OIL AND GAS

HYDROCARBON PRODUCTION WITH NUCLEAR EXPLOSIVES

by

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ABSTRACT

The tremendous energy of nuclear explosives and the small dimensions of the explosive package make an ideal combination for drill-hole explosive emplacement in deep, thick hydrocarbon deposits. Potential applications exist in fracturing low permeability natural-gas and petroleum formations for stimulating production, fracturing oil shale to permit in situ retorting, and creating storage chimneys for natural gas, liquefied petroleum gas, petroleum, petroleum products, helium, and other fluids. Calculations show, for example, that less than 100 shots per year would be needed to stabilize the natural gas reserves to production ratio. Under the Government-industry Plowshare program, two experiments, Projects Gasbuggy and Rulison, were conducted to stimulate natural gas production from low-permeability formations. Incomplete information indicates that both were technically successful.

Potential problems associated with the use of nuclear explosives for underground engineering applications are radioactive contamination, maximum yield limitations, high costs of detonating contained nuclear explosives, and adverse public opinion.

Results at Project Gasbuggy and other considerations indicated that the problem of radioactive contamination was about as predicted and not an insurmountable one. Also, it was demonstrated that shots at adequate depths could be detonated without appreciable damage to existing surface and subsurface buildings, natural features, and equipment. However, costs must be reduced and the public must be better informed before these techniques can be widely used in field operations.

On the basis of present knowledge, the potential of nuclear-explosive stimulation of hydrocarbon production appears good. Additional field experiments will be required to adequately explore that potential.

INTRODUCTION

The potential of peaceful uses of nuclear explosives is greatest in the production and storage of hydrocarbons and associated substances. Some uses of this technique are: (1) Fracturing deep, thick formations of low permeability containing natural gas and/or petroleum; (2) fracturing deep, thick oil-shale deposits to permit in situ retorting; and (3) creating storage chimneys for natural gas, liquefied petroleum gases, crude petroleum, petroleum products, helium, and other fluids.

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The first Government-industry Plowshare experiment, Project Gasbuggy, was successful, although not all technical questions were answered by the results obtained. The explosive yield and consequent subsurface effects appear to be very close to those predicted. There was no venting of radioactivity, and surface seismic damage was negligible. The concentrations of the principal radionuclides were close to those predicted for krypton-85 and xenon-133. They were less than those predicted for tritium and iodine-131 was not detected. Presumably, 200 days after detonation, 95 percent of the tritium then in the chimney was present as tritiated water, a fortunate circumstance since in this form it is easily handled for disposal. Production from the chimney at high rates was possible for limited periods, and it was apparent that fresh gas was entering the chimney as production tests were conducted, although at a rate somewhat lower than that predicted. It was not possible, however, to assess fully the productivity of the fractured zone because efforts to drill into it did not produce satisfactory test wells.

The Rulison (Colorado) experiment, detonated September 10, 1969, went about as scheduled. However, its effect on stimulating natural gas production will not be known until production tests are conducted this spring. These and other planned experiments should further demonstrate the technical feasibility and economic practicability of this new stimulative technique.

Promising results have been obtained from experiments in retorting random-size and random-grade oil shale in special retorting vessels, and in retorting oil shale in situ at a shallow depth fractured by more conventional means. This knowledge is being used in planning a nuclear-explosive fracturing, in situ retorting experiment in oil shale--Project Bronco. However, no site has been selected, and there as yet is no Government-industry contract for a joint experiment.

Likewise, for the storage of natural gas, Project Ketch has a design concept, but no site has been selected and no contract has been negotiated. As yet, there are no known experiments designed for nuclear-chimney storage of other fluids, or for nuclear-explosive stimulation of low-permeability oil reservoirs.

ENERGY DEMANDS AND SUPPLIES

The demand for energy is growing exponentially (fig. 1). By 1980, energy consumption in this country will be about 88 quadrillion Btu's; a 64-percent increase over that actually consumed in 1965.

Petroleum and natural gas will continue to provide most of the Nation's energy needs, but there is growing concern over industry's ability to meet the tremendous future demands for those commodities. The basis for this concern lies in the relationship between reserves and production.

Between 1959 and 1968, proved reserves of crude oil remained essentially constant at 30.7 to 31.8 billion barrels, while production increased 27 percent, from 2.6 to 3.3 billion barrels per year (fig. 2). Because of constant reserves and increasing production, the reserves-production (R/P) ratio decreased consistently from 12.3 in 1959 to the uncomfortably low value of 9.2 at the end of 1968.

Proved reserves of natural gas increased nearly every year over the same 10-year period, but production increased even faster (fig. 3). Thus, the R/P situation for natural gas nearly parallels that of petroleum, decreasing from 21.1 in 1959 to 14.6 at the end of 1968. This decline is actually the extension of a consistent and broad decline that began 23 years ago at an R/P ratio of 32.5 in 1946.

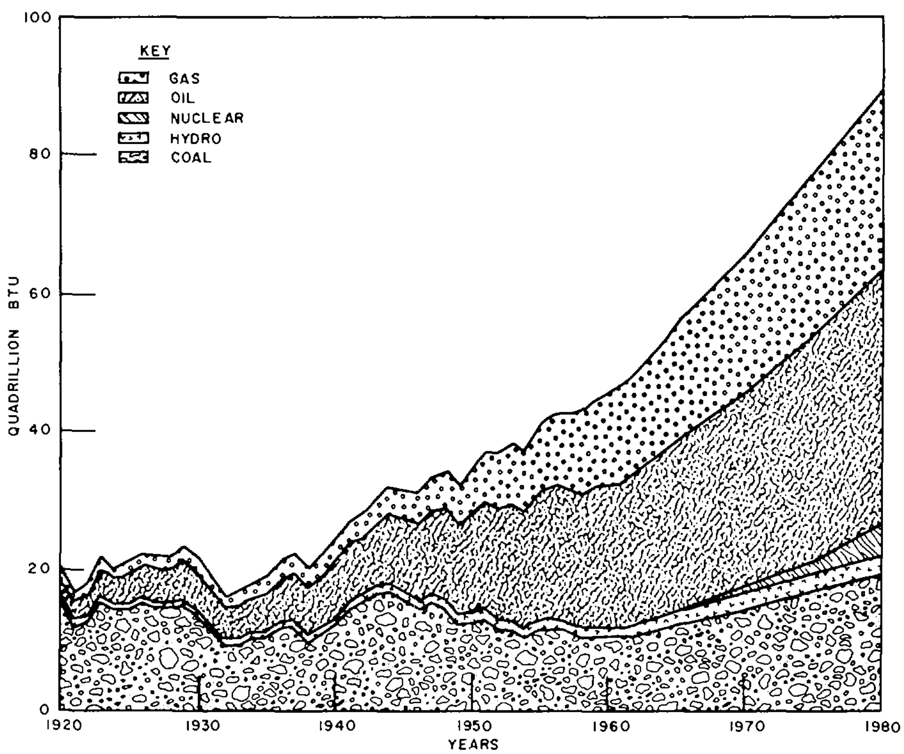

FIGURE 1.- United States Energy Consumption.

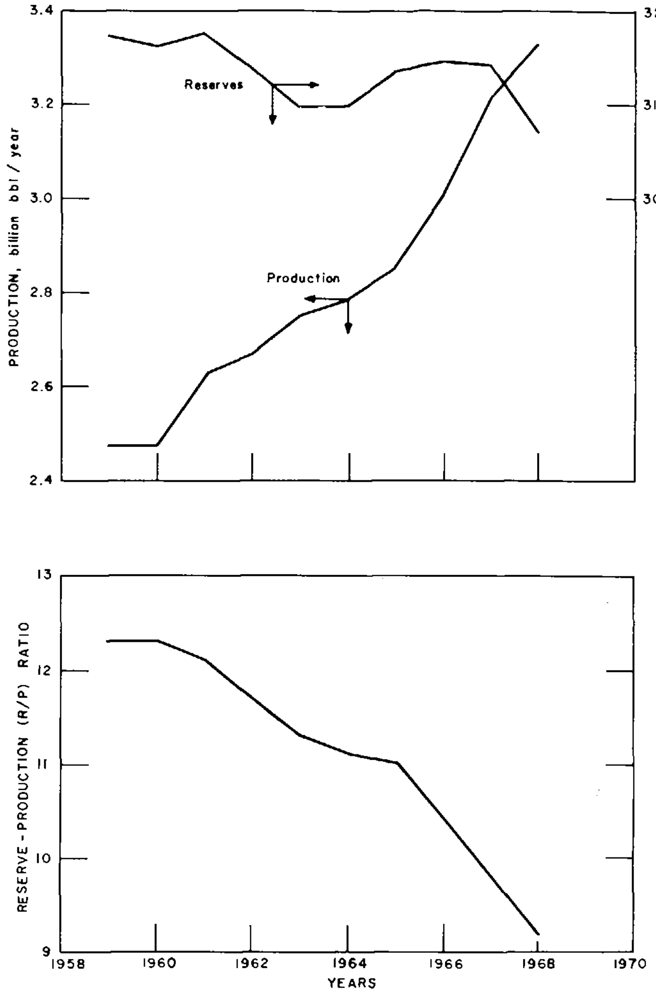

FIGURE 2.– United States Crude Oil Reserves and Production.

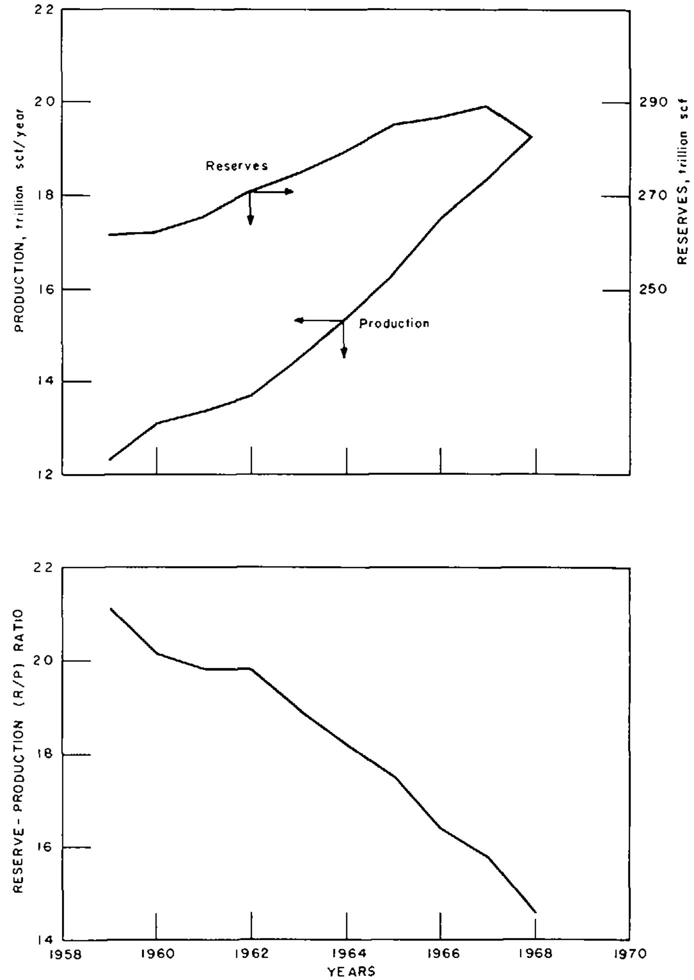

FIGURE 3.– United States Natural Gas Reserves and Production.

In the immediate future, the demand for oil and gas is expected to grow faster than reserve additions, leading to further declines in the R/P ratios. Alaskan oil will help arrest, or may temporarily reverse, the declining trend for oil, but further efforts will be required to stabilize these R/P ratio balances.

The methods by which our future supplies of petroleum and natural gas might be augmented are: (1) Increase foreign imports; (2) utilize substitute fuels; (3) find new reserves; and (4) convert resources into recoverable reserves through new technology.

Foreign imports might serve domestic needs, provided no national emergency caused imports to be cut off. However, the cost of foreign imports likely may increase as reserves decrease and foreign countries extract higher reimbursement for concessions. Practical substitutes for petroleum and natural gas are not now available economically, although technological breakthroughs in the production of gaseous and liquid fuels from oil shale and coal, favorable Government policies, or price increases for crude products could alter this situation. It is becoming increasingly difficult to find and produce new reserves of petroleum and natural gas, as evidenced by the problems and costs of offshore and Arctic North Slope exploration and production. New technology, therefore, appears to be the most immediately promising of the cited supply alternatives. The Plowshare program offers one means of exploiting deep, thick petroleum, natural-gas, and oil-shale deposits that cannot be economically developed with existing technology.

Figure 4 is a projection of the impact that nuclear-explosive fracturing may have on reversing the downward trend of the natural gas R/P ratio, provided it can be used economically. The assumptions here are: (1) Depth, 8,000 to 16,000 feet; (2) gas in place, 200 billion cubic feet per 640 acres; (3) area drained, 640 acres per shot; (4) yield, 100 kilotons per shot; and (5) recovery, 50 percent. As indicated, 10 shots per year would have comparatively little impact, whereas 100 shots per year would affect the R/P ratio appreciably. Between these extremes an optimum number of shots could be planned that would stabilize the R/P ratio at a predetermined level.

UNDEVELOPED RESOURCES

There are significant domestic deposits of petroleum and natural gas in deep, thick formations having permeabilities so low that the contained fluids can be neither practically nor economically produced by conventional well-completion and production-stimulation methods. Bureau of Mines engineers have estimated that, in Rocky Mountain basins alone, the potential reserves of natural gas producible through nuclear-explosive fracturing, if economically practicable, equal more than 300 trillion cubic feet, or more than our present proved natural-gas reserves. No estimate has been made for the petroleum resources in similar formations, but it is believed that they are significant.

Many estimates have been made of the oil potential of the Green River oil shale of Colorado, Utah, and Wyoming. Depending upon the grade and thickness of shale included in the resource estimates, the oil-equivalent estimate ranges as high as 2 trillion barrels. Obviously, all of this organic matter would not be recoverable, but a practicable, economic in situ process might be used to recover a very large portion where the deposits are both thick and deep, as in the Piceance Basin of Colorado where as much as 2,000 feet of continuous oil shale lies under up to 1,000 feet of overburden.

NUCLEAR EXPLOSIVES VERSUS CHEMICAL HIGH EXPLOSIVES

The tremendous difference in size of nuclear-explosive packages and the volume of conventional explosives required for an equivalent yield is easily illustrated (fig. 5). The nominal 40-kiloton Rulison fission explosive was encased in a canister 9 inches in diameter and 15 feet long. The underground emplacement of even 1 kiloton of pelletized TNT would require a sphere 40 feet in diameter or a room 50 by 100 by 10 feet. To emplace 40 kilotons of pelletized TNT would require a void volume of 2,000,000 cubic feet, an obviously impractical situation. Cost is another consideration in comparing nuclear explosives and conventional explosives. Projected costs for nuclear-explosive services cited by the Atomic Energy Commission range from $350,000 (10 kilotons) to $600,000 (2 megatons). The costs are projected on the assumptions of production in quantity and legislation authorizing AEC to sell nuclear-explosive services and include nuclear materials, fabrication, arming, firing, and supporting activities. As a basis of comparison, assuming the cost of pelletized TNT or other comparable chemical high explosives to be about 20 cents per pound, 10 kilotons would cost $4 million and 2 megatons would cost $800 million. In other words, chemical high explosives, based on yield only, are about 11 times more costly than nuclear explosives in a 10-kiloton range and 1,300 times more costly in the 2-megaton range.

For nuclear explosives to be used in extensive commercial applications, the highest yield devices compatible with containment and minimal seismic-shock damage must be used. Also, the present ancillary costs of contained nuclear detonations must be reduced materially.

POTENTIAL PROBLEMS

It is not a unique situation that the use of nuclear explosives presents potential problems. The same can be said for any method of rock breaking. None of the potential problems, however, is so serious that it cannot be solved.

Radioactivity

The three considerations with regard to radioactivity in using nuclear explosives are the necessity of preventing venting of radioactivity to the atmosphere, the necessity of preventing contamination of ground water, and the problems of radionuclides in the product.

Adequate data are available from more than 270 contained nuclear explosions in a number of rock media that containment may be assured, provided no fractures are present that might permit the transmission of radionuclides to the surface. Detailed geological studies can determine whether there is any likelihood of venting through fractures. Thus, the possibility of accidental venting in a properly designed experiment is essentially nil.

Similarly, detailed hydrological and geological studies, such as are made prior to all nuclear-explosive tests, yield data that may be used to so design the experiment to prevent the contamination of any ground water that may be used for any industrial purpose or that may migrate to the earth's surface.

Some radioactive contamination of produced hydrocarbons may be expected. The amount and kind of radioactive contaminants depend principally upon the kind of explosive used and the medium in which it is detonated. All-fission explosives may be preferable for natural-gas stimulation because they produce the least tritium and would minimize contamination of the gas by tritium exchange with hydrogen.

The quantity of radionuclides in the hydrocarbon fluid produced may be reduced by waiting for radioactivity decay, removal, and dilution. In natural-gas stimulation, iodine-131, for example, may be reduced to acceptable levels by waiting for the 8-day half-life radionuclide to decay. Any particulate matter or liquid may be easily separated from gases, and the unwanted substances may

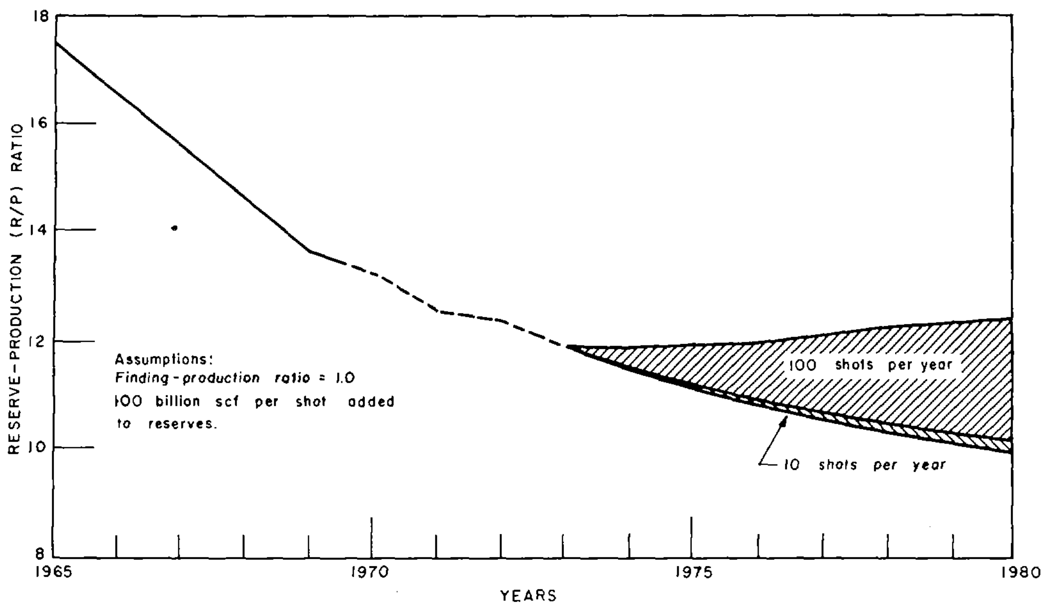

FIGURE 4.- Effect of Nuclear Explosion Stimulation on Natural Gas Reserve-Production Ratio.

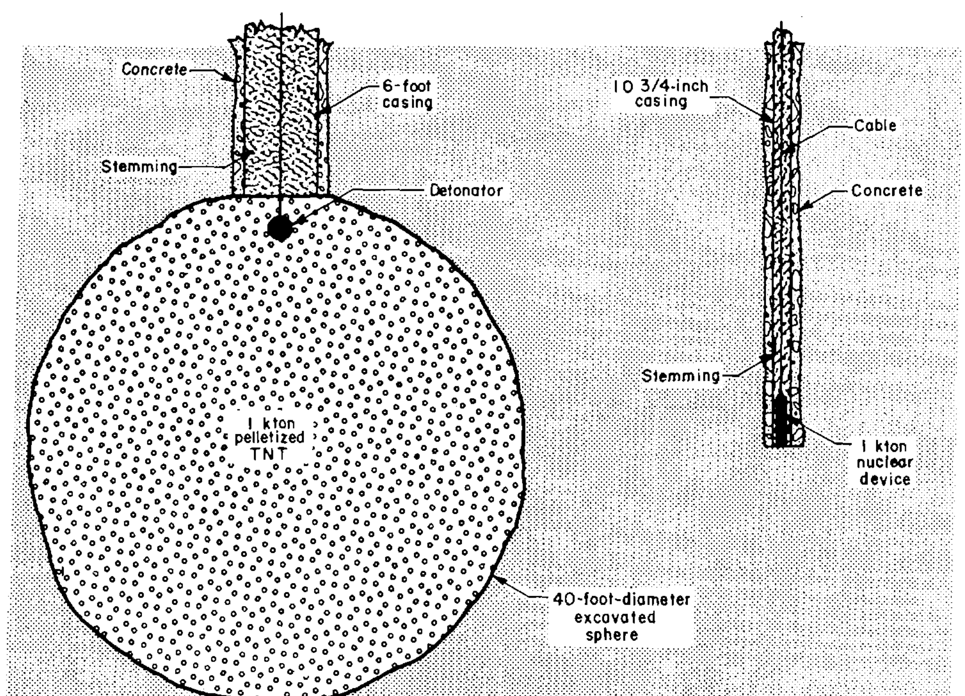

FIGURE 5.-Comparative Emplacement Techniques for Nuclear and Chemical Explosives.

be disposed of by safe and acceptable means. In the case of the Gasbuggy gas, for instance, the tritiated water, which contains most of the tritium, is easily separable from the gas. Finally, contaminated fluids may be mixed with uncontaminated fluids to reduce the specific radioactivity to acceptable levels.

The maximum permissible concentrations (MPC's) set by the International Commission on Radiation Protection, the National Committee on Radiation Protection, and the Federal Radiation Council have been accepted by AEC. However, these standards were not designed to cover the situation of tritium or krypton-85 in natural gas that is to be burned in a power-generation plant or a residence. Realistic guidelines for acceptable radionuclide levels in hydrocarbons are sorely needed and are in the process of derivation.

Seismic Shock

It has become increasingly apparent that the limiting factor in the maximum yield of contained nuclear explosives that can be permitted is not containment but the amount of surface seismic shock that can be tolerated. Fortunately, most of the known areas where nuclear explosives might be used to stimulate hydrocarbon production are relatively remote and are sparsely populated.

Costs of Using Contained Nuclear Explosives

It has been mentioned earlier that, for widespread commercial application of nuclear explosives, the present high costs of nuclear-explosive experiments will have to be reduced appreciably. A significant part of present costs results from associated scientific experiments and diagnostics and the intensive safety and environmental studies required to insure public health and safety and protect the environment and ecology. For strictly commercial applications, the costly add-on experiments would not be required and the necessity for diagnostic measurements would be greatly reduced. All of us want to protect public health and safety and preserve the environment. Therefore, safety, environmental, and ecological studies and controls still would be required. However, when such studies have been made and the results have been found acceptable for a general area, the studies should not have to be repeated in detail for each separate detonation within the area previously studied.

Public Opinion

The contrast in expressed public opinion before the Gasbuggy and the Rulison detonations was extreme. Prior to Gasbuggy, there was great interest, but essentially no local concern was expressed and there were few general adverse comments. Conversely, the Rulison experiment occasioned both local and national criticism, demonstrations, and motions for injunctions and restraining orders. In the court hearings, however, the plaintiffs established no case for opposing the experiment. It appears that much of the opposition came from those who were not fully aware of the facts pertinent to nuclear-explosive technology and phenomenology. It is obvious that improved public relations are required to better inform the general public of the real facts concerning nuclear detonations.

The point should be made that there is no method of providing the energy and minerals that the Nation requires, for either the civilian or the military economy, that does not affect the environment in some manner. This is true for the combustion of fossil fuels, nuclear-power generation, and even hydropower. Our objective, therefore, must be to assure an adequate supply of energy, at the lowest cost to the consumer, and with the <u>least</u> adverse impace on the environment and the ecology.

NATURAL GAS AND PETROLEUM PRODUCTION STIMULATION

The yield and chimney characteristics of Project Gasbuggy were very close to those predicted, as was the apparent extent of fracturing outside the nuclear chimney. Production from the chimney was materially increased, as evidenced by the fact that about 260 million cubic feet of gas has been produced in about 1 year's time from the chimney reentry well, whereas only about 80 million cubic feet of gas had been recovered over a producing life of 10 years from the nearest preshot production well, some 436 feet away from the chimney reentry well. The radioactivity was somewhat less than expected for tritium and about as expected for krypton-85; no iodine-131 was detected. Also, at this time, about 95 percent of the tritium apparently is present as tritiated water, rather than as a gas. This is fortunate, since tritiated water may be separated easily from the gas. Immediately after reentry, the hydrocarbon content of the chimney gas was about 52 percent, compared with the usual 99 percent in field wells. As a result of dilution by fresh gas from the formation, the hydrocarbon content is now about 90 percent. The radioactivity also has been reduced appreciably by dilution with uncontaminated formation gas. One of the unanswered questions in the Gasbuggy experiment is the productivity of the fractured zone. The postshot wells drilled into the fractured zone have quite low rates of production, indicating that communication between them and the chimney is probably poor.

The Rulison explosive was detonated with no venting of radioactive gases, an apparent yield close to that expected, and low surface seismic damage. The wellhead pressure on the Rulison emplacement well has been increasing since the detonation, indicating that the rock in the Mesaverde formation has been fractured appreciably around the point of detonation and that the gas is migrating upward in the casing of the well through the gravel, sand, and clay used as stemming material to the wellhead, where it is confined by a high-pressure "Christmas tree." Present plans call for reentry no sooner than 6 months after detonation.

NUCLEAR-EXPLOSIVE FRACTURING, IN SITU RETORTING OF OIL SHALE

The concept of fracturing essentially impermeable oil shale to permit retorting it in place is the most technically complex of all the proposed Plowshare hydrocarbon-production experiments. However, the advantages of a technically feasible and economically practicable in situ retorting experiment are so apparent, and the domestic oil-shale resource is so great, that testing of the concept deserves a high priority. The advantages are that: (1) Air and water pollution would be virtually eliminated; (2) disfigurement of the earth's surface would be greatly minimized; (3) a higher percentage of oil conversion and recovery may be possible than with room-and-pillar mining and aboveground retorting; (4) the cost and difficulty of disposing of spent shale would be eliminated; and (5) it may be possible to produce a higher quality oil than that produced from aboveground retorts.

Recent experiments on retorting random-size and random-grade particles of oil shale at the Bureau of Mines, Laramie Petroleum Research Center, approximating the particle-size and grade range that might be expected in a nuclear chimney, have been successful. Up to 85 percent of Fischer assay has been recovered. This, and the results of recent, shallow in situ retorting experiments, near Rock Springs, Wyo., have enhanced the potential attractiveness of in situ retorting. This is particularly true for the use of nuclear-explosive fracturing in the very deep, thick, rich oil-shale deposits that now do not appear amenable to production by present mining and retorting methods.

FLUID STORAGE

The first proposed application of nuclear explosives for creating a chimney to be used for natural-gas storage, Project Ketch, has not materialized. The principal reason for this was the opposition to the experiment voiced within Pennsylvania.

Regardless of the merits of the proposed Ketch experiment and the validity of the opinions of the opposition, the concept of using nuclear chimneys for fluid storage has many advantages. There is ample evidence that underground storage of natural gas is safer, cheaper, and much less deleterious to aesthetics and the environment than aboveground storage.

Most of the natural gas stored underground is kept in aquifers or depleted natural-gas reservoirs. Some is stored in salt formations, and there is one storage project in an abandoned coal mine. There are appreciable geographical areas of the United States, however, in which there are no suitable subsurface permeable formations with adequate caprocks, or rock salt in domes or sediments, that could be used for underground fluid storage. Underlying many of these areas, however, are massive deposits of impermeable shale or granite that could be converted for fluid storage through the use of nuclear explosives. The study made for Project Ketch indicated that nuclear-explosive creation of gas-storage chimneys can be economic. The storage of more valuable fluids, such as helium, and of strategically important fluids, such as petroleum products, should make the economics even more favorable.

CONCLUSIONS

Conclusions from the experience of Bureau of Mines personnel in Plowshare applications are:

1. There is a great potential in using nuclear explosives for converting certain domestic hydrocarbon resources to usable reserves.

2. For economic utilization of underground nuclear explosives, high-yield explosives will be required and the present cost must be reduced appreciably.

3. The use of nuclear explosives for creating fluid-storage chimneys appears attractive, especially in some geographic areas and for the more valuable and strategic fluids.

4. The limiting factor in using high-yield nuclear explosives is the maximum seismic shock that can be tolerated.

5. Radioactivity is a problem but not an insurmountable one.

6. Adverse public opinion probably is the most serious present problem, and more effective public relations are mandatory.