National Ignition Facility (NIF), optical systems, precision engineering, process development.


**References**

1. For more information on the early days of precision engineering at Livermore, see articles in *Energy & Technology Review*, Lawrence Livermore National Laboratory, Livermore, California, UCRL-52000-87-9 (September 1987). Many of the advances in precision metrology discussed in these articles have become commercial instruments.
2. See “Growing High-Quality KDP Crystals Quickly,” *Energy & Technology Review*, Lawrence Livermore National Laboratory, Livermore, California, UCRL-52000-94-11 (November 1994), pp. 3–5.
3. “New Interferometer Measures to Atomic Dimension,” *Science & Technology Review*, Lawrence Livermore National Laboratory, Livermore, California, UCRL-52000-97-10 (October 1997), pp. 6–7.
4. See “A New Precision Cutting Tool: The Femtosecond Laser,” *Science & Technology Review*, Lawrence Livermore National Laboratory, Livermore, California, UCRL-52000-97-10 (October 1997), pp. 10–11.



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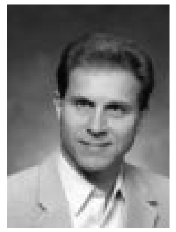
## About the Precision Engineers



**KENNETH BLAEDEL** is leader of the Precision Systems and Manufacturing Group (formerly the Machine Tool Development Group), part of the Engineering Directorate’s Manufacturing and Materials Engineering Division at Lawrence Livermore. He is a specialist in material removal processes, particularly the grinding of brittle materials, and in the design of machines to conduct these processes. He has been involved in the design and application of many of the precision diamond-turning machines at the Laboratory. He holds both a B.S. and Ph.D. in mechanical engineering from the University of Wisconsin and is an active member of the American Society for Precision Engineering. He has extensive experience in dimensional metrology and currently chairs the Environment for Dimensional Measurement Committee for the American Society of Mechanical Engineers/American National Standards Institute.

**DANIEL THOMPSON** has been associated with precision engineering at Livermore since joining the Laboratory in 1975. He is currently Program Leader for the Energy Directorate’s Precision Engineering Program and previously led Livermore’s Machine Tool Development Group for 11 years. He received a B.S. in mathematics from the University of Colorado and an M.E. in mechanical engineering from the Thayer School of Engineering at Dartmouth College. He is past president of the American Society for Precision Engineering and serves as associate editor for *Precision Engineering*. He received the Federal Laboratory Consortium award for excellence in technology transfer and has received two IR-100 (now R&D 100) awards for developments in precision engineering.





# Enhanced Surveillance of Aging Weapons

**Figure 1.** The relative size of the vacuum-tight microextractor assembly (left) and the coated microextraction fiber (right) compared to a quarter. The fiber is less than 400 micrometers in diameter.

WITHIN the Department of Energy, the word “surveillance” has a meaning closely akin to the word from which it derives—“vigilance.” For years, the DOE has had an ongoing surveillance program to verify the safety and reliability of U.S. nuclear weapons. Surveillance has always dealt with the possible effects that aging may have on weapon materials and components. The study of aging effects is even more important now that nuclear testing has ceased, no new weapons are being developed, and the existing arsenal is growing older. Current plans call for many of the weapon systems in the arsenal to be in the stockpile well beyond their design lifetimes, and scientists must be able to predict the behavior of these systems as they age.

DOE’s enhanced surveillance program is just one facet of science-based stockpile stewardship.[1] Since the program began in 1995, it has been managed by DOE’s Office of Defense Programs. But the work is actually being done by the seven DOE facilities that designed and fabricated the weapons in the first place—Livermore, Los Alamos, and Sandia national laboratories as well as the Y-12, Kansas City, Pantex, and Savannah River plants.

The objective of the enhanced surveillance program is to develop diagnostic tools and predictive models that will make it possible to analyze and predict the effects that aging may have on weapon materials, components, and systems. With this information, program participants will be able to determine if and when these possible effects will impact weapon reliability, safety, or performance and thus will be able to anticipate needs for weapon refurbishment. Because the DOE weapons complex has been reduced in numbers of plants and personnel, the lead time necessary to manufacture critical components must be as long as is practical. Enhanced surveillance is crucial to providing the longest lead time the DOE complex can afford to provide.

Specifically, the program’s goals are to predict component and material failure mechanisms; predict the service lives of materials, components, and overall systems; determine the feasibility of monitoring critical components in place, in real time, nondestructively; and develop diagnostics for failure mechanisms when time to failure cannot be adequately predicted.

### Surveillance of Thermonuclear Weapons

The seven participating facilities are working on 110 tasks in three focus areas: primaries, secondaries, and nonnuclear components. Livermore has only minor involvement with project work related to nonnuclear components, which is Sandia’s specialty. However, the Laboratory is heavily involved in the first two areas because its specialty has always been the development of primaries and secondaries, where the fission and fusion processes occur in a thermonuclear weapon. For the work at Livermore, Jeffrey Kass and John Kolb are leading a multidisciplinary team that includes physicists, engineers, materials specialists, and technicians from several directorates.

For weapon primaries, the Livermore team is evaluating changes that occur over time to the pit’s special nuclear materials and to various types of high explosives. For example, plutonium irradiates itself and, given enough time, may change shape ever so slightly. Other tasks involve developing sensors, imaging devices, and diagnostic techniques for nondestructive evaluation of a primary. The team is also developing methods for studying the dynamic properties of primaries through small-scale testing.

Similar work is under way for weapon secondaries, characterizing materials in detail and developing material aging models to predict material life. Livermore staff are also developing diagnostic technologies to verify material and system predictability.

The Livermore project contributes to the work of the Surveillance Information Group, which includes representatives from all the DOE laboratories and plants. The Surveillance Information Group has conducted pilot projects in support of the DOE-wide Nuclear Weapons Information Group,[2] whose mission is to develop a secure, Web-based, electronic archive of old and new classified documents and other information on weapons design, production, and testing.

### Nondestructive Evaluation

Livermore is leading a task to develop a technique called microextraction for nondestructive evaluation of the weapon primary. Microextraction is one of several technologies under development that will be used to determine how aging and the environment may affect the stability of a weapon's components.

Initial work with microextraction analyzed the primary's headspace gases. Studies show that primaries outgas at significant levels. To study these outgasses, Laboratory scientists exposed a microfiber coated with a solid-phase adsorbent to the weapon headspace gas to collect any chemical species. They then analyzed the microextraction fiber using gas chromatography and mass spectrometry. They have also developed methods to move the fiber as close to the weapon's purge valve as possible to permit essentially direct sampling of the weapon headspace and obtain more accurate data (Figure 1).

The Livermore team then characterized the material standards associated with various weapon systems. It found that many of the compounds absorbed in some high explosives may be traced to the use of other materials. For example, significant levels of toluene arise from its use as a solvent in the synthesis of the high explosive TATB. Data analysis thus far demonstrates that the outgassing and absorption processes observed on the core samples would not have significant effects on other materials in the near term because the outgassed species are nonreactive. The next step, which is still under way, is to complete an initial survey of systems and associated materials developed at Livermore.

Livermore is also leading an effort to implement microextraction to assess the aging of organics in closed environments. Valuable baseline information on new and aged weapons components has been obtained at DOE's Savannah River and Kansas City plants, with Livermore providing guidance on the effort.

Another task that Livermore is leading addresses modeling of material aging in the nuclear explosive package (NEP) of thermonuclear weapons. The NEP is a closed environment that contains exceptionally pristine and dry materials. It is enclosed in a can that prevents the interaction of the materials in the NEP with the outer atmosphere.

Livermore's goal is to develop a comprehensive computer model of the chemistry of this closed environment. Models are being developed of the interaction between the materials and between the materials and the gases left in the NEP during assembly. The time it will take for significant interaction to occur is important for the question of when these components will need to be refurbished or remanufactured.

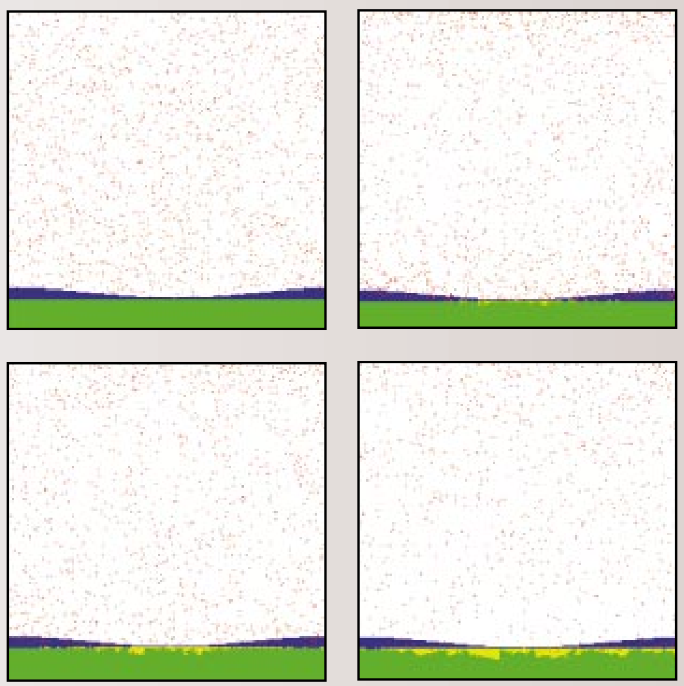


**Figure 2.** A two-dimensional model of the hydriding of a material surface inside a mock thermonuclear weapon's nuclear explosive package in the presence of a layer of oxide. Red particles represent hydrogen, the purple overlayer is metal oxide, green is pure metal, and yellow is the hydrided metal. The sequence is from left to right and top to bottom.





The team is developing models for the reaction of gases with materials and for the diffusion of gases through the NEP. The reaction of gases with metals is a complicated process. Frequently, a layer of oxide on the metal causes the reaction to occur nonuniformly. As shown in Figure 2, a two-dimensional model demonstrates the pitting that may occur during this reaction.

These reaction models must be incorporated into a larger model of the transport and reaction of gases in the system. The Livermore team has begun to do just that using TOPAZ, one of the computer codes developed at the Laboratory for calculating the mechanical properties of materials. The team has demonstrated that TOPAZ, which was designed to model thermal diffusion, can be adapted to calculate gas transport through the NEP system when the grid for TOPAZ is carefully developed. Detailed models of the transport paths in the NEP have already been produced.

Continuing work for this task includes creating advanced gas–solid reaction models and, more important, modifying the computer code to include these models.

### A Look Ahead

Work on the enhanced surveillance program continues. By about 2002 or 2003, DOE hopes to have in place the models and diagnostic tools it needs to determine when weapon components need replacement and ultimately to predict a weapon's safety, reliability, and lifespan. This knowledge will be significant for effective management of our nuclear arsenal.

—*Katie Walter*

**Key Words:** diagnostics, enhanced stockpile surveillance, high explosives, nondestructive evaluation, nuclear explosive package (NEP), Nuclear Weapons Information Group, stockpile stewardship.

**References**

1. For more information on science-based stockpile stewardship, see "Keeping the Nuclear Stockpile Safe, Secure, and Reliable," *Science & Technology Review*, Lawrence Livermore National Laboratory, Livermore, California, UCRL-52000-96-8 (August 1996), pp. 6–15.
2. See "Preserving Nuclear Weapons Information," *Science & Technology Review*, Lawrence Livermore National Laboratory, Livermore, California, UCRL-52000-97-5 (May 1997), pp. 18–19.

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# A National Strategy against Terrorism Using Weapons of Mass Destruction

THE World Trade Center and Oklahoma City bombings signaled a change in the character of terrorism in the U.S. Most of the previous acts of domestic terrorism have not involved mass casualties. However, recent incidents indicate an apparent desire of terrorists to injure or kill large numbers of innocent people—six people were killed and more than 1,000 injured in the World Trade Center bombing, and 168 people died in the bombing of the Alfred P. Murrah Federal Building.

As horrifying as these acts of terrorism were, damage and casualties could have been much greater if the terrorists had used weapons of mass destruction (WMD)—nuclear, chemical, or biological weapons. In March 1995, the Aum Shinrikyo cult demonstrated that terrorists can acquire WMD with its sarin nerve gas attacks in the Tokyo subway that killed 12 people and sickened more than 5,000.

An open society like ours in the U.S. is particularly vulnerable to WMD terrorism. Information on nuclear, chemical, and biological weapons is readily available on the Internet and in many how-to books. There is increasing evidence of illegal trafficking in nuclear materials. In addition, a number of countries hostile to the U.S. are known to be developing WMD capabilities, and some of them are known to support terrorist groups.

### Livermore Study Group Formed

In June 1996, the Director of Central Intelligence and the Deputy Secretary of Energy chartered a study of the threat posed by terrorist groups using nuclear, chemical, or biological weapons in the U.S. Organized by Lawrence Livermore with Associate Director Wayne Shotts as the sponsor, the group was chaired by R. James Woolsey, former Director of Central Intelligence, and Joseph S. Nye, Jr., former Assistant Secretary for Defense for International Security Affairs. Known as the Livermore Study Group, it included eminent experts from the Central Intelligence Agency, the Departments of Defense and Energy, the Federal Bureau of Investigation, the Arms Control and Disarmament Agency, Congress, U.S. industry, and academia.

The study group examined the potential of terrorist use of WMD against the U.S., reviewed current U.S. capabilities, and made recommendations for enhancing the nation's ability to prevent and respond to this threat.

### U.S. Poorly Prepared for WMD Terrorism

The study group concluded that the U.S. is ill-prepared to respond to a terrorist attack that uses WMD. According to co-chair Jim Woolsey, "Of all the threats that could inflict major damage to the U.S., terrorists using weapons of mass destruction is the threat for which the nation is least prepared." The study group notes that although existing capabilities work well for planned high-risk events like the 1996 Atlanta Olympics, no integrated system is in place to deal with a threat of the magnitude, complexity, and severity of WMD terrorism.

The study group recognized that a nascent national policy addressing the threat of WMD terrorism is in place, that it is being implemented at the level of the National Security Council (NSC) by a small staff, and that this high-level group's efforts are making progress in coordinating national resources to meet the challenges posed by WMD terrorism. However, much remains to be done.

**Table 1.** End-to-end strategy for responding to threats and acts of WMD terrorism.

| Intelligence and warning | Prevention | Crisis management | Consequence management | Retaliation |
|---|---|---|---|---|
| • Strategic warning<br>• Tactical warning | • Denial<br>• Demotivation<br>• Deterrence<br>• Elimination | • Detection<br>• Threat validation<br>• Location<br>• Weapon assessment<br>• Impact assessment<br>• Attribution<br>• Demotivation and deterrence<br>• Render safe | • Damage assessment<br>• Evacuation and protection<br>• Reconstitution<br>• Cleanup | • Attribution<br>• Prosecution<br>• Military response |



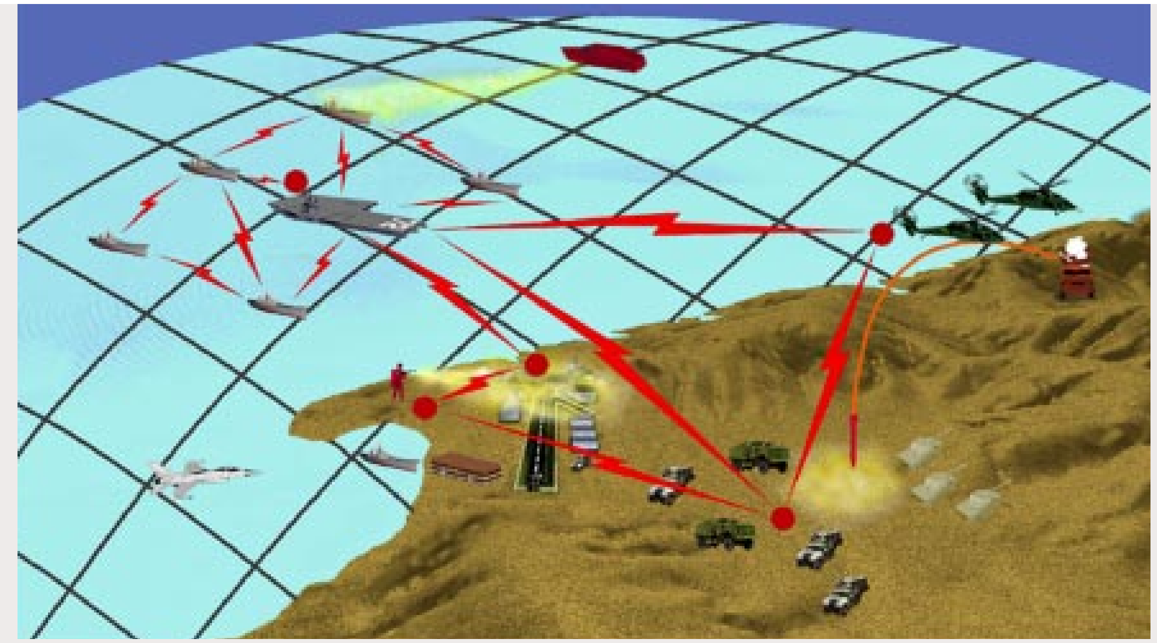

**Figure 1.** The Joint Biological Remote Early Warning System (JBREWS) is a system of networked sensors and communication links being developed to rapidly alert field troops of an attack with biological weapons.

### National Strategy Recommended

The study group's overriding recommendation is, therefore, to give the threat of terrorism using WMD the highest priority in U.S. national security policy. Specifically, it recommends an accelerated and intensified national program, integrated across the entire federal system and managed as a program out of the NSC, to address comprehensively the threat of WMD terrorism.

The study group emphasized that an end-to-end systematic strategy is the best defense against WMD terrorism. Through an enhanced national program, an end-to-end systematic strategy could be implemented that integrates technology, operations, and policy and provides a framework for coordinated local, state, and federal emergency response. "We are not alone in our thinking," says Wayne Shotts, Laboratory Associate Director for Nonproliferation, Arms Control, and International Security and study sponsor. "A number of other studies related to the WMD threat have echoed the recommendation for a more robust national program." The Livermore Study Group takes these recommendations several steps further, urging an end-to-end strategy to provide a multilayered defense—from detection and prevention to reversal and response—in which all phases of a potential WMD terrorist attack can be addressed (Table 1).

Regarding the need for enhanced capabilities, the study group recognizes that many of the agencies responsible for counterterrorism have initiated significant new efforts to enhance U.S. capabilities in this arena. Nevertheless, in looking at an end-to-end strategy, the group identified a number of promising activities to improve the nation's ability to counter the threat of WMD terrorism.

For example, in the area of intelligence and warning, the study group's key recommendations are for more and better technologies and systems for tracking materials and activities indicative of WMD development, production, or transport and for policies and approaches that allow U.S. law enforcement agencies to function effectively in the modern communications-technology environment.

For the prevention phase, the study group calls for additional exploitation of diplomatic efforts, foreign policy, and treaties to promote WMD nonproliferation, strengthen international law enforcement, counter the conditions that foster terrorism, and facilitate the use of technology to counter WMD terrorism. They also note the need for better material control programs worldwide to prevent weapons materials from reaching the hands of terrorists and for expanded border protection programs to detect and intercept WMD materials.

To improve U.S. capabilities in crisis management, the study group urges accelerated development of new sensor systems (or improvement of existing systems) for detecting, identifying, and locating WMD materials and devices as well as technical capabilities for disabling and rendering WMD devices safe. Also required for more effective response and deterrence are better technologies, databases, and other means of forensic identification and attribution of the source, origin, and pathways of weapon materials and devices.

For consequence management, the study group stresses the need for intensified planning and preparation to enable emergency response personnel and medical communities to deal with mass casualties caused by WMD agents. The group also calls for faster and more accurate atmospheric transport and deposition models for determining the populations at risk if biological or chemical agents are released.

"The study group recognizes that implementing an integrated national program to deal with the constantly changing threat of WMD terrorism will not be simple or straightforward," says Joe Nye, study co-chair. "However, we must not wait until a disaster of Pearl Harbor proportions forces us to recognize the severity of this threat and the need to mount an adequate defense."

### Strategic Support from New Technologies

While the study group's charter does not extend beyond analysis and recommendations regarding WMD terrorism, Dennis Imbro, a Livermore scientist who served as liaison to the group, notes that "there must be a marriage of technology and policy to effectively counter this threat." The national laboratories are a valuable source of innovative and advanced technologies and thus can make important contributions to this critical aspect of national security. A number of technologies are being developed or refined at Lawrence Livermore that can address gaps in current U.S. counterterrorism capabilities.

One particularly promising technology with anti-WMD-terrorism application is the Wide-Area Tracking System (WATS) for detecting and tracking a ground-delivered nuclear device. Another is the Joint Biological Remote Early Warning System (JBREWS) for alerting U.S. field troops of an attack with biological agents (Figure 1). Both systems consist of a network of sensors and communications links, with information continuously evaluated by unique data-fusion algorithms. The sensors can be permanently deployed at chosen locations or mounted in vans for deployment on demand to protect specific areas for specific situations or events.

**Figure 2.** The portable radiation detector being demonstrated by its inventor Anthony Lavietes can identify the precise isotopic signature of nuclear materials such as plutonium and uranium by detecting gamma radiation. It improves upon the large germanium-based detectors shown in the background and has a variety of applications, among them assistance with defense against terrorism using weapons of mass destruction.

A portable radiation detector developed at Livermore to monitor and detect nuclear materials in the field at ambient temperatures also has potential uses to defend against WMD terrorism (Figure 2). The new system is based on a relatively new cadmium–zinc–telluride detector material and can separate gamma- or x-radiation energies to identify the isotopic signature of nuclear materials such as plutonium and uranium. The system has immediate applications, for example, in detecting and deterring nuclear smuggling through airports and shipping ports and in national and international nuclear materials safeguard operations.

To detect biological weapons, Livermore has developed immunoassay and DNA recognition-based sensors. Unlike most biodetection instruments, which are bulky and can only be used in laboratory settings, the mini-flow cytometer and the mini-PCR (polymerase chain reaction) instrument can be used in the field to identify specific biological warfare agents. (See *S&TR*, July/August 1997, pp. 14–16.) Both have been tested successfully at the U.S. Army's Dugway Proving Ground in Utah.

Livermore is also home to the Forensic Science Center, which uses a wide range of advanced chemical, biological, and nuclear analysis techniques to examine samples for the U.S. government and law enforcement agencies. Forensic science techniques are essential for identifying the source of WMD.

These Laboratory technologies and capabilities and others like them contribute greatly to meeting the monumental challenge of countering the threat posed by WMD terrorism.

*—Lauren de Vore*

**Key Words:** counterterrorism, cytometer, Forensic Science Center, Joint Biological Remote Early Warning System (JBREWS), Livermore Study Group, polymerase chain reaction (PCR) instrument, portable radiation detector, weapons of mass destruction (WMD), Wide-Area Tracking System (WATS).

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## Patents and Awards

*Each month in this space we report on the patents issued to and/or the awards received by Laboratory employees. Our goal is to showcase the distinguished scientific and technical achievements of our employees as well as to indicate the scale and scope of the work done at the Laboratory.*

| Patent issued to | Patent title, number, and date of issue | Summary of disclosure |
|---|---|---|
| Thomas E. McEwan | **Time-of-Flight Radio Location System**<br><br>U.S. Patent 5,661,490<br>August 26, 1997 | An apparatus for measuring the time of flight of an electromagnetic pulse. A transmitter transmits a sequence of electromagnetic pulses in response to a transmit timing signal, and a receiver samples the sequence of electromagnetic pulses with controlled timing in response to a receive timing signal and generates a sample signal. A timing circuit supplies the transmit and receive timing signals. The receive timing signal causes the sampling by the receiver to sweep over a range of delays. An envelope detector converts the sample signal to a unipolar signal to eliminate effects of antenna-orientation mismatch. The envelope detector is an absolute-value circuit followed by a low-pass filter. A sample detection circuit indicates time of flight, from which the position of an electromagnetic pulse can be obtained. |
| Anthony M. McCarthy | **Method for Fabricating Transistors Using Crystalline Silicon Devices on Glass**<br><br>U.S. Patent 5,663,078<br>September 2, 1997 | A method for fabricating transistors on glass that overcomes the potential damage that may be caused during high-voltage bonding. A multilayer structure is formed on a silicon substrate and employs a metal layer that may be incorporated as part of the transistor. When the structure is bonded to a glass substrate, the voltage and current, because of the metal layer, pass through areas where transistors will not be fabricated. After removal of the silicon substrate, more metal may be deposited to form electrical contact or add functionality to the devices. By this method, both single and gate-all-around devices may be formed. |
| Stephen A. Payne<br>Joseph S. Hayden | **Ultrafast Pulsed Laser Utilizing Broad Bandwidth Laser Glass**<br><br>U.S. Patent 5,663,972<br>September 2, 1997 | An ultrafast laser that uses a neodymium-doped phosphate laser glass characterized by a particularly broad emission bandwidth to generate the shortest possible output pulses. The laser glass is composed primarily of phosphate ($P_2O_5$), alumina ($Al_2O_3$), and magnesium oxide (MgO) and possesses physical and thermal properties that are compatible with standard melting and manufacturing methods. The emission bandwidth is greater than 29 nanometers and more, preferably greater than 30.5 nanometers. The broad-bandwidth laser glass can be used in mode-locked oscillators as well as in amplifier modules. |
| Chuen-Tsai Sun<br>Jyh-Shing Jang<br>Chi-Yung Fu | **Intelligent System for Automatic Feature Detection and Selection or Identification**<br><br>U.S. Patent 5,664,066<br>September 2, 1997 | A neural network that uses a fuzzy membership function, the parameters of which are adaptive during the training process, to parameterize the interconnection weights between layers of the network. As in a conventional neural network, each node in each level, except the input level, produces an output value. In a conventional neural network, all of the connection weights are adjustable and must be "trained." To reduce the number of parameters that need to be adjusted, a fuzzy membership function is used to define the interconnection weights between two of these layers. A tremendous reduction in the number of parameters for training is achieved because the field of connection weights being input to a node has been parameterized. |
| Daniel M. Makowiecki<br>Alan F. Jankow | **Boron Containing Multilayer Coatings and Method of Fabrication**<br><br>U.S. Patent 5,670,252<br>September 23, 1997 | The production of multilayers containing thin boron, cubic boron nitride, or boron carbide films or coatings. The boron-containing multilayers may be deposited as hard coatings on surfaces, such as on tools or engine parts, and contain no morphological growth features. By alternating the formation of boron films or cubic boron nitride and boron carbide films, a multilayer boron/boron carbide, cubic boron nitride/boron carbide, or a boron/cubic boron nitride/boron carbide film or coating may be produced. The various layers of the multilayer may be diffused, blended, or graded to contain from 0 to 100% boron or cubic boron nitride or boron carbide, and the interfaces of the layers may be discrete or diffused. |
| John M. Gonsalves | **Pendulum Detector Testing Device**<br><br>U.S. Patent 5,672,807<br>September 30, 1997 | A testing device composed of several pieces of polyvinyl chloride tubing or pipe attached to a plastic holder. The test object, such as a weapon encapsulated in a protective cover, is secured in the holder. The holder and enclosed weapon are mounted in and swing through the archway of a walk-through detector system in a pendulum motion for any designated number of passes needed to complete the test. The components of the test device can be easily assembled and positioned in various locations of the detector facility archway, thereby simulating where the contraband might be concealed on a person walking through the detector system. The response of the detector system is observed. |