tial savings could be achieved by reducing the length of the tunnel, but this strategy would lower the beam energy by about 25%. "We have examined the physics potential that might be lost by lowering the machine energy by such an amount. It is always difficult to be precise in advance about the energy that is *needed* in a new machine. Certainly, no one knows enough to say that 20 TeV would be adequate but 19 TeV would not." The panelists even discussed operating a smaller 17 TeV ring and running the magnets at lower temperatures to raise the beam energy to possibly 20 TeV. This tactic, they agreed, would most likely require magnet changes and cryogenic upgrades that would nullify whatever savings could be achieved by a smaller collider ring.

For the study of relatively light particles, such as the top quark, should it elude detection at Fermilab's Tevatron, and the decay properties of the *b*-quark or of *W* bosons, the SSC's high energy and copious events may not be critical, says the subpanel. But the SSC will be essential where physics theory offers no energy threshold, such as measuring the production rate of hadron jets at high transverse momenta, testing the predictions of quantum chromodynamics and probing the structure of quarks.

As for the complex of phenomena associated with electroweak symmetry breaking, a centerpiece of the Standard Model, the SSC's energy and luminosity are vital to exploring the mass region of 2 TeV/c^2, where the Higgs boson, suggested by the theory, is almost certain to be found. Detection of the Higgs as a distinct resonance, the Drell group says, requires the SSC's full beam energy and design luminosity to search for new particles predicted by the Standard Model or, perhaps, particles that reveal a more complex order. "At reduced energies, the luminosity required for detection is increased, so that greater demands are placed on detectors." If the Higgs is heavier, so that it becomes so broad it cannot be identified as a distinct particle, or if it doesn't exist at all, then weak interactions among gauge bosons must become strong at energies above 1 TeV, where the SSC would most likely yield results.

Gramm: His job is to control damage.

Energy–luminosity tradeoffs

The subpanel notes that except for the increases in injection energy and magnet aperture, the parameters of the machine are identical to those put forward by the SSC Central Design Group in 1986. In considering the energy–luminosity tradeoffs, Drell had invited Carlo Rubbia, director general of CERN, to describe how his proposed Large Hadron Collider, if built, would operate with a maximum beam energy of 8 TeV and luminosity of $4 \times 10^{34}\ \mathrm{cm}^{-2}\,\mathrm{sec}^{-1}$, a factor of 40 higher than that of the SSC.

The Drell group dismissed the luminosity difference as not a central issue and concluded that the SSC could be upgraded easily in the future to even higher luminosities if detectors could be built to operate at such collision rates. Right now, the subpanel's report points out, general purpose detectors cannot operate above the SSC's designed luminosity, though a special purpose detector that would be limited to detecting only muons outside a metal shield, might be capable of handling experiments at the LHC's luminosity.

While Rubbia's plan to construct an 8-TeV hadron collider in the existing tunnel of the 17-mile Large Electron–Positron accelerator at CERN would provide a significant increase in capabilities over today's machines, the SSC would represent a great advance in high-energy physics research.

The only disagreement with the Drell subpanel's conclusions came from Karl Berkelman of Cornell on the issue of increasing the aperture size. Berkelman argued that leaving the aperture as is would save money and time by not requiring changes in the dipole magnets.

To the surprise and delight of DOE officials and HEPAP members, Senator Phil Gramm, the Texas Republican who has led the Congressional battle for the SSC, attended the meeting. It is somewhat ironic that although he is one of the Gramm–Rudman–Hollings team that wrote the 1985 budget-balancing law, he supports the SSC's increased cost. Gramm is no dilettante on the subject, having completed three physics courses in college and earned a PhD in economics. He cautioned that the SSC would not have an easy time at its higher cost. "We're competing with a lot of other megaprojects...." Even his quips carried a message: "It's important that we not end up with a Cadillac but with a Chevrolet.... I'll help Congress get over the sticker shock and you'll have to make sure of a sturdy and reliable Chevvy."

—Irwin Goodwin

MARS WARS: AS HEAD OF SPACE COUNCIL, QUAYLE ZAPS NASA AS LONE SPACE PILOT

Last July, on the 20th anniversary of the first men on the lunar surface, President Bush called for the US to establish a base camp on the Moon for an expedition to Mars and back. "Like Columbus," said the President, "we dream of distant shores we've not yet seen." Skeptics dismissed the idea as an impossible dream, given the nation's budget woes. Though Bush did not give any cost estimate or any timetable, officials at NASA and experts in other places reckon that the project could run as high as $400 billion over 30 years.

Well aware of the unearthly cost for the ambitious adventure, Bush put the project in the hands of his National Space Council, made up of four Cabinet members and six other top Administration officials, including the White House science adviser, and the directors of the CIA, the National Security Council and Office of Management and Budget. The council's chairman, Vice President Dan Quayle, and his strong-minded staff asked NASA to do a quick study of "what's needed for the next round of exploration—the necessary money, manpower and materials, the feasibility of international cooperation . . .to chart a new and continuing course to the Moon and Mars and beyond."

NASA's report, prepared by an agency "tiger team," evoked mixed reviews when it reached the White House last November. It laid out five approaches for meeting the President's goals, using techniques and technologies the agencies had studied for years and sometimes for decades. "It was a 'rah-rah, let's go' document," recalls a White House source who prefers to be anonymous, "but it was skimpy on imaginative approaches, relying on some off-the-shelf stuff and out-of-sight hardware for ferrying humans to Mars and for boosting the economy on Earth at the same time."

Seeking new directions

Later that month a panel of 15 scientists and aerospace specialists gathered at the Old Executive Office Building at Quayle's request to consider NASA's report. The group included Carl Sagan, Edward Teller, Charles H. Townes, former NASA Administrator Thomas Paine, George Washington University space-policy expert John M. Logsden and former astronaut and New Mexico Senator Harrison Schmitt. Logsden said the panel confirmed the views of Quayle and his top aide on the council, Mark Albrecht, that "a redirection was necessary for the success of the effort. The people around the table wanted some original great ideas and heard none." Another panelist expressed disappointment with NASA's failure to "cast a wider net for new technologies" and suggested the agency was content "with doing business as usual"—a conclusion, he admitted, that left him baffled and frustrated.

On 19 December, Quayle wrote NASA's Administrator, retired Vice Admiral Richard H. Truly, saying he wanted to make sure "all reasonable" conceptual alternatives for space exploration are being evaluated. For the Moon–Mars missions, Quayle declared, it is essential to consider "different architectures, new systems concepts, promising new technologies and innovative uses of existing technologies." Quayle directed NASA to "take the lead" in the search for clever new technologies.

While NASA's formal reply awaits delivery to Quayle sometime in February, Truly has been meeting fairly regularly with Albrecht. The encounters have been hostile at times—a battle of egos and turfs. Truly, a former astronaut known for his candor, admitted to Kathy Sawyer of *The Washington Post*: "When anybody criticizes NASA in a way I feel is unfair, I can be irascible. I can get upset."

As for relationships between NASA and the Space Council, Truly acknowledged "some natural tensions-. . .but that's not necessarily bad." A White House source who has observed the "Mars Wars" fracas calls it "creative tensions."

The stakes are potentially high. Using the approaches proposed by NASA, the cost would most likely add about $15 billion to $20 billion each year once the project got under way. NASA figures it would take a quarter of a century to reach Mars. "We're not in a race to Mars. Considering the troubles the Soviet Union has at home, it's unlikely to be a race," says Logsden. "Clearly, the cost is far too high and the goal is too far off."

AP/WIDE WORLD

Quayle: To Mars, at no loss to science.

This was one of the messages delivered by Quayle in a speech at the American Astronomical Society's 175th meeting in Crystal City, Virginia, on 10 January. Quayle left an open invitation to his audience of astronomers, astrophysicists and space scientists to come up with uncommon concepts for cheaper and faster ways of reaching into space. Since Project Apollo's lunar landings, Quayle lamented, "we have not maintained the momentum. . . . In space launch, our competitive advantage in technology has disappeared. We have not sufficiently developed space as an arena for private enterprise. . . . We have continued to have good ideas, but our programs seem to be taking too long and quite frankly costing too much to build. As a result, the rest of the world is catching up and may pass us by. And despite our continued scientific and technological preeminence, our government has not done as well as it could have in marshaling the resources and the leadership necessary to keep us ahead in space."

When the President set up the Space Council last year, said Quayle, he asked "that we shape a space program that is aggressive and innovative—and that we challenge accepted ways of doing business." The council's strategy is indeed startling, considering NASA's near monopoly in space projects. Quayle cited the Administration's intention "to develop our space launch capability and its related infrastructure as a natural resource." He compared launch facilities to the nation's interstate highway networks, built at Federal expense for maximum usage. Indeed, launch systems ought not be considered under the sole proprietorship of NASA but might be developed for multiple users from government, science and commercial interests. "We need to ensure reliable and affordable access to space."

Reasserting basic sciences

During his speech Quayle said he wanted to "reaffirm our commitment to the unmanned, as well as the manned, exploration of space." The audience of nearly 1000 responded predictably. Indeed, whenever Quayle mentioned scientific research, astronomical observatories or robot probes, the audience interrupted with applause—nine times before the end of his speech—most notably when he pledged the Bush Administration's commitment to a balanced scientific program. "The large exploration programs we are planning will not emphasize human activities at the expense of scientific excellence, " he said. Exploration of Mars will begin with a series of unmanned scientific probes. "This is the way we will use space to reassert America's leadership in basic sciences."

That does not necessarily mean the US intends to explore space on its own. Quayle mentioned joint ventures with Japan, explored during his meeting with Prime Minister Toshiki Kaifu in Tokyo last September. He left out of his talk the continuing discussions of collaborative space megaprojects with the Soviet Union.

To expand the nation's outlook on space, thoroughly and objectively, Quayle said he had asked the Aerospace Industries Association and the National Academy of Sciences to devise better, cheaper, more reliable technologies as well as new ways to improve the present Federal culture dealing with space flight by cutting through bureaucracies and procedures. Accordingly, a 20-member panel of aerospace executives and engineers had met in Washington in January to discuss what to report to the space council by the end of March. The panel is expected to examine NASA's decision-making process. One council aide described the panel's task as "looking over NASA's shoulder to make sure they're evaluating everything fairly."

In addition, a review of NASA's science and technology is to be undertaken by a committee of the National Academy of Sciences's National Research Council, under the chairmanship of H. Guyford Stever, President Ford's science adviser and a former director of the National Science Foundation. In late 1988, Stever headed another Research Council committee that issued a harsh "white paper" on space policy to the incoming Bush Administration. It accused NASA of running a program that is confused and overcommitted, as well as of lacking imaginative leaders and exciting goals (PHYSICS TODAY, April 1989, page 41). Though the Research Council's report is due at the end of February, the White House proposes that the academy will conduct additional reviews of the concepts and technologies for the long voyages to the Moon and Mars.

Among the new ideas already attracting notice is one from the Lawrence Livermore Laboratory that Teller brought to the Space Council's attention. It would use inflatable modules instead of rigid metal structures for many expensive megaprojects. The scheme was hatched for the Strategic Defense Initiative by a team led by Teller's protege, Lowell Wood, a prime mover behind the "Brilliant Pebbles" space-based anti-missile system that is already in the Star Wars portfolio of plans. The Livermore group claims its goal is to reduce the price tag for a voyage to Mars from $400 billion to $40 billion, roughly the same bottom line as the Apollo program during the 1960s and 1970s.

—IRWIN GOODWIN

ACADEMIES SAY ADVANCES IN MATERIALS WILL RECREATE INDUSTRIES IN 1990s

For most of human history, the world relied on such natural materials as stone, wood, gold, iron, vegetable fiber and animal tissue. The smelting of metals and production of glass represented notable extensions in the approach to materials. Only recently has scientific understanding of the structure of physical and biological matter, along with advances in experimental techniques and processing technology, made it possible to conceive a need and then devise a material to meet it, atom by atom.

The ramifications of this revolution in materials, it need hardly be stated, reaches well beyond science to create new opportunities for industry and new wealth for society. Companies engaged in the direct production of primary materials employ nearly 2 million wage and salaried workers—or about 1.5% of the US labor force. Each of those workers, what's more, has from two to three counterparts dependent on primary materials in other sectors of the economy. In a 1988 report, the Office of Technology Assessment, an analytical arm of Congress, projected that the cost of using advanced materials in such industries as aerospace, automotive, electronics, sporting goods and telecommunications would leap from about $2 billion then to nearly $20 billion by the year 2000.

Yet, despite US preeminence in R&D for the advanced materials that make up integrated circuits, optical fibers, reinforced plastics and ceramics, the OTA report is pessimistic. It is uncertain whether the US will lead the world in commercializing the materials. Advanced materials and fabrication processes are still in their infancy, the report declares, so their cost-effectiveness has not been demonstrated in large-scale commercial applications. Many US businessmen, seemingly preoccupied with immediate profits, have been unwilling to invest in advances that may not pay off for 10 to 15 years. By contrast, manufacturers in other countries, notably in Japan, have initiated aggressive programs to commercialize the new materials and have succeeded in bringing some advanced materials articles to market before comparable US products.

Business perspective

The conclusions by OTA were writ larger and bolder in "Materials Science and Engineering for the 1990s," a 279-page report based on a three-year study by a committee of the National Research Council, operated by the National Academies of Sciences and of Engineering. The study differs from most state-of-science examinations in that it was prepared from the point of view of American business. It bears little resemblance to a previous Research Council report, "Materials and Man's Needs," which dealt with issues related to strategic materials, fuel availability, biodegradable materials and scrap recovery—topics that were high on the nation's agenda when the report came out in 1975. Both the materials and the issues are now radically different.

To study the current situation, the Research Council appointed a 17-member committee under co-chairmen Praveen Chaudhari, a member of IBM's corporate technical committee, and Merton C. Flemings, Toyota Professor of Materials Science and Engineering at MIT. The committee was supplemented by 109 scientists, engineers, businessmen and even investment bankers who served on five panels, and some 400 others provided data, advice and comments of sorts. "We were extremely self-critical," says Chaudhari. "We agreed that the US has gradually lost its lead and if American companies can't deliver, the Japanese and Europeans will."

The result is an alloy—one part useful criticisms, one part comments on the consequences for economic growth, global competitiveness and cultural change. In fact, the report is larger than the sum of its parts: It represents what can and cannot be done with the new technologies.

In the 1980s, advanced materials provided many of the new technologies, most of them personal, portable, accessible—FAX machines, personal computers, cellular phones, video cassette recorders, body parts for automobiles and humans. Even the sinews of war have been transformed by new materials—steel, for example, is being replaced by a liquid crystal polymer and such ceramics as titanium diboride, silicon carbide, boron carbide and aluminum oxide.

The report correctly emphasizes the unity of materials science and engineering. Actually, the field is an amalgam of such disparate studies as metallurgy, ceramics, solid-state physics, polymer chemistry, electrical and mechanical engineering and other specialties. The convergence was essential to further understanding that was necessary to "tailor materials from the atomic scale upwards to achieve desired functional properties," says the report. Distinctions between classes of materials—metals and polymers, for instance—have be-