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POTENTIAL OF NUCLEAR EXPLOSIVES FOR PRODUCING HYDROCARBONS FROM DEPOSITS OF OIL, NATURAL GAS, OIL SHALE, AND TAR SANDS IN THE UNITED STATES

By J. Wade Watkins and C. C. Anderson

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
1964

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UNITED STATES DEPARTMENT OF THE INTERIOR
Stewart L. Udall, Secretary

BUREAU OF MINES
Marling J. Ankeny, Director

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by

J. Wade Watkins[1] and C. C. Anderson[2]

ABSTRACT

One potential peaceful application of nuclear explosives is stimulating the production of liquid or gaseous hydrocarbons from essentially nonproductive deposits of petroleum, natural gas, oil shale, and tar sands.

Within the United States the appreciable difference between producible proved reserves and ultimate reserves and resources of hydrocarbon deposits is of such magnitude that much petroleum, natural gas, shale oil, and bitumen will not be produced unless significant technological progress is made in production techniques. The shattering effect of contained nuclear explosives and, to a lesser extent, the heat produced, have been considered as stimulative forces when the thickness, depth, and nature of such deposits permit considering the use of nuclear devices.

Mechanical production problems would be less in an oil or gas reservoir than in an oil-shale or tar-sands deposit. Also, tar-sands resources in the United States may not be adequate to warrant serious consideration of applying nuclear-explosives stimulation. Gas reservoirs should present the least-radioactive-contamination problem.

The technical feasibility of using nuclear explosives cannot be evaluated fully at present. Additional information is needed on the effects of pressure, heat, and radioactivity on the solids and fluids of hydrocarbon deposits, the nature and extent of induced fractures in different rock media, and the possibility of isolating and confining or removing radioactive contaminants. Final technical feasibility can only be determined by a field test. If technical feasibility is established, economic feasibility will depend upon the comparative cost of producing hydrocarbons by nuclear explosives and by conventional means. It is probable that an economic comparison would favor nuclear stimulation only where devices of relatively high yield could be used practicably and safely.

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INTRODUCTION

During the 103 years that petroleum has been produced commercially in the United States, this nation and many other countries have come to depend upon liquid or gaseous hydrocarbons to supply much of the fuel required for transportation, stationary powerplants, and home uses. Scollon (16)[3] reported in 1962 that petroleum supplied 44 percent and natural gas 29 percent of the total energy consumption of the United States. The rapidly expanding petrochemical industry also has been responsible for the dependence in the home on a host of byproducts of petroleum. Consequently, petroleum has become an indispensable civilian and military commodity.

Thus, it is not surprising that economists are most concerned about future supplies of petroleum or petroleum substitutes or that many efforts have been made to relate present and future reserves to future production and demand. Periodically, the announcement has been made by some prognosticators that the United States is running out of oil. Such predictions have not been substantiated by performance, because the proved reserves of petroleum in the United States have increased in general and have shown annual increases for most years since the early days of the industry. Inasmuch as both production and consumption also have increased steadily, this means that the proved reserves added annually have more than kept pace with increases in annual production.

Nevertheless, it has become increasingly difficult and costly to find new reserves of petroleum, and it is apparent that petroleum reserves, not being inexhaustible, ultimately will reach the point when domestic proved reserves are diminishing. However, authorities do not agree on the time at which this reversal will occur. As reserves decrease and demand increases, and as petroleum becomes more valuable as a source of byproducts, it is logical to assume that other sources of fuel for power must gradually replace petroleum. Natural gas, petroleum substitutes such as shale oil and bitumen from tar sands, coal, and nuclear fuels have all been considered to be important in the power picture of the future.

It is important here to state that the term "reserves," as normally used by the oil industry, refers to known deposits that are recoverable by existing proved technology and under existing economics. Thus, finding new supplies of petroleum can augment existing reserves appreciably. Another significant means of increasing reserves is to improve the efficiency of present methods of recovery or to devise new production techniques. Not only is this applicable to petroleum reserves, but it also applies even more to the vast resources of oil shale, tar sands, and other media that contain hydrocarbons similar to, and usable as a substitute for, petroleum.

In 1957 the Atomic Energy Commission and the University of California Lawrence Radiation Laboratory announced publicly that a nuclear device, with an explosive force equivalent to 1,700 tons of TNT, had been detonated underground and successfully contained within a volcanic tuff formation at the

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[3] Underlined numbers in parentheses refer to items in the list of references at the end of this report.

Nevada Test Site at Mercury, Nev. To oil men used to fracturing oil-bearing rocks and applying heat and energy to oil reservoirs, the implications were obvious. Here, for the first time, was a physically small package of an explosive having extremely high energy release in the form of heat and pressure. Perhaps a nuclear explosive could be used to stimulate petroleum production.

The original enthusiasm for using nuclear explosives was tempered when several problems inherent in such an experiment were subsequently considered. Nuclear explosives were, and are, costly--about one-half to one million dollars per test in the present economy and state of the art. As the Atomic Energy Commission has a monopoly on nuclear explosives in the United States, the producer cannot order a nuclear shooting job by telephone as he can a chemical-explosives or hydraulic-fracturing job. The physical dimensions of available nuclear-explosive packages, although small, still require drilling a large-diameter emplacement hole. For a nuclear device to be used successfully in an oil-productive formation, the formation will have to be thick enough so that the resultant fractures will not extend into water-bearing formations and it will have to be deep enough to contain the shock from the explosion. However, the formation cannot lie so deep that the cost of emplacing a device through a large-diameter hole will be prohibitive. Essentially nothing was known about the in-situ effects on reservoir rocks and fluids of the shock, heat, and radioactivity released in a nuclear detonation. The extent of fracturing and heating and the consequent effect on oil recovery were unknown factors. Most important of all, the extent of contamination of reservoir fluids by radioactive fission and activation products and the feasibility of handling and decontaminating fluids containing radioactive materials were not known.

Although these problems were formidable, they were not so insurmountable as to preclude further consideration of using nuclear explosives in petroleum or natural-gas reservoirs, oil-shale deposits, or tar sands.

The original expressed interest appeared to center on applications in oil shale and tar sands, rather than oil or gas sands.[4] This apparently was the case because of the huge resources of hydrocarbons in oil shale and tar sands, difficulties in producing shale oil from oil shale and bitumen from tar sands, the comparative ease of producing oil and gas, and the assumed dearth of oil-bearing or gas-bearing formations from which production was difficult by existing methods and which had adequate thickness and subsurface depth to contain a nuclear explosion.

Early in 1958 contacts were made with the Atomic Energy Commission and the University of California Lawrence Radiation Laboratory at Livermore by numerous oil companies and research organization interested in practical peaceful uses of nuclear explosives. At least two specific proposals were made that are pertinent to this discussion. Richfield Oil Corporation (12)

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[4] The term "oil and gas sands" is used in this report in its generally accepted sense to denote all kinds of oil-bearing or gas-bearing rocks.

proposed the use of a nuclear device to produce bitumen from the McMurray tar sands in Canada. About the same time the Bureau of Mines (5) proposed to consider a test with a nuclear device in the thick oil-shale deposits of the Rocky Mountain area. Neither of these two projects has been undertaken, despite much interest expressed by numerous petroleum companies (14), the Atomic Energy Commission, and the Lawrence Radiation Laboratory.

Engineers at the Bureau of Mines Bartlesville Petroleum Research Center, early in 1959, began to consider areas in which there might be oil-productive formations suitable for an experiment with a nuclear device (1). This work was carried out informally on a limited scale with engineers of the Continental Oil Company and during the past two years it was carried out formally on an expanded scale with the Atomic Energy Commission. Some of the problems encountered in these investigations are discussed in succeeding sections of this report.

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HYDROCARBON RESERVES AND RESOURCES

In discussing the quantities of petroleum, natural gas, natural-gas liquids, and petroleum substitutes available in the United States, some terms should be clearly defined and understood. The term "reserves" has been defined earlier in this paper as it is normally used within the petroleum industry to comprise the petroleum, natural gas, or natural-gas liquids recoverable from deposits of known extent by using existing technology under the present economy. The term "resources" implies a greater quantity, not limited by present technology, economics, or precise knowledge of the extent of deposits and includes all of the oil present, whether producible or not, in a specified area. The total oil that ultimately may be produced in a given geographic area often is referred to as "ultimate reserves." This includes past production, present proved recoverable reserves, and additions to reserves through extensions of fields, revisions of estimates, and the discovery of new fields. This value, like that of proved reserves, usually is projected on the basis of constant dollars and the assumption that the efficiency of recovery will not improve.

In estimating reserves and resources of oil from oil shale and bitumen from tar sands, a similar distinction is made between reserves and resources. Data on resources of oil shale and, to a less extent, on tar sands in the United States, should be more reliable than data on petroleum resources. Most of the deposits are known and much information is available on the thickness, areal extent, and grades of deposits of oil shale and tar sands. Therefore, it should be easy to calculate the oil in place. Estimating reserves of oil from oil shale and of bitumen from tar sands, however, is more difficult because at present there are no large-scale oil-shale or tar-sands industries in this country upon which to base reserve figures.

To estimate or calculate ultimate reserves or resources of any mineral commodity inherently involves some margin of error. Landes (10) states:

> "It is completely futile to attempt to estimate the value of undiscovered reserves of any substance. It is true that oil and gas are confined to sedimentary basins and that the volume of basin sediment can be computed. But an accurate estimate of the amount of recoverable hydrocarbons per cubic mile of sediment in any basin is not possible because no basin has ever been exhausted of its oil and gas, so we have no yardstick."

Estimates of ultimate reserves and resources, however, do have a function in energy-source evaluations on a comparative basis, provided one recognizes the inherent inaccuracies involved. Such estimates are used in this paper only for general comparisons.

Petroleum, Natural Gas, and Natural-Gas Liquids

The American Petroleum Institute (API) and American Gas Association estimated (2) reserves for the United States at the end of 1961 as follows: Crude oil, 31,758,505,000 barrels;[5] natural gas liquids, 7,049,096,000 barrels (total liquid hydrocarbons, 38,807,601,000 barrels); and natural gas, 267,727,671,000 thousand cubic feet. The estimate for natural-gas liquids only pertains to plants in use, under construction, or planned and does not include those liquids that might be recovered through more extensive or more efficient processing of natural gas.

The API estimate only pertains to oil reserves known to be recoverable by continuing present methods of production in established fields. In the most recent estimates released by the Department of the Interior (19), an additional reserve of 16 billion barrels recoverable by initiating secondary recovery in known fields, cited by the Interstate Oil Compact Commission (17), has been added to give a total of 48 billion barrels.

It is apparent that our domestic resources and ultimate reserves of petroleum, natural-gas, and natural-gas liquids far exceed our present proved recoverable reserves. Many persons have used various methods to calculate future discoveries of, demands for, and productive capacities of petroleum in the United States and in other parts of the world. From such extrapolations ultimate reserves and total resources may be estimated.

The consequent estimated values cover a wide range. In 1958, Netschert (13) cited estimates of ultimate reserves of crude oil in the United States ranging from 140 to 300 billion barrels (neglecting an obviously high estimate of 2,000 billion barrels).

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[5] One barrel = 42 gallons.

In 1962, Hubbert (7) cited estimates for ultimate U.S. crude-oil reserves made in the years 1948 through 1962, covering a range from 110 to 590 billion barrels. It is obvious that some of the estimates cited by both authors must be in error. Weeks (20) in 1959, on the basis of a comprehensive survey and study of energy sources, estimated the ultimate recoverable liquid-petroleum reserves of the United States to be a total of 460 billion barrels (270 billion barrels by primary production methods and 190 billion barrels by secondary recovery). Weeks' figures included both land and water areas as well as natural-gas liquids with petroleum. In 1962, proved reserves of natural-gas liquids in the United States equalled approximately 18 percent of the total liquid hydrocarbons. On this basis, Weeks' values for crude oil alone might be assumed to be a total of approximately 377 billion barrels.

A more recent estimate, based on a statistical study by Moore (11), cites the ultimate recovery of crude oil in the United States as 364 billion barrels, based on a cumulative recovery of 75 percent of the oil originally in place. The most recent Department of the Interior estimate (19) cited a production and reserve figure of 318 billion barrels (70 billion barrels produced to January 1, 1962; 48 billion barrels of known recoverable reserves; and 200 billion barrels of undiscovered recoverable reserves).

These three estimates cannot be cited as being any more accurate than other estimates. However, they were based on careful study and analysis, although different methods of estimating the problem were used and they are reasonably comparable in magnitude. Therefore, for a basis of comparison with estimates of other resources only, a range of 315 to 375 billion barrels is used in this report.

For natural gas, Netschert (13) cited estimates of total future supply in the United States ranging from 510 to 1,200 trillion cubic feet. Hubbert (7) cited estimates ranging from 600 to 2,650 trillion cubic feet.

Weeks' (20) 1959 estimate for potential unproduced reserves of natural gas in the United States was 1,000 trillion cubic feet (plus cumulative production of 161 trillion cubic feet through 1958 equals 1,161 trillion cubic feet of ultimate reserves). The 1962 estimate of Hubbert (7) of the total ultimate natural-gas reserves was 1,000 trillion cubic feet. The most recent estimate of the Department of the Interior (19) of undiscovered reserves was 1,200 trillion cubic feet. This added to the API figure of 268 trillion cubic feet, plus 161 trillion cubic feet produced, equals 1,629 trillion cubic feet of ultimate reserves.

Estimates for ultimate reserves, resources, or total future supplies of natural-gas liquids are scarce because of the many variables involved. The Department of the Interior's recent estimate (19) of undiscovered recoverable reserves was 30 billion barrels. By adding the API estimate of 7 billion barrels of recoverable reserves and the production, through 1961, of 6 billion barrels, an ultimate-reserves figure of 43 billion barrels is obtained. No estimates are available for total natural-gas liquids resources; however, the Department's 1963 estimate (19) of undiscovered marginal resources was 60 billion barrels. It is reiterated that estimates of proved and ultimate reserves of natural-gas liquids are limited not only by present technology and economics but also by the projected use of extraction plants now in existence, under construction, or planned. Thus, the ratio of natural-gas to natural-gas liquids ultimate reserves will most likely change as additional extraction plants are constructed.

Oil Shale

The most recent estimate of shale-oil reserves in higher-grade oil shale (30 gallons per ton) in Colorado and Utah was given by the Department (19) as being 50 billion barrels, assuming 50 percent recovery of the oil content of the shale. Known marginal reserves were estimated at 2 trillion barrels and undiscovered marginal resources at 4 trillion barrels by the Department (19).

Tar Sands

Although the vast resources of tar sands in Canada have received much publicity, corresponding formations with appreciable reserves do not occur in the United States. The Alberta Conservation Board recently estimated (15) that the Athabaska tar sands in Alberta Province contained 450 billion barrels of bitumen (including only tar sand which contained 10 percent or more by volume of bitumen) and that 60 to 80 percent of the 450 billion barrels would be recovered ultimately. The Department of the Interior estimated in 1960 (18) that there were 2 to 3 billion barrels of bitumen in near surface deposits of bituminous sands in Utah, Texas, and California. Weeks (20) estimated the potential supply of oil from tar sands in the United States at 10 billion barrels. Measured or proved reserve figures for bitumen from bituminous sands in the United States, cited by the Department (19) in 1963, were 1 to 3 billion barrels assuming a recovery of 50 percent of the oil in place. Most of the estimates on oil from bituminous sands admittedly are conservative figures based on incomplete data.

PHYSICAL EFFECTS OF NUCLEAR EXPLOSIONS

The methods used for and problems encountered in producing hydrocarbon fluids from oil and gas sands, tar sands, and oil shale differ appreciably. Consequently, the potential application of nuclear explosives to stimulating production from these media must be considered separately, even though the same physical principles apply.

The phenomenology of contained nuclear explosives has been adequately discussed in the literature, especially with respect to tests in volcanic tuff (4, 8) and, to a lesser extent, in halite (3). Therefore, no additional detailed description will be given here.

In summary, three things distinguish a contained nuclear explosive--pressure, heat, and radioactivity. Nuclear explosives differ from chemical high explosives chiefly in the high ratio of yield to physical dimensions and the energy released in the form of ionizing radiation. The effects of radioactivity on hydrocarbon-reservoir fluids and solids are neither fully known nor completely understood. Enough information is available, however, so that one may conclude that the effects of radioactivity alone will be comparatively minor in physically affecting the production of hydrocarbons either beneficially or adversely. Therefore, the principal energy effects will be from heat and pressure.

Heat may be expected to have an effect in vaporizing solids and liquids within the cavity or "fire-ball" zone of a nuclear explosion and in reducing the viscosity of heavy oil or bitumen, within a somewhat greater radius, either permanently by cracking or temporarily through heating.

Pressure, acting as a shock wave, can affect hydrocarbon production by shattering reservoir rock and thereby materially increasing both the effective radii of well bores and the drainage system of the reservoir by means of cross-fracturing oriented natural fractures and extending new fractures to appreciable distances beyond the point of detonation.

The first problem in evaluating the effect of a contained nuclear blast upon hydrocarbon production, then, is one of assessing the probable effects of heat, pressure, and radioactivity in oil-shale, bituminous sands, and oil- and gas-bearing formations. Existing information on nuclear phenomenology is useful. But it is not nearly as adequate as it should be for this purpose. Comprehensive data are available only for volcanic tuff. Fewer data have been made public for shots in rock salt, desert alluvium, and granite. No data are available for the rock types in which hydrocarbon deposits generally occur--oil shale, bituminous sands, sandstone, limestone, and dolomite.

Scaling laws (9) for various radii and depths, in feet, have been derived from the results of contained nuclear shots in bedded tuff, where W equals the explosive yield in equivalent kilotons of TNT, as follows:

Radius of cavity and major radioactivity (R_r)...........	50 $W^{1/3}$
Radius of crushing (R_c).................................	110 $W^{1/3}$
Radius of fracturing or start of elastic propagation (R_f)	230 $W^{1/3}$
Radius for 3° C temperature rise (R_t)...................	125 $W^{1/3}$
Depth of burial for containment of radioactivity (D_c)....	400 $W^{1/3}$
Depth of burial for no visible surface evidence (D_v).....	1,000 $W^{1/3}$

Temperature

A 1-kiloton nuclear explosion should produce 10^{12} calories or 4.2×10^{19} ergs of energy. This energy is manifested principally in the forms of heat and pressure and, to a lesser extent, radioactivity. It has been estimated that one-half of the total energy release will occur in the form of heat. Thus, it is apparent that a very large amount of heat will be produced in a hydrocarbon-bearing formation by the detonation of a multikiloton device. Unfortunately, however, it is likely that the practical utilization of heat from a nuclear device for the production of hydrocarbons will not be very efficient for several reasons.

First, a significant portion of the heat will be used up at extremely high temperatures (approximately 1,000,000° K) in vaporizing all substances within a small radius of the working point and melting rock within a somewhat greater radius. Johnson and Violet (8) reported that these radii in the Rainier event, with a yield of 1.7 kilotons, were about 3 feet and 15 feet, respectively.

Second, although the heat remaining will be adequate to heat a very large volume of hydrocarbons, the rock in which the hydrocarbons are contained represents an appreciable mass which also must be heated.

Third, the heat-transfer characteristics of reservoir rock are quite poor, particularly for large blocks of rock. Unless the rock is shattered for a considerable distance around the zero point, heating will be an inefficient process.

Fourth, the heat distribution, even under conditions of adequate crushing and permeability, may be expected to be quite nonuniform. In Rainier, for example, about 5.7×10^{11} calories were required to melt 800 tons of tuff under the existing conditions (9). Yet, five months after the detonation, the temperature increase ranged from 140° F near the zero point to 5° F 100 feet away.

Despite these conditions, we cannot conclude that no benefit in increasing hydrocarbon production will be obtained from the heat of a contained nuclear detonation. The ease of producing some viscous oils, either asphaltic or paraffinic in base, may be increased appreciably by temperature increases of only a few degrees. If adequate fracturing is obtained and some driving force is available for distributing the heat through the formation, production may be facilitated. Such a driving energy may be a direct result of the nuclear detonation itself, may be caused by secondary gases generated by the resultant heat, or may be introduced by injecting gases through drill holes. However, it is apparent that the principal effect on hydrocarbon production will be caused by crushing and fracturing the rock and not by heating the hydrocarbons and rock.

Crushing and Fracturing

The scaling formulas cited earlier may be used to evaluate the extent of crushing and fracturing in a hydrocarbon reservoir. It must be recognized, however, that these formulas are based primarily on a single rock medium--volcanic tuff. Unfortunately, complete data are not yet available on the extent, nature, and orientation of fractures produced in granite--a much more competent rock; no nuclear experiments have been conducted in the rock media of particular interest in hydrocarbon production. It is almost certain that the crushing and fracturing effects will be different in oil shale, bituminous sands, sandstones, limestones, and dolomites. But what the differences will be and what their significance will be to hydrocarbon production cannot be predicted at this time.

The best assumption that can be made, then, is to calculate the effects in a hydrocarbon reservoir on the basis of available data and assume that the fracturing probably will be somewhat more extensive in a harder, less elastic medium than tuff. This difference probably cannot be expected to be as much as 10 times greater for harder rocks (6).

Using the maximum fracturing-radius formula ($R_f = 250\ W^{1/3}$) derived from Rainier data (fracture zone radii = 130 to 280 feet; 1.7 kilotons), the extent of fractures for a device of any yield may be calculated, remembering that the data were derived from one test in bedded tuff under Rainier conditions. It is unfortunate that extensive surveys have not been made (or, if they were made, they have not been reported publicly) for fracture radii in other tests made in tuff, halite, and granite. However, an approximation may be made of the general extent of fractures resulting from a nuclear detonation in oil shale, bituminous sands, and oil- and gas-bearing formations. It is probable that the result of such a calculation would represent a minimum radius of fracture propagation because of: (1) The likelihood of a greater fracture radius in a more competent and less elastic rock and (2) the possibility of explosion-induced fractures extending farther along preexplosion fractures in the rock.

Radioactivity

It is documented that both gamma and neutron irradiation can cause physical and chemical changes in reservoir solids and fluids. Data on such changes are by no means as complete as might be desired. Also, few data are available that may be extrapolated to the combined and simultaneous in-situ effects of the pressure, heat, and radioactivity resulting from a contained nuclear detonation in a hydrocarbon reservoir. It would be extremely difficult to duplicate comparable conditions in the laboratory. Efforts have been made to obtain some of this much needed information by exposing a group of samples of oils, rocks, and other substances supplied by petroleum-research laboratories in the Gnome event, conducted in rock salt near Carlsbad, N. Mex., in December 1961. The samples that were recovered now have been analyzed, and the results are being reported in another paper. Another group of samples was exposed in the Shoal event, conducted in granite near Fallon, Nev., in October 1963. No samples have been recovered yet at Shoal.

The information obtained from such experiments will be valuable in planning any nuclear experiment in a hydrocarbon reservoir and in planning any subsequent oil-production experiment.

It is predicted, however, that the effect of radioactivity alone on hydrocarbon production will not be nearly so great as that caused by fracturing of the rock and heating of the hydrocarbons.

Generation of Gases

Another probable effect of a nuclear explosion in a hydrocarbon reservoir, for which no data are available, will be the generation of gases as a result of the detonation. In addition to gases produced by the device itself, the effect on hydrocarbon production of water vapor and hydrocarbon gases may be expected to be of appreciable magnitude. Moreover, in a carbonaceous reservoir, very large quantities of carbon dioxide and other gases will be generated.

It is possible to calculate the quantities of hydrocarbon gases and carbon dioxide that will be produced by a device of given yield. The effect of these gases, however, combined with heat and pressure from detonation of the device, is not amenable to precise calculation. It can only be assumed that the effect upon hydrocarbon production will be significant.

APPLICABILITY OF NUCLEAR EXPLOSIVES TO TYPES OF HYDROCARBON DEPOSITS

In considering the feasibility of using nuclear explosives for producing hydrocarbons, three primary criteria must be considered. First, the hydrocarbon resource either must be essentially nonproductive by existing methods under the present economy or, all things considered, production by nuclear explosives must cost less than production by other means.

Second, the formation must be deep enough so that radioactive fission and activation products will not be vented to the ground surface and into the atmosphere.

Third, the productive formation must be thick enough so that the explosion will not cause fracturing into water-bearing formations, resulting either in drowning out hydrocarbon production or the unconfined release to aquifers of radioactive contaminants.

Other criteria that must be evaluated are remoteness of location, surface- and ground-water hydrology, ownership and availability of mineral and surface rights, and political and psychological factors.

Oil Sands

In most oil-productive formations, the oil in place may truly be considered a liquid, although oils from different reservoirs fall within an appreciable range of viscosity and gravity. Stimulative benefits from a nuclear explosion may be derived from both the heat and shock from a nuclear device, the extent of benefit depending upon the characteristics of the particular reservoir.

Gas Sands

In some respects the possibility of using nuclear explosives to increase the production of natural gas generally has not been considered favorably. First, natural gas usually is considerably more producible than oil. Second, if an equivalent reservoir volume is affected by a nuclear explosion, the potential economic returns should be somewhat greater from producing a liquid than from producing a gas.

There are, however, appreciable reserves of natural gas in U.S. reservoirs in which the formations are relatively nonproductive because of inadequate permeability and which have adequate depth and thickness that nuclear stimulation may be considered. Also, the problem of radioactivity contamination of produced fluids, one of the most formidable problems inherent to nuclear stimulation, would be minimized considerably if the fluid produced is a gas, rather than a liquid because most of the radioactive fission products resulting from a nuclear explosion are solids or condense to solids which have a high solubility in liquids.

Oil Shale

Considerable technology has been evolved on the mining, crushing, and retorting of oil shale, the refining of shale oil, and the utilization of shale-oil products. As of today, however, this country does not have an oil-shale industry, although interest in the the possible use of shale oil as a fuel has been maintained over many years and currently is high.

The use of nuclear explosives in producing oil from oil shale may be considered in two respects. Nuclear explosives instead of chemical high explosives might be used in conventional mining operations. This use would, of course, entail removing, crushing, and retorting the broken rock in surface facilities. Or the nuclear explosive might be used to crush the rock with the objective of retorting the oil from the rock in place. The success of such an operation would depend upon many factors about which there is inadequate present knowledge. To assess the feasibility of combining nuclear-explosive crushing and fracturing with in-situ retorting, it would be necessary to know much more about the size range and distribution of blocks and particles of oil shale that might be broken by a contained nuclear explosion Knowledge also would be required of the practicality of retorting in place shale crushed to a considerable range of block and particle sizes.

Some research has been performed on in-situ retorting of oil shale. However, the literature is essentially devoid of the results of these experiments.

Tar Sands

Bituminous sands have an advantage over oil shale as a potential medium in that the bitumen contained therein is a liquid, although a very viscous one, and the sands themselves do have permeability. Thus, the heat from the explosion might be expected to have some beneficial effect in reducing the viscosity of the bitumen either through cracking, or simple heating, or both. Inasmuch as bituminous sands in general, and the Athabaska tar sands in particular, are relatively unconsolidated and friable, it is possible that the force of the explosive would not be as effective in stimulating production as would be the case in harder and more consolidated rocks of oil and gas reservoirs.

PROBLEMS OF UTILIZING NUCLEAR EXPLOSIVES FOR HYDROCARBON PRODUCTION

Nuclear stimulation of hydrocarbon production presents many problems. Some are amenable to solution by research; others are not.

The foremost problem, and one that can only be answered by an actual field experiment, if theoretical feasibility is determined, is technical feasibility. Regardless of laboratory research that may be done, data that may be accumulated from underground nuclear tests in various media, and theoretical feasibility studies that may be made, no one will be able to say with certainty that a nuclear device may be used to stimulate hydrocarbon production until an experiment is actually conducted and the results are thoroughly evaluated.

The second principal problem is that of radioactivity contamination of subsurface rocks and fluids, particularly aquifers, and the necessity to avoid any venting and surface contamination. Laboratory research can aid in solving this problem. For example, the fusibility of reservoir rocks and leachability from the fused material of specific radionuclides of interest can be determined. Such research now is in progress within the Bureau of Mines. Furthermore, present research on producing "clean" nuclear devices (those with a low percentage of fission yield and, consequently, low yield of fission products) may result in greatly lowered contamination probabilities.

Another problem is the effect of a nuclear explosion on reservoir rocks and fluids, and the manner in which--if any--this might be expected to affect hydrocarbon production. The results of the sample-exposure program conducted in the Gnome and Shoal events, followed by subsequent specific laboratory research, should yield data that will at least partly answer this question.

The solutions to other problems can only be surmised, not solved, through experimentation. Approval by Federal and State regulatory bodies of an experiment, and later of nuclear stimulation of production, and the effect of public opinion concerning the use of nuclear stimulation and the marketing of the resultant hydrocarbons fall into this category of problems.

ECONOMICS

It perhaps is premature to consider economic factors before technical feasibility has been determined. If no additional hydrocarbons, or even a minimum volume can be produced through using nuclear devices, it is apparent that the stimulative method will be uneconomic.

It is axiomatic that an economic process requires the market value of the product to exceed the total cost of production enough for the producer to realize a reasonable profit. For nuclear stimulation of hydrocarbon production to be economic, the technical feasibility first must be established. It must be demonstrated adequately that environmental radioactivity contamination can be avoided and that any radioactive contaminants in the produced hydrocarbons can be removed successfully. Finally, the volume and value of the recovered hydrocarbons must be appreciable enough to exceed the production cost by a reasonable amount.

It is most difficult to cite a realistic cost for contained, subsurface nuclear explosions. The Atomic Energy Commission has cited costs of $500,000 to $1,000,000 per test for the device alone, dependent upon the range of yield of the device used. This cost comprises providing the device, emplacing it through an existing hole or shaft and drift, checking, arming, and firing the device, and providing much of the environmental safety work required. We may assume that the costs cited are somewhat arbitrary because they are based on past tests, all of which have been experimental. Furthermore, it may be reasonably assumed that the costs of nuclear explosives for experimentation may be reduced and that, if an extensive commercial peaceful application is developed, the costs may be reduced even more.

It may be concluded that, for commercial utility of nuclear explosives: (1) Present cited costs ultimately must be lowered appreciably; (2) low-yield devices probably never will be commercially practicable although those of moderate-to-high yield may be; and (3) the device diameter and construction must be such that the explosives may be emplaced and detonated through a drill hole of reasonable diameter (smaller than the 30- to 60-inch holes previously cited for present devices).

CONCLUSIONS

Information now available is not adequate to permit concluding either that nuclear explosives can be used or cannot be used to stimulate the production of hydrocarbon fluids. In fact, the desirability and the feasibility of conducting a field experiment have not been demonstrated conclusively. The potential is adequate that a determination should be made, relatively soon, as to whether a field experiment should be recommended and planned. If it is concluded that nuclear stimulation may be feasible for producing hydrocarbons, a field experiment is an absolute necessity for determining technical feasibility. Then, and only then, can the economic feasibility be determined.

On the basis of data now available, the fact that oil and gas reservoirs in general contain mobile fluids indicates that nuclear devices should be more useful in oil or gas reservoirs than in deposits of tar sands or oil shale. This indication is strengthened by calculations that show more potential benefit from fracturing than from heating.

The use of nuclear explosives in bituminous sands or oil-shale beds, however, cannot be ruled out on the basis of present knowledge. The tremendous reserves of hydrocarbons in oil shale in the United States and in bituminous sands in Canada and the relative cost and difficulty of producing shale oil and bitumen by present methods constitute a powerful incentive for additional consideration of the feasibility of nuclear stimulation in these media.

Generally, the economic incentive for stimulating the production of nonrecoverable oil is greater than that for nonrecoverable natural gas. However, the problem of radioactivity contamination should be minimized in gas reservoirs.

Radioactivity contamination still is perhaps the most formidable problem in considering peaceful uses of nuclear devices. In a formation containing enough silica, it may be hoped that most of the fission products would be fused in glass having negligible solubility. This possibility might be enhanced by surrounging the device with a suitable fusible material.

The spherical zone of effects of a nuclear explosion may be disadvantageous for an experiment in an oil or gas reservoir, because few nonproductive deposits are thick enough to permit using multikiloton devices. If, however, the force of the explosion could be directed into an ellipse, rather than a sphere, the benefits might be greater. This possibly could be done by design of the nuclear device itself, as is done with the shaped chemical explosives used for shooting oil wells. Also, it might be possible to initiate horizontal fractures within a reservoir by hydraulic fracturing, by the use of high explosives, or by perforating before the nuclear explosive is used, thereby extending the linear distance of fractures induced in the formation by the nuclear explosion.

For a final feasibility determination, prior to recommending an experiment with a nuclear device in a hydrocarbon reservoir, additional data are needed on the fusibility and leachability of reservoir rocks, on the in-situ effects upon reservoir solids and fluids of the shock, heat, and radioactivity from a nuclear explosive, and the nature, orientation, and extent of fractures in hard-rock media. Similar data are needed for oil-shale and tar-sands deposits. Research now in progress and planned should at least partly provide these needed data.

Although no one concerned with the petroleum industry can state at present that hydrocarbons can be produced, economically or otherwise, by using nuclear explosives, the potential is such that it warrants further careful study and consideration.

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