

HERA's construction resembles a covered-dish supper: DESY provided a menu with suggested contributions, such as magnets and correction coils. Each participating nation is paying for and building its agreed-upon components. Some of the R&D on superconducting quadrupoles is underway at the Centre d'Etudes Nucleaires, CEN, in Saclay. Italy is providing a large part of the superconducting bending magnets. The proton rf system is being built in collaboration with Chalk River Nuclear Laboratory in Canada. The superconducting quadrupole and sextupole correction coils have been built by NIKHEF, Amsterdam, in collaboration with Dutch industry. In addition, Great Britain and Israel have announced participation in HERA. Recently discussions on collaboration have begun with the US (Brookhaven), China (Institute of High-Energy Physics, Academia Sinica), and Poland (University of Krakow).

DESY has been exploring both the Brookhaven "cold iron" design and the Fermilab "warm iron" design for superconducting dipole bending magnets. The Brookhaven design for Isabelle surrounded the iron return of its mag-

nets with a cryostat. The Fermilab design for the Tevatron has "warm iron" for returning the flux of the magnets outside the cryostat (PHYSICS TODAY, March, page 17). DESY is doing the R&D on the warm-iron magnets and, in collaboration with Brown Boveri & Cie, is also doing R&D on cold-iron magnets. DESY has built and tested a number of 1-meter-long and 6-meter-long magnets. Now DESY is testing a 6-meter-long magnet with aluminum collars (whereas the collars used with the Tevatron are stainless steel). These test magnets have reached short-sample current in a few quenches; the maximum current reached is higher than that needed to reach 4.53 T, and the field quality is within tolerances. Meanwhile, Brown Boveri has produced its first 6-meter cold-iron magnet, which reached fields of 5.7 T, 25% above its design value.

Now 9-meter-long cold-iron hybrid magnets are being developed, combining the advantages of both previous designs. By the middle of 1985, DESY will decide what type of magnet to use.

Saclay has built and tested two superconducting quadrupoles that reached the necessary gradient (90 T/

meter) without quenching. Now Saclay is building more quadrupoles, which include a correction dipole and beam monitor within the same cryostat.

Volker Soergel is director of DESY. HERA project leaders are Gustav-Adolf Voss, responsible for civil engineering, the electron ring and the injection channels between PETRA and HERA, and Bjorn Wiik, responsible for the superconducting proton ring, including the cryogenic plant and the injection system for protons (linac, rebuilding of the synchrotron and rebuilding of PETRA).

This month a discussion meeting will be held in Geneva on plans for experiments at HERA. Letters of intent must be submitted by the end of June 1985. Those experiments recommended by the DESY Physics Research Committee will need to be presented as technical proposals in March 1986, with the final decision, on at most three detectors, being made in June 1986.

DESY hopes that the first circulating electron beam will be achieved in March 1988 and the first circulating proton beam in June 1989. First electron-proton collisions are expected in 1990.

—GBL

Has the Higgs boson been seen in the Crystal Ball?

From the Crystal Ball detector at the DORIS electron-positron collider in Hamburg comes strong evidence of an 8.3-GeV particle for which there appears to be no prosaic explanation. "If it's real, it has to be very important," says Gordon Kane (University of Michigan), expressing the widespread excitement that this new state has generated among high-energy theorists.

The Crystal Ball group, an international collaboration of 13 laboratories, finds evidence for this uncharged particle, which they call the zeta, in the radiative decay of the upsilon meson, a bound state of the bottom quark (b) and its antiparticle ($\bar{b}$) with a mass of 9.46 GeV (about 10 times the proton mass). If one didn't know better, the first explanation coming to mind would be that the zeta is simply the pseudoscalar ground state of the $b\bar{b}$ "bottomonium" system. But because the b quarks are so massive (about 5 GeV), theorists can apply nonrelativistic potential models to calculate the mass spectrum of $b\bar{b}$ bound states with considerable confidence. Such calculations clearly predict that the $b\bar{b}$ ground state should lie only about 40 MeV below the upsilon (9.46 GeV). The zeta (8.32 GeV) is more than a full GeV too light. With similar confidence in calculations of the charmonium spectrum, they dismiss the possibility that the zeta could be a highly excited $c\bar{c}$ state.

Higgs scalars. What most excites the high-energy community is the very real possibility that the zeta may be the long-sought-after Higgs particle. The standard theory of elementary particles makes almost no detailed predictions about the properties of the Higgs particle except to insist that it (or perhaps even several) must appear somewhere in the mass range between a few GeV and a few TeV.

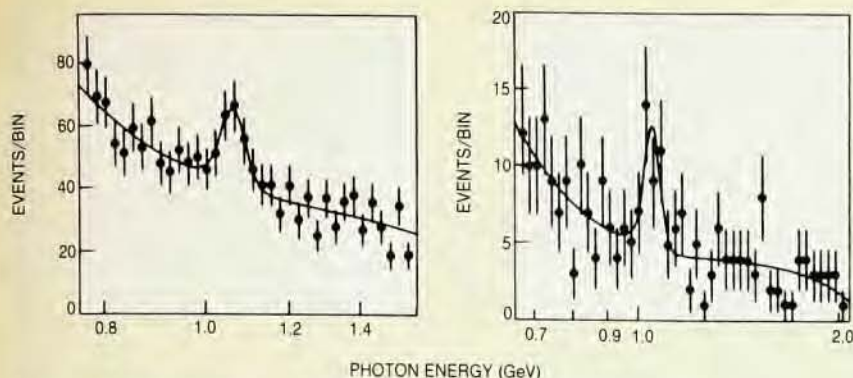
The predicted Higgs particle is a manifestation of the spontaneous-symmetry-breaking mechanism that permits the electromagnetic and weak interactions to look so different from one another despite the underlying symmetry of the Glashow-Salam-Weinberg electroweak theory that unifies them. This mechanism, invoking scalar fields with nonvanishing vacuum expectation values, was introduced twenty years ago by Peter Higgs (University of Edinburgh) to deal with the finite mass of the exchanged gauge boson in an early attempt at a gauge field theory of the strong interactions. We now know that any renormalizable gauge theory must have such additional Higgs fields if its gauge field quanta (the photon and the vector bosons $W^\pm$ and Z^0 , for example) and its fermions (the quarks and leptons) are not all to be massless.

The minimal Higgs mechanism for the electroweak theory predicts just one

doublet (in weak isospin space) of complex scalar Higgs fields. Thus there are four independent real component Higgs fields. When all four components vanish, one has a perfectly symmetrical state in which the vector bosons $W^\pm$ and Z^0 that mediate the weak interaction are just as massless as the photon, and all distinction between the weak and electromagnetic interactions disappears. But this symmetric state is not the lowest-energy "vacuum" state. In the true ground state, the Higgs fields "spontaneously" choose nonzero values, much as a ferromagnet chooses some aligned ground state despite the rotational symmetry of its Hamiltonian.

This spontaneous electroweak symmetry breaking is imagined to have occurred as a phase transition during the cooling of the early universe. As the Higgs field sought its lowest energy, its four component fields acquired nonzero vacuum expectation values, three of them becoming the longitudinal components of the weak vector bosons, giving the $W^\pm$ and the Z^0 the large masses (80-95 GeV) that characterize the weak interaction. (The photon remains massless; the electromagnetic field is purely transverse.) The remaining fourth Higgs component became the Higgs particle that all the experimenters are looking for.

What would this Higgs particle look



Evidence for the zeta was observed as a photon energy peak in two independent data samples by the Crystal Ball group. The appearance of this monochromatic photon signal indicates that the upsilon meson formed by e^+e^- collision in the DORIS storage ring decays radiatively to a previously unknown state of mass 8.32 GeV. The left plot shows the photon energy distribution for collisions with more than eight particles observed in the final state, suggesting that this new zeta particle decays to a pair of charmed quarks, each of which engenders a jet of hadrons. The plot at right, showing the photon distribution for events with fewer particles in the final state, suggests that the zeta also decays to $\tau^+\tau^-$ heavy-lepton pairs. No e^+e^- decay signal was observed. The two peaks, corresponding to the observed decay of about 114 zetas, have a combined statistical significance exceeding five standard deviations.

like? Although we have no useful prediction of its mass, we do expect it to have an extremely narrow resonant width—a few MeV at most for an 8-GeV Higgs. In the minimal one-doublet Higgs mechanism there is only one Higgs particle corresponding to electroweak symmetry breaking. It has charge and spin zero, and positive parity. (Grand unified theories uniting the electroweak and strong interactions predict additional much heavier Higgs particles, but these will have masses of at least 10^{14} GeV.)

Aside from its extraordinarily narrow width, the Higgs scalar should also be distinguishable from ordinary mesons by its decay modes. The Higgs interacts only weakly with quarks and leptons, but it is the source of their nonvanishing masses. Thus its decay rate into a particular fermion-antifermion pair is simply proportional to the square of the fermion mass. A Higgs particle with a mass of 8 GeV would thus decay primarily into heavy-fermion pairs— $\tau^+\tau^-$ lepton pairs and $c\bar{c}$ charmed-quark pairs. (The charmed quarks would not of course appear as bare quarks; they would manifest themselves as jets of hadrons.)

Selection rules permitting, an ordinary meson would decay overwhelmingly into hadrons, with a negligible branching fraction to lepton pairs. Even if energy considerations and selection rules suppress the hadronic decay of a meson, as is the case for upsilon (9.46 GeV), its leptonic decays would still look quite different from those of the Higgs. They would obey $e-\mu-\tau$ "universality". That is to say, because it couples to lepton pairs only by way of an intermediate virtual-

photon state, a decaying heavy meson would have roughly equal branching fractions to e^+e^- , $\mu^+\mu^-$ and $\tau^+\tau^-$. A Higgs particle, on the other hand, coupling directly into the mass of its decay products, would exhibit a strong preference for the 1.8-GeV tau, by far the heaviest of the known leptons; its decay to electron and muon pairs should be negligible.

The Crystal Ball detector is essentially a 2-meter-diameter spherical igloo made up of 732 NaI crystals. Elliott Bloom, spokesman for the group that built it in the late 1970s at the Stanford Linear Accelerator Center, told us that the basic idea for its geometry came from a Buckminster Fuller igloo depicted in the *Whole Earth Catalogue*. After operating for three years at the SPEAR e^+e^- storage-ring collider at SLAC, the Crystal Ball was moved to DESY (the Deutsches Elektronen-Synchrotron laboratory) in Hamburg in 1982, where DORIS had recently been upgraded to provide e^+e^- collision energies up to 11 GeV (in the center of mass). DORIS and SPEAR has begun life as very similar machines, with maximum collision energies less than 8 GeV, insufficient to produce the upsilon (9.46 GeV).

The detector surrounds the storage ring's electron-positron collision region almost completely with a highly segmented 16-inch-thick hollow sphere of crystalline NaI. Only about 2% of the full 4π solid-angle coverage is lost to the electron-positron beam pipe that must traverse the Crystal Ball. The principal purpose of this NaI igloo is to detect and measure high-energy photons, electrons and positrons emerging from an e^+e^- collision with high efficiency and high resolution in energy

and angle. These particles give up all of their energy in 16 inches of NaI, producing a scintillation signal that measures the particle's initial energy to within a few percent. The segmentation of the ball into 732 crystals, each with its own photomultiplier tube, not only provides good angular resolution; it also lets one distinguish between photons that come directly from the e^+e^- collision and those that come in tightly collimated pairs from π^0 decays.

Charged and neutral hadrons (pions, kaons and so on) also produce scintillation signals in the NaI, but in general they lose only a smaller, less predictable portion of their energy in the crystal. An array of charge-sensitive proportional-tube chambers in the hollow center of the Crystal Ball assists in counting and tracking charged hadrons and leptons produced in the e^+e^- collision, but there is no magnetic field to provide a momentum measurement by way of trajectory curvature.

The operation of the Crystal Ball at DORIS is a joint effort of six American and seven European groups. Bloom (SLAC) is the spokesman for the Americans and Johann Bienlein (DESY) is the European spokesman.

The zeta signal. The collaboration reported¹ its evidence for the narrow, massive new zeta state at the XXII International Conference on High Energy Physics at Leipzig in July. Running for half a year with the DORIS collision energy tuned precisely to 9.456 GeV, the mass of the upsilon, the group observed the decay of about 100 000 upsilons produced directly in e^+e^- collisions.

The Crystal Ball detector is particularly good at finding monochromatic photon peaks against a continuum background of photon energies. Such a peak would indicate the production and decay processes:

$$e^+ + e^- \rightarrow \Upsilon(9.46 \text{ GeV}) \rightarrow X + \gamma,$$

where the monochromatic photon peak signals a two-body radiative decay to some state X of definite mass, which one calculates straightforwardly from the observed photon energy.

The completely unanticipated evidence for the zeta appeared as narrow photon energy peaks in two independent data samples. Considering, first of all, collisions yielding "multihadron" final states—events with more than eight observed outgoing particles—the collaboration found a photon peak centered at 1.072 GeV with a width of only 70 MeV. Because 70 MeV is the detector's resolution for photons of this energy, the intrinsic width of the peak is presumed to be substantially narrower. This signal, exceeding four standard deviations, corresponds to the observation of about 90 upsilons decaying radiatively to a previously un-

known state with a mass of 8.32 GeV and a width too narrow to measure in the Crystal Ball detector.

This signal is presumed to represent the decay of the new state to an abundance of hadrons. The configuration of these events is consistent with the interpretation $\zeta(8.32 \text{ GeV}) \rightarrow c + \bar{c}$, the bare charmed quarks subsequently "clothing" themselves to form hadronic jets. Having seen a clear signal in this configuration, the group then looked for indications of the leptonic decay $\zeta(8.32 \text{ GeV}) \rightarrow \tau^+ + \tau^-$, which one would also expect to be prominent if the ζ is indeed the long-awaited Higgs particle. The tau lepton, invariably decaying within a few tenths of a millimeter of its production point, is not directly observable in the Crystal Ball. But because its predominant decay modes involve only a single (or occasionally three) charged particle, the group looked for $\zeta \rightarrow \tau^+ + \tau^-$ by selecting e^+e^- collisions with no more than eight particles observed in the final state.

They were rewarded with another narrow photon peak at almost precisely the same photon energy as the one found in the multihadron channel. This second peak suggests that about 24 zetas were seen decaying to a final configuration "enriched in $\tau^+\tau^-$ pairs," as Bloom puts it conservatively. No comparable zeta signal was seen in the e^+e^- final state, which is more clearly identified by the Crystal Ball detector. The combined statistical significance of the two zeta peaks is greater than 5 standard deviations, yielding a mass of $8.32 \pm 0.03 \text{ GeV}$ and an intrinsic width too narrow to measure.

The history of high-energy physics is replete with sad stories of 5-standard-deviation peaks that disappear when more data come in. But the group's confidence in the zeta signal is strengthened by the fact that it appears clearly in two independent final-state configurations. These results are based on 100 000 ψ decays observed in the first half of 1984. The collaboration is continuing to run at the ψ (9.46 GeV) energy, hoping that the zeta signal will still be about after several hundred thousand more ψ decays. Other groups at ψ and Cornell's CESR collider have now also begun looking for the zeta.

The interpretation of the $\zeta(8.32 \text{ GeV})$ as the Higgs particle runs into some immediate problems. The observed branching fraction for the ψ decay to $\zeta + \gamma$ is about 0.5%, a hundred times too large for the minimal one-doublet Higgs model as calculated by Frank Wilczek (then at Princeton) in 1977. The fact that the zeta has not yet been seen in the decay for first excited ψ state, $\psi'(10.02 \text{ GeV})$ presents

another difficulty. Naively one expects the branching fraction for the radiative decays of both ψ and ψ' to a Higgs particle to be roughly equal.

But the Higgs interpretation of the zeta is far from dead. Since the mid 1970's a number of theorists have proposed a fairly straightforward elaboration of the minimal Higgs model in which there would be two electroweak Higgs doublets. When Wilczek suggested in 1977 that the radiative decay of a heavy quarkonium state afforded perhaps the only reasonable opportunity to find the weakly coupling Higgs, he pointed out that a two-doublet mechanism would greatly enhance its coupling to quarkonium states like the ψ . Kane describes the motivation that led him and his Michigan colleagues Howard Haber and Thomas Sterling to work out the details of such a model five years ago as "largely esthetic." In the minimal model, they felt, the lone Higgs doublet was being asked to do too much—generating the masses of the gauge bosons and the fermions. Their model, in which the fermion masses are generated by one doublet, while the other generates the $W^\pm$ and Z^0 masses, corresponds better to the observed complexity of nature, Kane argues. How else does one explain the puzzling fact that the weak gauge bosons are so much more massive than the quarks and leptons, he asks rhetorically.

The high decay rate of ψ to ζ appears to rule out the minimal Higgs model decisively, but it can be accommodated by the two-doublet model. This model is a rather conservative extension of the minimal Higgs mechanism. It does not really do violence to the standard Glashow-Salam-Weinberg theory. The two-doublet Higgs model predicts the existence of five electroweak Higgs particles, three of them neutral and two charged. Two of the neutrals would have spin-parity 0^+ ; the third would be a 0^- pseudoscalar. The lone Higgs in the minimal theory must be a scalar. The Crystal Ball data have not yet pinned down the spin-parity of the zeta.

The absence of a zeta signal in the decay of the ψ' remains a problem. A recent detailed calculation of subtle bound-state effects by Henry Tye and James Pantaleone (Cornell) and Michael Peskin (SLAC) concludes that the branching fraction from the ψ' should be only 40% of that from the ψ ; but if no zeta signal is seen in the near future as the Crystal Ball gathers more data at the higher ψ' energy, the two-doublet Higgs model will also be in trouble. The suppression of the ψ' signal calculated by Tye and company (and required by the data) works only if the zeta is a scalar Higgs. While Kane's model suggests that a Higgs

particle as light as 8.3 GeV would indeed be a scalar, a competing two-doublet model recently put forward² by Wilczek (now at Santa Barbara), Kenneth Lane (Ohio State) and Sydney Meshkov (National Bureau of Standards) identifies the zeta with the pseudoscalar Higgs, leaving the ψ' problem unresolved.

An important confirmation required by the Higgs interpretation is a more definite identification of the $\tau^+\tau^-$ decay mode of the ζ . The Crystal Ball data suggest that the ζ decays to $\tau^+\tau^-$ very roughly $1/6$ of the time. But it will probably require one of the other detector systems to verify the $\tau^+\tau^-$ decay mode.

Other possible interpretations of the zeta appear to suffer worse maladies than does the Higgs. Heavy-quark bound states having been dismissed because of our confidence in the predictive powers of nonrelativistic potential models, one might consider high-lying light-quark states or even gluonium (quarkless bound states of gluons), where prediction is much more uncertain. But the high mass and narrow width of the zeta appear to preclude any such extended hadrons.

In supersymmetric theories, the gluon has a fermion partner—the "gluino." It has been speculated that the zeta might be a gluino-gluino bound state. But in all the supersymmetric models, Kane says, the bound-state width is too large and the decay rate from the ψ is too small to be accommodated by the Crystal Ball data. Furthermore, the experimental lower mass limit for an unstable gluino seems to preclude a bound state as light as 8 GeV, if the gluino is indeed unstable, as the supersymmetric theories suggest.

Tye and Carl Rosenfeld (Rochester) offer yet another possibility suggested by the supersymmetric theories. If there exist scalar quarks in addition to the ordinary spin- $1/2$ quarks, they calculate, a vector bound state of these "squarks" should be hiding directly under the ψ resonance. This state would decay radiatively into a squark-antisquark bound state that looks very much like the observed zeta. The phenomenological agreement is so good, they argue, that one might believe in these scalar quarks whether or not they are the squarks required by supersymmetry.

A certain *deja vu* attends the discovery of the zeta. A year ago, the Mark III detector group at SPEAR discovered³ a puzzling particle, the $\xi(2.22 \text{ GeV})$, which appears to be a lower-energy analog of the zeta. Found in the radioactive decay of the J/ψ (3.10 GeV) [the charmonium analog of the ψ (9.46 GeV)], the ξ lies 0.9 GeV below the J/ψ , too low to be the charmonium ground

state, and apparently too narrow to be a light-quark meson. There was at the time considerable speculation⁴ that this was the Higgs debut. The one-doublet Higgs mechanism requires that the Higgs be heavier than 7 GeV, but the two-doublet model merely requires that the quadratic sum of the three neutral Higgs particles exceed this lower limit. A recent calculation⁵ by Steven Godfrey, Richard Kokoski and Nathan Isgur at the University of Toronto, however, argues that the ξ is in fact a high-spin bound state of the strange quark and its antiquark.

"The structure of the Higgs sector is perhaps the greatest mystery of high-energy physics," Lane told the 1982 Snowmass summer study on elementary particles. "We all believe that the Higgs mechanism is responsible for electroweak symmetry breaking, but... we haven't a shred of experimental evidence that this is true, nor

what the Higgs sector consists of and how it works. Settling these issues, we believe, is the most important task of high-energy experiments in this decade."

—BMS

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R & D funding for the Super Collider

A group of 150 scientists led by Maury Tigner of Cornell submitted a report to DOE in May containing three reference designs for the Superconducting Super Collider. In June the Universities Research Association, which is to administer the R & D phase of the SSC project, designated Tigner as director of the SSC design and R&D program. The Department of Energy, in its FY 1985 budget request, had asked for \$20 million for R&D on the collider. However, it was not until mid-August that it decided to release the \$20 million at the start of FY 1985, on 1 October.

In a memo to DOE Secretary Donald P. Hodel, dated 10 August, Alvin Trivelpiece, head of the DOE Office of Energy Research, described the DOE review of the Reference Designs Study, which had estimated that SSC would cost about \$3 billion in FY 1984 dollars, excluding site costs, detectors, computer capability and start-up operations. An OER review of the study confirmed the cost estimates to within 10%. In addition the DOE Management and Administration Office of Project and Facilities Management reviewed the study and found that the "most studied of the three design options," presumably the 6.5-tesla magnet design, could be built for not more than 25% more construction money. Trivelpiece told us that both DOE reviews essentially support the design study's cost estimates, within experimental error.

Although only FY 1985 money has been committed, DOE is already working on the FY 1986 budget request and will presumably ask for more money for R&D. Trivelpiece said DOE plans to report back to Congress periodically

about progress on the SSC. "It's a big project," he explains, and both DOE and Congress want to keep close tabs on it. High-energy physicists who've been thinking about the SSC design estimate the R&D phase will take about three years and cost about \$200 million.

The SSC is conceived as a proton-proton collider with 20 TeV in each beam and luminosity up to 10^{33} $\text{cm}^{-2}\text{sec}^{-1}$. The Reference Designs Study (PHYSICS TODAY, June, page 17) considered three magnet types: a 3-tesla superferric magnet (proposed by a Texas consortium), a 5-tesla superconducting magnet (proposed by Fermilab) and a 6.5-tesla superconducting magnet (proposed by Brookhaven and Lawrence Berkeley Lab). During the first year of R&D, DOE expects the group to decide which type of magnet to use and to continue design efforts, improving cost estimates and identifying ways to reduce costs further.

Tigner expects that in the next several months he'll be setting up a central design group to guide the R&D effort and assign various tasks to groups around the country. Trivelpiece has just approved the URA recommendation of Lawrence Berkeley Lab as the site for the central design group.

By the end of the first year, Tigner says, the site criteria would be determined (because once the magnet decision is made, the main-ring diameter is fixed) and he could imagine DOE issuing a "general invitation to whom it may concern" to invite the SSC to be built in a particular region. Such an invitation would include a description of the facility and a long list of questions, such as: What's the depth of the

water table? Who owns the site? A year later, he speculates, a blue-ribbon panel might be formed, such as was done when Fermilab was being established. "This panel might identify six candidate sites, each equally well qualified. You then put them in a black box and out comes the answer."

When the "200-BeV" machine was under consideration in the early 1960's, the old Atomic Energy Commission had allocated a lump sum of money to Lawrence Radiation Lab in Berkeley to do a design study, rather than DOE's present plan of doling the money out a year at a time for the SSC design study. Once Fermilab was chosen as the site and Robert R. Wilson named director, the machine and its magnets were almost completely redesigned, although many of the parameters were retained. When Congress only appropriated \$250 million for the accelerator and the lab, although the Berkeley cost estimate was higher, Wilson and his colleagues delivered it on time, within the budget and capable eventually of reaching 400 GeV (the energy where it routinely operated for many years).

Presumably, such changes in scope are not reasonable for an SSC. Its \$3-billion cost, even allowing for inflation, is roughly three times the cost of establishing Fermilab. So the R&D and design effort for SSC will probably produce a design very close to the one that would eventually get built.

Two years from now, Trivelpiece told us, he hopes the R&D effort will have constructed enough magnets to show they can be produced at an acceptable cost.

Roughly three years hence, there should be enough information to make a clear commitment on whether or not to ask Congress for money to build SSC. Although the Tigner report estimated six years for construction, Trivelpiece remarked that budgetary limitations may prolong the construction time.

Secretary Hodel, in a memo to Trivelpiece dated 16 August, commended the OER and the many scientists and engineers who prepared and reviewed the SSC Reference Designs Study. Hodel continued, "I agree that this project is totally in the spirit of this Administration's commitment to the advancement of science and technology as an essential ingredient in the achievement of national goals. If our ultimate decision is to construct this machine, it will be a symbol of our dedication to scientific excellence."

Hodel urged Trivelpiece to encourage international collaboration for SSC. Trivelpiece heads a working group on international collaboration in high-energy physics through the Economic Summit Process. The Trivelpiece group next meets in France early next year.

—GBL □