stimulation, drilling 5,680 wells and detonating 29,680 nuclear explosives over a period ranging from about 35 to 65 years.

--For massive hydraulic fracturing, drilling about 22,720 wells over a period of about 60 to 115 years. (See p. 52.)

GAO noted two problems which could directly affect the feasibility of commercial programs using these experimental techniques. These problems areas relate to the following questions.

Would the recovery of gas using nuclear stimulation hinder underground mining of oil shale? The Rocky Mountain area contains oil shale and other mineral resources, such as coal, which are in some of the same areas as the gas. (See p. 53.)

Interior said its analysis of tests conducted near a recent nuclear field experiment tend to confirm that nuclear stimulation of gas should not be done prior to or concurrent with oil shale mining because fractures created by the nuclear explosion could collapse underground mines in the area of the explosion. (See p. 54.)

AEC said, however, that its studies of the recent nuclear field experiment showed that no significant damage had occurred to oil shale and that proper design and planning should render the concurrent recovery of gas and oil from oil shale compatible. (See p. 55.)

It is important to resolve this question at an early date so that plans for developing both these energy-producing resources may proceed on a sound basis. (See p. 57.)

Would there be enough water available for massive hydraulic fracturing and the development of other mineral resources? Large amounts of water could be needed to recover gas using massive hydraulic fracturing and the development of other mineral resources, such as coal and oil shale.

Because the Rocky Mountain area is arid, there is uncertainty as to whether enough water would be available to develop these resources. (See p. 57.)

Interior agreed with GAO that a study was needed to resolve this question. However, Interior believed that, such a study, because it would be costly, should not be started until more definitive information was available on the water requirements to develop these resources.

Interior said that it recently had established a task group to recommend policy guidance for resolving high-priority energy- and water-related issues and that the group planned to take the initial steps to address the question. (See p. 59.)

Certain information which could be important in determining the feasibility and desirability of a commercial development program using the nuclear stimulation technique is included in this report. The information relates to:

--The effects on homes, buildings, and persons near the underground nuclear detonations. (See pp. 61 and 63.)

--The effects of nuclear-stimulated gas on man. (See p. 64.)

--The releases of radioactivity to the atmosphere. (See pp. 68 and 71.)

--The disposal of contaminated water separated from nuclear-stimulated gas. (See p. 72.)

--AEC's capacity to produce the needed nuclear materials. (See p. 75.)

Prerequisite to use of nuclear stimulation on a commercial basis

Before nuclear stimulation could be used for commercial development of natural gas, the Congress would have to enact legislation to allow AEC to provide nuclear detonation services to private firms. (See p. 27.)

AEC's operating policy for its past field experiments was that detonations would not proceed without concurrence of appropriate State officials. Obtaining such concurrence was not a requirement of law. (See p. 30.)

RECOMMENDATIONS AND SUGGESTIONS

Because of their predominant energy-related aspects, GAO is referring problem areas involving the interest of various Federal agencies to the Administrator, Federal Energy Office.

In line with the purposes of the Executive order creating the Federal Energy Office within the Executive Office of the President, the Administrator could provide Federal leadership in determining the need and type of action called for to resolve these problems and thereby help increase energy production. (See p. 79.)

AGENCY ACTIONS AND UNRESOLVED ISSUES

AEC, FPC, and the Department of the Interior commented on this report and in general indicated concurrence with it. Their comments have been included in this report where appropriate.

MATTERS FOR CONSIDERATION BY THE CONGRESS

This report provides the Congress information on (1) techniques thought capable of stimulating the recovery of significant amounts of gas in tight geological formations and (2) certain problem areas affecting the development and use of other energy resources in the Rocky Mountain area. The report should help the Congress in considering the funding levels and priorities for the Federal programs designed to develop these gas stimulation techniques. It should also help the Congress in its deliberations on the Nation's energy problems.

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CHAPTER 1

INTRODUCTION

Natural gas is a fossil fuel formed by the decay of vegetable and animal matter under extreme heat and pressure over millions of years. It is within pores of rock that form underground reservoirs.

Natural gas is used throughout the United States. About one-third of this country's total energy requirements are met by natural gas. The natural gas consumption in the United States in 1970 was distributed among the following markets:

--50 percent for industrial.

--22 percent for residential.

--18 percent for electric utilities.

--10 percent for commercial.

The amount of gas available and expected to be available is not sufficient to meet current and anticipated demand through 1990. (See table on following page.) This shortage has affected and will affect consumers of natural gas. According to a Federal Power Commission (FPC) study, 15 interstate pipeline companies cut back gas deliveries by 565.6 billion cubic feet during the 1972-73 winter season. For the 1973-74 winter season, 14 companies have estimated cutbacks on deliveries of more than 679.7 billion cubic feet--about 20 percent more than in the 1972-73 winter season.

A February 1972 FPC report[1] shows that, even with increased volumes of imported gas, the shortage of gas in the United States will become progressively worse. The trends of increasing gas shortages and increasing dependence on gas imports are shown in the following table adapted from that FPC report on future domestic gas supply and demand.

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[1] Federal Power Commission, "National Gas Supply and Demand 1971-1990, Staff Report No. 2," Bureau of Natural Gas.

Year	Domestic production	Other domestic sources (note a)	Foreign sources	Total supply	Annual demand	Unsatisfied demand
	(trillion cubic feet)					
1966	17.5	-	0.4	17.9	17.9	-
1967	18.3	-	.5	18.8	18.8	-
1968	19.3	-	.6	19.9	19.9	-
1969	20.6	-	.7	21.3	21.3	-
1970	21.8	-	.8	22.6	22.6	-
1971	22.8	-	.9	23.7	24.6	0.9
1972	23.8	-	1.0	24.8	26.1	1.3
1973	24.7	-	1.1	25.8	27.7	1.9
1974	24.8	-	1.1	25.9	28.8	2.9
1975	24.7	-	1.5	26.2	29.8	3.6
1980	20.4	1.0	3.6	25.0	34.5	9.5
1985	18.5	2.7	4.9	26.1	39.8	13.7
1990	17.8	5.6	5.9	29.3	46.4	17.1

[a] Includes gas from Alaska and coal gasification.

As shown above, FPC expects that the United States will face natural gas shortages in 1985 and 1990 of 13.7 and 17.1 trillion cubic feet, respectively. In addition, the FPC report points out that:

--Domestic recovery of natural gas is expected to peak in the midseventies and to decline thereafter.

--Imports and other supplemental supplies of gas are expected to account for about 40 percent of consumption by 1990.

--The proven reserve gas inventory in the 48 contiguous States is expected to drop from its 1970 level of 259.6 trillion cubic feet to 170.4 trillion cubic feet by 1990.

To forecast the gas supply and demand shown in the table above, FPC adopted gas demand estimates made by the Future Requirements Committee--a group the gas industry established to periodically estimate long-range gas demands. The Future Requirements Committee estimated the gas demand for the period 1971-95 from replies to a poll taken of every public and private organization it identified as a supplier of natural gas. Its demand estimates were based on four assumptions:

1. A sufficient supply of gas would be available to meet all estimated requirements.

2. Current relationships of the cost of gas to the cost of other fuels would remain the same except for known changes in specific market areas.

3. No major war, depression, or catastrophe would occur during the forecast period.

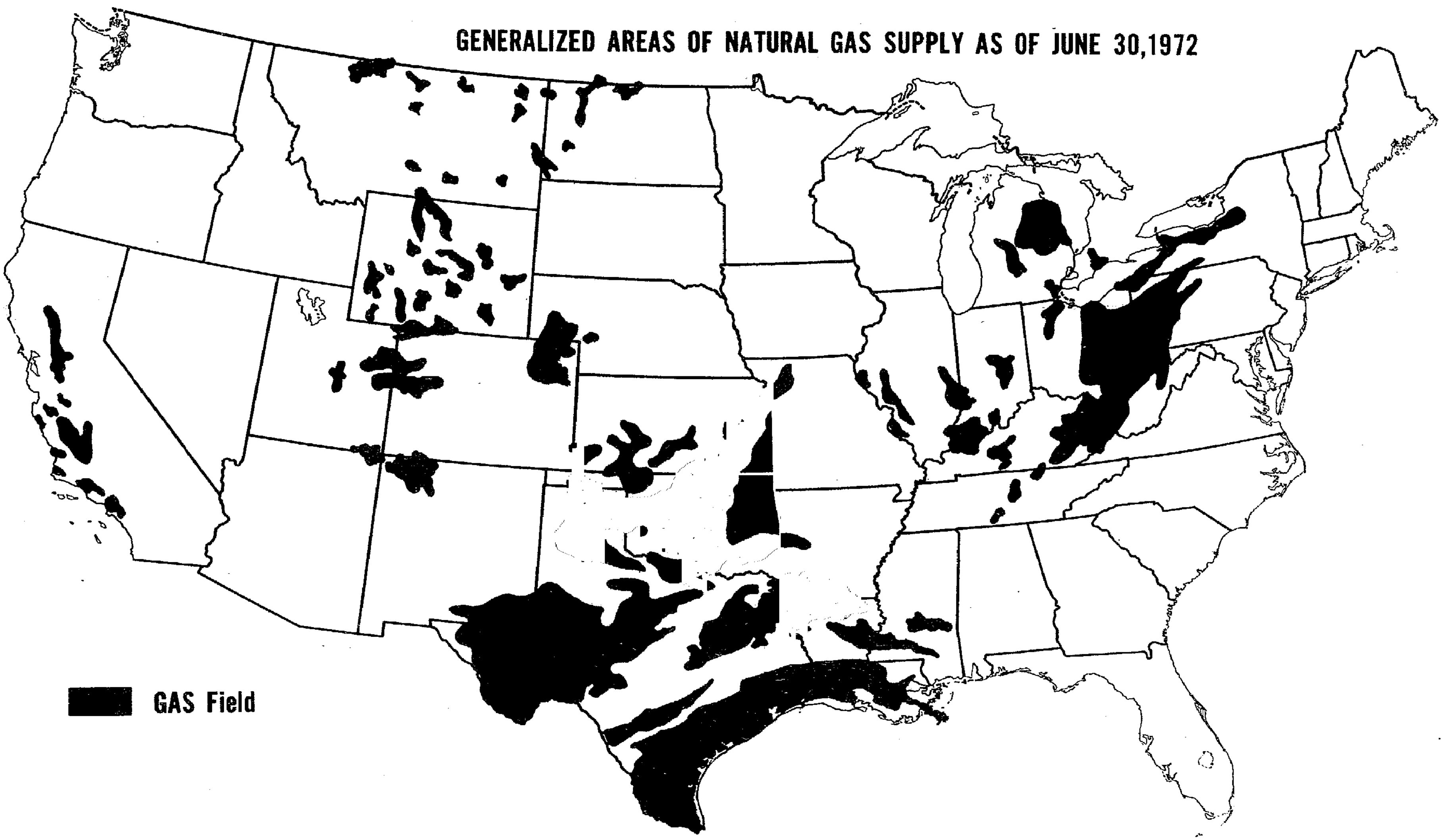
4. Technological development was evolutionary in nature.

FPC's gas supply projections were calculated independently and generally agreed with supply projections made by the Department of the Interior. The projections were based on those gas deposits from which gas can be economically recovered with conventional recovery techniques.

The conventional technique for recovering natural gas is to drill a well into a known gas reservoir and allow the gas to flow into the wellbore. The amount of gas flow depends on the permeability of the gas-bearing geological formation surrounding the wellbore. Permeability is the ease with which gas can flow through the formation--the higher the permeability, the larger the amount of gas recovered.

In low-permeability or tight formations, the simple drilling of a well might not recover enough gas to be economically feasible. In such cases the gas flow can be increased by using conventional stimulation techniques utilizing acids, hydraulics, or explosives. Acids are used to enlarge natural channels between gas-bearing formations and the wellbore by dissolving the channel walls and restrictions in the channels. Hydraulics involve injecting fluid under pressure to create fractures or widen existing fractures in the formation. Fractures are kept open by particles of sand or other substances. Explosives are used to remove material blocking the gas flow from the reservoir to the wellbore and to create fractures in rock or other tight formations. A map, furnished by FPC, showing the general areas where gas is produced by conventional drilling and stimulation techniques is on page 10.

GENERALIZED AREAS OF NATURAL GAS SUPPLY AS OF JUNE 30,1972



There are areas in the United States which have large amounts of natural gas in tight formations that cannot be economically recovered using conventional recovery techniques. Some of these formations are in the Rocky Mountain area. It should be noted, however, that there are regions in the Rocky Mountain area where gas is being economically recovered using conventional techniques.

An April 1973 report,[1] prepared by the Natural Gas Technology Task Force, identified gas in tight formations. The task force was primarily to assess the experimental techniques for recovering gas not considered part of the U.S. gas reserves. On the basis of estimates gas companies developed for gas in place within their respective areas of operation, the task force estimated that 600 trillion cubic feet of gas were in tight formations in the Rocky Mountain area in three basins.

	Trillion cubic feet
Green River Basin, Wyoming	240
Piceance Basin, Colorado	210
Uinta Basin, Utah	150

The task force was made up of 24 members, of whom 12 were officials of the following Federal agencies and offices: Bureau of Mines and Geological Survey, Department of the Interior; FPC; Office of Science and Technology; Environmental Protection Agency; Council on Environmental Quality; and the Atomic Energy Commission (AEC). The remaining 12 members represented various universities and companies in the gas industry. Various Federal officials told us that the task force report was the best source of information on the possible application of current experimental techniques thought capable of stimulating and recovering gas from the tight Rocky Mountain area formations. The task force report

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[1]Prepared for the Technical Advisory Committee of the National Gas Survey. The Survey, sponsored by FPC, was to compile comprehensive information on the natural gas industry and to develop the capability for using such information as an integral part of FPC's regulatory process.

pointed out that, of the three experimental techniques discussed below, either of two--nuclear stimulation or massive hydraulic fracturing--might be able to recover 40 to 50 percent of the 600 trillion cubic feet of gas in the Rocky Mountain area.

Another report, entitled "Production from Tight Gas Sands Using Advanced Stimulation Techniques," issued in July 1972, was prepared by the Office of Science and Technology with assistance from AEC, the Department of the Interior, and the Council on Environmental Quality. Officials who assisted in preparing this report told us that it was not as comprehensive or authoritative as the task force report. These officials said that they considered the task force report the best source of information on natural gas stimulation.

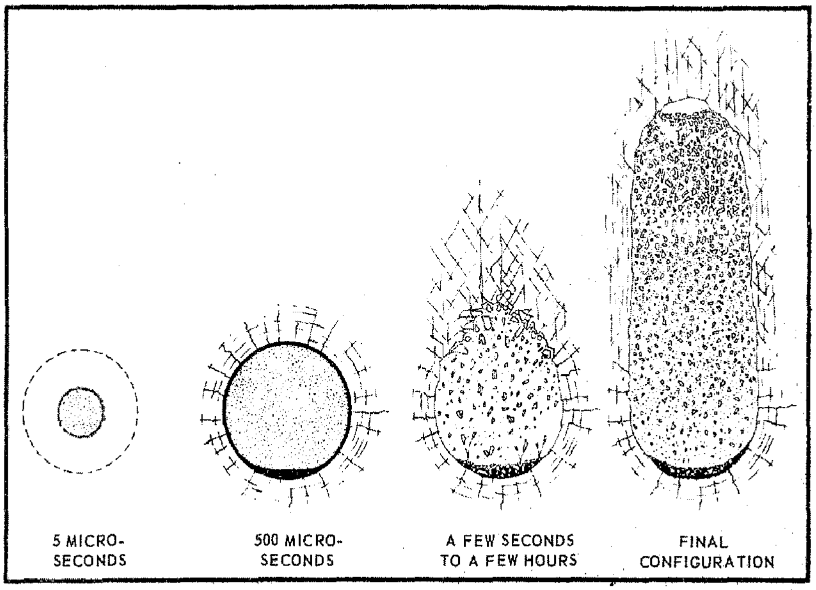
EXPERIMENTAL TECHNIQUES BEING DEVELOPED FOR RECOVERING GAS FROM TIGHT ROCKY MOUNTAIN AREA FORMATIONS

Three experimental techniques could be used for recovering natural gas in tight gas-bearing geological formations, such as those found in the Rocky Mountain area. These techniques are nuclear stimulation, massive hydraulic fracturing, and chemical explosive fracturing. Although chemical explosive and hydraulic fracturing have been used as conventional stimulation techniques for many years, they have not been successfully used in the deep, tight formations in the Rocky Mountain area. Since some development would be necessary before these techniques could be used there, hydraulic and chemical explosive fracturing are considered experimental in their application in that area.

Nuclear stimulation

Nuclear stimulation of gas involves detonating one or more nuclear explosives in a wellbore. The explosion produces a region of broken rock called a chimney and a fracture system that surrounds and is connected to the chimney. A nuclear detonation creates, in the gas formation, a wellbore with a diameter of several hundred feet, instead of one of several inches, which causes more gas to be recovered. AEC-furnished sketches of the sequence of events surrounding an underground nuclear explosion and how nuclear explosives might be used to enhance gas recovery from tight formations are shown on the next page.

SEQUENCE OF EVENTS IN AN UNDERGROUND NUCLEAR DETONATION



A typical sequence of events when a nuclear explosion is detonated underground. Different geological formations would cause variations in the general outcome.

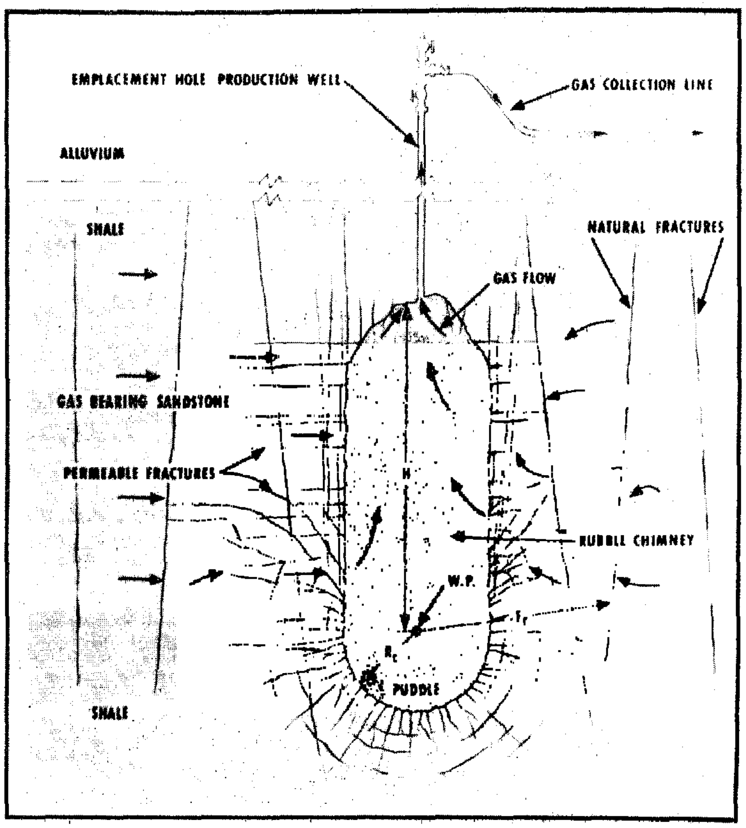
1. During the first few micro-seconds the explosion creates a spherical cavity filled with hot gases at extremely high pressures.

2. The high pressure forces the cavity to expand. When the pressure inside the cavity is equal to that of the overburden, expansion ceases.

3. As the cavity cools, some of the gases liquefy and the molten rock runs to the bottom. Within a few seconds the cavity roof begins to collapse.

4. Falling rock from the roof creates the chimney of broken rock, which is typical of underground explosions. As the chimney rises to a point where the roof becomes self supporting, its growth ceases. Surrounding the chimney is a broad, high fractured area which results from the shock of the nuclear explosion.

NUCLEAR STIMULATION OF GAS FORMATION



W.P. : LOCATION OF EXPLOSIVE
R_c : CAVITY RADIUS
r_f : FRACTURE RADIUS
r_d : RADIUS OF DRAINAGE
H : HEIGHT OF CHIMNEY
h : DEPTH OF BURIAL

A large part of AEC's overall program for peaceful uses of nuclear explosives, referred to as the Plowshare program, involves developing the technology to use nuclear devices to stimulate gas flow. The Plowshare program is authorized under section 31 of the Atomic Energy Act of 1954 (42 U.S.C. 2051). This section authorizes AEC to exercise its powers to insure continued research and development activities in various fields by private or public institutions. Under the act, only AEC can test nuclear weapons and explosives. Although a number of private firms have made significant monetary and technical contributions to the development of nuclear stimulation, private firms cannot independently develop or experiment with the nuclear stimulation technique.

AEC has studied using nuclear explosives to stimulate gas flow for about 10 years. The purpose of AEC's nuclear stimulation program, conducted jointly with private firms, is to develop this technique for use by private industry on a commercial basis. As shown in the table below, AEC estimated that it spent about $33.7 million of Plowshare program funds during fiscal years 1964-73 to develop and test the nuclear stimulation technology.

Fiscal year	Projects	Device development	Research and development	Total
	(000 omitted)			
1964	$ 717	$ -	$ 278	$ 995
1965	893	-	269	1,162
1966	107	-	632	739
1967	380	-	1,281	1,661
1968	2,789	-	2,055	4,844
1969	662	-	1,640	2,302
1970	781	-	2,635	3,416
1971	750	1,400	3,675	5,825
1972	770	1,865	4,150	6,785
1973	516	1,732	3,752	6,000
	$8,365	$4,997	$20,367	$33,729

AEC estimated also that private firms had spent about $46 million on nuclear stimulation technology during fiscal years 1965-73. According to AEC, these firms spent about $30.5 million to support experiments with AEC and spent the remaining $15.5 million for permanent staffs to keep abreast of developments in the area of nuclear stimulation.

Management responsibility for the nuclear stimulation program, insofar as AEC is concerned, is divided among the Division of Applied Technology at AEC Headquarters; AEC's Nevada Operations Office; and an AEC-owned, contractor-operated laboratory selected for each experiment. The Lawrence Livermore Laboratory, Livermore, California, and the Los Alamos Scientific Laboratory, Los Alamos, New Mexico, provided the technical direction for three experiments under the nuclear stimulation program to date. (See p. 18.) The Division directs the program and provides such program management services as cost analysis and control. The responsibilities of the various AEC organizations concerned with the nuclear stimulation of gas is shown in appendix I.

Although the Nevada Operations Office has conducted the detonations, the Department of the Interior has exercised management jurisdiction over operational activities in the field and has provided technical assistance in various areas of scientific expertise.

Massive hydraulic fracturing

Hydraulic fracturing has been used by private firms for a considerable period to increase gas flow from tight formations. It has not been used successfully, however, in the deep, tight, gas-bearing formations in the Rocky Mountain area that contain sand which, in the presence of water, could swell and restrict gas flow. To hydraulically fracture these formations will require large or massive amounts of a type of fluid which will not cause the sand to swell and which can be injected into the wellbore under high pressure. Although private firms have been developing the massive hydraulic fracturing technique, the development of this technique was not funded under any Federal program until fiscal year 1974.

The April 1973 task force report points out that tight formations in other areas of the United States contain gas that cannot be economically recovered using conventional techniques. According to the task force report, although these areas are generally not remote enough for using nuclear stimulation, they are prospective candidates for using massive hydraulic fracturing.

Chemical explosive fracturing

The concept of chemical explosive fracturing that could be used in the tight Rocky Mountain area formations involves injecting and detonating high explosives in existing fractures in the earth's subsurface that were either naturally present or created by hydraulic fracturing. The objective is to lengthen and widen these fractures so that more natural gas can flow through them and into the wellbore.

The Bureau of Mines has been developing chemical explosive fracturing for about 10 years. The Bureau estimates that it spent about $380,000 on developing this technique at its Bartlesville, Oklahoma, Energy Research Center during fiscal years 1968-73. Two attempts by private firms to use chemical explosives as a stimulation technique have resulted in premature detonations and fatal accidents.

CHAPTER 2

FEDERAL AND INDUSTRY EFFORTS TO DEVELOP TECHNIQUES TO INCREASE RECOVERY OF NATURAL GAS

The status of the three experimental techniques--nuclear stimulation, massive hydraulic fracturing, and chemical explosive fracturing--which could eventually be used to economically recover natural gas in the tight geological formations in the Rocky Mountain area is generally as follows:

--Nuclear stimulation experiments--involving single explosives--indicate that, in similar geological formations, several times more gas can be recovered, over a well's life, using nuclear stimulation than can be recovered using conventional techniques. AEC and private firms involved in developing nuclear stimulation believe that nuclear stimulation, by sequentially detonating several explosives in one wellbore, has the potential to recover even more gas than demonstrated by past experiments, but they have not yet developed the technology to demonstrate this increased potential.

--Experiments using the massive hydraulic fracturing technique have not been conducted in the tight Rocky Mountain area formations, and Federal Government and industry officials are not sure whether this technique can be successfully applied there. Although experiments using this technique were not funded in the past by the Federal Government, the AEC and Department of the Interior budgets for fiscal year 1974 include about $1.2 million which could be used to develop this technique. The Department's fiscal year 1975 budget estimate includes about $1 million for further development of this technique.

--Field experiments with chemical explosive fracturing have not been successful. Industry and Federal Government officials told us that development of this technique was significantly behind both massive hydraulic fracturing and nuclear stimulation.

NUCLEAR STIMULATION

A gas-bearing formation can be stimulated to produce more gas by detonating in a wellbore one nuclear device or two or more nuclear devices simultaneously or sequentially. Such factors as the thickness of the gas-bearing formation, the desired dimensions of the fracture system, and the explosive yield limit[1] would determine the optimum number and placement of the devices. The explosive yield limit would vary from location to location, depending on the geological conditions, population density and location, and the resultant seismic damage anticipated. AEC and Lawrence Livermore Laboratory officials told us that as a general rule explosive yields should be limited to about 100 kilotons[2] per well for simultaneous detonations and per explosion for sequential detonations.

Since 1967 AEC has participated in three nuclear gas stimulation experiments--called the Gasbuggy, Rulison, and Rio Blanco experiments--under its Plowshare program. These experiments were for evaluating (1) gas recovery increases, (2) radioactive contamination of the gas, (3) seismic effects, and (4) economics of nuclear stimulation. AEC officials told us that these experiments were designed as technical experiments rather than commercial projects and were not intended to prove commercial feasibility. The Lawrence Livermore Laboratory directed the technical aspects of the Gasbuggy and Rio Blanco experiments, and the Los Alamos Scientific Laboratory directed the Rulison experiment. The experiments--on Federal lands--were conducted by AEC in accordance with plans of operations reviewed and approved by the Geological Survey and other agencies of the Department of the Interior.

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[1]The maximum amount of total energy released by an explosion which will not result in seismic damage unacceptable to AEC.

[2]A kiloton is an explosive force equivalent to that of 1,000 tons of TNT.

Private firms paid a large part of the experiments' costs and provided much of the technical expertise, especially in areas relating to natural gas production. Many of AEC's records and reports on nuclear stimulation are based on data AEC received from these firms. Although we relied primarily on AEC's records and reports for information on nuclear stimulation, the extent of these private firms' interest or participation in developing this technique should not be minimized.

Gasbuggy experiment

AEC, the El Paso Natural Gas Company, and the Department of the Interior conducted this experiment, which used a single explosive yielding 29 kilotons. According to AEC, the total cost of the experiment was about $5.7 million,[1] of which AEC paid about $3.4 million, or about 60 percent, and the El Paso Natural Gas Company paid the remaining $2.3 million, or about 40 percent.

The explosive was detonated on December 10, 1967, in the San Juan Basin, New Mexico. Although this basin was not one of the three basins the task force identified in its survey, it was selected as the site for the experiment because it was regarded as a low-permeability area in which conventional techniques for gas production were not adequate. An AEC-furnished picture, shown on the next page, shows the Gasbuggy explosive about to be lowered into the wellbore. On the basis of gas recovery tests which began in November 1968, the project participants estimated that, over a 20-year period, 900 million cubic feet of gas could be recovered from the well. AEC records state that estimated recovery from conventional wells in the area has been less than one-fifth of that amount.

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[1]The total reported cost of this experiment, as well as the costs of the Rulison and Rio Blanco experiments, does not include the cost of special nuclear material or salaries and travel expenses of Federal employees.

Gasbuggy explosive about to be lowered into the wellbore

AEC and Lawrence Livermore Laboratory officials told us that, as of September 1972, about one-half of the estimated 900 million cubic feet of gas had been recovered. They said that whether 450 million additional cubic feet of gas could be recovered could be determined only after making gas recovery tests over the remaining 15-year life of the well.

Rulison experiment

This experiment, which used a single explosive device yielding 43 kilotons, was conducted in the Piceance Basin on September 10, 1969. AEC joined in this experiment with the Austral Oil Company and the Department of the Interior. According to AEC, the total cost of the experiment was about $8 million, of which Austral Oil Company paid about 80 percent and AEC paid about 20 percent. On the basis of gas recovery tests which began in the fall of 1970, the project participants estimated that the experiment achieved about a fivefold increase in gas recovery over nearby conventional wells. Also AEC determined that the explosive, as had been expected, had stimulated less than one-fourth of the gas-bearing formation in that area.

Rio Blanco experiment

This experiment was conducted on May 17, 1973, in the Piceance Basin. It was cosponsored by AEC and CER Geonuclear, Inc. The experiment involved three 30-kiloton explosives which were emplaced at depths of 5,840, 6,230, and 6,690 feet, respectively, and which were detonated simultaneously. AEC estimates the experiment's total cost will be about $8.4 million, of which the industrial participants will pay about 85 percent. AEC predicted that 20 to 25 billion cubic feet of gas would be recovered from this well over a 20-year period. Gas recovery tests for Rio Blanco began in November 1973.

Results of AEC's experiments

AEC's records on its gas recovery tests showed that its first two experiments involving single nuclear explosives recovered at least five times more gas than nearby conventional wells. To get a more comprehensive picture of the results of these experiments, we asked AEC whether (1) the experiments had been as successful as anticipated and

(2) the gas recovered or to be recovered from these experiments economically justified using single explosive detonations. AEC gave us the anticipated and final results of the experiments for cavity radius, fracture radius, and chimney height, as shown in the table below.

	Gasbuggy		Rulison		Rio Blanco	
	Pre-shot prediction	Post-shot estimate	Pre-shot prediction	Post-shot estimate	Pre-shot prediction	Post-shot estimate
	(feet)					
Cavity radius	78	80	76	78	74	(a)
Fracture radius	393	340	276	275	266	(a)
Chimney height	334	333	276	275	1,400	(a)

[a]Cannot be determined until AEC evaluates gas production tests which began in November 1973.

As shown in the table, the results of the experiments were very close to what AEC anticipated. The Rulison explosive, which had a larger yield than the Gasbuggy explosive, created a smaller cavity, fracture, and chimney height than the Gasbuggy explosive. AEC officials said this occurred because the Rulison explosive was buried about twice as deep as the Gasbuggy explosive and the increased depth acted to reduce the effects of the explosive.

Reports issued by the project participants before the experiments showed estimated gas recovery from Gasbuggy and Rulison of about 3.7 billion cubic feet and 1.7 to 7.1 billion cubic feet, respectively. However, on the basis of tests after the explosives were detonated, the estimates were revised to 0.9 billion cubic feet for Gasbuggy and from 2 to 6 billion cubic feet for Rulison. A Bureau of Mines official told us that the gas recovery estimates had been changed because actual geological conditions differed from those on which the predictions had been based.

He said also that postdetonation tests indicated that the fractures extending from the chimneys of the Gasbuggy and Rulison experiments might have been in the process of closing, which greatly reduced the amount of gas to be recovered. (See p. 42 for an analysis of the effect that fracture closings could have on gas production and cost.) He said, however, that enough postdetonation tests, especially for the Rulison experiment, had not been made to confirm this indication. Officials of Lawrence Livermore Laboratory also told us that data from the Gasbuggy and Rulison experiments had not proved conclusively whether fractures had closed and that it might take years to make such a determination.

With respect to whether the Gasbuggy and Rulison experiments stimulated enough gas production to economically justify using single explosives, AEC officials told us that they believed, even before Gasbuggy had been conducted, that multiple explosives would be necessary to economically recover gas using nuclear stimulation.

Gas recovery testing on the Rio Blanco experiment began on November 14, 1973. On November 20, 1973, the testing was stopped to allow time for equipment changes and to analyze a rapid decline in pressure.

This testing showed that gas was being produced only from the top chimney created by the three explosives. On December 10 and 11, 1973, the project participants met to discuss this unanticipated problem. The participants determined that (1) insufficient data existed to determine why gas had not been produced from the two lower chimneys and (2) production testing should proceed as originally planned. The participants also decided to discuss further operations necessary to determine why the gas production had not been as expected.

As of January 25, 1974, the participants were planning to meet to recommend one or possibly two optional courses of action that could provide the necessary answers. According to AEC officials, the participants, recognizing that substantial additional funds for this project would not be readily available, expected that the minimal program necessary to get the required answers would be recommended.

In commenting on this report, the Department pointed out, in regard to the minimal program, that, in a February 8, 1973, letter, both the AEC Chairman and the Secretary of the Interior gave the Governor of Colorado the following assurances regarding the Rio Blanco experiment and any further experiments.

"Execution of this experiment will, of course, in no way imply any Federal commitment or assurance, either directly or indirectly, that there will be any further nuclear stimulation events in the Piceance Basin or elsewhere. Any further nuclear gas stimulation events would be considered only if a thorough assessment of all the aspects of the Rio Blanco [experiment] give strong assurance of the validity of this energy option and of its compatiblity with the environmental, health, and safety, and alternate energy resource development." (Underscoring supplied.)

The Department stated that:

"It is difficult to see how the minimal test program * * * can provide the strong assurances required before any further nuclear gas stimulation events will be considered."

Multiple explosives stimulation

Simultaneous detonation

According to AEC, detonating one explosive yielding about 100 kilotons does not stimulate enough of the tight, thick gas-bearing formations in the Rocky Mountain area to be an economic method for recovering gas. Simultaneously detonating several explosives yielding a total of about 100 kilotons, such as in the Rio Blanco experiment, should stimulate more of the thick gas-bearing formation and should result in greater amounts of gas recovered.

AEC officials told us that the Rio Blanco experiment should prove the economic and technical feasibility of simultaneously detonating explosives to stimulate gas production. AEC plans to limit further experiments using simultaneous detonations, to minimizing the cost of the nuclear explosives used in this method. They said that, although AEC did not plan to fund any additional experiments using simultaneous detonations, AEC could provide, under existing authority, detonation services for a limited number of experiments or demonstration projects funded by private industry.

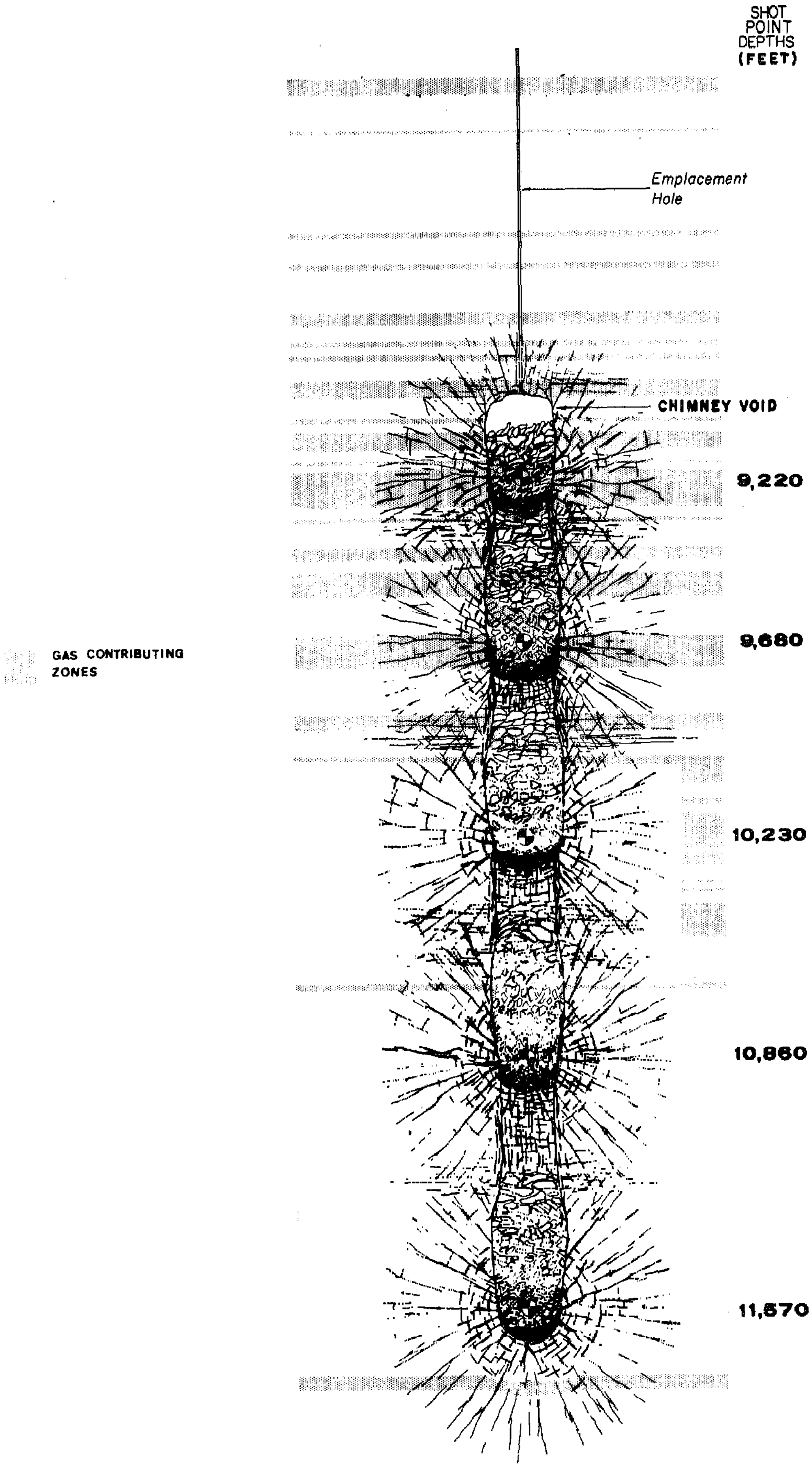
According to AEC officials, the simultaneous detonation method might be used economically in most areas of the Piceance and Uinta Basins but only in certain areas of the Green River Basin because the gas-bearing formations in the Green River Basin are generally thicker (vertically), deeper, and less permeable than the formations in the two other basins. For these formations, they said, simultaneously detonating explosives yielding a total of 100 kilotons in one wellbore cannot create chimneys and fracture systems large enough for economical gas recovery.

According to AEC officials, detonating a number of explosives sequentially could make gas recovery in these thicker and deeper geological formations economical. They pointed out that sequentially detonating a number of explosives, each yielding 100 kilotons would not produce any greater seismic effects than simultaneously detonating a number of explosives yielding a total of 100 kilotons. Lawrence Livermore Laboratory officials told us the time lag between the sequential detonations should be between 5 and 30 minutes.

Sequential detonation

To test the sequential detonation method, AEC had planned to conduct an experiment--called Wagon Wheel--in the Green River Basin. The Wagon Wheel experiment was to involve sequential detonation of five 100-kiloton explosives emplaced in a single wellbore--beginning with the bottom explosive. (See the AEC-furnished sketch on p. .) The industrial cosponsor which proposed this project had wanted the Wagon Wheel experiment to be conducted late in 1973. AEC officials told us, however, that AEC had not decided whether to request funds for this experiment. Thus the execution of Wagon Wheel is now uncertain.

According to AEC officials, sequential detonations would result in the most economical method of commercially producing gas. A classified study by the Lawrence Livermore Laboratory compared the cost of gas recovered with sequentally and simultaneously detonated nuclear explosives. The study showed that the price of gas recovered with the sequential method would be substantially lower than the price of gas recovered with the simultaneous method because more gas would be recovered with the sequential method.



ARTIST CONCEPT OF WAGON WHEEL CHIMNEY REGION

Prerequisites to using nuclear stimulation on a commercial basis

Nuclear stimulation could not be used on a commercial basis unless the Atomic Energy Act of 1954 were amended to authorize AEC to furnish and detonate nuclear explosives for private industry at a stated price. In the event that amending the act is proposed, AEC expects to make a generic analysis of the environmental effects of nuclear stimulation, including a risk-benefit analysis. Assuming that such amendatory legislation would not change the present framework of the Atomic Energy Act, reviews and approvals would be necessary by both the AEC General Manager, who is responsible for developing atomic energy, and the Director of Regulation, who is responsible for licensing the use of atomic energy by private organizations, before commercial development could proceed. Although AEC officials were not certain of the details of how these review and appoval processes would be carried out, they expressed to us their views of the major aspects of these processes as follows:

If the act is amended

A firm that would like to have AEC's General Manager furnish and detonate a nuclear explosive for gas stimulation would have to submit its proposed commercial development program to the General Manager for evaluation. Before the proposed program could be approved, the General Manager, probably in conjunction with the firm, would develop an environmental impact statement assessing the effects of using nuclear stimulation in that commercial program. Federal and State agencies and the public would have the opportunity to comment on that statement.

If the General Manager approved the commercial development program

AEC's regulatory organization or an agreement State[1] would have to license the firms involved in recovering,

[1]A State which has entered into an agreement with AEC to assume responsibility for regulating the possession, use, and distribution of certain radioactive materials in accordance with section 274 of the Atomic Energy Act.

transporting, distributing, and using the gas, unless such use or distribution was exempted from licensing. It may also be necessary to obtain a license from AEC's regulatory organization or from an agreement State for the possession of byproduct material from the well which was produced by the explosion. Licenses for processing and distributing the nuclearly stimulated gas also probably would require assessment of the environmental impact for the specific distribution conditions. AEC has not yet determined whether to authorize widespread distribution of nuclearly stimulated gas. As part of that decisionmaking process, it is expected that a generic analysis, including a risk-benefit analysis, would be made of the environmental effects of distributing gas containing specified amounts of radioactivity.

AEC's regulatory organization controls, through a licensing program, the possession, use, and transportation of certain nuclear materials by private firms. Regulatory officials said they were not sure whether AEC would issue a license for each well or for a series of wells. Before widespread development and distribution of gas could proceed, the gas consumers would have to be exempted from the requirement for a license since they would be using radioactive gas. This would require AEC to revise its regulations.

AEC has studied distribution of the gas from the Rulison experiment well for use by the public but has received no request for commercial distribution of that gas. Thus AEC has not acted to allow or not allow distribution of gas from the Rulison well. AEC regulations would have to be amended before AEC could issue a license for distributing gas from the Rulison well or any well stimulated by nuclear explosives.

Before the gas from the Rulison well or any other nuclearly stimulated well can be used by the public, the industrial companies involved would be expected to submit a petition for a rule change, an application for commercial distribution, and comprehensive supporting information in the form of an environmental report. A decision to allow or not allow Rulison gas to be distributed should not be considered to be a determination regarding the acceptability of widespread distribution of nuclearly stimulated gas.

Before issuing a license to a firm wanting to use nuclear stimulation services provided by AEC to produce gas for widespread distribution, AEC's regulatory organization would require an application describing the potential effects that using the gas would have on the environment and on the populace. Any environmental statement prepared by the regulatory organization would address the question of whether the benefits of having this gas outweighed the potential hazards or the impact on the environment and on the populace connected with its recovery and use. Furthermore, the statement would not necessarily be prepared for each license authorizing distribution, but would be prepared for distribution of nuclearly stimulated gas from a region.

According to AEC regulatory officials, the industrial participant in the Rulison experiment and two gas companies plan to apply for the necessary licenses and revisions to the regulations to allow the gas from the Rulison experiment to be distributed to consumers. These officials told us that the gas from the Rulison experiment would be put into a pipeline containing conventionally recovered gas and therefore would be diluted by the gas from conventional wells.

An official of one of those gas companies told us that his company would not apply until commercial development using nuclear stimulation appears imminent. He said that the results of the Rio Blanco experiment to date had been disappointing and had not produced the hoped-for impetus to commercial development.

AEC officials said that, if the necessary legislative authorization, program funding, industry interest, and approval to use the radioactive gas were achieved, commercial development using the simultaneous detonation method could start as early as fiscal year 1975. In 1968, 1969, and 1972, bills were introduced in the Congress, but not enacted, which would have authorized AEC to furnish, on a compensated basis, nuclear detonation services to private firms.

According to AEC, if legislation, such as that considered by the Congress in 1968, 1969, or 1972, were enacted, its activities would seemingly be immune to State and local regulation. This view was expressed by AEC's General Counsel in a November 1969 letter to the Joint Committee on Atomic Energy in response to the Committee's request that AEC comment on the proposition that:

> "* * * if Plowshare projects are viewed essentially as operational functions of the AEC, apparently an individual state would have very little choice as to whether or not this federal function should be carried out within it borders."

In commenting on our report, AEC officials told us that the above paragraph presented only AEC's legal position regarding nuclear stimulation which was developed over 4 years ago. This legal position, they said, differed from AEC's operating policy which three chairmen of AEC had affirmed, as indicated in a February 9, 1973, letter from the AEC Chairman to the Governor of Colorado, as follows:

> "The Atomic Energy Commission (AEC) will continue to keep you fully and currently informed as to all aspects of the proposed Rio Blanco Project, as it has done during the development of this Project. It has long been recognized that the full cooperation of the State, its member agencies and local governments is necessary to the successful conduct of Plowshare program applications. In the case of Project Rio Blanco, this policy was specifically stated in Chairman Seaborg's December 17, 1970 letter to you indicating assurance '...that the AEC will not proceed with any detonation in connection with the Rio Blanco experiment without the concurrence of appropriate State officials.'
>
> "Chairman Schlesinger's letter of January 11, 1973 to you reaffirmed Chairman Seaborg's commitment, 'recognizing that this is not a question of legal right but an example of intergovernment comity.' Chairman Schlesinger further explained that the final decision with respect to proceeding with the Project would 'reflect the appropriate balancing of Federal and State

interests and concerns' and 'intergovernmental consultation rather than exercise of State authority.'"

It should be noted that, under the legislative authorization proposed in 1968, 1969, and 1972, concurrence of appropriate State officials would not have been necessary to proceed with commercial development.

In the event the Congress authorizes AEC to provide nuclear detonation services to private firms for commercial development of natural gas, appropriate language would have to be included in the authorizing legislation if it is desired to provide individual States with a choice as to whether such detonations could take place within their borders.

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In a letter dated March 21, 1974, commenting on this report, the Chairman, AEC, stated:

> "We believe that our limited nuclear explosive research program, together with considerable project participation from industry, has brought the Nation closer to having a useful new technology for recovering significant amounts of natural gas from tight gas sands. We continue to believe that nuclear stimulation holds promise for adding significant amounts of natural gas to our proven reserves. This continued confidence is based on the Gasbuggy and Rulison experiments. We do not have, at this time, all of the results from the Rio Blanco experiment, but believe that this experiment will also provide data for use in understanding the effects of the explosion and its potential as a tool to recover natural gas. The information collected and analyzed by our scientists enables them to predict the potential results of the application of a developed technology."

MASSIVE HYDRAULIC FRACTURING

As of June 30, 1973, there were no Federal programs or funds for developing massive hydraulic fracturing. AEC's and the Bureau of Mines' fiscal year 1974 budgets, however, include about $1.2 million that could be used for such development. The Department of the Interior's fiscal year 1975 budget estimate includes about $1 million for further development of this technique.

Oil and gas recovery companies have, for a considerable period, successfully used hydraulic fracturing to increase gas recovery, but not from the deep, tight formations of the

Rocky Mountain area. The report by the Office of Science and Technology (see p. 12) stated that gas recovery from thousands of gas wells had been increased by hydraulic fracturing. The report indicated, however, that assessing the economic feasibility of using massive hydraulic fracturing in tight, gas-bearing formations was clouded by the lack of experimental evidence. According to the study, only a few companies with the necessary experience, expertise, and equipment could carry out massive hydraulic fracturing experiments.

Federal and industry representatives are not sure whether massive hydraulic fracturing can be successfully used in the Rocky Mountain area basins. For example, AEC and Bureau officials told us the conditions in the Piceance and Green River Basins might present insurmountable problems to the successful use of massive hydraulic fracturing. They pointed out that the Piceance Basin contained water-sensitive sands and clays which could react with the fracturing fluid to block the flow of gas.

However, representatives of two private firms told us that this problem could be resolved by using a convertible fracturing fluid which changes from a liquid to a gas after fractures have been created. Officials of one of these firms said their firm had used this fluid successfully but not in the deep, tight formations of the Rocky Mountain area.

A problem facing the massive hydraulic fracturing technique in the Green River Basin is the great depths at which the fluid must be used. The gas-bearing formations in this basin are at depths of about 8,000 to 15,800 feet. At such depths, massive amounts of fluids and tremendous pressure would be necessary to create sufficiently long fractures. Bureau officials told us that it might not be possible to inject the necessary amount of fluid in the wellbore to obtain the necessary pressure to create fractures at those depths. In addition, they stated that the equipment needed to pump massive amounts of fluid to such depths probably was not readily available.

Information developed by a Bureau official indicated that fluid amounts, injection rates, depths, and fracture lengths necessary for gas stimulation in deep formations had been attained but not in the same well. For example, the most fluid injected in a well was 1,075,200 gallons, but the highest injection rate (547 barrels a minute) occurred in a different well. The deepest well hydraulically fractured was 20,438 feet. In a 7,500-foot-deep well, hydraulic fracturing created a fracture 1,400 feet long from the wellbore. According to this Bureau official, if the fluid amount, injection rate, depth and fracture length attained in these separate wells could be attained in one well, they would be adequate for successfully using massive hydraulic fracturing in the Rocky Mountain area, if other technical problems, such as water-sensitive sands and clays, could be overcome.

We asked representatives of a firm that provided stimulation services whether they had the necessary equipment to use massive hydraulic fracturing in the Rocky Mountain area. They said that, since the gas was in layers at various depths throughout the formation, massive hydraulic fracturing could be done in a series of separate treatments that would coincide with these layers. Consequently, they believed they would have the necessary equipment.

For fiscal year 1974, the Congress authorized and appropriated $800,000 to AEC for the purpose of evaluating massive hydraulic fracturing. The Office of Management and Budget apportioned these funds to AEC in December 1973. In addition, the Office of Management and Budget requested AEC to coordinate its efforts with those of the Bureau of Mines, which has been appropriated about $1.8 million for research in massive hydraulic fracturing, combined hydraulic and chemical explosive fracturing, and another technique that utilizes natural fractures in the earth. Bureau of Mines officials told us that about $435,000 of that amount could be used in fiscal year 1974 for research in massive hydraulic fracturing.

According to AEC officials, AEC and the Bureau are in the process of determining the optimum use of their funds. They tentatively plan to conduct an experiment using massive hydraulic fracturing at a location near the site of the Rio Blanco nuclear stimulation experiment.

The Department's fiscal year 1975 budget estimate includes about $1 million for development of massive hydraulic fracturing; AEC's fiscal year 1975 budget estimate does not include any amount for massive hydraulic fracturing.

CHEMICAL EXPLOSIVE FRACTURING

According to the Bureau of Mines, chemical explosive fracturing can be best used when fractures are already connected to the wellbore. Since the tight basins in the Rocky Mountain area are generally void of natural fractures, fractures would have to be created before the chemical explosives could be used.

The Bureau has funded the development of chemical explosive fracturing for about 10 years. The development has been aimed at using this technique in formations shallower than those found in the Rocky Mountain area. Bureau officials told us that past development efforts with chemical explosives had not been totally successful, primarily because of premature detonations of the chemical explosives. Such detonations are caused primarily by the heat and pressure in the wellbore that increase as the wellbore depth increases.

Two attempts by private firms to use chemical explosives as a stimulation technique have resulted in premature detonations and fatal accidents. One accident, in November 1970, killed nine members of a research team testing the effectiveness of injecting and detonating a liquid explosive in an underground formation in Oklahoma. According to Bureau officials, the problem of premature detonation would be increased in the deep wellbores of the Rocky Mountain area.

The Bureau, through its Bartlesville Energy Research Center, has participated in three field tests involving chemical explosive fracturing. Two of these tests were done in shallow, gas-bearing formations in Oklahoma. In these two tests, 890 and 1,000 quarts of liquid nitroglycerin, respectively, were displaced into hydraulic fractures connected to the wellbores. The chemical explosives did not substantially improve gas recovery from one of the wells. According to Bureau officials, the gas flow capacity of the second well was improved 40 percent by the chemical explosives.

The third field test took place in July 1971 in West Virginia. About 15,000 pounds of an explosive slurry (mushy liquid) was successfully displaced into a natural fracture system, and a device to detonate the slurry was lowered in the wellbore. The slurry never detonated. Although the cause of the detonation failure is uncertain, Bureau officials thought that the slurry might have gone too far into the natural fracture system and thus might have been too far from the detonation device to explode.

The July 1971 field test was the last chemical explosive fracturing test in which the Bureau participated. According to Bureau officials, their current efforts consist primarily of monitoring and evaluating private industry's attempts to further develop and test the chemical explosive fracturing technique.

Several private firms are trying to develop types of chemical explosives which could be used safely in deep formations. One firm is developing a system whereby the explosive is separated into two components and pumped into the well in different pipes. The explosive is designed to detonate after the components are mixed in the wellbore. According to Bureau officials, this firm has successfully demonstrated this system in shallow wells with low temperatures and pressure. The firm's laborabory tests indicated, according to Bureau officials, that the system would work in deep wells at high temperatures and pressure, but, since this new system has not been field tested in deep wells, its feasibility is uncertain.

Since natural fractures are not present in the Rocky Mountain area basins, fractures must first be created to optimize the effectiveness of the chemical explosives. According to Bureau officials, two alternatives for creating these fractures are (1) using a nonexplosive fluid for hydraulic fracturing that would be removed after the fractures were created or (2) using an explosive substance which could first hydraulically fracture the formation and then be detonated to widen the fractures it created.

Officials of a private firm which develops and provides stimulation services for oil and gas companies told us that the use of an explosive fluid was the preferred alternative. They explained that, if a nonexplosive fluid were used, the fluid must be removed from the wellbore and fractures before a chemical explosive could be injected into the well. This removal process, they said, would be too costly. They said also that simply increasing the size and intensity of the hydraulic fracturing process would probably be more economical than removing the fracturing fluid and using chemical explosives.

They also told us, however, that the second alternative--the explosive fluid--would be difficult to develop. It requires that the dual-purpose substance be rugged enough to withstand, without detonating, the extreme heat and pressure while being used to hydraulically fracture a formation and yet be sensitive enough to detonate at the desired time when displaced in the fractures it created.

According to Bureau officials and two private firms involved in natural gas recovery, the development of the chemical explosive technique is significantly behind that of both massive hydraulic fracturing and nuclear stimulation. For this reason in the remaining chapters of this report we discuss only the massive hydraulic fracturing and nuclear stimulation techniques.

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If both stimulation techniques--nuclear and massive hydraulic fracturing--were proven capable of significantly increasing gas recovery from the Rocky Mountain area, an important consideration in determining which technique is more suitable for commerical use would be the price the consumer would pay for this gas. The price to the consumer is based on the cost to recover the gas, prepare it for transmission, and transport and distribute it. The cost to recover the gas and prepare it for transmission (wellhead cost) varies, depending on whether conventional techniques or either of the experimental techniques were used to recover it. The costs to transport and distribute the gas to the consumer should generally be the same, regardless of which recovery technique is used.

According to the task force report, if the nuclear and massive hydraulic fracturing techniques were developed and used in the tight formations of the Rocky Mountain area, the wellhead cost of the gas recovered there would be higher than the wellhead cost of gas recovered in other areas using conventional techniques. Because the price an interstate gas producer can charge his customers is regulated by FPC through an area rate system, the producer would have to obtain FPC's permission to pass these higher costs on to its customers. FPC could, under its regulations, permit a producer to charge a price higher than the area rate, if the producer demonstrates to FPC that a higher price is necessary to recover its costs. The factors which could impact on the wellhead cost and the effect wellhead cost has on the price the consumer pays for gas are discussed in the next chapter.

CHAPTER 3

FACTORS HAVING AN IMPACT ON THE WELLHEAD COST

OF ROCKY MOUNTAIN AREA GAS

In its April 1973 report, the task force estimated the wellhead cost of recovering gas using both massive hydraulic fracturing and nuclear stimulation. The report showed that, under most circumstances, gas could be recovered at a lower wellhead cost using massive hydraulic fracturing but pointed out that there was a significant amount of uncertainty in these estimates and that therefore both techniques need to be thoroughly tested and evaluated.

To determine the sensitivity of some of the task force's major assumptions in computing the wellhead cost of gas, we changed these assumptions to include possible conditions that would favorably and unfavorably affect the wellhead cost for each technique. When the assumptions are changed to include conditions unfavorable to both techniques, there is an even greater cost advantage to recovering gas with massive hydraulic fracturing. However, when favorable conditions are included, there is a cost advantage to using nuclear stimulation.

As previously mentioned, the wellhead cost of gas recovered using either of the experimental gas stimulation techniques would probably be higher than the wellhead cost of gas recovered by conventional techniques. The effect that the increased cost would have on the price paid by the consumer would depend on the amount of the higher costing gas that would be mixed with the lower costing gas currently used by consumers.

If, as predicted by the task force, the supply of the lower priced, conventionally produced gas falls short of demand, this supply shortage could be met from competing alternative sources. These alternative sources include synthetic coal gas and the gas recovered from the Rocky Mountain area using either the nuclear or the hydraulic fracturing technique. On the basis of available cost data, it appears that the estimated cost of gas recovered using either experimental technique would generally be lower than the cost of gas from alternative sources and also lower than the cost of some gas recovered with conventional techniques and sold intrastate.

ESTIMATED WELLHEAD COST TO RECOVER GAS IN TIGHT FORMATIONS

For each of the two stimulation techniques--massive hydraulic fracturing and nuclear stimulation--the task force estimated for a single well the (1) initial capital investment required and (2) amount of gas that could be recovered. On the basis of these estimates and assuming rates of return of 10, 15, and 20 percent of initial investment and annual inflation factors, the task force computed, for the years 1980, 1990, and 2000, the estimated wellhead cost of gas which would result from using these techniques on a commercial basis. The estimated wellhead costs in the task force report are shown below.

Estimated Wellhead Cost of Gas, High-Recovery Case (per thousand cubic feet of gas) (notes a and b)

	Piceance Basin		Green River Basin		Uinta Basin	
	Nuclear	Hydraulic	Nuclear	Hydraulic	Nuclear	Hydraulic
10% rate of return:						
1980	$0.36	$0.33	$0.52	$0.54	$0.19	$0.20
1990	.49	.45	.71	.73	.26	.27
2000	.65	.61	.95	.98	.36	.37
15% rate of return:						
1980	.45	.38	.66	.63	.25	.23
1990	.61	.51	.90	.85	.34	.31
2000	.81	.69	1.21	1.14	.46	.42
20% rate of return:						
1980	.54	.42	.80	.72	.31	.26
1990	.73	.57	1.08	.97	.42	.35
2000	.98	.77	1.45	1.30	.56	.47

Estimated Wellhead Cost of Gas, Low-Recovery Case (per thousand cubic feet of gas) (notes a and b)

	Piceance Basin		Green River Basin		Uinta Basin	
	Nuclear	Hydraulic	Nuclear	Hydraulic	Nuclear	Hydraulic
10% rate of return:						
1980	$0.79	$0.62	$0.52	$0.54	$0.45	$0.37
1990	1.07	.84	.71	.73	.60	.50
2000	1.44	1.13	.95	.98	.81	.67
15% rate of return:						
1980	.93	.72	.66	.63	.55	.43
1990	1.27	.97	.90	.85	.74	.58
2000	1.70	1.31	1.21	1.14	.99	.78
20% rate of return:						
1980	1.07	.82	.80	.72	.65	.49
1990	1.44	1.10	1.08	.97	.87	.66
2000	1.94	1.48	1.45	1.30	1.17	.89

[a] The task force based its estimates of gas production on sequentially detonating 100-kiloton explosives; four explosives per well were assumed in the Uinta Basin, five explosives per well in the Piceance Basin and six explosives per well in the Green River Basin. Cost for nuclear stimulation does not include $0.10 per thousand cubic feet for surface facilities. (See p. 45.)

[b] The high-recovery case assumes that favorable geologic conditions exist leading to a faster rate of drilling and stimulating wells and the low-recovery case assumes the opposite. For the Green River Basin, a single recovery case was estimated, rather than high- and low-recovery cases, because the geologic conditions were better known.

The task force report and our discussions with various Federal officials, including FPC officials, indicated that certain factors would be likely to change during commercial development of these techniques and that such changes could affect the comparison of wellhead costs. These factors are the

--closing of fractures created by nuclear stimulation,

--cost of the nuclear explosives used,

--surface facilities needed to process nuclear-stimulated gas,

--length of fractures created by massive hydraulic fracturing, and

--cost of fluid used for massive hydraulic fracturing.

To establish how changes in these factors would effect wellhead costs, we changed one factor at a time, to account for other conditions that might be experienced during commercial development. Although we made this analysis for only the Green River Basin, we believe that our results would have general applicability to the other two basins in the Rocky Mountain area because (1) the task force method of computing the wellhead costs was essentially the same for all three basins and (2) the factors which could affect cost would be the same for all three basins. Also we used rates of return on investment of 15 and 20 percent, because a 10-percent return might be too low, considering the uncertainty of these techniques. At the time of our review, FPC was using a rate of return of 15 percent to compute area rates for gas recovered using conventional techniques.

FACTORS AFFECTING WELLHEAD COST USING NUCLEAR STIMULATION

Two major factors which affect the cost of nuclear-stimulated gas are (1) uncertainty as to whether the fractures created by a nuclear explosion close and (2) the cost of the nuclear explosive.

Closing of fractures

The wellhead cost of gas is very sensitive to the quantity of gas recovered, which, in turn, is dependent upon the fracture system created by the nuclear explosion and the length of time the fractures remain open. Although the wellhead costs in the task force report were based on the assumption that the fractures would remain open for the life of the well, the report calculated the effect on gas production for three different cases relating to the closing of fractures.

Case 1. Fractures assumed to close uniformly as a result of the pressure of the ground above the fractures over periods of 10 and 20 years.

Case 2. Fractures assumed to close, starting at the outer limit of the fracture and moving into the chimney, over periods of 10 and 20 years.

Case 3. Fractures assumed not to have been created by the explosion.

For each of these cases, the task force estimated the percentage of gas that would be recovered in relation to the amount that would have been recovered if the fractures remained open. On the basis of these percentages, we determined the effect on wellhead cost of gas resulting from the closure of fractures if nuclear stimulation were used on a commercial basis.

Case	Description	Task Force estimate of gas recovered	GAO estimate of wellhead costs for 1980 (per thousand cubic feet) 15% rate of return	20% rate of return
Task force	Fractures remain open	100%	[a]$0.66	[a]$0.80
1.	Fractures close over 10-year period	75	[b].77	[b].90
	Fractures close over 20-year period	86	[b].70	[b].83
2.	Fractures close over 10-year period	77	[b].82	[b].96
	Fractures close over 20-year period	83	[b].73	[b].86
3.	Fractures not created	60	[b]1.46	[b]1.77

[a]From task force report.

[b]Does not include $0.10 per thousand cubic feet for surface facilities. (See p. 45.)

As the table shows, the closing of the fractures could have a large impact on the wellhead cost of gas, depending on how quickly they close. If fractures are not created, the amount of gas recovery is significantly reduced and the wellhead costs are significantly increased. The task force director stated that fractures were necessary to provide sustained productivity and high recovery efficiency. He also said that the key question regarding nuclear stimulation was whether fractures stay open to provide, for many years, a permeable flow path to the chimney.

Officials of AEC and the Bureau of Mines told us that fractures were definitely created in both the Gasbuggy and the Rulison nuclear stimulation experiments. These officials disagreed, however, on whether these fractures had started to close.

The Bureau official told us that his analysis of tests conducted after these experiments indicated that the fractures might have been closing at the time the tests were made.

AEC officials said that their analysis of these tests indicated that the fractures remained open. They said, however, that they recognized that other persons knowledgeable of nuclear stimulation disagreed with their interpretation of the test results.

Because this issue is important to the economics of nuclear stimulation and its cost comparison with massive hydraulic fracturing, more should be done to minimize the uncertainty as to whether fractures created by nuclear stimulation close and the rate of such closure before nuclear stimulation can be considered economically acceptable. AEC officials said that additional tests, although very costly, could be made that would provide better data to evaluate whether fractures in the Gasbuggy and Rulison experiments had closed.

Cost of nuclear explosives

AEC has promoted participation by industry and other groups in its Plowshare program by encouraging them to analyze the possible uses of nuclear explosives in their specific fields. AEC published cost estimates for nuclear explosives and related services, including safety studies. AEC's most recent estimate--made in 1964--of a 100-kiloton explosive was $450,000.

To estimate wellhead costs, the task force used AEC's 1964 cost estimate of $450,000 for a 100-kiloton explosive. The cost of the nuclear explosives represents about one-half of the investment costs that the task force considered necessary to use nuclear stimulation. Because AEC has not computed more recent cost estimates for nuclear explosives, considerable uncertainty exists in this large segment of the total cost. By holding all other factors constant and increasing and decreasing the cost of the explosives in $50,000 increments, we computed the effect on estimated wellhead costs.

Cost of explosive	Increase or decrease(-) in cost from task force report	GAO estimate of wellhead costs for 1980 (per thousand cubic feet) (note a)	
		15% rate of return	20% rate of return
$250,000	-$200,000	$0.51	$0.62
300,000	-150,000	.55	.66
350,000	-100,000	.59	.70
400,000	-50,000	.63	.75
450,000	-	[b] .66	[b] .80
500,000	50,000	.70	.84
550,000	100,000	.74	.88
600,000	150,000	.77	.93
650,000	200,000	.81	.97

[a] Cost for nuclear stimulation does not include $0.10 per thousand cubic feet for surface facilities. (See below.)

[b] From task force report.

As the table shows, for each $50,000 increment in the cost of the explosive, the wellhead cost changes by about $0.04 per thousand cubic feet.

Additional cost for surface facilities

The task force report points out that the gas recovered with nuclear stimulation would be too hot (thermally) to put into a pipeline and would contain radioactive (tritium) water. The gas also would contain carbon dioxide which must be removed before the gas could be used.

The task force report assumes that the water would be removed from the gas and pumped from each well through a surface line to a common point for a group of wells and then pipelined up to 200 miles for disposal. The task force report estimates that the cost of the surface facilities necessary to remove the carbon dioxide, cool the gas, and dispose of the water would increase the cost of gas in all three basins by about $0.10 per thousand cubic feet. As pointed out in chapter 4, Lawrence Livermore Laboratory officials believe the method suggested by the task force report for disposing of the tritiated water is too expensive although they did not select an alternative method.

FACTORS AFFECTING WELLHEAD COST USING MASSIVE HYDRAULIC FRACTURING

Length of fracture

Two federally funded studies disagree on the length of the fractures that massive hydraulic fracturing create. The task force report, which shows that massive hydraulic fracturing would be more economical than nuclear stimulation under most circumstances, is based on the assumption that massive hydraulic fracturing would create fractures extending out 500 feet from the wellbore. The Office of Science and Technology, in its July 1972 report, indicated that nuclear stimulation would be more economical than massive hydraulic fracturing in the Uinta and Green River Basins. This report was based on the assumption, however, that the fracture length created by massive hydraulic fracturing would be 275 feet.

Assuming that only 275-foot fractures were created rather than 500-foot fractures, we computed, on the basis of the task force data, that the 1980 wellhead costs of gas recovered with massive hydraulic fracturing would increase

- --$0.25 per thousand cubic feet to a total of $0.88 for a 15-percent rate of return or

- --$0.30 per thousand cubic feet to a total of $1.02 for a 20-percent rate of return.

We asked Bureau of Mines officials and representatives of two private firms that had experience with hydraulic fracturing whether 500-foot fractures could be achieved in the Rocky Mountain area. It was their opinion that 500-foot fractures was a reasonable assumption. The representatives of the private firms said that 500-foot fractures might even be a conservative assumption. Information in the task force report indicated that fracture lengths over 500 feet resulted in relatively insignificant decreases in wellhead cost.

Cost of fracturing fluid

The task force report assumed the cost of the fracturing fluid to be $0.50 a gallon. This cost is meant to cover the cost of fluids and materials used to keep fractures open and other charges associated with massive hydraulic fracturing. As mentioned previously, a gaseous fracturing fluid might be necessary to resolve the problem of the water-sensitive clays and sands found in the Rocky Mountain area. One representative of a private firm told us that a gaseous fluid would cost from $0.75 to $1 a gallon. We calculated that increasing the cost of fluid to $1 a gallon would increase the 1980 wellhead cost

--$0.01 per thousand cubic feet to a total of $.64 for a 15-percent rate of return or

--$0.02 per thousand cubic feet to a total of $0.74 for a 20-percent rate of return.

BEST CASE AND WORST CASE

To determine the effect of changing more than one factor at a time, we calculated the best and worst cases for each technique. That is, we used cost data and assumptions which would have the greatest impact on the wellhead cost to get the lowest wellhead cost (best case) and the highest wellhead cost (worst case). We obtained the data and assumptions we used, except for the cost of nuclear explosives, from the task force report, the Office of Science and Technology report, or the officials we talked with. Because AEC had not calculated the actual price of the explosive and because the price, if calculated, would be classified, we assumed a hypothetical best price of the explosive of $250,000 and a hypothetical worst price of $650,000.

Best case	Wellhead cost for 1980 (per thousand cubic feet) 15% rate of return	20% rate of return
Nuclear--fractures remain open, no surface facilities, explosives cost $250,000	$0.51	$0.62
Massive hydraulic fracturing--fractures extend 500 or more feet, fluid costs $0.50 a gallon	[a].63	[a].72
Worst case		
Nuclear--fractures close over a 10-year period, surface facilities increase gas cost $0.10 per thousand cubic feet, explosives cost $650,000	1.10	1.28
Massive hydraulic fracturing--fractures extend 275 feet, fluid costs $1 a gallon	.89	1.03

[a]According to the task force report, fracture lengths greater than 500 feet result in relatively insignificant decreases in wellhead cost.

The table shows that, if certain assumed favorable conditions should exist with each technique, the wellhead cost of gas recovered with nuclear stimulation would be $0.10 to $0.12 lower than the cost of gas recovered with massive hydraulic fracturing. If, however, each technique is faced with certain assumed unfavorable conditions, the wellhead cost of gas recovered with massive hydraulic fracturing would be $0.21 to $0.25 lower than gas recovered with nuclear stimulation. Also massive hydraulic fracturing has a smaller impact on wellhead cost than does nuclear stimulation.

The worst case for nuclear stimulation assumes that fractures close over a 10-year period rather than that they are not created, which was the task force assumption under which the wellhead cost of nuclearly stimulated gas was the highest. We did not use the task force assumption for fractures in the worst case for nuclear stimulation, because the Federal officials we talked with said that fractures had definitely been created at the Gasbuggy and Rulison experiments.

ALTERNATIVE SOURCES OF GAS

FPC reports show that there is a shortage of the lower priced, conventionally produced gas and predict that the shortage will get worse. Alternative sources of gas would compete with each other to make up this gas shortage. If gas in the tight formations in the Rocky Mountain area is to be recovered using either experimental stimulation technique, the costs to recover gas and transport it to the using markets must be low enough to compete with the price of gas from alternative sources.

The table below presents the market areas where Rocky Mountain area gas could be sold, the cost of potential alternative sources of gas, the cost to transport Rocky Mountain area gas to the market areas, and the cost at which Rocky Mountain area gas must be recovered to be competitive. The table is based on a presentation regarding the Rocky Mountain area gas rates made to FPC by an economic consulting firm. The costs were estimated as of May 1971, but we escalated them to 1980 by using the same inflation factors used in the task force report so that these wellhead costs could be compared to the task force report wellhead costs. (See p. 40.)

Market area	Alternative source of supply	Cost of alternative supply	Cost of transporting gas from Rocky Mountain to market areas	Wellhead cost at which gas must be recovered with either experimental technique to be competitive (note a)
		(per thousand cubic feet of gas)		
Rocky Mountain	Synthetic coal gas	$1.05 to 1.40	$ -	$1.05 to 1.40
Los Angeles	Liquified natural gas	1.02	0.32	.70
	Synthetic coal gas	1.40	.32	1.08
	Alaskan North Slope natural gas	1.05 to 1.40	.32	.73 to 1.08
Minneapolis-St. Paul	Alaskan North Slope natural gas	1.05 to 1.40	.28	.77 to 1.12

[a]Computed by subtracting column four from column three. These costs may be compared with the task force estimated wellhead costs for 1980 as shown on page 40.

As the table shows, if gas can be recovered with either experimental technique at wellhead costs ranging from $0.70 to $1.40 per thousand cubic feet, it can compete with alternative sources in the market areas listed.

For example, the table shows that, in the Los Angeles area, synthetic coal gas could be purchased for $1.40 per thousand cubic feet. The cost to transport gas recovered from the Rocky Mountain area to Los Angeles is $0.32 per thousand cubic feet. If gas in the Rocky Mountain area could be recovered and prepared for transporting for $1.08 per thousand cubic feet or less (wellhead cost), this gas could be transported to and sold in Los Angeles in 1980 at a price competitive with that of synthetic coal gas.

Price to consumer

The price the consumer pays for gas is determined by the combined charges of recovering, transporting, and distributing it. According to statistics of the gas utility industry, the average price for gas paid by all consumers in 1972 was about $0.73 per thousand cubic feet. Transportation and distribution charges presently account for a much larger share of the price to the consumer than do the recovery charges. According to an American Gas Association official, transportation and distribution charges accounted for about three-quarters of the average price of gas paid by all consumers in 1972.

Gas carried in the pipelines of transporters is usually a mixture of gas from several sources at different prices. The cost of this gas to the transporter is the weighted-average cost of the gas from several sources. For example, if 50 percent of a mixture of gas costs $0.20 per thousand cubic feet and 50 percent costs $0.40 per thousand cubic feet, the cost of the gas to the transporter would be $0.30 per thousand cubic feet. To determine the price the consumer would pay for this gas, transportation and distribution charges would have to be added.

Gas produced by nuclear stimulation or massive hydraulic fracturing probably would have a higher wellhead cost than would the other gas in the mixture. For example, gas recovered since about 1970 from permeable formations in the Rocky Mountain area with conventional techniques costs about $0.23 per thousand cubic feet at the wellhead. Adding gas recovered by either technique to a mixture would, in turn, increase the cost of the mixed gas.

For example, if a mixture contained equal amounts of gas costing $0.20 and $0.40 per thousand cubic feet and a third equal amount of gas was added that was recovered by either experimental technique at a wellhead cost of $0.60, the new average mixture price would be $0.40 per thousand cubic feet. Although nuclear or hydraulic stimulated gas was $0.30 per thousand cubic feet more expensive than the average cost of the other gases in the mixture, the addition of the stimulated gas raised the cost of the mixture by only $0.10 per thousand cubic feet. Presumably, this $0.10 cost increase would be passed on to the consumer.

The effect that the higher priced gas could have on the price a consumer would pay for gas in 1980 is shown in the table below. We prepared the table on the basis of projected gas prices given to us by the Colorado Interstate Gas Company. In the table the gas to the consumer is assumed to contain conventionally recovered gas costing $0.29 per thousand cubic feet at the wellhead and various percentages of higher priced gas at various wellhead costs. Under these assumptions, the price to the consumer of gas containing the higher priced gas would range from $0.94 to $1.22. If none of the higher priced gas is in the gas to the consumer, the consumer would pay about $0.91 per thousand cubic feet.

Price of Gas to the Consumer
(per thousand cubic feet)

Wellhead cost of higher priced gas	Percent of higher priced gas in the gas to the consumer			
	0	20	40	60
$0.45	$0.91	$0.94	$0.97	$1.01
.60	.91	.97	1.03	1.10
.80	.91	1.01	1.11	1.22

On the basis of this price data, the price the consumer pays for gas would increase from 3 to 34 percent, depending on the amount and wellhead cost of the higher priced gas in the gas to the consumer.

CHAPTER 4

OTHER FACTORS WHICH COULD IMPACT ON COMMERCIAL DEVELOPMENT OF GAS IN THE ROCKY MOUNTAIN AREA

The task force report described the magnitude of a commercial development program that would be necessary to recover 40 to 50 percent of the gas in the Rocky Mountain area using either stimulation technique--nuclear stimulation or massive hydraulic fracturing. For nuclear stimulation, the task force estimated the program would involve drilling 5,680 wells and detonating 29,680 nuclear explosives, each with a 100-kiloton yield, over a period ranging from about 35 to 65 years. AEC and Lawrence Livermore Laboratory officials said they consider the task force's estimate reasonable. For massive hydraulic fracturing, the task force report indicated the program would involve drilling about 22,720 wells over a period of about 60 to 115 years.

More than $33 million of Federal funds have been spent on developing nuclear stimulation, but no Federal funds had been spent on massive hydraulic fracturing before fiscal year 1974. Also three nuclear stimulation experiments have been conducted in the Rocky Mountain area, but no experiments with massive hydraulic fracturing have been conducted there. As a result, the information available to us during our review related, in the main, to nuclear stimulation.

We noted two problems which could directly affect the feasibility of commercial programs using these experimental techniques.

--Would the recovery of gas using nuclear stimulation hinder the underground mining of oil shale?

--Would there be enough water available for massive hydraulic fracturing and the development of other mineral resources?

We also noted certain matters which could be important in determining the feasibility and desirability of a commercial development program using the nuclear stimulation technique. These matters relate to

--the effects on homes, buildings, and persons near the underground nuclear detonations;

--the effects of nuclear-stimulated gas on man;

--the releases of radioactivity to the atmosphere;

--the disposal of contaminated water separated from nuclear-stimulated gas; and

--AEC's capacity to produce the needed nuclear material.

COMMERCIAL PROGRAMS TO RECOVER NATURAL GAS IN THE ROCKY MOUNTAIN AREA MIGHT NOT BE COMPATIBLE WITH DEVELOPMENT OF OTHER MINERAL RESOURCES IN THE AREA

A commercial program to use either massive hydraulic fracturing or nuclear stimulation to recover natural gas in the Rocky Mountain area could present problems for the recovery of the oil shale and other mineral resources in the area. Using nuclear stimulation might be incompatible with the concurrent underground mining of oil shale and other minerals in the area, because of the possibility of seismic waves created by the nuclear explosives' collapsing underground mines.

The use of massive hydraulic fracturing on a commercial basis could require large amounts of water, if water is used in the fracturing fluid. It is uncertain whether the Rocky Mountain area contains enough water for both massive hydraulic fracturing and the development of other resources, such as oil shale and coal, in the area.

Recovery of gas using nuclear stimulation might not be compatible with underground mining of oil shale in the same area

The Department of the Interior is responsible for managing the development of resources on or under public lands. The Department can lease lands to companies wanting to develop such resources and can require these companies to develop the resources in a manner which would not jeopardize recovery of other resources in the same area.

The Department estimated, in its August 1973 final environmental impact statement for its prototype oil shale leasing program,[1] that 1,800 billion barrels of oil, including 600 billion barrels of oil from high-grade oil shale, are contained in oil shale formations in the Rocky Mountain area. These oil shale formations are generally in the same areas as the natural gas. About 80 percent of the oil shale and 75 percent of the natural gas in the Rocky Mountain area are estimated to be under Federal lands.

According to the Department's environmental statement, recovery of oil from oil shale might begin in 1975. A Department official told us that the recovery of oil from oil shale could continue over the next 100 years. The oil shale could be recovered by underground mining or surface (open-pit or strip) mining and then processed on the surface to extract the oil. Oil can also be recovered by underground processing in which heat is applied to the oil shale while it is in the ground, and the resulting oil is then pumped to the surface. According to a Department official, if the oil shale in the Rocky Mountain area is mined, underground mining probably would be used to recover most of it.

A Department official involved in coordinating programs for recovering oil shale told us that the Department had not estimated the amount of oil that could be recovered from the shale. He believes, however, that 300 billion barrels of oil could be recovered from the high-grade oil shale. Of the known high-grade oil deposits, 80 percent are in Colorado, 15 percent in Utah, and 5 percent in Wyoming. The 300 billion barrels of oil contain about six times as much heating value as 300 trillion cubic feet of natural gas--the maximum amount of gas the task force estimated to be recoverable.

Before the Rio Blanco experiment, the Department reviewed the technical issues involved in concurrently recovering gas on a commercial basis using nuclear stimulation and oil shale using underground mining. This review was done only for the Rio Blanco area of the Piceance Basin in Colorado. The Department concluded that underground mining

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[1]The prototype oil shale leasing program makes available for private development, through leasing, a specified amount of Federal lands in the Rocky Mountain area containing oil shale.

of the oil shale might be incompatible with concurrent recovery, using nuclear stimulation, of gas in the same area. In explaining why they might be incompatible, a Department official told us that the nuclear explosions might collapse underground mines in the area. Also he said that, since underground mining might be used extensively in Colorado and Utah to recover oil shale, the Department's concern was not limited to the Rio Blanco area but applied also to much of the area proposed for oil shale development in Colorado and Utah. He said that underground mining of oil shale was considered feasible in some parts of Wyoming.

In commenting on our report, the Department stated, in a February 11, 1974, letter:

> "* * * the apparent incompatibility of nuclear fracturing techniques with concurrent or subsequent mining of oil shale and other mineral resources in the same area is viewed as a most unfavorable feature of fracturing techniques which use nuclear explosives."

In addition, the Department stated that hydrological evidence obtained from tests conducted after the Rio Blanco experiment by a Department study group tended to confirm that:

> "* * * nuclear fracturing of the gas sands underlying the oil shale should not be conducted prior to, or concurrent with, oil shale mining."

The Department concluded that:

> "Thus, a factor which has a significant bearing on the feasibility of further experimentation using nuclear explosives is the fact that detonation of such devices may result in the waste of significant quantities of valuable oil shale resources."

According to AEC, however, its studies conducted on project Rio Blanco showed that no significant damage had occurred to oil shale. AEC said that proper design and planning should render the concurrent recovery of gas and oil shale compatible.

The task force, in its April 1973 report, discussed the issue of concurrent development of gas and oil located in the same areas and the question of possible mine damage. The report stated that:

> "Concern has been expressed over the possible effects of gas stimulation detonations on other commercial minerals in the same geographic regions which might be affected by seismic shocks or increases in water intrusion.
>
> "For example, at the Rio Blanco site potential effects on such mineral resources as oil shale and sodium and aluminum-bearing minerals (nahcolite and dawsonite), have been calculated in detail. Estimates of such detonation-caused effects indicate no appreciable degradation in the potential value of these resources. The effects considered included fracturing of the rock by the outgoing shock wave, the possibility of mine damage, and the possible increase of water intrusion * * *.
>
> "Similar evaluations of such potential effects will need to be made in each location for which nuclear stimulation is proposed. However, on the basis of the Rio Blanco studies it would appear that no threat will be presented to the development of mineral resources in these areas and that future development of these gas reservoirs can be accomplished prior to, or concurrent with, mineral resource development using cooperation and good management techniques."

AEC's environmental statement on the Rio Blanco experiment also addressed the question of recovering oil from the oil shale in the Rocky Mountain area. It pointed out that the overriding consideration in studying the question of developing both resources might be the relative environmental impact of the two recovery technologies. The environmental statement summarized the principal effects of recovering oil from the oil shale in the Rocky Mountain area as:

--Disposing of spent oil shale in canyons or elsewhere would produce a marked alteration in natural landscape contours.

--Disruptions to ground water supplies because of the required "dewatering" of underground regions before mining could be undertaken.

--Contaminating water with an alkali due to rain and melted snow passing through spent-oil-shale dumps.

We believe that it is important to resolve, as soon as practicable, the question of the compatibility of recovering natural gas using nuclear stimulation and the underground mining of oil shale so that plans for developing both of these energy-producing resources may be soundly based.

Uncertainty as to the availability of enough water for massive hydraulic fracturing and the development of other mineral resources

The task force report said that, because the Rocky Mountain area is arid, water sources might have to be developed to permit the use of massive hydraulic fracturing on a commercial basis. The report estimated that, if water were used in the fracturing fluid, the water required for massive hydraulic fracturing would range from 250,000 to 2 million gallons or more for each well. The task force report said that the water requirement could be a significant factor because up to eight wells in a square mile might use massive hydraulic fracturing.

The development of the oil shale in the area will also require large amounts of water. A representative of the Geological Survey told us that the Department had studied the availability of water in the Rocky Mountain area for developing the oil shale deposits and had concluded that sufficient water was available. He said that oil shale development could require much more water than massive hydraulic fracturing and that, in his opinion, there was enough water for (1) recovering the oil shale and (2) using massive hydraulic fracturing to stimulate gas on a commercial basis.

Processing other mineral resources might require large amounts of water. For example, developing a process for converting the large amounts of coal in the Rocky Mountain area into gas (coal gasification) could consume significant quantities of water. According to a Department official, a coal gasification plant would circulate 100,000 gallons of water a minute, of which 20,000 gallons would be consumed.

The availability of sufficient quantities of water in the Rocky Mountain area to support the use of massive hydraulic fracturing on a commercial basis is a question that should be resolved when considering other water requirements that would be placed on the Rocky Mountain area. A Department official told us that the Department had not studied the broad question of whether the Rocky Mountain area contained enough water to meet the total requirements that would be presented by (1) massive hydraulic fracturing, (2) oil shale development, (3) coal processing, and (4) other activities, such as recreation and irrigation.

We suggested the desirability of a study to resolve the question of whether the Rocky Mountain area contained enough water to support massive hydraulic fracturing and development of other mineral resources in the area.

In commenting on our suggestion, the Department said that the availability of water was not expected to be a factor in determining the feasibility of using the massive hydraulic fracturing technique and would not prevent the use of the technique in a large number of wells over the next 20 years. In addition, the Department said that:

> "It might be well to note that it has been estimated that initiation of the studies recommended by G.A.O. * * * to determine whether the Rocky Mountain region contains enough water to support massive hydraulic fracturing and development of the other mineral resources of the region would require the creation of a new program employing over 1,000 scientists, engineers and support personnel and costing over $30,000,000 per year to identify and inventory the various mineral resources in the region, to identify and inventory the available water supplies and the demands thereon and, once established, to maintain said inventories in a relatively current status.

"In addition it should be remembered that the right to appropriate and use water is controlled by the individual States. The amount of water each of the States in the oil shale areas can use is governed by the Colorado River Compact and the Upper Colorado River Basin Compact. The States have already dedicated large amounts of water for industrial development and additional water could be made available from water now used or committed to agriculture. Although oil shale retorting, coal gasification, coal liquification, and electric power generation will all be large users of water, the amounts used by untested commercial processes have yet to be determined. The precise locations of such plants and the rate at which plants will be built must also be determined. Although water availability may eventually limit the industrial capacity of some areas in the region, no major problems should develop until after several plants have been built, and their water needs have been established. Changes in technology * * * [for recovering] both oil shale and coal will reduce the amount of water needed."

In discussing the Department's comments, the Deputy Assistant Secretary for Energy and Minerals told us that the Department agreed with us that this question would have to be answered to insure the orderly development of the resources in the area. He stated, however, that a study of the magnitude indicated above should not be made until more definitive information is available on the water requirements and siting of the facilities and plants that would use water to develop the resources. He also mentioned that the Department recently had established a task group which would recommend policy guidance for resolving high-priority energy- and water-related issues and that the task group planned to take the initial steps to address the question.

RECOVERING BOTH NATURAL GAS AND OIL SHALE IN THE SAME AREA COULD INCREASE RECOVERY COSTS OF BOTH RESOURCES

The Department's environmental statement also points out that drilling gas wells and developing oil shale in the same areas would require greater safety-related expenditures and more difficult and costly drilling techniques than would developing these resources in different areas. For example, gas-producing wells which penetrate areas where underground mining is done would require special safety precautions because of the possibility of gas entering the mines. Also, drilling gas wells through shale surface mines or drilling a gas well from outside a surface mine to a gas formation beneath the surface mine is more expensive than drilling gas wells in areas where surface mining has not been done.

The potential problems discussed in the environmental statement would be greater if massive hydraulic fracturing were used to recover the gas because, as the task force pointed out, hydraulic fracturing would require four or more times as many wells as would nuclear stimulation to commercially develop the tight natural gas formations in the Rocky Mountain area.

FACTORS AFFECTING FEASIBILITY OR DESIRABILITY OF NUCLEAR STIMULATION IN COMMERCIAL DEVELOPMENT OF GAS

Effect of nuclear detonations on surface structures

When nuclear explosives are detonated underground, energy is transferred into the surrounding rock in the form of a seismic wave and is transmitted through the rock to the earth's surface, which causes the ground to move. The degree of ground motion and the damage done to surface structures depends primarily on (1) the yield of the explosion, (2) the distance of the explosion from the structures, and (3) the type of rock near the explosion, under the structures, and in the path between the explosion and the structures. Other factors, such as the structures' age and condition, would affect the amount of damage the seismic waves could cause.

In response to our request, AEC gave us the following information on the predicted and actual damage done to surface structures by the three nuclear stimulation experiments.

Gasbuggy experiment

Damage predictions were made using two separate procedures. The first procedure, an engineering estimate based on experiences of damage resulting from earthquakes and underground nuclear detonations, forecasted about $20,000 damage. The second procedure, a detailed computerized procedure, forecasted about $35,000 damage.

AEC received three claims. Two were denied, and one is still pending. A settlement offer of $900 has not yet been accepted by the claimant.

Rulison experiment

An AEC contractor, using engineering experience of damage resulting from earthquakes and underground nuclear detonations, estimated that damage would approximate $123,000.

AEC received 359 claims, of which 326 were settled for a total of $155,676 and 33 were denied.

Rio Blanco experiment

A contractor to the industrial participant on this experiment, using a statistical method, estimated the damage at $50,000 to residential structures. Where AEC determined that damage to industrial and commercial facilities was possible, extensive bracing and other predetonation preventive work was done. The industrial participant spent about $142,500 for structural bracing, of which about $100,000 was for bracing one structure.

As of December 17, 1973, 166 claims had been reported, of which 111 were settled for a total of about $39,246, 51 were denied or were reported as requiring no further action, and 4 are pending.

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The damage to structures from the three experiments resulted from detonating (1) single explosives yielding less than 50 kilotons or (2) simultaneously three explosives yielding less than 100 kilotons. Accordingly, we asked Lawrence Livermore Laboratory officials whether the damage to the structures that could result from sequentially detonating a large number of 100-kiloton explosives in one area had been evaluated.

They told us that they had concluded, from nuclear tests conducted under AEC's underground nuclear weapons testing program, that architectural damage to structures, such as plaster cracks, would continually decrease for each detonation in a series of detonations. For example, if a 100-kiloton explosion caused architectural damage of $5,000 to nearby structures, the amount of architectural damage caused by the second-100 kiloton explosion in the series would be somewhat less than $5,000, and so on. They said, however, that they could not estimate how much less the damage would be with each additional explosion.

In addition, these officials stated that underground nuclear detonations could also cause structural damage, such as weakened foundation supports. They pointed out, however, that the structural damage caused by sequentially detonating a large number of explosives had not been determined.

Effect of nuclear detonations on persons

For its three nuclear stimulation experiments, AEC established safety and precautionary measures to insure that persons who lived or worked near the experiments would not be injured by the explosives' effects. The major aspects of the safety and precautionary measures planned and, according to AEC, carried out for the Rio Blanco experiment are described below to show (1) the consideration that AEC gave to safety and (2) the inconvenience such measures caused persons near the experiment.

1. Persons within a radius of about 7.5 miles of the test site were to evacuate the area before the detonation. Persons between 7.5 miles and about 14.5 miles from the test site were asked to stay away from all buildings at the time of the detonation. The same request was made of persons more than 14.5 miles from the test site whose buildings appeared to be vulnerable to detonation-induced rockfall damage. Medical patients or persons needing special care were moved, in conformance with their personal physicians' recommendations to appropriate places outside the 14.5 mile zone. A number of plants in the area had their workers go outside the buildings to open terrain at detonation time.

2. Within a radius of about 7.5 miles, butane tanks were disconnected or braced, gasoline storage barrels were removed from their steel support frames or were strapped to ground anchors, and mobile homes' underpinnings were checked for adequacy. Other structures, such as dams and schools, that were found to have some possibility for damage were analyzed to determine their possible need for precautionary measures.

3. To prevent problems arising from broken or leaking gaslines, all utility systems within 7.5 miles of the test site were prepared to withstand ground-motion-induced stresses by either being disconnected or having rigid pipe couplings replaced with flexible tubing. Within the same area, an inspection was made of all houses, to ascertain the adequacy of the electrial wiring and the proper functioning of fuses and circuit-breaker systems. Where necessary, the electricity was turned off before the residents left the area.

4. To eliminate the possibility that rockfalls in mines and quarries might cause injury to mine personnel, all eight

mines within 53 miles of the test site were evacuated. Also, roadlocks were set up and other traffic control measures were taken to protect personnel and property from potential rock-falls.

AEC officials also pointed out that:

1. Persons and businesses which were evacuated during the three nuclear stimulation experiments were compensated.

2. The cost of bracing structures thought to be susceptible to seismic damage was paid by the project participants.

AEC officials told us that essentially the same program as the one used for the Rio Blanco experiment would be used in the event of commercial development. They pointed out that the program used in commercial development probably would cover a number of wells stimulated on 1 day, which would reduce the cost per well of such a program.

Information given to us by AEC indicated that, during commercial development, the safety and precautionary measures might have to cover periods, ranging from 5 to 30 hours or more, of detonations spaced 5 to 30 minutes apart. The information also indicated that these periods could occur four times a year.

In commenting on this report, AEC officials gave us the following statement.

> "A 30 hour evacuation would be unusual with a maximum of 8 hours expected, not very many people would be involved for each well and it would be different people for each area. But, more important, people so inconvenienced would be compensated and experience has shown from the reaction of people actually involved in past projects that this is a very workable arrangement."

The effects on man of using nuclearly stimulated gas

AEC estimates that gas produced using nuclear stimulation contains levels of radioactivity which are much lower than the maximum levels recommended by the Federal Radiation

Council[1] and the International Commission on Radiological Protection--organizations that set radiation standards.

A Lawrence Livermore Laboratory study, conducted for AEC, discussed the radiation doses that consumers would get from using nuclearly stimulated gas diluted with gas recovered conventionally. The study showed that the average radiation dose to consumers from using this diluted radioactive gas would be less than 1 percent of the recommended maximum exposure level set by the Federal Radiation Council, even if the customer used gas from the first year's production of a nuclear-stimulated well. The first year's gas production from each well contains about 99 percent of the radioactivity in the gas.

This study also showed that the added radiation exposure to consumers using such gas would amount to less than 1 percent of the naturally occurring background radiation in the United States. A graph supplied to us by a Lawrence Livermore Laboratory official showing this relationship for Denver, Colorado, is on page 66. Other studies by Lawrence Livermore Laboratory and Oak Ridge National Laboratory (an AEC-owned, contractor-operated facility) indicated that the radiological effects on people would be minimal compared to the exposure they receive from natural background radioactivity. AEC officials told us that studies made for the Environmental Protection Agency supported the conclusions reached by the AEC laboratories.

Some scientists maintain that any exposure above natural background radiation should be avoided because it has not been conclusively determined that exposure to long-term, low levels of radiation has no adverse biological effects. An AEC report on the safety of nuclear power reactors discussed the biological effects from exposure to low levels of radiation. The report stated that:

> "There is inadequate data to show that there are no effects [from very low levels of radiation], but if there are effects they have not been detected or measured in human population groups

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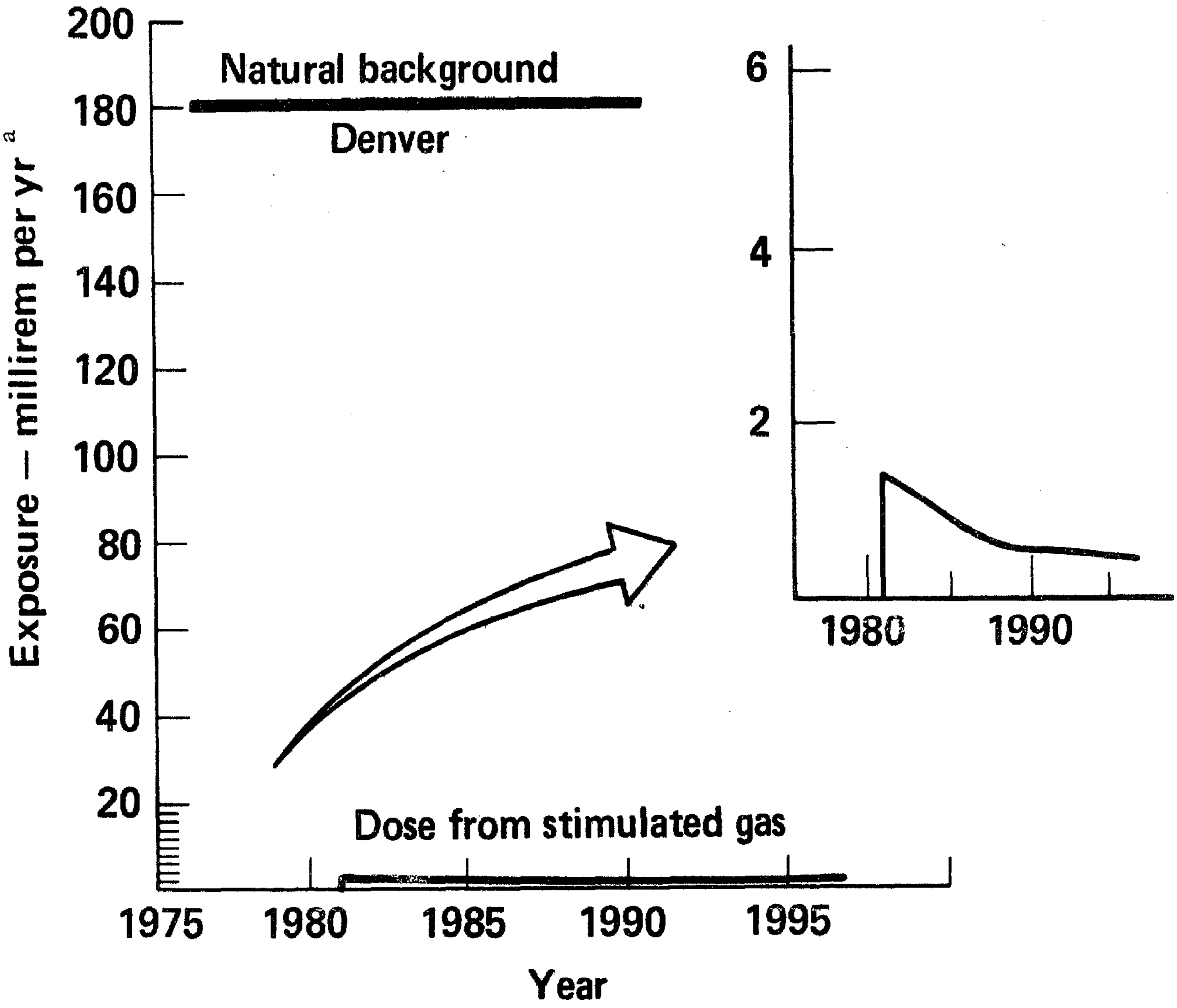
[1]Now a part of the Environmental Protection Agency.

CALCULATED RADIATION EXPOSURE



[a] Rem, an acronym for roentgen equivalent man, is a unit of measuring radiation doses. A millirem is a thousandth of a rem.

with existing techniques. One reason for this dilemma is that ionizing radiation does not produce exotic, previously unknown effects in man. What is at question for low levels of radiation * * * is the possibility that they may contribute to some small increase in the numbers of cancers, leukemias, hereditary defects, etc. already occurring in the population in relatively large numbers. The problem, then, is to detect a small change, if any, in the fairly substantial number of cases occurring each year in the population, in a manner that would allow clear attribution to low doses of radiation. A direct answer to this general question would require the observation of many millions of people over several generations under laboratory-like controls."

This report further pointed out that:

"* * * even though the assumption is made that no levels of exposure to radiation can be considered to be absolutely free of risk, the risks associated with low levels of exposure are evidently so low that it is quite reasonable to carry on many activities resulting in exposures to man-made radiation, if the risks resulting from exposures to radiation are less important than the benefits to individuals and to society from activities which result in the exposure."

The task force report and the Office of Science and Technology report recognized this risk and concluded that:

"* * * The potential risk resulting from this exposure [of using nuclearly stimulated gas] should be evaluated by using the results of research in these areas and by comparison with established standards and with existing naturally occurring levels of radiation. This risk should then be balanced against the benefits of using the gas as contrasted to other energy sources."

Unplanned radioactivity releases to the atmosphere

The task force report, as well as several AEC reports, indicates that uncontrolled releases of radioactivity to the environment resulting from nuclear detonations are highly unlikely. The task force report points out that the depths contemplated for the nuclear explosions in relationship to the kilotonnage of the explosions are so great that releases of radioactivity are not credible.

We asked AEC Headquarters and Lawrence Livermore Laboratory officials whether radioactivity had been released from any of the three nuclear stimulation experiments. In the Gasbuggy experiment, they said, radioactivity was detected on the surface after the detonation. They said that the radioactivity had seeped through a permeable firing cable, but that they expected no such seepage in subsequent experiments because the newer firing cables being used were designed to be impermeable to such seepage. These officials told us that no releases or seepages occurred at either the Rulison or the Rio Blanco experiment.

In addition to the three nuclear stimulation experiments, the only experience this country has had with containing radioactivity from explosives detonated underground is in the weapon-testing program at the Nevada Test Site. The Nevada Test Site is the principal place where the United States conducts its underground nuclear tests. About 245 announced tests have been conducted at the Nevada Test Site over the last 10 years, and, according to an AEC official, about 20 percent of these tests released detectable amounts of radioactivity. These 245 tests included, AEC officials told us, complex tests performed in horizontal tunnels, mined rooms, holes with open line-of-sight pipes to the surface (designed to rapidly close after detonation), and other sophisticated tests.

Most of the radioactive releases were from tests of explosives that had low yields--less than 20 kilotons. Lawrence Livermore Laboratory officials told us that the causes for releases from explosives under 20 kilotons were not understood.

One test under 20 kilotons resulted, according to AEC officials, in the release of perhaps the largest amount of radioactive debris of all the underground tests. This test, called Baneberry, was conducted on December 18, 1970, and involved an explosive buried 910 feet deep. AEC attributed the Baneberry release to, basically, a greater explosive effect than had been anticipated. According to AEC's summary report on Baneberry, this greater explosive effect was due to more water in the ground around the Baneberry explosive than AEC had anticipated.

The Baneberry release exposed persons, both on and off the Nevada Test Site, to radioactivity. However, AEC's summary report on Baneberry stated that "radiation exposures to * * * [these persons] were below currently established Federal Radiation Council standards for normal peacetime operations."

According to AEC, because the phenomena which led to the Baneberry release were not evident, AEC suspended its testing at the Nevada Test Site until it had reviewed the Baneberry release in detail and was convinced that all reasonable precautions were initiated to minimize the probability of a similar future occurrence.

On the basis of its review of the Baneberry release, AEC improved technical and administrative testing procedures to reduce the probability of a similar future occurrence. These actions included, among other things, more extensive geologic and geophysical investigations, more stringent controls over personnel and facilities near the detonation, and a more vigorous analytical program so that the behavior of underground nuclear detonations could be better understood. Increasing the burial depth for low-yield experiments was emphasized.

After AEC took all of these actions, another announced test having a yield of less than 20 kilotons released radioactivity which was detected off the Nevada Test Site. The test released airborne radioactivity which was detected during a flight monitoring the atmosphere for radioactivity resulting from the test.

In commenting on this test, AEC said:

> "This test was designed from a containment standpoint to pre-Baneberry standards. Prior to

detonation it was reviewed with respect to containment by a panel of scientific and technical consultants. In their opinion radioactivity from the detonation would be contained. Also, in their opinion, in the event release of radioactivity might occur they considered it would at most be only a minor gaseous seepage, which in fact is what actually occurred. It was considered that this evaluation together with the considerations of scientific knowledge to be gained and funds invested in the emplacement and design of the test provided full justification for proceeding with the test. Since the implementation of all the actions indicated by the Baneberry investigation, the 16 announced tests have been fully contained."

AEC officials told us that the experience of radioactivity releases at the Nevada Test Site should not be directly related to the possibility of releases from a nuclear stimulation commercial development program. They explained that the depths planned for all explosives used in nuclear stimulation were significantly greater than the depths at which comparable explosives were detonated at the Nevada Test Site. The environmental impact statement on the proposed Wagon Wheel gas stimulation experiment pointed out that the top explosive of the Wagon Wheel's five 100-kiloton explosives was planned to be buried more than three times as deep as, in standard practice, a 500-kiloton explosive would be buried at the Nevada Test Site.

In commenting on our report, AEC officials provided us with the following statement regarding containment of underground nuclear explosions at the Nevada Test Site.

"From an empirical point of view, containment is well understood. There is substantial experience of successful containment of nuclear explosions over a broad range of yields. From this experience, scaling factors have been developed which are used as basic guidelines to assure that each explosive is buried deeply enough to be contained. However, the phenomenology of the interactions between an explosion and the surrounding earth is highly complex and cannot be completely explained in terms of therory, because not all of the mechanisms which come into play in the process of containment are fully understood. Additional investigations may fill in some of the missing knowledge. Meanwhile, in the absence of a complete understanding of the containment process, careful use is made of the scaling factors in order to assure a high probability of containment. As a result, explosive emplacement practices that are used today generally assure comfortable margins of containment safety. Many tests have unusual geometries or are sited in an unusual location. For such tests, the detailed containment design requires that consideration be given to the individual characteristics of the test and its site must be considered in the design of the containment facility."

We recognize that AEC's experience at the Nevada Test Site is not directly related to the nuclear stimulation program. Nevertheless, AEC's experience does show that (1) AEC does not completely understand the interactions between an explosion and the surrounding earth and (2) radioactive releases have occurred at the Nevada Test Site even though AEC has taken many precautions designed to preclude such releases. A May 1972 report by the General Advisory Committee--a nine-member body established by the Atomic Energy Act of 1954 (42 U.S.C. 2036) to advise AEC on scientific and technical matters--stated that:

"* * * although the safety of the underground nuclear weapons testing program has been impressive with no nuclear accidents and only a few cases of venting in more than 300 announced underground tests, the risks are probably larger for the 1900 explosives required for * * * [a limited commercial development program] <u>and certainly larger for the 30,000 explosives required for the release of the 300 trillion cubic feet of gas."</u> (Underscoring supplied.)

<u>Planned releases of radioactivity to the atmosphere</u>

After a well has been drilled, its potential productivity is determined by allowing some gas to flow out of the wellbore. The rate at which the gas flows, among other things, determines the well's potential productivity. Gas production companies are interested in a well's potential productivity to determine, for example, whether a well's productivity economically justifies extending a pipeline to the well. If the gas, after it is measured, is not put into a pipeline, the normal practice is to burn or flare the gas rather than release it to the atmosphere. Releasing the gas to the atmosphere could, according to Department officials, result in pockets of gas or of explosive mixtures of air and gas--situations which would be potentially hazardous to life and property.

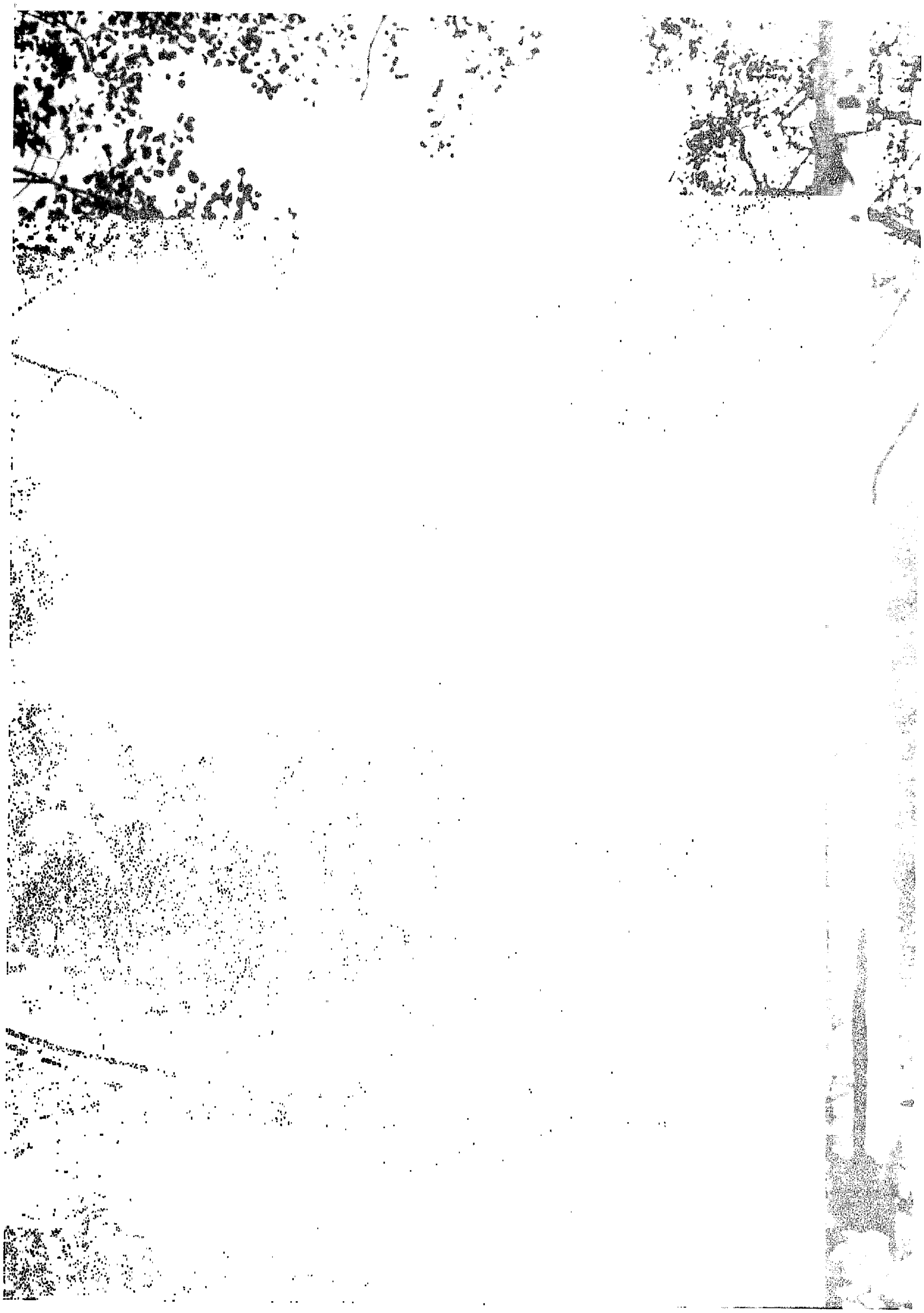
Gas was flared during production tests at the Gasbuggy and Rulison experiments, which thereby released the radioactivity contained in the gas to the atmosphere. (See the AEC-furnished picture of a flaring operation on the next page.) These production tests cover periods of weeks and sometimes months. However, according to the AEC environmental statement on the proposed Wagon Wheel experiment, the Gasbuggy and Rulison experiments demonstrated that the levels of radioactivity produced during flaring were extremely low and posed no health risk.

AEC's environmental statement for the Rio Blanco experiment stated that alternatives to flaring had been examined but that, if these alternatives had been used for the Rio Blanco experiment, the cost of the Rio Blanco experiment would have more than doubled.

Officials of the Bureau of Mines and AEC told us that, if nuclear stimulation were used on a commercial basis, production testing would be done on each well but only for several hours. AEC officials told us that flaring this gas for several hours on each well during commercial development would result in insignificant releases of radioactivity to the atmosphere.

<u>Disposal of contaminated water separated from the gas</u>

According to the task force report, gas recovered with nuclear stimulation during the first 2 years of gas production contains radioactive (tritium) water. This water must be removed before accurate measurements of gas flow can be made or before the gas can be transported through a pipeline. The task force report estimates that this water could contain



Gas being flared

radioactivity in the range of .02 to .15 microcuries per milliliter. AEC estimates that the water to be removed from the gas from the Rio Blanco experiment will contain radioactivity falling within this range. This range is 20 to 150 times higher than the accepted standard of the International Commission on Radiological Protection for drinkable water.

In its environmental impact statement on the proposed Wagon Wheel experiment, AEC stated that the alternatives for disposing of this water included (1) reinjecting it into the flame of the flare to evaporate it, (2) putting it in evaporation ponds, (3) putting it in nearby streams, (4) injecting it in porous rock formations below ground surface, (5) reinjecting it into the chimney, or (6) burying it in an authorized nuclear waste disposal area.

Water produced during recovery testing at the Gasbuggy and Rulison experiments was evaporated by reinjecting it into the flame of the flare, which released the radioactivity in the water, as well as the radioactivity in the gas that was flared, to the atmosphere. AEC's environmental impact statement on the Wagon Wheel experiment stated that the alternatives for disposing of the tritiated water had been evaluated and that the most desirable alternative appeared to be reinjecting the water into the flame of the flare. It pointed out that the radiation resulting from using this disposal method was estimated to be less than 1 percent of natural-occurring background radiation.

However, to reduce the total radioactive release to the atmosphere, water produced during recovery testing at the Rio Blanco experiment is to be injected into a tight rock formation at about the same depth as the Rio Blanco explosives.

A September 1972 report[1] by the Geological Survey stated that, if the injection of the tritiated water from the Rio Blanco project creates fractures in the rock formation, the fractures could extend a considerable distance from the injection point. A Geological Survey official told us that the Survey's concern was that the fractures might provide a pathway for the tritiated water to reach the oil shale deposits. To insure that the injected water does not create fractures, the Geological Survey has imposed limits on the rate at which

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[1]Study group report, Project Rio Blanco.

the water from the Rio Blanco project can be injected. Officials of both the Geological Survey and the Lawrence Livermore Laboratory told us that these limits were conservative and would insure that fractures were not created.

The task force report estimated that, during commercial development, each nuclearly stimulated well would produce water at a rate of 1,000 to 3,000 barrels a day for about a year and at a decreasing rate in the second year. AEC estimated that the proposed Wagon Wheel experiment would produce a maximum of 500,000 barrels of water.

Officials of Lawrence Livermore Laboratory told us that, although a number of methods for disposing of tritiated water resulting from commercial development had been identified, AEC had not determined the most appropriate method. Evaporation of the water, they said, was not desirable since it released tritium to the atmosphere. The solution proposed in the task force report--building special pipelines to carry the water as far as 200 miles to a disposal area--would not be acceptable, Lawrence Livermore Laboratory officials said, because it would increase the cost of the gas by an estimated $0.10 per thousand cubic feet.

AEC's capacity to produce
the needed nuclear material

Nuclear weapons utilize highly enriched uranium and plutonium. The explosives detonated in the three nuclear experiments utilized such materials. However, AEC's current capacity to supply highly enriched uranium would not be sufficient to meet its total demands to (1) support the Department of Defense's weapons requirements, (2) meet the requirements of the nuclear power industry for enrichment services, and (3) provide industry with a sufficient number of nuclear devices to support a commercial program for nuclear gas stimulation.

Because the current supply of enriched uranium may not be available in the quantities needed to support a commercial program for nuclear gas stimulation, AEC established a task force in April 1972 to study, among other things, the physics and engineering feasibility of designing a new nuclear stimulation explosive using plutonium produced by light-water reactors in lieu of highly enriched uranium. The AEC task force summarized its findings in a report issued in October 1973. Although the AEC task force's findings are classified and therefore not discussed in this report, AEC officials told us that the task force report indicated that the availability of nuclear material was not expected to be a limiting factor for a commercial nuclear stimulation program because AEC's capacity to produce the nuclear material needed for explosives could be increased.

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In a letter dated March 21, 1974, commenting on this report, the Chairman, AEC, stated:

> "One of our principal concerns is that the nuclear stimulation method of recovering gas will be viewed unfavorably when compared with massive hydraulic fracturing, because the GAO report identifies a greater number of potential problems to be considered relating to the nuclear stimulation method. This situation comes about because insufficient research has been performed with respect to massive hydraulic fracturing to identify problem areas associated with that technique. It should also be emphasized that none of the potential problems relating to nuclear stimulation is of such magnitude as to suggest that further consideration of this method of recovering gas is undesirable."

The Chairman further stated:

> "* * * let me say that the best interests of this Nation will be served by instituting positive, timely research and development programs aimed at alleviating this Nation's energy shortage and developing domestic energy resources to support an independent national economy. All such programs deserve serious consideration, and every effort should be made to achieve compatibility among potentially conflicting programs, such as nuclear gas stimulation and oil shale development, so that the greatest potential can be developed in the shortest reasonable time period."

CHAPTER 5

PROBLEM AREAS WHICH NEED TO BE ADDRESSED

The Nation's present energy problem requires that actions affecting energy be based on sound knowledge of essential facts. In the preceding chapters we pointed out several problem areas affecting the development and use of energy resources, the resolution of which will depend upon the attainment and evaluation of reliable, pertinent data, not now existent. These problem areas are summarized below.

UNCERTAINTY AS TO WHETHER FRACTURES CREATED BY NUCLEAR EXPLOSIVES CLOSE

AEC and Bureau officials disagree as to whether fractures in the Gasbuggy and Rulison experiments are closing. Our analysis showed that, if fractures created by nuclear detonation close, the wellhead cost of gas increases significantly, depending on how quickly the fractures close. (See p. 42.)

Because this issue is important to the economics of nuclear stimulation and its cost comparison with massive hydraulic fracturing, more should be done to minimize the uncertainty on this issue before nuclear stimulation can be considered economically acceptable. AEC officials stated that additional tests, although very costly, could be conducted to provide better data to evaluate whether fractures in the Gasbuggy and Rulison experiments have closed. (See p. 44.)

UNCERTAINTY AS TO WHETHER RECOVERY OF GAS USING NUCLEAR STIMULATION IS COMPATIBLE WITH UNDERGROUND MINING OF OIL SHALE

According to the Department of the Interior, underground mining of oil shale might be incompatible with the prior or concurrent use of nuclear stimulation because fractures created by the nuclear explosives might collapse underground mines in the area of the explosion. According to AEC, however, its studies of the effects of nuclear explosives indicate that such recovery of both resources would be compatible (See p. 55.)

We consider it important to resolve this question as soon as practicable so that plans for developing both of these energy-producing resources may proceed on a sound basis. The fact that the right to develop the oil shale resources of a single 5,000-acre tract was recently sold by the Federal Government for $210 million seems to underline the importance of an early resolution of this question.

UNCERTAINTY AS TO WHETHER THERE IS ENOUGH WATER AVAILABLE FOR MASSIVE HYDRAULIC FRACTURING AND DEVELOPMENT OF OTHER MINERAL RESOURCES IN THE ROCKY MOUNTAIN AREA

Large amounts of water could be needed to recover gas using massive hydraulic fracturing. Oil shale development could require much more water than would massive hydraulic fracturing. The processing of other mineral resources might also require large amounts of water. According to a Department official, a coal gasification plant would circulate 100,000 gallons a minute, of which 20,000 gallons would be consumed. Because the Rocky Mountain area is arid, it is uncertain whether enough water would be available to meet the total water requirements of developing all of these resources. (See p. 57.)

The Department agreed with us that a study was needed to resolve this matter. However, the Department believed that such a study, because it would be costly, should not be started until more definitive information is available on the water requirements and siting of the facilities and plants that would use water to develop the resources. (See p. 59.)

The Department said that it recently had established a task group to recommend policy guidance for resolving high-priority energy- and water-related issues and questions and that the group planned to take the initial steps to address this matter.

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In commenting on our report, the Chairman, AEC, stated that these problems "require further consideration before a final decision can be reached as to the feasibility and desirability of using any particular stimulation technology for the recovery of natural gas in the Rocky Mountain area".

Pending approval of a legislative proposal to create a Federal Energy Administration, the President, by Executive order dated December 4, 1973, created the Federal Energy Office within the Executive Office of the President. A White House Fact Sheet dealing with the creation of these organizations pointed out that the Federal Energy Office should, to the extent possible within existing authority, immediately move to create the framework for the Federal Energy Administration and to provide the basis for improved management and coordination of Federal energy resources activities.

Because of the predominant energy-related aspects of the above problems involving the interests of various Federal agencies, we are referring these problems to the Administrator, Federal Energy Office, who could provide Federal leadership in determining the need and type of action called for to resolve these problems and thereby help increase energy production.

CHAPTER 6

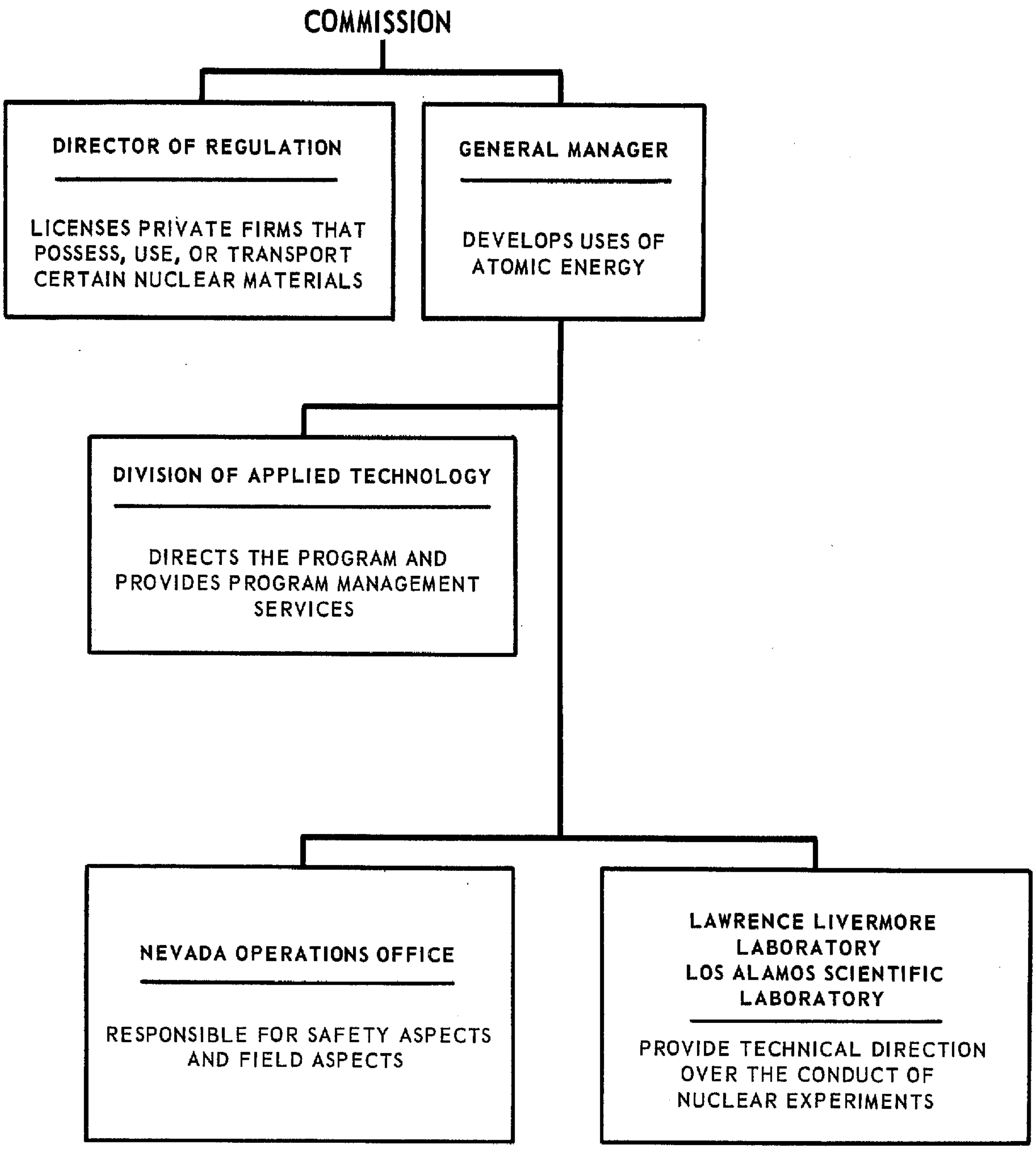
SCOPE OF REVIEW

We obtained most of the information on nuclear stimulation, chemical explosive fracturing, and massive hydraulic fracturing from AEC, FPC, and the Department of the Interior, As appropriate, this information included funding history of the programs, legislative authorization for the programs, development of and experiments with the techniques, and the environmental and cost factors associated with using the techniques. Where we deemed necessary, we supplemented this information by meeting with, and obtaining reports of, officials of associations, companies, universities, and other Federal agencies that had knowledge of, or participated in, the activities discussed in this report.

We selected for inclusion in the report the information which we believed best described the progress that had been made and the problems that had been or might be encountered in the development of these techniques.

We made our review at AEC Headquarters, Germantown, Maryland; AEC's regulatory office, Bethesda, Maryland; the Bureau of Mines, Arlington, Virginia; the Federal Power Commission, Washington, D.C.; the Lawrence Livermore Laboratory; and the Bureau of Mines Energy Research Center, Bartlesville.

AEC ORGANIZATIONAL RESPONSIBILITIES FOR DEVELOPING THE NUCLEAR STIMULATION TECHNIQUE



PRINCIPAL OFFICIALS OF THE ATOMIC ENERGY COMMISSION, THE DEPARTMENT OF THE INTERIOR, AND THE FEDERAL POWER COMMISSION RESPONSIBLE FOR ADMINISTERING THE ACTIVITIES DISCUSSED IN THIS REPORT

	Tenure of office	
	From	To
ATOMIC ENERGY COMMISSION		
Chairman:		
Dixy Lee Ray	Feb. 1973	Present
James R. Schlesinger	Aug. 1971	Feb. 1973
Glenn T. Seaborg	Mar. 1961	Aug. 1971
General Manager:		
John A. Erlewine	Jan. 1974	Present
Robert E. Hollingsworth	Aug. 1964	Jan. 1974
Director of Regulations:		
L. Manning Muntzing	Oct. 1971	Present
Harold L. Price	Sept. 1961	Oct. 1971
FEDERAL POWER COMMISSION		
Chairman:		
John N. Nassikas	Aug. 1969	Present
Lee C. White	Mar. 1966	Aug. 1969
Chief, Bureau of Natural Gas:		
Frank C. Allen	Sept. 1973	Present
Thomas J. Joyce	Dec. 1969	Sept. 1973
Joseph Curry (acting)	Oct. 1969	Dec. 1969
John F. O'Leary	Jan. 1968	Oct. 1969

	Tenure of office From	To
DEPARTMENT OF THE INTERIOR		
Secretary of the Interior:		
Rogers C. B. Morton	Jan. 1971	Present
Walter J. Hickel	Jan. 1969	Jan. 1971
Stewart L. Udall	Jan. 1961	Jan. 1969
Director, Geological Survey:		
Vincent E. McKelvey	Dec. 1971	Present
William A. Radlinski (acting)	May 1971	Dec. 1971
Dr. William T. Pecora	Jan. 1966	May 1971
Director, Bureau of Mines:		
Dr. John Morgan	Sept. 1973	Present
Elburt F. Osborn	Oct. 1970	Sept. 1973
Vacant	Mar. 1970	Oct. 1970
John F. O'Leary	Oct. 1968	Mar. 1970
Vacant	Apr. 1968	Oct. 1968
Walter I. Hibbard	Jan. 1966	Apr. 1968
Director, Bureau of Land Management:		
Curt Berklund	July 1973	Present
Burton W. Silcock	June 1971	July 1973
Lloyd L. Rasmussen	Jan. 1966	June 1971

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