LANDMARC

Making Land-Mine Detection and Removal Practical

WHILE diplomats work to restrict the manufacture, sale, and use of land mines worldwide, a massive cleanup effort is needed to find and destroy the estimated 100 million land mines still buried in 65 countries. Land mines left behind from wars worldwide are one of the century's main unsolved problems of war and remain the focus of humanitarian mine detection and removal primarily in Europe, Africa, Asia, and Central and South America.

A combination of technologies from Lawrence Livermore National Laboratory is being directed toward the most daunting challenge presented by land mines—quickly determining the location of each individual land mine in an area so all of them can be removed. The Laboratory's patented micropower impulse radar and advanced imaging technologies are being combined in a practical system called the Land-Mine Detection Advanced Radar Concept, or LANDMARC, that is making pivotal advances in meeting the challenge of land-mine detection.

The Detection Dilemma

Effective solution of the problem posed by land mines means that close to 100% of the mines in any area must be detected at the fastest rate possible and with few false alarms (i.e., mistaking a buried object, such as a rock, for a mine). The United Nations, for example, has set the detection goal at 99.6%, and the U.S. Army's allowable false-alarm rate is one false alarm in every 1.25 square meters. No existing land-mine detection system meets these criteria. And the reasons for this failure have as much to do with the mines themselves and the variety of environments in which they are buried as with the limits or flaws in the current technology.

Land mines are of two basic types—antitank and antipersonnel. Antitank mines are larger and more powerful than antipersonnel mines. However, antipersonnel mines are the most common type of mine, yet the most difficult to find because they are small and often made of plastic. Antitank mines generally contain more metal than do antipersonnel mines and are thus more easily detectable by simple metal detectors. Both types are buried as close to the surface as possible and are found in a variety of soils and terrain—rocky or sandy soil, open fields, forested areas, steep terrain, jungle. For both types of mines, detonation is typically caused by pressure, although some are activated by a trip-wire or other mechanisms. Thus, a land-mine detector must do its job without having direct contact with a mine. It also must be able to locate all types of mines individually in a variety of environments.

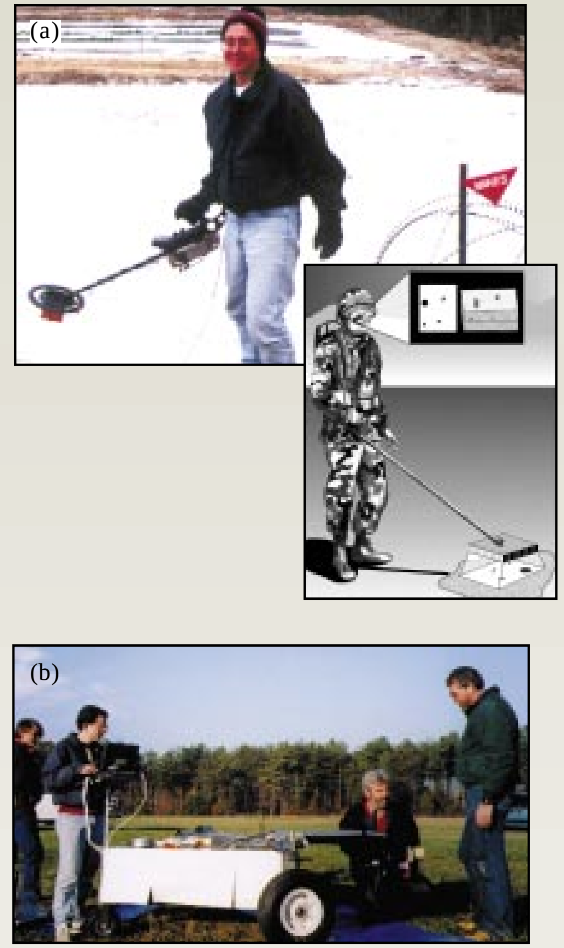

Figure 1. (a) Hand-held and (b) vehicle-mounted LANDMARC systems.

Other Detection Technologies

Various detection technologies are currently used, each with limits or flaws. Dogs and other "sniffers" have high ongoing expenses, are subject to fatigue, and can be fooled by masked scents. Metal detectors are sensitive to metal mines and firing pins but cannot reliably find plastic mines. Infrared detectors effectively detect recently placed mines, but they are expensive and limited to certain temperature conditions. Thermal neutron activation detectors are accurate but are large for field use, slow, and expensive.

In early attempts, ground-penetrating radar was sensitive to large mines, had good coverage rate at a distance, and with signal processing, could discriminate antitank mines from clutter such as rocks beneath the ground surface. This type of radar, however, remains expensive, cannot detect antipersonnel mines because its resolution is too low, and frequently records false alarms from clutter sources.

Livermore's ongoing LANDMARC project addresses all of these problems and stands a good chance of solving them,

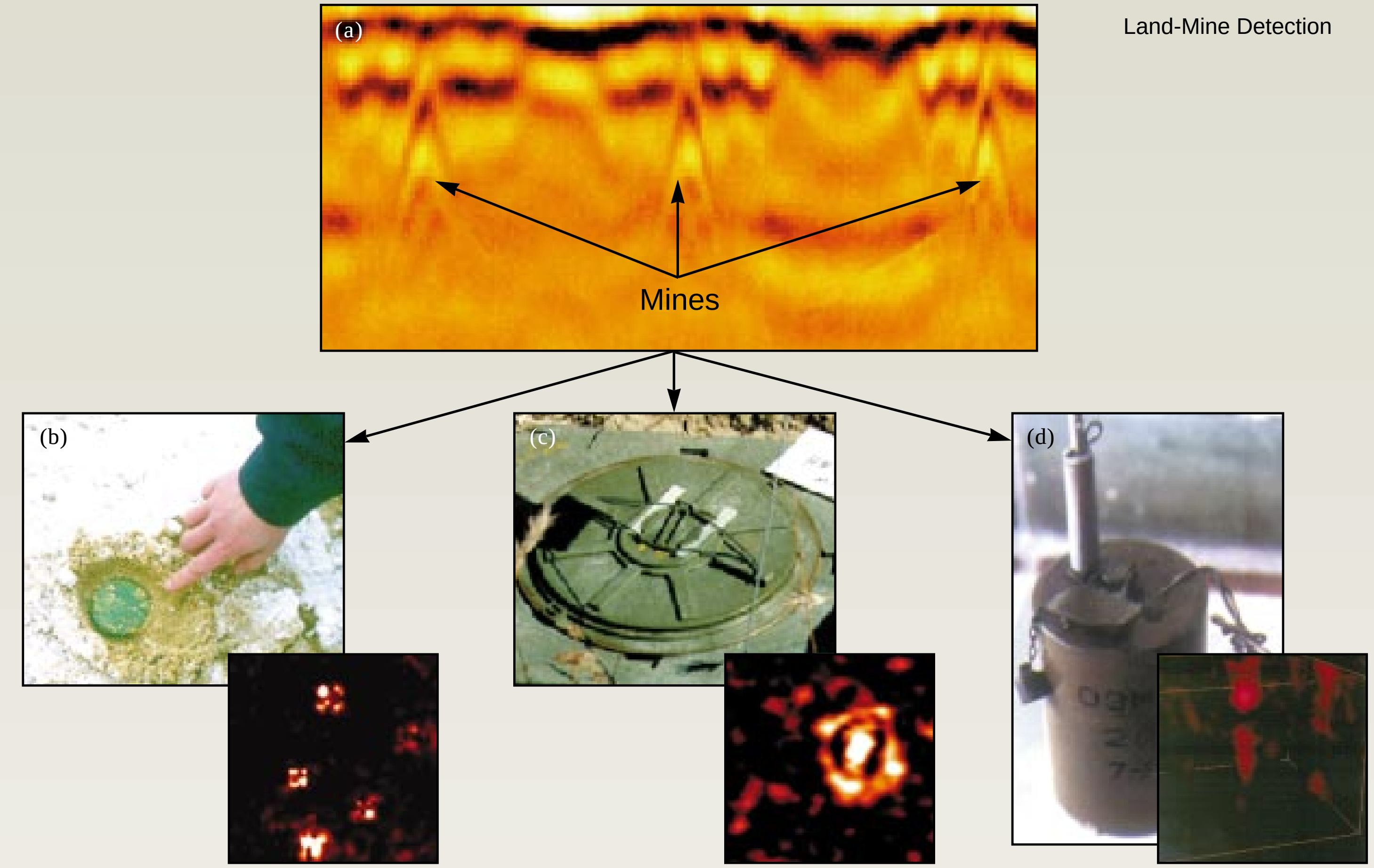

Figure 2. The LANDMARC system has the power to process (a) raw radar data into two-dimensional tomographic images of (b) antipersonnel and (c) antitank mines in a few seconds. In the same time frame, it can also process (d) three-dimensional renderings of, in this case, a buried antitank mine.

especially the problems of detecting small plastic antipersonnel mines and reducing the false-alarm rate.

Livermore's Systems Approach

The LANDMARC system's enabling technology is micropower impulse radar (MIR), which was invented at Livermore in 1993 as an outgrowth of the Nova laser program.[1] The invention, which won an R&D 100 Award in 1993 and an Excellence in Technology Transfer award from the Federal Laboratory Consortium in 1996, led directly to a battery-operated pulsed radar that is remarkably small and inexpensive, has a wide frequency band, and works well at short ranges[2]—all necessary attributes of land-mine detection systems.

MIR's small size, light weight, and low power requirements make it superior to any previous attempts to use ground-penetrating radar to detect land mines. MIR's ultrawide bandwidth is the source of the high-resolution imaging capabilities that differentiate LANDMARC from similar land-mine-detection technologies. Furthermore, the ability to group individual MIR units in arrays increases the speed and coverage area of LANDMARC's detection work.

Livermore's LANDMARC team has combined MIR units with a high-performance imaging system that uses sophisticated computer algorithms to convert large amounts of raw waveform data from the MIR units to high-resolution two- and three-dimensional images of the subsurface. The prototype systems enable users to visualize both antitank and antipersonnel mines and to differentiate them from rocks and other clutter of similar size and shape by the reflected MIR signal. Once the mines can be "seen" and identified, they can be recovered and destroyed.

LANDMARC prototypes have multiple MIR units that are either configured in a hand-held wand, much like that used for simple metal detectors, or mounted on a small robotic cart (Figure 1). In either configuration, the MIR array is passed over the ground with the antennas of the units about 10 centimeters above the surface. The units rapidly emit microwave impulses with very short risetimes (100 trillionths of a second) that radiate from transmitting antennas and penetrate the ground. These impulses strike and penetrate buried objects, bounce back to a receiving antenna, and are sampled and processed by an onboard computer to measure changes in the dielectric and conductivity properties of the subsurface. In a few seconds, the data reconstruction algorithms convert the raw radar data into high-resolution two- and three-dimensional tomographic images of the subsurface (Figure 2). On the system currently under development, the images will appear on either a laptop computer or the operator's headset screen.

LANDMARC Innovations

One of LANDMARC's chief contributions to land-mine detection technology is combining MIR units with a high-performance imaging system.[3] LANDMARC's MIR-based imaging software, which was originally developed for radar inspection of steel-reinforced concrete bridge decks, provides a great improvement over previous land-mine detection technology in sorting out clutter—the most difficult of the imaging tasks—and lowering the false-alarm rate.

Central to perfecting LANDMARC's imaging capabilities are the comprehensive signal and noise models being developed by the Livermore team. These models are based on the contributions from temperature differences, inhomogeneity in the soil, increased noise resulting from multiple reflections in MIR arrays, surface reflections, and subsurface clutter such as rocks, roots, and voids. They identify terrain and soil conditions where radar is likely to work well and other situations where different types of sensors would be more appropriate. More important, the models are used to design algorithms to help reduce the false-alarm rate and increase the positive identification rate in laboratory and field tests, both of which, in turn, improve LANDMARC's ability to discriminate between mines and clutter.

Results from Field Testing

Preliminary experiments identified the operational requirements of the prototype systems. The LANDMARC team developed the reconstruction algorithms that generate a three-dimensional image and is using them to investigate design trade-offs such as array size, sampling rate, and overall speed. In laboratory tests, the prototype clearly distinguished plastic antipersonnel mines from surrounding soils. In field tests at Fort Carson in Colorado and Fort A. P. Hill in Virginia, funded by the U.S. Defense Advanced Research Projects Agency (DARPA), the system performed well, though at a slow pace. The images it produced indicated that much progress has been made in removing the strong ground-surface reflection and other noise sources—that is, improving the signal-to-clutter ratio.

Field tests also indicated areas for additional refinement, among them using higher frequencies (that is, wider bandwidth) to improve resolution and better distinguish mines from clutter, and providing the system with a means of communicating a more accurate field position of the imaged mines.

Future Plans

When field tests with the prototypes are complete, the LANDMARC team plans to conduct blind tests at U.S. Army mine fields to measure detection probabilities under realistic conditions. In addition, plans to speed up the scan rate with advanced arrays are under way. Already experienced in industrial licensing of the MIR technology, the team will then direct LANDMARC toward external sponsorship for deployment in actual mine fields. The Department of Defense, U.S. industries, nongovernmental organizations such as Operation USA and the World Bank, and foreign governments have all shown interest in using Livermore's land-mine detection technology.

–Sue Stull

Key Words: antipersonnel mines, antitank mines, humanitarian land-mine detection, ground-penetrating radar, LANDMARC (Land-Mine Detection Advanced Radar Concept), micropower impulse radar (MIR), subsurface imaging, ultrawide bandwidth.

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2. "Micropower Impulse Radar," *Science & Technology Review*, Lawrence Livermore National Laboratory, Livermore, California, UCRL-52000-96-1/2 (January/February 1996), pp. 16–29.
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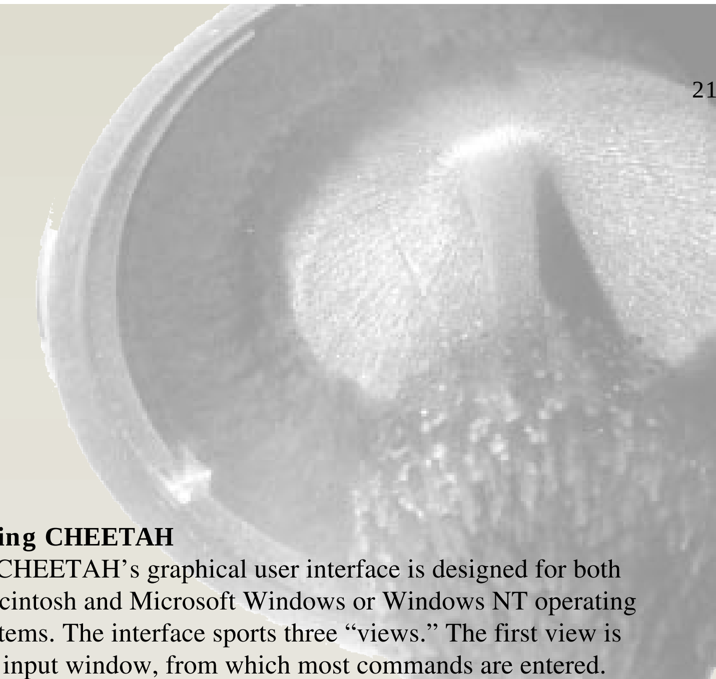
For licensing and MIR partnering information contact (510) 423-1077 (mir@llnl.gov).
Also see the MIR home page (http://www-lasers.llnl.gov/lasers/idp/mir/mir.html).



Improved Detonation Modeling with CHEETAH

A Livermore software program called CHEETAH, an important, even indispensable tool for energetic materials researchers worldwide, was made more powerful in the summer of 1997 with the release of CHEETAH 2.0, an advanced version that simulates a wider variety of detonations.

Derived from more than 40 years of experiments on high explosives at Lawrence Livermore and Los Alamos national laboratories, CHEETAH predicts the results from detonating a mixture of specified reactants. It operates by solving thermodynamic equations to predict detonation products and such properties as temperature, pressure, volume, and total energy released. The code is prized by synthesis chemists and other researchers because it allows them to vary the starting molecules and conditions to optimize the desired performance properties.

One of the Laboratory's most popular computer codes, CHEETAH is used at more than 200 sites worldwide, including ones in England, Canada, Sweden, Switzerland, and France. Most sites are defense-related, although a few users, such as Japanese fireworks researchers, are in the civilian sector. In the U.S., the software has become the Department of Defense's preferred code for designing new explosives (Figure 1) and, to a lesser extent, propellants. (The Livermore work is supported under a Memorandum of Understanding between the Departments of Defense and Energy and is administered through the Office of the Secretary of Defense, Office of Munitions.) CHEETAH is also used by many defense contractors, such as Lockheed Martin and Thiokol, and by small detonation companies.

CHEETAH was developed in 1993 by Livermore chemist Larry Fried and his colleagues at the Laboratory's High Explosives Applications Facility (HEAF) in an effort to update the long-standing TIGER thermochemical code. TIGER, in turn, was a derivative of the Laboratory's original RUBY code from the 1960s. The goal in creating CHEETAH, says Fried, was to make the use of thermochemical codes more attractive to high-explosive formulators through fast, yet scientifically rigorous codes, convenient user interface, and time-saving features such as a library of 200 starting reactants and 6,000 possible products.

Using CHEETAH

CHEETAH's graphical user interface is designed for both Macintosh and Microsoft Windows or Windows NT operating systems. The interface sports three "views." The first view is the input window, from which most commands are entered. The second view is the main output file, in which text is displayed in black when CHEETAH is inactive and red when a calculation is being performed. The third view provides a concise summary of the calculations. Advanced Windows and Macintosh users can also access CHEETAH's command line interface. This command interface is the only form of input possible on systems running the UNIX operating system.

The user first chooses the starting reactants by clicking on the reactant button represented by an Erlenmeyer flask icon. CHEETAH's database of starting reactants, which includes the most frequently used explosives and binders, saves the user the inconvenience of looking up thermodynamic constants for each reactant.

Next, the user chooses one of three different kinds of calculations corresponding to a high-explosive detonation or to the firing of an artillery gun or a rocket. Runs are accomplished by clicking on the green-light icon.

Alternatively, the user could employ the automatic formulator that adjusts the relative proportions of starting materials to match desired performance. For example, a shaped charge designed to penetrate armor needs to deliver its energy as quickly as possible, say, in 10 microseconds. By contrast, high explosives used in rock blasting must deliver energy more slowly, over tens of milliseconds. In this way, researchers can use CHEETAH to "test" new high-explosive formulations without resorting to actual small-scale tests.

The States menu allows the user to specify the thermodynamic states that CHEETAH will calculate. For example, the user can determine the total energy of detonation or the energy of explosion at constant volume.

Updates Expand Capabilities

In 1996, the Livermore team released CHEETAH 1.40, which had extensive improvements to stability and user-friendliness and included advanced features to make its

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(b)

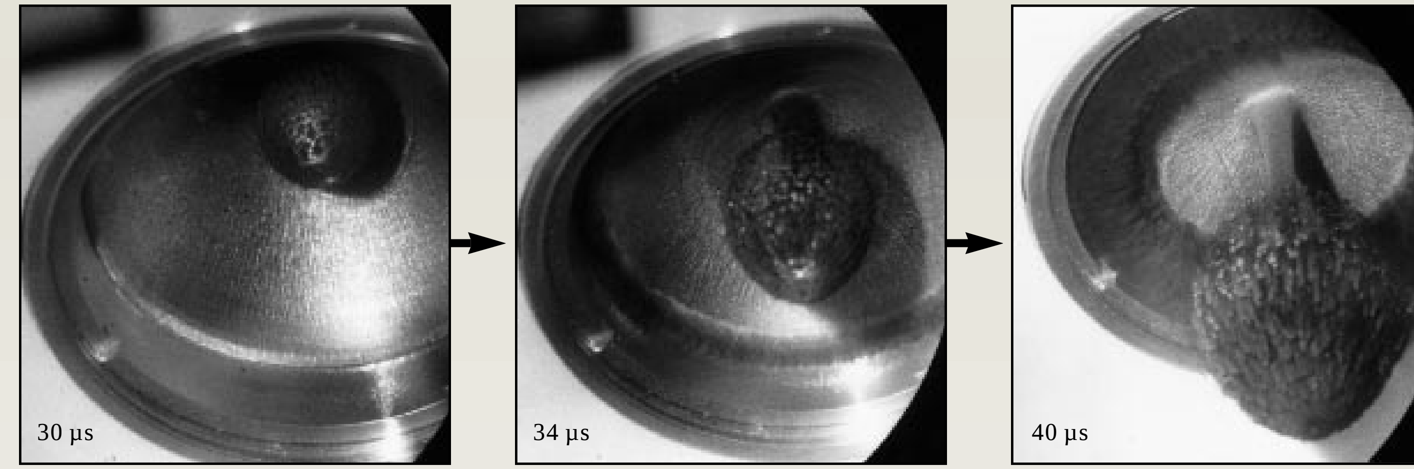

Figure 1. (a) This new explosive paste material was designed using CHEETAH to deliver high energy very quickly for use against armored tanks. (b) After formulation, it was used in an experimental shaped charge, which launches a copper metal jet in only 10 microseconds.

calculations more reliable over a wider range of material types and applications.

Fried says that the most significant improvement in CHEETAH 2.0 is the addition of chemical kinetics, which should help greatly in treating nonideal (slow) detonation processes. The addition of a chemical kinetic framework, based upon modern Wood–Kirkwood detonation theory, allows for modeling of time-dependent phenomena such as partial detonation.

Such nonideal phenomena are often poorly modeled by traditional Chapman–Jouguet thermodynamic theory, the basis for most of CHEETAH's calculations. Chapman–Jouguet theory assumes that thermodynamic equilibrium of the detonation products is reached instantaneously and that all products are consumed completely. In truth, actual situations may give different results because some components of the explosive react too late to drive the detonation front and because heat flows too slowly to bring all components into thermal equilibrium.

Fried has found that with chemical kinetics, CHEETAH can predict the detonation velocity of slowly reacting materials such as PBXN-11 (a mixture of the explosive RDX and aluminum, ammonium perchlorate, and rubber binder, with a detonation velocity of 8 millimeters per microsecond) to within 0.2 millimeters per microsecond. A calculation ignoring kinetics is only accurate to within 2 millimeters, and thus, CHEETAH improves prediction of detonation velocity tenfold.

CHEETAH and Weapons Stewardship

The new chemical kinetics capability is very important for simulating the insensitive high explosives used in nuclear weapons. Simulating these materials has traditionally been difficult because they are much slower to react than classical high explosives. Yet, realistically modeling insensitive high explosives has acquired much greater importance in the current era of no nuclear testing and with the advent of the Department of Energy's Stockpile Stewardship and Management Program.

"As the Laboratory's mission changes to nuclear weapon stewardship, we need to change our tools from those focusing on design to those looking at aging," says Fried. "High explosives change over time, and we need to know more about how those changes could affect their performance."

Toward that end, a major effort was launched last year, in collaboration with Livermore computer scientists Steve Anderson and Shawn Dawson, to link CHEETAH to the extensive hydrodynamic codes of DOE's Accelerated Strategic Computing Initiative. The goal is to create more complete models of high-explosive detonations.

User Satisfaction

At Livermore, CHEETAH is being used to help guide the work of both synthesis and formulating chemists in a molecular design process similar to that found in pharmaceutical research (see June 1997 *Science & Technology Review*, pp. 4–13). It is part of the Laboratory's effort to provide more rigorous scientific structure for a field long dominated by intuition and trial and error.

Fried reports high satisfaction among CHEETAH users. He notes that in the current era of constrained funding, the software can take the place of many actual experiments, thereby saving money by permitting the user to see the result of different formulations. And when cost savings are combined with safer and faster operation of experiments, there is even greater cause for user satisfaction. What's more, the program, now supplied on a CD-ROM, is free of charge to researchers in nonsensitive nations.

There is also no charge for customer support in the form of e-mail dialogues with Fried. User problems and their resolutions are posted electronically in the hope of alerting users to commonly encountered problems.

Fried and fellow researchers Clark Souers and Michael Howard continue to update and strengthen CHEETAH's capabilities. Fried is considering establishing a World Wide Web site so that a researcher lacking good computer resources could log onto one of Lawrence Livermore's smaller computer systems. A Web site could also provide a forum for discussions with users as well as provide ready electronic access to the 300-page manual.

—Arnie Heller

Key Words: Accelerated Strategic Computing Initiative (ASCI), Chapman–Jouguet thermodynamic theory, CHEETAH, High Explosives Applications Facility (HEAF).

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