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