LASL 79-9

Produced by: the C-2 Documentation Group and the Public Relations Department

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Contract W-7405-Eng. 36 with the United States Department of Energy.

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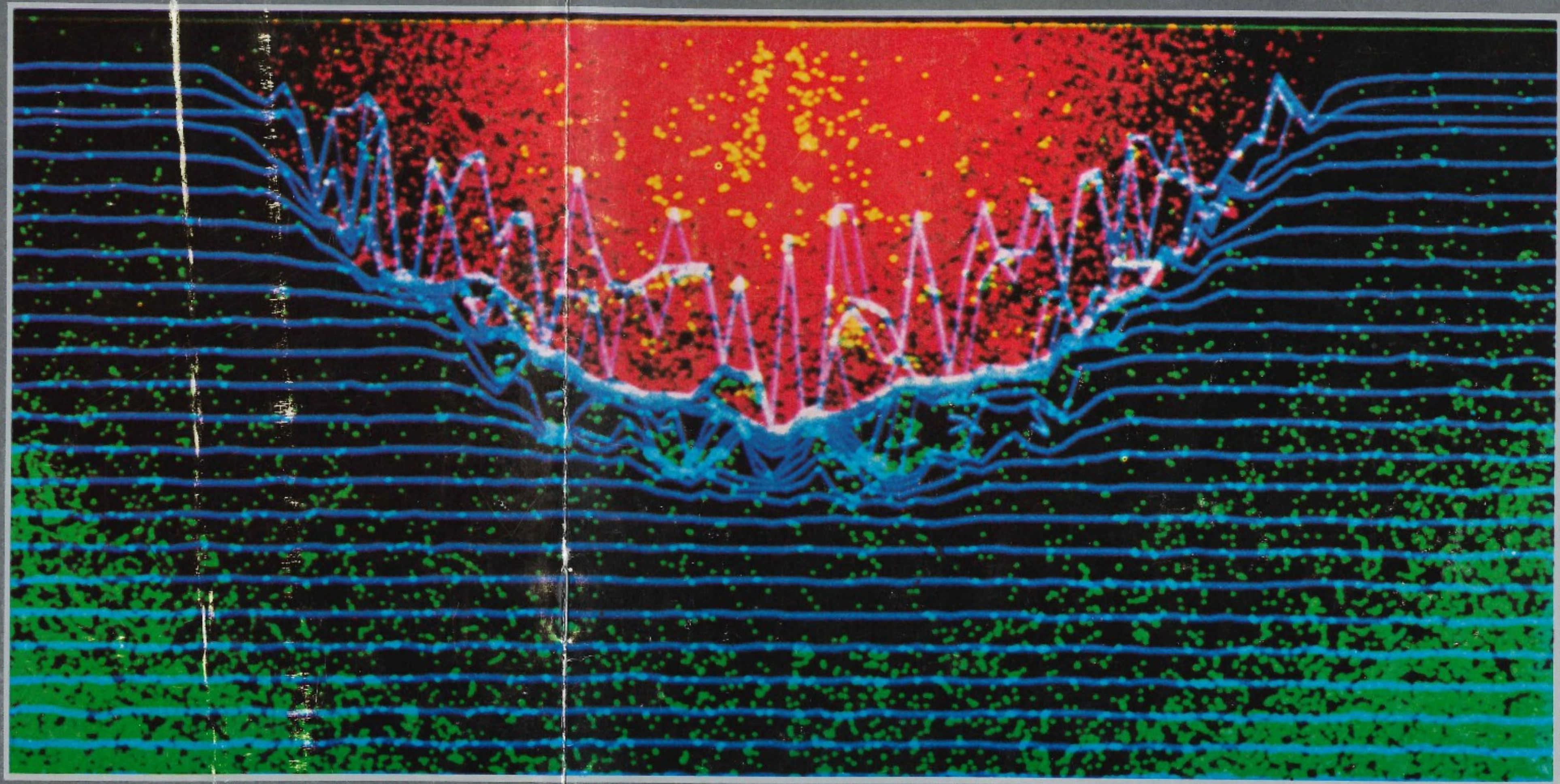
SUPERCOMPUTERS



The CRAY-1 at LASL. The first CRAY-1 supercomputer ever produced was installed at LASL in March 1976. After six months, it was concluded to be the fastest computer so far evaluated by the U.S. Department of Energy. It can perform some 20-60 million floating-point operations per second, which is 2-6 times as fast as the CDC 7600.

FRONT COVER: Weapons atmospheric research. Hot gas expands in ionized air within the confines of a magnetic field.

SUPERCOMPUTERS

What are supercomputers?

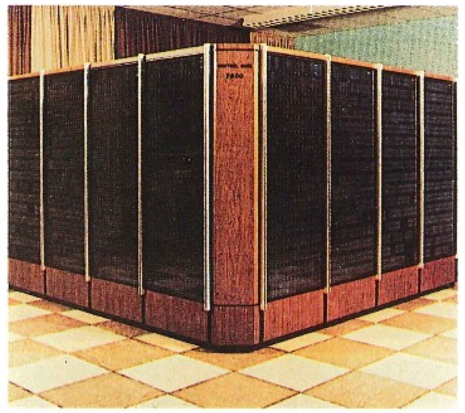
Supercomputers are the most powerful large-scale computers available at any given time. Here, powerful means how fast the computer can execute operations like addition, multiplication, subtraction, and division; how much storage is available; and how precisely it calculates (the number of digits used).

The CDC 7600 and the IBM 370/195 are supercomputers developed during the early and mid 1970s. These computers execute at least 10 million operations per second, have main memory capacities of more than 500,000 "words" (or numbers), and operate on data in which each word has about 15 decimal digits of precision. In contrast, UNIVAC 1, the first commercial computer (1951), operated at about 1000 operations per second, with a main memory of 1000 words.

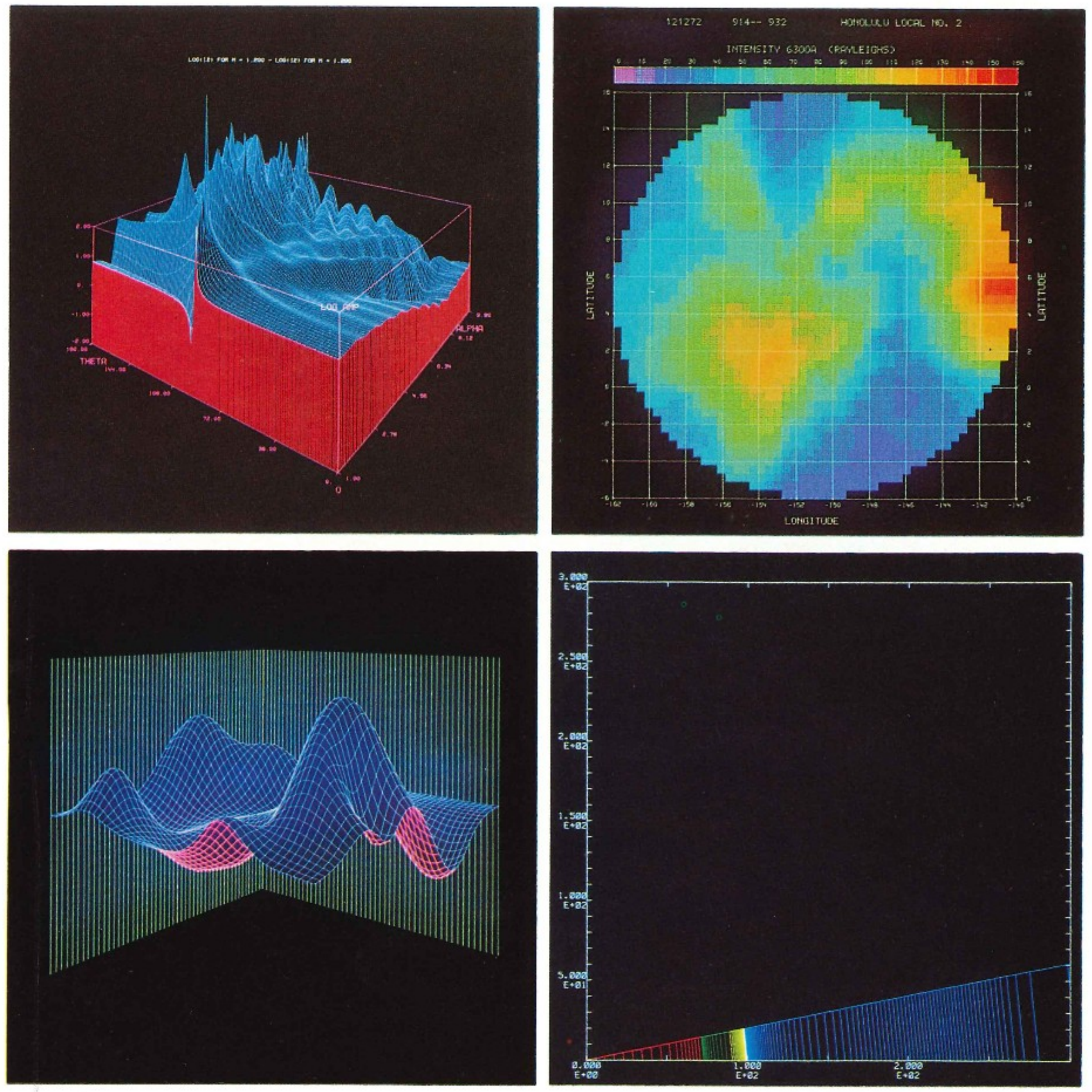
There are relatively few supercomputers in use—probably not more than 100 in the world. The total computer population, on the other hand, is approaching 1,000,000.

Only a few companies manufacture supercomputers because the market is negligible compared to business and general scientific markets and because the design problems are particularly complicated. In fact, several manufacturers have abandoned the market after unsuccessful attempts to penetrate it.

With strong financial support from their governments, however, Japanese and British computer manufacturers will soon be able to produce supercomputers, and the leadership of the United States in this area is in danger of being challenged.



ABOVE: The CDC 7600, which was first delivered to LASL in 1970, is the workhorse supercomputer of the 1970s. It executes 10 million operations per second.
BELOW: STRETCH, one of the early supercomputers, was delivered to LASL in 1961. It was 25 times as fast as its predecessor.



TOP LEFT: Mie scattering—the scattering of light from particles in the atmosphere. Scientists use Mie scattering to study what causes rainbows and halos around the sun and what happens if more particles are put into the atmosphere.
TOP RIGHT: A light intensity plot of aurora borealis (northern lights) as seen from Honolulu.
BOTTOM LEFT: Mathematics—the summation of several bivariate normal distribution functions. Mathematical relationships can be seen more easily in graphic form than in a list of equations.
BOTTOM RIGHT: A computer simulation of a laser-driven, high-density target, which was shot on the Helios CO_2 laser facility at Los Alamos Scientific Laboratory. With a computer simulation, scientists can "slow down" the experiment, which is over in 1 nanosecond (one billionth of a second).

SUPERCOMPUTERS

Why supercomputers?

Most supercomputers are used for scientific computing, that is, simulating complex physical processes with computers. In many cases, the objective is to approximate what occurs in nature. These computer simulations are called "models." The Los Alamos Scientific Laboratory, for example, conducts research and development for the U. S. Department of Energy in two major areas: national security and advanced energy technology. This research includes problems that can often be studied best—and sometimes only—with supercomputers. There are several reasons why this is so:

- Some physical environments cannot be duplicated in a laboratory—for example, the temperatures, pressures, and short time scales of nuclear weapons performance.
- Physical experiments are often expensive and time-consuming and sometimes politically restricted.
- Because it is difficult to measure extreme environments, such as very high temperatures and pressures, physical experiments may not provide adequate data.
- The systems being studied may be so complex that the equations defining their performance can be solved only by computational methods.

The saving of both time and money is perhaps the most dramatic reason for using supercomputers. In many research and development projects, a large number of studies must be conducted on feasibility, performance, safety, security, economics, and other concerns. Conducting dozens, even hundreds, of such studies through physical experiments is simply out of the question because of time and money limitations. The computer is the only practical means of providing the necessary information within a reasonable length of time and at a reasonable cost.

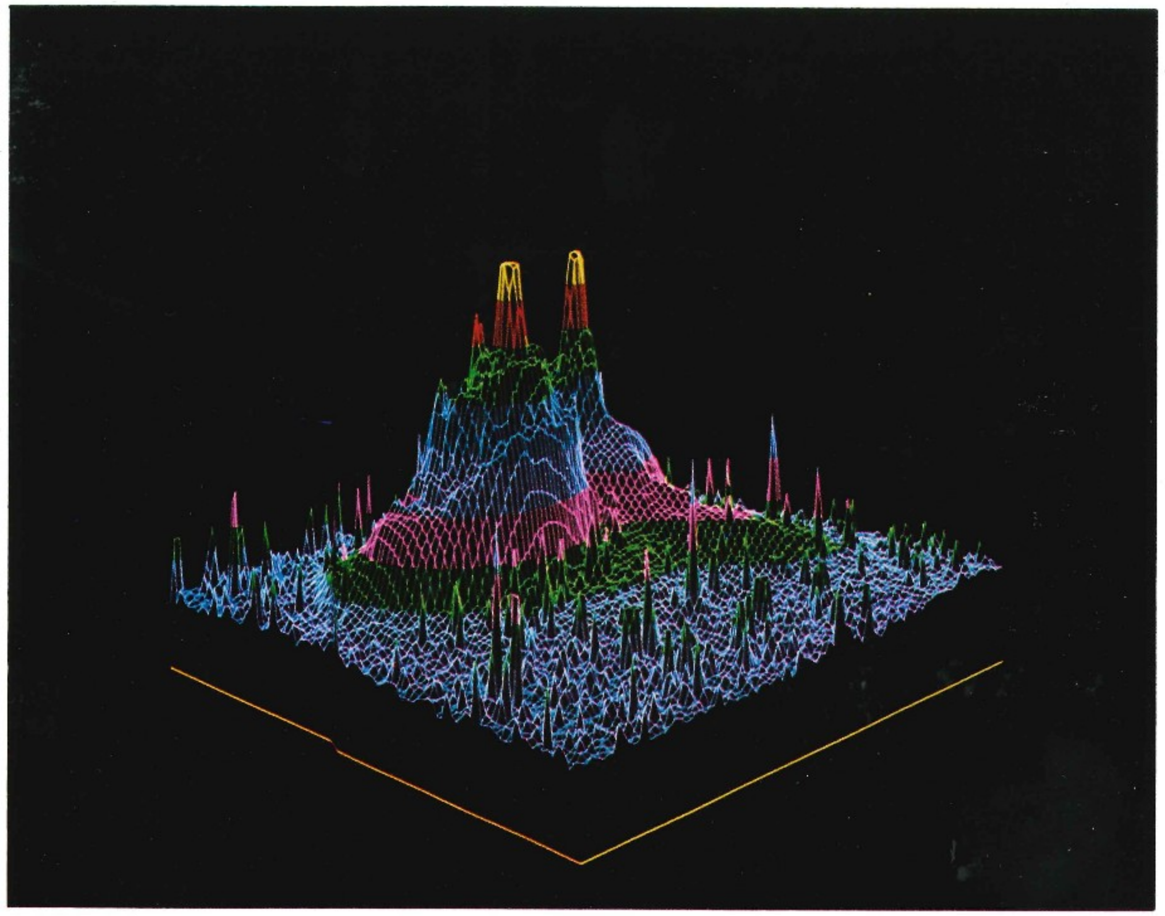
SUPERCOMPUTERS

The problem of growing complexity

Growing complexity is characteristic of science and technology; an obvious example is the contrast between the Wright brothers' airplane and a supersonic jetliner. In the same manner, weapons and energy technologies are also becoming more complicated, and as system complexity grows, more exhaustive studies of both technical and economic alternatives must be conducted.

To study these complex alternatives, improved computer models that include the following features are necessary:
- more complete and accurate representation of the laws of physics;
- more two- and three-dimensional calculations instead of simpler one-dimensional approximations;
- smaller spatial zones, so that the complexity of the system or device can be more accurately represented; and
- smaller time steps, so that rapidly changing physical processes can be more thoroughly tracked.

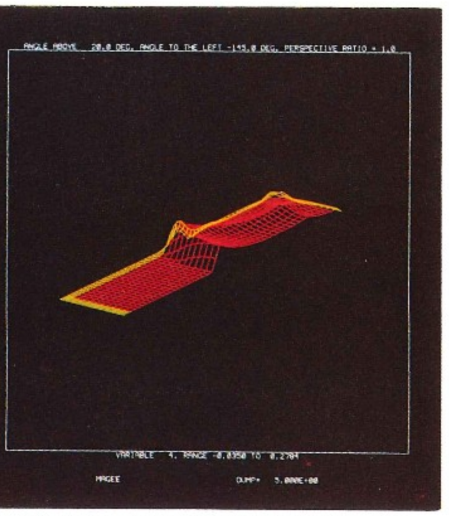
Incorporating these features into computer models means that the computer must deal with more variables and must perform more operations in a given period of time, which in turn demands increasingly powerful computers.



A single frame from a computer-generated movie. This movie is an astronomical study of a complex double galaxy, M51. The height represents brightness; the different colors represent different levels of intensity; the two peaks represent the centers of the two galaxies; and the spikes represent the light intensities of individual stars.

SUPERCOMPUTERS

Some research applications of supercomputers



A plot of part of a hydrodynamic calculation used in nuclear weapons design—a detonating explosive encased in steel.

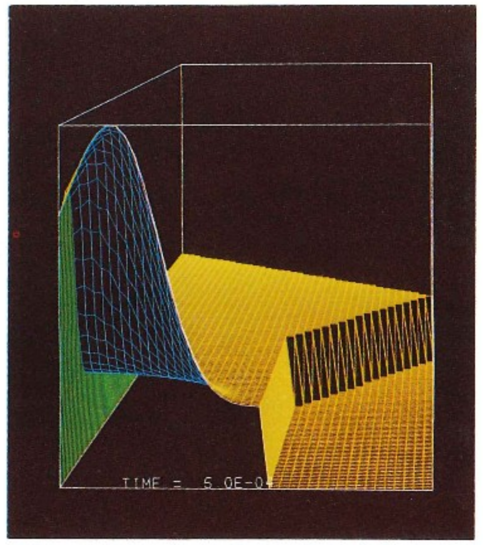
National Security

For most research and development, neither computation nor experimentation alone is adequate. These two methods complement each other: the computations predict how a system will perform, whereas the experiments supply physical data from the real world and verify the computations.

However, the nuclear weapons program's unusually high degree of dependence on computer modeling is perhaps unique because of the political, economic, and technical limitations on nuclear testing. By using computer models of nuclear weapon performance, weapons designers are able to conduct literally hundreds of "experiments" on computers.

Reducing the need for field testing by increasing computer power saves far more than the cost of computing. For example, a nuclear weapon designed with more accurate computer models on the CDC 7600 was certified for the stockpile with only six field tests, whereas a similar, earlier weapon designed with less accurate models on the CDC 6600, which has about one-fourth the speed of the 7600, required 23 field tests. (As a general rule, the faster the computer, the more accurate the model, because a faster, more powerful computer can handle more elaborate equations.) The elimination of 17 tests at a typical cost of $5 million per test saved about $85 million, and this figure does not include the accompanying savings in real time.

Because of the near-perfect safety, security, reliability, and performance required of nuclear weapons, supercomputers will continue to be indispensable to nuclear weapon design.

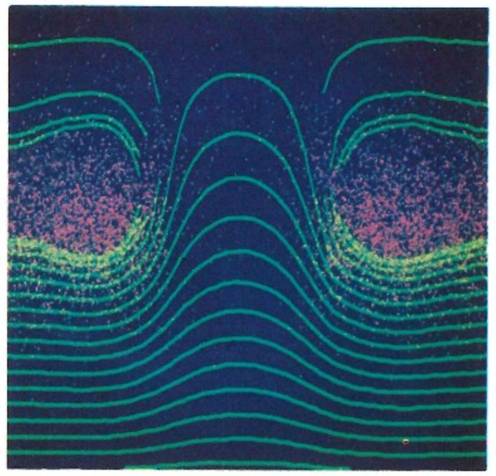


A three-dimensional plot of the magnetic field in a reaction cavity of a conceptual laser fusion power plant.

Laser Fusion

The ultimate success of laser-initiated thermonuclear fusion as a power source depends to a large extent on computer simulations of target behavior. Current computer programs for designing targets use the fastest available computers for up to 50 hours per run because they must incorporate an exceedingly large number of physical models. The typical computer program for designing targets represents years of effort and thousands of hours of computer time. Even so, the current computer programs used in laser fusion studies are a compromise between doing things right and not doing them at all.

Laser fusion experimental facilities cost between $50 million and $200 million to build, so it is imperative that as much as possible be known about them beforehand. Because even more comprehensive computational studies must be done on future laser target systems, even more powerful supercomputers will be needed by the laser fusion program.

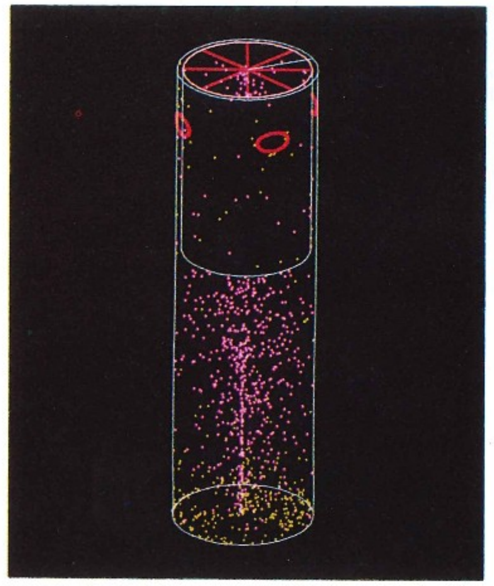


The containment of plasma in a magnetic field.

Magnetic Fusion

At Los Alamos, scientists and engineers are also using supercomputers to study magnetic confinement systems, which will ultimately lead to the development of fusion power reactors. First, supercomputers are used to model "magnetic bottles" to get data both on how plasmas move and on what reactions are taking place. Second, supercomputers allow scientists to model the movement of individual particles in the magnetic field, thereby suggesting ways of managing the plasma so that fusion occurs. Third, supercomputers can perform sophisticated design studies of actual power plants, whereas smaller computers can model only parts of such systems and cannot handle the system as a whole.

As fusion reactor development progresses further and the hardware becomes more complex and more expensive (in the billion-dollar range), scientists and engineers will increasingly rely on supercomputers to guide the program and to help avoid costly errors.



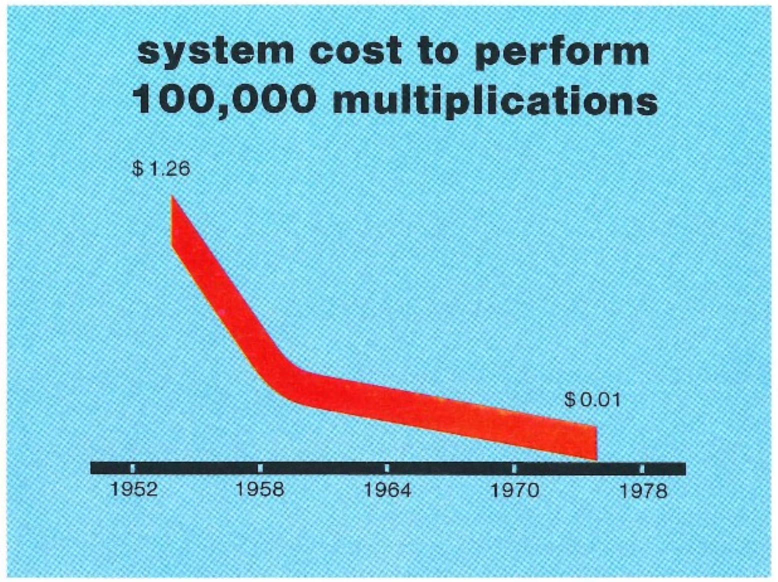
A single frame from a computer-generated movie. The movie displays the flow of water (yellow) and steam (magenta) in a pressure vessel (fuel tank) from a nuclear reactor during a hypothetical LOCA (loss of coolant accident).

Reactor Safety

What would be the consequences of a nuclear reactor accident? This question is a governing issue in the licensing and large-scale expansion of nuclear power plants. It is impractical to perform large numbers of experiments with actual reactors. Instead, reactor behavior during hypothetical accidents, including the adequacy of emergency safety systems, is evaluated with large, complex computer programs.

Concern about the accuracy of these evaluations has occasioned the development of detailed, advanced computer programs that can be carefully compared to experimental results. These programs are at the limit of current computing capabilities; a single calculation can take up to 20 hours on a CDC 7600-class computer.

These large calculations are justified, however, because of the importance of reactor safety and because of the enormous capital investment associated with both large-scale experiments and actual nuclear power plants.



SUPERCOMPUTERS

Trends in supercomputer costs

A remarkable characteristic of computer technology is the trend toward lower cost per operation. For example, UNIVAC 1, which operated at about 1000 operations per second, cost about $750,000.

Although modern supercomputers cost about 10 times more than UNIVAC 1, they can perform up to 100 million operations per second—some 100,000 times faster than UNIVAC 1. As a result, it is as much as 10,000 times cheaper to execute a given calculation on modern supercomputers than it was on UNIVAC 1.

The trend to faster computers is still continuing, but at a slower pace than in the past. Memory capacities, however, are still growing rapidly because of new developments in semiconductor technology. The costs for memory and logic components continue to decrease at a combined rate of about 25% per year, so the price/performance ratio of supercomputers should continue to decline, at least for the near future.

These trends will make it technically and economically feasible to solve increasingly complex problems in nuclear weapons and energy research with the most advanced supercomputers.

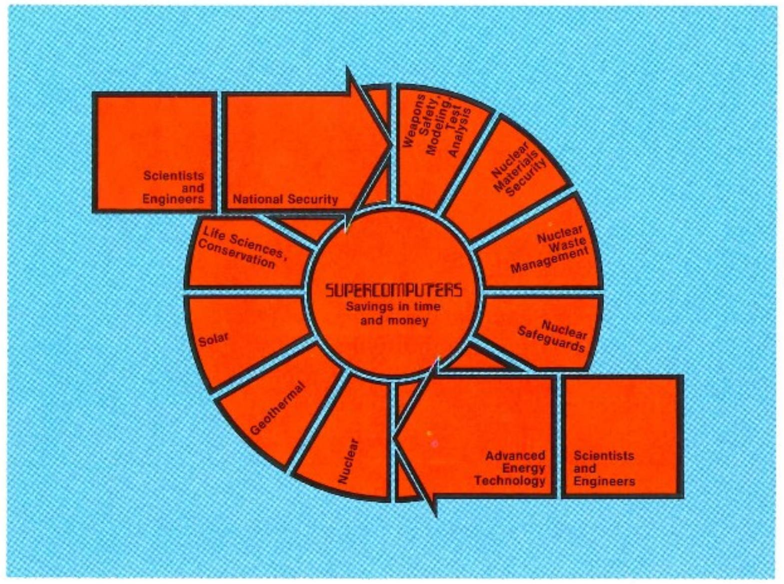
Conclusion

Supercomputers are extremely valuable scientific research tools—so valuable, in fact, that it is against national policy to export them to potential adversaries of the United States. Among the important benefits supercomputers provide are:

- reducing the need for, and increasing the gains from, physical tests;
- increasing the efficiency and effectiveness of new weapons and energy systems;
- improving the ability to meet time schedules; and
- shortening the time needed to develop new energy options for the United States.

Research and development programs gain many advantages from a relatively small investment in supercomputers. The value of a supercomputer far exceeds its cost, which is small compared to the total costs of the weapons and energy systems under development in the United States and the experimental research involved in these programs.

Supercomputers, in conjunction with modern experimental facilities, are indispensable if the United States is to maintain its position as world leader in nuclear weapons and energy technology.



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