same month, Soviet researchers at Kurchatov were responsible for significant discoveries concerning tokamak startup.

The Princeton results in July were particularly significant for their impact on both the world scientific community and political leadership. Newspapers from New York, to Moscow, to Paris began to report that "The tokamak results from Princeton prove that thermonculear fusion is possible" (*Le Matin*, Aug. 16).

A remarkable record

In the year 1979, many significant breakthroughs occurred in materials development, superconducting magnets and materials, fuel processing and control, plasma heating technology, and special diagnostic, measuring and monitoring equipment for experiments. When all of it was reported at December 1979 congressional hearings on fusion, which featured members of the Hirsch panel set up in collaboration with Congressman McCormack's energy research subcommittee, it became clear that no industrial or technological project had registered a comparable record of achievement in a recent period. And the fusion program had stayed well within its stringent budget, meeting or beating its timetables despite inflation and animosity from as high as the office of the energy secretary.

The testimony of Dr. Paul J. Reardon, head of the Princeton tokamak program, at the December 1979 congressional hearings, removed any remaining basis for lingering doubts. Reardon stressed to the congressional audience that the U.S. fusion program has already gone most of the distance to reactor-level technology.

In the past 10 years, the U.S. fusion program has increased the plasma volume in tokamaks by a factor of more than 10. For a working reactor, only a fractional increase beyond this is needed. In terms of **energy gain**, determined by multiplying temperature and density-confinement time, Princeton's Tokamak Fusion Test Reactor, the first industrial-scale magnetic fusion project, has improved on previous accomplishments by a factor of 10,000! Only another factor of 10 is necessary.

Thus, recent progress has not only demonstrated the scientific principles, but has laid the basis for the actual development of the engineering technology to which the McCormack bill now commits the nation. All-important from the economic standpoint, changes have been developed in tokamak designs that have led to much smaller reactors with a significantly higher power density. As a result, the capital-budget costs have been brought down to a level that is, even now, approximately equivalent to those of nuclear fission plants of the same size. But unlike conventional nuclear plants, once built, a fusion reactor's basic costs are over—the fuel is virtually free.

The impact on U.S. industry

A large and continually growing involvement of industry in fusion research and technology development will be the result of government efforts to meet the goals of the McCormack fusion bill, said Stephen O. Dean in a recent interview. "All the engineering technology needed means getting programs going in the private sector," said Dean.

Stephen Dean was formerly director of the Department of Energy's fusion confinement programs. He now heads Fusion Power Associates, a consortium of industrial and engineering firms created to promote fusion development.

Today, the U.S. magnetic fusion program is by far the largest and most rapidly progressing advanced research effort in the country. Both small, advanced technology firms and large aerospace corporations are already essential components of the program. There is a great deal more involvement of industry that is less conspicuous, according to Dean, and during the next 10 years, in which the United States is to complete construction of a fusion engineering device, he forecasts the involvement of both small and large companies from a variety of industrial sectors, and the revival of many industrial research and development capabilities that are presently idle.

The special expertise of the nuclear industry, aerospace and electronics concerns, computer firms, all the way to milling and metallurgical companies, will be required to develop and build power systems, special materials, superconducting magnets, special diagnostic equipment and instrumentation, and other technologies whose need only becomes clear in the course of the program's development.

Moreover, as in the NASA program of the 1960s, most of the technologies required for the fusion program will have immediate application in other areas.

Industrial involvement in the fusion program is nothing new, reported Dean. The first stellarator device in the late 1950s was wholly built by Allis-Chalmers and RCA. United Technologies, predominantly an aerospace firm, just completed construction of a tokamak device at the University of Texas, and has the capability right now to "build a slew of tokamaks if there was a demand for them, here or abroad," he said. Similarly, the Tokamak

Fusion Test Reactor now under construction at Princeton—it will be the first industrial-scale fusion device—is wholly contracted out to private industrial and engineering firms under Ebasco Services, a leading U.S. architectural and engineering design company, and a member of Dean's consortium.

In a similar way, Dean indicated, the construction of the fusion engineering device or FED specified in the McCormack bill will "involve many pieces of hardware to be contracted out, through government disbursements directly, or subsystem pieces put out on bid by a prime contractor like Westinghouse." By the end of the year, the Department of Energy will have laid out a policy for the next decade, he said. Beyond that, into the year 2000's realization of an actual commercial fusion reactor, the requirements are difficult to foresee at this time.

"It is not clear yet how many fusion test devices may be needed," said Dean. "We may require two or three generations of such devices, operating in parallel, rather than going directly from the FED to a reactor."

The status of the program

At present, the magnetic fusion program, funded by the Department of Energy at $350-$400 million, involves more than 2,000 engineers, scientists, and technicians primarily located at four national laboratories: Los Alamos Scientific Laboratory in New Mexico, Lawrence Livermore Laboratory in California, Oak Ridge National Laboratory in Tennessee, and Princeton Plasma Physics Laboratory in New Jersey.

Major experiments are also being conducted at General Atomic Corporation in San Diego and the Plasma Fusion Laboratory at Massachusetts Institute of Technology in Boston. Smaller efforts are supported at scores of universities and companies which either maintain separate small-scale fusion programs or are contractors for the major experiments underway at national labs.

Involved is frontier research and development into superconducting magnets, high-power microwave generators, large vacuum and refrigeration systems (cryogenic systems), diagnostics, computer control, and advanced materials including metal alloys, composites, and insulators.

Two of the largest and most complex industrial-scale projects in the United States are now being constructed for the fusion program. One is the Tokamak Fusion Test Reactor (TFTR) under construction at Princeton, scheduled for completion in 1982, and the second is the Livermore tandem mirror (MFTF-B) facility to be completed in 1984. TFTR is being constructed by the Grumman Corporation, the aerospace-defense firm that played a major role in NASA's moonshot program. Ebasco is the primary designer.

The Elmo Bumpy Torus is a major alternative confinement concept for which McDonnell Douglas, another aerospace firm, has already won the contract. Most of the funds for this device will go to a score of subcontractors involved in advanced technology areas such as microwave generators. Other major projects, such as the Engineeering Test Facility, the Large Coil Project, and the Blanket and Shelf Test Facility, will involve or already involve industrial corporations as the primary contractors.

As this indicates, two-thirds to three-quarters of the $400 million fusion budget goes to industry, either directly or indirectly. To obtain a commercial reactor by the year 2000, approximately $20 billion 1980 dollars will have to be spent, with a higher percentage going to private companies than currently, with a greater private industry input and management role, according to Stephen Dean.

The power supply industry

Dean gave an example of what would be needed from industry. "Fusion systems require ultralarge power systems. But right now reliability is a major problem. Blowouts, shorts, and all kinds of things can shut down an experiment for weeks or even months. The reason for this is simply that the power heaters or magnets, neutral beam heaters involving 100 kilowatts and up, are now beyond the state-of-the-art. If the fusion program's experiments are to progress at the pace required, we need a power supply that works every day for years at a time, not one or two days a week as at present. Industry must develop a power supply that works."

At present, he pointed out, the major companies like General Electric and Westinghouse are "booked up" producing conventional power systems. They do play a role in the fusion program's power systems, which are staged such that a motor generator will produce power for a more power-intensive device, and so forth. The big companies now produce only the first-stage motor generators, while smaller, specialized, high-technology entrepreneurial firms like Universal Voltronics produce the customized power-generating devices down the line.

The metallurgical industry

In other things, like cryogenic or super-refrigeration systems, needed to cool superconducting magnets and vacuum systems, the national labs have developed working experimental types, but scaling these up to the size required for a reactor will depend on industrial expertise.

"Whole new alloys must also be developed," said Dean. Experiments at the national labs will determine the specifications of the needed material. But then, the labs will have to go to the traditional milling and metals manufacturing firms to explain those specifications. They must help us learn how to fabricate the needed materials in a cost-effective way, meaning contracts for research and development."

The nuclear industry

Dean defined three special contributions that the U.S. nuclear industry could make. First, the industry's developed ability to do "neutronics calculations." High energy neutrons are the primary, energy-bearing product of fusion reactions, and complex calculations will be required at every stage of fusion experiments to determine how they behave. Second, the materials used in nuclear plants are precision-made and of higher-than-ordinary quality construction materials. This will be doubly the case in fusion device construction. Third, is remote handling of intensely irradiated materials. Special capabilities in this area have been developed by both the nuclear utilities and the aerospace firms, the latter for remote handling of objects in space.

The aerospace industry

As in NASA's space program, many primary-contractor functions in the fusion program will fall to aerospace firms.

The aerospace and electronics industries spread across the United States represent both a concentration of technology and a strategically located pool of manpower for the expanded U.S. fusion program. In the past, aerospace and electronics have engaged in 50 percent of all the research and development activities of U.S. industry, and have employed nearly half the scientists and engineers in all U.S. industry.

Because of the importance of these firms to the economies of a number of regions of the country, their redeployment into the development of fusion power could have obvious, dramatic benefits in terms of employment opportunities in all skill categories in these regions.

Aerospace and electronics have key contributions to make in special materials, superconducting technology, and switching and power storage techniques demanded by the high-pulse energy requirements of fusion reactors. Second, these industries can aid in building the large-scale test reactors for the 1980s and 1990s. This involves the rapid construction of complex, one-of-a-kind machines—dictated by test results and theoretical work. The experience of the aerospace and electronics firms in the space program makes them ideally suited for this kind of contractual work.

The computer industry

As Stephen Dean pointed out, "The fusion program at present has the biggest, fastest computer system in the entire country—with all labs hooked up by satellite." Instrumentation and diagnostic equipment must be computerized for high precision in fusion experiments. Computers also play a key role in simulations of plasma behavior. "To date, the national labs have developed the software for the specialized needs of fusion experiments," said Dean. "The computer firms will have to develop the hardware."

Dean summarized: "Over the next ten years, the fusion development program will require a lot from the aerospace industry and a lot from the power supply industry. Then there is the vacuum industry, the gyrotron and electronics industry, the high-power tool industry, and the instrumentation and computerized control industry. We'll need a lot from the existing nuclear industry, too. And of course, metallurgy and mining."

He might have continued the list. The construction of fusion reactor plants will readily incorporate the manufacturers of fossil-fueled boilers, fission reactors, heat exchangers, steam and turbine generators, and related equipment. Some of these industries will have to develop new technologies for manufacturing new magnet and vacuum systems. The chemical extraction and mining industries will be involved in the areas of reactor fueling and fuel supply, on-site fuel processing and production, and special alloys and materials: all told, an unprecedented development of existing industries, and the creation of many new ones.

The potential contractors

Fusion Power Associates, the industrial-engineering consortium headed by Stephen O. Dean, former director of the government's fusion confinement division, has a membership that begins to indicate the companies, large and small, that are now involved or will become involved in the development of fusion power technology. At present, the charter members are:

Aydin Energy Systems, BDM Corporation, Burns & Roe, Inc., Ebasco Services, General Atomic Company, Gilbert/Commonwealth, ILC Technology, Inc., JAYCOR, KMS Fusion, Inc., Mathematical Sciences, Northwest, Inc., McDonnell Douglas, Quadrex Corporation, Science Applications, Inc., Stone & Webster Engineering Corporation, Thermo-Electron Corporation, TRW, Inc., Universal Voltronics Corporation, Westinghouse.