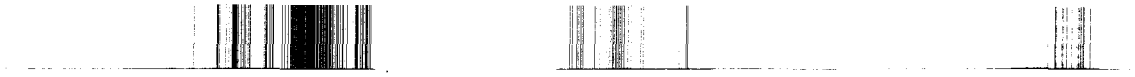
The U.S. industry is in a very different position. While U.S. high-technology industries have lost part of their competitiveness to Japan's and other countries' high-technology industries, these losses have occurred to a large extent among products of lower technical sophistication, such as consumer products.

The microcomputer market is a case in point. (The emphasis is on the electronic and computer goods industries because over half of the added sales measured by the *CERN Contracts Study* occurred in electronics, optics, and computers. See Table B-1.) Imports to the United States from Korea, and other newly industrialized Asian countries, consist mainly of less sophisticated IBM-compatible personal computers. IBM, Compaq, Apple, SUN, and other U.S. companies still control the more technologically advanced segment of that market. Since scientists and technicians working on particle accelerator physics need the best equipment available, in the field of microcomputer technology they will be pushing for advances in the segment of the market the United States already dominates. Of course, not all markets divide as neatly as the microcomputer market: Japan, for instance, has made substantial inroads into markets for leading-edge semiconductors and semiconductor manufacturing equipment.

One of the benefits of CERN contracts mentioned in the study is that they help small firms to export to other European Community nations. The barriers to interstate commerce in the United States are nowhere near as high as they are in Europe. U.S. industries share legal traditions and systems, language, professional and trade journals and magazines, and trade associations. Given this lack of internal barriers, small firms in the United States should need little help to ship elsewhere in the United States.



## APPENDIX C

# COST INCREASES IN DOE ACCELERATORS

The tables in this appendix present detailed information on the increases in the construction costs of Department of Energy accelerators from their initial submission as a construction project to final completion. The data here are derived from DOE budget requests. All estimates are in current dollars. (For constant dollar comparisons, see Chapter III of this report.)

TABLE C-1. CHANGES IN THE COST OF THE ENERGY SAVER ACCELERATOR (In thousands of current dollars)

| Category | Initial Estimated Cost | Final Estimated Cost |
|---|---|---|
| Engineering, Design, and Inspection | 4,500 | 2,700 |
| Construction Costs | | |
| Magnets | 13,500 | 38,300 |
| Refrigeration | 10,000 | 5,600 |
| Power supplies and controls | 850 | 1,600 |
| Radio frequency source | 1,300 | 200 |
| Extraction | 900 | a |
| Special facilities | 600 | 1,000 |
| Conventional facilities | 1,950 | a |
| Total, construction | 29,100 | 46,700 |
| Contingency | 5,300 | 1,400 |
| Research and Development | 28,900 | 68,668 |
| Other Costs | 6,000 | 13,000 |
| Total | 73,800 | 132,468 |

SOURCE: Congressional Budget Office, derived from Department of Energy budget requests for fiscal years 1979 and 1982.

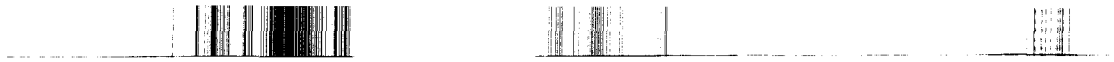
a. Not separately included in DOE's 1982 budget request.

TABLE C-2. CHANGES IN THE COST OF THE TEVATRON ACCELERATOR (In thousands of current dollars)

| Category | Initial Estimated Cost | Final Estimated Cost[a] |
|---|---|---|
| **Hardware Costs** | | |
| Engineering, Design, and Inspection | 4,200 | 10,100 |
| Construction Costs | | |
| Experimental areas | 7,300 | 11,600 |
| Ring and beam line housing | 3,300 | 12,700 |
| Antiproton source | 10,400 | 23,500 |
| Accelerator components | 7,600 | 12,300 |
| Subtotal | 28,600 | 60,100 |
| Contingency | 6,700 | 13,800 |
| Total, hardware costs | 39,500 | 84,000 |
| **Other Development Costs** | | |
| Research and Development | 18,800 | 50,504 |
| Detectors | 20,000 | 55,353 |
| Total, other development costs | 38,800 | 105,857 |
| **Offsets** | | |
| Total Project Costs | 78,300 | 189,857 |
| Foreign Contributions for Detectors | -7,800 | -15,654 |
| Net U.S. Costs | 70,500 | 174,203 |

SOURCE: Congressional Budget Office, derived from Department of Energy budget requests for fiscal years 1981 and 1987. Details on foreign contributions for detectors from Fermilab budget activity reports, 1981-1985.

a. Does not include $8.9 million in pre-1981 costs incurred during the conceptual design phase, which DOE no longer includes in its estimate of project costs.



## GLOSSARY

These definitions are mostly taken or derived from National Research Council, *Physics Through the 1990s: Elementary Particle Physics* (Washington, D.C.: National Academy Press, 1986).

Absolute zero. The lowest possible temperature defined by the cessation of vibration of molecules. Zero degrees Kelvin.

Accelerator. A device that increases the energy of charged particles such as electrons and protons.

Antimatter. Matter composed of antiparticles, for example, antiprotons, antineutrons, antielectrons, instead of ordinary protons, neutrons, electrons.

Antiparticle. Each particle has a partner, called an antiparticle, which is identical except that all chargelike properties (electric charge, strangeness, charm, for example) are opposite to those of the particle. When a particle and its antiparticle meet, these properties cancel each other out in an explosive process called annihilation. The particle and antiparticle can then disappear and other particles be produced.

Antiproton. The antiparticle partner of the proton.

Atom. The smallest unit of a chemical element, approximately 1/100,000,000 centimeter in size, consisting of a nucleus surrounded by electrons.

Beam. A stream of particles produced by an accelerator.

CERN. The European Organization for Nuclear Research, located near Geneva, Switzerland, and supported by most of the nations of Western Europe.

Circular accelerator. An accelerator in which the particles move around a circle many times, being accelerated further in each revolution.

Collider. When a high-energy particle collides with a stationary target, a large portion of the energy resides in the continuing forward motion. Only a small portion of the energy is available for creating new particles. In a collider, collisions take place between high-energy particles that are moving toward each other. In such an arrangement, most of the energy is available for creating new particles.

Cosmology. The parts of astrophysics and astronomy having to do with the large-scale behavior of the universe and its origin.

Cryogenics. The science and technology of producing and using very low temperatures, even approaching absolute zero (zero degrees Kelvin).

DESY. Deutsches Electronen Synchrotron. The laboratory in Hamburg, Federal Republic of Germany.

Electromagnetic force or interaction. The long-range force and interaction associated with the electric and magnetic properties of particles. This force is intermediate in strength between the weak and strong forces. The carrier of the electromagnetic force is the photon.

Electron. An elementary particle with a single negative unit of electrical charge and a mass 1/1,840 that of the proton. Electrons surround an atom's positively charged nucleus and determine the atom's chemical properties. Electrons are members of the lepton family.

Electron volt. The amount of energy of motion acquired by an electron accelerated by an electric potential of one volt: MeV, million electron volts; GeV, billion electron volts; TeV, trillion electron volts.

Electroweak force or interaction. The force and interaction that represents the unification of the electromagnetic force and the weak force.

Elementary particle. A particle (piece of matter) that has no other kinds of particles inside it and no subparts that can be identified. Hence, the simplest kind of matter.

Elementary-particle physics. The area of basic science whose goal is to determine and understand the structure and forces of the most basic constituents of matter and energy. Synonymous with high-energy physics.

Fermilab. The Fermi National Accelerator Laboratory in Batavia, Illinois.

GeV. Giga electron volt, a unit of energy equal to one billion ($10^9$) electron volts.

Gluon. A massless particle that carries the strong force.

Hadron. A subnuclear, but not elementary, particle composed of quarks, including protons, antiprotons, and neutrons. These particles all have the capability of interacting with each other via the strong force.

HERA. An electron-proton circular collider, located at the DESY laboratory in Hamburg, Federal Republic of Germany.

Higgs Boson. See Higgs mechanism and particle.

Higgs mechanism and particle. A mechanism that may explain the origin and value of the mass of all or some of the elementary particles. The mechanism includes a proposed set of particles called Higgs particles or Higgs Bosons.

High-energy physics. Another name for elementary-particle physics. The name arises from the high energies required for experiments in this field.

Ions. Atoms or molecules that have a net electrical charge.

Kelvin. A scale of temperature. Zero degrees Kelvin (absolute zero) is equivalent to minus 273 Celsius or minus 523 degrees Fahrenheit.

LEP. Large Electron Positron collider. A circular electron-positron collider with a maximum design energy of about 200 GeV being constructed at CERN, Switzerland.

Lepton. A member of the family of weakly interacting particles, which includes the electron, muon, tau, and their associated neutrinos and antiparticles. Leptons are not acted on by the strong force but are acted on by the electroweak and gravitational forces.

Linear accelerator. In this type of accelerator, particles travel in a straight line and gain energy by passing once through a series of electric fields.

Luminosity. A measure of the rate at which particles in a collider interact. The larger the luminosity the greater the rate of interaction.

Magnet. A device that produces a magnetic field and thus causes charged particles to move in curved paths. Magnets are essential elements of all circular accelerators and colliders, as well as of many particle detectors.

Magnetron. A device used to generate microwaves.

Mass. The measure of the amount of matter in a particle and an intrinsic property of the particle.

Mass reach. The highest level of elementary-particle mass that an accelerator can produce with regularity. This number involves a combination of the beam energy levels and the luminosity. Proton colliders have a lower mass reach than electron-positron colliders of the same beam energy, because the protons they use are composed of quarks and gluons. Each of these has only a fraction of the proton's total energy.

MeV. Mega electron volt, a unit of energy equal to one million electron volts.

Molecule. A type of matter made up of two or more atoms.

Muon. A particle in the lepton family with a mass 207 times that of the electron and having other properties similar to those of the electron. Muons may have a positive or negative electrical charge.

Neutron. An electrically uncharged, strongly interacting particle with mass slightly greater than that of the proton; a constituent of all atomic nuclei except hydrogen.

Nucleon. A neutron or a proton.

Nucleus. The central core of an atom, made up of neutrons and protons held together by the strong force.

Particle. A small piece of matter. An elementary particle is a particle so small that it cannot be further divided; it is a fundamental constituent of matter.

Particle detector. A device that is used to detect particles that pass through it.

PEP. An electron-positron circular collider with a maximum energy of 36 GeV, located at the Stanford Linear Accelerator Center in Stanford, California.

PETRA. An electron-positron circular collider with a maximum energy of 46 GeV, located at the DESY laboratory in Hamburg, Federal Republic of Germany.

Photon. A unit of electromagnetic energy. A unique massless particle that carries the electromagnetic force.

Positron. The antiparticle of the electron.

Proton. A particle with a single positive unit of electric charge and a mass approximately 1,840 times that of the electron. It is the nucleus of the hydrogen atom and a constituent of all atomic nuclei.

Quantum mechanics. The mathematical framework for describing the behavior of photons, molecules, atoms, and subatomic particles. According to quantum mechanics, the forces between these particles

act through the exchange of discrete units or bundles of energy called quanta.

Quarks. The family of elementary particles that make up the hadrons. The quarks are acted on by the strong, electroweak, and gravitational forces. Five are known: up, down, strange, charm, and bottom. A sixth, called top, is expected to exist.

Scattering. When two particles collide, they are said to scatter off each other during the collision.

SLC. Stanford Linear Collider, a linear electron-positron collider with an initial total energy of about 100 GeV at the Stanford Linear Accelerator Center in Stanford, California.

SSC. See Superconducting Super Collider.

Standard model. A collection of established experimental knowledge and theories in particle physics that summarizes the present understanding of that field. It includes the three generations of quarks and leptons, the electroweak theory of the weak and electromagnetic forces, and the quantum chromodynamic theory of the strong force. It does not include answers to some basic questions such as how to unify the electroweak forces with the strong or gravitational forces.

Storage ring. An accelerator-like machine composed of magnets arranged in a ring used to store circulating particles or to act as a collider. Sometimes a synonym for a collider.

Strong force or interaction. The short-range force and interaction between quarks that is carried by the gluon. The strong force also dominates the behavior of interacting mesons and baryons and accounts for the strong binding among the components of an atom's nucleus.

Superconducting magnet. See Superconductivity.

Superconducting Super Collider (SSC). A design being developed in the United States for a circular proton-proton collider with a total energy that could be as high as 40 TeV.

Superconductivity. A property of some metals that when they are cooled to a temperature close to absolute zero, their electrical resistance disappears. Magnets with superconducting coils can produce large magnetic fields while keeping size and power costs small.

Synchrotron. A type of circular particle accelerator in which the frequency of acceleration is synchronized with the particle as it makes successive orbits.

TeV. Tera electron volt, a unit of energy equal to one trillion ($10^{12}$) electron volts.

Tesla. A unit of magnetic strength, defined as one weber per meter squared.

Tevatron. A complex of accelerator facilities and beam lines at Fermilab. The main facility, called Tevatron I in this report, is a circular proton-antiproton collider with a total energy of 2 TeV. Tevatron II is an addition allowing the particle beams to be directed against a fixed target.

TRISTAN. A circular electron-positron collider with a total energy of 60 to 70 GeV under construction in Tsukuba, Japan.

Unification theories. Theories of forces in which the behavior of different kinds of forces is described by a unified or single set of equations and has a common origin. For example, the electric and magnetic forces are unified in the theory of electromagnetism.

Weak force or interaction. The force and interaction that is much weaker than the strong force, but stronger than gravity. It causes the decay of many particles and nuclei.

Weber. A unit of magnetic flux that, in linking a circuit of one turn, produces an electromotive force of one volt as it is reduced to zero in one second. One weber per meter squared is equal to one tesla.

X rays. Photons produced when atoms in states of high energy decay to states of lower energy.