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THE SAVANNAH RIVER TECHNOLOGY CENTER, A LEADER IN SENSOR TECHNOLOGY

by

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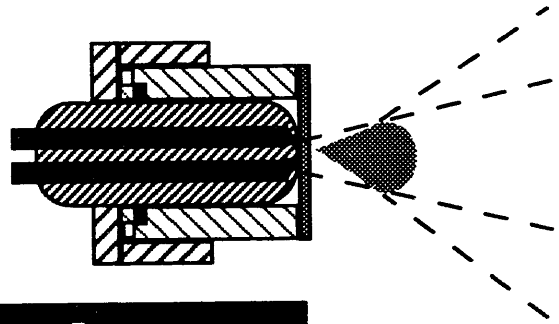
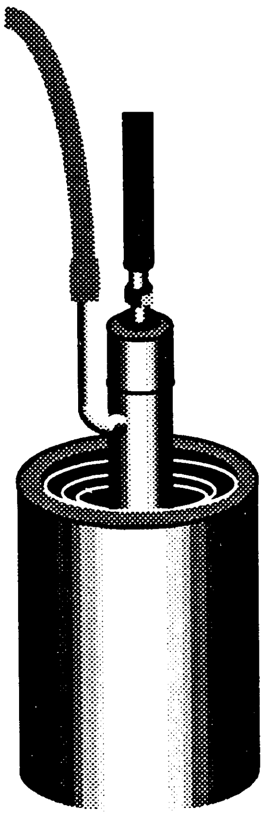
The Savannah River Site

The SAVANNAH RIVER TECHNOLOGY CENTER

A leader in =SENSOR technology





A team of scientists and engineers in the

***A**NALYTICAL **D**EVELOPMENT **S**ECTION*

creates innovative techniques for industrial and environmental chemical analysis

Sensor Technology

Industry needs an edge in the global market

Fiber-optic sensor systems can help U.S. compete

Today's economic environment presents a pair of formidable challenges - surviving in an intensely competitive global market, while living up to higher standards of environmental responsibility.

These twin pressures drive industry to improve manufacturing efficiency and remain conscious of how its operations affect the world around it.

By combining diverse technologies and expertise, Savannah River Site (SRS) scientists have developed robust fiber-optic sensor systems that can help industry compete on the economic battlefield. These techniques, products of the Savannah River Technology Center's Analytical Development Section (ADS), measure properties such as chemicals, temperature and acidity, and provide SRS with high-quality analyses in areas where site and industry needs overlap: on-line chemical process control and in-situ environmental monitoring.

"Chemical processes here aren't that different from what goes on in many chemical companies," notes ADS scientist Stanley Nave. "Our work has direct application to real-world processes."

A combination of several technologies, the sensor systems operate optically, shining light through a solution and identifying chemicals present by their color. In principle, it's like light passing through a glass of lemonade, explains ADS fellow scientist Patrick O'Rourke. The lemonade appears yellow because it absorbs all light but the yellow.

"You throw light at a sample, then the sample modifies it," O'Rourke says. "You can iden-

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Talking about the technology

Sensor: A device that measures or detects something of interest.

Probe: A piece of hardware engineered to hold a sensor that allows placement of the sensor at a desired measurement point.

On-line: A type of automated measurement made either in a process stream or on a side stream.

Real-time: Information that represents the current status of the measured system with no time delay.

In-situ: A type of measurement made without removal of a sample or otherwise disturbing or disrupting the system being measured.

Spectrophotometer: An instrument that measures the intensity of light separated into its constituent colors.

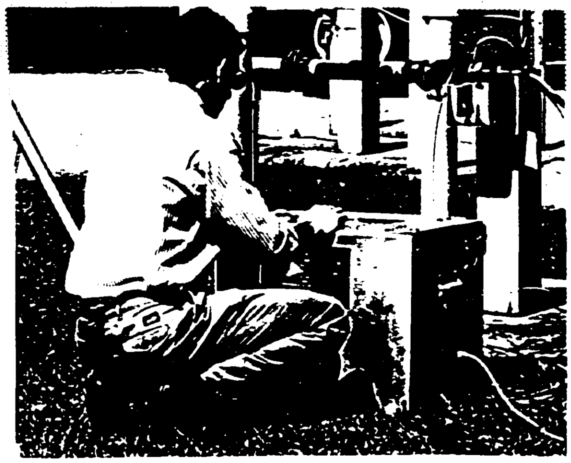
Chemometrics: Mathematical tools that turn spectral data into information like chemical concentrations or temperature.

Multiplexer: A device that sequentially channels light from one source/detector to many different points.

Cone-penetrometer: A sampling device used to punch sensors underground.

Fiber-optics: Glass fibers that channel light efficiently over long distances.

Spectrophotometry System



SRTC scientists refined equipment that once filled a 7-foot-tall rack to fit in the portable package in use at right, which is about 2 feet square. The package contains a light source; a multiplexer to connect a single unit to multiple sampling points in a process stream via fiber-optic cables; an absorption spectrophotometer to analyze light from the fiber optics; and a computer that uses advanced chemometric software to automatically convert the absorption data to useful, reliable chemical information.

Fiber-Optic Cables

One fiber-optic cable carries light to the sample, then another brings light modified by the sample back to the spectrophotometer. Fiber optics allow for remote analysis - keeping an operator away from possible toxic or hazardous environments - and are a simple, cost-effective way to link a single spectrophotometer system to any number of probes and sensors.

A Basic Fiber-Optic Sensor System

Probes and Sensors

Probes and sensors at the end of fiber-optic cables allow the sample to interact with the light. SRTC scientists have developed several variations of probes and sensors that can detect chemicals in many different environments, such as industrial process streams, groundwater and well water. This technology can track changes in chemical concentrations over time, and by eliminating the need to gather samples, can save a tremendous amount of money and effort.

Absorption spectrum gives chemical away

SRTC sensor systems shine light through a solution and identify the chemicals present by their absorption spectra - or how they absorb light. The amount of light absorbed reveals the concentration of the chemical.

ADS sensor systems are portable, and can be taken into the field for in-situ chemical analysis, as scientist Bruce Buchanan demonstrates. Filling a wide variety of environmental remediation roles, in-situ analysis techniques provide timely chemical information, and save tremendous amounts of time, effort and money.

tify chemical compounds by how they absorb light. Every compound has an absorption spectrum." The color identifies the chemical, and the amount of light absorbed reveals the concentration.

These basic components form the core of the ADS systems: a light source, fiber-optic cables, probes and sensors, and a spectrometer.

The fiber-optic cables carry the light to the sample, where probes and sensors at the end of the cables allow the sample to interact with the light. The sample modifies the light during the interaction, and fiber-optic cables carry the modified light back to the spectrometer. There, advanced ADS chemometric software automatically analyzes the data.

"By looking at differences in the light I put out there and the light coming back, the computer software can tell me what's there and how much," says O'Rourke.

Chemometrics turn data gathered by the sensors into easily understood information, highlighting a major advantage of the ADS systems - simplicity.

"The information gets turned into single numbers that people can understand, like a pH number," O'Rourke says. "Or even simpler, like a 'good' or 'bad' reading.

"We've taken the technology and pushed it to the point it can be used in the field by people who aren't experts."

ADS group manager Wayne Jenkins also looks for simplicity and reliability in a sensor system. "I wanted to see more of an emphasis on simple sensors," he says. "It's a very robust system.

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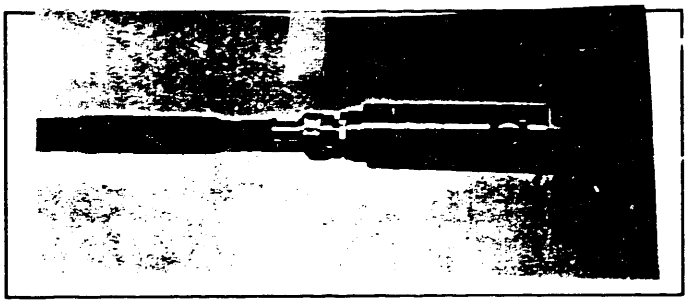
SRTC monitoring systems employ

3 Basic Types of Probes

Scattered Light Probe

This probe is used for analyzing substances that light can't shine through, such as dirt, paint, slurries, solids, etc. Light from one fiber bounces off the sample and then is collected by other fibers. Like the human eye, this probe detects reflected light.

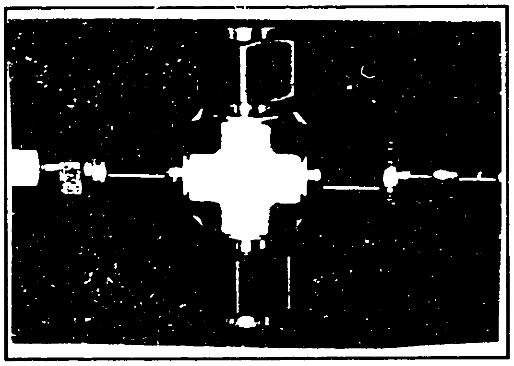
Transflectance Cell



Called a "dip probe," this device can be inserted in places like tanks, reactors, vessels, etc. Light from one fiber is transmitted through the solution, then reflected back through that solution off a mirror and collected by another fiber.

Flow Cell

This transmission probe is used for analyzing fluids flowing through a pipe. Light from one fiber is collimated (beamed in a column) and transmitted through the solution and then refocused on another fiber.



An Award-Winning SRTC innovation

Before environmental scientists at Savannah River Site could validate the concept of using radio-frequency soil heating to remove volatile organic contaminants from the ground, they had to find a way to monitor the soil temperature during the experiment.

The Environmental Sciences Section (ESS) approached Analytical Development scientists in search of a solution. Thermocouples, thermistors, resistance thermometers and other common monitoring devices contain electrically-conducting materials that make them susceptible to electrical interference. They would be useless in high radio-frequency environments. A sensor was needed that would not be affected by radio waves.

A Savannah River Technology Center team of Analytical Development scientists and glass specialists created a new class of temperature sensor that exceeded ESS' original needs. The new sensors utilize fiber-optic probes which determine the temperature of a material by measuring changes in the way it absorbs light. The optical sensors contain no metallic or electrically-conducting components, and the durable optical fibers resist corrosion and heat, and are immune to electrical or magnetic interference.

For their efforts, each member of the SRTC team won the prestigious George Westinghouse Signature Award of Excellence. Westinghouse Electric Corporation presents only 10 of these awards each year, to honor achievement in Westinghouse engineering and manufacturing worldwide.

Customer requirements for the temperature sensors were these:

• The sensors must obtain real-time measurements without being affected by radiofrequency fields.

• They must operate accurately from 0 to 150 degrees Centigrade.

• They must be relatively inexpensive.

• 200 feet lead lengths from measurement point to readout point were needed.

• They must remain stable for weeks, needing no recalibration.

In less than six months, the SRTC team had the temperature sensors developed for installation. The devices exceeded the capabilities of a commercially available sensor - and did so at a cost savings for the customer.

Among the advantages of the SRTC temperature sensors:

• They are rugged and can be used hundreds of feet away from the readout system, allowing remote monitoring in inaccessible or hazardous environments.

• They function well in high electromagnetic fields.

• The calibration process renders variations in each sensor inconsequential, eliminating the expense of calibrating individual sensors.

• They operate over a very wide temperature range, from -200 to 500 degrees Centigrade.

"We ended up with a very effective sensor," says ADS group manager Jeff Griffin. "It looks like it has tremendous commercial possibilities. It's generated a very big interest off site."

The SRTC sensors carry advantages that make the technology very attractive to a wide range of U.S. industry. Measuring and controlling temperature are central to many industrial, medical, household and research applications. Systems to control temperature are found in nuclear reactor vessels and coolant systems, treatment facilities for administration of chemotherapy or radiotherapy, conventional and microwave ovens, and many industrial processes. Temperature is also monitored at underground nuclear waste-disposal sites, chemical dumping sites and geothermal wells.

Development of the temperature sensor is good example of applying innovation and state-of-the-art technology to meet a customer's requirements in a timely manner.

Says ADS scientist Ron Livingston: "They came to us and said, 'This is the problem we have to solve.' They knew there were fiber-optic systems available commercially, but they needed something less expensive that could be implemented quickly. They wanted to know if anything could be developed here. We then used information from previous experience to build a device."

"That's the way the Analytical Development Section operates," he adds. By pulling together parts from different places to develop a system, they can create "something that's unique."

ADS scientist Patrick O'Rourke examines the optical properties of a transmission flow cell with a diode-array spectrophotometer. This is done to obtain a reference reading on the flow cell before the device is installed for industrial process analysis.

You just set it out there and the thing runs.

"I believe this is the kind of stuff the world wants."

According to O'Rourke, the fiber-optic system can be readily tailored to fit a wide variety of process and remediation conditions. "If someone calls, we can be collecting data within two weeks," he says.

And different parts can be interchanged or swapped out easily. For example, many different probes can be adapted to the system, without having to change the spectrometer.

"It has a very, very wide range of applicability," O'Rourke notes. "We had to make it flexible enough to handle all the different types of analysis we had to do at the site." He cites the ADS philosophy:

"Keep it simple. If it's not simple, it breaks."

Chemical Process Analysis

"With the types of hostile environments we have to deal with, we had to develop these sensors."

Nave describes the harsh chemical and radioactive processes at SRS as the motivation behind the on-line sensor systems. Safety, in O'Rourke's words the "biggest driving force we have" at SRS, was a major concern.

The task required reducing the risk of worker exposure to radioactive or hazardous materials, while still supplying the timely, precise information critical for efficient chemical operations. The ADS on-line analysis systems meet the challenge. They allow operators to monitor the process well

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Advanced Software Analyzes Data Automatically

The key feature of Analytical Development sensor systems is the ability to automatically analyze data. Using chemometrics, advanced computer software boils a large amount of raw information down to a simple number that can be recognized by a non-expert operator.

Chemometrics are computer models based on known concentrations of a chemical substance. The models act as standards - standards (your known) that can be compared to spectral data (your unknown) to derive the concentration of chemicals present in an industrial process or environmental situation.

Each particular chemical requires its own model, and ADS scientists have developed chemometric models for a variety of chemical compounds.

"Spectral data by itself isn't very useful," says ADS scientist Bruce Buchanan. "Chemometrics reduces the difficult-to-understand data to useful information. You don't really have to understand the mechanics behind it."

He says the driving force behind the development of chemometrics was the desire to create an integrated package. "It's very difficult to put an instrument into the field and automate it when you're constrained by the manufacturers software," Buchanan notes. "Now, we can take a new instrument and develop a software interface."

This means different components of the fiber-optic sensor systems can be substituted depending on the particular application. For example, if a different range of light was called for, only the light source would have to be changed.

The operator doesn't need to worry about a particular instrument, because "we design the software so he sees the same data collection format no matter what instrument he's using," Buchanan says.

"It's the tie that binds" all parts of the system together, he adds. "It gives us a lot of freedom to do whatever we need to do."

In sum, chemometrics equal speed - speed in building new chemical models, and in collecting and analyzing data. What used to be a three-hour analysis process can now be done in a few seconds, allowing constant analysis of a process and saving a major amounts of time and money.

"You can monitor your process much closer," Buchanan says. "And the data is real-time. You're getting what you need to know right now."

away from the potential hazards, free from the risks involved with conventional sample collection.

Besides possible exposure to dangerous materials, pulling a sample can present other problems - problems solved with on-line analysis.

A good sample can be hard to come by. The very act of drawing the sample can compromise it. "Often, the biggest problem with monitoring is getting a piece of what you want to monitor that's truly representative," O'Rourke says.

Because the sample does not have to be removed from the process and sent elsewhere for analysis, there's simply less chance of contaminating a sample with on-line systems.

"Getting a sample is 50 percent of the battle," notes Jenkins. "With on-line, in-situ techniques, you don't have an opportunity to mess the sample up."

With a multiplexer, an on-line analysis system can compare results from many samples and reveal the process effects on samples over time, presenting a truer picture of the process.

The multiplexer plays an important role in the ADS systems. It directs light through fiber-optic cables to many sampling points, allowing analysis of the entire process, from start to finish, with the

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ADS scientist Lewis Baylor (at computer) worked with George Wicks, a Savannah River Technology Center sol-gel expert, to develop a class of sensors that use sol-gels to hold an indicator.

same spectrometer.

On-line techniques also allow "real-time" analysis - a constant flow of chemical information on a manufacturing process from many points in that process, with no waiting for results from a lab. This adds up to tremendous improvements in efficiency and quality control.

If it takes hours to have a sample analyzed, and if the results show the chemical concentration, for example, is too high or too low, then often the damage has been done.

"But when you measure it as it goes," says ADS scientist Lewis Baylor, "If something goes wrong, you can flag it and stop the process to correct it."

The benefits reaped from on-line analysis spell major savings in time and money. There's no need to interrupt the process to take a sample, and no need for expensive laboratory analysis. Also, there's less waste. What happens to a sample after it's analyzed? Often, it's thrown away. But with on-line analysis a sample often can be returned to the process stream, and disposal costs avoided.

"We want people to be able to run their operations continuously," says O'Rourke, "With good chemical information about their systems." Stopping operations to take a sample can waste time and resources, he adds, and with processes like those at SRS, if you have to stop them, "Often, it's too late."

O'Rourke sums up ADS goals: "We feel our mission is to provide the means for operators of this plant and its systems to control their operations more safely and efficiently. And to be able to measure the quality of their operations as rapidly and effectively as possible."

With on-line analysis technology, industry can reap the same benefits, and see efficiency and quality improve. And this rugged sensor technology, developed to meet the harsh process conditions of SRS, can be readily adapted to and operate easily in industrial

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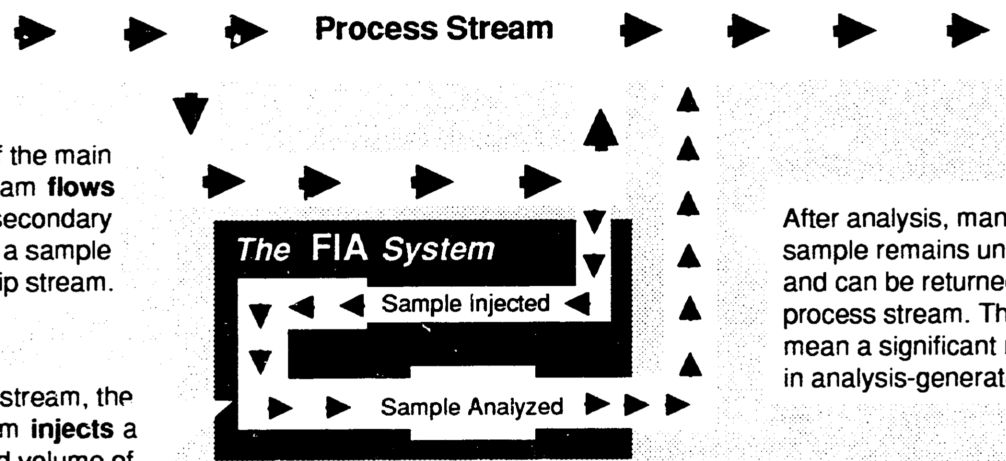


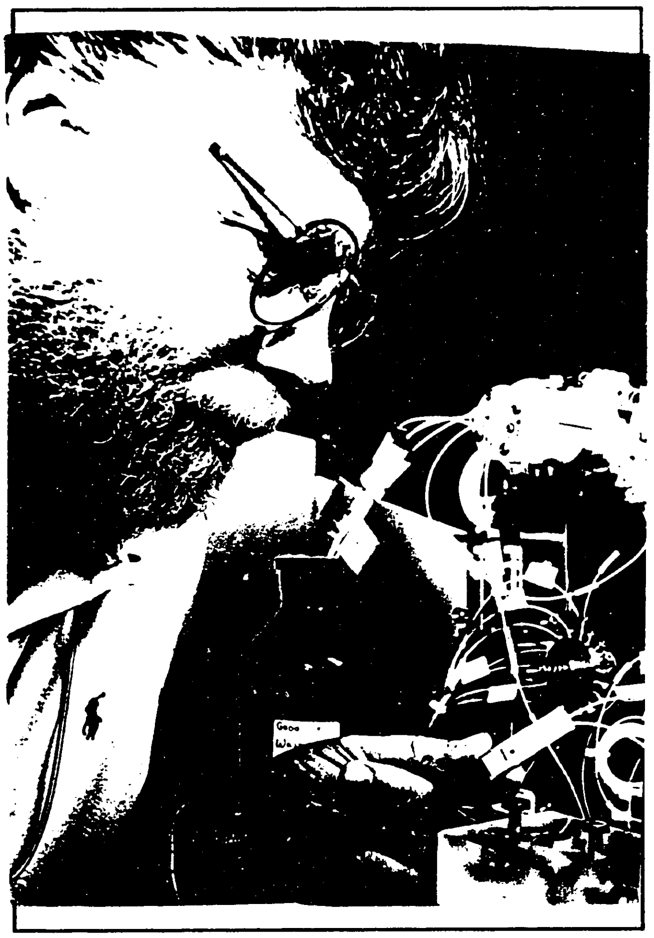
1. A portion of the main process stream **flows** through a secondary conduit called a sample slip stream.

2. From the slip stream, the FIA system **injects** a well-defined volume of sample into another conduit called a carrier stream. The carrier stream transports the sample through a sensor monitoring device, completing analysis of the process stream.

3. After analysis, many times a sample remains unchanged and can be returned to the process stream. This can mean a significant reduction in analysis-generated waste.

Flow Injection Analysis

Automating Solution Chemistry



SRTC scientist Mike Whitaker, an expert in the field of Flow Injection Analysis, is shown here with a lab scale FIA system. By removing a representative, well-defined volume of sample from the process stream, FIA provides a flexible variety of analytical and chemical techniques that can be performed on a sample. Whitaker describes FIA as a "technique to automate solution chemistry - that is, to automate on-line or in a laboratory environment what chemists normally do on the benchtop with their hands." FIA offers major advantages over manual procedures when it comes to improving efficiency, reducing waste, and minimizing an analyst's exposure to toxic samples. At SRS: "We have demonstrated that our FIA systems can achieve reductions of 95% in analysis time and 98% in generated waste for certain methodologies. Those are very significant percentages in terms of safety for our analyst and the amount of dollars you're saving," Whitaker says.

chemical environments.

"Business can generate better products by having some form of real-time control," says Nave. "Good on-line sensors will make a company more competitive. No doubt about it."

Environmental Remediation

The changing mission of U.S. defense facilities and growing public demand have refocused attention on the environment. In response, ADS scientists have worked closely with environmental sections at SRS, developing in-situ sensor systems for remediation techniques.

"Our group has shifted emphasis to environmental analysis and assistance," notes Baylor. "There is definitely a feeling that we have to look at other uses for our technology, like environmental applications."

The sensors help map out and characterize sites at SRS targeted for cleanup, says ADS group manager Jeff Griffin. "We do things like finding out what's there, and identifying the contaminants and the level of contamination. Other groups use our data to determine the risk and what the remediation should be."

In environmental cases, sensor applications are many. They can be used to monitor chemical concentrations in waste water streams, waste tanks, incinerator stack gas, wells, groundwater, soil, lakes, rivers, mine runoff and so on.

The ADS fiber-optic sensor systems bring the same advantages to remediation and waste management as they bring to process control - fast, reliable in-situ analysis from many sampling points by an operator well away from the sampling site. The in-situ techniques can mean huge cost and time savings.

"Sampling wells is extremely expensive, and can cost anywhere from $1,000 to $5,000 a sample," says O'Rourke. "But a probe? You just dip it in, and it reduces the cost considerably."

Adds Jenkins: "It takes a lot of time to collect samples and then send them to a lab. You're talking months."

And with a device like a cone-penetrometer, probes and sensors can be punched into the ground, offering a fast survey of an area with no need for drilling. Keeping a drilling rig in the field is not cheap.

Basically, the ADS in-situ analysis techniques allow operators to accomplish in the field much of what normally was done in a lab. Also, the in-situ sensor systems offer more timely results and allow analysis to continue during actual remediation efforts.

"The big savings come in the fact that you don't have to drill a well, or spend money on expensive lab analysis," Griffin notes. "You get more bang for the buck."

Adds ex-ADS manager Gene Coffey: "We know there are a number of sites at SRS where there have been spills, both big and small. You can't just leave it; you have to clean it up. And it's in this cleanup phase where we can save millions."

Treaty Verification

Fiber-optic sensor technology developed at the Savannah River Technology Center could have a hand in wiping out the horror of chemical warfare, or at least in seriously reducing the threat. ADS scientists envision their systems in use at chemical weapons destruction sites - in Iraq and the former

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