their bolometer at sub-millimeter frequencies, by making the first interstellar observation[5] of the ground-state fine-structure line of atomic carbon (492 GHz), with a bolometer receiver aboard the NASA Kuiper Airborne Observatory. But the bolometer mixer suffers at present from an excessively narrow bandwith. With a bandwidth of only 1 MHz, the InSb bolometer requires several observations to measure a single Doppler-broadened spectral line from an interstellar molecular cloud. This narrow bandwidth also slows down the search for spectral lines whose wavelengths are not well known.

Before settling on SIS quasi-particle tunnel junctions, Richards had tried for years to harness Josephson pair tunneling for radioastronomy. He and other workers pursuing this goal have found the Josephson effect too uncontrollably complex to yield suitable mixers and photon detectors. The next big question, Phillips believes, is whether SIS receivers can successfully function at submillimeter frequencies (greater than 300 GHz). —BMS

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Tokamak ready for engineering test

"The Panel is pleased to record its view that the taxpayers are receiving their money's worth . . . While the US magnetic-fusion program represents only about a third of the worldwide effort, the US has become its unquestioned leader. As a result of this progress, the US is now ready to embark on the next step . . . exploration of the engineering feasibility of fusion power."

These encouraging words are to be found in the introduction of the Fusion Review Panel's report submitted in June to DOE's Energy Research Advisory Board. The Panel, headed by Solomon Buchsbaum of Bell Labs, cautions that the report is to be regarded as preliminary until ERAB acts on it at its next meeting, 18–22 August. The preliminary report was made public to solicit outside comment. Last February Edward Frieman, DOE Director of Energy Research, had asked Buchsbaum, as chairman of ERAB, to convene a panel to review the Department's magnetic-fusion program. The Panel was to consider "the judicious choice of the next major steps to be undertaken in proceeding from the current generation of experimental devices toward demonstration of economic fusion production."

After four months of meetings and visits to principal laboratories, the Panel concluded that recent progress in plasma confinement justifies confidence that "energy breakeven is near." The demonstration of breakeven (fusion power output equal to power input) is expected in at least one of the large tokamaks currently under construction—for example,the Tokamak Fusion Test Reactor at Princeton. Tokamak confinement, the Panel concludes, is sufficiently well understood that one can now make a realistic extrapolation to ignited plasmas. A plasma is said to be ignited when the fusion reaction supplies sufficient heat to maintain itself. The report expresses confidence that a device containing an ignited plasma can be built and successfully operated.

But the state of our knowledge is not yet adequate to determine an optimal plasma or field configuration for a working reactor, the Panel believes. "Nor can we be sure today that a safe, environmentally acceptable, economically attractive fusion reactor can be built and operated."

Recommendations. Their findings have led the Panel to a number of recommendations:

▶ Fusion engineering. The Panel concurs with the consensus it finds in the magnetic-fusion community that a tokamak engineering facility of some sort should be built "forthwith." This device, which would serve as the focus of a broad program of engineering experimentation and analysis, should contain a burning, perhaps even an ignited, plasma. A plasma is described as burning when it reaches energy breakeven.

But the Panel expresses "misgivings about the ETF, as it has been presented to us." This Engineering Test Facility is currently under conceptual development by a multidisciplinary group at Oak Ridge. A magnetic-fusion bill now before Congress, drafted by Rep. Mike McCormack (D-Wash), envisions the completion of such an ETF by1987. (See PHYSICS TODAY, May 1980, page 114.)

The Panel finds the ETF, as envisioned by the Oak Ridge group, "too ambitious. Specifically, we question the role envisioned for the ETF . . . .to bridge the gap . . . to the knowledge required to design [demonstration power reactors]. In our view the number of steps between such a test facility and a commercial reactor cannot now be specified." The desire to use the ETF as the ultimate testing facility for materials and engineering design parameters, the Panel feels, results in excessively "stressful requirements"—very high neutron fluxes, low component downtime, long burn times. As a result, "the complexity, cost and risk of failure are high."

Nevertheless, with present knowledge and what we will soon learn from the tokamaks now under construction, the Panel feels that a device containing an ignited deuterium–tritium plasma can be built. In this connection they urge that Princeton's TFTR "be exploited as early as possible."

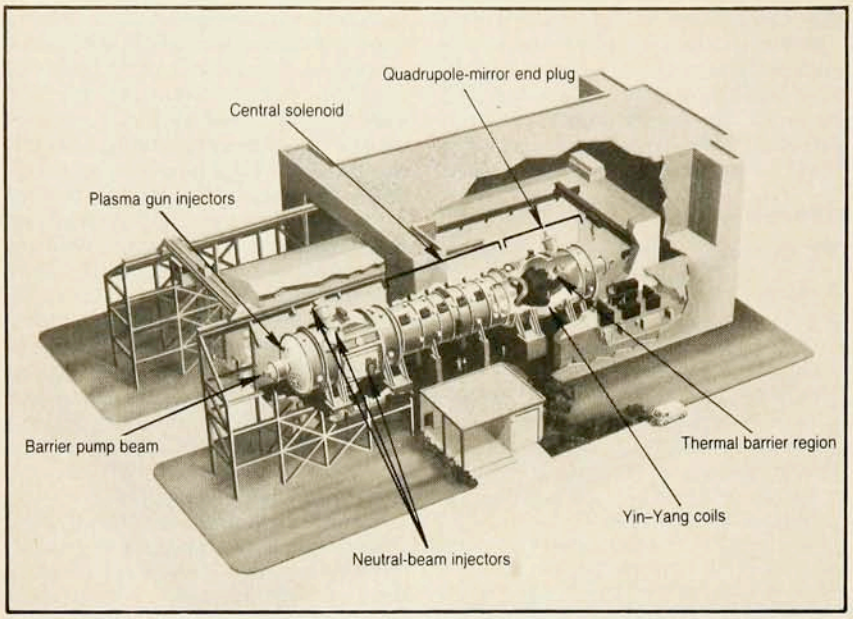
Instead of the ETF as currently conceived, the Panel proposes a more modest device, which it calls the "Fusion Engineering Device." This FED should be built during this decade at a cost not exceeding about one billion (current) dollars. It should nonetheless provide an ignited, or at least a burning plasma. Among the technological questions this device should address are problems of operator and public safety.

The Report proposes that DOE establish a Center for Fusion Engineering to coordinate a broad program of investigation in all areas pertinent to reactor engineering—for example, tritium handling and breeding, heat removal, rf power supplies, remote maintenance, fuel injection and "first-wall" technology. Major funding increases for this engineering program would not be needed till about 1983-84, by which time TFTR data should be available to help guide the design details of the Fusion Engineering Device.

▶ Fusion physics. In parallel with the engineering program, the Panel stresses the need for continuing basic investigations of fusion confinement in tokamaks, mirrors and alternative devices. "Such work is indispensable . . . and should be shielded from encroachment by the FED. No operating funds [for such] experimentation should be diverted to construction."The Panel calls for DOE to undertake a "vigorous advanced tokamak research program experimentation to study physics issues . . . " At present no such plans extend beyond the TFTR.

To make the tokamak attractive as a reactor, the report suggests, progress must be made toward steady-state (rather than pulsed) plasma-current drive, and more convenient plasma heating. One must better understand and control wall interactions, impurity behavior in long pulses, and plasma disruptions.

On a more basic level, an understanding of anomalous electron ther-



The Tandem Mirror Facility (MFTF-B), recommended by the Buchsbaum report for construction at Livermore, would be an expansion of the Mirror Fusion Test Facility currently under construction. An MFTF mirror would plug each end of a central magnetic solenoid. The higher temperature and lower pressure of the plasma in the end plugs would serve as a thermal barrier.

mal transport in tokamaks is needed, particularly at high temperatures and pressures. Macroscopic plasma behavior under these conditions is as yet untested. Recent theoretical results give grounds for optimism that plasma stability in tokamaks can be achieved at higher plasma pressures and greater helical twisting of the toroidal field than was previously believed possible. This could yield a significant payoff in size and cost of tokamak reactors. Therefore the Panel recommends the continued exploitation of relatively inexpensive, very-high-field tokamaks such as the Alcator devices at MIT, devoted to the study of plasmas "at interesting plasma parameters ... Other variants such as stellarators ... should be pursued on a modest scale."

Such an experimental program, the report suggests, "could be paid for in part by discontinuing or converting some present devices ... The Doublet III facility (at General Atomic) should be examined for conversion to a long-pulse, D-shaped, high-β tokamak ... The US program should continue to take advantage of productive international cooperation ... and avoid unnecessary duplication. The joint program with Japan seems especially attractive."

Two recent inventions—the tandem mirror and the thermal barrier—"have led to a resurgence of interest in the reactor potential of mirror machines." A tandem mirror system is basically a solenoid plugged at both ends by mirror machines. The thermal-barrier idea suggests that the confinement in such tandem systems be enhanced by having a lower-density, hotter plasma in the end plugs. The Panel recommends that the large Mirror Fusion Test Facility now under construction at Livermore (PHYSICS TODAY, March 1979, page 17) "be expanded at about twice the original cost into a comprehensive test" of the tandem and thermal-barrier ideas. This so-called MFTF-B facility is to be regarded "as a proof-of-principle experiment for open confinement systems." Recent theory suggests that axisymmetric end plugs might do better than quadrupole mirrors of the kind now under construction. The Panel recommends that the MFTF-B design be sufficiently flexible to allow a future conversion to such alternative end plugs.

The Elmo Bumpy Torus is something of a tokamak-mirror hybrid, combining attractive features of both. The Panel feels that work on the EBT should be strengthened, "with effort aimed at clarifying some near-term key physics questions." But they feel that the proposed "EBT-P" proof-of-principle device (see PHYSICS TODAY, October 1979, page 18) "is too large an investment, given the existing uncertainties in the physics of the EBT configuration." They suggest exploring the possibility of more modest experiments until more of the physics is known.

With regard to other alternatives to tokamaks and mirrors, the Panel finds that "the present level of effort ... is appropriate. We recommend that these levels remain commensurate with new discoveries in physics ... We do not recommend that each concept be pushed to the proof-of-principle level ... DOE should be highly discriminating in advancing existing alternative concepts much beyond their present scopes."

Commenting on advanced full cycles, beyond deuterium–tritium fusion, the Panel recommends "a strong, well-balanced program of theory, experiment and reactor analysis." A deuterium–deuterium cycle, for example, would eliminate the need for breeding radioactive tritium. Proton-based cycles are even more difficult to attain, but they "offer correspondingly higher potential rewards." Gaseous radioactivity is negligible, and the power output is primarily electromagnetic radiation rather than neutrons.

▶ Universities and industry. Universities have till now made major contributions to the physics of fusion, but their role in engineering and reactor design has been more limited. The report urges that "universities be called upon for an expanded role in engineering." A crucial byproduct would be the education of engineers with backgrounds appropriate to future needs.

At the moment, the role of industry is largely restricted to supplying equipment and services. The Panel feels that industry must become more centrally involved as fusion enters the engineering phase. But industry, the report cautions, will not invest heavily in a fusion program that does not have the "manifest long-term interest and support of the government, and in which initial competition for design research does not receive direct government support." The Panel intends that the Center for Fusion Engineering play a major role in securing competitive industrial participation.

Other members of the Panel were Robert Conn (UCLA), James Fletcher (Burroughs), John Foster (TRW), Eugene Fubini (Fubini Consultants Ltd), Marvin Goldberger and Roy Gould (Caltech), Wolfgang Panofsky (SLAC), Marshall Rosenbluth (Institute for Advanced Study, and Institute for Fusion Studies at the University of Texas) and Thomas Johnson (West Point).

The day after the Fusion Review Panel's report was released in June, the House of Representatives voted to restore $21 million of $23 million that the Appropriations Committee had previously cut from the President's proposed budget of $396 million for magnetic fusion in FY 1981. Whether or not this restoration reflects the influence of the Panel's report is not clear. But we are told that excerpts from the report were extensively, and at times passionately, cited during the floor debate. —BMS□