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Status Report on the Three Nuclear Experiments For Stimulation of Tight Gas Sands

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STATUS REPORT ON THE THREE NUCLEAR EXPERIMENTS FOR STIMULATION OF TIGHT GAS SANDS

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INTRODUCTION

The National Gas Survey published by the Federal Power Commission (FPC) in 1973 speculated that there could be as much as 600 trillion cubic feet of natural gas in low-permeable reservoirs in the Green River, Uintah, and Piceance Basins (Figure 1). This gas is contained in multiple sand lenses interspersed throughout 2000 to 4000 foot thick intervals. The report identified that although technology had not been developed which would allow commercial exploitation of this resource, two potential technologies, stimulation by massive hydraulic fracturing and by the use of nuclear explosives, should be explored.

This presentation is limited to discussion of the three experiments utilizing nuclear explosives performed to date: Project Gasbuggy detonated on December 10, 1967; Project Rulison detonated on September 10, 1969; and Project Rio Blanco detonated on May 17, 1973. No significant activities are currently being conducted on Gasbuggy and Rulison, however, there are continuing tests being conducted at the Project Rio Blanco site. Figure 1 shows the location of the three experiments and their relative relationship to the tight gas reservoirs.

Project Gasbuggy, being the first experiment to use nuclear explosives, was designed primarily to investigate the mechanisms which controlled the gas production and to determine gas quality subsequent to the detonation. Information gained from this experiment led to a second experiment, Project Rulison, which had as its primary objective the task of evaluating the economics associated with the potential development of the Rulison field.

Since multiple nuclear explosives were required for economical operations, two explosives detonated simultaneously in a single wellbore were initially proposed; however, it was decided to use a single explosive until questions related to ground motion effects could be answered. The experiment was designed to enhance the predictive capabilities developed during Gasbuggy related to reservoir modeling, gas quality, the various physical effects such as damage caused by ground motion, and seismic disturbances, and to develop more efficient operating practices. The costs associated with the experiment were much more than had been anticipated, however, much of the increase was due to misdirected environmental concern, legal activities, and the resulting operational constraints.

The technical information gained from Project Rulison was encouraging and led to Project Rio Blanco, which was designed to use three nuclear explosives detonated simultaneously in a single wellbore to stimulate a large vertical interval containing multiple sands. Since this was to have been Phase I of a field development demonstration program, the scope of activities investigating the potential effects on the environment, public health and safety, and future operations were somewhat greater than that required for an isolated experiment.

It was believed that the most desirable economics involved the use of explosives designed for sequential detonations, however, this would require further explosive development. Consequently, expediency limited the scope to demonstrating the feasibility of stimulating the large vertical intervals, particularly since a fourth experiment, Project Wagon Wheel, in the Green River Basin was being designed to utilize sequential detonations.

PROJECT GASBUGGY

Project Gasbuggy utilized a 29 ± 3 kiloton thermonuclear explosive detonated at 4240 ft in the Lewis Shale Formation in the San Juan Basin. The mechanical effects were determined through data gained by drilling pre and postdetonation wells and production tests.

Figure 2 depicts both the drill holes and an artist's concept of the chimney and fracture configuration.[1] Several methods were utilized in calculating a void volume of 2.3 to 2.6×10^6 ft^3; and the cavity radius (R_c) of 80 to 88 ft. The height of the chimney above the detonation point was determined to be 330 ft by the reentry drilling program. No lower extent was physically determined, but it is assumed to be equal to at least one cavity radii making the overall chimney height approximately 415 ft. Cores were taken to investigate the lateral extent of the fractures and no change in the rock was detectable beyond 350 ft. The effective fracture radius as determined by production testing appeared to be on the order of 300 ft. The data indicate that any fracture closure after the detonation occurs quickly and the effect, if any, is incorporated in the estimated effective fracture radius. A late time fracture closure seems to have been ruled out through a six-month's production test conducted in 1973 which detected no major changes in the producing characteristics over the preceding six years.

Gas quality had been a major concern, however, the results of the experiment showed:

1. Particulate radiation produced with the gas would not be a problem.

2. If gas production were delayed four months, it would principally contain two radioactive nuclides, tritium and ^{85}Kr; and of the two, tritium was established as the component of greatest biological concern.

3. Although heat from the nuclear detonation decomposes minerals from the sandstone creating a sizable quantity of CO_2; it is a one time occurrence and can be handled by conventional processing.

4. After two to three cavity volumes of gas have been produced, the gas composition becomes essentially that of the native reservoir.

PROJECT RULISON

Project Rulison utilized a 43±8 kiloton explosive detonated at a depth of 8426 ft in the Mesaverde Formation. A small diameter explosive was emplaced in a 10-3/4-inch casing thereby providing a sizable economic advantage over Gasbuggy which required a 20-inch casing. In addition, the resulting residual tritium was approximately one-fourth that of Gasbuggy.

One of the questions favorably answered was that Gasbuggy data could be extrapolated to detonations occurring at the much greater depths where much of the resource in the Rocky Mountains occurred. Rulison demonstrated that although some minor modification was needed to reconcile the Gasbuggy data to that obtained from Rulison, the predictive techniques were essentially correct and could be confidently utilized for future experiments. Figure 3 shows an artist's concept of the chimney configuration. It should be noted that only one physical parameter was obtained through drilling, and this was the point where extensive fracturing was encountered. Penetration into a void volume did not occur. The interpretation is that while slant drilling, the target area was overshot and the drill hole is located in a highly fractured area just outside the rubblized zone associated with the chimney. The cavity radius was determined by production testing to be approximately 75 ft. The chimney height above the detonation point is assumed to be near the point of total lost circulation or approximately 265 ft. Assuming the lower boundary to be one cavity radii, this gives a total chimney height of 350 ft.

Postdetonation gas quality measurements agreed with the predictions derived from experience developed from Gasbuggy. The initial chimney gas contained a large percentage of CO_2; but, again, it decreased with production. Both tritium and krypton-85 concentrations were essentially as predicted and declined with gas production as shown in Figure 4.[2] A total of 108 days of flow testing was conducted in three different stages with an accumulated total gas production of 455 MMCF. The data associated with the gas flow and subsequent buildup was utilized in a reservoir simulation model to calculate the long-term production associated with the well as shown in Figure 6.

An important result from Project Rulison was the experience gained in predicting ground motion and the corresponding damage to structures. Several thousand buildings within a 20-mile radius of the emplacement well resulted in 325 claims averaging approximately $375 apiece. Of these, over 100 were associated with old chimneys, some of which were initially unstable and many had deteriorated mortar. A small program established to investigate the effect of bracing to structures at detonation time led to the conclusion that much of the damage could have been avoided by applying structural bracing techniques on a large scale.

PROJECT RIO BLANCO

Project Rio Blanco involved the detonation of three 30 kiloton nuclear explosives emplaced in a single wellbore at depths of 5840, 6230 and 6690 ft in an attempt to stimulate a 1300 ft interval in the Fort Union and Mesaverde Formations. The explosives were specifically designed for gas stimulation with 1) each explosive system containing a cooling package to allow it to be utilized in high temperature environments, 2) a small diameter of less than 8-inches and 3) a combined total residual tritium of less than 10 percent of that associated with Gasbuggy. The explosive control system, capable of being located in a remote area, utilized microwave signals for command and monitoring of the explosive and nearby effects experiments. The explosives were lowered into the 10-3/4-inch encased hole on 7-inch casing, and containment was provided by placing a 2400 ft cement plug and water to the wellhead above the explosives.

Because this was to be the first stimulated well in a minimum 26 well demonstration program and one of the first Atomic Energy Commission activities requiring an environmental impact statement, the efforts in collecting pre and postdetonation data were a great deal more extensive than either of the previous experiments. Effects experiments associated with ground motion, hydrology, seismicity, rock falls, fault motion and even subsurface experiments related to shock waves effects upon oil shale were instituted. Seventeen wells were drilled for effects measurements and eleven existing water wells were instrumented. In addition, long-term sampling programs were conducted on other existing water wells and springs within a radius of 15 miles. Extensive environmental sampling was performed to establish a radioactive background baseline and detect any postdetonation changes. As a result of the Rulison experience, a more elaborate structural bracing program was instituted to minimize potential damage due to ground motion. In addition to further the commercialism of the technology, private insurance to cover damages due to ground motion from nuclear explosions was obtained for the first time.

The postdetonation information associated with these efforts confirmed within expectations virtually all of the predictive techniques related to these activities and added to the body of data needed to refine them.

The reentry into the cavity was delayed for about four months in order to allow the more troublesome radionuclides to decay. The reentry was accomplished by quickly drilling out the cement plug in the 7-inch casing; however, communication was not established through the pre-emplaced production casing as planned due to buckled casing near the explosive.

A sidetracked hole was used to encounter the heavily fractured region at 246 ft above the top explosive. Production test data used in the reservoir model indicated a cavity radius of 66 ft. Both of these dimensions were within predictions. However, gas flow tests also indicated that the expected coalescence between the three explosive regions had not occurred. Upon completion of the test program for the top chimney, a second reentry well, RB-AR-02, was drilled. It intercepted first the fractures resulting from the bottom explosion at 107 ft from its emplacement point, and secondly the chimney boundary at approximately 77 ft from the emplacement point (Figure 5). Again, both flow tests and chemical analyses indicated that the lower chimney region was not in communication with the upper two. The confidence level is high that all three explosives detonated successfully with approximately equal yields. The chimney height of the top explosion and the chimney radius of the bottom obtained through reentry drilling confirms past experience about single chimney geometries. It had been predicted that simultaneous detonations would result in a significant fracture enhancement between the explosives; however, this did not seem to occur, and there is no substantiated explanation available on the lack of communication.

Several independent evaluations of the reservoir at the Rio Blanco site were performed prior to the detonation, and the resulting estimated reservoir capacity within the interval to be stimulated by the top explosion ranged from 4.1 to 7.6 millidarcy-feet (md-ft). Measurements from the top chimney indicate a capacity of only 0.73 md-ft, which is a factor of 6 to 10 times lower than expected. Properties of the Mesaverde Formation in the vicinity of the bottom chimney appear to be in much better agreement with the predetonation estimates. All of the reservoir analysts judged the reservoir capacity predetonation to be ~1.0 md-ft compared to ~0.5 md-ft deduced postdetonation.

These deduced results should not be considered as representative to the overall Piceance Basin reservoir properties. The experiment is located on the edge of a large unit comprised of approximately 145 sections in an area known to be marginal. It was important to be adjacent to one of the two wells tested during the feasibility study and time and cost considerations did not appear to warrant drilling a new evaluation well at a more favorable location. Experience has raised questions as to the validity of using production tests on one set of sands and extrapolating these to others on the basis of logs as was done in this case. Consequently, a decision was made to drill a well (RB-U-4) just outside the fracture region within 600 ft of the emplacement well for further virgin reservoir evaluation to more precisely define the stimulation which has occurred. Shut-in pressure and flow tests will be conducted over the next few months in this evaluation well, and possibly interest in the phenomenology associated with the simultaneous detonation of explosives will lead to the conduct of a third reentry through the region between the uppermost and middle chimney penetrating into the second cavity. There are no definite plans for this latter program since it is totally dependent upon future Federal budget allocations.

A calculation of the potential production from the top Rio Blanco chimney region along with a comparison with similar calculations for Gasbuggy and Rulison is shown in Figure 6. Preliminary economic calculations have been made using a modified completion technique which doesn't depend on chimney interconnection and consists of drilling a production well which intersects the individual fractured regions. The assumptions for the modified technique are stated in Table 1. A range of numbers shown in Table 2 were developed to compare with those of the FPC's Task Force using two different cases: one utilizing ruggedized explosives which could be detonated sequentially and the other involving smaller yield simultaneous detonations. In both cases a lack of communication between chimneys was assumed. The Task Force study envisioned the use of sequentially detonated explosives and communication between chimneys.

The concentrations of CO_2 and the principal radionuclides in the produced gas from the upper chimney were generally within the range of predictability except that only 5 percent of the produced tritium was in the gas rather than the predicted 15 percent. There were some differences in the chemical composition of the gas produced from the lower chimney but only a few percent. The concentration of ^{85}Kr, however, was significantly lower in the bottom chimney, initially 300 pCi/ml as compared to 400 pCi/ml. Additional testing of the bottom chimney will be needed to resolve this difference. In any case, these concentrations present no health hazard as a result of the production testing.

It is of interest to note that radiation concentrations in the gas are very small and can be adjusted to lower levels by dilution. A case study(3) of a specific example of providing heating and industry-processed gas from nuclear stimulation in the Piceance Basin showed that a relatively modest program could supply a significant amount of gas to Colorado consumers through 1995. While there would be some residual radioactivity in the gas, the resultant radiation dosage to individuals would be less than one percent of natural background. Figure 7 shows the exposure to individual gas consumers as a result of such usage and for comparison the Denver level of natural radioactivity background of 180 millirems per year.

The utilization of gas from the Rulison well has been studied in detail by the Oak Ridge National Laboratory(4) in cooperation with Colorado Interstate Gas Company, and they have also concluded that the dose accruing to users would be less than one percent of background.

Colorado Interstate Gas Company(5) in investigating the marketing of the Rulison gas found that the regulatory problems associated with the utilization of radioactive by-product material were substantial. First, in order for a consumer to use the gas, a basis must be established for a license exempt classification no matter how small the radioactive content. This would require a change of current rules and an environmental statement. Then, the producer and the pipeliner of the gas must be licensed to manufacture and possess the radioactive material.

It was estimated that this regulatory process, between the time of application and the time in which a license was granted, could take up to two years as well as costing an applicant a substantial amount of money. This fact has discouraged further efforts in marketing of the gas which is particularly unfortunate when one considers that the Rulison gas is a safe supply of a scarce commodity and is available in a much needed location.

CONCLUSIONS

The information obtained from the three experiments indicates that the development of nuclear gas stimulation technology is technically feasible but that a substantial development program would be required. The costs associated with the experiments have been excessive, however, much of this was due to misdirected environmental and safety concern, legal action, political opposition, and administrative procedures. These factors resulted in abnormal operational constraints, time delays and a multitude of unnecessary experiments and superfluous activities. Although experiments have demonstrated that nuclear explosives can be safely utilized for resource extraction; and it appears that acceptable operational costs can be attained, the success or failure of alternate energy programs along with social and political factors will govern whether such development will ever take place.

In the November 1974 elections a Constitutional Amendment was approved in the State of Colorado which would require any further detonations of nuclear explosives in that State to be specifically approved by popular vote. It is important to note that the Amendment was phrased in such a way that the public was not asked to vote to approve a ban on further experimentation but simply that they be allowed to have a say in the matter. Unfortunately, the practical effect is, any further experimentation with nuclear explosives in that State is unlikely. There does not seem to be any significant political pressure to pursue the technology in any other location; and, consequently, the need for gas will have to be very severe and other methods of extraction very difficult and costly before nuclear explosives will be used.

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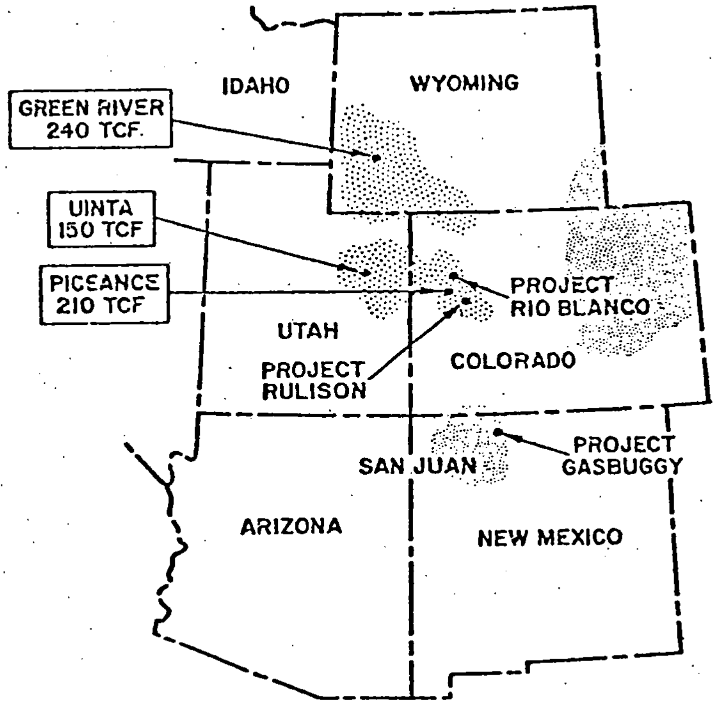

Fig. 1. Tight gas reservoirs.

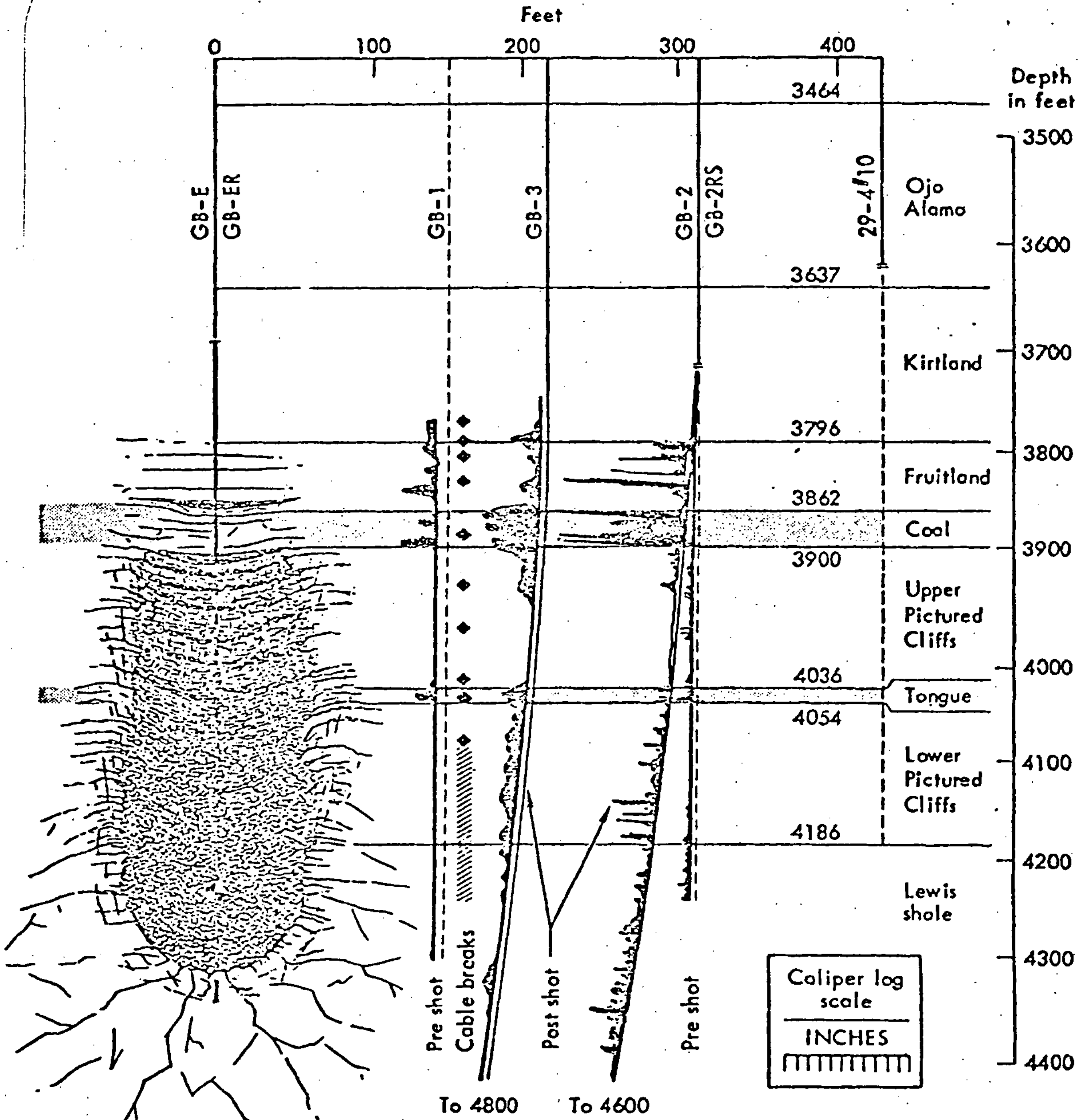

Fig. 2

Schematic cross-section through Gasbuggy. The scale of this figure is approximate only. The results of pre-shot and post-shot caliper logs, giving an indication of the fractured nature of the formation, are shown. (Holzer, reference 1)

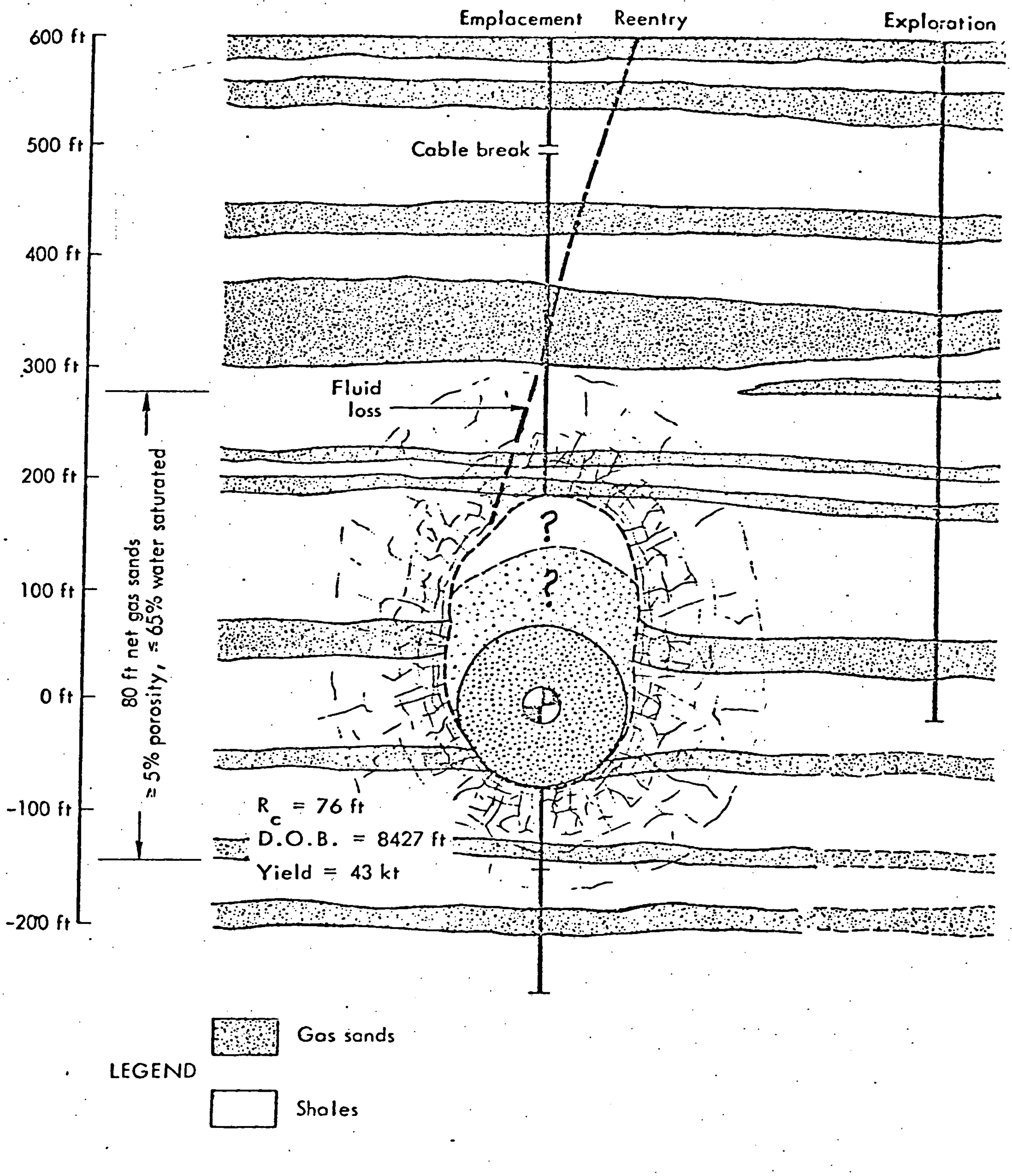

Fig. 3 Postshot cross section of the Rulison experiment. R_c = cavity radius; D.O.B. = depth of burial.

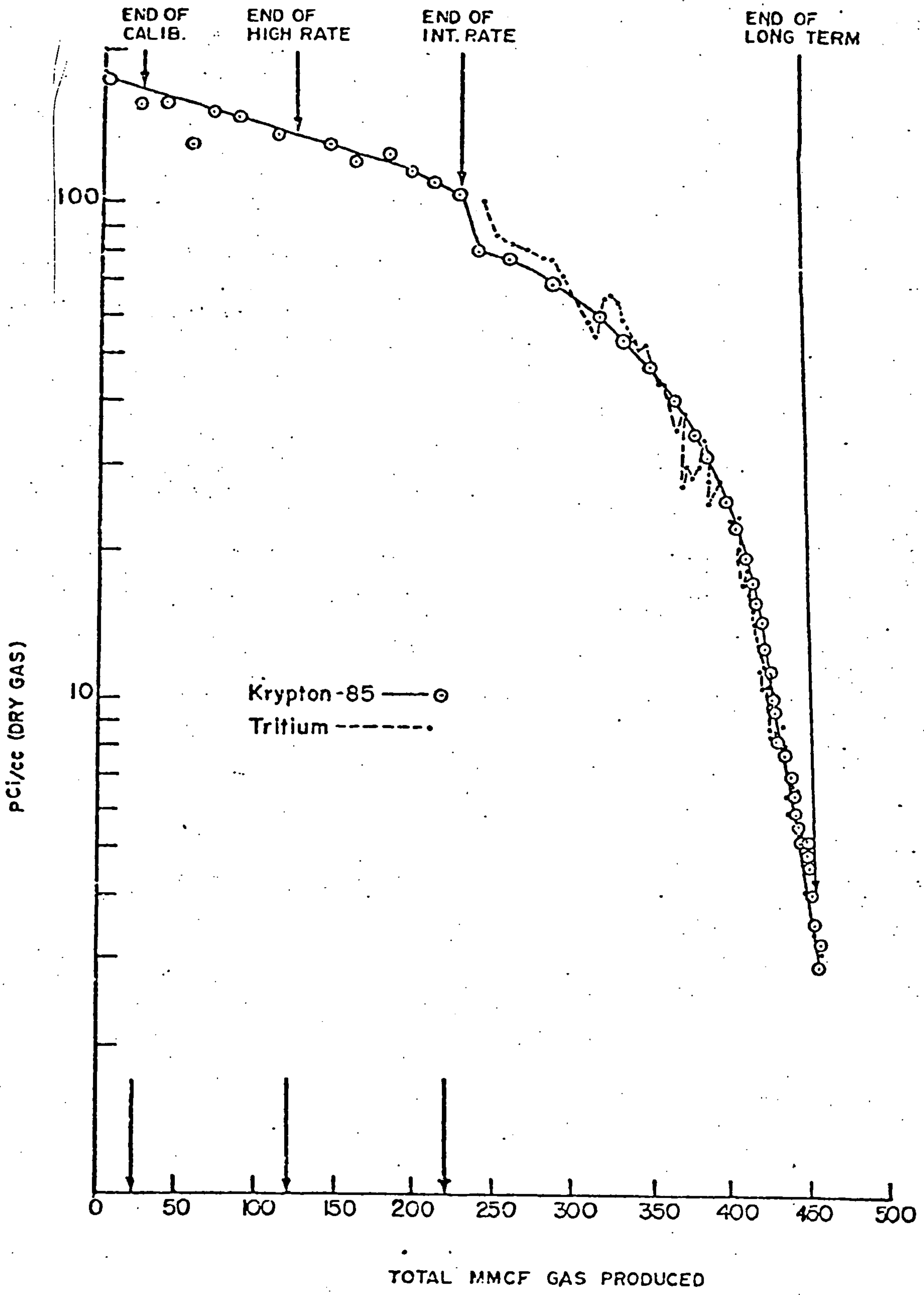

Figure 4. ^{3}H and ^{85}Kr concentrations in dry Rulison gas vs. volume of gas produced.

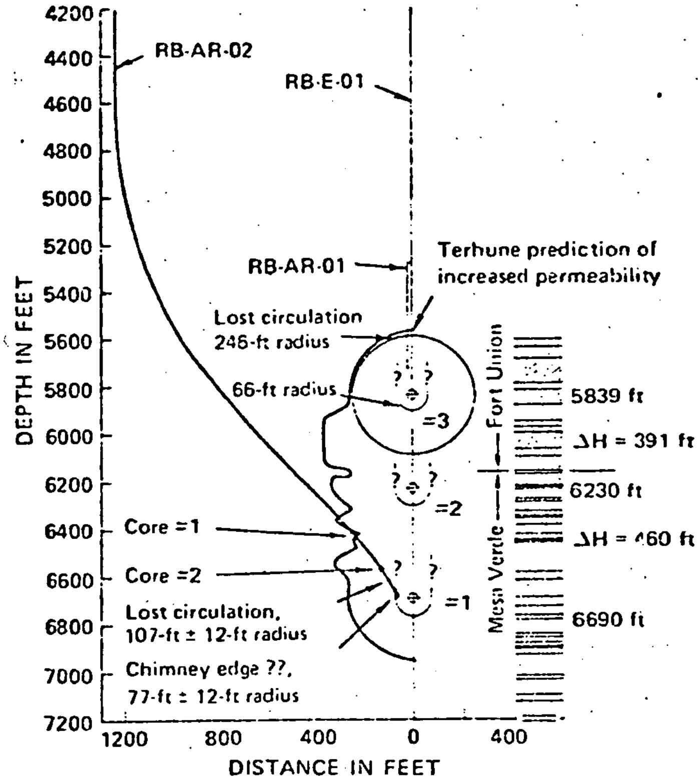

Fig. 5 Rio Blanco wells.

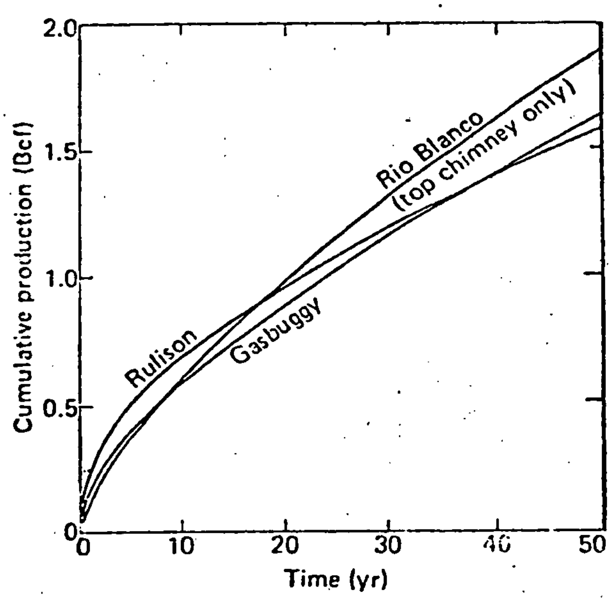

Fig. 6. Calculated long-term production.

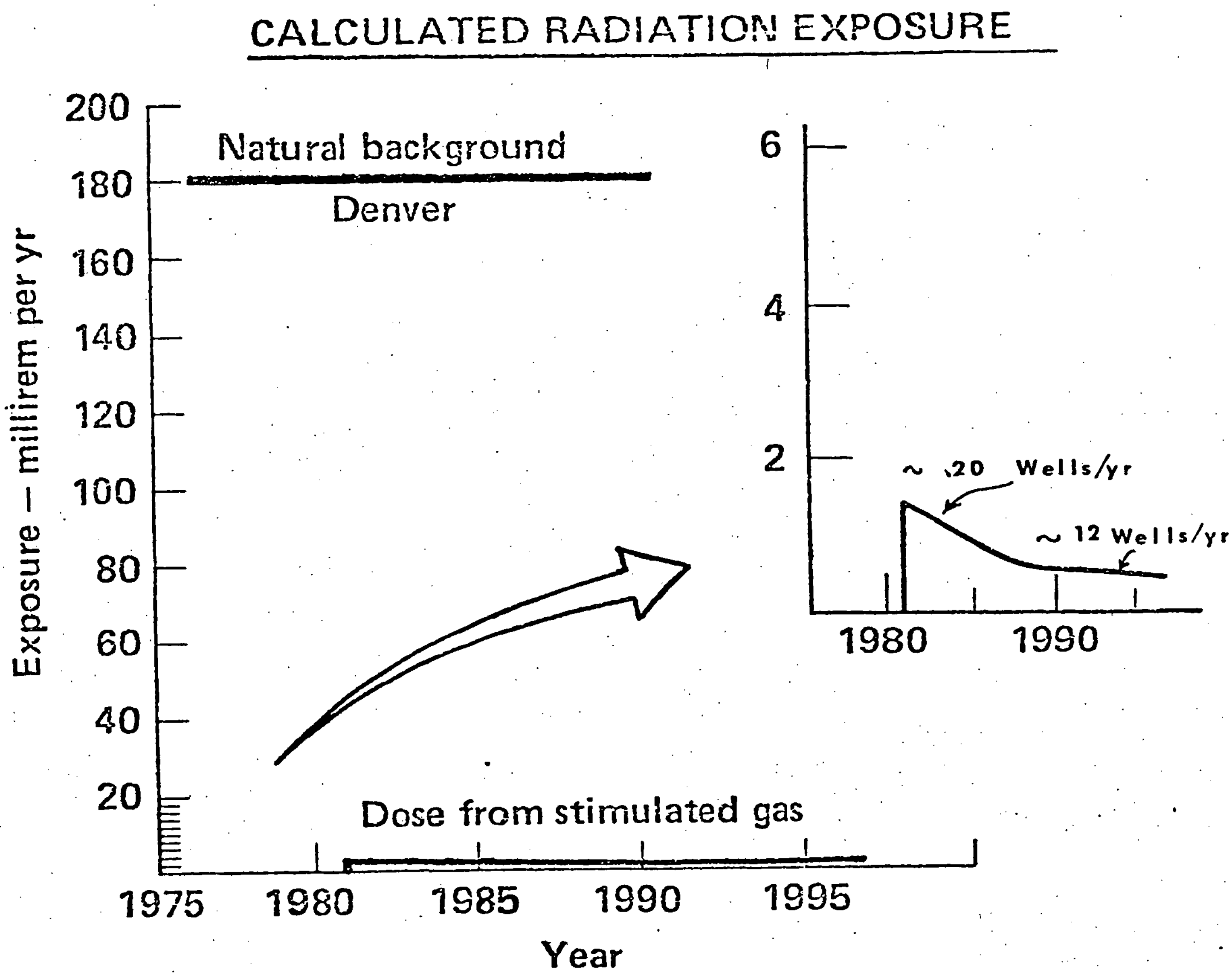

Figure 7. Calculated radiation exposure.