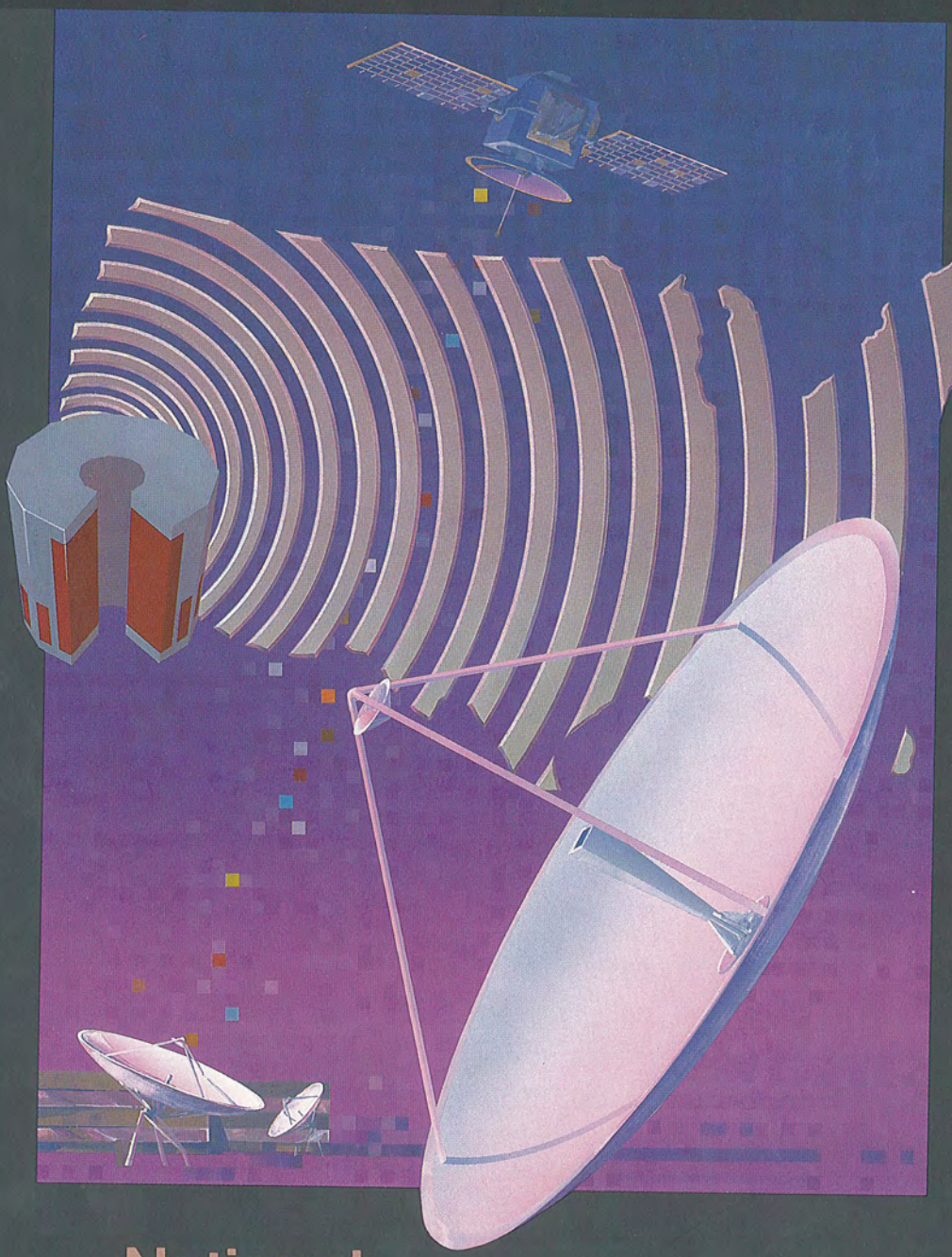


National Magnetic Fusion Energy Computer Center

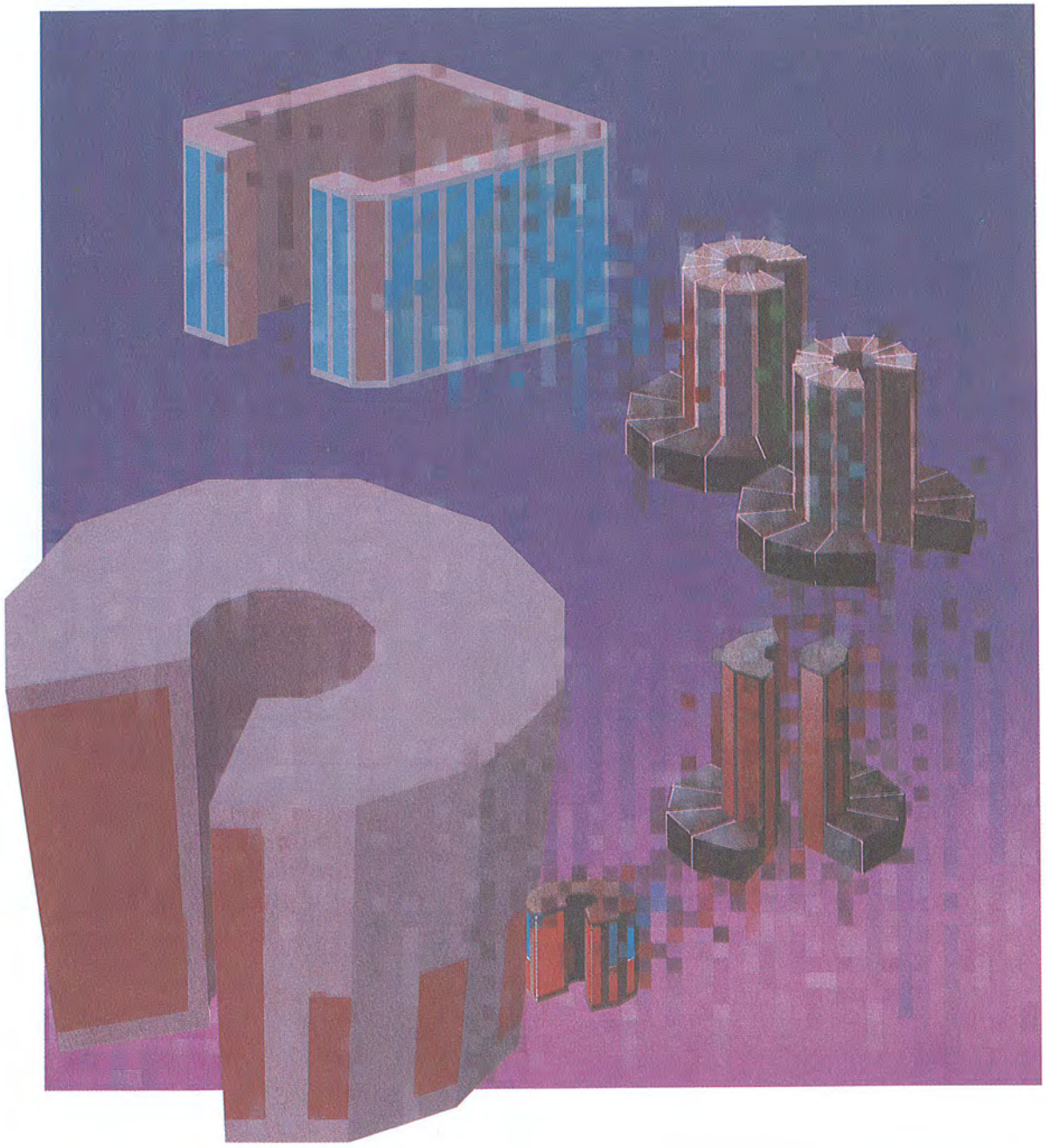
LLL-TB-81

National Magnetic Fusion Energy . . .

. . . Computer Center

The NMFECC building at Lawrence Livermore National Laboratory, Livermore, California.

Sponsored by the Department of Energy, the National Magnetic Fusion Energy Computer Center maintains some of the world's most sophisticated supercomputers. The Center is known for fielding the latest in supercomputer technology, and has housed computers ranging from a CDC 7600 to a CRAY-1 to the Serial 1 CRAY-2. Though today's supercomputers dwarf the early machines in comparison—the Center's CRAYs now represent over 200 times the computing power of that first CDC 7600—each generation of machine paves the way for the next. And each new supercomputer helps bring researchers closer to solving tomorrow's energy needs.



Contents

2 **Our Mission** . . . to provide state-of-the-art supercomputer service to energy researchers throughout the U.S.

3 **Computers** . . . essential for energy research

6 **File Storage** . . . convenient, fast, and reliable

8 **The Network** . . . provides online access nationwide

10 **Our User Community** . . . collaborating today for tomorrow's energy needs

11 **User Services** . . . there's more to running a computer center than operating the computers

- The consultants
- User education
- Engineering codes
- LIBRIS
- Documentation
- Electronic mail, news, and bulletin boards
- Graphics
- Specialized software
- Traditional software support
- CTSS—the operating system
- UNIX subsystem on CTSS

16 **Specific Applications** . . . large-scale computing results in major breakthroughs

- Modeling of stability in a compact torus
- Modeling of heating in a Tokamak
- Modeling nonlinear dynamics-strange attractors

18 **The Future—What's Next?** . . . a new generation of supercomputers to aid international cooperation

Our Mission

NMFECC: a national resource

The primary mission of the National Magnetic Fusion Energy Computer Center (NMFECC) is to provide state-of-the-art supercomputer service to energy researchers throughout the United States. To accomplish this mission, a staff of computer specialists develops and maintains all of the necessary software—the operating system, the libraries, and the utilities—to make a supercomputer available to users immediately upon delivery, and to keep that computer in service during its lifetime.

As an engine is only one part of many in an automobile, so a supercomputer is only a single ingredient in a total environment. Supercomputers are the "number crunchers" in an overall system that includes an input/output system and a file storage and retrieval system. In the process of developing and maintaining software for these support systems, NMFECC purchases hardware from a variety of vendors and integrates it into an already existing total service environment, with an absolute minimum amount of disruption to the supercomputer user community. All supercomputers at the Center are operated in a timesharing mode.

NMFECC maintains a nationwide data communications network (MFENET) that allows researchers online access to the machines via wide-band satellite and terrestrial communications facilities. The Center also maintains a centralized file storage system for its users.

Long recognized as a model in the arena of supercomputer services, the Center is proud of its reputation for excellence. The National Science Foundation, in its effort to establish supercomputer centers for universities, has cited NMFECC as proof that such centers with data communications networks are a cost effective way to meet supercomputer needs on a national scale.

A long standing tradition at NMFECC, the daily nine o'clock "morning meeting" provides an opportunity for all staff members to be aware of important Center happenings. Consultants voice user concerns, programmers announce new developments and downtime schedules, editors listen for news that may affect the online documentation system, and managers keep staff informed of pertinent policy and organization changes.

Computers, essential for energy research

Modern supercomputers are essential to research aimed at the advancement of energy science and technology. Today, the traditional scientific methods of analytic theory and experimentation have been joined by an important third methodology—computational science. The memory size and computational speed of supercomputers have made it feasible to represent the laws of physics more realistically, and thus to create computer simulations of complex natural processes. The need for ever increasing realism in computer simulations has been an important driving factor in the development of supercomputers. Because of this, what may be a supercomputer today may well not be tomorrow. The term "supercomputer" has come to mean the most powerful machine currently available for performing arithmetic operations.

The energy research disciplines with supercomputing needs include magnetic fusion research, high energy physics, nuclear physics, chemical and material sciences, engineering and applied mathematical sciences, geological and meteorological sciences, and the biological and related sciences. Under the sponsorship of the Department of Energy's Office of Enery Research, NMFECC provides access to supercomputers for scientists in all of these disciplines at laboratories, universities, and industrial firms across the nation.

As is clear from the Center's name, the application of computers to magnetic fusion research has been a critical emphasis since the Center began operation in 1975. Computational physics activities have produced a dramatic transformation in the way in which magnetic fusion research is carried out. Theoretical models, developed and enhanced by computations, help predict the behavior of plasma confinement systems and the operating characteristics of fusion power reactors. As the fusion program moves on to large, complex experimental systems with burning plasmas, computational studies provide critical input for guiding system design, predicting system performance, and discovering and solving unanticipated problems.

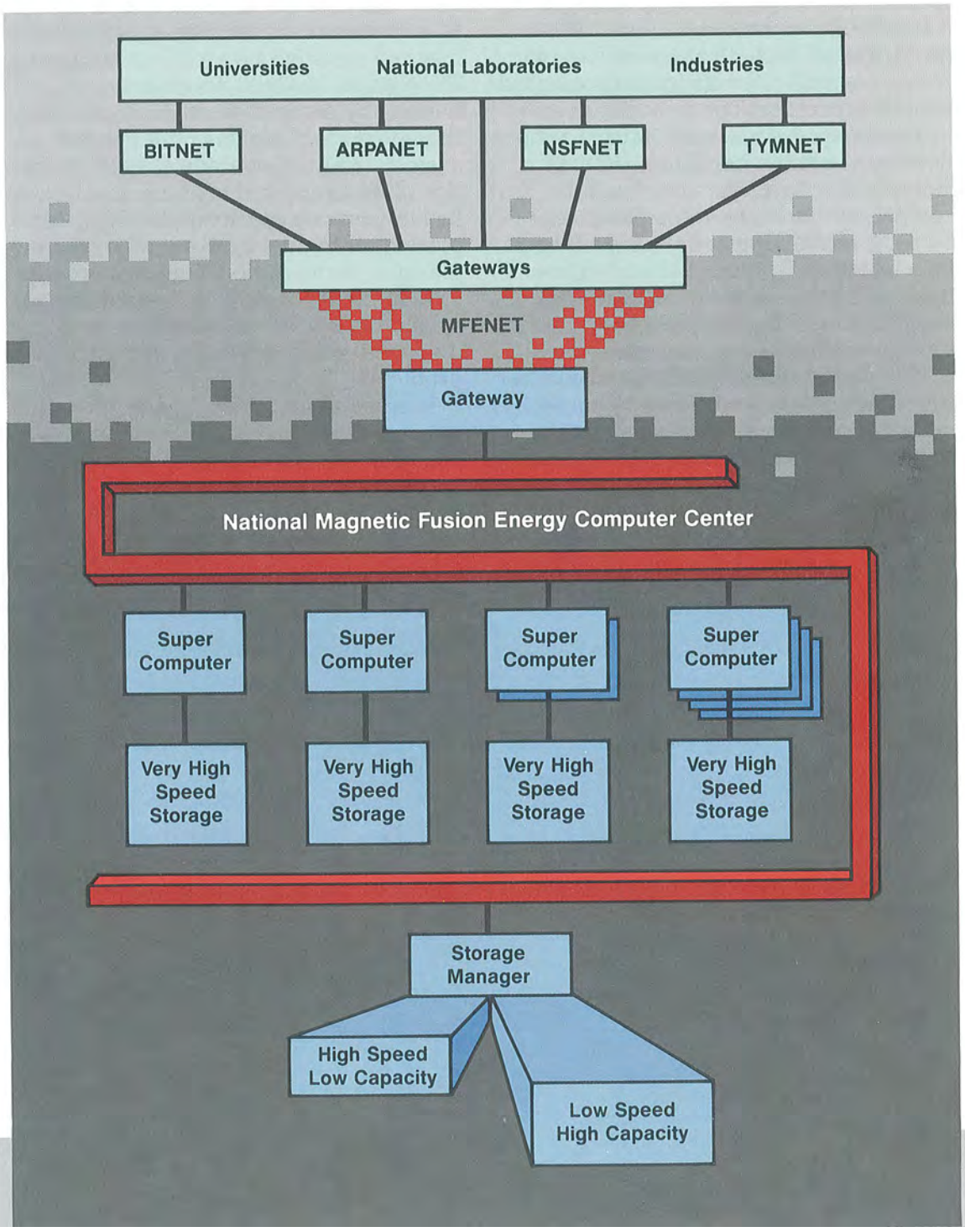
Supercomputers and advanced computational methods have permanently changed the way in which theoretical physics research is conducted. Accellerator design and measurement techniques for high energy physics research have been dramatically enhanced by today's supercomputers,

Fast and powerful CRAY computers and disk drives exemplify the Center's commitment to using the best hardware available to meet the special needs of the energy research community.

but even more capability is needed. The most powerful computers available today are not capable of adequately simulating a large storage ring such as the Superconducting Super Collider (SSC), which is currently in the planning stage for construction in this decade.

In the area of basic energy sciences, computer simulations provide information about phenomena and processes in material systems with refined microscopic spatial and temporal resolution. Researchers can then investigate the dynamic evolution of complex systems under extreme conditions where data from experiments or other methods of investigation are not attainable.

NMFECC's reputation rests on providing leading-edge supercomputing capability in a timely, user-friendly, reliable, and efficient way. To meet the



NMFECC's hardware configuration. The supercomputers and storage devices located at the Center are shown here in blue. The red "S" shape represents the hyperchannel that connects this equipment to our national network gateway.

needs of its users, the Center plans for supercomputer acquisition years before the actual delivery. Historically, supercomputer hardware is ready for use before vendor software is available. In order to have a robust operating system available upon delivery of a machine, the Center develops the software system as the hardware itself is being developed and produced. In 1978, for example, NMFECC acquired the first CRAY-1 at Lawrence Livermore National Laboratory and adapted the Livermore TimeSharing System (LTSS) to run on the CRAY-1. That system, the first timesharing system to run on a CRAY, came to be called CTSS (CRAY TimeSharing System). The CTSS operating system now runs on many machines at a number of centers throughout the world.

Multitasking

In 1983, the Center's user community indicated the need for increased capability to solve larger, more complex problems. Single processor speeds were not increasing fast enough, and the computer industry was proposing multiprocessor systems to compensate. Multitasking, the ability to apply more than one processor to a problem, was seen as the solution. Thus, the Center, to meet its user's needs, began preparing for a multitasking environment two years before its first multiprocessor machine was installed.

Multitasking support within the CTSS environment involved cooperative planning among a number of heavily interdependent groups: operating system, compiler, libraries, memory manager, basic utilities, and the application codes. The development of this environment touched almost every piece of software at the Center, largely because of the very different linkage required to allow the same instruction stream to be used simultaneously by different processors, with different sets of data, without duplicating the instructions.

The CRAY-2

The Center selected the CRAY-2 as its next-generation, multiprocessing supercomputer. Its 4 CPUs and 65 million words of memory satisfied the capability requirements of the user community. Each of the CRAY-2's four processors performs up to 250 million arithmetic operations per second. Once the CRAY-2 was selected, the Center's task was to install a multitasking version of CTSS on the CRAY-2's new architecture, which contained a different instruction and register set, and different I/O interfaces. Some of the preparatory tasks for the CRAY-2 took one to two years to complete. Since there was no actual CRAY-2 upon which to test the codes, the Center developed and built both a software simulator on the CRAY-1 and a hardware emulator. The hardware emulator was built using a bit-slice micro-coded controller to emulate every instruction in the CRAY-2. Both simulators were made flexible enough to change as the CRAY-2 design itself changed. The years of planning and labor proved to be well worth the effort: the CRAY-2 was available for users one month after delivery.

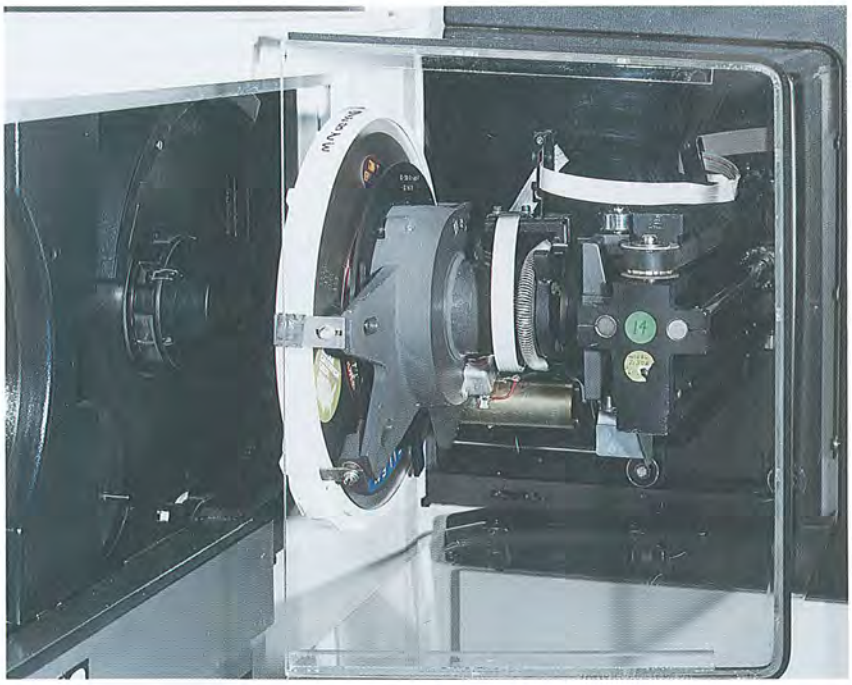
The CRAY-2 has a unique liquid immersion cooling method. Two hundred gallons of colorless, odorless, nontoxic, inert fluorocarbon liquid is in direct contact with the integrated circuit packages. The coolant flows through the module circuit boards at a velocity of one inch per second. This allows for densely packed components, which results in shorter signal paths and, therefore, higher speeds.

Convenient, fast, reliable file storage and retrieval

A centralized file storage system has been an integral part of NMFECC since its inception in 1974. There are at least three reasons why a system such as this is necessary: First, while it is possible to transmit files to and from a remote site, the storage system allows the network to concentrate on files that must be transmitted (input and output) rather than on files that need not be transmitted (codes, data bases, libraries, etc.). Second, while complete file privacy is the normal mode, the centralized storage system allows for files to be shared, which promotes collaboration among researchers. And third, it is more cost effective to provide state-of-the-art hardware and software resources centrally rather than having each local installation duplicating the effort.

The Center's file management system is a multilevel, highly versatile system that lets users store and retrieve programs and data files for an indefinite period of time—hours, days, or years. It is comprised of different types of storage hardware selected by cost and performance trade-offs. It is managed by software that matches the files' usage patterns with the appropriate level of hardware performance.

A file that is heavily accessed is typically found at the highest level of the storage hierarchy—rotating magnetic disks—which provides the fastest access, but is the most expensive in terms of dollars per bit stored. An infrequently used file will be migrated by the storage system software to the slowest, but least expensive media—a typical example is manually-mounted magnetic tapes. In between these two extremes are the robotically-mounted cartridge devices for storing files with moderate usage patterns. The behind-the-scenes software that resides in the



The Center's two Automated Tape Libraries (ATLs) (both from Braegen Corporation) provide nine robotically controlled magnetic tape stations and storage for almost 7000 tapes, or 800,000 megabytes. A robot runs on a track through the tape vault, picking up and delivering requested tapes to one of the high-density tape drives. It may take from a few seconds to several minutes to access a file, depending on its location on the tape.

file management system provides the intelligence for controlling the migration of the files either downward or upward, depending upon commands from the user, usage patterns, and available resources.

This storage system is accessible both interactively by users and by batch jobs. Users can write files individually or they can group files under directories for organizational purposes. Files can be replaced or deleted as necessary. Charges for the use of this storage environment are based on the number of files, their size, and storage media. The storage environment also provides the foundation for other utilities that must span multiple host machines or that need access to shared files. The electronic mail system and the online user documentation system are examples.

During its lifetime, the number of files written into this system has been steadily growing as the power of the supercomputers increases—from a small handful at the beginning to well over a million files that represent trillions of bits for thousands of NMFECC users.

The Network

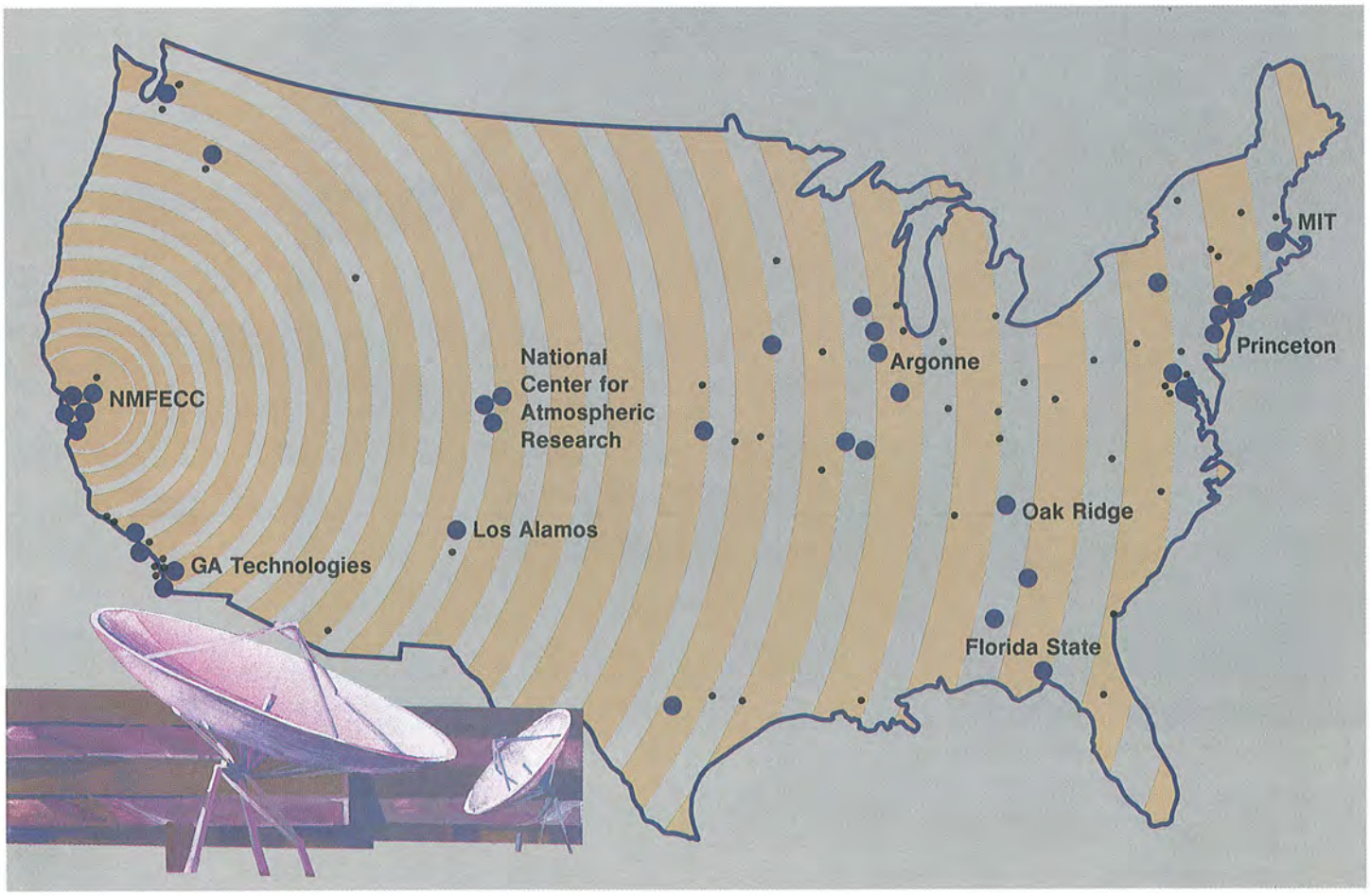
A nationwide data communications network provides online access

Most researchers who use NMFECC's supercomputers are located at sites remote from the Center, some as far away as Germany and Japan. A data communications network, MFENET, allows them to use the Center's resources from their office—wherever it is—as easily as if the computers were in the next room. The MFENET (designed, installed, and operated by NMFECC) makes it possible for researchers to connect their terminals to any computer on the network willing to serve as a "host," including any of the supercomputers at NMFECC. MFENET also allows computers to send text, graphical, numeric, or binary (unstructured) data to each other, and ensures that the data is delivered without error.

More sophisticated uses of the network include:

- Electronic Mail—A researcher may type a message and then give it to the electronic mail system for delivery to the named recipient. This provides a quick and easy mechanism for all users on

The labeled sites (violet dots) are connected to NMFECC by high-bandwidth 56,000 bits/s links. The unlabeled violet dots indicate sites connected to these sites via lower bandwidth lines. Still, other sites, (small black dots) use alternate connections such as ARPANET, TYMNET, and commercial telephone lines.



the MFENET to communicate with each other without the inherent inefficiencies in telephoning. Users can also use MFENET to send electronic mail through other networks, such as the ARPANET, BITNET, and SDSCNET. These networks are connected through "gateway computers." Users can send a message to Switzerland, for example, just as easily as they can send it to the downstairs office.

- Graphics Display—a file (a collection of data with a name) containing several graphics images may be sent through the network to a local display device, designed by NMFECC, which allows the researcher to view a "mini-movie" of computational results on a TV screen in their offices.
- Text Editing—a text editor has been developed that splits the editing job between a personal computer (PC) and a CRAY. Data and commands are exchanged between the two computers, giving the researcher the responsiveness of the PC and the power of the CRAY.

The MFENET is continually changing to meet user demands. Some of the dramatic changes that will be happening in the next few years include:

- Communication processors—the current minicomputers that handle the network data will be upgraded with newer communication processors that are faster and that can handle much more data.
- Protocols—the network protocols (rules for assuring that data is sent and received without errors) are always moving toward newer protocols that conform to international standards.
- The network structure is evolving into a more open architecture that permits network and supercomputer access with commercially available software. This allows access to a much wider community of users.
- Distributed Programs—NMFECC programmers are developing "distributed" programs or applications in which a piece of a job is handled by the workstation in a user's office and another piece of the job is executed on the Center's supercomputers. This, like distributed text editing, gives users the instant response of a workstation, coupled with the power of a supercomputer.

Super Networks

In response to the concept of internetworking, MFENET is evolving into a more generalized communications carrier. Internetworking joins existing networks into larger internetworks, which are in fact networks of networks. This will reduce costs in instances where duplication exists, but more importantly, it will provide access to resources and to new communities of researchers where such access would not otherwise be possible. MFENET is a major contributer to this "SUPERNET" effort.

Data streams between the national center and major centers across the United States. Dual satellites help NMFECC maintain its enviable record as a leader in speed, power, convenience, reliability, at a reasonable cost.

Our User Community

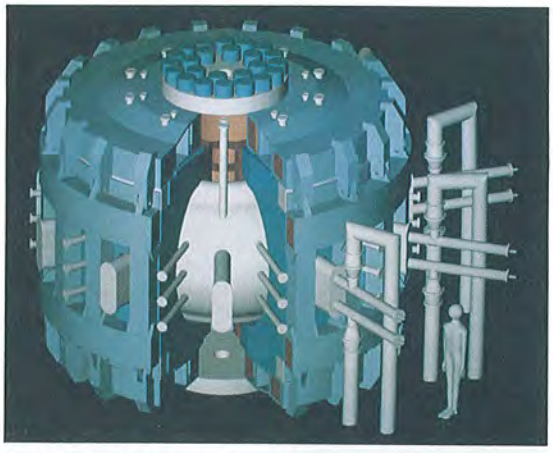
A community of researchers collaborating today for tomorrow's energy needs

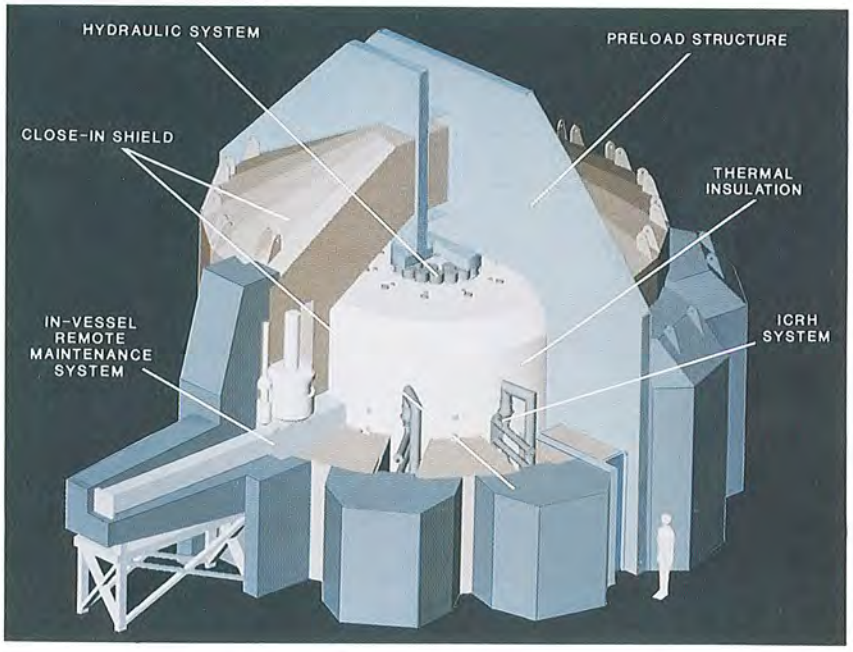
Committed to the belief that pooling resources furthers progress, NMFECC encourages communication among energy researchers. The Center facilitates the sharing of information, codes, data, manpower, and computer power. The nationwide network offers a range of local input/output services and distributed processing, depending on the need in a given area. All local host facilities provide, through the network, interactive and batch access to the supercomputers at NMFECC.

To further aid collaboration, NMFECC is developing its network into a more generalized, multi-functional data communications network that can serve all energy research programs and locations. Advances in communications technology have widely expanded the use of functions such as electronic mail and file transfer.

NMFECC provides supercomputer service to researchers of the Office of Fusion Energy, the Office of Basic Energy Sciences, the Office of High Energy and Nuclear Physics, and the Office of Health and Environmental Research. These offices comprise the Office of Energy Research in the Department of Energy. All together, the Center serves about 4000 users at over 100 locations throughout the United States.

The Center serves theoretical physicists and design engineers as they develop concepts and design and build experiments. The supercomputer service relieves many institutions of costly equipment purchases, while guaranteeing the best in computational power and speed.





These Computer Aided Design (CAD) models represent a collaborative design effort by engineers at Princeton Plasma Physics Laboratory, the Fusion Engineering Design Center at Oak Ridge, Oak Ridge National Laboratory, GA Technologies, Inc., and MIT. The models were made using Computer Vision CAD systems and NMFECC's CRAYs. (Above) Isometric view of the Compact Ignition Tokamak highlighting the reactor core and close-in shield that surrounds the device. (Right) Isometric view of the reactor core of the Compact Ignition Tokamak showing detailed components.

There's more to running a computer center than operating the computers . . .

In addition to 24-hour-per-day, 365-day-per-year access to the Center's machines, NMFECC offers its users an expert consulting staff, always up-to-date online documentation, state-of-the-art system and user software, interactive color graphics, a file storage and retrieval system, a central method for storing and sharing abstracts and codes, and specialized software packages that include a UNIX subsystem.

The Consultants

What happens when a researcher has trouble making some software or a piece of hardware do exactly what he or she wants it to do? How can a person cope, as a dial-up user at a remote location, when stymied by an error in the program he or she has written?

No matter where a problem arises, the Center has experienced software and hardware people on hand to respond quickly in a direct and personal way. These professional consultants may be contacted either in person, by telephone, or by sending a message via the computer network's electronic mail system.

The Center's staff also includes specialists in mathematics, physics, and engineering software who can help users find existing codes that might solve their problems.

Users can get help from a friendly consultant either by electronic mail, in person, or by telephone.

At Your Online Newstands Now

A monthly newsletter, the *Buffer*, keeps the user community informed of current events and future plans of the Center. Fully generated and produced online each month, the *Buffer* is made available to users both in traditional hard copy form and online. While it is being printed and distributed (a process that can take from three to four weeks), users who don't want to wait for their hard copy *Buffer* to arrive in the mail can access the newsletter online as soon as it is completed.

User Education

The Center periodically sponsors classes for new users. Lectures by the consulting staff and other NMFECC experts include discussions about the most frequently used utilities, I/O, math and graphics libraries, and debugging techniques. Classes for more experienced users include such topics as multitasking techniques and optimizing large codes on the supercomputers.

Engineering Codes

Engineers and other researchers will find many online codes to help in all phases of research and development. Current resources include programs for applications in mechanical, electronics, and chemical engineering. Some other areas covered are: neutron and gamma transport, magnet design, and accident analysis.

LIBRIS

One can search for and read engineering and physics code abstracts using the Center's LIBRIS utility. With LIBRIS, a user can obtain descriptions of codes and search for codes pertinent to a given research problem.

Documentation

Up-to-date documentation is available online. Users can refer, at their own terminal, to any of approximately 200 documents, the equivalent of over 18,000 pages of information. The documentation data base (DOCUMENT) covers all aspects of the system services.

DOCUMENT will guide a user in a step-by-step manner concerning use of the system. Information can be viewed using the key-word-oriented option in DOCUMENT. DOCUMENT can query a user about what he or she seeks until it is clear, and then say where to find it. DOCUMENT will also print hard copy on various printing devices, e.g., printers and microfiche film recorders.

Electronic Mail, News, and Bulletin Boards

Electronic mail, news, and bulletin boards are electronically generated and distributed to the Center's user community. Users can post online news notices at the local site only, or at all

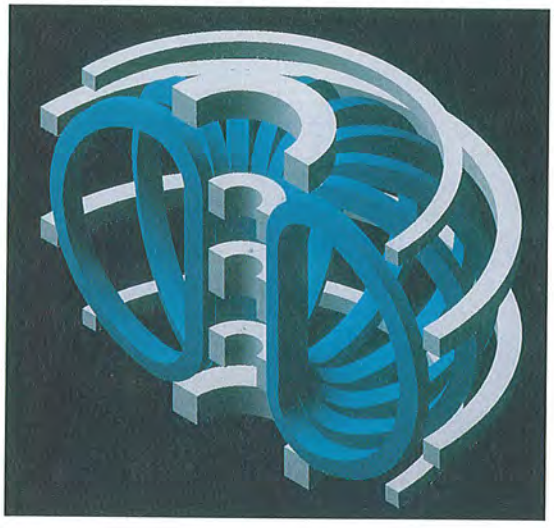
user sites on the system. The electronic bulletin board system permits posting messages in a categorized manner.

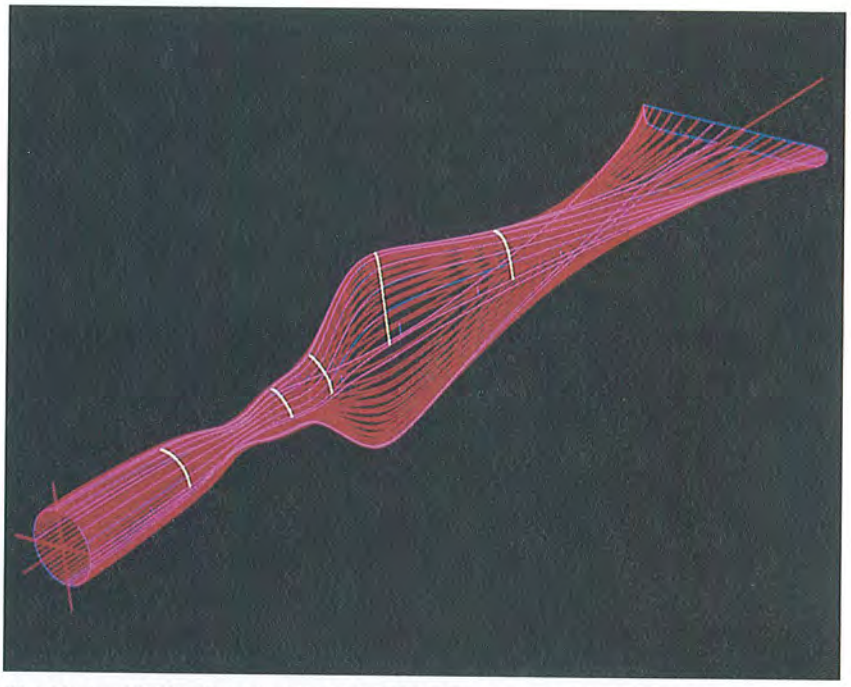
Graphics

A general-purpose graphics software library serves Center users, on the CRAYs or the remote network host. Included in this extensive graphics package are simple routines for drawing lines, points and characters, as well as complex routines for drawing contours, grids, shaded areas and three-dimensional objects. Various utility routines allow the user to view pictures on graphics terminals or to print them on any of the network's printers/plotters.

The Center's Dicomed D48 Graphic Film Recorder is designed for high-performance black-and-white and full-color graphic film recording. This system produces vectors and characters of high quality for graphic COM (Computer Output Microfilm) and, in addition, provides equivalent quality production of raster gray-scale images. The Dicomed D48 can produce 35-mm film in both black-and-white and full-color, 16-mm film and 105-mm microfiche.

Magnet set from Tiber II, a newly proposed small superconducting Tokamak fusion device.

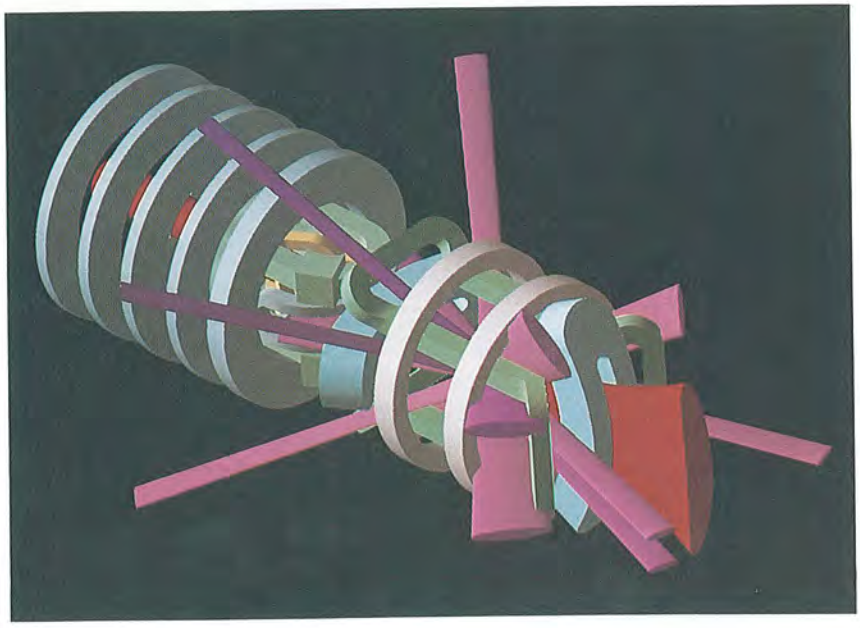




The Magnetic Fusion Engineering Division at Lawrence Livermore National Laboratory is using its Computer Aided Design (CAD) system to construct three-dimensional models of various magnet sets. These models are used for diagnostic placement, interference checking, and visualization of complex shapes generated on the NMFECC supercomputers. The magnetic flux surface shown here was created on the Magnetic Fusion Engineering's CAD system from physics data transferred from NMFECC's CRAYs. The white bands represent cross sections taken through the model. This model was generated in a few hours, whereas plotting this same data by hand would take several days.

Specialized Software

To help its users save time and be more productive, the Center offers an extraordinarily broad spectrum of specialized software. For example, the Center provides mathematicians/physicists with an interactive symbolic algebra program. It provides engineers with codes dealing with accelerator beam design; state-of-the-art structural analysis, heat transfer, and neutronics; circuit analysis; and magnet design. Some codes come from commercial sources, others come from within the energy sciences community.



Computer simulation of an advanced fusion reactor design concept. This shaded surface model of the Tandem Mirror Experiment Upgrade was generated on the Magnetic Fusion Engineering Division's CAD system and processed on NMFECC's CRAYs. This model contains the magnet coil set, the neutral-beam injectors (magenta), and the plasma bundle (red).

Traditional Software Support

The Center also supports an abundance of traditional software: Fortran language compilers; input/output libraries; math and graphics libraries; utilities for symbolic/dynamic debugging; text and report editors; and numerous other activities whose commands may also be invoked under batch processing.

CTSS—The Operating System

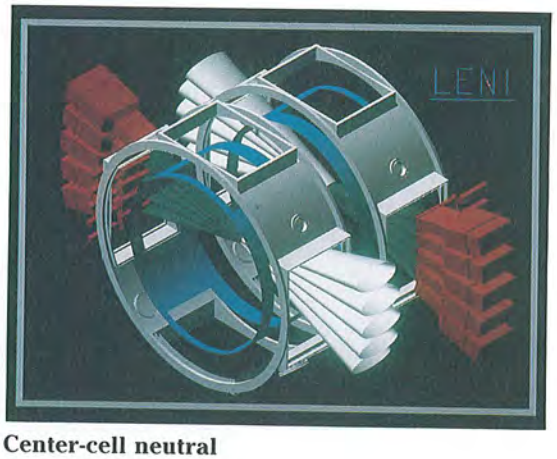
Such a large array of software could not be assembled without a powerful and flexible operating system. The system in use on the main computers is the CRAY Time-Sharing System (CTSS), which has been developed by the Center's computer scientists. It is a fully interactive system that lends itself to rapid code development.

CTSS offers capabilities in addition to interactivity. It permits a program to run other programs. Programs may exchange messages with other programs. Programs may easily expand their size after they start running and learn the size of the problem they must accommodate. Asynchronous, word addressable, random access disk I/O is available. System recovery is so good that codes usually need not bother making restart dumps. With minor changes, a code developed and debugged in timesharing mode can run later in batch processing mode.

CTSS can serve thousands of users. It can serve hundreds of terminals and jobs at any instant. A user can run up to five different jobs from his terminal (through "windows"), or he can submit jobs to batch streams. Each job can spawn other jobs.

UNIX Subsystem on CTSS

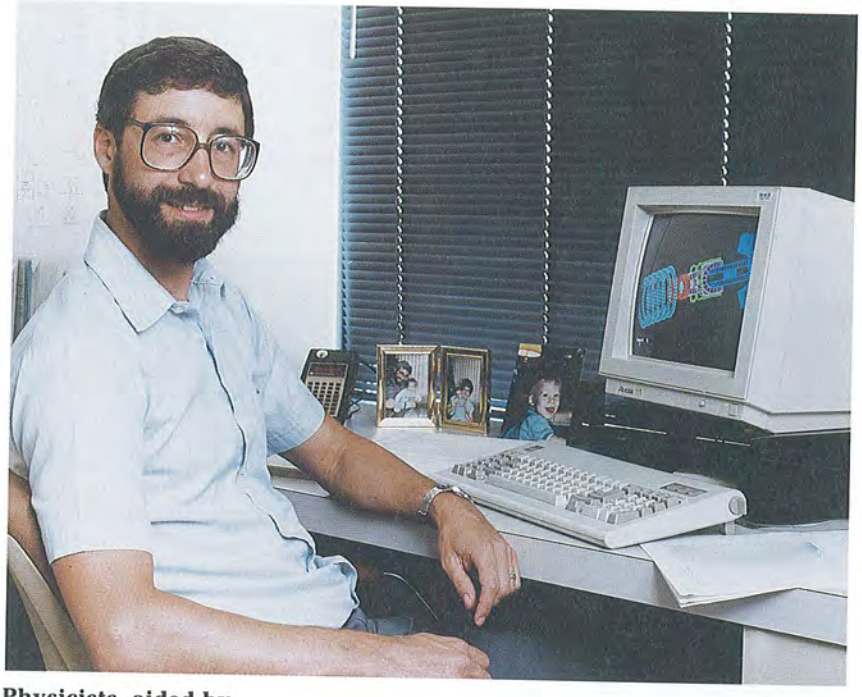
As an added service to CTSS, the Center constructed a CTSS-UNIX subsystem that provides most standard UNIX features: a process scheduler, the ability to run multiple foreground and background processes, a C shell, the Bourne shell, pipes, I/O redirection, and full implementation of the UNIX hierarchical file structure. Any CTSS tools and utilities a user may need while running UNIX are available. The Center provided CTSS-UNIX in response to user requests, and believes that a UNIX program execution environment helps promote the interchange of software with other CRAY sites.



Center-cell neutral beam assembly from the Tandem Mirror Experiment Upgrade.

Large-scale computing results in major breakthroughs

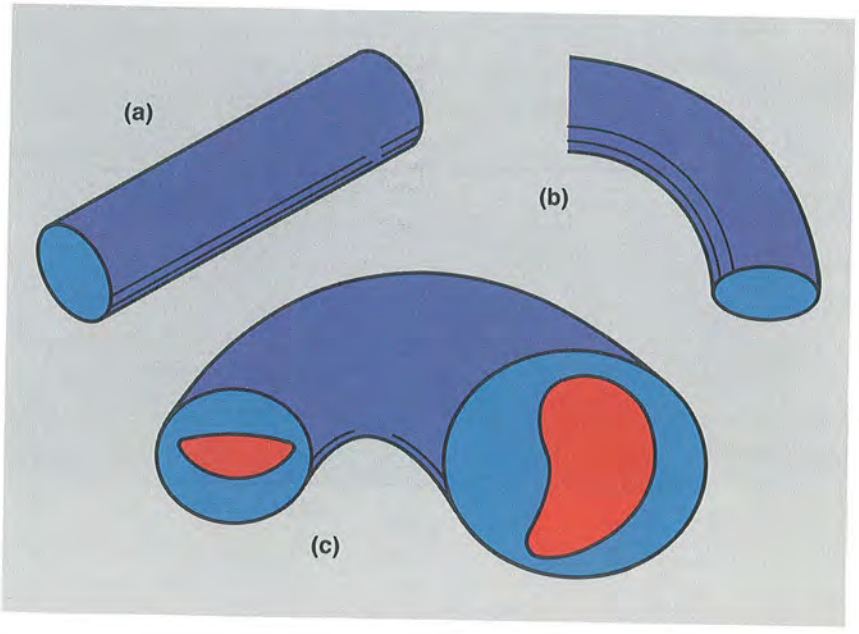
Large-scale computers are essential for the kinds of energy research being conducted today. The ability to carry out highly advanced calculations is primarily a result of the rapid increase in available computer power, and as such, it represents a permanent change in the way theoretical physics activities are carried out. Shown here are some specific applications.



Physicists, aided by the supercomputers at NMFECC, report major breakthroughs in energy research.

Modeling of Confinement in a Tokamak

Determining the maximum amount of plasma that can be confined by a given magnetic configuration is of paramount importance. This may be ascertained through the solution of the evolutionary equations of magnetohydrodynamics (MHD). For cases in which the aspect ratio (ratio of major radius to minor radius) is large (see *b*), the torus may often be approximated by a periodic cylinder (see *a*); this results in a simplified set of equations. Such calculations are usually tractable on a CRAY-1. On the CRAY-2, however, it is possible to perform three-dimensional simulations of smaller aspect ratio, varying cross-sectional devices (see *c*). Examples of current interest include Doublet IIID, the Compact Ignition Tokamak, and the Joint European Torus.



Modeling Nonlinear Dynamics—Strange Attractors

One important aspect of nonlinear dynamics is the study of the long-term behavior of systems of ordinary differential equations. These equations are used to model a physical process, and describe how a given quantity is changing in time as a function of certain other quantities. For instance, these equations might be used to predict next year's mosquito population based on parameters like this year's rainfall, number of birds, and acres of swampland. Knowledge of the solutions of such equations can lead to a more complete understanding of the physical systems they model.

In recent years, many nonlinear systems have been discovered whose solutions are chaotic; that is, the solutions oscillate irregularly, never settling down to a regular pattern. Even so, their behavior is not completely random; the solutions approach marvelously complex sets, called "strange attractors," that have remarkable structure. No matter how much one magnifies a given part of a strange attractor, one sees well defined structure as shown in the accompanying figure. Examples of chaotic systems of equations have been found in disciplines as diverse as solid state physics, neurophysiology, meterology, and plasma fusion. Although the equations have widely different forms, the ways in which the solutions become chaotic and the properties of the chaotic solutions themselves seem to exhibit certain patterns. It now appears that chaos is a fundamental property of nature. Just as the theory of relativity revolutionized physics in the early part of this century, a mathematical understanding of chaos and strange attractors is of enormous scientific importance in a wide variety of fields.

Because this research is nonlinear in nature, it relies heavily on numerical experiments. Before the advent of supercomputers like the CRAY-2, this work was limited to very simple mathematical models and to systems with few dimensions. The CRAY-2's large memory and speed have greatly enhanced the study of nonlinear dynamics.

This is a representation of a computer study of multiple basins of attraction for the forced damped pendulum. The differential equation

$$\frac{d^2\theta}{dt^2} + \frac{1}{10}\frac{d\theta}{dt} + \sin\theta = \frac{7}{4}\cos t$$

represents a pendulum that is allowed to swing through 306°. Starting at a red dot (θ, $d\theta/dt$) at time $t = 0$ means the solution is attracted to a periodic orbit that winds clockwise. The blue represents initial points that have the opposite asymptotic behavior, winding counterclockwise. The lighter the color, the more rapid the convergence. The greenish-white region designates initial points that are attracted to a periodic orbit that does not flip overhead. Black points either behave chaotically for a relatively long time or do not settle down to any of these three. There are six attractors for this equation.

The Future—What's Next?

In the race to build the next generation of supercomputers, scientists are experimenting with a variety of architectural designs. The new architectures will have as few as two processors with shared memories to extensive parallel architectures with hundreds of local memories and processors, all executing instructions simultaneously. Whatever form future supercomputers take, NMFECC will be there at the forefront.

Improvements in supercomputer technology will provide tremendous leverage in addressing problems in contemporary and future science. Out of necessity, computational models in the past have made simplifying assumptions about the laws of physics in order to keep the calculations from running too long. Improved supercomputers will enable researchers to develop more realistic models of physical phenomena.

Supercomputers are a powerful stimulus to scientific advancement in many disciplines. There is no better way to improve the quality and impact of scientific inquiry in the United States than to provide the widest possible access to modern supercomputers. The future is rich with promise as an increasing number of users are gaining access to supercomputers at centers like NMFECC. Such access, combined with improvements in supercomputer technology, will help uplift the whole technological base of our country.

International Cooperation

Increasingly, international commitments are being made that emphasize the potential importance of the work aimed at using controlled thermonuclear fusion for peaceful purposes, and that advocate the widest practicable development of international cooperation in obtaining this source of energy, which is essentially inexhaustible, for the benefit of all mankind. International cooperation in this, and all energy science research, will greatly accelerate the progress and the goal of developing practical energy sources.

The National Magnetic Fusion Energy Computer Center is proud of its role in this area. The Center provides computing service to energy researchers in the belief that it is indispensable, that it must be convenient to be useful, and that the computing service increases in value when members of the research community are successfully encouraged to share resources with one another.

If you would like to contact us, please call our user services representative.

(415) 422-1544 or FTS: 532-1544

You may also write to us.

National Magnetic Fusion Energy Computer Center
User Services Representative
Lawrence Livermore National Laboratory
Livermore, California 94550

Editor
Jeanette Jenness

Artists
Julia Davidson
Tim Pierce

Compositor
Sonnya Raasch

Photographer
Joseph Martinez

Contributors
Gary Brandt
Tom Brown
Hans Bruijnes
John Fitzgerald
Celso Grebogi
Bruce Griffing
John Killeen
Jim Leighton
Art Mirin
Jean Shuler

DISCLAIMER

This document was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor the University of California nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial products, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government thereof, and shall not be used for advertising or product endorsement purposes.

LLL-TB-81

Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

U.S. Government Printing Office: 1986/9 687-063/48404