bureaucrats go about their business with the aid of "readers," outside scientists who would read grant applications sent to them and comment on them in writing. Readers would not necessarily know anything about other applications that were submitted in the same category and would, therefore, no longer make comparative judgments. There would, of course, be no more study section meetings.

The threatened abolition of study sections hits biomedical scientists hard. At the spring meeting of the Institute of Medicine of the National Academy of Sciences (NAS) earlier this month, peer review was very much on everybody's mind. As far as its impact on the biomedical community is concerned, the destruction of study sections would make the demise of training grants look like child's play. Though training grants have been enormously important to the financial stability of medical schools and research institutions, the peer review system has been the central mechanism by which researchers as a group control their own professional lives. Peer review places responsibility for decision-making squarely within the scientific community, where most researchers believe it belongs.

The rumored abolition of peer review by study section first came up for formal discussion at a meeting of the institute's committee on science policy, chaired by Leon O. Jacobson, dean of medicine at the University of Chicago. Henry Kaplan of Stanford University proposed that the institute and the academy jointly offer to study the peer review system with an eye to recommending any appropriate reforms. He expressed a feeling that many scientists share when he said that study sections may be too limited in their approach to life in that they tend to act only as juries. It might be useful, Kaplan suggested, if study sections took the initiative in pointing out experiments in need of doing, areas of research deserving of special effort, and so forth. Daniel Tosteson of Duke University agreed with Kaplan, reemphasizing the idea that the institute offer to take a hard look at the situation.

Throughout an hour's discussion of the problem, people seemed intent on taking a sensible approach to the threat. Nobody suggested dashing a telegram off to the President and many opposed taking the matter to the press before they could have an opportunity to lay their case before Weinberger and Edwards. While it was apparent that the measure of concern institute members were feeling ran deep, the hysterical responses that characterized many biologists' reactions to the training grant abolition was notably absent among these people who are desperately hoping to affect policy.

The most outspoken statement on the threat to peer review as it is known came the second day of the institute meeting when academy president Philip Handler addressed institute members at his own request. Until now, Handler has been relatively silent on health policy matters that have come up since the beginning of the year but he decided not to keep his peace any longer.

The very foundation of the biomedical research enterprise, Handler said in a brief extemporaneous speech, rests on open competition for research support. Now that the national cancer and heart institutes are channeling more and more of their resources into directed research through contracts, there is less and less chance for the individual researcher, especially the young. With more and more centrally directed research through contracts, institutions themselves are becoming the principal investigators in many cases, he noted, and went on to point out that by curtailing opportunities for broad participation in scientific decision-making, one opened the way for "small mistakes to become colossal mistakes." Acknowledging that the system erected by the NIH may not be perfect, Handler declared that it is preferable to "benevolent despotism which we have learned not to trust." He concluded by declaring that "this town is rife with rumors that the peer review system is about to be destroyed. If there is such a threat, it is the greatest so far to this remarkable biomedical research establishment." After his speech, Handler said that the issue should be brought to the attention of appropriate congressional staffs, particularly in view of the fact that there is no longer a science adviser to the President to whom one can go with issues that need to be dealt with above the departmental level.

Later that afternoon, the council of the Institute of Medicine passed a resolution urging its president, John R. Hogness, and Handler, to prepare a joint statement to the effect that no changes be made in the peer review system without a thorough study.

—BARBARA J. CULLITON

Rio Blanco: Stimulating Gas and Conflict in Colorado

Project Rio Blanco, a gas stimulation experiment in western Colorado involving three simultaneous 30-kiloton nuclear explosions in a single well, is regarded by critics of current national energy policies as fresh evidence of just how confused those policies can be. Barring a court injunction, the Rio Blanco shot will have been held on 17 May, just as this issue of *Science* is appearing. Environmentalists and certain other interests have been protesting the project, but, if this first nuclear detonation should in itself do significant damage, many of the protesters themselves will be surprised. What they principally are afraid of are the several hundreds, or indeed several thousands, of gas stimulation shots that might *conceivably* follow if the results of the initial detonation come up to the expectations of project sponsors.

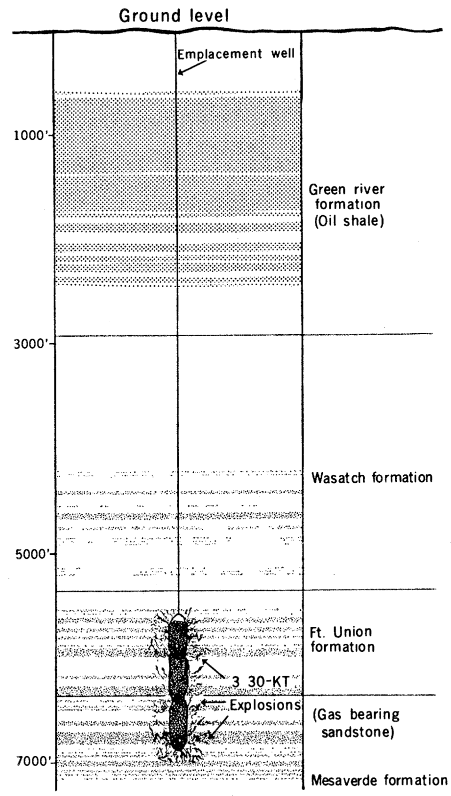
Yet, in truth, even officials of the Atomic Energy Commission (AEC), to say nothing of political leaders in Colorado and other Western states where "tight" gas-bearing rock formations occur, are in no little doubt whether conducting such large numbers of nuclear shots would ever be politically acceptable. Therefore, Rio Blanco raises the question whether, in the name of a purported national "energy crisis" and a very real natural gas shortage, an undue emphasis is not being placed on the use of nuclear technology and the AEC's unique capabilities in that field. The question becomes particularly pointed in the light of possible conflicts between nuclear stimulation of gas and timely exploitation of shale oil, a much more important energy resource.

The site of the gas stimulation experiment is in Rio Blanco County in the Piceance Creek Basin, a relatively high (5000 to 8500 feet), semiarid, sparsely populated region of northwestern Colorado. Ranching, together with some limited production of feed crops, is the region's major economic activity, although deer hunting brings many visitors and some money into the area each fall. The several towns in the basin, such as Meeker, Rangely, and Grand Valley, are all at least 30 miles from the Rio Blanco "emplacement well," where the three nuclear devices are to be detonated at depths between 5300 and 7000 feet.

Oil is produced in Rio Blanco County's Rangely Field, and there is some gas production from the Piceance Creek dome gas field east of the nuclear stimulation site. In general, however, Rio Blanco County is a place where a fabulous oil and gas bonanza has long been just around the corner, but not quite in reach. The reason is that, in the Piceance basin, the principal hydrocarbon resources exist in a form or in a medium which cannot be tapped economically by conventional petroleum technology.

High in the geologic column lies the Green River Formation, extraordinarily rich in oil shale. Of the 600 billion barrels of high-grade *recoverable* shale oil reserves in the Rocky Mountain region, two-thirds or more are found in the Piceance basin, making this 1500-square-mile area potentially the richest source of hydrocarbon energy on earth. The shale oil has thus far remained untapped because, so long as relatively cheap reserves of domestic and foreign crude oil have been available, mining the shale and producing the oil by a special retorting process has not been economically attractive.

Now, however, with domestic reserves of crude dwindling and the cost of foreign oil increasing, the economics of shale oil are becoming more appealing. In fact, the U.S. Department of the Interior, which manages the federal public domain lands making up most of the Piceance basin, already has planned a prototype oil shale leasing program for two 5120-acre tracts in the Piceance basin and four tracts in similar basins in Utah and Wyoming. Interior may call for competitive bids on these tracts by midsummer.



Geologic section at Rio Blanco site

Horizontal scale equal to vertical scale

[Kenneth Smith]

The other essentially untapped energy resource of the Piceance basin is the natural gas trapped in the pores of the sandstone of the deep-lying Fort Union and Mesa Verde formations, a mile to more than 1½ miles underground. About a third of the 300 trillion cubic feet of the possibly recoverable natural gas estimated to exist in rock formations in the Rocky Mountain states is in the Piceance basin, with the availability of this resource depending upon the development of effective stimulation processes. If indeed recoverable, this gas in tight formations in the Piceance and other basins would more than equal all other proven domestic gas reserves. Natural gas can in no case meet more than a small fraction of U.S. long-term energy needs, but it could continue to be used for several more decades as a clean, convenient fuel for home heating and other purposes.

The Equity Oil Company of Salt Lake City, which holds federal gas leases on some 55,000 acres in the Piceance basin, has been thoroughly frustrated in its efforts at producing gas there. Indeed, of the 50 wells Equity has drilled in the basin, only one has been successful. Gas will not be produced in significant quantities without an economical means of fracturing the sandstone formations around the well borings, and thus allowing the gas trapped in the pores in the rock to flow.

In some other gas-bearing formations not permeable enough for gas to flow freely, conventional hydraulic fracturing has sufficed to bring wells into production. As fluid is pumped into the well under pressure, a system of vertical fractures is created, reaching out laterally about 150 feet from the well bore into relatively shallow "pay" zones (the fracture system so created might be likened to the spreading, downward-sloping limbs of a Christmas tree). This conventional technology has not worked, however, in the Piceance basin sandstone because of the great thickness of the gas-bearing formations and the extreme impermeability of the rock.

As it happens, the AEC, in its Plowshare program for developing peaceful uses for nuclear technology, has been experimenting with nuclear stimulation of gas in tight formations since 1967 and its Gas Buggy experiment in New Mexico. The 29-kiloton Gas Buggy shot, and the subsequent 43-kiloton Rulison shot of 1969 in the lower Piceance basin, have in fact demonstrated that the flow of gas to wells can be successfully stimulated by such detonations. At the Rulison well, gas production was increased by at least ten times what might have been achieved by conventional technology.

Yet Gas Buggy and Rulison have not provided the answer to the problem of gas stimulation in the Piceance basin. As expected, these early stimulation shots caused some tritium contamination of the gas. Also, even the large "chimney" cavity and associated fracture system created by the explosion of a single nuclear device were not large enough to reach from the top of the deep gas-bearing formations to the bottom. To attain its theoretical ideal, nuclear stimulation requires an ability to place a string of "clean" nuclear devices in a single well bore, each at a different depth in the formation, to be fired either simultaneously or sequentially (the latter being preferable inasmuch as the seismic effects will be less).

The Rio Blanco experiment, featuring a string of three devices designed to explode simultaneously and leave less tritium contamination than either Gas Buggy or Rulison, is meant closely to approach this ideal. For anyone unfamiliar with the rarified realm of underground nuclear testing, merely the equipment put in place for Rio Blanco is startling to contemplate. Each of the three canisters containing a nuclear device and its related electronic hardware is about 30 feet long, has a maximum diameter of less than 8 inches, and weighs 2500 pounds. For each explosive canister there is a cooling system unit, placed in the well bore above the canister, containing a 33-foot water tank and three 36-foot absorber tanks.

The Rio Blanco shot will cost about $8 million, 85 percent of the expense to be borne by Rio Blanco's industrial sponsor, CER Geonuclear, Inc., of Las Vegas, which has a 50 percent interest in all gas produced under the Equity Oil Company leases. From the standpoint of the AEC's now much diminished Plowshare program, Rio Blanco is about the only game in the house. Otherwise, the AEC has nothing under way except a study by Kennecott Copper Company of the feasibility of in situ mining of copper with nuclear explosions, plus a preliminary study of the possibility of using such explosions for the in situ retorting of shale oil.

Of course, if the Rio Blanco project should begin and end with a single

Technological Innovation: New Study Sponsored by NSF

Until fairly recently, the working assumption in the United States has been that the relationship between basic research and technological innovation fitted the fable of the goose that laid the golden eggs. It was difficult to demonstrate a causal connection between science and successful technology in any but the most general way, but that didn't matter much until the rise in the research budget prompted a demand for proof that basic research produced an economic payoff. One result of this demand was to give impetus to the systematic study of the innovative process. The National Science Foundation (NSF), a chief federal patron of basic research, with an increasing responsibility for stimulating technological innovation, has had a major interest in such work and recently released a study called *Interactions of Science and Technology in the Innovative Process: Some Case Studies*,* done for it by Battelle Columbus Laboratories.

The new study, which cost $250,000, is a lineal descendant of TRACES (*Technology in Retrospect and Critical Events in Science*, an earlier NSF study) and, in almost every respect but that of a suitable acronymic title, represents an advance on TRACES. The same case-history approach is used in both studies, and in *Interactions*, in fact, three of eight case studies were taken from TRACES. These are on oral contraceptives, magnetic ferrites, and the video tape recorder. The five new subjects are the heart pacemaker, hybrid grains and the Green Revolution, electrophotography, input-output economic analysis, and organophosphorous insecticides. The new study builds on TRACES methodology, notably the concept of "events" to document progress toward innovation. But the Battelle report refines the analysis, by, for example, identifying "decisive events," and by stressing socioeconomic and managerial factors.

In the eight case histories, the authors put the aggregate number of innovations at ten, since they decided that the hybrid grains–Green Revolution case involved three major innovations (hybrid wheat, corn, and small grains). Analysis of the cases yielded a list of 21 "factors" deemed important in determining the direction and rate of the innovative process. "Recognition of a technical opportunity," "recognition of a need" for a particular innovation, and "internal R & D management" were the factors given highest ranking.

The authors were seeking to make generalizing statements about innovation. When they examined the cases in the light of eight "characteristics" reported in previous studies, they found that the importance of the "technical entrepreneur" was highlighted in eight of the ten innovations. They concluded that, "If any suggestion were to be made as to what should be done to promote innovation it would be to find—if one can!—technical entrepreneurs."

NSF set guidelines for the new report when it decided to fund a contract calling specifically for a "follow on" to TRACES. And *Interactions* can be best appraised when seen in the perspective of TRACES and other major earlier reports.

One criticism of research on the innovation process has been that the studies tend to reflect the interests and biases of those who perform them. Studies done in schools of business tend to stress managerial factors. Technologists are likely to stress applied research.

The first studies on innovation to gain public notice seemed mainly aimed at answering the question of whether spending on basic research was justified by technological results. A report titled Project Hindsight sponsored by the Department of Defense attracted fairly wide attention when its main findings appeared in 1966. Hindsight researchers backtracked on the trails of science and technology embodied in a score of major weapons systems and examined the assumption that investment in basic research by the military ultimately pays off in increased military power.

To the consternation of the partisans of basic research, the Hindsight conclusions were that basic research has very little to do with the development of weapons systems, mission-oriented research emphatically does.

The TRACES study carried out by the Illinois Institute of Technology Research Institute appeared in 1968

* A limited supply of a summary report titled *Science, Technology and Innovation* is available on request from the Division of Science Resource Studies, National Science Foundation, Washington, D.C., 20550.

bang, the only thing accomplished will have been to add to the technical lore about nuclear stimulation. The real payoff comes after the second and third phases of the stimulation experiment, when full development of the government's 93,000-acre Rio Blanco unit would be undertaken (wholly with private financing).

Yet, carried to fulfillment, Rio Blanco would be ambitious to say the least. Phase 2 of Rio Blanco would involve from four to six more well stimulations, with three to five explosions per well. Phase 3 would involve perhaps 20 to 60 more stimulations, with one emplacement well to each 640-acre section included in the project. Thus, the total number of devices detonated might exceed 300 even before the full development stage is attained. In the latter stage, the number of detonations might reach 1000, a number several times greater than the total of all those ever announced by the AEC in connection with its weapons-testing and Plowshare programs.

Quite aside from the possibility that something may go wrong, just the special safety precautions required for a large-scale and continuing program of nuclear stimulation are extraordinary. For instance, in the case of the initial Rio Blanco shot, all residents living within 7.5 miles of the emplacement well are to be removed to special assembly centers before the detonation. All mining operations within 53 miles of the well will cease temporarily, against the chance that miners might be injured in rock falls caused by seismic effects of the explosion. Also, traffic control is being established on all roads within the region, inasmuch as the explosion could cause rockfalls

Takes Socioeconomic, Managerial Factors into Account

and was interpreted as a riposte to Hindsight. TRACES focused on civilian innovations and concluded not that Hindsight's authors were wrong about basic research, but that they had erred simply by not going back far enough, that is, by limiting their quest to basic research only in the postwar years. Some skeptics noted that the NSF front office was solicitous about the fate of basic research and suggested TRACES was used as ammunition to defend fundamental research. If the critics did detect a note of special pleading in TRACES, there were also plenty of signs of a broader concern for finding ways to stimulate technological innovation. And this concern is even more pronounced in the new report.

Reaction to *Interactions* from those familiar with work on the subject seems to be that the new study is useful and an improvement on TRACES but that it is hardly definitive. The critics for the most part fault the study not for what it does but what it does not do. The criteria for the selection of cases were mainly (i) high social impact and (ii) selection from among a diversity of fields of technology and applications. The cases certainly fit these criteria, but there remains the question of whether they represent the full range of major types of innovation.

Herbert Holloman, former Commerce Department assistant secretary for science and technology and now at M.I.T., for example, notes that the case studies in *Interactions*, except for the one on input-output economics, are all "technically based" in the sense that they depend on an identifiable major breakthrough in science and technology. Many innovations depend on applications of simple ideas very much in the public domain, such as the supermarket cart, which made possible the self-service store, or on incremental advances as in the case of most safety devices and mechanical improvements in autos.

Another question raised was whether there isn't much to be learned from failures as well as successes. British researchers at the University of Sussex have followed this line of inquiry, gathering information on a number of "paired" cases of success and failure where similar innovations were involved.

At the time when the United States is facing a serious balance of payments problem and seems to be losing ground in the international competition in high technology products, an exercise such as *Interactions* might be expected to provide some analysis of the American position. The *Interactions* case studies stop, however, with the first successful marketing of the product or general use of the process made possible by the innovation. A study, for example, of the history of the electron microscope after its commercial introduction in the United States would throw light on how the Japanese were able to move in so successfully with further development and marketing of the instruments. As Holloman suggests, it would be interesting to see in detail how the United States "lost" the black-and-white television business. There have been some studies of the "diffusion" and "rate of adaptation" of technological innovation and it seems likely such studies will get more attention in the future.

What *Interactions* does best is to clarify the phases of the innovation process up to the point of innovation. It does not portray the process as a straight-line sequence of basic research, mission-oriented research, and development. Even in its schematic "historiographs" it shows how basic research findings feed into the process at different points and how progress toward one innovation often gives impetus to other innovations.

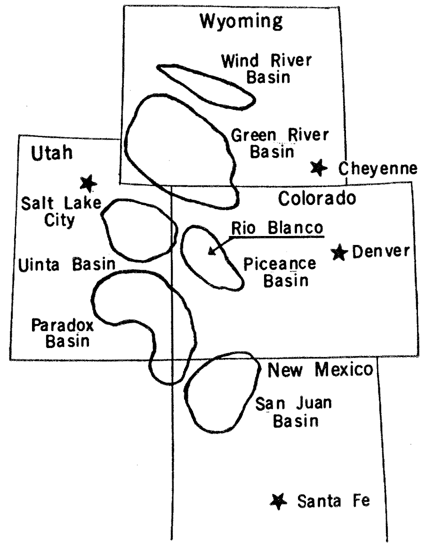
Such studies are necessarily simplifications aimed at identifying common factors of the process. Nobody has done for technological innovation what James Watson did for molecular biology in *The Double Helix*. Development of the Xerox machine no doubt involved an interplay of egos and accidents that doesn't show up in the charts. The authors of *Interactions* recognize this when they address themselves to the inevitable question, "Can technology be managed?" Their answer is a qualified yes. They think it is possible with the right timing, the right management, adequate funding, and the "confluence of technology," which means orchestrating contributions from several disciplines. Which pretty much means that innovation requires both luck and good management.—JOHN WALSH from the steep cuts and bluffs along highways.

Under conditions of full field development phased over the better part of a decade, nuclear stimulations might be limited to perhaps 30 a year, with these grouped so as to limit the total number of detonation days to as few as possible. Even so, the stimulation program, whatever its benefits, could be a worrisome nuisance, with new cracks in the wall plaster every year (CER Geonuclear is insured to cover claims arising from seismic damage; as many as 210 claims are expected from the first shot).

In its formal environmental impact statement on this initial detonation, the AEC seeks to lay to rest every fear raised by environmentalists and oil shale interests about things possibly going wrong. Any radioactive contamination of the oil shale beds, or any fracturing of those beds (which could make room-and-pillar mining methods impossible), would leave the well stimulation program almost friendless. But the AEC observes that its theoretical calculations and past underground tests indicate that no fracturing of the rock will occur more than 430 feet above the uppermost detonation, whereas the shale beds lie some 3000 feet above the point of detonation.

Moreover, the great depth of the detonation, the impermeability of the gas-bearing formations, and the absence of mobile groundwater there virtually preclude significant contamination of aquifers higher in the geologic column or the accidental venting of radioactivity to the atmosphere, the agency contends. The only deliberate release of radioactivity will result from flaring of the gas withdrawn during production testing. From this source, the AEC says, the radiation received by persons living as close as 5 miles to the Rio Blanco site will equal much less than 1 percent of annual background radiation.

The AEC has not always been right in predicting the effects of its underground tests, but its record is good enough that, for any given detonation, the chances of its being proved wrong seem fairly low. On the other hand, the chances of its being consistently right with respect to the environmental effects of hundreds or even thousands (if nuclear stimulation were used in other basins besides the Piceance) of detonations are perhaps none too high. In any case, the AEC certainly is not claiming that full field development of



Basins with deep, 'tight' gas-bearing formations
[Kenneth Smith]

nuclear stimulation is environmentally acceptable. To the contrary, it is emphasizing that the *only* thing currently approved is the one Rio Blanco shot now scheduled.

One immediate policy question is whether it is realistic, however small the hazard to public safety and the oil shale resource, to believe that Coloradans will accept a long-continued, large-scale program of nuclear stimulation. And, if not, why then undertake even the initial shot? Rio Blanco is intensely controversial in Colorado, and, even though Governor John A. Love and other responsible state officials have approved the first shot, their support is tepid if not grudging. For instance, the Governor is going along but only "reluctantly."

U.S. Senator Floyd K. Haskell, Colorado's newly elected Democratic senator, is flatly opposed to Rio Blanco and has been calling on the Nixon Administration to cancel or postpone the shot. Haskell's position in part reflects the attitude of environmental groups such as the Colorado Open Space Council and Citizens for Colorado's Future, which have brought suit against the state Water Pollution Control Commission in an effort to have a permit for Rio Blanco rescinded. (This suit was dismissed on 14 May, but a further court challenge is a possibility.) But sample polls taken in some of the towns in the Piceance basin show that, even there, at least a sizable minority of citizens is opposed to the Rio Blanco experiment. This is so despite the support for Rio Blanco among local business and political leaders who see Rio Blanco as the key to unlock long-inaccessible regional gas reserves (the AEC estimates that, over a 20-year period of gas recovery, each well stimulation would lead to the collection of $116,000 in county severance taxes, $674,000 in state ad valorem taxes, $3.6 million in federal income taxes, and $1.7 million in federal royalties).

The Rio Blanco experiment clearly cannot be justified with the argument that it is one part of a balanced, well-integrated R & D effort looking toward timely and maximum recovery of domestic energy resources. If it were, the operative question would be, How can gas in tight rock formations best be stimulated?, rather than the question the AEC has asked in Plowshare, How best to stimulate gas with nuclear detonations?

Indeed, there is some reason to think that the most acceptable way to stimulate gas in the Piceance basin, especially in light of the early start to be made on oil shale development, will be by *massive* hydraulic fracturing. This technique, already in use in some gas fields, is promising because the fractures produced can be up to 1000 feet or more in length, or five times the length of those produced in conventional hydraulic fracturing. Although it is as yet untried in the Piceance basin, where the extreme impermeability and depth of the gas-bearing sandstone pose a special challenge, Richard A. Morse, petroleum engineer at Texas A & M University, is confident that massive hydraulic fracturing will work there. Morse is a past president of the American Society of Petroleum Engineers and former head of petroleum exploration and production research for the Gulf Oil Company. He has been a member of a National Gas Survey task force which recently concluded that the gas of the tight sandstone formations of the West is susceptible to stimulation by either nuclear or hydraulic fracturing.

Significantly, Assistant Secretary of the Interior Stephen A. Wakefield, in a letter to Senator Haskell, has acknowledged that full field development of the Rio Blanco unit by nuclear stimulation is a "dubious proposition" and that more conventional alternatives, such as massive hydraulic fracturing, should also be investigated. The problem, he said, was that Interior had no funds to finance such a study. Thus, the field is left exclusively to the AEC, to try once again to find a useful peaceful application for its nuclear "devices."—LUTHER J. CARTER