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March 1989

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Special Issue: Verification of Arms Control Treaties

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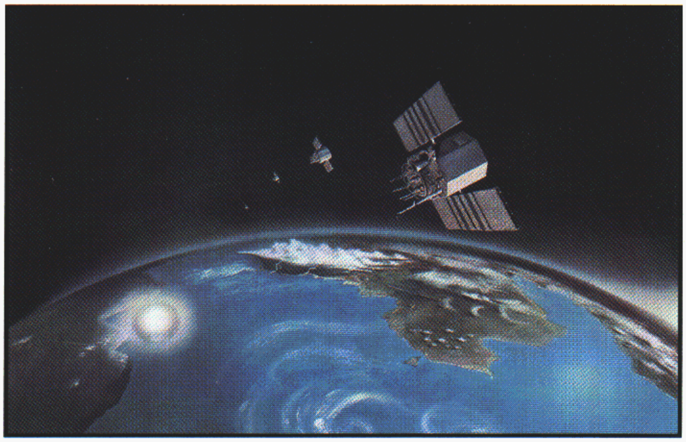

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Sandia is providing optical sensors for the Global Positioning System. This constellation of satellites will provide navigation data and monitoring capability for test bans by providing data on nuclear detonations.

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Sandia National Laboratories
Sandia is a multiprogram laboratory operated for the Department of Energy with major facilities at Albuquerque, New Mexico, and Livermore, California, and a test range near Tonopah, Nevada. Our primary responsibilities are research and development of nuclear weapon systems from concept to retirement. We also have extensive responsibilities in other areas of national importance that are related to our primary mission. These include fusion energy, reactor safety, nuclear safeguards, energy research, microelectronics, and other undertakings that exploit our research and development capabilities. Our technological activities and accomplishments are reported in two corporation publications. Unclassified articles appear in *Sandia Technology*. Classified work is reported in *Sandia Weapons Review*.

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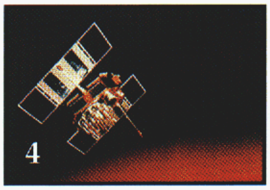

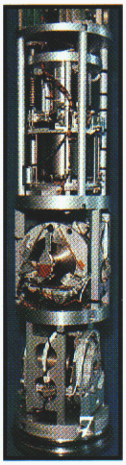

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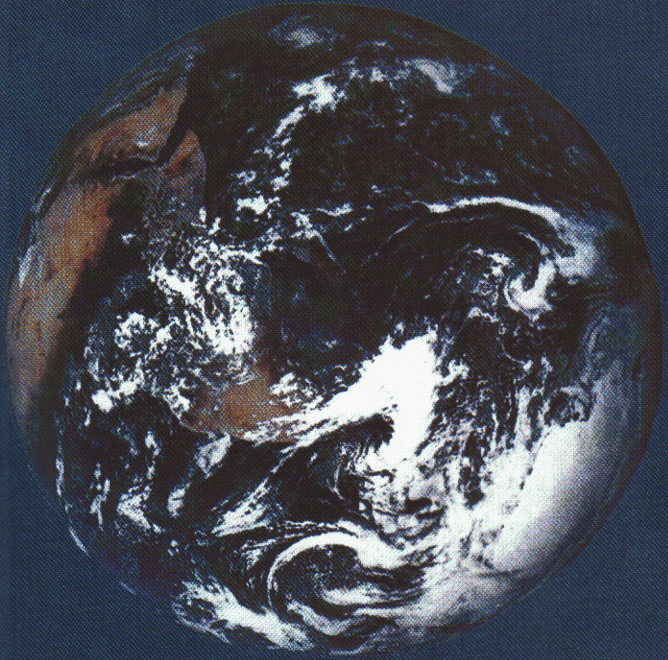
Verification Perspective

Nuclear Age History

1945	First US fission-based explosive, Trinity
	Nuclear bombing of Hiroshima and Nagasaki, Japan
1949	First USSR fission-based explosive
1952	First US fusion-based explosive
1953	First USSR fusion-based explosive

Treaties and Agreements



1961	Antarctic Treaty
1963	Hotline Agreement
	Limited Test Ban Treaty
1967	Outer Space Treaty
1968	Treaty for Prohibition of Nuclear Weapons in Latin America
1970	Non-proliferation Treaty
1971	Accident Agreement
	Hotline Modernization Agreement
1972	Seabed Arms Control Treaty
	Strategic Arms Limitation Talks (SALT) Anti-Ballistic Missiles Treaty
	SALT Interim Agreement
1973	Prevention of Nuclear War Agreement
1974	Threshold Test Ban Treaty
1975	Biological Weapons Convention
1976	Peaceful Nuclear Explosions Treaty
1979	SALT II Strategic Offensive Arms Agreement
1980	Environmental Modification Convention
1986	Conference on Disarmament in Europe
1987	Nuclear Risk Reduction Center Agreement
1988	Intermediate-range Nuclear Forces Treaty
1988	Joint Verification Experiment Agreement

Ongoing Talks

Nuclear Testing Talks
Chemical Warfare Convention Negotiations
Defense and Space Talks
START Strategic Arms Limitation Talks
Mutual and Balanced Force Reduction Talks
Conventional Stability Talks
Conference on Security and Cooperation in Europe

Sandia National Laboratories
Albuquerque, New Mexico 87185

Irwin Welber
President

March 27, 1989

Nuclear deterrence, a cornerstone of US national security policy, has helped prevent global conflict for over 40 years. The DOE and DoD share responsibility for this vital part of national security. The US will continue to rely on nuclear deterrence for the foreseeable future.

In the late 1950s, Sandia developed satellite-borne nuclear burst detection systems to support the treaty banning atmospheric nuclear tests. This activity has continued to expand and diversify. When the Non-Proliferation Treaty was ratified in 1970, we began to develop technologies to protect nuclear materials from falling into unauthorized hands. This program grew and now includes systems for monitoring the movement and storage of nuclear materials, detecting tampering, and transmiting sensitive data securely.

In the late 1970s, negotiations to further limit underground nuclear testing were being actively pursued. In less than 18 months, we fielded the National Seismic Station, an unattended observatory for in-country monitoring of nuclear tests.

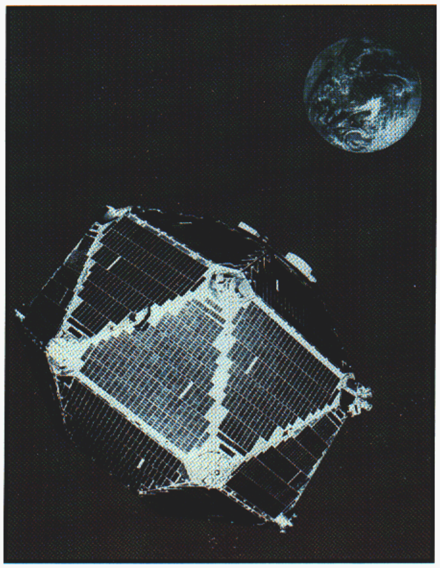
In the mid-1980s, arms-control interest shifted to facility monitoring and on-site inspection. Our Technical On-site Inspection Facility is the national test bed for perimeter and portal monitoring technology and the prototype for the inspection portal that was recently installed in the USSR under the Intermediate-Range Nuclear Forces accord.

The articles in the special issue of *Sandia Technology* describe some of our current contributions to verification technology. This work supports the US policy to seek realistic arms control agreements while maintaining our national security.

Irwin Welber

Irwin Welber
President

Figure 1. A VELA satellite views the earth from its circular orbit. The optical sensor sunshades project in the earth-looking direction; direct-radiation sensors look out into space.



Satellite Instruments

These instruments monitor conformance to nuclear test bans and non-proliferation treaties.

In the 1960s, Sandia National Laboratories and Los Alamos National Laboratory began designing special-purpose instrumentation for VELA satellites (Figure 1). These spacecraft were devoted to developing the capability to detect nuclear detonations, first in space, and later in the atmosphere. The VELA experience provided the early technology for treaty verification, and the satellites collected data from numerous detonations in the atmosphere by nations that had not signed the 1963 Limited Test Ban Treaty. The VELA program demonstrated the continuing need for follow-on surveillance systems to assure compliance with test-ban and non-proliferation treaties.

The Limited Test Ban Treaty, ratified by the US, USSR, UK, and over 100 other nations, prohibits testing in the atmosphere, in space, or underwater. The 1974 Threshold Test Ban Treaty limits the size of nuclear devices tested underground. Other agreements limit the spread of nuclear weapons and the materials required for their manufacture. Groups in the US and other nations now expect considerable pressure to further limit, if not eliminate, underground testing.

These limits on testing raise concern over clandestine testing by known and potential nuclear powers. For this reason, the Department of Energy and the Department of Defense maintain a strong surveillance program. Satellite-based detectors complement debris-collection and seismic programs to cover all reasonable clandestine test scenarios. Here we will briefly outline some of the modern satellite instruments in which Sandia plays a key role.

Satellite-borne instruments must distinguish between the radiation generated by nuclear detonations and natural or background radiation.

A nuclear detonation in space generates various types of direct radiation (Figure 2), of which x-rays can be detected most readily. The sensors for detecting x-rays and other radiation from space bursts were designed by Los Alamos scientists who also design instruments to measure the natural background radiation at a satellite. Background measurements allow a continuous assessment of radiation environment changes due to solar storms and flares.

A detonation in the atmosphere generates the same direct radiations as in space, but these are quickly transformed by the atmosphere into other observables. The most easily observed is the visible and near-visible light from the fireball. Our optical detectors are designed to detect and measure this radiation to determine the approximate size and location of atmospheric bursts. Electromagnetic-pulse detectors, similar to those developed for VELA satellites, will be used in addition to the optical sensors on later Global Positioning System satellites to enhance their capability to locate detonations in the atmosphere more precisely.

A new generation of Global Positioning System satellites (Figure 3) has been developed and is being prepared for launches beginning in 1989. Los Alamos is providing the

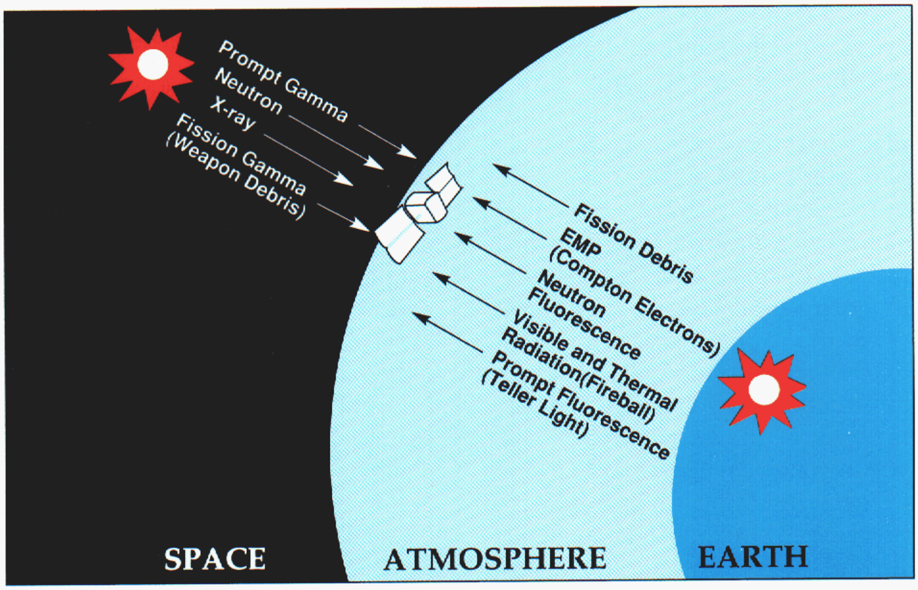


Figure 2. Instruments must distinguish between nuclear detonations and the natural radiation background of space and earth. They also must respond reliably to the different types of radiation from detonations in space and in the atmosphere. We are developing new designs that can sense detonations millions of miles from earth.

x-ray sensors and dosimeters, and Rockwell International is providing the spacecraft and electromagnetic-pulse sensors.

Our optical sensors, data processors, and power supplies support all the sensors used by US satellites for monitoring nuclear detonations.

Our optical sensor is a type of radiometer with a conical sunshade, a light-collecting lens, and a photodetector (Figure 4). The electronic signal processor for distributing power and commands to the sensors and collecting data from them is shown in Figure 5. The processor provides digital irradiance-vs-time histories of all optical signals that exceed trigger threshold requirements.

The threshold level required to trigger the sensor can be adjusted from ground control stations that send commands to the satellites. The sensors can also be stimulated by calibration commands from the

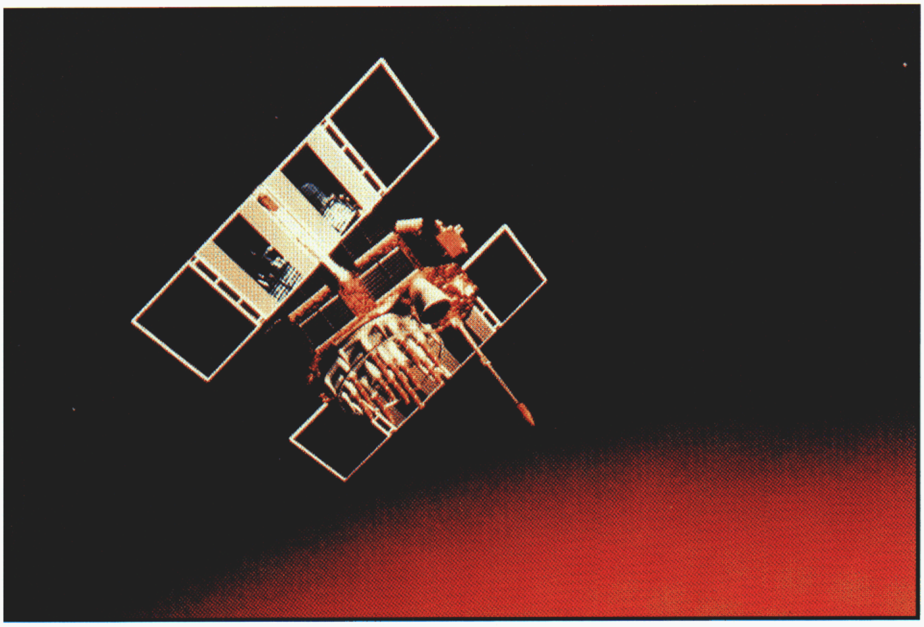


Figure 3. The Global Positioning System is a critical part of the US defense system for the 1990s and the next century. The constellation of 18 satellites in six orbital planes will provide accurate navigation data and detect nuclear detonations to monitor conformance with test bans. Ten developmental satellites were launched from 1978 through 1984 for proof testing. The 21 Block II units will be launched from 1989 through 1992 to provide 18 online and 3 reserve satellites.

ground stations; these commands activate a light-emitting diode built into the sensor to provide a known source of light for testing the complete detection system, both before and after launch.

The processor samples the sensor signals and digitizes them for transmission over the satellite telemetry link to ground stations. It also provides all the power and commands for the sensors and adds timing information to events reported by the sensors. To discriminate between nuclear bursts and false triggers (lightning, for example), the processor tests signal characteristics such as the rise-time and intensity of the optical flash, pulse duration, and possible signal coincidences from several photodetectors. More complex signal analysis is performed at the ground stations.

The processor is a microcomputer. Data from the sensors are processed and stored in memory, if necessary, before transmission to the ground. Random Access Memories provide working, event-storage, and state-of-health memory. All electronics are radiation hardened and backed up to increase the overall reliability of the data processor.

State-of-health data show how well the instrumentation is configured and functioning. Changes in the data are processed to verify that commands sent from the ground have been received and "understood." The data also change as the satellite orbits the earth; for example, state-of-health measurements vary as the amount of light reflected by the earth changes. Other environmental changes cause time variations in other measurements. Ground control operators analyze the data from the satellites and optimize mission performance by sending commands to reconfigure the instruments in response to these changing conditions.

For more information, call **Brick Dumas** (505) 844-5377.

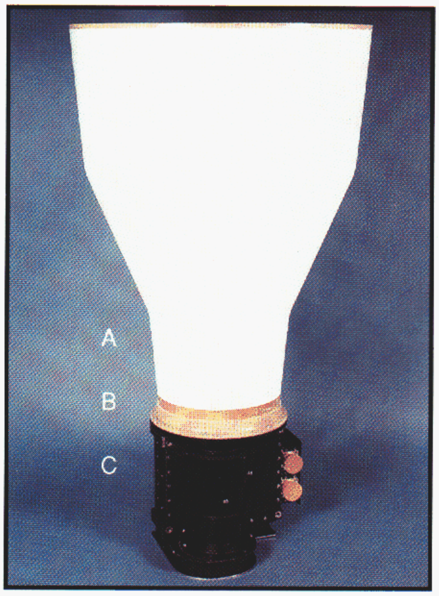


Figure 4. Sandia's optical sensor for satellites consists of a sunshade (A), lens assembly (B), and photodiode (C). Since the first optical sensor was deployed in the 1960s, we have improved the sensor technology and the supporting electronic signal conditioning.

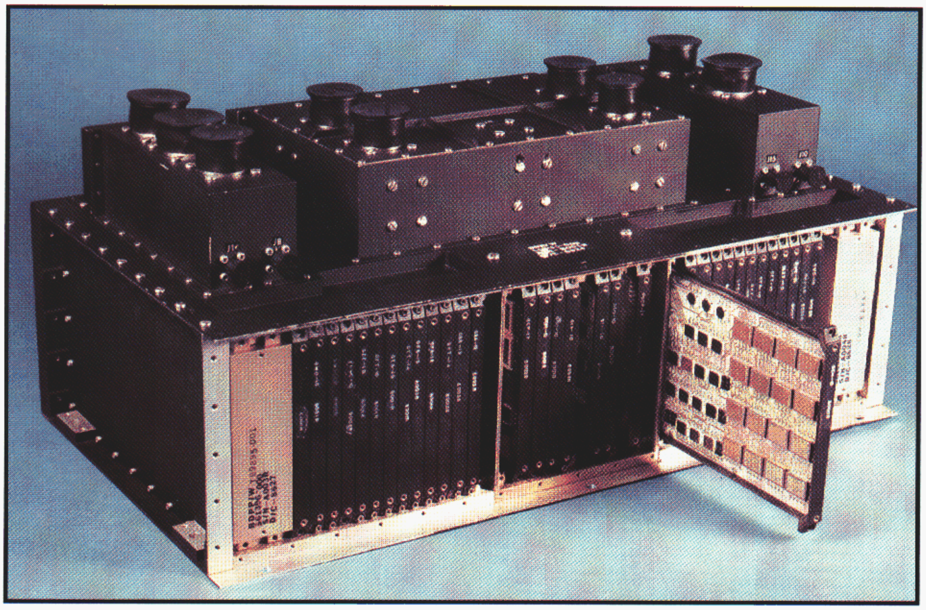


Figure 5. We provide the computer-based signal processor that links the optical, x-ray, and radiation-dosimeter sensors with the satellite telemetry system. In new designs we are adding more data processing capability. All critical parts of the processor are used in parallel to increase the reliability of the satellite payload.

Seismic Verification Programs

Our seismic monitoring systems and data analyses have made major contributions to our capability to verify adherence to treaties limiting underground nuclear testing.

History of Sandia involvement in seismic verification.

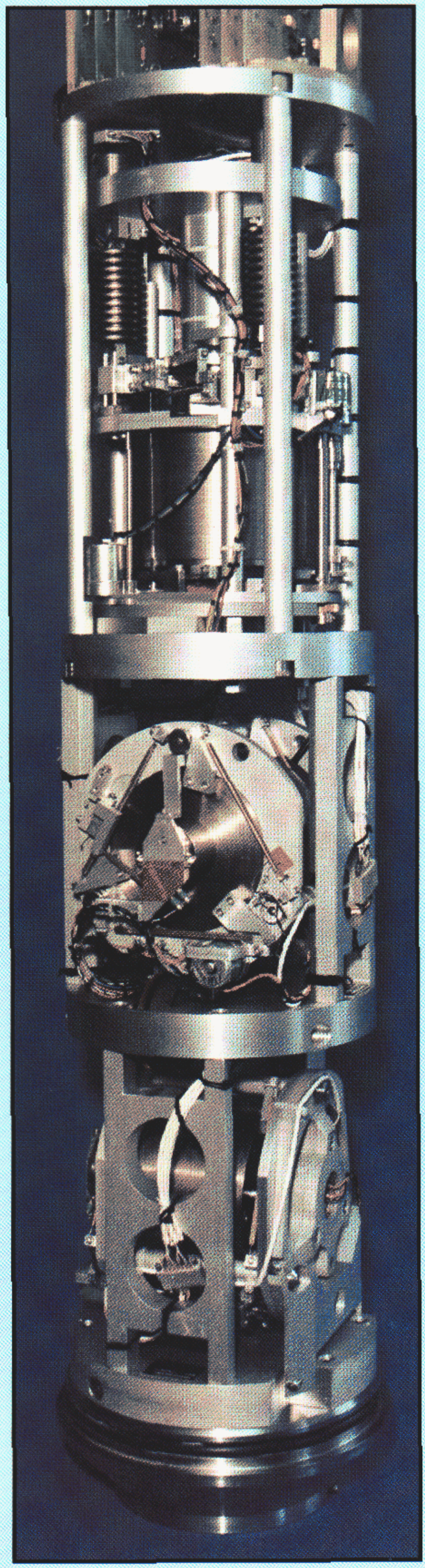
The 1963 Limited Test Ban Treaty relegated nuclear explosive testing to underground. Since then, Sandia has been developing seismic monitoring technology for treaty verification. Our role and major achievements to date relate to the following events:

1963	US and USSR ratify the Limited Test Ban Treaty
1964	Advanced Research Projects Agency initiates seismic monitoring study
1966	Advanced Research Projects Agency sponsors development of three unmanned seismic observatories
1973	Arms Control and Disarmament Agency sponsors study of satellite communication concepts and seismic instrumentation
1974	Advanced Research Projects Agency sponsors study of data authentication concepts
1974	US and USSR sign Threshold Test Ban Treaty
1976	Local seismic network and hydrodynamic yield measurement concept adopted for verifying Peaceful Nuclear Explosions Treaty (signed in 1976)
1977	Trilateral Comprehensive Test Ban Treaty negotiations initiated
1978	Prototype National Seismic Station deployed
1982	Five-station Regional Seismic Test Network in North America using National Seismic Stations starts operation
1983	Joint Defense Advanced Research Projects Agency/Department of Energy Regional Seismic Array development initiated
1984	First regional seismic array deployed in southern Norway
1986	Department of Energy-sponsored Deployable Seismic Verification System development initiated
1987	Second regional seismic array deployed in northern Norway
1989	Prototype Deployable Seismic Verification System station available for demonstration

The 1963 Limited Test Ban Treaty, which limited nuclear explosive testing to underground, presumed that subsequent negotiations would eventually ban testing completely; indeed, the 1974 Threshold Test Ban Treaty limits the size of underground tests to 150 kt. However, further limitations have not been negotiated, in part because of verification concerns.

Seismic monitoring (see box on page 8) may provide the primary method for verifying compliance with treaties that would further limit underground nuclear testing. For an acceptable verification capability, the seismic monitoring system and the associated analysis methods must provide the capability to detect, locate, and identify seismic events. In addition, when treaties permit underground explosions but limit yield, the seismic monitoring system must provide a yield estimation capability.

A seismic monitoring network must account for the earth's natural seismic noise. For a seismic event to be detected, located, and identified, its seismic signal must exceed the earth's natural seismic noise or other interfering seismic signals. To adequately detect small, clandestine



SEISMOLOGY

Verifying a ban on nuclear testing requires global monitoring systems capable of detecting explosions in the atmosphere, under water, and below ground. The most uncertain part of these global systems is monitoring underground nuclear explosions. The main technical tools for monitoring these explosions come from the field of seismology, the study of earthquakes and related phenomena.

Shock waves cause compression and relaxation of the surrounding earth. The resulting seismic waves travel through the earth and can be recorded by special instruments called seismometers. By studying seismic records and the properties of the paths taken by the waves, seismologists can calculate the distance to the seismic event and the type of motion that caused the wave. One of the challenges seismologists face is discerning explosions and earthquakes from background noise. Wind, ocean waves, tides, and mining operations cause continual "background" noise that limits our ability to detect small earthquakes and explosions.

Seismic waves from earthquakes and explosions travel long distances through the body of the earth (body waves) or along the earth's surface (surface waves). Body and surface waves that can be detected over 2000 km from the event that caused them are called "teleseismic" waves; "regional" waves travel through the earth's crust or outer layers and are observed at distances less than 2000 km.

When seismic waves reach a seismic station they cause ground motion that is recorded by seismometers. Plots of these waves are called seismograms. Different waves travel at different speeds and along different paths, so they arrive at seismic stations at different times. The farther away a seismic station is from the source of the waves, the more dispersed in time the different waves will be.

Seismometers, as illustrated at left, record earth motion in three directions at right angles to each other, typically, north-south, east-west, and vertical. The seismometer has a heavy mass, freely supported from a frame fixed to the earth. The frame shakes in response to the earth's motion when the seismic waves arrive; the heavy mass tends to remain stationary. The displacement of the frame relative to the mass is a measure of the ground motion. This displacement is electronically amplified so that displacements as small as 0.00000001 centimeter can be detected.

Seismic arrays are alternatives or supplements to single three-axis seismometers. An array is a distributed group of seismometers. The signals from the various instruments can be combined to improve the detection and identification of weak signals. Arrays can be made sensitive to waves coming from a particular direction while excluding waves from other directions.

nuclear explosions or explosions that have been decoupled or "muffled" by a porous medium or cavity, the monitoring stations must be deployed in a closely spaced network. To verify compliance with a Comprehensive Test Ban Treaty or a low-yield Threshold Test Ban Treaty, a network with station separations of 100 to 1000 kilometers is needed. This means the monitoring network must be inside the borders of large countries such as the US or the USSR.

Several US agencies are actively developing and operating seismic monitoring systems. Within the DOE, Sandia has primary responsibility for developing seismic monitoring systems and the related technology, while Lawrence Livermore National Laboratory has the primary responsibility for developing analysis concepts and methods to analyze seismic data acquired by a network of monitoring stations. Within the DoD, the Defense Advanced Research Projects Agency has played a major role in the development of seismic monitoring system technology and the conduct of basic geophysical research to support our national seismic monitoring capability. Other DoD agencies have played a major role in the development and operation of a national seismic monitoring capability. This article reviews Sandia's current seismic monitoring system development activities.

Seismic arrays enhance selected seismic signals referenced to the earth's seismic noise or to interfering seismic signals.

A seismic array consists of multiple seismic sensors that are spatially distributed. The array can be tuned to magnify selected seismic signals based on their direction and velocity.

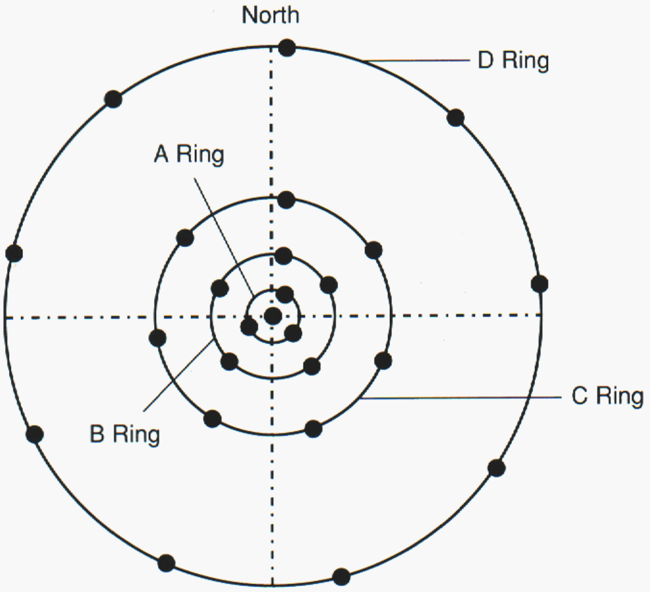


Figure 1. The geometry of the first seismic array deployed in Norway consists of concentric rings whose diameters increase exponentially. This configuration ensures good performance over a wide range of frequencies. Each ring has an odd number of seismometers to enhance the uniformity of response to seismic signals, regardless of their direction of travel.

One form of array, a planar array, deploys seismometers in a near-horizontal plane. Two arrays of this type, consisting of 25 seismometers in a 3-km-diameter circle, have been deployed in Norway (Figure 1). They provide a unique and valuable source of data to support ongoing studies by the DOE and DoD. These studies allow us to design more effective arrays and to define more effective signal processing techniques for using seismic data.

The two Norwegian seismic arrays have functioned well. However, they were not designed to satisfy all requirements for treaty monitoring, a mode requiring unattended operation with high operational reliability and data security. Our ongoing array performance studies and related system component development will lead to definition of a second-generation planar array that will satisfy reliability and operational requirements for in-country, unattended operation.

Seismic arrays can also be linear, commonly placed in a vertical line. To further study this configuration, we will conduct experiments with a linear array of seismometers in a 2-km-deep borehole near Amarillo, TX.

Advantages of a vertical, linear array include lower background noise with depth. Moreover, a vertical array of instruments in one borehole is less intrusive than a planar array spread over several square kilometers. However, because the borehole depth required for significant signal enhancement increases as the seismic signal frequency decreases, at reasonable borehole depths (2 to 3 kilometers) the linear arrays may be restricted to higher frequencies.

Our contributions to the US seismic verification program are varied.

High Frequency Monitoring

The main limitation to future monitoring capabilities will be the constraint that the signal from a nuclear explosion must be stronger than the earth's seismic noise within the frequency bands of interest. A nuclear explosion must also be distinguishable from small earthquakes and from quarry and mining blasts, which can be as strong as those from low-yield nuclear explosions, especially those muffled (decoupled) by their location in a cavity.

One proposed concept for improved detection and effective discrimination is to use high-frequency (up to 40 Hz) seismic data. This is well above the frequency range that is currently used for seismic monitoring.

Seismic signal spectra are assumed to be constant up to a frequency called a corner frequency; above the corner, they decrease (Figure 2). The proposal predicts that this decrease in spectral characteristics of earthquakes and explosions will be different. For example, P-wave (compressional) spectra of earthquakes are predicted to decrease faster beyond the corner frequency than the spectra from explosions. Thus, at high frequencies, explosion signals should be stronger than signals from earthquakes. When seismic noise is taken into account, explosions should be detectable when earthquakes of comparable magnitude would not.

To test the theory, we installed a broad-band seismometer at Nelson, NV, one of the stations used for many years to monitor Nevada Test Site explosions. This site also records seismic signals from nearby earthquakes. Figure 3 shows the seismic spectra from an explosion and from an earthquake just east of

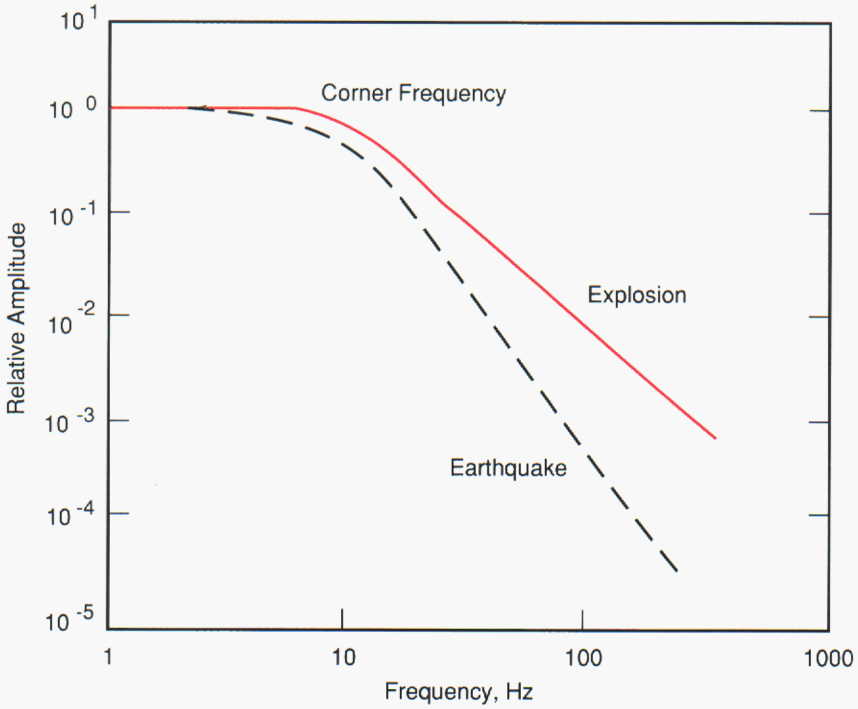


Figure 2. One theory predicts that seismic spectra from explosions decrease above a corner frequency more slowly than those from earthquakes. This difference, combined with a lower corner frequency for earthquakes, would make high-frequency seismic signals from explosions larger than those from earthquakes of comparable magnitude.

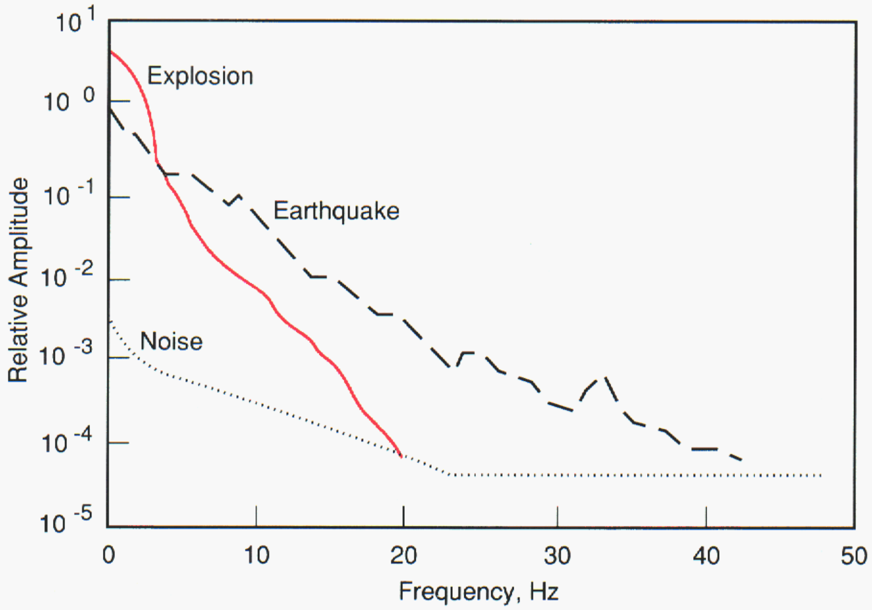


Figure 3. The power in the P-wave velocity spectrum from a Nevada Test Site explosion is less than that from an earthquake of about the same magnitude. This is contrary to the prediction shown in Figure 2.

the test site. The two events have similar low-frequency spectra.

Contrary to the theory, the explosion spectrum falls off much faster with frequency than the earthquake spectrum. In fact, above 20 Hz, only the earthquake signal exceeds the background seismic activity. The two sources, each located 180 km from Nelson, were only about 20 km apart (a difference of 7° in direction). This indicates the signals traveled by almost the same path, so path differences do not explain the spectral differences.

We have more examples of earthquake and explosion data that show similar results, but we cannot yet explain why the data disagree with theory (Figure 2). We have also analyzed data from many small Scandinavian earthquakes and mining explosions and find that in this environment earthquakes have nearly the same spectral character as explosions.

These limited data do not support general conclusions about the potential value of high frequency seismic monitoring throughout the USSR. We are continuing to acquire data from other regions for a broader assessment of high-frequency seismic monitoring. We presently believe that high-frequency data must be used with caution for test detection and discrimination.

Monitoring Capability Analyses

In terms of detection thresholds and location accuracies, designing a seismic monitoring network and estimating the expected network monitoring capabilities requires detailed characterization of station capabilities over a wide range of operating environments. We are also developing a detailed understanding of the expected range of geophysical parameters such as seismic propagation parameters and seismic noise levels.

To assist in analyzing the vast quantities of data acquired by the

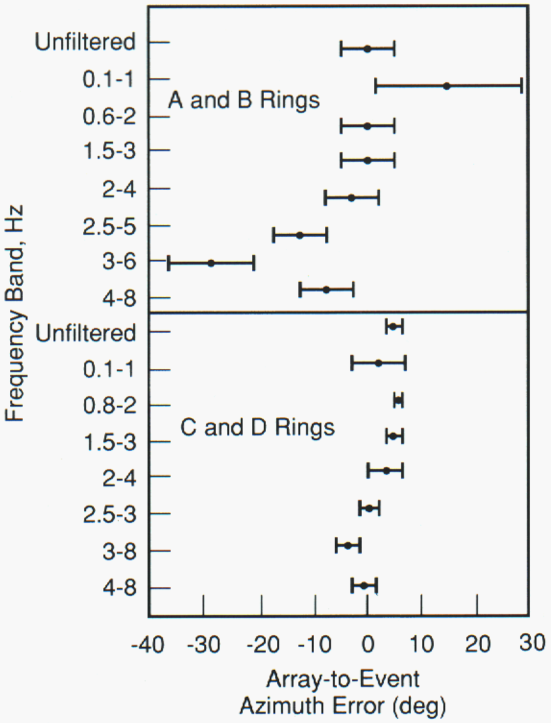


Figure 4. Example of output from our expert system showing mean azimuth error as a function of two configurations (Figure 1) and eight frequency bands for twenty Kazakhstan explosions. Error bars show 90% confidence intervals.

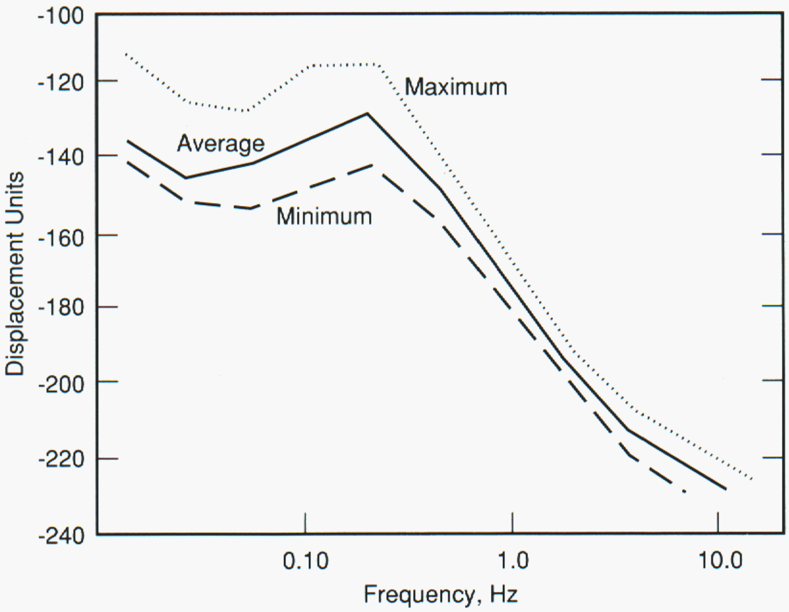


Figure 5. Variations in seismic background levels as observed at the first Norwegian seismic array during a two-year period.

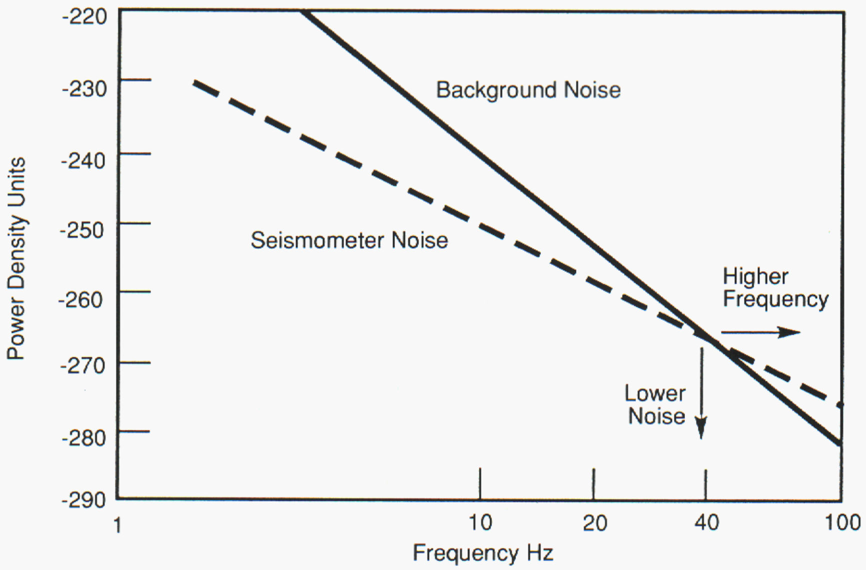


Figure 6. Today's best seismometers have inherent system noise levels that, up to 40 Hz, are quieter than background noise levels at Lajitas, TX, a site noted for its low noise level. Present seismometers must be improved if measurements are made above 40 Hz or if seismic sites with lower background noise levels are to be used.

Norwegian arrays, we developed an "expert system" to archive a database for our analyses and to automate the analyses for meaningful definition of array performance. Figure 4 shows a typical set of event location azimuth errors as a function of array geometry and signal frequency band.

A record of seismic background noise at stations in the Regional Seismic Test Network of the Norwegian arrays has been maintained. Analyses of these data provide essential inputs for designing seismic monitoring networks. Figure 5 shows a typical result from these analyses. These and other performance data provide the bases for detailed network performance analyses we are currently developing.

Data Authentication

Treaty verification requires that seismic data recorded at unattended stations accurately measure the events. Our system verifies the authenticity of the data without resorting to encryption and gives the host country immediate access to the data while assuring them that we are collecting and transmitting only seismic data.

Data authentication was developed for the National Seismic Station instrument packages. We authenticate data by generating a digital word that is a unique function of the seismic data and an authenticator key word stored in the authenticator memory. We authenticate the seismic data in 1-second blocks and transmit the authentication word together with the data block.

The authentication circuits are protected from tampering by their location downhole, near the sensitive seismometers. If someone tries to raise the downhole assembly, the authenticator words are destroyed.

For long-term security, the key word in the authenticator is changed automatically on a periodic basis; enough words are stored to last for several years. A radiation shield around the authenticator prevents unauthorized probing for the key words. The new seismic systems we are considering will require authentication at higher data rates; these and other operational needs will require that we develop new concepts and hardware.

Seismometers

We have seismometers compatible with today's requirements. The dashed line in Figure 6 shows the inherent system noise of our best high-frequency seismometer, expressed in terms of ground motion. The solid line shows the noise level of the quietest site we know, at Lajitas, TX, near Big Bend National Park. The present seismometer is quieter than background noise for frequencies below 40 Hz. However, improved seismometers will be needed to measure power densities above 40 Hz at the quiet sites.

Simpler, more reliable, smaller seismometers are also being studied. Today's seismometers are based on mechanical systems and may have reached the limit of their inherent capability. Optical detection offers alternative technologies to measure ground motion.

High-Resolution Digitizers

The increasing emphasis on broad-bandwidth seismometers dictates higher-resolution digitizers, especially for spectral discrimination systems. The present high-frequency seismometers in the Norwegian arrays use 20-bit digitizers. We are evaluating 24-bit digitizers for newer systems.

Energy Sources

The National Seismic Station system uses propane tanks that fire thermoelectric generators; a typical system consists of two 2000-liter tanks. This source keeps the 150-watt system operating for about a year. Newer systems, especially arrays, are likely to need more power. That means we must either have more tanks, or they must be refueled more often, both unattractive alternatives for low-maintenance operation. Also, propane may not be universally available, so we are studying other fuels such as jet fuel or kerosene. Radioisotopic thermoelectric generators are also being considered.

Deployable Seismic Verification System

If test bans become more restrictive (low-yield thresholds, for example, possibly with a few higher-yield shots permitted, or complete bans), verification systems must meet stricter requirements.

The systems and analysis techniques discussed here assume a low-yield threshold. Treaties with such limits require in-country seismic monitoring with sophisticated instrument systems; for this purpose, we are building the Deployable Seismic Verification System.

This system would be used to verify a treaty in which tests are permitted, but only at declared test sites and only of limited yield. In this case, the declared site might be monitored by a network resembling our current network around the Nevada Test Site; it would be used to estimate the yields of permitted tests. With a low or zero-yield test ban treaty, the rest of the country would also need to be monitored with a more extensive network of stations.

This system is similar to earlier ones (Figure 7). Individual seismic stations would communicate with a central receiving and monitoring station, probably by satellite. This much of the system would be a DOE responsibility. The resulting data would be provided to a network data analysis center operated by the DoD.

For more information, call
Jim Durham (505) 846-0038 or
Eric Chael (505) 846-4880.

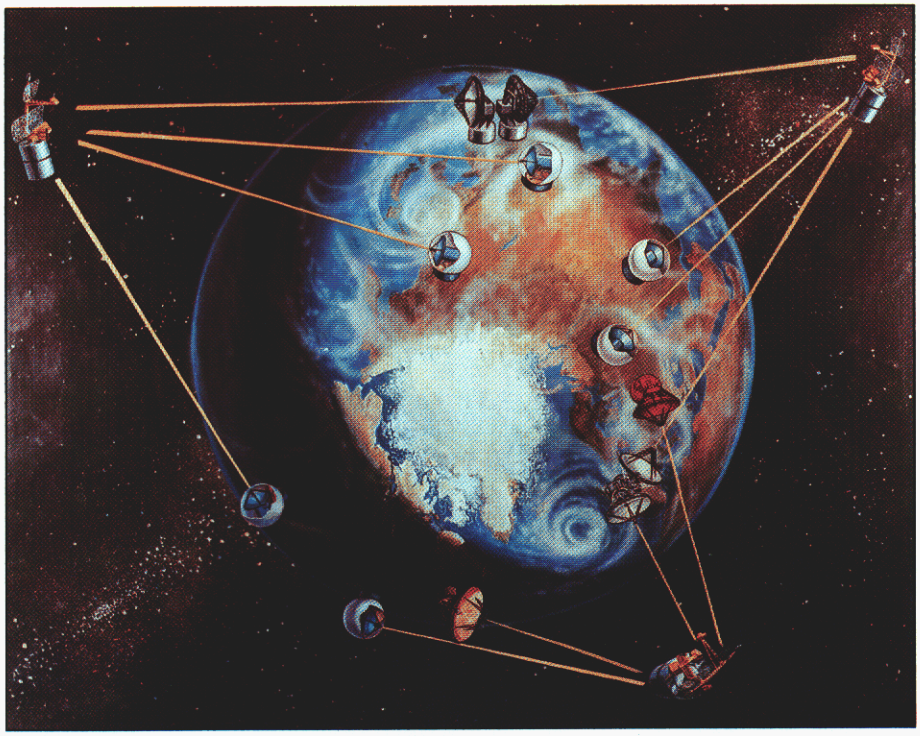


Figure 7. The proposed Deployable Seismic Verification System will have individual stations much like those in the former Regional Seismic Test Network. Satellite data-communication links will transmit data from these stations to a central receiving and monitoring station. Data from this center will feed to a DoD-operated network data analysis center where detection, location, and discrimination processing will be performed.

Remote Atmospheric Monitoring Project

Atmospheric radioactivity can now be analyzed in the field and the results sent to a central station by satellite.

Sandia has developed a remote atmospheric monitoring project that uses a commercial satellite link to relay gamma spectral data to a central facility for analysis. We have been operating two of these stations in the US for more than a year, and have recently deployed four more stations for a realistic field test (Figure 1).

Historically, information from atmospheric monitoring stations was mailed to a central laboratory for analysis. This takes time, especially from remote stations. The new system permits prompt data analysis so that data on short-lived radionuclides are not lost. A gamma spectrum is measured in the field, and the resulting data are returned by satellite in near-real time when the station is queried by the central station.

The new system will extend an existing system of ground sampling stations operated by the DOE Environmental Measurement Laboratory.

The Environmental Measurement Laboratory is studying the temporal and spatial distributions of natural and man-made radionuclides. Concentrations of cosmogenic ^{7}Be are of particular interest because their seasonal variations appear to be the effects of exchange between the stratosphere and the troposphere and of vertical mixing within the troposphere. At high latitudes they also depend on the rate of transfer of air masses from midlatitudes. The new system will also be useful in detecting radioactive debris from nuclear accidents or atmospheric nuclear explosions, should any occur. The system uses commercial satellite transmitters to relay data to the measurement laboratory for radiochemical analysis.

Each station will be operated by a local resident, usually someone with little technical background. In the current field trials, it is that

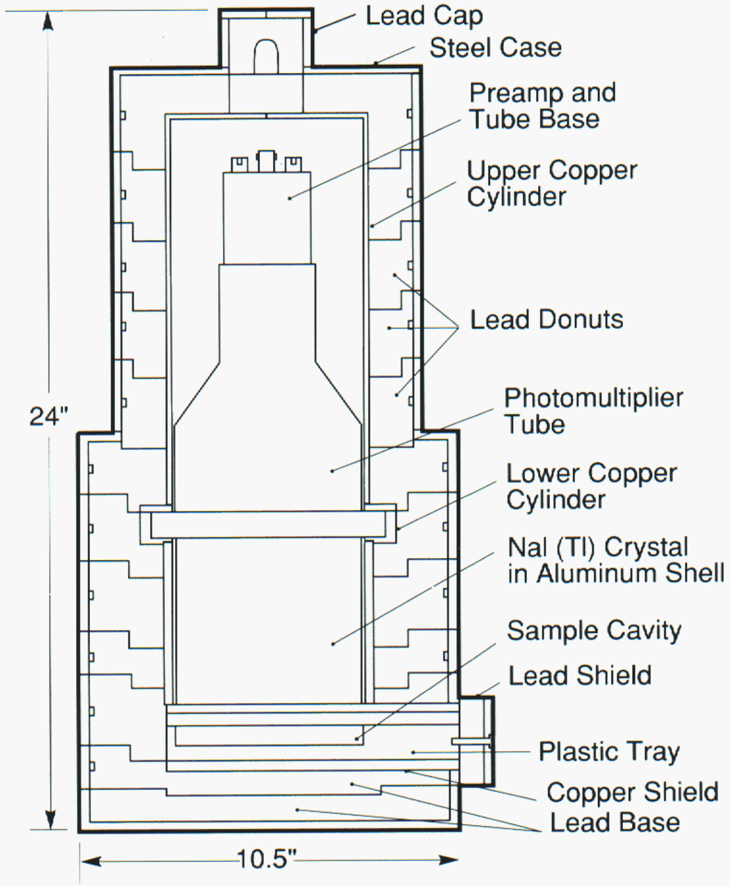
Figure 1. This air sampler is at Murdoch University in Perth, Australia.

person's responsibility to ensure that the system operates properly; to change filters at proper intervals; and to start the analysis of each filter, which then continues automatically. The operator also makes background and calibration checks as required and mails the filters back to the laboratory.

> ***This system consists of commercial samplers and a newly developed sample detection and spectral analysis system.***

The monitoring project uses sodium iodide (NaI) detectors for spectral analysis instead of the high-purity germanium (HPGe) detectors more commonly used in laboratories. Unlike HPGe detectors, NaI scintillation detectors do not require cryogenic cooling, a feature that permits measurement of gamma spectra in remote locations.

Figure 2. The shield around the detector consists of a stack of low-background lead rings with steel cases. Samples are placed in the plastic tray cavity for analysis.



The disadvantage of NaI is that its luminescent spectra tend to lack easily identifiable photopeaks like those provided by HPGe detectors. Spectral analysis with NaI detectors yields peaks whose widths are typically 7% of the central energy, a poor resolution compared to 0.2% for HPGe. When several radionuclides are contributing to a spectrum, as from a debris sample, the resulting spectrum can be very complex. To make the use of NaI practical, we have also developed a capability for resolving spectra from multi-isotope samples into their component radioisotopes.

Our detector employs a thallium-doped NaI scintillator obtained from BICRON Corp and housed in a 1.2-in-thick lead shield (Figure 2). A thin copper liner surrounds the detector and photomultiplier tube to absorb x-rays produced by gamma interactions in the lead shield. The sample tray is made of plastic.

Detector output is sent to a Canberra multichannel analyzer using special software written specifically for the project for use by people with minimal technical knowledge. We designed the power supply with a trickle charger on an automobile battery to buffer irregularities in the line voltage and also to operate the system for up to a day in case of power failure. The equipment is located in a constant-temperature environmental chamber.

> ***The spectra are resolved into their component radionuclides.***

Figure 3 shows a relatively simple spectrum from ^{88}Y and a more complex one from ^{228}Th and its daughters. Yttrium emits only photons of two energies, appearing here at 898 and 1836 keV as broad peaks. The third peak at ~2750 keV results from two gammas striking the detector simultaneously. The continuous background is principally Compton scattering, in which gammas give up part of their energy in the detector. The thorium spectrum has many more peaks, because of ^{228}Th's complex decay, which has seven short-lived daughters.

In calibrating the detectors, we use the thorium-chain peaks at 239 keV (from the decay of ^{212}Pb to ^{212}Bi) and at 2614 keV (from the decay of ^{208}Tl to stable ^{208}Pb). The many other peaks are due to other decay processes in the thorium chain, coincidence peaks, etc. The calibration source is a Coleman-lantern mantle, which contains natural ^{232}Th and its daughters.

These spectra illustrate the complexity arising from even single radionuclides. If several radionuclides are present in a sample, the resulting spectrum can be very complex. The software written to unfold such spectra, called Gamma Detector Response and Analysis Software, uses an ensemble of such computed curves or templates. This software uses regression analysis to find the combination of radionuclides chosen from a library of potential atmospheric contaminants that best fits the observed spectrum.

The VAX-750 computer at the Environmental Measurement Laboratory communicates with the satellite computer every 2 hours to retrieve information. When a spectrum is complete, the computer automatically begins its analysis. Results are printed for examination, and the data are archived for later correlation studies. The standard counting period is about 1 day; another day is required to complete the transmission across the satellite link. Thus the concentration of radionuclides at remote locations can be determined at the lab within 48 hours of sample collection, as

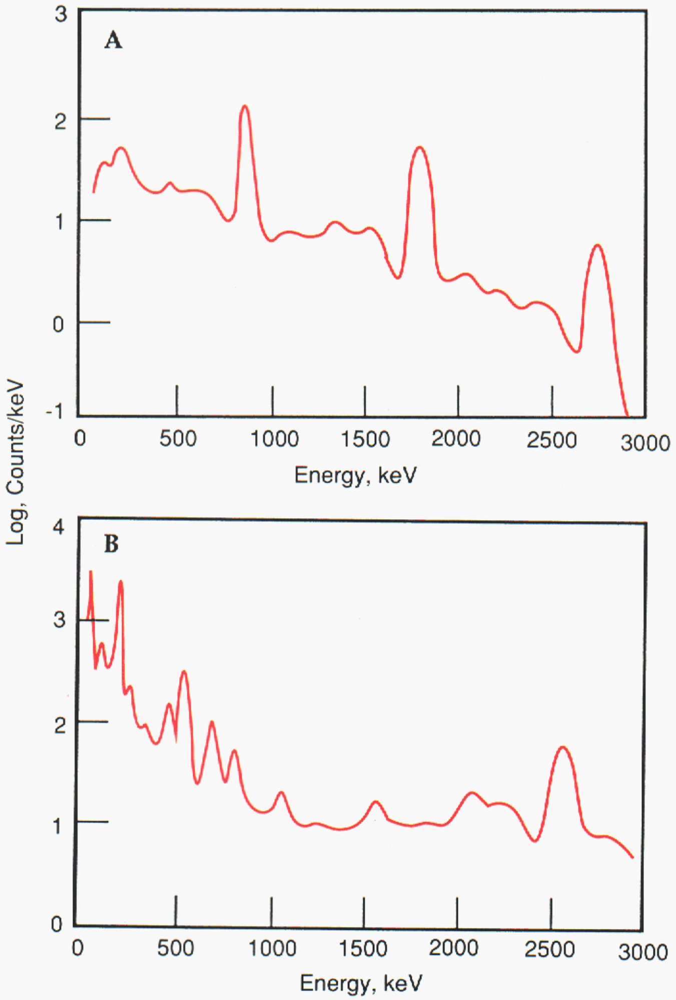


Figure 3. The spectrum of yttrium as analyzed by a detector is fairly simple (A), because yttrium has photons of only two energies (plus the coincidence peak above 2500 keV). The spectrum of ^{228}Th, on the other hand, is complex (B) because the thorium also contains seven radioactive daughters. The curves are the computed spectra.

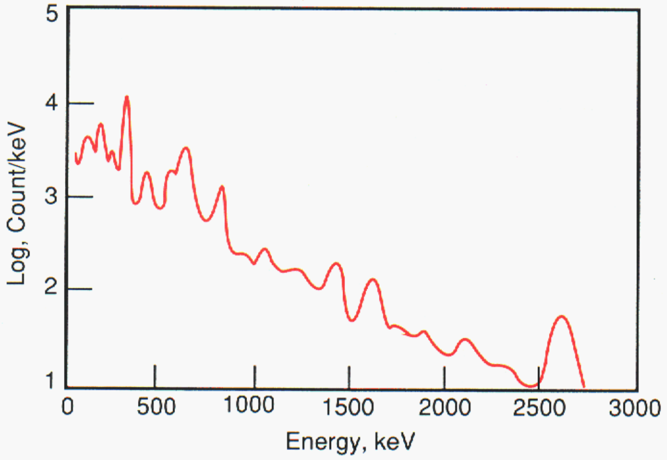


Figure 4. The spectrum of Chernobyl debris collected in New York City on May 11, 1986, when radioactivity at that location was most intense, shows the presence of several radionuclides. The highest peak, at 364 keV, is from ^{131}I. To its right are the photopeak of cosmogenic ^{7}Be at 477 keV and an asymmetric peak resulting from the superposition of ^{134}Cs, ^{137}Cs, ^{131}I, and ^{132}I peaks ranging from 605 to 668 keV.

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opposed to periods frequently exceeding a month when air filter samples are mailed to the lab for analysis.

Chernobyl fallout was analyzed by our detector.

By chance, a prototype of this system was operating on the roof of the Environmental Measurement Laboratory building in New York City at the time of the Chernobyl accident. An analysis of the sample taken May 11, 1986, when the fallout at that location was most intense, produced the spectrum in Figure 4. This very complex spectrum was fitted with a linear combination of templates corresponding to 12 radionuclides. The highest peak is that of ^{131}I at 364 keV; the next highest is a combination of two cesium and two iodine peaks near 650 keV.

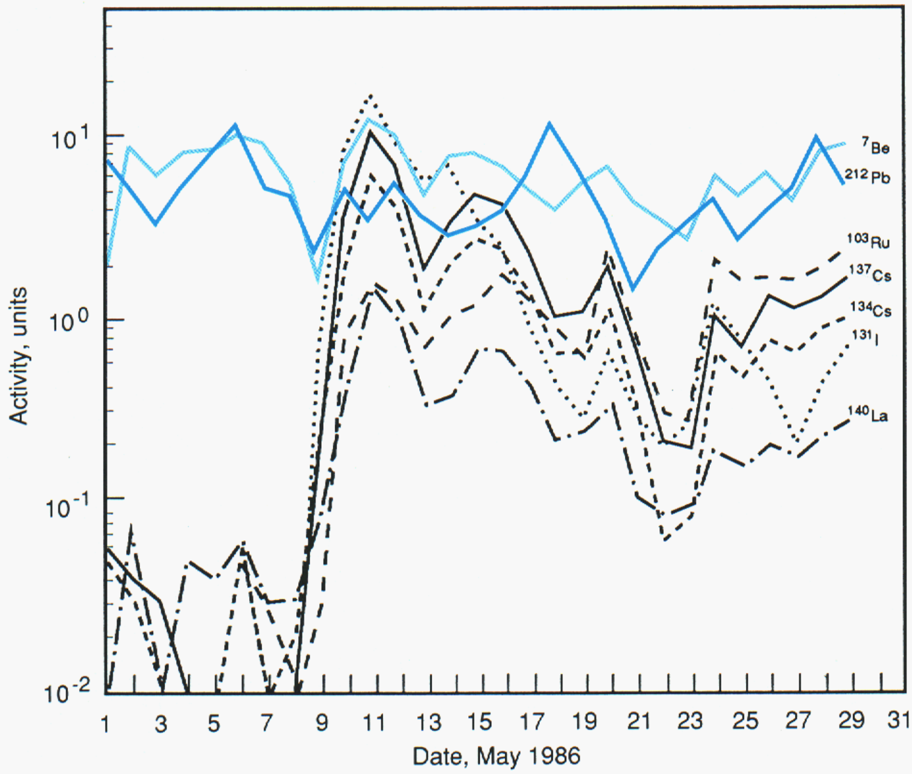
Figure 5 summarizes the Chernobyl data on concentrations of individual nuclides. At the beginning of the month, only background radionuclides were present. The ^{7}Be is formed in the upper atmosphere by the interaction of cosmic-ray-produced neutrons with nitrogen. The concentration of ^{212}Pb, which is a radon gas daughter, was unusually high during May 1986. It was concluded that its high concentration was attributable to radon released from the underlying rock or from materials used at a nearby construction project; after the construction was complete, the lead signature disappeared. Although lead and beryllium appear to dominate in this figure, fission products were present in substantial quantities after May 8. The air-sample filters corresponding to these samples were measured both by the NaI detectors and by the lab's HPGe detectors. Results agreed within experimental error.

We are now engaged in field trials of the system.

Field trials of the system are underway at Perth, Australia; Cape Grim on Tasmania, Australia; Wellington, New Zealand; and Norfolk Island, about 1700 km east-northeast of Sydney, Australia. All but the New Zealand site are near present stations in the measurement network in the southern hemisphere. If the Remote Atmospheric Monitoring Project proves itself, it will be turned over to the sponsors for commercial procurement and deployment in places that are not readily accessible.

For more information, call
Dean Mitchell (505) 844-8868

Figure 5. Analysis for individual radionuclides throughout May 1986 shows that ^{7}Be and ^{212}Pb were present throughout the month, but that other nuclides arrived with the Chernobyl debris after May.



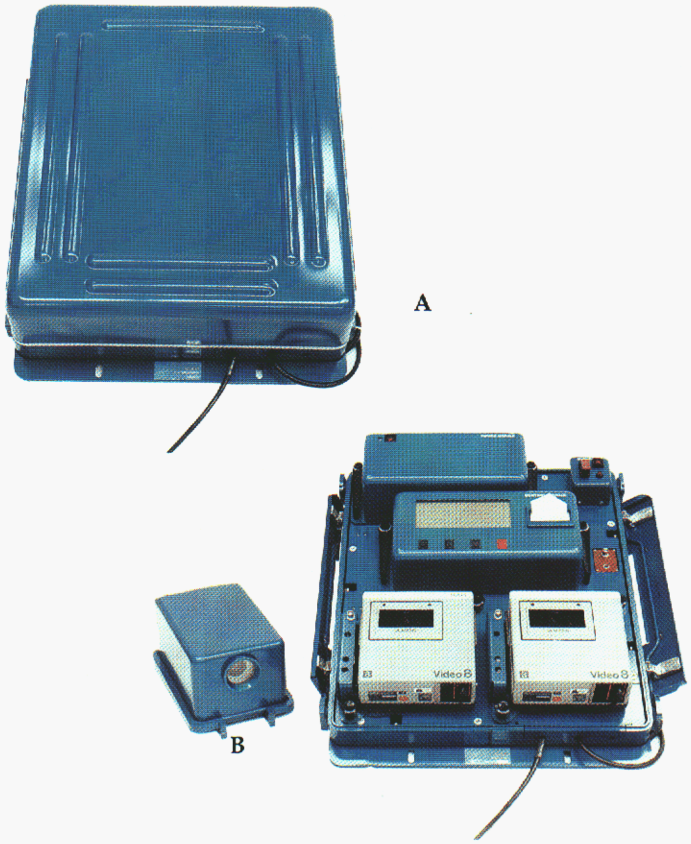
Instruments for Containment and Surveillance Applications in International Safeguards

Our Containment and Surveillance technology supports non-proliferation agreements.

An objective of the Nuclear Non-Proliferation Treaty and similar agreements is to assure the international community that non-nuclear nations are not diverting nuclear materials from peaceful uses to weapon production. Each nation that accepts such an obligation negotiates agreements with the International Atomic Energy Agency, under which the Agency monitors nuclear-material-related activities at facilities where such material is used or stored.

In international safeguards, material control and accountancy play a major role, with Containment and Surveillance technology applied to assure "continuity of knowledge" during the absence of an Agency inspector. Our responsibility is to maintain a technology base from which Containment and Surveillance measures can be drawn. This work is supported by the US Department of Energy / Office of Safeguards and Security's International Support Program. In addition, through the US Support Program to the Agency, funded by the Department of State, we work directly with the Agency to transfer this technology. Four instruments were described previously in *Sandia Technology Vol. 8 No.2, 11/84* — Surveillance Television and Recording System, MINISTAR, Integrated Monitoring System, and Cobra Seal System.

This article highlights a new video surveillance system (Figure 1),



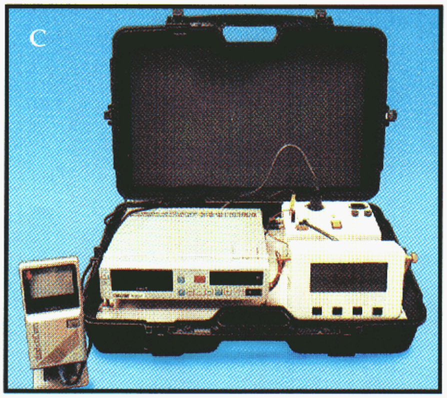


Figure 1. The major components of the Modular Integrated Video System are the Control and Recording Unit with cover (A), the Camera Housing (B), and the Review Station (C). The system can record 26,000 snapshots (scenes) of video surveillance.

ultrasonic seal technology, and some new, advanced concepts for Containment and Surveillance applications. Remember that "Containment and Surveillance" imply that this equipment has to operate unattended; thus to ensure data integrity, the equipment must be highly reliable and able to detect tampering.

The Modular Integrated Video System reliably records a snapshot of all activities within its field of view.

The Agency's present workhorse to provide optical surveillance data is called the Twin Minolta Film Camera System. More than 200 of these systems are deployed by the Agency. This system, which uses 8-mm film, was designed to operate unattended for three months at a time, during which it recorded approximately 7,000 scenes (snapshots) at 20-min intervals.

Because 8-mm film technology is becoming obsolete, the Agency requested development of a video system that could replace the Twin Minolta system in certain applications. Fundamental requirements were that the system be easy to operate, highly reliable, tamper-protected over a three-month unattended operating period, and easy to maintain. Also to be provided was a capability to review the video tapes recorded by the system. This system, known as the Modular Integrated Video System, is shown in Figure 1. The three basic elements are the Control and Recording Unit, the Camera Housing, and the Review Station. The Control and Recording Unit is modular in construction for ease of maintenance.

The video system and the review station offer the following features:

- The inspection system is menu driven (like automated bank teller machines).
- Tamper-indicating features are incorporated in the design of the unit.
- Authentication of the signal between the camera and the control unit is provided.

Improvement of containment and surveillance technology is an international effort.

US Department of Energy Technology Exchange Activities

Canada
Atomic Energy Control Board • Atomic Energy of Canada Limited

Commission of European Communities
Joint Research Center • EURATOM Safeguards Directorate

Federal Republic of Germany
Kernforschungsanlage – Juelich

Japan
Japan Atomic Energy Research Institute
Power Reactor and Nuclear Fuel Development Corporation

Sweden
Swedish Nuclear Power Inspectorate

United Kingdom
Department of Energy
Atomic Energy Research Establishment
British Nuclear Fuel Limited

In addition to supporting the International Atomic Energy Agency, the US has several formal and informal cooperative agreements with other nations ranging from technology exchange and evaluation to programs for developing new safeguards systems. These agreements also give us access to facilities that do not exist in the US, such as fast breeder reactors and commercial fuel-reprocessing plants.

- An automatic printout of the setup data and the surveillance period summary, including maintenance-related diagnostics, is provided.
- The time interval between scenes can be selected from 1 min to 99 min.

Ten units recently completed extensive reliability tests at the Agency. There were no incidents of loss of surveillance in these tests, which simulated 2.5 years of operation, the expected operational life of the commercial recorders used in the system. The reliability of the system exceeds 99%.

The EURATOM Safeguards Directorate has two units presently undergoing field evaluation. Another unit was modified to interface with an electronic seal developed for Agency use by the Federal Republic of Germany.

Ultrasonic seals are used to identify nuclear fuel assemblies stored underwater, and provide integrity for the assembly closure.

In the early 1980s, we started developing seals based on ultrasonic technology that could be installed and read underwater. The goal of this early work was to design a seal that could be placed on a boiling water reactor spent-fuel assembly to uniquely identify the assembly and ensure that the assembly had not been opened to remove fuel rods. This effort led to the Fuel Assembly Identification Device shown in Figure 2.

The system has three major components: the seal, designed so that removal destroys its unique signature; a reading head containing transducers to provide the ultrasonic excitation pulse and read the reflected signature; and the seal pattern reader that processes signals and determines if the seal is the one it should be and if it is intact. A data storage device called a bubble cassette stores up to 50 reference signatures. This system was successfully field tested in a reactor in the Federal Republic of Germany, where it was determined that the concept was sound and the effects of radiation were insignificant. Although it was designed specifically for use on boiling water reactor fuel assemblies, the application of this technology to other types of fuel assemblies or fuel storage racks is straightforward. Uniqueness of other enclosures is accounted for in the specifics of the seal design, modified to fit the enclosure. The device functions of signal processing, identity correlation, and integrity check remain.

In a joint program with Atomic Energy of Canada Limited, we assisted in the development of an ultrasonic sealing system for use on reactor fuel storage trays. This system (Figure 3) underwent extensive field evaluation by the Agency at a heavy water reactor in Canada, and in May 1988, the system was accepted for routine use at all reactors of this type.

A further extension of this technology is directed at developing a seal for use on fresh mixed-oxide

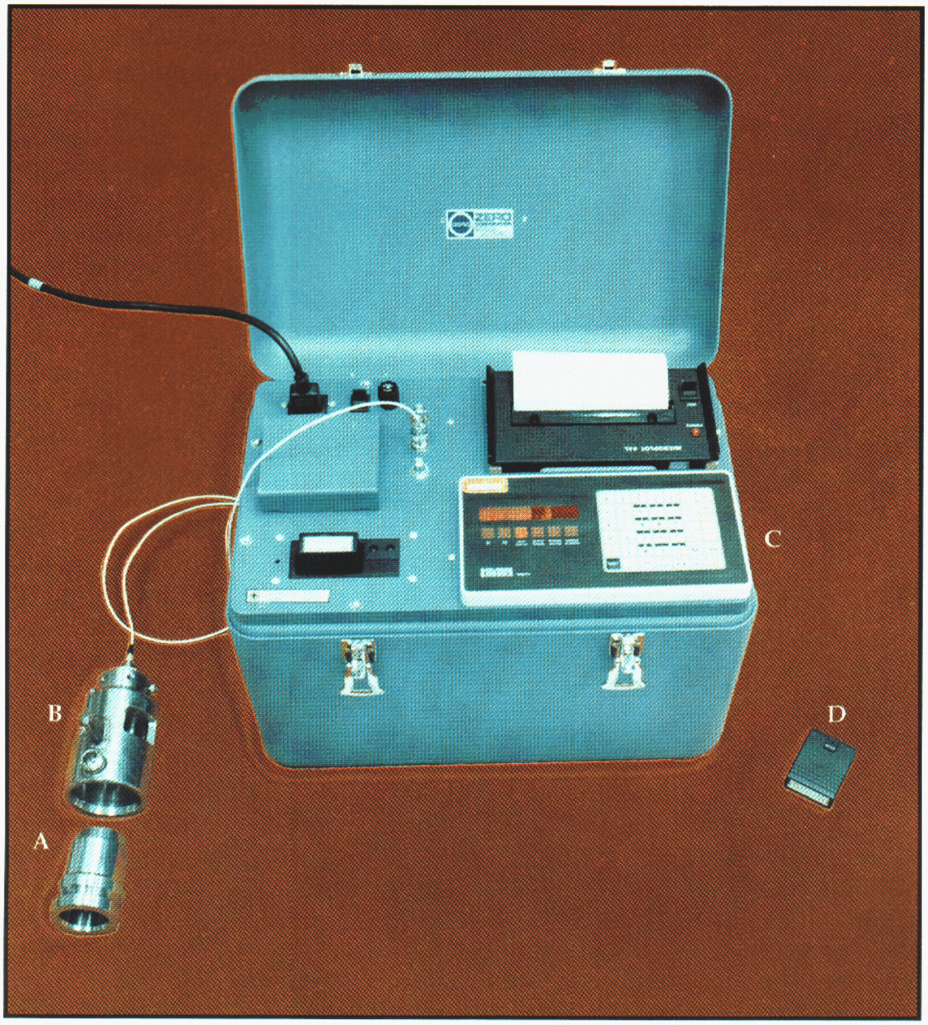


Figure 2. The Fuel Assembly Identification Device is an ultrasonic sealing system developed to provide identity for boiling water reactor spent-fuel assemblies and assurance that the final assembly has not been opened. This device consists of the seal (A), reading head (B), seal pattern reader (C), and bubble cassette (D).

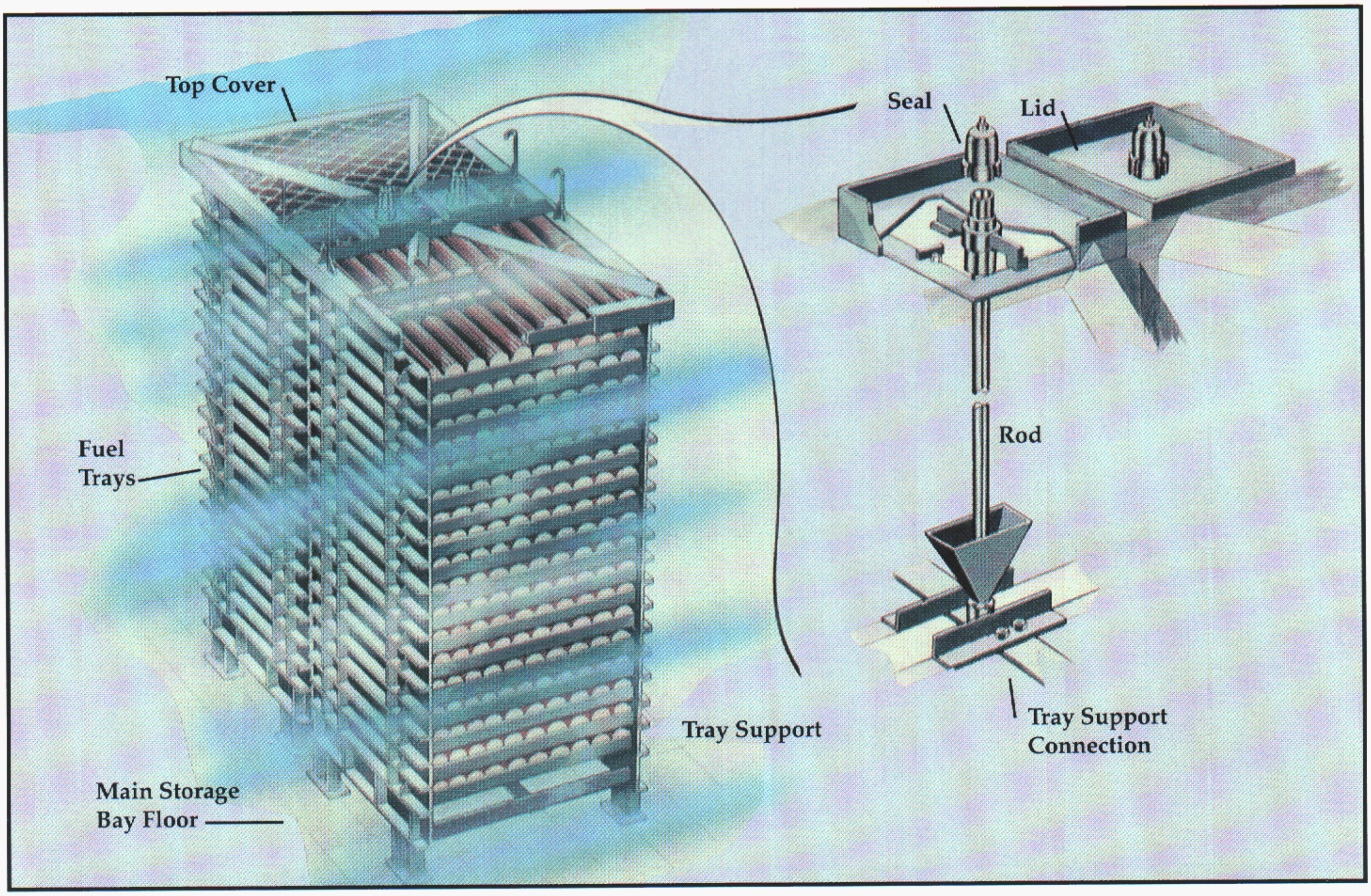


Figure 3. We and Atomic Energy of Canada, Ltd designed an ultrasonic sealing system for use on spent-fuel stacking trays.

fuel assemblies for use in pressurized water reactors. As part of this development, the original seal pattern reader, with its bubble cassette, is being replaced with a personal-computer-based seal pattern reader.

This development is a joint venture between us; the Commission of European Communities Joint Research Centre of Ispra, Italy; and the International Atomic Energy Agency.

State-of-the-art technologies are contributing to advanced concepts for containment and surveillance.

Recent work has provided a more tamper-resistant Cobra seal and a still video disk seal verifier, which was demonstrated to the Agency and the EURATOM Safeguards Directorate. Improved seals and verifiers are expected to be delivered to these inspectorates in 1989 for field evaluation and eventual use in international safeguards roles.

We are also nearing completion of the Authenticated Item Monitoring System, which uses a simple motion detector and a low-power transmitter packaged in a small container. This detector and transmitter package would be mounted to a nuclear material container that facility operators declare to be in static storage. It would transmit a state-of-health signal and a motion detection signal to a nearby receiver, which would store all data for subsequent review by Agency inspectors.

In April, 1989, we will install and field test advanced signal line and video authentication equipment. This equipment will be incorporated into equipment designed for Agency safeguards use. It will provide state-of-health data, as well as indicate whether tampering occurs.

Because of its use in an unattended manner, all Containment and Surveillance equipment is designed for high reliability and tamper detection and resistance. These features have allowed consideration of this equipment in other treaty verification applications, as discussed elsewhere in this issue.

For further information, call
Dennis L. Mangan (505) 844-9176
or **Cecil S. Sonnier** (505) 844-2124

A Portal and Perimeter System for Monitoring USSR Missile Production

We have demonstrated an on-site inspection method for verifying the number of treaty-limited missiles being shipped from a Soviet missile production facility.

Figure 1. We have constructed a full-scale portal and perimeter demonstration site to show our concepts to government agencies involved in arms control. Two portals are shown: a screening portal through which vehicles too small to contain treaty-limited items may exit, and an inspection portal for inspecting larger objects. The monitored portals would be the only openings in a perimeter fence surrounding a missile production or assembly facility in the USSR. This arrangement is designed to verify that treaty-limited items are not being secretly shipped from the site. The cylinder shows the size of typical objects to be monitored.

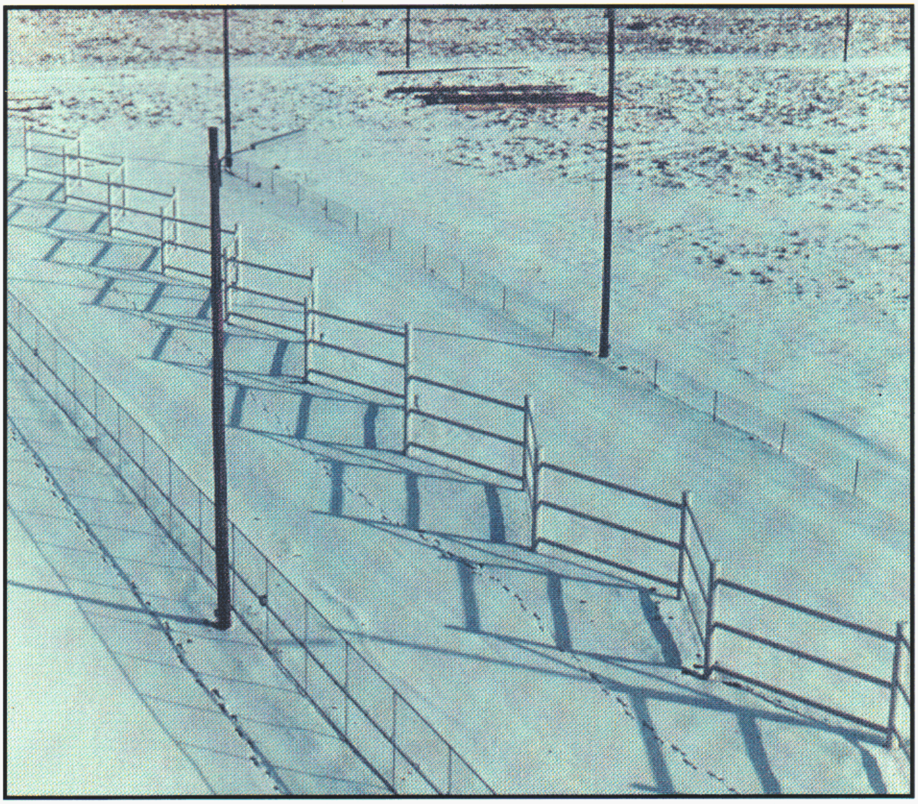


Figure 2. A low zigzag fence or one of similar design would surround a USSR assembly facility. Other fences in the photograph are typical of fences used in the USSR. Our fence would have TV cameras scanning each segment for unusual events. A fiber-optic cable running through the fence would, if broken, alert us of any attempt to break through the perimeter.

Sandia has demonstrated methods for monitoring sites that the Soviets declare are the only sources of certain types of their nuclear weapon delivery vehicles. These technical on-site inspection concepts were developed for both the Intermediate-range Nuclear Forces Treaty and the ongoing Strategic Arms Reduction Talks. In their development we worked very closely with the US treaty verification community to ensure that the systems being investigated achieve their verification requirements.

A portal and perimeter monitoring system at a Soviet missile production or assembly site would ensure that only a certain type and quantity of missiles had been produced.

The essence of nuclear arms reduction verification concepts is to verify limitations on the number of certain classes of USSR and US missiles and their associated warheads. Verification of limits on warheads is difficult because they are too small to identify easily. Therefore, we try to identify a component of the delivery system that is sufficiently large that it would be difficult to conceal, such as first-stage rocket motors 2-m across, 9-m long, and weighing as much as 30,000 kg. These items could be treaty-limited because their size and complexity require assembly at a central production facility, a site that we would monitor.

In 1986 we received an urgent request from the Office of the Secretary of Defense, working through the Air Force, to construct a full-scale test bed that illustrated our concept (Figure 1). The purpose of this facility was to demonstrate the features of a portal-perimeter monitoring system designed for use at a USSR rocket-motor production site and to provide firsthand experience of how such an inspection system would work.

We constructed a facility in Albuquerque in three months and continue to upgrade it as our research and development identifies better technology or as verification requirements change.

Our perimeter monitoring system would ensure that movement of cargo is restricted to designated portals.

USSR rocket-motor production and assembly sites are high-security facilities, sometimes several square kilometers in area. They may be surrounded by several fences ensuring a no-access perimeter as wide as 50 m. In addition, there is frequently a solid wall ~3 m high around it, presumably to prevent unauthorized people from observing in-plant activities.

The Intermediate-range Nuclear Forces treaty does not provide for a sensor-based perimeter monitoring system, relying instead on periodic foot patrols. For future treaties, we are proposing a fence structure located within the existing 50-m-wide fenced zone with cameras aimed along the perimeter to monitor the fence (Figure 2). The fence could zigzag with a horizontal width of several meters, making passage of a rocket motor through the perimeter more difficult (for example, by lifting it over the fence), and easier to detect by TV cameras. A continuous fiber-optic cable would be placed inside the horizontal and vertical elements of the fence. If this cable is severed, an alarm would sound at the control center indicating an attempt to penetrate the barrier. Our inspectors would inspect the perimeter periodically to make sure that none of its components had been tampered with.

The method of monitoring the fence would differ from other security perimeters because it is not meant to detect the presence of human intruders or small vehicles.

Figure 3. As vehicles pass through the screening portal, they interrupt horizontal and vertical infrared light beams. The profile of each vehicle is then determined to see if the cargo space is large enough to contain a treaty-limited item. All vehicles would be weighed by scales embedded in the roadway.

Figure 4. TV monitors and other detection equipment in both on-site portal control rooms and off-site observation centers could be used to observe the perimeter and the nature of traffic through the exit portals.

Thus, some of the methods we have for intrusion detection at our own installations are not appropriate. Instead, our cameras would randomly photograph the perimeter, with personnel in the control room able to call up any particular camera to see what is taking place. A camera would also automatically take a picture of any fence segment whose alarm indicates a continuity break in the fiber-optic cable.

We simply want to prevent a large truck carrying a treaty-limited item from breeching the perimeter undetected.

The portal system controls what goes out, verifying declarations as to whether a shipment is a treaty-limited item. Three different types of portals at our demonstration site illustrate different types of exit control: a screening portal, an inspection portal, and an emergency-vehicle entrance portal. In addition, a personnel portal, too small to permit vehicle passage, is provided. The screening portal provides an exit for all vehicles declared not to contain either a treaty-limited item or an object that might be confused with one. Vehicles would exit through the inspection portal when rocket motors or benign rocket motor look-alikes are shipped off-site.

To some degree these labels are arbitrary because the Soviets would decide for themselves which portal to use when leaving the facility. But to save time, it is in their interest to send small or light traffic out through the screening portal. All vehicles would automatically be measured and weighed. If a vehicle is too small or too light to contain a treaty-limited item, the traffic light would turn green, a barrier arm would be raised, and the vehicle could be driven through the portal without stopping.

If the vehicle were both big enough and heavy enough to contain a treaty-limited item it would either have to go back into the facility or stop and be inspected. If it exits the facility without stopping, a violation of treaty provisions would have occurred by treaty definition, and a video picture would be taken to record the violation.

The inspection portal is designed for large road vehicles, for rail traffic, and for loads that are declared to be treaty-limited items. Each vehicle would be checked by our inspectors. The first question when cargo exits through the inspection portal is whether it is a declared treaty-limited item. Some simple rules are possible. If, for example, a railcar is big enough to contain no more than three rocket motors and is so declared, then we would simply credit them with three motors and no further inspection would be necessary. On the other hand, if a shipment is big enough and heavy enough to contain three motors and only one motor is declared, or if it is declared that there are no treaty-limited items present, then procedures are defined to verify the statements. If inspection of a particular shipment is not permitted, then the shipment must be returned to the facility or a violation occurs.

Scales and infrared breakbeams measure the weight and size of a transport vehicle to see if it is large enough to carry rocket motors.

The size of a transport vehicle entering the screening portal would be measured with infrared breakbeams (Figure 3). These are similar to the frequently encountered automatic actuators on building or elevator doors. A vertical array of breakbeams measures the height of the vehicle as it passes through the portal; a horizontal array of beams determines the vehicle's position for each height measurement. This information is used to generate a profile of the vehicle. The cross-sectional area of the vehicle cargo space, calculated from its profile, is then compared with the size of a treaty-limited item to see if one would fit inside. To weigh the vehicles, we use a road scale that is essentially the same as that used by highway departments to determine if trucks are overweight.

Inspection data may be sent off-site for further review.

An on-site data center, located in the control building of one of the portals, would be used to monitor what is going on around the entire site. At least one person would watch the camera monitors, respond to alarms, and observe traffic flow through the portals (Figure 4). In addition, all data and pictures generated on-site may be transmitted by satellite link to an off-site data center for further review and storage. (Under the Intermediate-range Nuclear Forces treaty, no data will be transmitted off-site). This off-site data center could be located in the US, in a neutral country such as Finland or Switzerland, or even in Moscow.

Deployment of on-site inspection stations in the USSR is underway.

The Intermediate-range Nuclear Forces treaty allows the US to deploy a portal monitoring system at the Soviet rocket motor assembly facility at Votkinsk, a city approximately 1000 km east of Moscow. We have developed the hardware for this deployable unit and a prototype is currently being installed in the USSR. Based on the technology used at the demonstration facility, this hardware includes modular buildings, a full computer-control system, and portal sensors.

For more information, call
Stan Fraley (505) 846-4464.

Unique Identifiers for Monitoring Treaty-limited Items

We are developing advanced tagging methods for verifying conformance to treaty limitations.

An advanced inspection concept under study is that of a unique "fingerprint" or tag to attach to a treaty-limited item. When an item would be declared by the Soviets as one of those allowed by a treaty, we would affix a permanent tag to it, uniquely identifying the item. The identification would be maintained in a file for comparison to readings taken from tags on treaty-limited items found during subsequent on-site inspections.

Tags provide a solution to a major verification problem: counting mobile treaty-limited items. Numerical limitations on these systems cannot be verified by the standard method of counting using National Technical Means because they may not stay in place long enough to be counted. By distinguishing between legal and illegal items, tagging solves this problem.

One type of tag is composed of a mixture of a clear plastic material and crystalline particles that would be painted onto a treaty-limited item (Figure 1). The particles are randomly located, and their reflective surfaces are at random angles. After the tag is applied, it would be read with a special set of lights and video still camera. An image would be taken with each light illuminated in sequence. The pattern descriptions can be recorded on 2-inch magnetic disks in a file of legal tags. The readings of tags taken during on-site inspections would be compared to the original readings stored on a portable computer.

Comparing patterns is possible even if the tags have degraded. An illegal missile, painted with similar material, would be detected because the fingerprint of the counterfeit would not match the recorded one.

We are also investigating other tagging concepts. One, an electronic identification device, would consist of a small integrated circuit bonded in a non-removable manner to a treaty-limited item. When interrogated, the tag would respond with a message to uniquely identify itself and, therefore, the item to which it is attached. Unlike reflective-particle types, electronic tags can be interrogated remotely, possibly through the wall of a shipping or launch canister. We are working on the challenging problems of ensuring that the secret identification information cannot be intercepted and that tags cannot be removed and put on illegal items.

For more information, call
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Figure 1. Reflections from light projected at various angles onto a reflective tag would uniquely identify a treaty item. The paint contains randomly oriented particles that create three-dimensional reflections, making it virtually impossible to counterfeit the tag.

Arms Control Analysis Program

Research on arms control provides options for use in future treaty negotiations.

Sandia's involvement in arms control and verification research ranges from studies to determine how various arms control concepts might affect the DOE production complex, to development of a wide variety of methods of data authentication and tamper detection. Some of our surveillance methods are reported in other articles in this issue. This article describes some of the conceptual studies that we use to identify and evaluate new capabilities needed for future treaty negotiations.

We provide technical consultation to the DOE during ongoing international disarmament discussions.

For several years, a Sandia staff member has been a DOE technical consultant to delegations of both the UN General Assembly First Committee and the Conference on Disarmament in Geneva. These assemblies meet to discuss general arms control policy, as well as more specific topics such as chemical weapons, radiological warfare, and nuclear testing. In addition, our personnel played an active role in the negotiation and implementation of the recently signed Intermediate-range Nuclear Forces Treaty. (Figure 1)

We recently sponsored a technical conference on verification organized in two parts — a path game and keynote talks. In the path game (similar to a war game), we set up several groups to play the roles of opposing delegations seeking to create a comprehensive ban on nuclear testing. High-level representation from government agencies lent realism to the exercise and the results were documented for detailed evaluation. During the conference portion, various speakers addressed issues of compliance and verification technology in relation to the current Strategic Arms Reduction Talks and Intermediate-range Nuclear Forces Treaty.

Figure 1. On Dec. 8, 1987, the US and USSR signed the Intermediate-range Nuclear Forces Treaty. The historic agreement will lead to significant reduction of US and USSR nuclear arms. This poster was created by the USSR in honor of the signing.

We have played a significant role in evaluation of on-site inspection dynamics.

The issue of on-site inspection has been, and will continue to be, one of the most discussed aspects of verification. On-site inspection as a verification measure was proposed by then-Vice Pesident George Bush in 1984. To ensure compliance, this proposal would have permitted inspection on short notice to look for chemical weapons or their precursors. Because this would include the US national laboratories and the weapon production complex, the DOE appointed a committee to evaluate how the national laboratories could (1) satisfy their statutory obligation to protect classified information, (2) honor the Non-proliferation Treaty commitment to prevent the proliferation of nuclear weapon technology, and at the same time, (3) comply with any on-site inspection requests by foreign countries.

With the signing of the Intermediate-range Nuclear Forces Treaty in December 1987, on-site inspection has become an important aspect of arms control analysis, a complex topic containing many interrelated issues (Figure 2). We are heavily involved in studying various on-site inspection methods and their implementation. Several of our projects have simulated actual inspections. In one program, we selected a facility associated with restricted systems and assembled an inspection team of security-cleared members familiar with the technology but not necessarily with the details of the facility. Their mission was to learn all they could about the facility during the inspection. We wanted to evaluate both the vulnerability of US national facilities to inspections on short notice (the defensive aspect of on-site inspection), and the effectiveness of on-site inspection as a means of verifying compliance (the offensive aspect of on-site inspection).

The conclusions from these studies have been used to influence treaty provisions and to help us form a plan for hosting inspectors if the treaty provisions are adopted.

To illustrate the urgency of the need for response planning, negotiations regarding chemical weapons have progressed to the point where the USSR invited delegates from the Conference on Disarmament to inspect a site where they destroy chemical munitions. The US reciprocated by offering the USSR the opportunity to inspect our chemical weapons demilitarization site. In addition, the current Strategic Arms Reduction Talks may allow short-notice inspections at suspect sites chosen by the inspectors. If these trends continue, we could soon be asked by the DOE to provide a plan for trial inspections at even more sensitive facilities.

Warhead dismantlement in an arms control context is being evaluated.

Modern disarmament proposals began after World War II when the US proposed stopping the production of fissionable material (an approach commonly known as "cutoff") as the most effective way to control arms. In its final form, the agreement would have included dismantlement of nuclear warheads coupled with a "turn-in" of the recovered special nuclear material to an international agency. This proposal was shelved in the mid-1960s when other arms control alternatives, such as limiting launchers and restricting testing, became more popular.

Proposals for cutoff and warhead dismantlement have reappeared recently, both in the Congress and in public fora. Therefore, in an effort to respond responsibly to legitimate inquiries as well as to address various contingencies, the DOE has asked us to examine

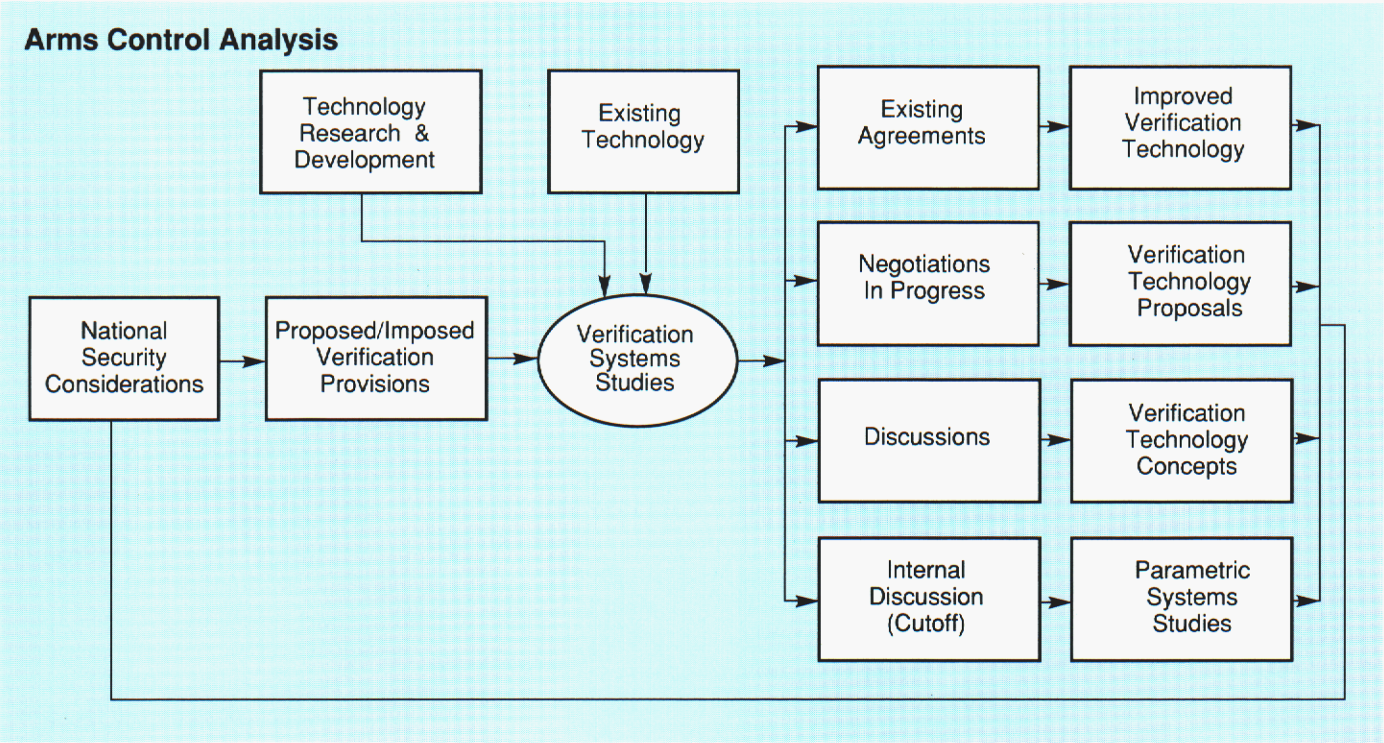

Figure 2. Arms control analysis consists of many complex, interrelated issues.

the technologies and evaluate several approaches to warhead dismantlement. We have also been asked to evaluate various provisions requiring controls on production of special nuclear materials.

Our arms control analysis studies enable us to target technologies for the future.

Our studies will allow us to identify technologies that must be improved as new arms control regimes are proposed. One of these technologies involves the detection of special nuclear materials. The arms control community has developed some fairly sophisticated technologies for identifying the presence of these materials and for assaying them to find out what they are and how much is present. "Fingerprinting" techniques are also under development for use in verifying that a piece of special nuclear material is the same one an inspector observed in the past. In theory, fingerprints can be obtained that disclose how much special nuclear material is present without revealing the component design.

Sandia has been involved in portal and perimeter studies for many years. Recently, we have extended those technologies to verification-related applications and continue to evaluate new concepts. The advantages and disadvantages of various portal and perimeter concepts must be clearly understood. Part of this technology involves portable perimeters that can be set up rapidly and then dismantled at sites where a permanent presence is not needed.

Finally, improved methods of sealing, prevention of tampering through the use of measurement devices, and methods of analyzing the results are other major parts of Sandia's program.

By learning how to improve the technologies, and by making them resistant to tampering, we can provide our negotiators up-to-date expertise for future arms control negotiations.

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Monitoring Inactive Chemical Weapons Facilities

We have developed tamper-proof enclosures for sensors used to verify that inactive chemical weapon sites are not used secretly.

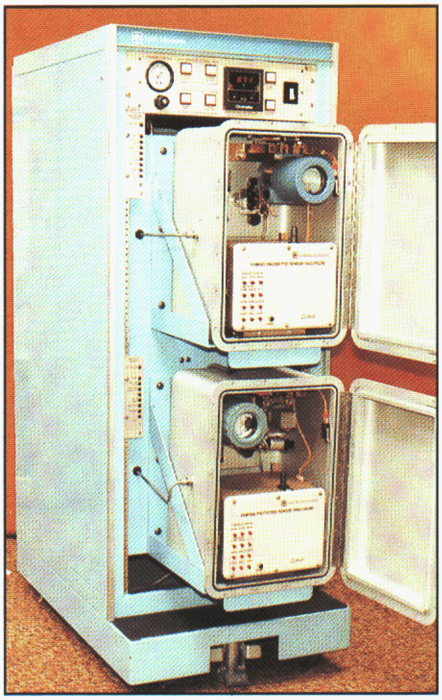

Figure 1. Temperature and pressure sensors for surveillance of chemical-weapon processing equipment are contained in a tamper-proof enclosure.

Inspection of inactive facilities to verify that certain types of weapons are no longer produced is often an issue in disarmament conferences. During the 1984 Conference on Disarmament in Geneva, delegates tabled a US version of a treaty banning chemical weapons in which the US proposed to monitor designated production facilities by combining inspection visits with on-site surveillance instruments. Under this proposal, deactivated production plants would require both periodic inspections and remote monitoring between inspections.

Shortly after this session, the US Arms Control and Disarmament Agency requested Sandia's assistance in developing tamper-resistant sensors (see box) to monitor inactive or deactivated chemical weapons production sites. We were already working on remote sensor technology for monitoring nuclear weapons production, deployment, and testing. Our experience helped us determine the overall system requirements for monitoring chemical weapons facilities.

Tamper-resistant systems can be either passive or active. Passive systems are called tamper-indicating and depend on some irreversible physical evidence of intrusion, such as scratch marks. Active systems are called tamper-detecting and use electronic means to detect and irreversibly record intrusion attempts.

To start, we applied tamper-detecting methods to temperature and pressure sensors. These sensors, enclosed in tamper-indicating containers, would be placed on critical pipes, tanks, and processing units in inactive plants to detect any changes from ambient conditions. Evidence of tampering within the closed and sealed enclosures can be obtained either remotely through data transmitted from the monitoring units, or locally by an inspector who periodically checks the system.

Our sensor development is also part of a bilateral effort between the US and Japan, in which Japanese industry will provide monitors and a communications link. The Japanese method of interrogating sensors is like the system they are developing for the International Atomic Energy Agency to monitor transoceanic shipments of special nuclear material. The Japanese chemical weapons monitoring units will be used to query sensors for tampering and to receive sensor data. Transmitted data will first be sent to a communications satellite parked over the Pacific Ocean, and then to a central location for interpretation.

We packaged commercially available temperature and pressure sensors.

Several features provide an indication that someone has attempted to enter the enclosure covertly (Figure 1). First, a current must pass continuously through the sensors to ensure that they are operating correctly. Interruption of the current constitutes a failure of the system and activates a backup system. If the current in backup sensors also lapses (backup power is provided in case of power failures), we assume that tampering has occurred.

Sensors inside the container monitor temperature and pressure deviations and detect unusual magnetic fields or radiation levels. Other sensors detect if the enclosure has been tilted or shaken. These are physical phenomena that an adversary might use to circumvent the tamper detection system. Finally, we alarmed the door to detect unauthorized opening. Should the door alarm fail, a light sensor would detect any change from the normal light level within the enclosure.

Although this system is specifically designed to relay data to a Japanese operating unit, it can also operate in total isolation. A monitored, external supply provides ac power for the electronics. If power is interrupted, batteries inside the enclosure provide backup for over 12 hours of operation.

We put signal-activated, self-test capabilities into the unit to exercise the electronic components. We decided not to test the sensors periodically because that would introduce a vulnerability into the system during the test. For example, knowing that temperature sensors were being tested, a relatively long test, an adversary might use a temperature attack to circumvent the system. Data from other electronic tests can be collected in a short time and the system returned quickly to active status without vulnerability concerns.

We have completed development of the temperature and pressure sensor systems but have not yet field tested them. Our next task is to develop a tamper-detecting load cell. This unit could be used to weigh items such as vessels that contain chemical agents, or even artillery shells brought to a decommissioning facility for destruction. A present complication is the need for continuous visual inspection of the load cell. We must ensure that no one tries to defeat the load cell by shifting the load to some other support, like a jack. We are considering use of the Modular Integrated Video System, described elsewhere in this issue, for that purpose.

For more information, call
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