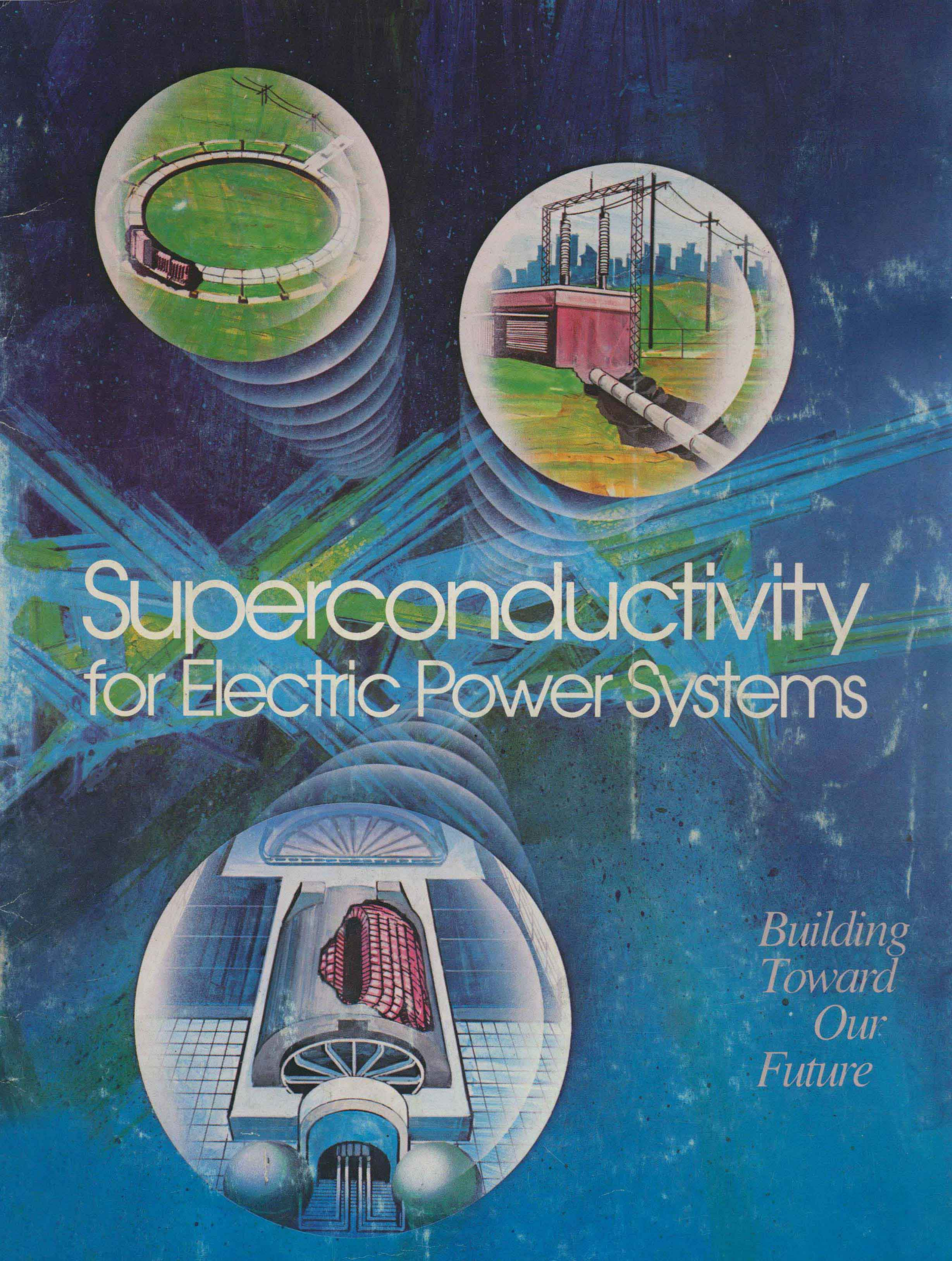
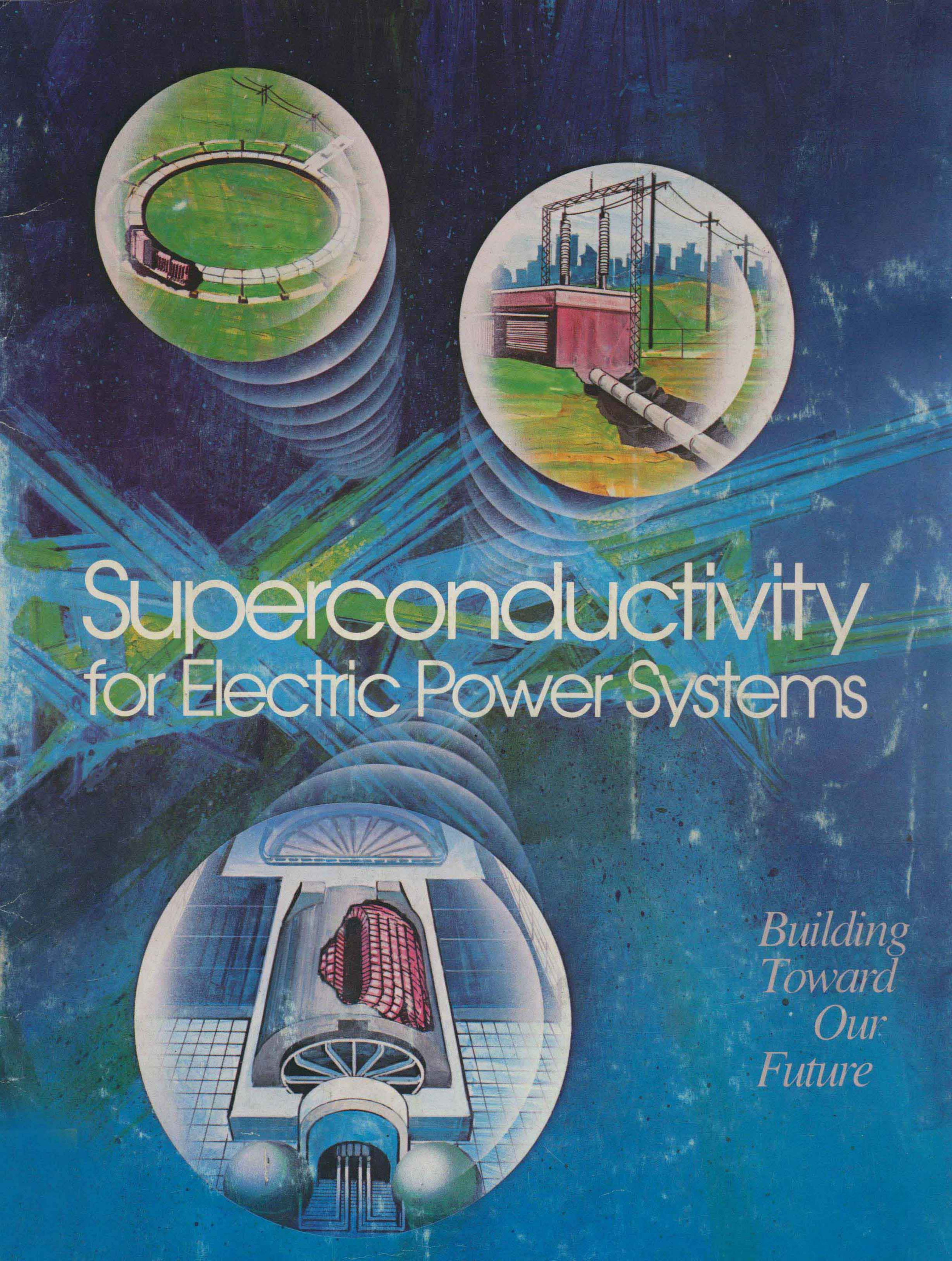


Superconductivity for Electric Power Systems

Building Toward Our Future



Superconductivity for Electric Power Systems

Building Toward Our Future

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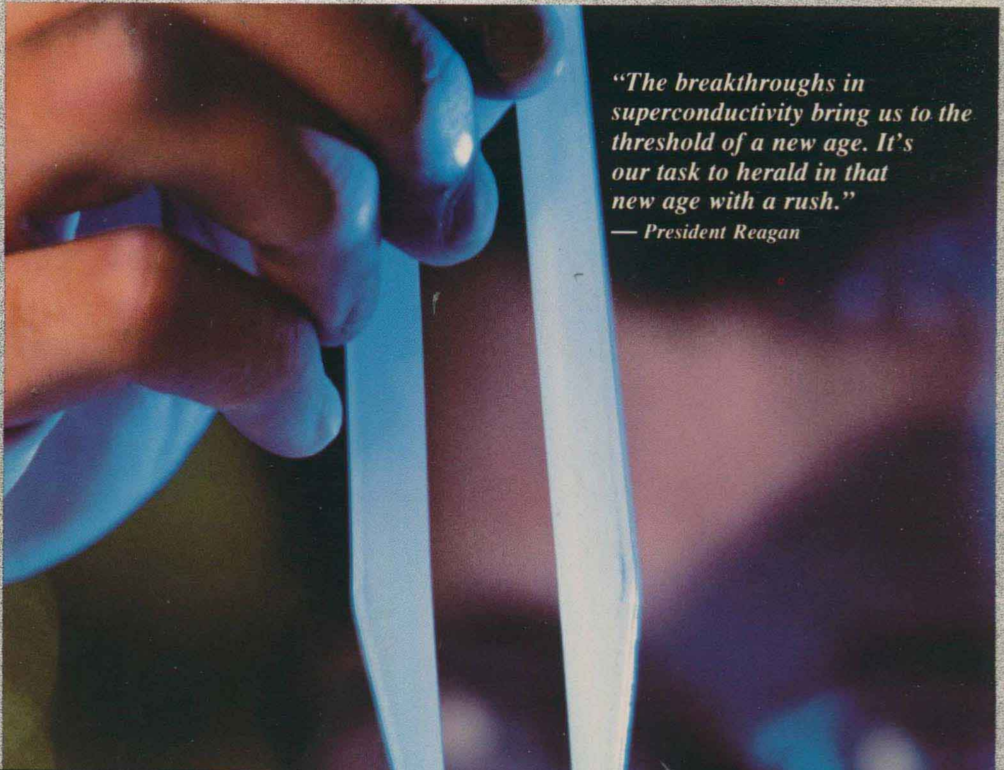
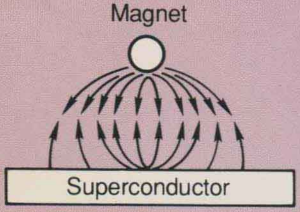


"The breakthroughs in superconductivity bring us to the threshold of a new age. It's our task to herald in that new age with a rush."
— President Reagan

[redacted]

One property of superconductors is their ability to exclude a magnetic field. If a superconducting material is placed in a modest magnetic field, it will expel the field, acting as though it has itself become a magnet that repels the field. Because of this, a magnet will float above a superconductor.



On the Cover

Superconducting technology has applications in electric power systems. Shown are artists' concepts of a magnetic energy storage device (upper left), electric power transmission cable (upper right), and electric generator (bottom).

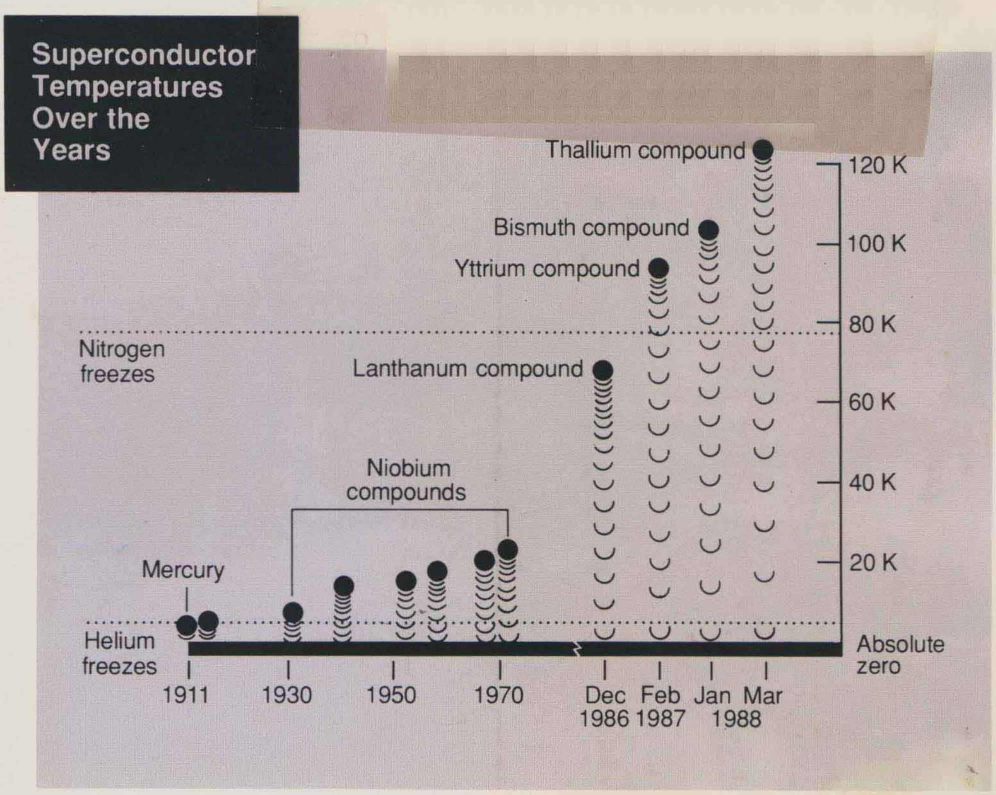
Few laboratory breakthroughs have captured the imagination of scientists, policy makers, and the public as quickly as high-temperature superconductivity — the ability of a material to conduct electricity with no resistance at relatively high temperatures. Startling advances in the first half of 1987 plunged the scientific world into a frenzy. With a media blitz that included the front cover of *Time* magazine, high-temperature superconductivity has been touted as the successor to the light bulb and the transistor in the annals of technological progress.

Why all the attention? To put it simply, with their unique properties, high-temperature superconducting materials may have a staggering impact on modern technology in many different fields.

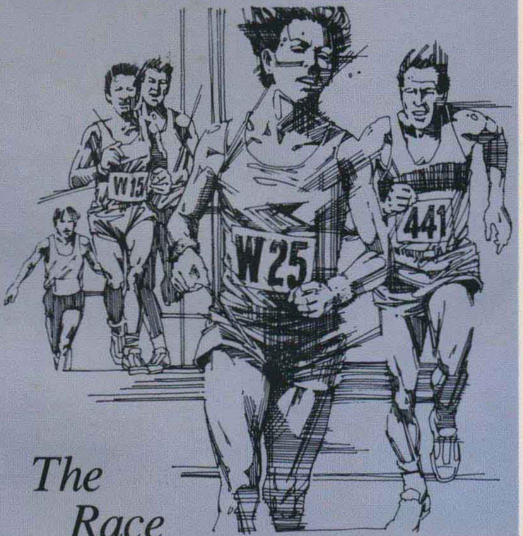
Low-temperature superconductors, available since the 1960s, have already proven themselves in such important applications as sophisticated medical diagnostic devices, high-energy particle accelerators, instruments for geologic research, high-speed electronics, and magnetically levitated trains. Low-temperature superconductors will function only at temperatures near absolute zero (or 0 Kelvin, K, a point at -460° Fahrenheit), and must be cooled to that temperature by liquid helium.

Today, high-temperature superconductors can function at temperatures as high as 125 K (-234°F) and can therefore be cooled with liquid nitrogen. Nitrogen is widely available; maintaining liquid nitrogen temperatures is inexpensive and reliable. The new superconductors are likely to find their first uses as replacements in applications already using low-temperature superconductors.

The lower refrigeration cost of high-temperature superconductors could also make many new applications economically possible: motors and generators that can operate more efficiently, magnetic bearings for high-speed rotors, magnetic heat pumps, electrical transmission lines, magnetic energy storage, magnetic separation processes for industry, superfast computers, and electromagnetic launching facilities. The implications for many different technologies are incredible. Estimates of the potential size of the market range from $1.4 billion three years from now to $12 billion ten years from now.


Superconductor Temperatures Over the Years

Superconducting magnets have been developed for magnetically levitated trains. Japan already has a working prototype.



The Race Is On

As one government official stated, "The race to commercialize superconductivity is on and the economic prizes await the nation which first discovers a viable, marketable technology."

Japan and the United States are taking the lead. In Fiscal Year (FY) 1988, the United States put about $145 million into all superconductivity research and development (R&D) — the Japanese, about $135 million.

Japan has formed a consortium of more than 80 Japanese companies, three U.S.-based companies, and others. The consortium is headed by Shoji Tanaka, the R&D chief who led Japan's charge into semiconductor development in the 1970s. The United States also has several smaller consortia. Advisors have recommended that the U.S. government sponsor a series of broad-based consortia. The Department of Energy's pilot center concept (see p. 7) is the beginning of this type of effort.

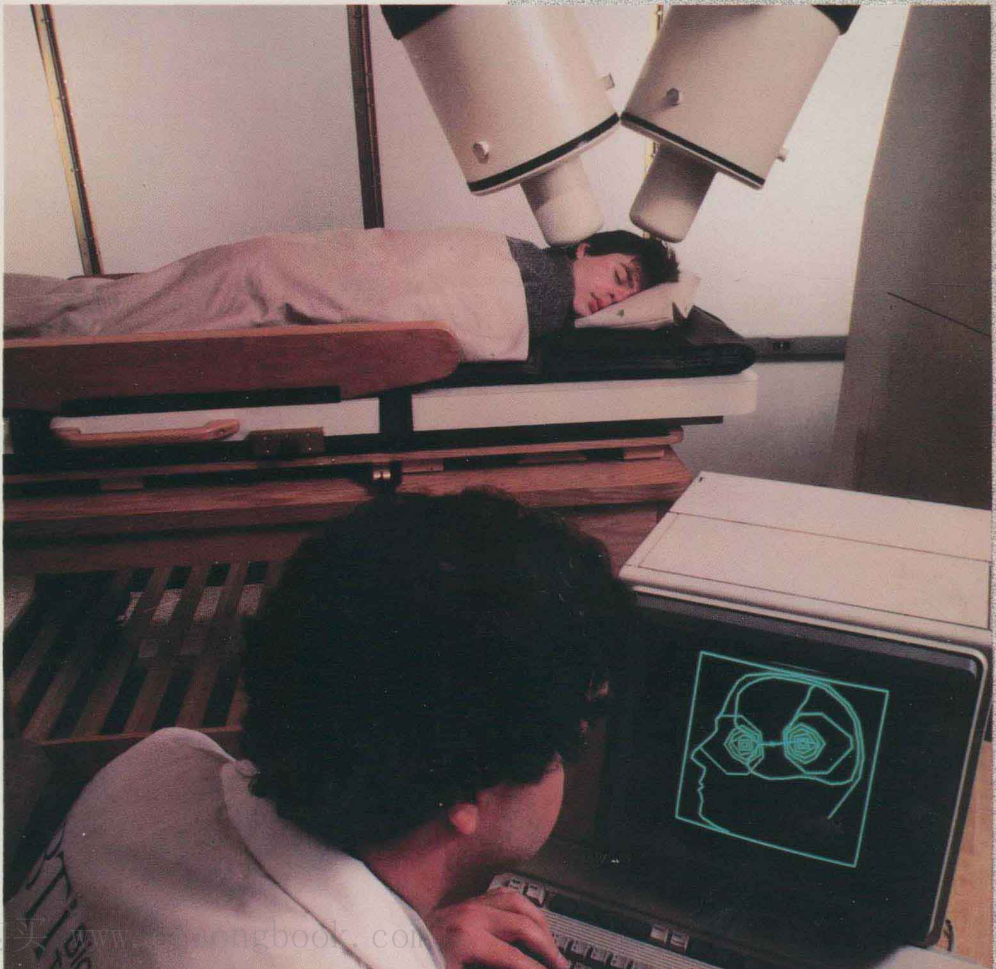
Gearing Up Around the World

	FY 1988 Funding ($ millions)
United States	145
Japan	135
United Kingdom	25
France	20
West Germany	15

"When you think of something that conducts electricity with no resistance at all, the first idea that comes to mind is electrical power transmission."
— David Goodstein, Caltech

The Department of Energy has been involved in superconductivity research for 15 years. At Brookhaven National Laboratory, scientists have developed a superconducting cable. Transmission systems using new high-temperature superconductors can reduce electricity losses and transmit more power economically over long distances and existing rights of way.

Superconducting technology is available today for medical diagnostics. This instrument detects the magnetic fields created within the brain and can locate the center of the fields in three dimensions.



Facing the Challenge

How has the United States responded to these exciting advances? In 1988, the White House announced an 11-point initiative designed to promote further work in the field of superconductivity. The U.S. effort is being supported by federal funds from the Department of Energy (DOE), the Department of Defense, the National Science Foundation, and the National Institute for Standards and Technology. This federal funding totaled about $184 million in Fiscal Year (FY) 1989 for all superconductivity research.

> ***"Our goals are clear...to develop a practical high-temperature superconductor and to develop innovative designs for electrical devices." — Kenneth Klein, Director, Office of Energy Storage and Distribution***

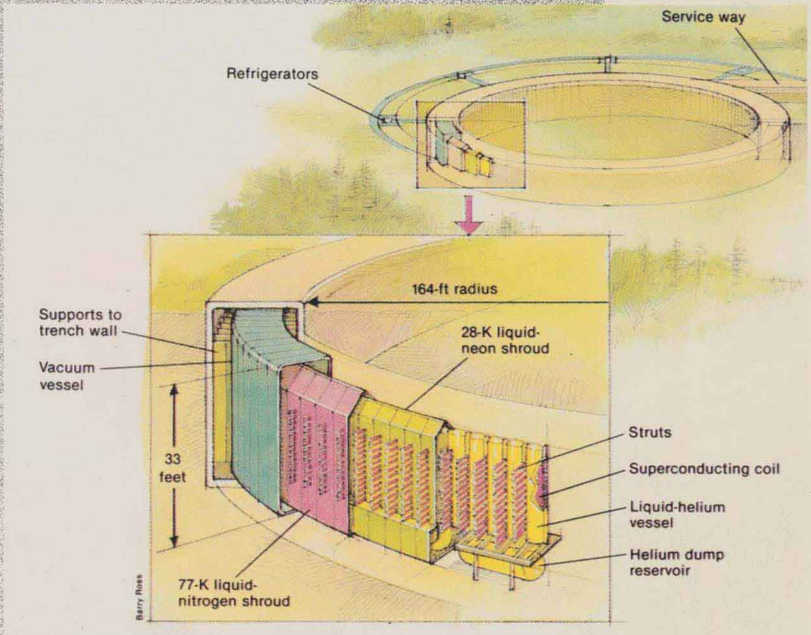
At DOE's Office of Energy Storage and Distribution (OESD), we have been supporting research and development in superconductivity for more than 15 years. These early research efforts take on renewed importance with the discovery of high-temperature superconductivity.

OESD leads a national research and development (R&D) program to translate technical and scientific breakthroughs into options for electric energy storage and distribution. Superconducting technology can benefit electric power industries in several ways, including lower life-cycle costs for transmission cables, generators, and transformers. Superconducting magnetic energy storage devices can store energy during off-peak times to be used when energy is more expensive, avoiding the need to build significant amounts of generating capacity.

Our high-temperature superconductivity R&D program has two important objectives: to speed up the process of moving superconductivity from the research laboratory to the marketplace (through the pilot centers) and to develop the technology for large-scale applications (under the Superconducting Technology for Electric Power Systems [STEPS] research program).

Life-Cycle Cost Savings (%) with High-Temperature Superconductors

	Compared with Low-Temperature System	Compared with Conventional System
Generator (300 megawatt)	27	63
Transformer (1,000 megavolt-ampere)	36	60
Transmission Line (10,000 megavolt-ampere, 230-kilovolt)	23	43
Motors	11	21
Magnetic Separators	15	20



Superconducting magnetic energy storage (SMES) is one of the promising applications for high-temperature superconductors. Current circulates with no resistance in a superconducting ring, installed below ground. With SMES, power plants could charge the ring with excess energy at night for use later during peak daytime periods.

A Three-Dimensional Critical Surface

When electrons pass through a conductor such as copper wire, they collide with imperfections in the lattice-like structure of the metal and lose energy as heat. This loss of energy is called resistance. A superconducting material is different: electrons can pass through without losing energy.

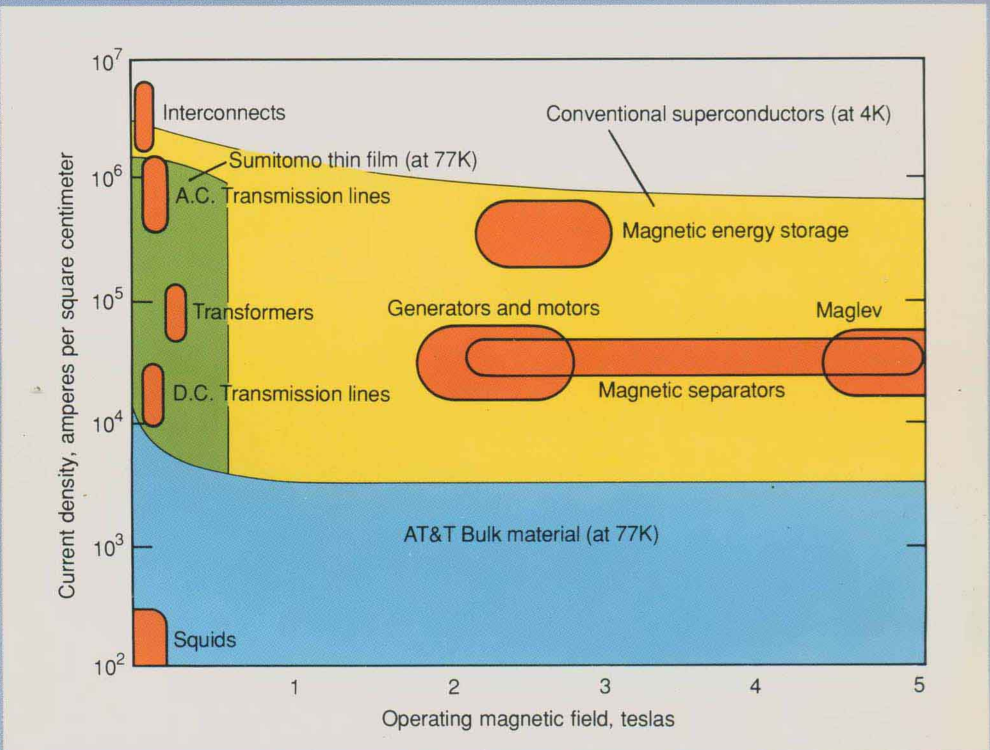
Maintaining this remarkable state is tricky, however. Three factors must be kept within a tight envelope to keep a material superconducting: the temperature of the material, the strength of the magnetic field present, and the amount of current passing through the material. If any one of these factors is too high relative to the others, the material will revert to a normal conductor (or "go normal").

The higher the temperature at a given magnetic field and current density, the fewer the number of electrons that will be superconducting. When no electrons are superconducting, the material has reached its critical temperature, or T_c. Until 1986, the highest critical temperature known was for a niobium alloy at 23 K (-418°F). The highest critical temperature for the new ceramic superconductors in early 1989 was 125 K (-234°F).

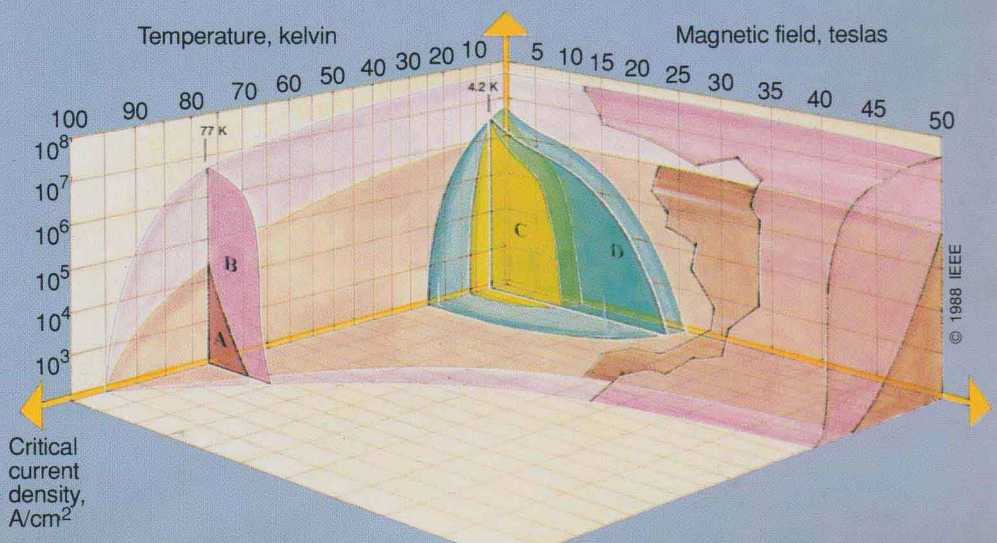
One of the most important applications of superconductors is to make strong magnets. A current, run through superconducting wire wound into a coil, generates magnetic fields far more powerful than those generated using conventional materials. For a given temperature, there is an "upper critical field," H_c, at which the material goes normal. The new ceramics generally have very high critical fields, on the order of 100 teslas (about 50 times the strength of an iron magnet) at the temperature of liquid nitrogen.

The amount of current a material can carry through a given cross-sectional area also affects its superconductivity. Trying to carry too much current forces the material to go normal. The point at which this happens is the "critical current density," J_c. Although critical temperature and critical field are basic properties of the materials used, the critical current density can be improved by processing techniques. Bulk samples of the new ceramic superconductors tend to have very low critical currents (10-1000 amperes per square centimeter, A/cm^2), whereas thin-film values tend to be much higher (100,000 to 1,000,000 A/cm^2).

Different applications require different characteristics from high-temperature superconductors. Conventional superconductors (niobium alloys) meet the requirements for many applications. The Sumitomo thin film and the AT&T bulk material represent typical high-temperature superconductor characteristics at 77 K as of early 1989 technology.



Three factors control superconductivity — temperature, current density, and magnetic field. Superconductivity disappears outside a three–dimensional surface unique to each material. The critical surfaces for bulk (A) and thin–film (B) yttrium barrium copper oxide extend beyond the liquid nitrogen temperature (77 K). The critical surfaces of conventional niobium superconductors (C, D) are small, forcing them to operate at the liquid helium temperature (4 K).



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> ***"Pilot centers are unique. Intellectual rights and simple contracting are changing the way we do business."***
> ***— Robert San Martin, Deputy Assistant Secretary, Renewable Energy, U.S. Department of Energy***

> ***"Our collaborations with industry play across the spectrum — from the very difficult that will take us five to ten years, to the things we can do right now."***
> ***— Rod Quinn, Director, Superconductivity Pilot Center, Los Alamos National Laboratory***

Pilot Centers: New Opportunities for Industry

The key to commercializing the new superconductors rapidly is the collaboration of American industry, universities, and national laboratories. Our program is designed to include industries and universities right from the start.

The benefits of this synergism are far-reaching. Industries and universities will be able to obtain funding for research and will benefit from the expert staff and state-of-the-art facilities at the national laboratories. Conversely, the national laboratories will benefit from the interaction with university and industry scientists, as well as the insight industry can give on the best directions for research. Industry's early participation will help focus research on the most promising technologies for commercialization — a benefit for the entire nation.

To streamline the cooperative process, we have set up three pilot centers that will make the resources of the national laboratories available to American companies. These pilot centers are Oak Ridge National Laboratory, Argonne National Laboratory, and Los Alamos National Laboratory. The centers use simplified and expedited contracting procedures and can make flexible arrangements for patents and other property rights. They also have outreach programs to seek corporate partners. Private sector interest in collaborative agreements with DOE has increased enormously since the pilot centers were formed.

Selected Partnerships in Superconductivity R&D*

Laboratory	Partner(s)	Area of Research
Ames Laboratory	Babcock & Wilcox	Filament formation technique
Argonne National Laboratory	Beldencooper Industries Grumman Corp. CBI Research	Shielding measurements Radio frequency cavities Superconducting magnetic energy storage coils
	American Superconductor	Wire fabrication
Brookhaven National Laboratory	State University of New York Massachusetts Institute of Technology	Tape fabrication Model of magnet performance
Lawrence Berkeley Laboratory	University of California at Berkeley	Thin-film properties
	Quantum Optics	Sol gel processing
Los Alamos National Laboratory	Rockwell International University of Missouri, Rolla	Thallium-based developments Melt processing
Sandia National Laboratories	University of Nevada, Reno	Fluidized bed calcination

* The number of partnerships is growing rapidly. These are just a few examples to show the breadth of work under way.

The old concept of the government always holding proprietary rights to research at its laboratories is no longer true. Since 1986, companies have been able to obtain title to patents emanating from cooperative work and can license other rights that might be needed to commercialize the technology. The pilot centers are able to protect information produced under cooperative agreements.

How does a partnership begin? Simply with a technical problem of mutual interest to a DOE laboratory and an industrial or university partner. The working arrangements are negotiated on a case-by-case basis and may include cooperative R&D, contract R&D, staff exchanges, consortia, or joint ventures.

The Inner Workings

"The discovery of high-temperature superconductors will force us to change our way of thinking about superconductivity in solids." — ***Victor Emery, Brookhaven National Laboratory***

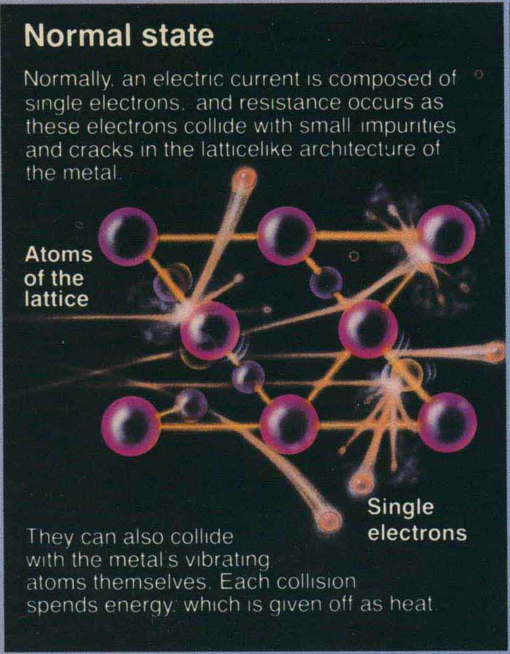
In 1957, the Nobel Prize was awarded to three researchers from the University of Illinois (John Bardeen, Leon Cooper, and Robert Schrieffer) for their explanation of superconductivity. According to their "BCS" theory, superconductivity arises when electrons become paired. The pairs, unlike single electrons, can travel through the lattice without resistance.

A negatively charged electron moving through a metal's lattice structure attracts positive ions very slightly, and this causes them to vibrate. In a few materials, a small unit of this vibrational energy attracts another electron with opposite magnetic spin and momentum. The two electrons thereby become indirectly linked and move together as a pair (called a Cooper pair). Even the pairs become linked, and the electrons flow effortlessly through the lattice.

However, the links between the electrons are so fragile that a slight rise in temperature gives them enough energy to break the linkage (the critical temperature). The BCS theory predicts that the highest critical temperature possible in any material is 30 to 40 K.

Already, the new ceramic superconductors are reaching a critical temperature of 125 K. So, many modified theories have been put forth, involving other types of interactions. In searching for explanations, researchers have focused attention on the crystal structures of the new materials. They all share the common feature of parallel planes of copper and oxygen atoms. Electrons moving in these planes appear to be affected so that superconductivity results.

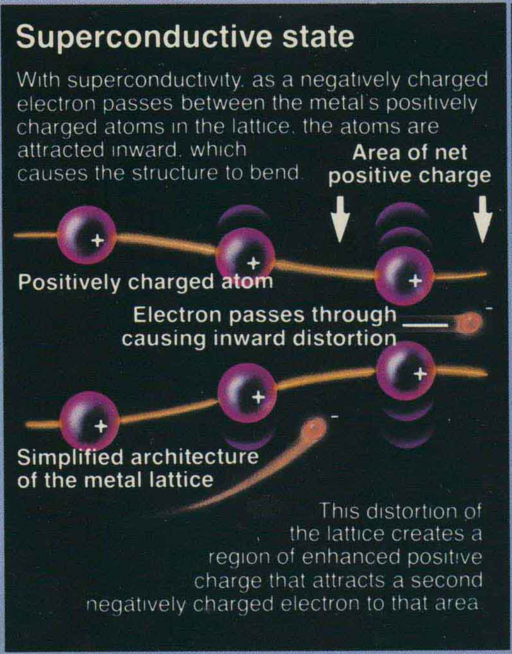
Electron Pairs Encounter No Resistance



Normal state

Normally, an electric current is composed of single electrons, and resistance occurs as these electrons collide with small impurities and cracks in the latticelike architecture of the metal.

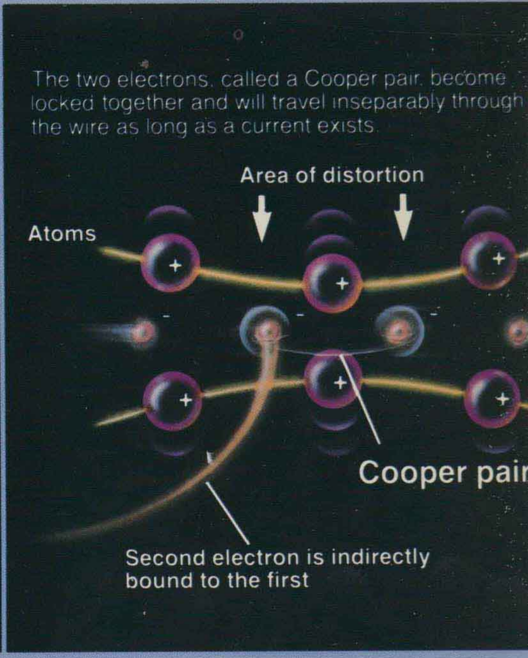
They can also collide with the metal's vibrating atoms themselves. Each collision spends energy, which is given off as heat.



Superconductive state

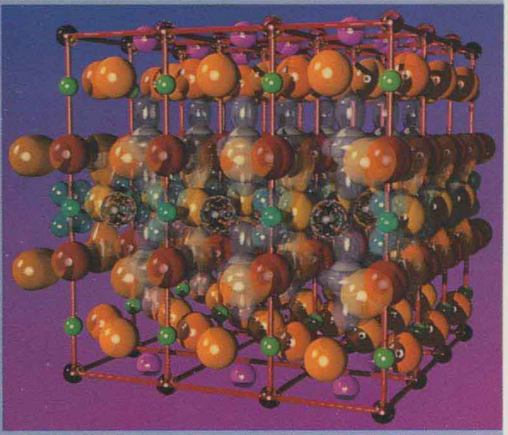
With superconductivity, as a negatively charged electron passes between the metal's positively charged atoms in the lattice, the atoms are attracted inward, which causes the structure to bend.

This distortion of the lattice creates a region of enhanced positive charge that attracts a second negatively charged electron to that area.



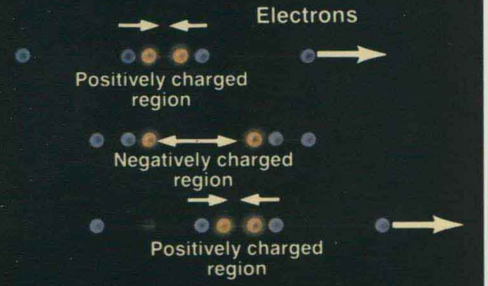
The two electrons, called a Cooper pair, become locked together and will travel inseparably through the wire as long as a current exists.

This computer generated graphic shows the molecular structure of a yttrium-barium-copper-oxide superconductor.

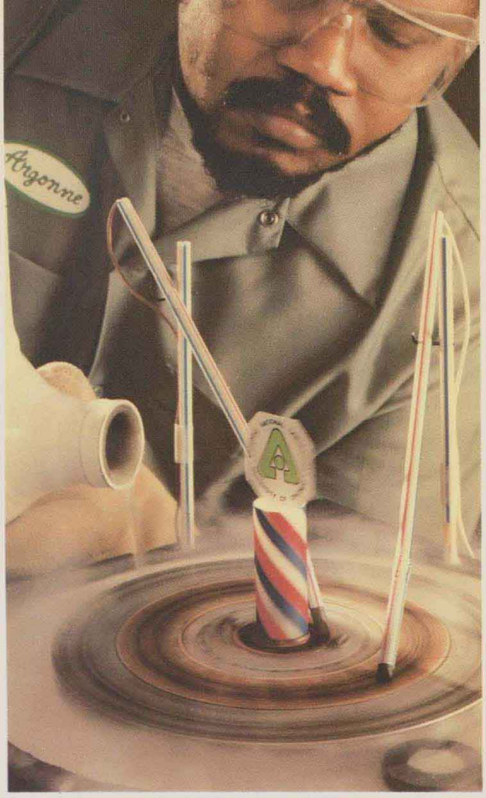


Lockstep progression

The Cooper pairs are held together not only through their own indirect attraction but also due to the electron pair in front and behind, marching along in tight formation.



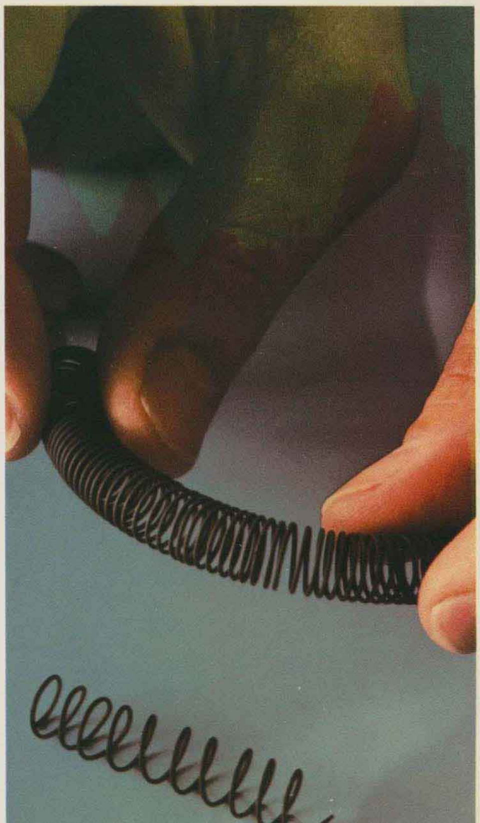
When the atoms of the lattice oscillate as positive and negative regions, the electron pair is alternately pulled together and pushed apart without a collision, resulting in efficient flow of the current.



Argonne National Laboratory developed the first working motor using high-temperature superconducting materials.

STEPS: Superconducting Technology for Electric Power Systems

Our high-temperature superconductivity research program began in the second half of FY 1988. Its goals are twofold: to advance the knowledge of superconducting technology, and to apply that knowledge to large-scale applications in the U.S. electric power industry. To incorporate the talents of a broad spectrum of researchers, we funded ten major DOE laboratories with more than $2.7 million in FY 1988. An additional $7 million was awarded in FY 1989.

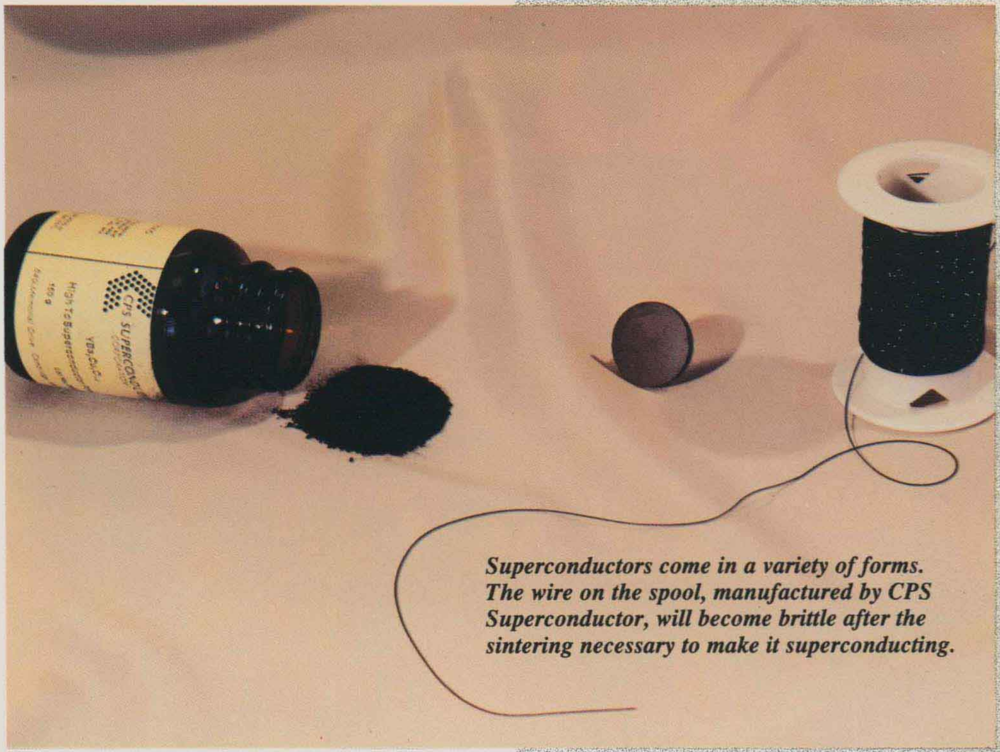


This coil is made of sintered yttrium-barium-copper-oxide superconductor from ICI Advanced Materials. Superconducting coils are necessary for making powerful magnets.

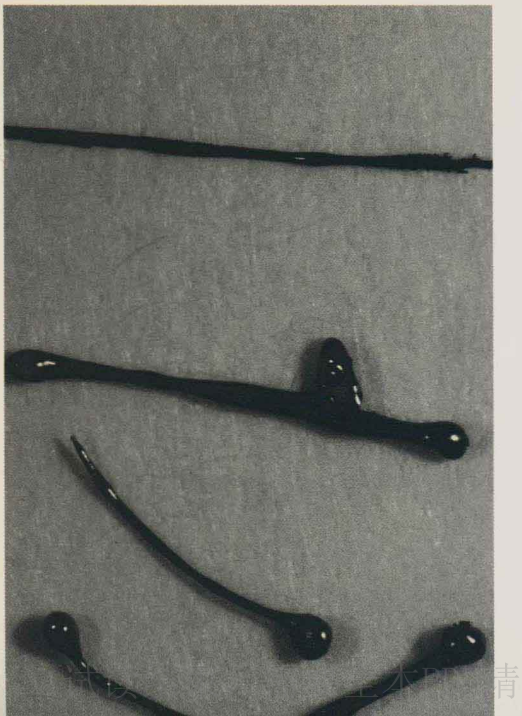
Los Alamos LBL ornl AMES LABORATORY bnl PNL

Superconductivity was discovered, long before its recent resurgence, by a Dutch physicist in 1911. But not until the 1960s and 1970s did researchers develop the first practical low-temperature superconducting technologies.

High-temperature superconductors will also take some time to develop because they present substantial material problems. Unlike the metallic low-temperature superconductors, the new high-temperature superconductors are ceramic. And like most ceramics, they are not able to carry large amounts of current in some forms, are brittle, and do not bond easily to metals. Also, they can be damaged by water and other common materials. Before we can apply high-temperature superconductors in the electric power industry, we must overcome these problems and form the new materials into useful shapes (wires, tapes, filaments, and castings).



Superconductors come in a variety of forms. The wire on the spool, manufactured by CPS Superconductor, will become brittle after the sintering necessary to make it superconducting.



Working with Ames Laboratory, Babcock & Wilcox is developing bismuth-based superconducting filaments by blowing molten material into strings that are typically 0.1mm in diamter and 10mm long. These filaments are combined with a normal conducting metal to create a flexible superconducting wire.

W.R. Grace has made flexible composite films and polymers of yttrium barium copper oxide. After being fired to become superconducting, the composites become brittle.

SERI

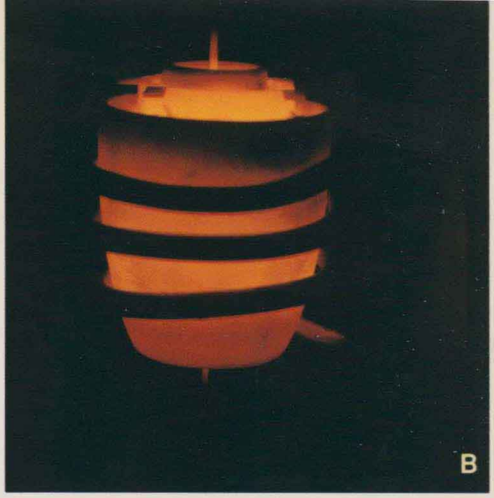
ARGONNE NATIONAL LABORATORY
UNIVERSITY OF CHICAGO

Sandia
National
Laboratories

Focus on 1988

The pilot centers were first established at the close of FY 1988. The first emphasis will be on outreach programs to seek corporate partners and acquaint industry with national laboratory capablities and resources. Already, we have 17 contracts with private industry either signed or in final negotiations. DOE funding for FY 1989 is $2 million for each pilot center.

Bulk superconductors (yttrium barium copper oxide) tend to have crystals that are not oriented in any particular direction.



Since we began the STEPS program in the middle of FY 1988, research is forging ahead in two major areas: bulk superconductors and thin films. Bulk superconductors are devices (wires, pellets, etc.) made totally of superconducting material. Thin-film superconductors have a thin film of a superconducting material (about one-tenth the thickness of a human hair) deposited on an inert substrate.

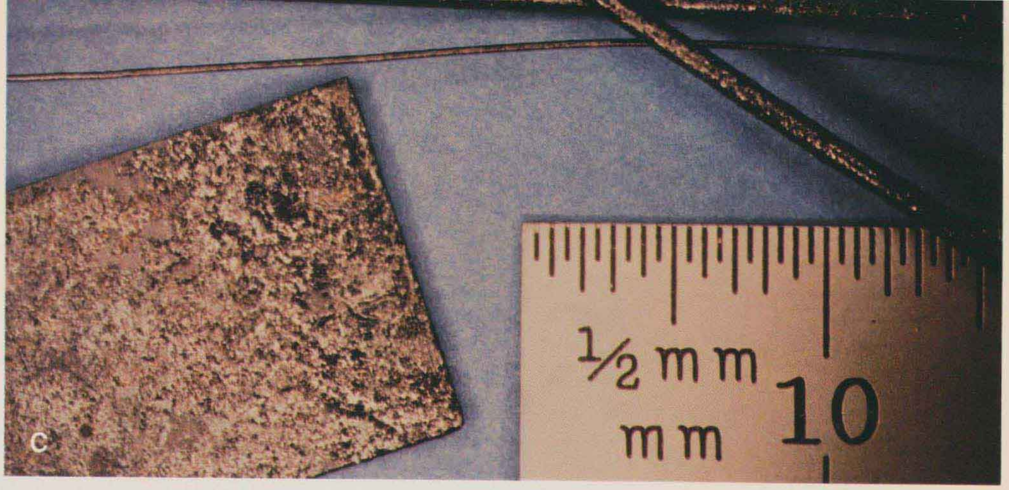
The material properties and processing of these two types of superconductors are quite different. The major drawback to bulk superconductors is that they have a very poor ability to carry current. To be used in electric utility systems, their current density needs to be 10 to 100 times greater than today's technology. Areas of non-superconducting material between the grains of superconducting material makes it difficult for the current to move from one crystal grain to another in the bulk material.

Researchers are working on ways to align crystals (and therefore, the planes of copper and oxygen atoms) to improve current density. By eliminating microstructural flaws and by adding dopants (small amounts of impurities, such as silver), they are beginning to increase the flexibility and toughness of the materials. At least seven different processing methods are currently under investigation.

Thin-film superconductors, in contrast to bulk, can carry much more current. Because of the way they are fabricated, the crystal structure in thin films is easier to control than that in bulk materials. In fact, the current density in thin films is already adequate for most applications. Researchers have already reported current densities of 1,000,000 A/cm^2, the level needed for practical conductor applications.

Unlike their bulk counterparts, thin-film superconductors (bismuth strontium calcium copper oxide) tend to have longer, thinner crystals that have some degree of orientation.

(A) At the Solar Energy Research Institute (SERI), various shapes can be continuously coated with a thin film of bismuth superconducting material, using a molten mixture of the oxides. (B) Inductive heating coils raise the reaction temperature to 1100°C as a filament is pulled through the crucible. (C) Filaments and tapes are just some of the shapes that can be coated.



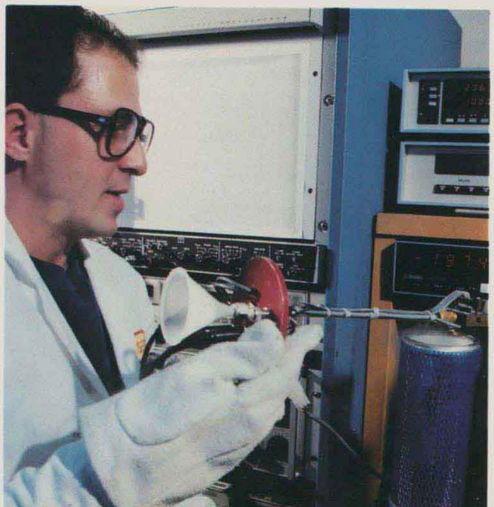
Thin films can be deposited on substrates of different shapes to make superconductors in a variety of configurations. For example, thin films deposited on long narrow ribbon substrates could form a conductor suitable for making magnets or power lines. Researchers are currently developing sputtering and other fabrication techniques.

As scientists make new samples of bulk and thin-film superconductors, they must have fast, accurate ways to measure the electrical and magnetic properties of the material. Several laboratories are developing automated electrical characterization systems and have found various solutions to the problem of how to make fast, low-resistance electrical contacts to the samples. For future applications, researchers have also made permanent copper-to-ceramic contacts that have withstood tearing forces in excess of 100 pounds per square inch.

The emphasis of the STEPS program will gradually shift from its current focus on practical conductor development toward device technology and prototype development. But researchers have already begun to develop computer models to help them identify the critical electrical characteristics needed for superconducting transformers, magnetic coils, and other devices. They have also developed equipment to measure the mechanical and thermal properties of superconductors, as well as computer programs to model costing methodologies.

As part of our continuing effort to work hand-in-hand with industry, in 1988 we organized a successful forum on high-temperature superconductivity applications and the first-ever conference on the science and technology of thin-film superconductors.

Argonne National Laboratory has successfully bonded superconducting materials to copper contacts, to withstand tearing forces in excess of 100 pounds per square inch. Connecting superconductors and normal conductors is crucial for future applications.



SERI and other laboratories have developed state-of-the-art facilities for electrical and magnetic characterization of materials. Here, a sample is loaded for resistance measurements.

Technical Highlights

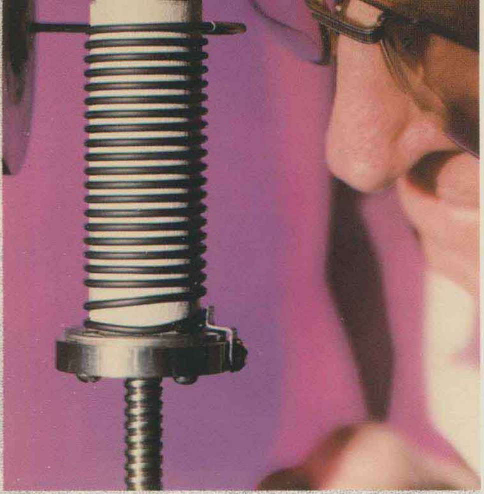
Definitions:

YBCO	yttrium-barium-copper-oxide superconductor
BSCCO	bismuth-strontium-calcium-copper-oxide superconductor
TCBCO	thallium-calcium-barium-copper-oxide superconductor
K	Kelvin, a measure of temperature
T_c	critical temperature, beyond which the material no longer superconducts
J_c	critical current density, beyond which the material no longer superconducts
H_c	critical magnetic field, beyond which the material no longer superconducts
A/cm^2	amperes per square centimeter, a measure of current density

Practical Conductor Development

Bulk Processing Fabrication

- Developed a processing technique to fabricate a flexible sintered composite tape of YBCO that can withstand a mechanical strain ten times that of other YBCO materials. *(ANL)*
- Evaluated the mechanical properties of YBCO and composites doped with various amounts of silver powder. Showed that the average strength, elastic modulus, hardness, and J_c improved while still maintaining T_c in the range of 88 K. *(ANL)*
- Determined from viscosity measurements that it is easier to blow fibers from BSCCO than from YBCO. *(Ames/Babcock & Wilcox)*
- Fabricated BSCCO microfilaments with extremely small diameters, typically 0.1 mm in diameter and 10 mm long. These filaments will be combined with a normal conducting metal such as copper to create a flexible superconducting wire. *(AMES/Babcock & Wilcox)*
- Coated carbon steel substrates with uniform coatings (about 0.1-0.3 mm thick) of YBCO overlayer by solution-plasma spraying methods, and measured T_c values of 88-92 K. *(BNL/State University of New York, Stony Brook)*
- Devised thallium operating procedures and set up laboratories with the proper safety equipment to process bulk thallium-based superconductors. *(LANL)*
- Fabricated a 200-ft length of continuous YBCO wire (0.1 mm diameter) from the melt using the drawn-glass-tube Taylor wire approach. *(LANL/University of Missouri, Rolla)*
- Improved the current-carrying capacity in bulk YBCO superconducting material by high-pressure oxygen and high annealing temperatures. *(ORNL)*
- Found that the YBCO compound is unstable at low annealing temperatures; transformation rate depends mostly on oxygen pressure; high-temperature, high-pressure oxygen anneals yielded the best samples. *(ORNL)*
- Developed a chemical precipitation process (patent filed) to produce powders superior to those prepared with ball mills and mixed oxides. *(SNL)*



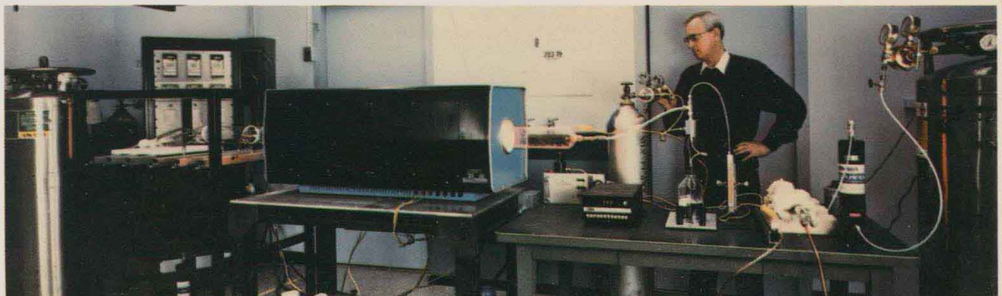
Fabricating a superconducting coil is made easier with Argonne National Laboratory's new extrusion process, shown here producing a 3-cm-diameter coil of "1-2-3" wire.

- Developed a "flash" calcination process to produce bulk YBCO superconducting ceramics with the highest known critical densities (1450 A/cm^2 at 76 K) — higher than those prepared by conventional sintering. *(SNL)*
- Fabricated research-size specimens using a gas gun and dynamic explosive compaction of oxide powders in a metal matrix (patented). The process is ready for development to fabricate long superconductors. *(LLNL)*
- Conducted decomposition studies of superconducting ceramic oxides under high-temperature, high-oxygen pressure to fabricate superconducting wires. *(LLNL)*
- Fabricated disk-type bonds of high-T_c ceramics to copper metal structures by a pressure-bonding method, and successfully produced bonds that have withstood tearing forces in excess of 100 psi. *(ANL)*
- Discovered an oxide-melt process to make dense specimens and coat wires and sheets with the BSCCO superconductor; demonstrated that removing the sheet coatings produced free-standing sheets. *(SERI)*

Thin Films

- Developed a technique to make reliable low-resistance contacts to BSCCO and TCBCO thin films by depositing gold before annealing. *(ANL)*
- Prepared superconducting YBCO films by sputtering from a single mixed-oxide target. Determined that magnesium oxide buffer-layer films are highly oriented and independent of the type of substrate used. This allows films to be grown under practical conditions. *(LBL)*
- Developed a laser ablation system using a high-energy excimer laser, and successfully produced superconducting films of YBCO strontium titanate substrate. *(LBL/LLNL)*
- Prepared suitable starting compounds to produce mixed oxides of YBCO composition by hydrolysis. The resulting solutions will be coated onto substrates to produce superconducting films. *(LBL)*
- Sputtered a high-quality YBCO superconductor by in situ vapor deposition onto Pt films and onto single-crystal substrates of strontium titanate. *(LANL)*
- Deposited in situ superconducting thin films of BSCCO by magnetron sputtering, and analyzed their composition and structure. Uncovered a relationship that lattice constants of high T_c phases are two times larger than those of lower T_c phases. *(SERI)*
- Built a new physical vapor deposition system that is capable of simultaneously controlling the deposition rate of up to five different elements. *(SERI)*

Oak Ridge National Laboratory has developed an aerosol flow system for producing mixed oxide powders.



A plume rises from a sample of mixed oxides being struck by a laser. Lawrence Berkeley Laboratory has developed a laser ablation process to produce films of yttrium barium copper oxide on a strontium substrate.

Property Measurement

- Completed preliminary work on identifying the most suitable measurement techniques for the rapid turn-around characterization of materials up to 9 teslas and from 4.2 to 300 K. *(SNL)*
- Developed a plasma-arc spray process that produces silver contacts with about 10^{-8} ohm-cm^2 resistivities to facilitate transport measurements of bulk samples. *(LANL)*
- Developed an ion-etching, gold-film, low-resistance contacting procedure to solve poor electrical contacts. *(LANL)*
- Completed extensive Auger compositional depth profiling of gold, silver, and indium contacts on YBCO materials for fabricating extremely low-resistance contacts. *(SERI/National Institute for Standards and Technology)*

Device Technology

Component/Device Design

- Adapted a computer model to compare several designs of conventional and superconducting step-up transformers. *(PNL)*
- Modified a computer code to model the stability of high-T_c superconducting magnetic coils cooled by liquid nitrogen. *(ANL)*

System Studies/Modeling

- Performed preliminary tests to determine 60-Hz AC properties of composite specimens of cylindrical YBCO for power transmission studies. *(BNL)*
- Developed a computer program for flux penetration into superconducting tapes to allow computations of AC loss in non-ideal geometries. *(BNL/Massachusetts Institute of Technology)*
- Modified an existing computer program to study epoxy-impregnated magnets operating between 4.2 and 300 K for use in studying YBCO materials. *(BNL/Massachusetts Institute of Technology)*

Technical and Economic Evaluation

- Constructed an apparatus with a complete computer data acquisition system to measure thermal contraction and mechanical properties of YBCO disks between 77 and 300 K. *(BNL/Massachusetts Institute of Technology)*
- Completed the report, "Advances in Applied Superconductivity: Preliminary Evaluation of Goals and Impact." *(ANL)*
- Selected computer programs to analyze life-cycle costing of superconducting power equipment for electric utilities. *(PNL)*
- Formed an effective Study Advisory Group (SAG) to provide a mechanism for evaluating new research and technological information. *(PNL)*
- Held an international conference on the science and technology of thin-film superconductors, attracting over 200 researchers from ten countries. *(SERI)*