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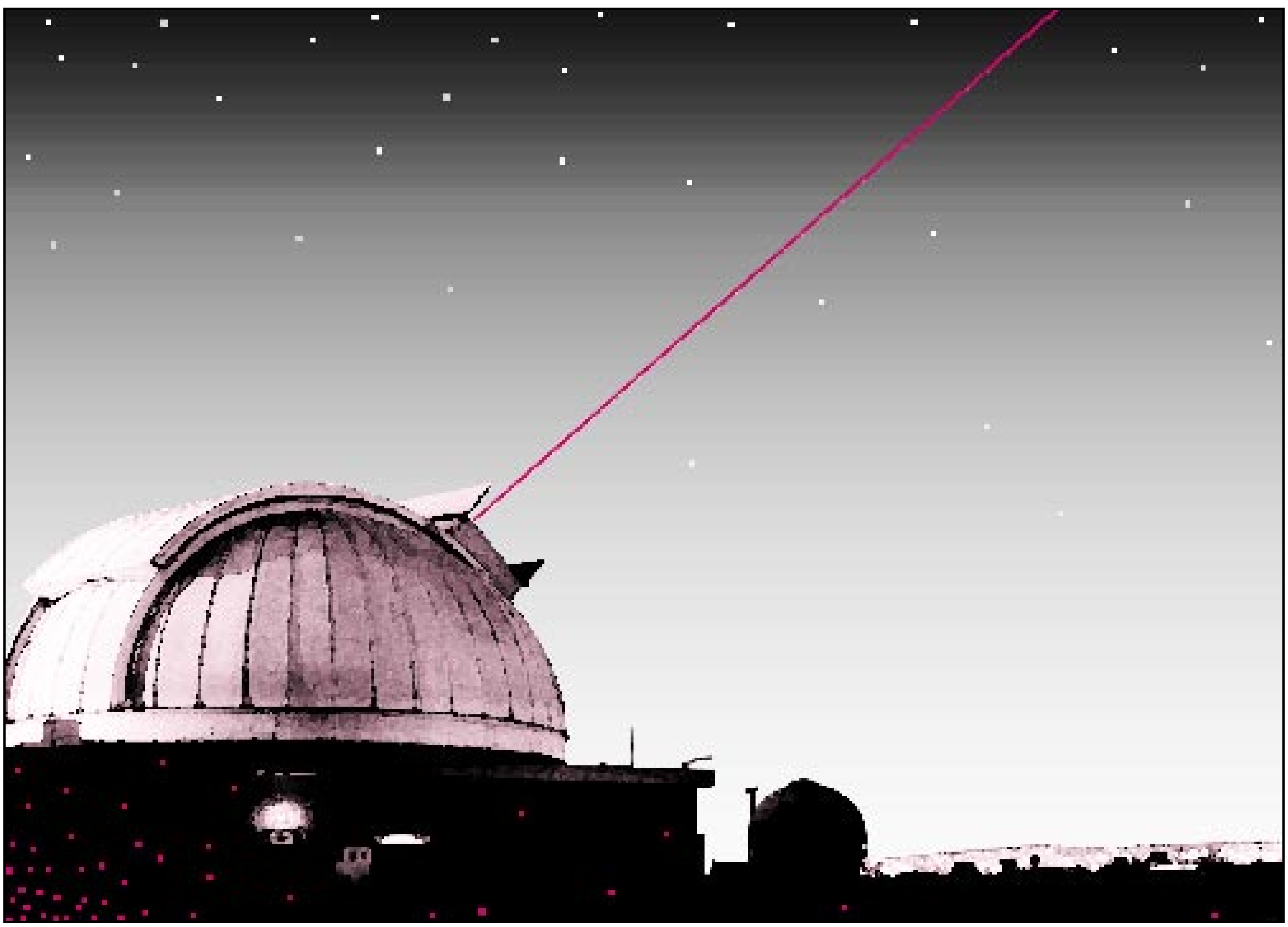
Arms Control and Nonproliferation Technologies

Third/Fourth Quarters 1993



The cover

A neodymium beam is transmitted from the Sandia laser site with the lights of Albuquerque as a backdrop. Actual calibration of the GPS bhangmeters is accomplished using a ruby laser system (see article on page 13).

The purpose of *Arms Control and Nonproliferation Technologies* is to enhance communication between the technologists who develop means to verify compliance with agreements and the policy makers who negotiate agreements.

Detection Technologies

This issue of *Arms Control and Nonproliferation Technologies* is another in a series of issues about specific means for detecting and identifying proliferation and other suspect activities outside the realm of arms control treaties. All the projects discussed are funded by the Office of Research and Development of the Department of Energy's Office of Nonproliferation and National Security.

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Microchannel plate gamma-ray detector

Mark Rowland
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Lawrence Livermore National Laboratory (LLNL) has designed and tested a prototype microchannel plate gamma-ray detector that discriminates special nuclear material (SNM) or nuclear weapons from non-nuclear items. The instrument is based on a leaded-glass microchannel plate (MCP) electron multiplier that senses gamma rays by counting Compton-scattered electrons formed in the microchannel plate. Applications include chain-of-custody weapon verification and weapon-component diversion monitoring. This instrument counts gamma rays but does not measure their energy. It is hand-held, battery-powered, and designed to survive temperature extremes from about -20 to 50°C.

Highlights of the prototype

The LLNL prototype detector can discriminate SNM or nuclear weapons. Measurements of gamma sources and weapons demonstrate the concept.

This detector is designed not to indicate nuclear-weapon-design information; it is incapable of measuring gamma-ray energies. Thus, the MCP gamma-ray detection mechanism is inherently nonintrusive.

Detection sensitivity can be increased by adding more MCPs; however, detector volume increases only insignificantly because the MCP has a density advantage over a Geiger tube. Nominally, LLNL's prototype detector contains a three-plate stack of MCPs; the active working volume of the detector is about 100 times smaller than that of an equally sensitive Geiger tube.

Applications

The microchannel plate gamma-ray detector is designed for nonintrusive detection of physically obscured SNM, including nuclear weapons. Three example applications are

- Distinguishing between nuclear and non-nuclear weapons during a cooperative inspection in which legitimate numbers of each may be present. In this scenario, the MCP identifies the number of nuclear and non-nuclear weapons.
- Classifying the type of nuclear weapon (for example, type A or type B) based on a benchmarked gamma-ray count rate from each package type.
- Chain-of-custody monitoring based on the count rate for identification as warheads are moved from the field to dismantlement facilities.

In the first scenario, the MCP identifies the nuclear weapon; in the second, it also indicates the type of weapon; and in the third, the MCP nonintrusively tracks weapon movements.

Background

Recent history establishes a precedent for nuclear-detection-based measurements and a motivation to develop the MCP detector concept. For example, the Intermediate-Range Nuclear Forces (INF) Treaty contains a provision for using a nonintrusive instrument to map the radiation flux outside a nuclear-tipped missile to verify that it does not contain more than one warhead. No gamma-ray detector was thought to be acceptable for the INF Treaty. Thus, the neutron detector instrument chosen was non-energy-resolving because both parties to the treaty were concerned that an energy-resolving detector might reveal sensitive information about the nuclear weapon. Even concepts that would obfuscate the intrusive information contained in the data from the typical gamma-ray detector were met with skepticism because of the fear of covertly recovering the intrusive part of the data.

It is theoretically possible to operate a Geiger tube as a proportional ion chamber and extract some energy resolution (which would be intrusive to a country); however, the MCP cannot produce energy resolution because its gain depends on where, along the tubule length, the gamma ray strikes. The large volume in the Geiger tube could allow unambiguous charge collection that could be related to incident gamma-ray energy. In the case of the MCP, the gain-producing structures are thousands of adjacent tubules less than one electron-mean-free path apart with a length that ensures nonproportional operation. If a Compton electron traverses the tubule wall, then at least two tubules will initiate amplified charge collection. The advantage of the thick MCP detector is that many tubules contribute random quantities of charge because of the random longitudinal locations from which the avalanche originates, thereby making it impractical to obtain energy resolution, even at reduced bias. Figure 1 shows the concept.

A second motivation to develop the MCP detector is that not all nuclear materials offer an easily measurable spontaneous source of neutrons.

The MCP detector is designed to overcome these limitations because it has no inherent spectrometric capability and is therefore not intrusive like the Geiger tube, plastic scintillator, NaI- or high-purity Ge-based gamma-ray detectors. The issue of detectivity (the inverse of necessary measurement time for acceptable discrimination) is addressed by using a scalable detector technology with a volume-to-sensitivity ratio 100 times higher than that of a Geiger tube because it is a relatively dense honeycomb of sensitive material. The measured sensitivity for a 1-in.-diameter by 4-in. Geiger tube is approximately equal to a three-plate stack of microchannel plates with total dimensions of 0.1 in. thick by 1 in. in diameter. With this advantage and miniaturized electronics, a pocket-sized detector is practical to develop next.

And finally, because not all weapons emit neutrons, the MCP detector offers an alternative to the standard neutron detector, or it may complement the inspector's toolbox that already includes a neutron detector.

When a particular application or scenario is chosen for the MCP detector, the combination of scenario particulars, red-teaming results, and treaty requirements will determine the required detectivity. The number of MCPs necessary for a particular scenario is likely to be three plates if the intent is to detect nuclear material shielded no more than what is required for typical safety reasons. The detection of very heavily shielded materials would require special measures to reduce the background noise.

Detector operation and performance

Operationally, an inspector would carry the MCP instrument (Figure 2) to the object to be measured (such as a treaty-limited item), press the acquire button, and wait until the instrument is ready for a background measurement. A background measurement would be acquired several meters away from the treaty-limited item or other object. The

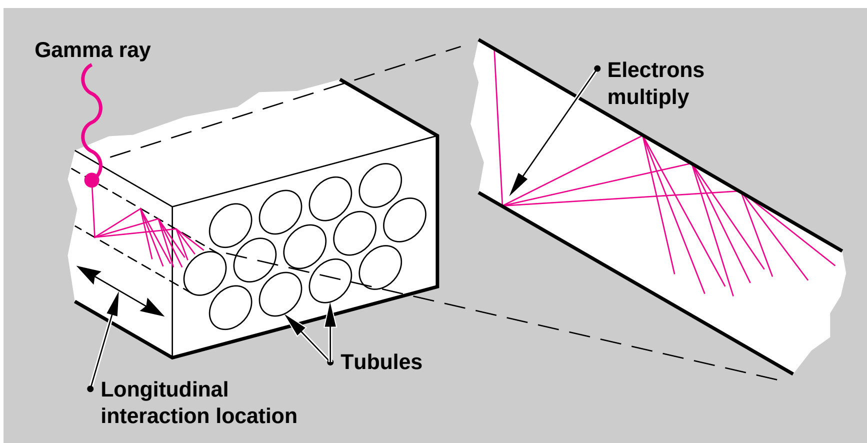
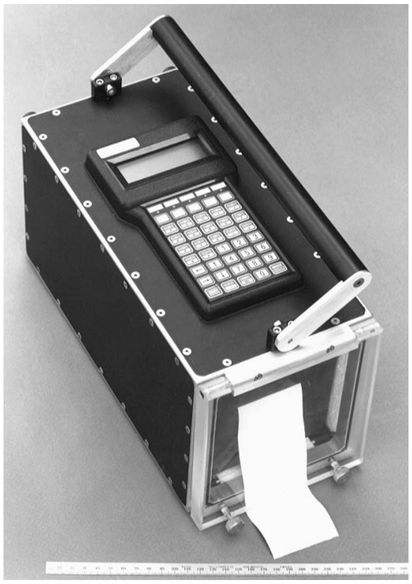


Figure 1. Gamma rays that interact with the tubules are counted when they exit the tubules. The output signal magnitude depends on the location of the interaction in the longitudinal direction.

(a)



(b)

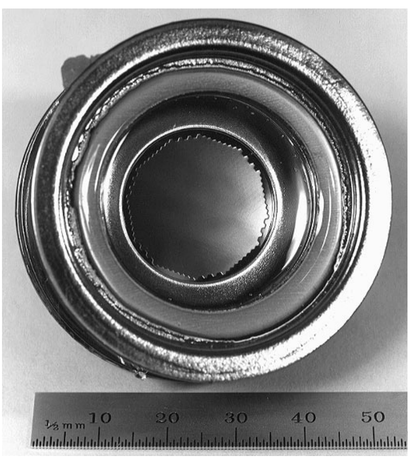


Figure 2. (a) The MCP gamma-ray detector counts gamma rays nonintrusively, computes their statistical significance, and logs results in real time on a printout. The hand-held, battery-powered instrument is designed to survive temperature extremes in the field. (b) Its detector element is inside the instrument.

instrument then computes the statistical significance of the measurement and reports the result on the built-in paper printout device. Total count, statistical significance, date, and comments are printed on the paper strip. The instrument is designed to function in warm and cold weather, and its functional battery life is expected to be a nominal working day. The complete prototype detector weighs only 22 pounds (about half of which are batteries), which is much less than the detector used for the INF Treaty.

One MCP detector system was fabricated and tested. Three radioactive sources were measured at a 1-m distance, including background. This was compared to Delta Rate Meter measurements (CMS, Inc., model MGS-2) and Geiger-counter measurements (Eberline model E-120). The Delta Rate Meter (DRM), a 2-in.-thick by 5-in.-diam. sodium iodide gamma-ray detector, was included in the comparison because it is somewhat common. The DRM instrument was designed with a very high sensitivity to aid in a blind search for a radioactive source. The DRM is considered highly intrusive in a treaty-motivated, nuclear-weapon identification scenario because it has inherent energy resolution.

The Geiger tube was attached to an Eberline counter model E120 and has about the same sensitivity as the prototype MCP gamma-ray detector.

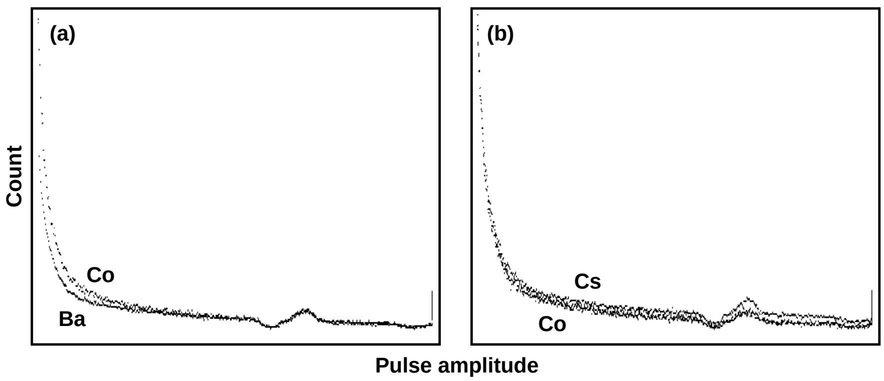
The radioactive gamma-ray sources were nominally 60 microCurie activities of Ba-133, Co-60, and Cs-137. They were held at a 1-m distance to collect data. The two objectives were to compute detection times and to prove there is no inherent spectral energy resolution.

A signal-to-noise ratio of three standard deviations was arbitrarily chosen for a simple measure of detectivity. In practice, the instrument should be allowed to count for at least a minute and the user would rely on the statistical significance reported on the paper printout as a guide for measurement reliability.

To demonstrate the inherent nonintrusiveness (no spectral resolution) of the detector, MCP output amplitude spectra were collected with a multichannel analyzer. Three radioactive sources were chosen for their distinct spectral features to illustrate the lack of spectral resolution in the MCP detector. Cs-137 has a prominent 662-KeV gamma ray, Co-60 has a 1.1- and a 1.3-MeV gamma ray, and Ba-133 has a variety of gamma-rays about as diverse as a plutonium spectrum.

The data shown in Figure 3 (a and b) are Co-60 compared with Ba-133 and Cs-137 compared with Co-60. Both plots have linear horizontal and vertical scales, and the data have been scaled to account for integral count differences, so any relative plot differences may be seen. The vertical scale is the count plotted against the amplitude of pulses from the MCP detector. This pulse amplitude normally would correspond to the gamma-ray energy, but because the detector has no energy resolution, the scale is difficult to calibrate. Instead, the amplifier and MCP bias were adjusted so that every pulse amplitude created was recorded. The two plots demonstrate there is no distinct difference in the MCP detector response for even large differences in input gamma-ray spectrum.

The "S" shaped feature on the right third of each plot is known as a "channel hot spot," meaning there is a low-electron emission work function about two-thirds of the way up the potential well, inside this particular MCP. Hot spots do not affect the intended detector operation because a background measurement occurs with each unknown item inspection, and the detector's electronics integrate the entire spectrum.



■ *Figure 3. No distinct energy difference is discernible and information contents are equivalent in amplitude spectra collected with a multichannel analyzer for radioactive sources: (a) Co-60 compared with Ba-133 and (b) Cs-137 compared with Co-60.*

Note that there is no significant spectral difference among the three data curves and certainly no photopeak structure anywhere. Without photopeak structure sensitivity, the instrument is only capable of sensing that something is radioactive.

An Oralloy (no plutonium) nuclear weapon also was measured to verify that it was detectable at a reasonable distance. The weapon included a nominal amount of mock high explosive and some steel, in a substantial aluminum and polyethylene package. For this measurement, the distances were a maximum of 2 m. In all cases, the detection times were very short, on the order of a few seconds. The detectivity for plutonium-bearing weapons is higher, since plutonium has a faster decay rate.

Field neutron spectrometer

Roger Byrd
Los Alamos National Laboratory

The technology of boron-loaded scintillators, originally developed by Los Alamos and the Bicron Corporation for space applications, combines the excellent background rejection of neutron-capture reactions with the information content of neutron interactions in a plastic scintillator. The goal of the Field Neutron Spectrometer project is to develop and demonstrate a portable survey instrument for identifying nuclear weapons and materials.

Introduction

Spectroscopic scans for penetrating neutron and gamma-ray radiation are the most common ways of locating, identifying, and characterizing nuclear weapons or nuclear material. Some postulated inspection activities often include both radiation types because there is no single convenient way to disguise both radiation signatures. Heavy, dense materials shield gamma rays, whereas bulky, hydrogenous materials shield neutrons.

As useful as these scans are to identify specific gamma rays associated with particular nuclear materials, they may not be appropriate in cooperative inspections because they may divulge information about structures and materials in the nuclear weapons.

In contrast to intrusive gamma-ray measurements, neutron spectra indicate little more than the presence of a fission source and some suggestion about its type and the surrounding materials. As a result, the comparison between neutron measurements and benchmarks is a possible approach for identifying nuclear weapons.

The technology

When a fast neutron is absorbed in boron-loaded plastic (see Figure 1), it produces a characteristic sequence of two pulses. The first pulse occurs when the neutron bounces off (or "scatters" from) a proton at a large angle and transfers most of its energy to the recoiling proton. The second pulse occurs after repeated scattering of the neutron slows it down enough to be captured by the boron. If a detector's electronics are designed to require this two-pulse coincidence, only those fast neutrons that have deposited essentially all their energy in the scintillator would be recorded. Thus, the sum of the proton-recoil signals would yield the energy spectrum for the incident neutrons.

Two features of this approach are important for field applications: (1) the excellent rejection of all non-neutron backgrounds (by subtraction of random coincidences) and (2) an internal energy-calibration signal (from the reaction products of the capture reaction).

Operation

In the expected operation of a portable field detector, software options would allow simultaneous data accumulation in three modes.

- The high-selectivity "spectral" mode uses the two-pulse coincidence to accept only absorbed fast neutrons in the fission energy range from 0.5 to 15 MeV.

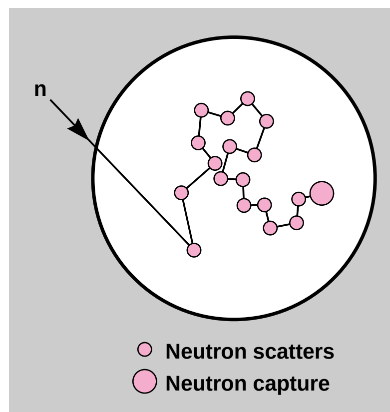


Figure 1. Schematic of the scatter-and-capture mechanism used in a boron-loaded scintillator to select only the neutrons that deposit all their energy in the detector. The proton-recoil pulses produced by the scattering of these neutrons provide the spectrum of their incident energies.

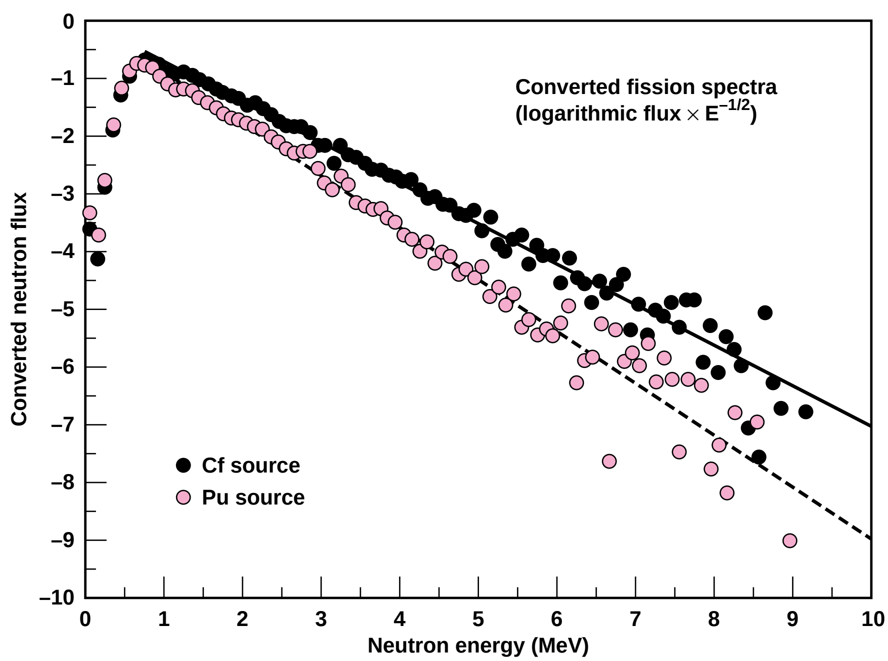
- The "neutron" mode mimics a conventional neutron-capture counter by requiring only the capture pulse, which provides additional count rate by including low-energy scattered neutrons.
- The high-sensitivity "radiation" mode counts all pulses, including neutrons at all energies and Compton-scattered gamma rays.

In practice, surveying a site for radioactive materials could initially use the high-sensitivity radiation mode and then focus on the more-selective neutron and spectral modes to provide confirmation at close range. An optional enhancement of the field neutron spectrometer instrument could improve the search capability by using a multi-element version of the scintillator to measure the counting rate in different directions. An asymmetric counting rate could indicate the presence of a radiation source, as opposed to an isotropic background, and provide an accurate direction and estimated distance for the source. This concept was developed by means of computer simulations and has been verified by measurements with a prototype detector; it is also the subject of a patent application.

Status

In the Field Neutron Spectrometer program's first year of funding by DOE, the instrument's front-end electronics have been designed, and the hardware and software for the data-acquisition system are on order. Existing computer programs are being adapted to model the neutron and gamma-ray responses of the instrument. To provide a data base of weapon signatures, we have analyzed several measurements, made with a prototype detector, from mockups of nuclear weapons. Figure 2, a sample of our data, demonstrates the expected difference in slope between a standard spontaneous fission source (californium) and a sample of nuclear weapon material (plutonium). Although the difference may be smaller for well-shielded weapons, the additional materials and structures should provide their own distinguishing spectral features. Further measurements and calculations will be needed to develop automated discrimination algorithms for various applications, but the approach is very promising for distinguishing different sources of neutrons.

■ *Cooperative nuclear weapon inspections could benefit from a new scintillator technology that provides energy spectra for fission neutrons and count rates for gamma rays and low-energy neutrons.*



■ *Figure 2. Comparison of measured energy spectra for a laboratory neutron source (californium) and nuclear material (plutonium). We have converted the distributions to logarithmic form by dividing by the square root of the neutron energy; the lines show theoretical predictions.*

Remotely observed signatures

A. R. Jacobson
Los Alamos National Laboratory

Remotely observed signatures in the thermosphere of explosive releases (ROSTER) is a remote-sensing system being developed at Los Alamos National Laboratory to detect low-yield nuclear detonations. It could provide the basis for a future network of remote sensors for detecting clandestine, low-yield tests in violation of Nuclear Non-Proliferation Treaty.

Introduction

The problem of detecting clandestine, proliferant nuclear tests remains a technical challenge despite three decades of development of sensors for remotely sensing nuclear detonations. This is because our present sensors are optimized to detect signatures of powerful, efficient, and sophisticated devices. It is likely, however, that early efforts by proliferant countries will be low-yield tests of very inefficient, unsophisticated devices. Moreover, signatures of small nuclear devices can be significantly reduced or corrupted by even very simple civil-engineering measures such as within a thick-walled vault. Thus, to complement our existing sensor systems, it is timely to consider developing relatively cheap, alternative remote-sensing systems designed to look at other detonation signatures that are not susceptible to such concealment measures.

Background

Toward this end, Los Alamos is developing a remote-sensing system, called ROSTER, to detect, locate, and time explosions with yields of 0.1 to 10 kilotons (kt). The physical principle behind this system is that explosions generate long-period acoustic waves, which, upon reaching the upper atmosphere, stretch to still longer periods and come to occupy a spectral range that is extremely "quiet" in terms of the competing geophysical background. The acoustic output of explosions in the range of 0.1 to 10 kt cannot be feasibly concealed, and in this sense, it is unlike the signature outputs currently detected by our operational nonseismic sensors.

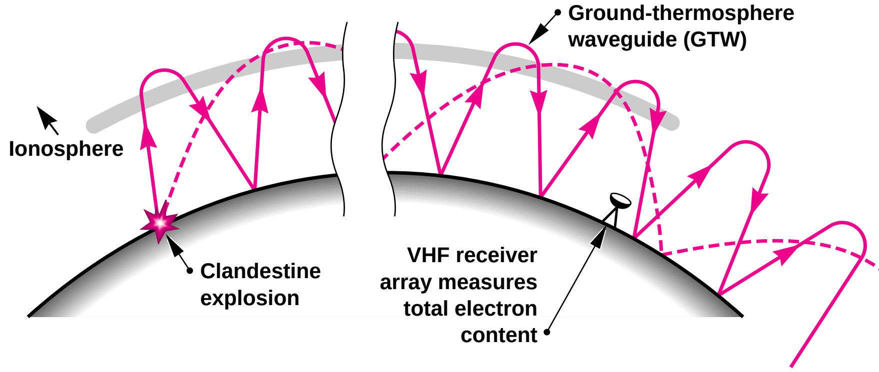
The speed of sound increases from 300 m/s at the base of the thermosphere (an altitude of 90 km) to 500–900 m/s at the top (250 km). This serves to reflect sound waves back toward the ground, where they are again reflected. For *far-infrasound* waves (periods of 30 to 300 s), these multiple ricochets constitute the *ground-thermosphere waveguide* (GTW). Since the early 1970s, the GTW has been known to convey, over global distances, forensically relevant far-infrasound signals from explosions. Whereas at ground level the far-infrasound natural background level is usually too high (1 to 100 µbar), it is extremely quiet at ionospheric heights, where almost the entire natural background is confined to longer-period waves (300 to 3000 s). Moreover, the relative overpressure of far-infrasound waves is naturally amplified by a factor of 10,000 between sea level and 200 km, and the *relative* overpressure is what matters for detection. These two considerations motivate us to detect and characterize far-infrasound signatures at the top of the GTW by using a radio remote-sensing technology with sensitivity and reliability that have been substantially improved during the last decade.

ROSTER development

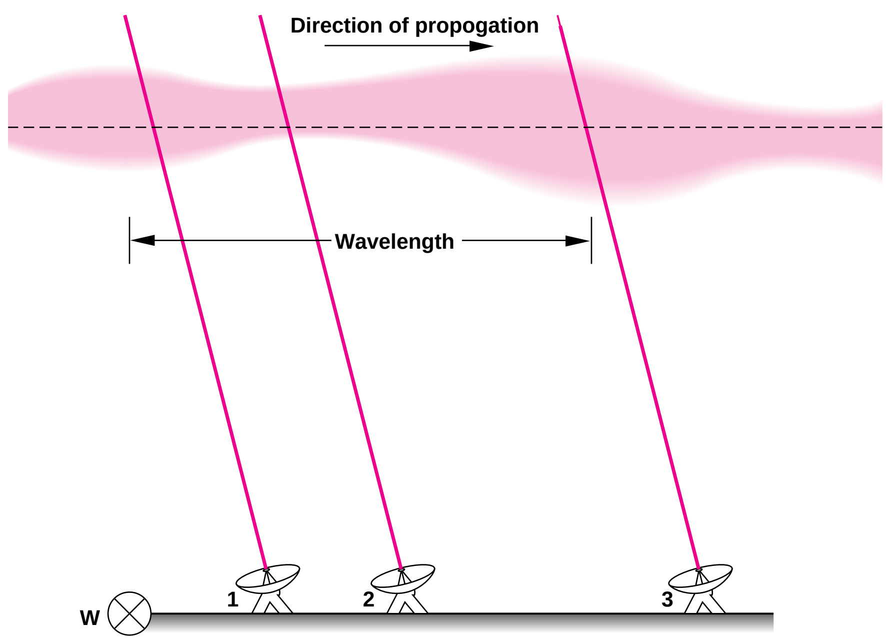
The ROSTER scheme, shown in Figure 1, is adapted to detect explosive releases at all explosion heights between shallow-buried and the upper atmosphere because all such events feed a calculable fraction of their hydrodynamic energy into the GTW. The lower altitudes are particularly useful for the nonproliferation-treaty regime and for remote sensing.

We have proved the principle of using astronomical radio sources for remote sensing of far-infrasound waves in the upper atmosphere (see Figure 2). Although our ultimate deployed system would use satellite-beacon radio sources and simple, dedicated, ground-based receiver stations, we are presently using the very large array (VLA) radiotelescope system to perform an interim proof-of-principle study. The technical goals of this interim study are (1) to determine the sensitivity of the instrument and, more important, (2) to determine the natural geophysical background "noise" in the far-infrasound spectral window. Our initial results tend to validate our concept of detecting and characterizing explosions in a noncooperative, proliferation regime, in which yield and evasion scenarios would be a problem for existing national technical means sensors.

More recently, we have concentrated on designing, building, fielding, and operating our own radio-receiver interferometer array, which will make use of the beacons of several existing geostationary satellites. We now have eight array stations, four at fixed sites near Los Alamos, and four near explosive sources of interest. During the next two years, we will use one of the latter to characterize the plume of the space shuttle's main-engine burn, which will provide a convenient test of the radio-interferometer's far-infrasound remote-sensing capabilities.



■ *Figure 1. An explosion generates far-infrasound waves that are alternately refracted in the upper atmosphere's thermocline and reflected at the Earth's surface. The resulting ground-thermosphere waveguide (GTW) conveys the waves to a remote radio-interferometer array, where they can be detected as ionospheric electron-density perturbations.*



■ *Figure 2. ROSTER is based on remote sensing of ionospheric waves. Consider three antennas all aimed at the same satellite and receiving the same radio signal from it. Since the satellite is very far away (~10^4 km) compared to the distance to the ionosphere (~10^2 km), the lines of sight from the antennas are approximately parallel. Now, assume an upper-atmospheric far-infrasound wave as a moving wave-like modulation (the shaded region). Each antenna's received radio signal undergoes a phase shift, modulated by the passage of the wave, and this phase shift occurs sequentially at the three antennas as the wave passes by. With a two-dimensional array on the ground, we can thus deduce the horizontal trace velocity vector of the wave from this sequence of phase shifts.*

Unlike the eight-station array, the VLA cannot be moved similarly into the path of explosive infrasound. However, it was used on two occasions (in June 1989 and June 1991) to detect infrasound at ionospheric heights arising from explosions at the Permanent High Explosive Test Site. Figure 3 shows the difference in total electron content versus time on a 6-km, north-south baseline looking at a source near zenith in June 1991. The 70-s burst is easily distinguishable from the background noise at similar frequencies. The calculated trace velocity agreed perfectly with the direction of the explosion hypercenter.

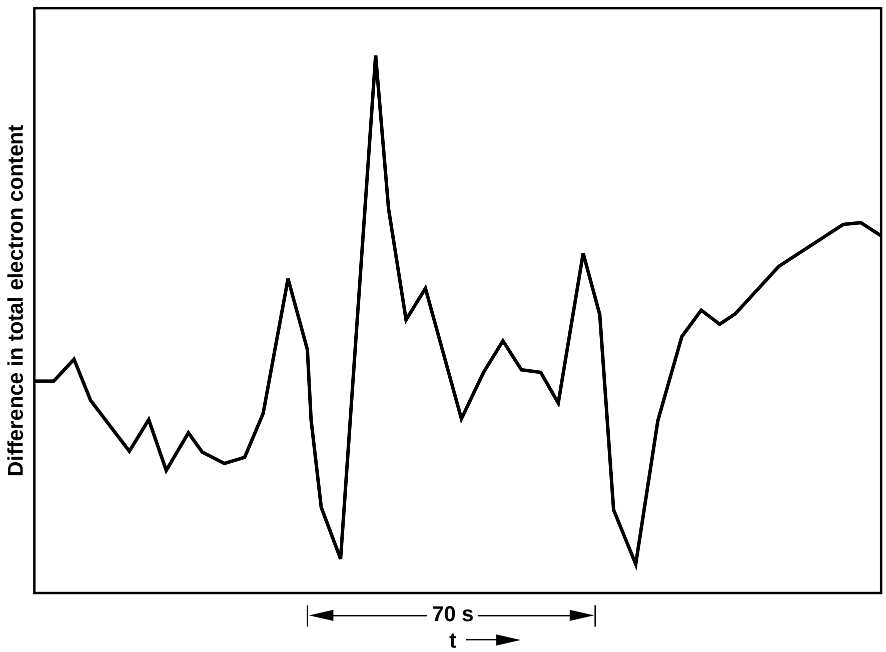


Figure 3. Example of baseline-differenced total-electron-content perturbation recorded in data from the very large array following a chemical explosion.

Future work

The transition from astronomical radio sources to satellite beacons will allow ROSTER to operate relocatable detection arrays, rather than being merely occasional users of a radiotelescope array. Should the ROSTER detection results continue to be technically encouraging, these arrays could be, in several years, the basis for a global detection network capable of monitoring low-yield explosions. The number of arrays is likely to be on the order of 10, lying at low latitudes and distributed in longitude.

Nuclear detonation detection system on the GPS satellites

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The Global Positioning System/Nuclear Detonation Detection System (GPS/NDS) contributes to the United States' capability for detecting and identifying the occurrence of an atmospheric or exoatmospheric nuclear explosion—either a test by an emerging nuclear power, or actual weapon used in combat. Systems such as the GPS/NDS, using diverse means to detect signals characteristic of nuclear explosions, are thus essential to national security interests.

Introduction

When President Kennedy and Chairman Khrushchev signed the Limited Test Ban Treaty (LTBT) on August 5, 1963, one of the conditions was that each party to the treaty could use its own technical means to monitor testing in the atmosphere or in space. On the U.S. side, this technical means was provided by the Vela satellites, which were developed jointly by the Air Force and the Atomic Energy Commission, a predecessor of the Department of Energy. The Vela payload was based on considerable experience obtained from developing measurement instruments for rockets flown during the Dominic high-altitude nuclear tests (April to November 1962). The first Vela satellite was launched on October 17, 1963. Today, the nuclear threat against the U.S. is of a different nature, but the nuclear test monitoring requirements remain. Whereas the nuclear testing by the Soviet Union was the threat during the Cold War, today a principal concern is with the diffusion of nuclear capability to other nations. More than ever, the U.S. needs to maintain a capability for detecting nuclear tests anywhere in the world.

Part of the U.S. capability is provided by the GPS/NDS. The fact that the GPS satellites can detect nuclear detonations has never been classified, but it has not been well advertised either. The GPS/NDS, like its Vela predecessor, is a joint program between the Air Force and the Department of Energy. The Air Force provides the GPS satellites and operates the system, while DOE, through its Sandia and Los Alamos National Laboratories, provides the NDS sensors. Together with other sensors on other satellite platforms, as well as seismic and other networks that monitor underground tests, the U.S. maintains a complete capability for monitoring tests in all environments.

It is well known that nuclear explosions in the atmosphere or in space are characterized by certain physical signals—light, gamma rays, x rays, and neutrons—as well as secondary effects resulting from the interactions of these primary forms of energy output with the atmosphere. Measurement of the output of a possible nuclear event, using instruments sensitive to different phenomena, helps to discriminate between a nuclear detonation and natural phenomena, such as lightning. GPS/NDS thus uses multiple sensing mechanisms to increase the probability of detection and to reduce the probability of a false alarm.

X-ray monitoring systems

Figure 1 shows an x-ray instrument from a GPS Block I satellite, a simple sensor designed to measure the intense burst of x rays from an exoatmospheric detonation of a nuclear weapon. Because such a burst would occur in less than 1 microsecond, sensors must monitor for such an event continuously. Should such an event occur, data from all the satellites observing it would be transmitted to ground terminals for processing.

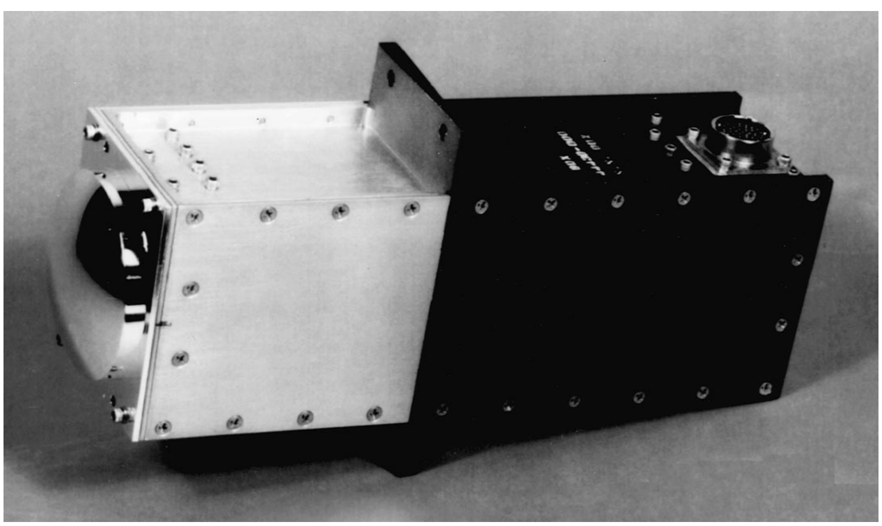
Because x rays from a nuclear detonation would travel outward from the event in a spherical shell expanding at the speed of light, the location of the event can be determined from accurate timing information provided by each responding satellite. Measurement of the time differences of arrival of x rays at four or more satellites permits calculation of the time of the event and its spatial coordinates. This is essentially the reverse of the navigation problem (the better-known mission of the GPS network), in which a receiver at a fixed point receives accurate time marks from several satellites to determine its location. In addition to location and time, the sensor measures the intensity of the x rays impinging on it, and the combination of the data can be used to estimate the yield of the device that was detonated.

Twenty-four satellites operate for complete coverage in the GPS constellation; 21 of them carry x-ray instruments. The other three carry special instruments for measuring natural particle fluxes in the Van Allen radiation belts through which the satellites pass. This background information is important to ensure proper interpretation of data from the x-ray and other sensors. The essential difference is that the background monitor operates continuously, providing copious amounts of data—which of course are not desired from the x-ray sensors. Figure 2 shows the head of a Block I background instrument. Holes in a composite dome allow flux sampling over one hemisphere while reducing the background fluxes of energetic electrons to acceptable counting-rate levels. A filter at the bottom of each hole provides an energy threshold so that the dose can be measured for a certain range of equivalent radiation shielding.

The background instrument interfaces to the spacecraft in an identical manner to that of the x-ray sensors, making the two interchangeable as far as the spacecraft is concerned. Besides providing information for interpretation of other sensor data and on satellite radiation dose, the background sensors provide valuable scientific information by measuring, at least crudely, a region of the magnetosphere not otherwise routinely investigated. Data from this instrument also aid in the investigation of any anomalous behavior of equipment of the GPS satellites or other satellites in the same space environment.

Optical and radio-frequency monitoring systems

An optical radiometer developed by Sandia National Laboratories, called a bhangmeter, records signals from nuclear explosions in the atmosphere. The most prominent feature from an atmospheric nuclear explosion is the fireball, whose light intensity, as it appears to a distant observer, undergoes fluctuations that result in two distinct peaks. Detection of these peaks is critical to identifying the event as a nuclear explosion. The bhangmeter is a nonimaging radiometer that continuously monitors the full earth disk for these double-peaked signals. When a flash of light within its field of view exceeds a preset level and exhibits other characteristics of a nuclear



■ *Figure 1. The x-ray instrument for the Block I GPS satellites. A dome-shaped filter reduces the flux of particles passing through it and thereby reduces the background noise. Dual sensors behind the filter provide redundancy.*

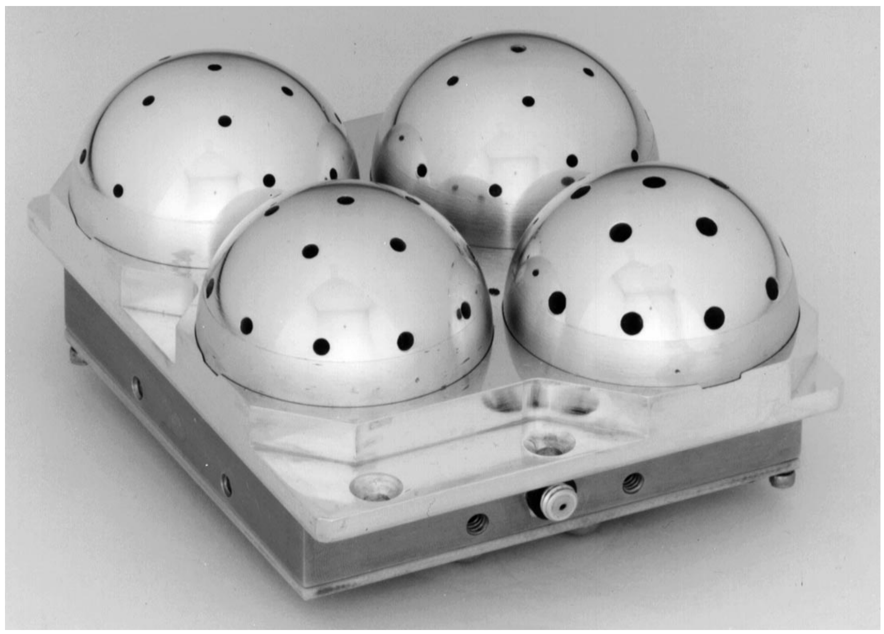
explosion signal, the bhangmeter triggers and records the optical intensity history.

Bhangmeters, like other optical instruments on earth-orbiting satellites, respond to many signals that have nothing to do with nuclear explosions. The most significant of these is reflected sunlight from the earth. A fully sunlit earth disk illuminates the sensor with more than 10,000 times the intensity seen from some nuclear explosions. Therefore, the slowly varying signal from earth-reflected sunlight is suppressed electronically to permit the sensor to detect a much dimmer but fast-rising signal from a nuclear explosion. Transient false-alarm signals can result from lightning, an event that occurs many thousands of times each day over the earth, and from sun glints off water surfaces. False signals can also result when high-energy particles strike the bhangmeter's detector elements. The bhangmeter is designed to reject these false triggers, thereby maintaining a high probability of detection of atmospheric nuclear explosions.

Calibration of GPS satellite bhangmeters is accomplished by using a ground-based ruby laser system located at Sandia (see cover illustration). GPS clocks at the laser site accurately time-tag the fast-rising laser pulses, and the bhangmeter system aboard the satellite records their times of arrival. The data obtained from this procedure provide an end-to-end test of all the processing functions involved in calculating satellite positions and correcting timing data. Data sets from different satellites are combined to evaluate the location capability of the optical sensors.

Finally, a nuclear explosion also results in the generation of intense radio waves, which arise from energized electrons (Compton currents) produced by the interaction of the bomb's radiation with the atmosphere. The Compton currents are turned by the Earth's magnetic field to produce an electromagnetic pulse (EMP). The GPS satellites carry specialized antennae and electronics to detect and measure the EMP from a nuclear detonation.

Together, these multiple detection systems provide a significant enhancement of the U.S. capability to detect any nuclear explosion, including a weapons test by an emerging nuclear power. So long as such tests remain a possibility, systems like the GPS/NDS are vital to national security.



■ *Figure 2. Four domes of the background instrument. Holes surrounded by thick material allow the flux to be sampled over a hemisphere at a counting rate that can be conveniently handled by the electronics. A hemispherical filter inside each dome defines an energy threshold for the particles entering the holes. Thus, four energy channels can be defined for the dose measured by the instrument.*

Public-key data authentication for compliance monitoring

Timothy J. Draelos and
Victoria Hamilton
Sandia National Laboratories

Monitoring arms control and nonproliferation requires data to verify compliance with agreements. In some monitoring scenarios, equipment is deployed in foreign and possibly hostile environments and left unattended for long periods. Data acquired by such remote stations is vulnerable to tampering during transmission or transportation to the user. Public-key data authentication by means of a digital signature algorithm assures the user that the data have not been modified after they were produced by the monitoring system, and it identifies and verifies the origin of the data.

We have developed a public-key treaty data authentication system based on the National Institute of Standards and Technology (NIST) digital signature standard to support compliance monitoring. It can be used to authenticate digital data of arbitrary content and size. Because of the public-key nature of the system's algorithm, data may be sent to multiple recipients without either compromising the accuracy of the data or allowing the sender to be impersonated. The system can be embedded within an authenticated data-communication subsystem that provides transparent data authentication and communications, thereby concealing the details of secure authentication and communication and enforcing authentication on all communicated data. The system has been designed according to the NIST security guidelines for cryptographic modules.

System overview

This data-authentication system is being developed for use in compliance monitoring. This system has the capability to "sign" and "validate" data and to protect secret parameters used in the signing process. It implements the NIST's digital signature standard to authenticate the source and integrity of data. Two versions of the software needed to implement the standard are being developed. One version is written in ANSI-compliant C, and the other implements the digital signature algorithm in assembly language on a Motorola DSP56001 microprocessor, which offers better performance and protection of all secret parameters stored on a custom memory board.

The validation process of the treaty data authentication system involves three important tasks:

- Verifying that the received public key, station identifier, and other parameters to be used in the validation process are valid.
- Verifying that previously received frames are not substituted for the current frame.
- Validating the digital signature of the message.

The system's signature-generation process involves accepting a message of arbitrary length and computing its digital signature, which must accompany the message. A header consisting of a frame count, the public key, a station identifier, and an alarm status is appended to the message prior to authentication. This header serves as a certified piece of information. An important aspect of the signature-generation function is the ability to destroy all secret information, such as the private key, upon activation of a tamper signal. If the private key is destroyed, data will continue to be authenticated by means of a backup key. Thus, an adversary cannot use tampering to deny information to another user.

Software products

Four software packages have been developed to serve various layers of the authentication process, ranging from a library that isolates the user from the details of authentication to a library of core mathematical routines necessary for authentication.

The authenticated data communications subsystem, the highest level product, provides transparent authentication and communication services. It can act as a data security barrier, enforcing authentication operations on all incoming and outgoing data. Hiding the authentication and communications issues from the user allows certain security measurements to be enforced and controlled within a single subsystem.

The User Interface Core Software Library will contain portable software routines that users may call to execute signature generation, signature validation, and data protection.

The Digital Signature Algorithm Software Library will provide the routines necessary to perform the digital signature algorithm: multiple-precision modular arithmetic, secure hashing, and data protection.

The Key Management Software Library will provide generation of cryptographic parameters and database management of parameters for multiple treaty data authentication system installations.

Implementation and performance

The digital signature algorithm involves modular arithmetic operations on large multiple-precision integers. The Motorola DSP56001, a special-purpose processor that is the core computational element of the authentication system, provides high-speed implementation. A treaty data authentication system suitable for remote deployment has been developed that includes a host 80×86 family processor board and a DSP56001 processor board with an accompanying data-protection daughter board. In addition, an ANSI-C portable version of the system is under development and will be capable of running on any platform that supports a C compiler. Communications available in the system include asynchronous communications via standard COM ports, and HDLC communications via a dedicated processor board. Figure 1 shows a typical configuration of the system in a compliance-monitoring scenario.

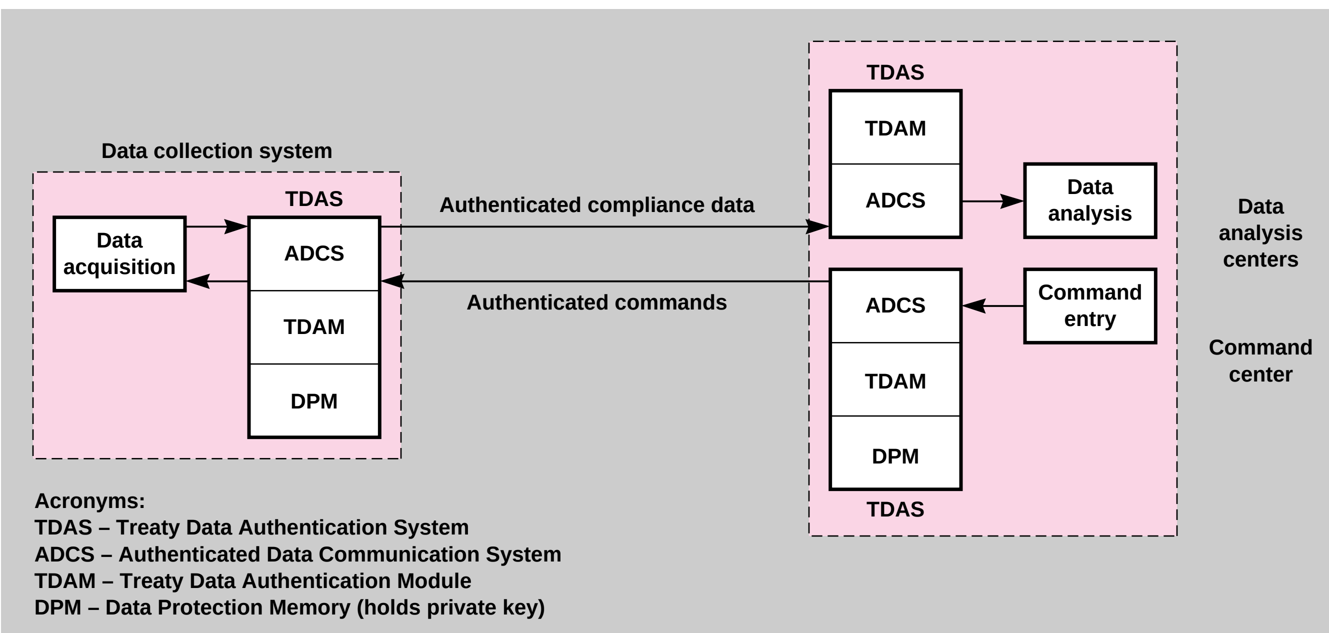


Figure 1. Compliance monitoring using the treaty data authentication system (TDAS).

Using the DSP56001, the treaty data authentication system is capable of signing approximately five short messages (less than 1000 bytes) every second. Large messages, such as a compressed video message of 40,000 bytes, will take approximately 1 s. Given the same computing platform, validation takes twice as long as signing for short messages, but can be performed on a computer that is as powerful as desired.

Conclusion

Data authentication is a critical component in acquiring trustworthy data for use in determining compliance to a treaty or agreement. Public-key data authentication offers advantages over private-key systems, especially in multilateral agreements, by allowing multiple recipients to validate data integrity without the ability to modify the data or impersonate the sender of the data.

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Summer Research Internship Program

Eileen Vergino
Lawrence Livermore National Laboratory

The Summer Research Internship Program provides opportunities at Lawrence Livermore National Laboratory for local teachers to participate in ongoing research and develop new curricula during their summer break. During summer 1993, 38 teachers participated in the program. Their projects included developing a demonstration of Virtual Telepresence for the classroom, constructing a new laser interpretive display, and adapting our seismic verification field trailer, "Mr. Ed," for students' use at local schools when it's not on field deployment. Support for this program comes, in part, from the Office of Research and Development, DOE/IS.

Background

The program began in 1991 with 20 teachers placed as interns in programs lab-wide. In 1992, the number increased to 33, and in 1993, to 38. In 1991 the interns were exclusively high school science and math teachers. Since then we have recruited teachers from additional disciplines and grade levels and emphasize developing projects that will provide the teachers with opportunities to refresh skills in their current fields and experience the multidisciplinary aspect of scientific research. This approach is consistent with the current emphasis in California for teaching science as a multidisciplinary subject. While we stress improving science and mathematics education in the schools, we also promote the use of technology in traditionally nontechnical areas, such as publishing and library science. This emphasis allows us to highlight and promote the "high-tech" research focus inherent in our Laboratory programs.

This year's program

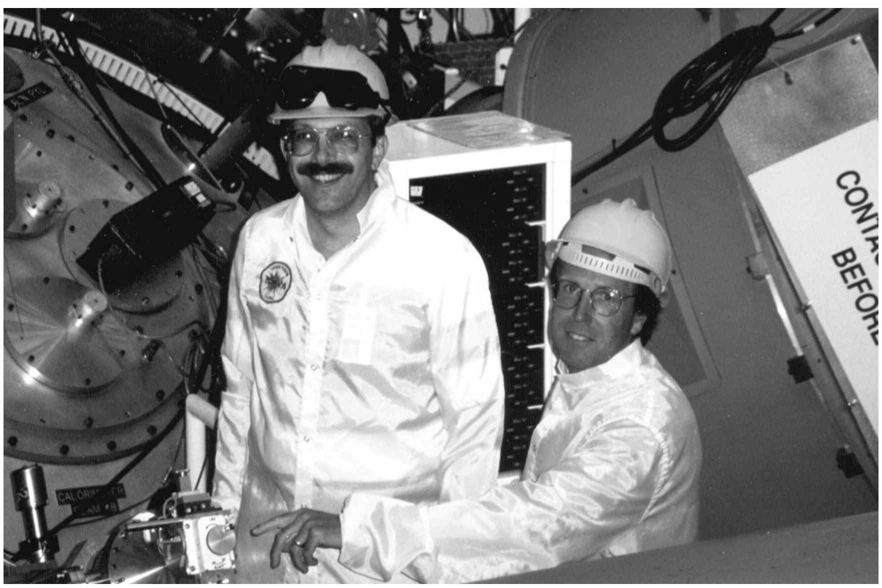
Included in their regular work week, the teachers met 2 hours each week for a series of technical presentations, which also provided opportunities to exchange information and ideas. The focus of the 1993 presentations included issues in treaty verification and nuclear nonproliferation. They also participated in several special activities, including a seismic walking tour of the Bay Area and a biotechnology workshop offered by the LLNL Science Education Center in collaboration with San Francisco State University.

Consistent with the Laboratory's commitment to diversity awareness, in 1992 we conducted a diversity-awareness training workshop, the goal of which was to help the teachers develop strategies to improve their communication with students from underrepresented groups and encourage their interest in science, math, and technology.

In 1993, we also offered the teachers a workshop in proposal writing, which several teachers requested after discovering many untapped resources available for education. They had little knowledge of how to go after those monies, search for funders and collaborators, or write a proposal. The program provided the perfect opportunity for developing contacts and ideas for proposals. Indeed, now several teachers are developing proposals, including one which will focus on the use of technology to motivate "at-risk" students.

Each year the program's finale is a demonstration of the summer's work. (See Figures 1 and 2.) We encouraged the teachers to form several core groups to work together to produce projects and demonstrations for this exciting event. Projects last year included using Laboratory resources and personnel to program one high school's new schedule and develop a 13-minute video describing the program and several videos highlighting some technical presentations and field trips. Several teachers in the technology group, along with their Laboratory mentors, developed hands-on portable science demonstration modules for their curricula. In addition, the teachers initiated a newsletter, *The Connection*, which continues to be published bimonthly to document the activities and communicate information to the program participants and others in the community. It focuses on the activities of the teachers at all DOE facilities who are supported in the area of treaty verification and nonproliferation.

This year's core groups evaluated commercial software for classroom use; developed plans for how to develop a school computer network; developed plans for a "Build a Better..." competition, which will include having the students form multidisciplinary teams to design, build, test, understand, and document a model which will demonstrate some basic scientific principles; and developed a "Technology Resources Guide," containing materials to document new technologies that the teachers can use in their classrooms and provide information on how to obtain this technology.



■ *Figure 1. High school teacher Jim Sagray and elementary school teacher David Iverson learned about LLNL's Nova target chamber while they developed the interactive laser display.*

Toward the future

We encourage the teachers to participate in our program for up to three years. We found that one year provides the teacher with only a brief glimpse into Laboratory research efforts. Subsequent summers allow the teachers to participate more fully in actual research and develop hands-on curricula based on their specific areas of research. LLNL is happy to work with other interested DOE facilities to establish such programs or to consult about the types of projects we have found to be successful. In addition we would be delighted to document the activities in our newsletter.

The Connection

Science Dome

Volume II, Number 3 — August 30, 1993

How Old is Old?
by Jim Willis

Steve Honett, a Dublin High School teacher and chairman of the science department, has an interesting project this summer at the Lab. As part of the Lazarus Project, he is growing old alfalfa to feed to old mice! What's that, you say? In fact, he helps grow some mice that are approximately 35,000 years old. Let me explain.

Carbon fourteen (14C) is a naturally occurring radio isotope of normal carbon. Steve's job is to produce complex carbohydrates (sugars, starches, etc.) low in 14C to add to the diet of experimental mice. Since 14C is an isotope common to our atmosphere in the form of CO_2, has a half-life of some 5,000 years, and is used by plants to build carbohydrates, Steve's goal is to get "very old" CO_2 (CO_2 not exposed to the atmosphere) and feed it to plants. "Very old" means that it has been out of atmospheric circulation for thousands of years. The bottle of CO_2 Steve is using comes from a petroleum source and carbon-dates at about 47,000 years. The carbon dating is done at the Center for Accelerated Mass Spectrometry under the guidance of Steve's mentor and physicist, Jay Davis.

The old $C^{12}O_2$ (Carbon dioxide high in 12C and low in 14C) creates, through photosynthesis, complex carbohydrates such as sugar, starch and cellulose which are then used as roughage in themouse diet. Through this method, a batch of alfalfa was grown that carbon-dated at about 26,000 years.

Steve Honett

Steve, with the help of Paul Daley, a plant physiologist and environmental scientist, has to control the growth of the plants, eliminating modern atmospheric CO_2, and they are testing several variations on growth chamber design because in one chamber the alfalfa crop (two feet square) was previously devastated by a mold of the genus Fusarium. They finally solved the problem, and Steve hopes that the chamber will be the pilot for a much larger chamber that will be designed, built and operated by students at Dublin High School as part of the Lab's Explorer Post program run by Joe Schinn, an LLNL environmental scientist.

The Connection — Page 1

■ *Figure 2. A sample of* The Connection*, which is produced by the Summer Research Internship Program.*

Technology Briefs

MOXE: U.S.–Russian collaboration in space astronomy

William Priedhorsky
Los Alamos National Laboratory

A long-standing Los Alamos interest in time-variable x-ray stars has borne fruit in the form of a U.S.–Russian collaboration to develop a powerful, x-ray pinhole camera monitor for a space-based observatory. The project's collaborators, led by Los Alamos National Laboratory, include the Goddard Space Flight Center (Greenbelt, MD) and the Russia Institute for Space Research.

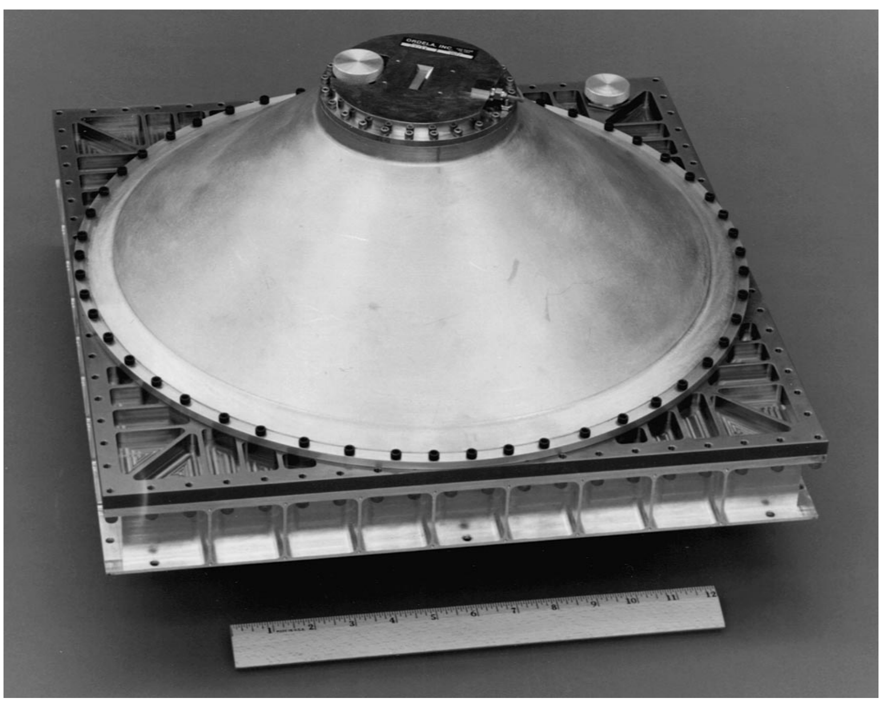
In 1969, the Atomic Energy Commission launched a simple x-ray monitor on its Vela 5B verification satellite that revealed flaring and transient x-ray stars and periodic variability on all time scales. Periodic variability provides information about the physics of the most peculiar objects in our galaxy: black holes and neutron stars.

With modern technology, we have built x-ray monitors that are 100 times as sensitive as the monitor on Vela. These powerful instruments, x-ray pinhole cameras, rely on imaging x-ray detector technology that parallels technologies used for space verification, but is simplified for export.

In 1989, the then–Soviet Academy of Sciences invited the U.S. to collaborate in the design of an instrument for the Russian Spectrum-X-Gamma (SRG) x-ray observatory. The result, called MOXE (Monitoring X-Ray Experiment), is an all-sky monitor. When launched by a Russian proton booster in late 1995, SRG will carry instruments from Russia, Finland, Denmark, Germany, Italy, Canada, Switzerland, France, Israel, Hungary, Poland, Spain, the United Kingdom, and the U.S.

Serving as a transient alarm for the entire observatory, MOXE will develop an archival record of hundreds of x-ray stars on time scales of seconds to years. The first x-ray, all-sky monitor to continuously observe most of the sky, MOXE may discover fast transient phenomena previously undetected. Six large x-ray pinhole cameras, one of which is shown in Figure 1, will cover the entire sky. The final flight instruments are presently being fabricated.

MOXE is important not just for the astrophysics it will do, but for its pathfinding role as a U.S.–Russian hardware collaboration for space science.



■ *Figure 1. One of six large x-ray pinhole cameras that can observe the entire sky. They will be launched aboard the SRG x-ray observatory in 1995.*

Hand-held scintillating fiber-optic neutron detector

M. Bliss and R. A. Warner
Pacific Northwest Laboratory

Pacific Northwest Laboratory has constructed and demonstrated a hand-held neutron detector suitable for field use in nonproliferation applications such as searches for fissionable material. The detector package weighs 3.2 kg, exclusive of processing electronics (see Figure 1), which can be easily miniaturized.

The detector was made from a flexible mat of cerium-activated lithium-aluminum-silicate glass fibers. A “neutron capture” in the fiber causes the cerium to scintillate, or emit a pulse of light. A fraction of this light travels to the fiber ends where it is detected by photomultipliers. When light pulses above a pre-selected amplitude are observed in coincidence at each end of the fiber, a neutron capture event is identified.

The sensor has two demonstrated operational configurations: the sealed sensor package and the sensor package in an aluminum carrying case with two 2.5-cm sheets of polyethylene moderator, which add most of the 22.3 kg of this configuration’s weight.

The sensor was tested with a neutron source and a Co-60 gamma source. In these tests, 80% of the neutron events were detected while simultaneously 80% of the gamma events were rejected. Greater rejection could be obtained at the expense of some neutron events by adjusting the signal amplitude required to record an event. The results are important because the dominant interference with the signal for detectors of this type is not from neutrons but from gamma rays.

Basic materials research continues to improve the glass detector’s durability and reliability.

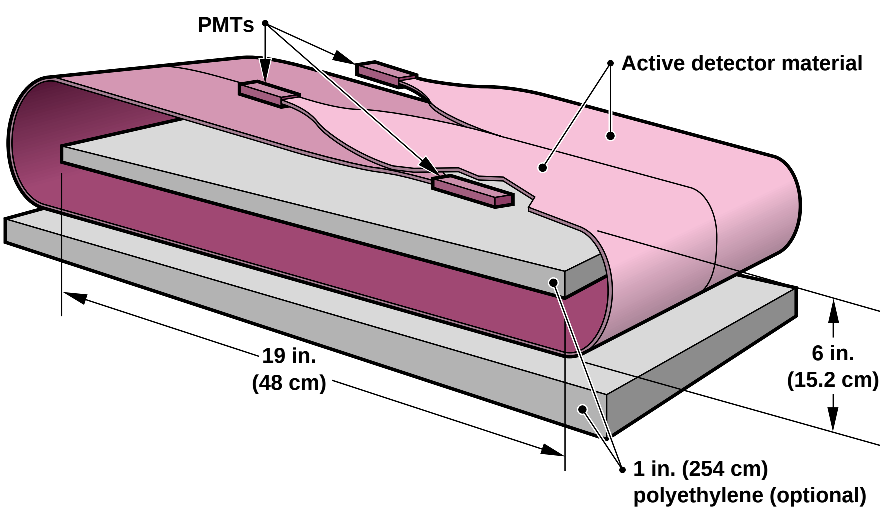


Figure 1. The active parts of the hand-held scintillating fiber-optic neutron detector are its photomultiplier tubes (PMTs) and thermal neutron-sensing glass fibers on a base of polyethylene.

ALEXIS satellite nearly operational

David J. Simons
Los Alamos National Laboratory

The 113-kg ALEXIS satellite that carries an ultra-soft, x-ray telescope array (the ALEXIS experiment) and a high-speed, VHF receiver/digitizer (the Blackbeard experiment) is up and almost fully operational after a very traumatic beginning. The Air Force Space Test Program launched the satellite aboard a Pegasus booster into a 844-by-749-km orbit of 70 degrees inclination on April 25, 1993.

The principal mission of the ALEXIS program, sponsored by the DOE Office of Nonproliferation and National Security, is to demonstrate advanced instrumentation for x-ray imaging and broadband radio detection. This capability may be used in future space systems for detecting nuclear weapon proliferation.

The launch nominally placed the ALEXIS satellite in very near to the planned orbit, but attempts were unsuccessful to contact the satellite after the launch. One of the satellite’s solar panels (including the magnetometer that provides attitude reference data) was damaged during launch. The problems were complicated by the inadvertent identification of the third stage as the satellite by the Air Force and by subsequent attempts to make radio contact with the wrong object for the first three days of passes over the ground station. By this time, the satellite batteries had lost much of their power, and the satellite had gone into a preplanned safe-keeping mode, which cycled on only intermittently while waiting for further instructions.

The team at Los Alamos, undertaking a rescue mission that lasted into mid-July, attempted to salvage what was possible from an (as yet) undetermined catastrophe. Using radar systems and optical systems around the country, they determined that the satellite had deployed its solar paddles and thus had been operational after leaving the last stage. Considerable modeling based on performance design and on information about spacecraft orientation led the ALEXIS team to believe that there was an opportunity to contact the satellite and gain control once the orbit had precessed sufficiently to increase the total solar illumination during a complete orbit. The ground station was kept operational during every potential contact, and finally ALEXIS spoke on June 2. The spacecraft sent a 15-second transmission with sufficient housekeeping information to tell the team that many important systems were functional. Four more weeks passed before ALEXIS transmitted again, this time sending a strong 4-minute signal telling everything the team needed to know. The problems, however, did not end there. The autonomous orientation program was not functioning because the magnetometer was dead, the batteries were running down in a hopeless chase to reorient the satellite, and the spacecraft could no longer measure its own spin rate. On the next pass, the team turned off all noncritical systems to allow the batteries to charge.

The ALEXIS team worked day and night to develop new software to allow for semi-autonomous operation for power cycling and orientation control. By the end of July ALEXIS was undergoing routine system check-out and sending and receiving on every pass. The first Blackbeard scientific experiments were performed during August, and the first x-ray data was taken in September. The satellite is now functioning in a nearly routine manner and should produce significant technical results over the next year.

Tech transfer from tagging technology

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Pacific Northwest Laboratory
Dennis D. Rogers
General Motors Corporation
Michael Wiezbowski
Chrysler Corporation

Pacific Northwest Laboratory (PNL), like the other DOE national laboratories, seeks commercial spin-offs to technologies that were originally developed for arms control applications. One success at PNL is the use of the ultrasonic intrinsic tagging (UIT) technology[1,2] to address a dilemma plaguing U.S. machinery manufacturers, quality control of hardened steel components. The problem has been two-fold: (1) the long delay between hardening a steel component and taking the measurement (i.e., 30 minutes or more for each automotive front-wheel-drive axle tested) and (2) the destructive nature of the test itself.

The UIT is a nondestructive verification technology that was originally developed by the Department of Energy’s Office of Nonproliferation and National Security in support of the Strategic Arms Reduction Treaty (START). Because the UIT was designed to detect subsurface microstructural features, UIT measurements give feedback of processes where material microstructure is important. A potential spin-off, therefore, is in the machinery manufacturing industry, where heat treatment is used to alter the material microstructure when hardening a steel component.

Data acquired from a modified UIT instrument tested on manufactured components at the Saginaw Division of General Motors Corporation (GM) indicate that a fast feedback process is now possible. This technology is expected to save tens of millions of dollars per year for the automotive industry, and also may impact other elements of U.S. machinery manufacturing, including the defense industry.

A critical factor in developing a commercial instrument is cost, which is being minimized by integrating several strategies. One is to enlist a number of industrial partners to share costs; a second is to use matching federal funds provided by DOE and other government agencies. Without these important funding resources, the technology transfer work could not occur.

Avenues used by PNL in the UIT technology transfer have included a DOE staff exchange, DOE Cooperative Research and Development Agreements (CRADAs), and the Technology Reinvestment Program (TRP). To enhance the technological base, PNL also sought the use of technology resources from Iowa State University and the National Institute for Standards and Technology (NIST). Efforts were structured to bring together (1) machinery manufacturers to define industrial needs and test prototype instruments, (2) technology sources such as PNL to develop prototype instruments, and (3) a U.S. vendor of inspection instrumentation to facilitate technology commercialization.

Background of the UIT

In 1989, PNL began developing an instrument for uniquely identifying items using subsurface intrinsic signatures. The intended application was high-confidence identification (tagging) of treaty-limited items for use in the proposed START, although tagging provisions were later deleted from the Treaty's requirements. The initial program focused on composite rocket motors used in the configuration of mobile ballistic missiles; in 1991, the technology was extended to metallic objects.

The fundamental principle of UIT involves scanning an ultrasonic beam over a small surface area of an object and recording responses originating from a selected depth internal to the material. Localized variations within the scanned area provide the basis for a random signature for unique identification of a composite or metal structure. A side benefit of this process is a nondestructive measurement of the depth to which a steel component has hardened. These new measurements are expected to spur design changes to reduce the material mass in hardened automotive components by 10 percent.

Interactions with U.S. industry

When GM and Chrysler Corporation toured the DOE laboratories in 1991, they sought technology that would be advantageous to their manufacturing plants. One need was near real-time feedback of their heat treatment processes for hardening steel components. Using UIT technology to do this was explored in 1992 during a three-week staff exchange at the Saginaw Division of GM.[3,4] Three factors contributed to the successful exchange: (1) PNL evaluated several GM steering linkage rods prior to the exchange, (2) the UIT technology was demonstrated on GM components with a portable instrument during the exchange, and (3) GM personnel met with a DOE Energy Research Laboratory–Technology Transfer (ERL–TT) Program official to voice their interest in expanding the evaluation with prototype systems along a GM production line.

CRADAs: installing prototype systems and measuring hardness depth

A DOE–GM CRADA began in August 1993 for installing at GM two prototype units, the UIT data acquisition module coupled to a scanning mechanism. The purpose of the installation was to permit GM to correlate the nondestructive measurements of the prototypes with the destructive measurements required by current statistical sampling practices.

Funding for a second CRADA was budgeted in October 1993. The work addresses the broad needs of industry and includes UIT as well as several other technologies to handle all the industrial product configurations due to a variety of hardening processes, component geometries, and production needs. Companies involved include GM, Chrysler Corporation, and TRW Automotive.

Benefits

The proposed technology will be accurate, nondestructive, objective, and immediate compared with destructive tests, in which statistical feedback is slow and measurement accuracy is typically inconsistent and subjective. Experts say improved process controls and consistency will continue to be one of the four most needed advancements over the next five to ten years for the heat treating industry.[5]

Use of UIT technology in industry will allow U.S. manufacturing industry greater productivity and higher-quality machinery at a lower cost. In turn, U.S. industry will find expanded markets for increased exports of manufactured machinery and components, help regain a national reputation for quality, and retain and/or create U.S. jobs.

A direct benefit to the U.S. government will be reduced vehicle maintenance costs. Improved components may include sprocket gears, the gun follower of the M1 tank, helicopter transmissions, and gas turbine engine bearings.[6]

The UIT technology will contribute to improved consistency of component strength and the ability to reduce component mass by 10 percent. Although only hardened steel components are affected, implementation across the entire U.S. automotive fleet will result in large long-term energy savings.

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CRADA to apply weighing technology to highways of the future

Susan Sperrow
Oak Ridge National Laboratory

A cooperative research and development agreement (CRADA) to apply DOE-developed Weigh-in-Motion (WIM) technology to advanced vehicle-weighing and axle-counting products recently was signed at Oak Ridge National Laboratory. International Road Dynamics, Inc., a leading U.S. manufacturer of integrated traffic-monitoring and weight-enforcement systems, will join Oak Ridge in a project to further develop WIM technology for its highway product line.

The new technology is based on an innovative use of fiber optics. Unlike vehicle-weighing systems that use load cells or piezoelectric transducers, the new system measures changes in the conductance of a flexible, silicone-rubber, optical fiber as the fiber deforms. Accurate weights, number of axles, tire footprints, and weight distribution of moving vehicles can be measured.

The technology initially was developed during a 1990–1991 feasibility effort funded by what was then the DOE Office of Arms Control and Nonproliferation through its Conventional Forces in Europe Verification Technologies Program.

■ *Figure 1. The weigh-in-motion (WIM) technology is demonstrated on a road.*

SYNTH: a gamma-ray spectrum synthesizer

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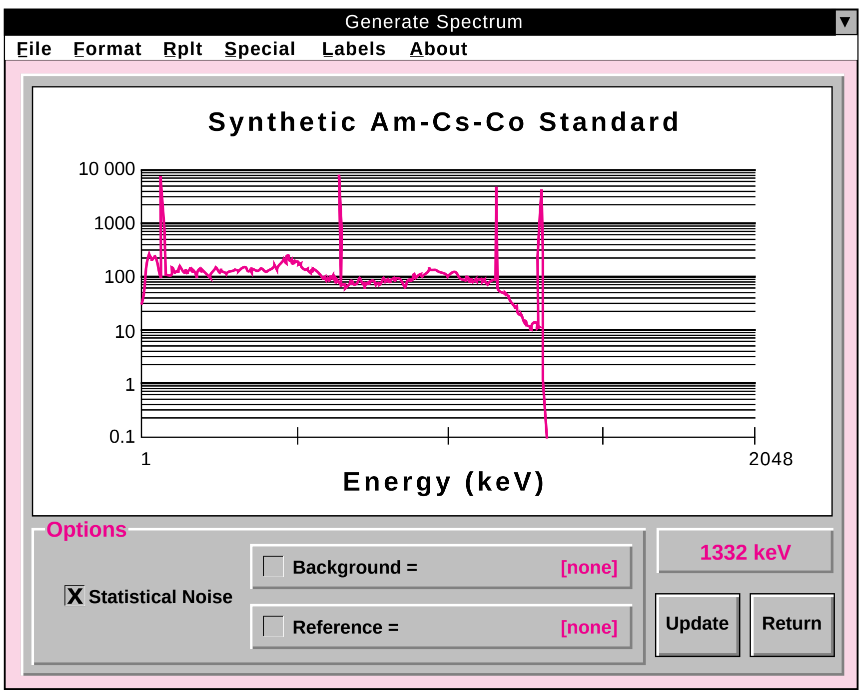
Pacific Northwest Laboratory
A. D. McKinnon, M. E. Panisko,
R. M. Savard
Students sponsored by Pacific Northwest Laboratory

Personal computer software has been developed at Pacific Northwest Laboratory to predict the gamma-ray spectra acquired with germanium and sodium-iodide detectors. Dubbed SYNTH, the software has a graphical user interface that allows the either the technical or the unsophisticated user to quickly set up a hypothetical nuclear chemistry experiment and then determine the results within seconds (Figure 1). For example, users can perform previously tedious tasks such as evaluating detectors for a specific use, developing detector procurement specifications, predicting the sensitivity of a measurement technique (such as finding radioactive waste buried in soil with naturally occurring radioisotopes), and designing a calibration source.

This capability is useful in situations as widely varied as a laboratory bristling with science gear or a field inspection site having only a detector and a personal computer. It also gives an inexperienced technician the benefit of years of intuition developed by nuclear chemistry professionals.

In 1983, SYNTH began as an academic exercise that produced a computer algorithm to predict the spectrum that would be obtained from a single gamma ray in a germanium detector. By 1991, about $50 had been spent to obtain a database of radioisotopes in an independent effort to develop a computerized radioisotope identification utility. In 1991, SYNTH was born from the fusion of these and other algorithms and funded as a DOE/OAC Advanced Concepts project. Today, after developing the Windows interface and adding several features, PNL staff are pursuing the commercialization of SYNTH to allow it to become more widely available.



■ *Figure 1. SYNTH output of a synthetic spectrum. Here the effect of statistical fluctuations present in all experiments is included in the spectrum ("Statistical Noise" is selected with an "X."), while background noise and reference have not been selected. Pull-down menus also allow variation in the display mode.*

How SYNTH works

The user input (either interactive or from existing files of default parameters) consists of simple descriptions of the size and physical make-up of a hypothetical source of radiation, such as a 55-gallon drum of sand. The user also selects the radioactive isotopes to be placed in the drum, either at the center or uniformly mixed, and indicates the distance between the source and detector. The user then describes the detector itself: its dimensions, resolution, and other parameters listed on the manufacturer's spec sheet. Finally, the user enters the requisite electronic settings that would be used in a laboratory experiment, such as amplifier gain and experiment duration. Most parameters can be placed in a default parameter file to eliminate repetitive keyboarding.

The result of a SYNTH calculation is a spectrum that includes correct photopeak intensities, single and double escape peaks, Compton edges, peak-to-Compton ratios, and statistical fluctuations.

Since the code allows a real spectrum (such as natural background) from a user's detector to be added to a synthetic spectrum, extraordinarily accurate results can be generated. The code has been validated against actual spectra with excellent results; in fact, a SYNTH spectrum can fool an experienced gamma-ray spectroscopist.

Although a number of Monte Carlo programs can achieve very accurate predictions of the results of an experiment, they cannot be operated by inexperienced users. They also take large amounts of time on large computers and employ no convenient user interface that assures reasonable starting parameters. Thus, the overhead of effort and the learning curve for beginners are frequently so large that many potential users often do without. With SYNTH, however, meaningful results are available in a few minutes. SYNTH is different from Monte Carlo programs in that they mathematically create and follow hundreds of thousands of nuclear events to gradually build a picture of the process being studied. Instead, SYNTH has hard-coded algorithms based on laboratory experience with many detectors, so it achieves good accuracy (10% uncertainty) from exceedingly complex nuclear decays, with literally hundreds of peaks in a spectrum, in as few as three minutes on a fast personal computer.

SYNTH leads the user through each step required to perform a real measurement, so users also become acquainted with gamma-ray spectroscopy. The first screen (Figure 2) shows the logical sequence of steps that must be done before the spectrum can be generated, and indicates which steps have been completed. When an icon is selected, the user is led through a series of choices in that subject area.

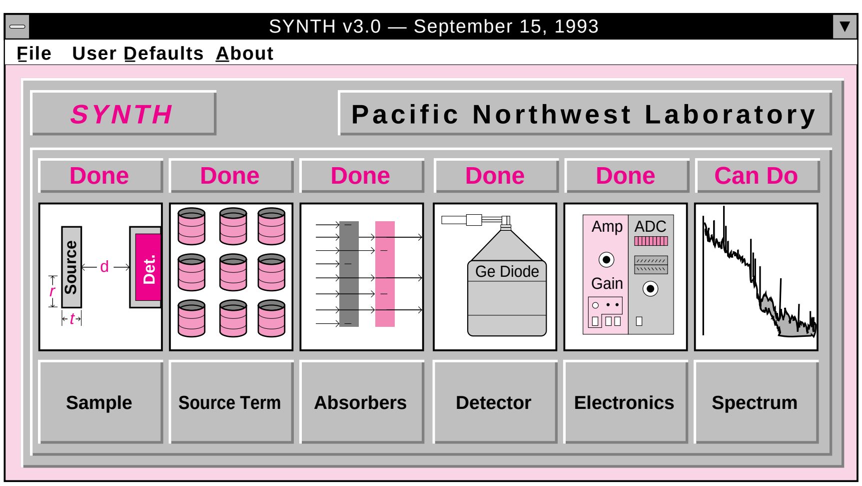


Figure 2. The computer screen in SYNTH is shown at the point after all measurement parameters have been selected. Each selection (now marked "done") prompted an interactive process in which the user selected the parameters of a nuclear measurement. Here the user would be ready to select "Spectrum," which creates the estimated spectrum.

Surface-enhanced raman scattering (SERS)

Joseph B. Dooley
Martin Marietta Energy Systems, Inc.

Martin Marietta Energy Systems, Inc. (MMES), has licensed a new Oak Ridge National Laboratory-developed continuous monitoring technique to GAMMA-METRICS of San Diego, California, for measuring concentrations of chemical contaminants and other pollutants in water, soil, and wastes.

The new technology is a surface-enhanced Raman scattering (SERS) technique, which uses lasers to excite organic molecules adsorbed on a silver-coated surface to provide continuous and almost instant measurements of contaminants present in water or some other medium. SERS is a powerful analytical technique that can be used for environmental monitoring and pollutant control. For many organic chemicals, SERS is superior to other in-situ analytical techniques.

The SERS technology is based on the principle that certain molecules, when placed on a silver-coated metal surface and excited by laser light, will strongly scatter the laser light at shifted frequencies. The frequency and intensity of the scattered laser light is characteristic of the unique vibrational modes of the adsorbed molecules. Detection and measurement of the Raman light allow the identification and measurement of the concentration of the adsorbed molecule.

DOE funded this particular SERS technology (Figure 1) to enhance methods for detecting very low concentrations of effluents from nuclear proliferation activities. The technology also was tested for use against precursors, effluents, and degradation products. Modifications to the technique permit separation of the acquisition and analysis activity and the ability to "archive" exposed collection substrates for later re-analysis.

MMES granted GAMMA-METRICS the exclusive rights to commercialize the laser-based SERS to perform real-time, in-situ chemical analysis. Initially, the company will use the technology to measure concentrations of toxic chemicals for site assessments in DOE's Environmental Restoration and Waste Management program.

"The SERS technology extends our analytical and spectroscopic capabilities to the molecular domain," said GAMMA-METRICS president Ernesto Corte. The company plans to built a portable instrument that incorporates the technology while making engineering and other changes needed to accelerate the development and marketing of the analytical technique.

GAMMA-METRICS develops, manufactures, markets, and services instrumentation for diverse industrial applications, such as safety instrumentation for nuclear power plants; pollution control analyzers for the coal industry; analytical instruments and process control for mining, construction, and environmental industries; and equipment for the high-threat security industries.

Figure 1. The newly licensed SERS is a powerful analytical technique that can be used for environmental monitoring and pollutant control. It was developed by Tuan Vo-Dinh (left) of ORNL. With him (left to right) are contractors Jean-Pierre Alarie and David Stokes and Gordon Miller of ORNL.

Detector system for pulses of ionizing radiation

James L. Jones
Idaho National Engineering Laboratory

The Idaho National Engineering Laboratory has developed and successfully tested two similar portable systems for detecting and characterizing high-intensity pulsed photons, such as x rays and gamma rays. Although developed for on-site, charged-particle weapon-detection scenarios, the detectors also have potential commercial use. Tests show that each of the systems can accurately measure the average photon energy and intensity of short bursts of x rays in real time.

One detection unit comprises eight detectors made of bismuth germanate scintillation crystals; the other has ten detectors made of cesium iodide crystals. The total photon energy deposited in a crystal determines the intensity of the unsaturated pulse response. Simultaneous detection of photon pulses in two or more crystals in a detection unit triggers data collection, a feature that eliminates most random background counts. Both units automatically compensate for the intensity of short bursts of photons so that unsaturated detection can occur.

Each detector in a unit is unique, either in the size of the crystal or in the thickness of lead shielding surrounding it. Because larger sizes of scintillator material and thicker lead shields absorb higher percentages of the photons having lower energies, the energy of the photons can be calculated by comparing the individual detector responses.

The detection units of both systems each fit into a small suitcase and weigh 35 and 45 pounds (Figure 1). The difference in weight is primarily due to the reduced lead shielding requirements of the smaller cesium iodide detectors. Both units can operate with no external support for 18 hours or more on internal battery power and are self-activated when pulsed radiation is detected. The complete data reduction and analysis package for either system, also battery operated, fits into a third suitcase and weighs about 35 pounds.

The systems have potential commercial application for measurements of radiation exposure during pulsed accelerator operations such as x-ray radiography, medical radiation therapy, and high-energy physics research.

Figure 1. The detector system for pulses of ionizing radiation is carried by one of its developers, Robert S. Lawrence, of Idaho National Engineering Laboratory. Inset shows an opened portable detection unit with the ten cesium iodide crystal detectors (array of six at lower right and four lead-shielded units across upper right), the electronics system (large aluminum case on the left side with additional units connected by cable to the detectors), and the removable memory card assembly (immediately to the left and above the case handle) with card in place.

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