than one asks of a telescope sitting firmly on a mountain top.

"The Solar Optical Telescope is the cornerstone of our solar physics program for the rest of the decade," we were told by Edmund Reeves, NASA Program Manager for the SOT. Stuart Jordan (Goddard Space Flight Center) NASA's Project Scientist, will organize periodic working-group meetings of potential SOT users to further the implimentation of the project's scientific objectives. Estimated to cost an order of magnitude less than the $750-million Space Telescope, the SOT will be funded as part of the general Shuttle payload-development program; it will not need the separate Congressional approval a budgetary line item would require. The SOT is expected to fly on one of the presently existing Shuttles, but the first launch date, 1988 to 1989, depends on funding levels, Reeves told us. —BMS

High-energy electrons to probe nuclei

Quantum chromodynamics, the gauge field theory that describes strongly interacting particles in terms of their quark constituents and the "colored" gluons that bind them, promises us a definitive theory of the nuclear force. QCD has evolved in the past few years primarily through the rich theoretical and experimental progress of elementary-particle physics at very high energies. Now the nuclear-physics community, whose traditional experimental realm has largely been confined to much lower collision energies, has begun looking to QCD and multi-GeV electron accelerators to provide for the first time an adequate basis for understanding the short-range behavior of nuclear phenomena.

Because many details of QCD are still unclear and nuclei are complex many-body systems, this quest will require an extensive experimental effort. To this end, the Subcommittee on Electromagnetic Interactions of NSAC (the Nuclear Science Advisory Committee) has strong recommended the construction of a variable-energy electron-beam facility capable of high current, continuous (that is, cw rather than pulsed) operation up to 4 GeV. This is the principal recommendation of the Subcommittee's report, *The Role of Electromagnetic Interactions in Nuclear Science*, which was recently approved by NSAC for submission to DOE and NSF. The Subcommittee, headed by Peter Barnes of Carnegie–Mellon University, argued that a 4-GeV machine was needed to investigate the transition region from nucleon–meson to quark–gluon degrees of freedom in nuclei, and to provide sufficiently large momentum transfers to probe nuclei adequately at sub-fermi distances. Electrons are favored as the most suitable probes because they are pointlike particles, impervious to the nuclear force; their electromagnetic interaction with the constituents of nuclear matter is well understood.

This recommendation goes well beyond an earlier preliminary suggestion contained in NSAC's 1980 *Long Range Plan for Nuclear Science* (PHYSICS TODAY, May 1980, page 20), which called for a cw electron accelerator with a maximum beam energy of only 2 GeV. The stress on cw operation comes from the requirements of coincidence experiments. There already exist pulsed linacs (for example the two-mile-long Stanford Linear Accelerator) that provide nuclear physicists with electron beams of energy higher than 4 GeV. But when all the electrons arrive in microsecond bunches, true coincident signals are swamped by a background of spurious accidental coincidences.

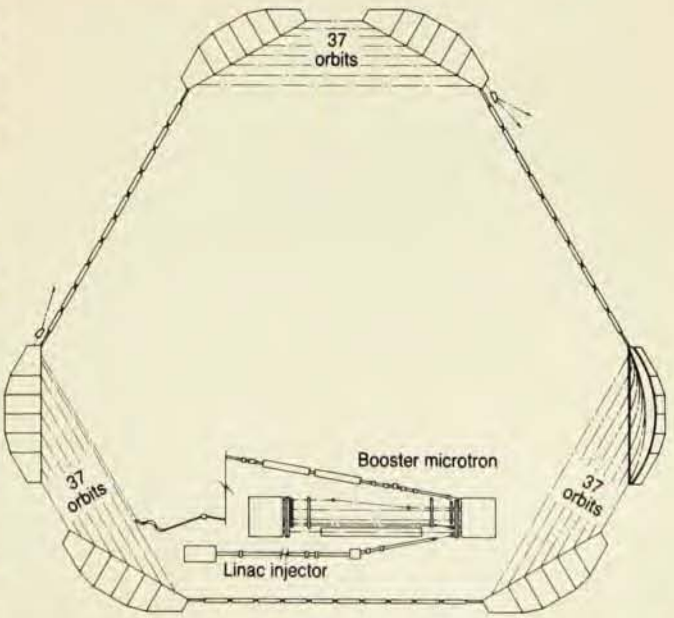
Three groups are preparing to submit proposals to NSAC by the end of the year for the construction of a 4-GeV, high-current, cw electron-beam facility. The Southeastern Universities Research Association, a consortium of 22 universities, has prepared a detailed proposal for a National Electron Accelerator Laboratory to be built at the site of the former NASA Space Radiation Effects Laboratory in Newport News, Virginia. The SURA accelerator would consist of a 2-GeV pulsed linac through which the electron beam would be recirculated once before injection into a pulse-stretcher storage ring—a device for converting the originally pulsed beam into one or more cw beams for experimenters.

Argonne National Laboratory will propose the construction of a 4-GeV "hexatron," a multi-sided, scaled-up generalization of a microtron. (The classic microtron is a small, low-energy, circular electron accelerator, somewhat akin to a cyclotron, first developed almost forty years ago in the Soviet Union.) Electrons will travel repeatedly around a hexagonal loop (hence the name) consisting of three linacs separated by three dispersive bending sections. The Hexatron is designed to fit into the ring building until recently occupied by Argonne's ZGS proton synchrotron.

The Bates Accelerator Laboratory at MIT is examining several alternative options for using the present Bates 400-MeV pulsed linac as the starting point for a 4-GeV cw electron facility. One possibility is to modify the linac for cw operation at reduced energy and build a system of multiple return magnets to recirculate the beam through the linac 15 or 20 times. Alternatively one could extend and modify the Bates linac for higher-energy pulsed operation and use a pulse-stretcher storage ring like the one proposed by SURA to produce continuous electron beams. The group will also propose, as a first step, a 1-GeV cw linac-stretcher facility which could be completed sooner and at lower cost. This would involve a more modest upgrading of the Bates linac and a smaller prototype stretcher ring. Although the technology of rf linacs and electron storage rings is well tried, the only tandem system of pulsed linac and pulse stretcher presently operating is a recently completed 150-MeV facility at Tohoku University in Japan.

Pulse-stretcher rings. RF linacs are

The hexatron, a six-sided microtron design with which the Argonne group proposes to achieve a continuous, high-current beam of 4-GeV electrons. Three 28-meter-long, 35-MeV linacs are interspersed with three pairs of bending magnets. The beam traverses the loop 37 times, each time with a larger radius of curvature in the bending magnets as its energy increases. The 185-MeV injection booster microtron is shown double scale.



capable of producing high-energy electron beams of very good quality, but pulsed operation is their natural mode. In continuous operation, their accelerating gradient would be severely limited by their high impedance. A cw linac with an accelerating gradient equal to that of the SLAC linac, for example, would dissipate 10 *megawatts* of heat per meter. Thus the SLAC linac must operate with a duty factor of less than 10^{-3}; microsecond pulses are produced with a repetition rate of about three hundred pulses per second. To do the coincidence experiments that are central to the program laid out by the Barnes Subcommittee with a tolerable accidental background rate (for example, the simultaneous detection of the scattered electron and a proton or pion), one wants to spread out the arrival time of the electrons so that the duty factor is close to unity.

The pulse-stretcher storage ring is an attempt to do just that. In the SURA design, 1.2 microsec pulses of electrons, having traversed the 2-GeV linac twice, are injected at 4 GeV into a storage ring of 380-meter circumference. Traveling near the speed of light, each 1.2 microsec pulse is 360 meters long, thus almost filling the ring. The pulse will traverse the ring about 800 times before the linac, with a kilohertz repetition rate, is ready to inject the next pulse.

During its first 30 circulations in the ring, the beam is subjected to pulsed rf energy compression; its energy spread is reduced to about 2 parts in 10^4 by an amplitude-modulated rf system. (The experimenters generally want electron beams with the narrowest possible energy definition.) For the remainder of the 800 circulations the beam is slowly and continuously extracted by septum magnets to one or more beam lines leading to the experiments. The SURA linac–stretcher project is headed by Harry Holmgren (University of Maryland) and James McCarthy (University of Virginia).

The microtron was proposed by V. I. Veksler in 1944 to deal with the problem that electrons, even at energies of only a few MeV, are too relativistic to be accelerated in the fixed-frequency cyclotrons used for heavier particles. In the classic low-energy microtron, extensively developed by Sergei Kapitsa and V. N. Melekhin (Institute for Physical Problems, Moscow), and Olle Wernholm (Royal Institute of Technology, Stockholm), a single rf accelerating gap is located near the edge of a circular vacuum chamber upon which a constant magnetic field is imposed. Electrons pass repeatedly through the gap, executing a larger circular return orbit around the chamber after each acceleration. If the electrons were nonrelativistic, the period of these cyclotron orbits would be energy independent. But in fact, each return of the relativistic electron takes longer than the one before. The microtron idea is to keep the returning electrons in synchronization with the constant-frequency rf field across the accelerating gap by setting the parameters so that each orbit period is precisely one rf period longer than the one before.

Such circular single-magnet microtrons have been limited to electron energies of a few tens of MeV, basically because the required magnet volume, and hence the cost, grows as E^3. To postpone this cubic growth of cost with energy, nuclear physicists have gone to generalized microtron configurations in which the 360° orbit bending is performed by a sequence of smaller magnets rather than a single massive magnet. The highest-energy microtrons presently in operation are two similar racetrack-shaped 100-MeV machines, at the Universities of Wisconsin and Lund, each with two bending magnets separated by a linac. The Wisconsin microtron will serve as a pulsed injector for the Aladdin synchrotron light source.

Microtrons lend themselves rather easily to cw operation. In the mid-1970s, Alfred Hanson and his colleagues at the University of Illinois built a cw, low-current, 66-MeV racetrack microtron with a single superconducting linac. In response to the recommendation for a 2-GeV cw electron machine included in NSAC's 1980 long-range plan, Harold Jackson and his colleagues at Argonne designed a racetrack-shaped microtron with two linacs and four 90° dispersive magnets. No matter what the configuration, the basic microtron concept remains the same: each successive traversal of the loop involves a larger path that takes a small whole number of rf periods longer to arrive at the accelerating element(s). When the recent study by the Barnes Subcommittee recommended an electron-machine energy of 4 GeV, Jackson told us, the two-linac microtron design was dead. The E^3 scaling of costs made a four-magnet configuration impractical at 4 GeV.

The Argonne group is therefore now working on the details of the hexatron proposal. To reach 4 GeV, the electron must traverse its hexagonal loop of three 35-MeV linacs interspersed with three dispersive, two-magnet bending sections 37 times. There would actually be 37 separate vacuum pipes in each dispersive section, to accommodate the increased radius of curvature of each successive circuit. Jackson stresses that this configuration would permit the easy extraction of three simultaneous experimental beams at three different energies.

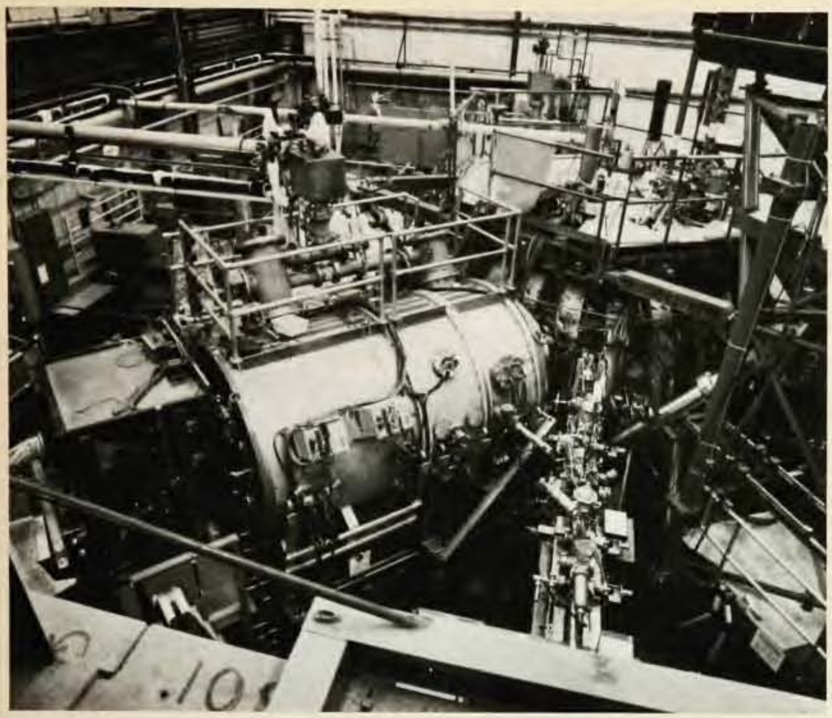
The primary complexity of the hexatron scheme is the problem of beam optics in the dispersive sections for orbit containment. Although the detailed Hexatron design is not yet as complete as SURA's, Jackson told us that the Argonne group has already demonstrated on paper that their focusing system will contain the 37 orbits. Quantum fluctuations in the synchrotron radiation, the primary source of energy spread at 4 GeV, should not present a problem for orbit phase stability, they conclude.

Multiple recirculation through a single cw linac is one of the two principal alternatives under study by the MIT Bates group. A single recirculation system has just been completed at the existing 400-MeV Bates linac, providing a maximum electron energy of 750 MeV with a duty factor of about 1%. To achieve continuous operation at 4 GeV one would have to install new cw klystrons, reducing the acceleration per pass to about 200 MeV, and recirculate the beam 20 times. Peter Demos, director of the Bates Lab, told us that they should be able to get 100 MeV of acceleration per pass with cw klystrons and other modifications of the present accelerating waveguide. "200-MeV per pass with a continuous beam will require an extension of the waveguide," he added.

"We will have to look at the relative technical and cost effectiveness of multiple recirculation and the stretcher-ring concept," Demos told us. Twenty recirculations to achieve 2 to 4 GeV will require a nested set of return magnets and the construction of additional return tunnels for the higher-energy paths. "We are tending toward an adiabatic approach," he told us, "planning to upgrade our present facility to make 1-GeV cw beams available relatively soon, and going to higher energy as the developing physics becomes clearer and the funds become available."

Beginning in the late 1960s, a Stanford High Energy Physics Lab group has been developing a small superconducting linac with a multiple recirculation scheme similar to the Bates idea, except that all the recirculations use a common pair of multi-track bending magnets rather than the nested set of separate magnets favored at Bates. Mutual interaction between successive beams and between the beam and the linac itself have limited the electron current of the HEPL accelerator to a few tens of microamps.

The Barnes Subcommittee report points out that at mometum transfers larger than 1 GeV/c, accessible with a 4-GeV accelerator, the scattered electron (more specifically, the virtual photon it emits) can probe the target nucleus at distances less than 0.2 fermi. At these short distances one begins to



Neutral-beam injectors operating at Doublet III. The photo shows two of the neutral-beam injectors at the experimental fusion facility operated by General Atomic Company in San Diego; six such beam injectors will eventually be installed. Four of the injectors are now in place and can deposit up to 5 MW in the Doublet III plasma. Earlier experiments with 2 MW of heating power have produced plasma temperatures up to 10^7 K. The Doublet III experiments are a Japanese–US collaborative effort.

resolve the point-like quark current in the nucleus. The report identifies a variety of new experimental opportunities that would be made available by this high resolving power of a 4-GeV cw electron accelerator:

▶ Precision measurements of nucleon form factors at distances of the order of 0.1 fermi would clarify the spatial extension and quark substructure of protons and neutrons.

▶ Form-factor measurement and inelastic scattering processes in deuterium and other light nuclei "will be crucial" in studying the interface between conventional nuclear dynamics and QCD.

▶ Electro- and photoproduction of vector mesons by polarized electron beams would elucidate the spin properties of vector-meson coupling to nucleons. Such experiments can also study nucleon isobar propagation throughout the nuclear volume.

▶ As a "subsidiary recommendation," the Barnes Subcommittee suggests the construction of a 1-GeV, cw electron accelerator. At this lower energy, coincidence experiments looking simultaneously at the electron scattered off a complex nucleus and an emitted nucleon, deuteron or alpha are needed to map the quantum numbers and strengths of discrete excited nuclear states and giant resonances. Whereas low-energy electrons can only knock nucleons out of outer nuclear shells, a 1-GeV beam can release nucleons that lie deeper inside the nucleus. At still higher energies, such studies will be relatively insensitive to final-state interactions, thus permitting good separation of transverse and longitudinal response functions in the study of single-nucleon hole states.

▶ Deep-inelastic electron scattering off complex nuclei can reveal quark substructure by the observation of deviations from single-nucleon additivity.

▶ Searches for parity violation in high-momentum-transfer elastic scattering off nuclei will provide tests of weak-interaction theories.

NSAC is expected to review the various proposals early next year and then make its recommendations to the funding agencies. The estimated cost of the SURA proposal is $75 million, with an additional $15 for spectrometers and other experimental equipment. "As we approach the energy regime previously reserved for elementary-particle physics," McCarthy told us, "we will need spectrometers as elaborate and costly as theirs." McCarthy stresses that SURA's linac–stretcher system can be upgraded to 6 GeV with relative ease. The SURA design can also accommodate supplementary rings to provide a dedicated synchrotron light source and an internal-target storage ring.

Although the Argonne group has not yet made a firm cost estimate for the hexatron, Jackson points out that the use of the existing ZGS facility represents enormous potential savings. The replacement cost of the ring building and experimental hall, he estimates, is about $50 million.

The 4-GeV proposals are all in the $100-million realm; they are not likely to be in operation much before the end of the decade. In the interim, Demos suggests, the nuclear-physics community could make very good use of a 1-GeV cw electron accelerator that could be built quickly, at considerably lower cost. Echoing this sentiment in its subsidiary recommendation, the Barnes Subcommittee did not specify whether the 1- and 4-GeV accelerators should be built at the same facility.

Samuel Penner's group at the National Bureau of Standards plans to propose a high-current, cw, 1-GeV racetrack microtron with a single, room-temperature linac. Previous attempts to produce cw microtrons of such a configuration with superconducting linacs have been limited to very low beam currents. —BMS

IUPAP handbook on symbols and units

The International Union of Pure and Applied Physics is in the process of revising its handbook, "Symbols, Units and Nomenclature in Physics." To take into account the views of the wider physics community, the Commission conducting the review is soliciting comments and suggestions on any of the matters covered in the report.

Comments on Sections 1, 2, 3, and 9, covering general recommendations for physical quantities, units, numbers and international symbols for units, should be directed to Pierre Giacomo, Directeur, Bureau International des Poids et Mesures, Pavillon de Breteuil, F-92310 Sèvres, France.

Comments on Sections 4, 5, 6, 7, and 8, covering symbols for chemical elements, nuclides and particles, quantum states, nomenclature, recommended symbols for physical quantities, and recommended mathematical symbols, should be sent to E. Richard Cohen, Science Center, Rockwell International, 1049 Camino dos Rios, Thousand Oaks, CA 91360, USA.

Additional single copies of the handbook (document U.I.P. 20) can be obtained from R. C. Barber, Secretary, IUPAP Commission on SUN–AMCO, University of Manitoba, Department of Physics, Winnipeg, Manitoba R3T 2N2, Canada. If more than five copies are needed there will be a charge of $0.50 per copy, plus handling charges. □