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Active Fiber Optic Technologies Used As Tamper-Indicating Devices

Patrick R. V. Horton, Ivan G. Waddoups

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ACTIVE FIBER OPTIC TECHNOLOGIES USED AS TAMPER-INDICATING DEVICES

Patrick R.V. Horton
Safeguards Seals Evaluation Program Coordinator

Ivan G. Waddoups
Insider Technology Department, Manager
Sandia National Laboratories/NM
Albuquerque, NM 87185-0759

Abstract

The Safeguards Seals Evaluation Program is considering new fiber optic active seal technologies (AST) that can be used at DOE facilities. The goal is to investigate tamper-indicating devices (TID) that can be used to monitor secured containers within vaults while personnel remain outside the vault area. Such a system would allow minimal required access into vaults to verify container TID integrity while ensuring container content accountability. The TID concepts that hold the most promise and keep cost factors down are fiber optic and radio frequency technologies. Four existing manufactured technologies were considered and tested.

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- **Steve Koonce**, Inovonics (Boulder, CO),) for providing product support on his active seals technology.

CONTENTS

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ACTIVE FIBER OPTIC TECHNOLOGIES USED AS TAMPER-INDICATING DEVICES

1.0 Introduction

The Sandia National Laboratories (SNL) Safeguards and Seals Evaluation Program is evaluating new fiber optic active seal technologies for use at Department of Energy (DOE) facilities. The goal of the program is to investigate active seal technologies that can monitor secured containers storing special nuclear materials (SNM) within DOE vaults. Specifically investigated were active seal technologies that can be used as tamper-indicating devices to monitor secured containers within vaults while personnel remain outside the vault area. Such a system would allow minimal access into vaults while ensuring container content accountability.

The purpose of this report is to discuss tamper-indicating devices that were evaluated for possible DOE use. While previous seal evaluations (Phase I and II) considered overall facility applications, this discussion focuses specifically on their use in vault storage situations. The report will highlight general background information, specifications and requirements, and test procedures. Also discussed are the systems available from four manufacturers: Interactive Technologies, Inc., Fiber SenSys, Inc., Inovonics, Inc., and Valve Security Systems.

2.0 Background

Sealed containers store SNM in DOE facility vaults under the two-person access rule. In this environment, the relatively unsophisticated tamper-indicating devices provide significant protection against tampering of SNM containers and help to decrease the time personnel spend inventorying SNM. Site personnel quickly and easily determine if the containers have been tampered with which results in reduced radiation exposure.

The tamper-indicating devices currently used are one of two types: pressure sensitive seals or loop seals. These seals (a term used interchangeably with tamper-indicating devices) are placed on the containers to ensure that the contents have not been compromised.

The containers that require seals come in various textures, shapes, and sizes. The largest containers (5-, 10-, 30-, and 55-gallon) are typically painted drums with closure-locking collars. Smaller sized cans (1/8-, 1-, 3-, and 5-gallon) are usually plated.

All containers using tamper-indicating devices are located primarily in protected environments (i.e., inside buildings), and are stored in various configurations. For instance, some drums or cans are placed in an open storage environment, while others are stacked on shelves or in cabinets. The storage method is determined by container content, the amount of containers, and the need for accessibility.

3.0 Specifications and Requirements

In order for DOE to rely on tamper-indicating devices to monitor SNM and other critical assets, these seals must meet the following specifications:

- be sold at a reasonable cost
- remain intact, readable, and viable for at least 2 years after application
- indicate seal integrity
- secure a variety of containers or storage cabinets
- indicate any attempt to tamper with the device
- provide relative ease and speed of application
- fit a variety of containers.

Another somewhat arbitrary goal for the active seal technologies is that the system cost $100 or less per container monitored. This cost factor, therefore, must be considered when determining the type of tamper-indicating device and the storage method.

4.0 Test Procedures

The goal of the SNL testing was to ensure that the seals operated properly in known environmental conditions and that they met the specifications mentioned above. To meet this objective, SNL personnel used the military standard 810D, dated July 19, 1983, to establish the proper conditions for testing seals. These included temperature/humidity and radiation exposure tests.

4.1 Temperature/Humidity Test

The following 24-hour temperature/humidity procedure tested the seals at various temperatures and levels of humidity over a 20-day period. This determination is valuable because the tamper-indicating devices are used in situations and conditions where the temperature and humidity vary.

- The test began at **72° F** and **35%** humidity. This condition stayed constant for ***6 hours***.
- During the next ***6 hours***, the chamber temperature was slowly raised to **95° F** and the humidity level was raised to **95%**.
- Once the chamber reached **95° F** and **95%** humidity, the temperature was maintained for ***6 hours*** and the humidity level was kept constant for ***5 hours***.
- At the end of ***5 hours***, personnel started to drop the **95%** humidity to **35%**.
- At the end of ***6 hours***, personnel started to drop the **95° F** temperature back down to **72° F**. This took ***6 hours***. (This portion of the test determined humidity tolerance but kept the humidity below the dew point, which would have caused condensation.)
- One 24-hour cycle was completed at this point. The cycle was repeated 20 times.

All tamper-indicating devices passed the temperature/humidity tests.

4.2 Radiation Test

Units from three of the manufacturers - Interactive Technologies, Inc., Fiber SenSys, Inc., and Valve Security Systems - were tested at the SNL Gamma Irradiation Facility using Cobalt 60. To monitor total radiation exposure, thermoluminescence dosimeters were placed on the front and back of the circuit cards of each of the sensor units. The dosimeters were labeled, and total shot times were recorded.

The three units were irradiated at a rate of 1500 R per hour for 2.5 hours (a total of 3,750 R). They were then inspected to determine if the tamper-indicating features responded to a tamper. One such feature is a tamper-indicating light that acts as a "state-of-health" indicator. These lights were visually inspected through an inspection window every 10 minutes.

After receiving 6,808 R (approximately 5 hours into the test), the Fiber SenSys unit failed. A "hands-on" evaluation was then conducted, and the unit was removed from the chamber. The two remaining units were tested for 2.5 more hours. These received a total of 8,918 R and were determined to have passed the test.

The Inovonics units were received too late for the Cobalt 60 testing but an opportunity opened for a slightly different test. This test also provided an opportunity to utilize lower dose rates. Two units were tested using Cesium 137 at the SNL Radiation Standards Facility at a dose rate of 15 R per hour. These units failed at an average level of 6,833 R.

4.3 Radiation Data

Though not directly tested at SNL, the effects of radiation on fiber optic cables were researched. Three of the four manufacturers use plastic fiber optic cables that are sold by Mitsubishi Corporation. As part of the effort to determine radiation effects on the total tamper-indicating device systems, we obtained a data sheet from Mitsubishi Corporation that presents radiation data (Table 1). The sheet specifically highlights the attenuation change that occurs in the fiber optic cables after exposure to Cobalt 60 radiation.

Table 1 - Mitsubishi Radiation Data on Fiber Optics

dosage RAD	attenuation before radiation	attenuation change		
		immediately after radiation	1 hour after radiation	1 month after radiation
9,300	140 dB/km	408 dB/km	426 dB/km	154 dB/km
90,300	140 dB/km	474 dB/km	528 dB/km	185 dB/km
900,300	140 dB/km	2,917 dB/km	2,420 dB/km	153 dB/km

The Mitsubishi data shows that the fiber light attenuation immediately increases a significant amount when exposed to fairly high radiation levels. After one month, the fiber demonstrates a "self-healing" process that returns the attenuation value near the original. This data and our testing lead us to the conclusion that the low dose rates (20 - 200 MR per hour) at DOE facilities should result in 1) minimal attenuation increases when the dose is incurred and 2) very little long-term accumulated attenuation.

Data on Corning glass fiber optic cables was not available. However, several U.S. scientists who have tested both types of fiber optics believe that glass fiber optics perform better than plastic units. Another important factor in performance is the quality of glass used. An inferior glass product can perform poorly.

5.0 Available Tamper-Indicating Device Systems

The following section discusses four manufacturer's systems presently on the market that might be used to monitor secured containers within vaults. These systems employ various fiber optic and radio frequency technologies and offer unique sensing capabilities. In all four discussions, a 55-gallon drum will be used to discuss possible DOE applications. Although it may be desirable in some applications, we have not included in-line connectors for ease of loop opening. If three connectors are included, the maximum loop length is reduced by 20%. Individual system costs are also discussed.

5.1 Interactive Technologies, Inc. – The LightGard System

Interactive Technologies, Inc., (ITI) uses plastic fiber optics and radio frequency technologies in security systems for businesses and universities. These systems contain in-line fiber optic connectors for removing secured property (i.e., for inventory or property transfer). The ITI transceiver is designed to use a maximum of 150 feet of fiber optic cable and can protect up to 16 drums in an open shelf/large container vault (Figure 1).

The system's SX-V central processing unit (CPU) can handle 61 of the LightGard transceivers (zones) and is tied into a central station receiver (CSR). The CSR can handle 336,000 SX-Vs via secured phone line. The electronics of the LightGard pulses a light source through one end of the fiber optic loop. The same pulse should be seen through the other end of the loop which is connected to a light-sensing photo detector. If the pulse is not seen, an RF or hardwire signal is delivered to the SX-V that transmits a signal to the CSR.

The transceiver body enclosure measures 4" x 6.5" x 2.5" and provides three external LED indicators. The green is 'power on,' the red is the fiber-optic loop 'alarm,' and the yellow is the 'tamper switch' that alarms when the enclosure is lifted from a horizontal surface. Another internal switch alarms when the lid is removed.

Table 2 illustrates the ITI system components and their cost. As illustrated, one zone with 16 containers does not meet the $100 maximum average cost. However, three zones with 48 containers would cost $84 per container.

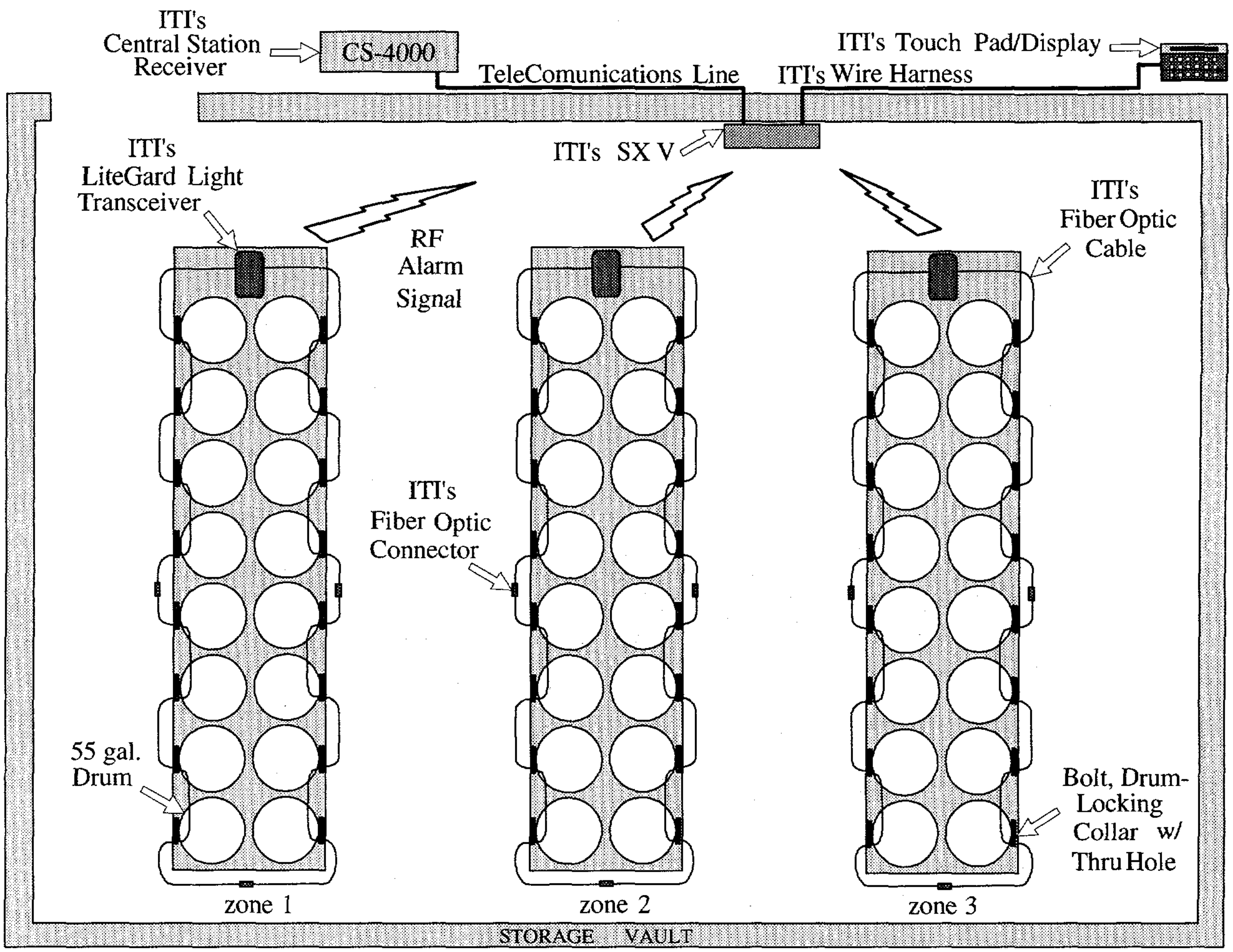

Figure 1 - ITI System Implementation

Table 2 - ITI Components and Cost Elements

Zones		1	3	10	30	61	122	244
Total Containers		16	48	160	480	976	1,952	3,904
Equipment	**Description**	**Cost**						
CS4000	Central Station Receiver	$2,950	$2,950	$2,950	$2,950	$2,950	$2,950	$2,950
SX-V	Central Processing Unit	$469	$469	$469	$469	$469	$938	$1,876
LightGard	Transceiver w/Fiber Optic Cable	$206	$618	$2,060	$6,180	$12,566	$25,132	$50,264
Total System Cost		$3,625	$4,037	$5,749	$9,599	$15,985	$29,020	$55,090
Cost Per Container		**$227**	**$84**	**$34**	**$20**	**$16**	**$15**	**$14**

5.2 Fiber SenSys, Inc. – Fiber Optic Intrusion Detection System

Fiber SenSys, Inc., (FSI) manufactures intrusion detection systems using a unique fiber optic technology developed by Corning, Inc. FSI uses these systems to provide underground perimeter and fence-mounted protection for corporate and government facilities. This system provides signal processing that differentiates natural phenomenon from an intruder. In addition, the glass fiber optic sensing cable can detect motion, vibration, and pressure changes along the entire length of the fiber optic loop.

Figure 2 illustrates the FSI system's assembly that could be used in a vault. The system could secure 100 containers in one zone using 656 feet of fiber optic cable.

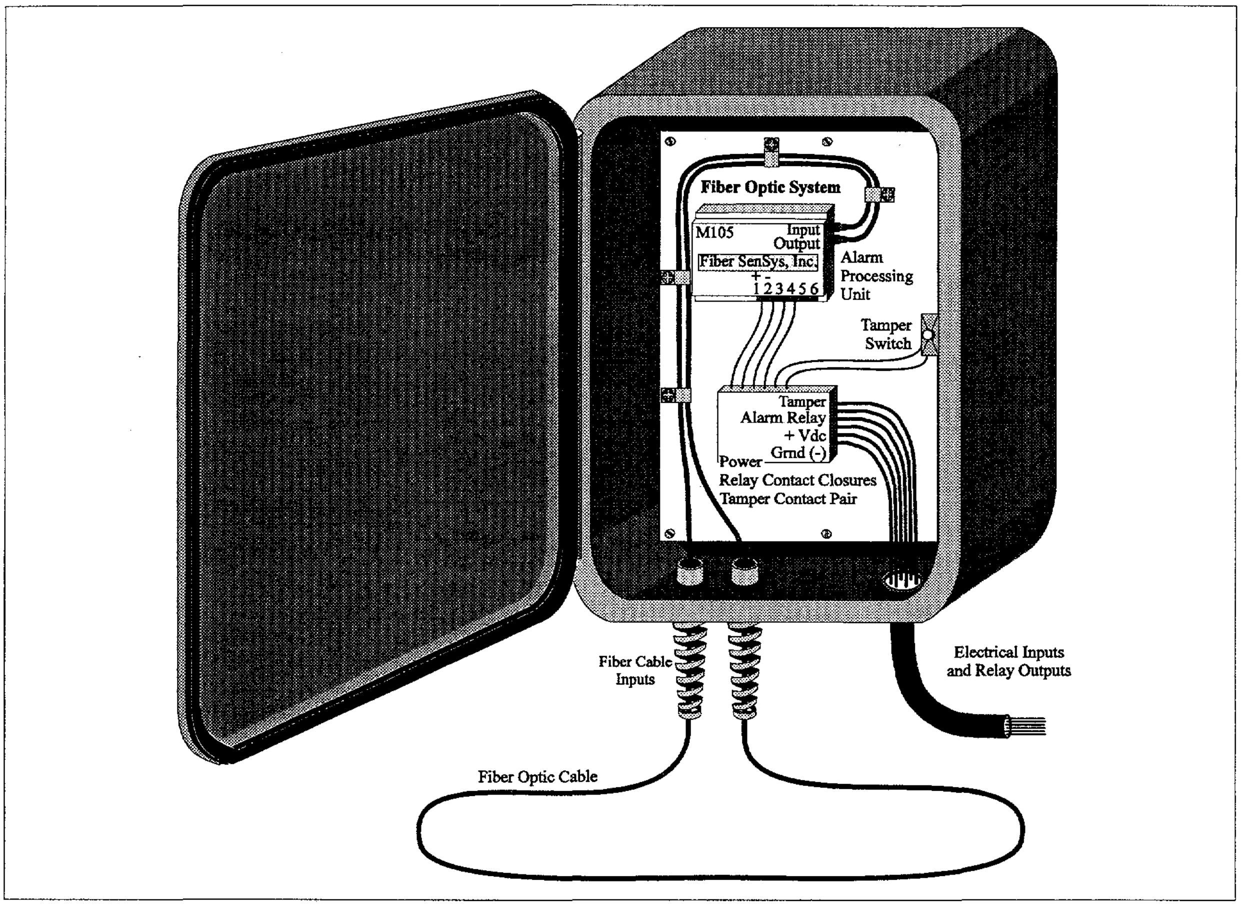

Figure 2 - FSI Fiber Optic System

The FSI system pulses a laser light source through one end of the fiber optic loop. The same pulse should be seen through the other end of the loop that is connected within the same RF unit. If the pulse is not as expected, a radio frequency or hardwire signal is delivered to the transceiver which in turn transmits a signal to a computer link. The alarm processing unit (APU) is radio frequency linked to a transceiver that can handle 100 APUs.

The FSI system requires a hand-held calibrator with a security key. The calibrator is a programming unit with an alphanumeric keypad and a two-line LCD display. The system also contains seven alarm processing parameters that are used to discriminate natural phenomena from an intruder. Figure 3 shows how this alarm process works.

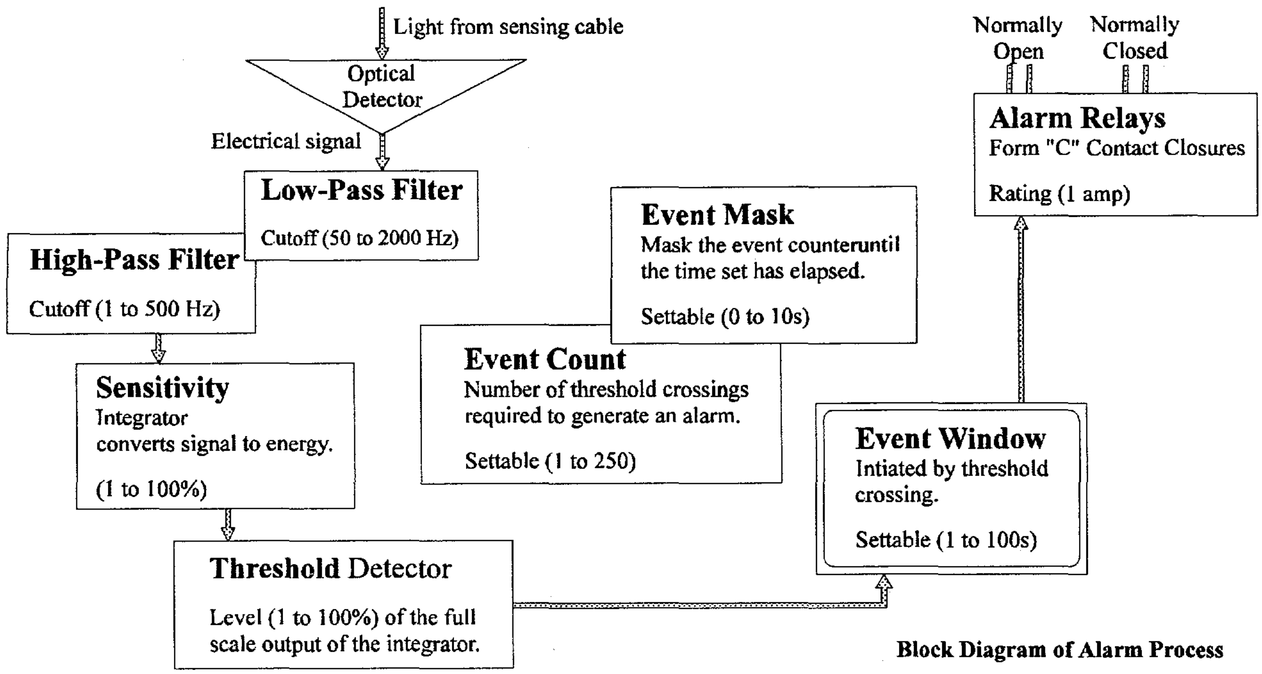

Figure 3 - FSI Alarm Process

Table 3 shows the FSI system components and their cost. As illustrated, one zone with 100 containers does not meet the $100 maximum average cost. However, two zones with 200 containers would cost $93 per container.

Table 3 - FSI Components and Cost Elements

	Zones	1	2	3	20	40	60
	Total Containers	100	200	300	2,000	4,000	6,000
Equip.	**Description**	**Cost**					
CPU	PC, Printer, Software	$4,000	$4,000	$4,000	$4,000	$4,000	$4,000
Annunicator Panel	Up to 100 zones	$3,500	$3,500	$3,500	$3,500	$3,500	$3,500
M105	Alarm processing card	$1,850	$3,700	$5,550	$37,000	$66,600	$99,900
SC-200	Fiber optic cable 656 ft. lengths	$550	$1,100	$1,650	$5,500	$5,500	$5,500
Calibrator	Hand calibrator for sensors	$1,350	$1,350	$1,350	$1,350	$1,350	$1,350
Transceiver RF Set	RF transceiver pair & antennas	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000
	Total System Cost	$16,300	$18,650	$21,050	$56,000	$84,000	$140,000
	Cost per container	**$163**	**$93**	**$70**	**$28**	**$21**	**$20**

5.3 Inovonics – Optical Tamper Sensor

The C-209 Optical Tamper Sensor (OTS) by Inovonics is a sensor manufactured for a single customer who requires a high-security, tamper-resistant unit. SNL's On-Site Monitoring Technology Department, in conjunction with Inovonics, is implementing a modified OTS unit into

Technology Department, in conjunction with Inovonics, is implementing a modified OTS unit into their Universal Authenticated Item Monitoring System (AIMS). The OTS is a plastic fiber optic seal sensor that uses up to 100 feet of fiber optics with a random-pulsing light and radio frequency link to an Inovonics C-403 serial receiver. This modified OTS is referred to as the AIMS Fiber Optic Seal (AFOS) sensor. The modifications provide the sensor with an authenticated radio frequency communication link that communicates with an RPU and a computer interface. However, due to the cost of the modified OTS and the RPU, it was decided to evaluate the OTS as received from Inovonics.

Figure 4 illustrates an Inovonics layout in a vault with stacked 55-gallon drums. The Inovonics C-403 serial receiver is hardwire connected to an RS-232 compatible serial port. The global outputs of the C-403 can indicate when any point in the system reports a fault or fails to report as expected. The programmable options of the C-403 are stored in an Electronically Erasable Programmable Memory. These options may be modified through the receiver's serial port that is connected to a serial port on a personal computer or other host device.

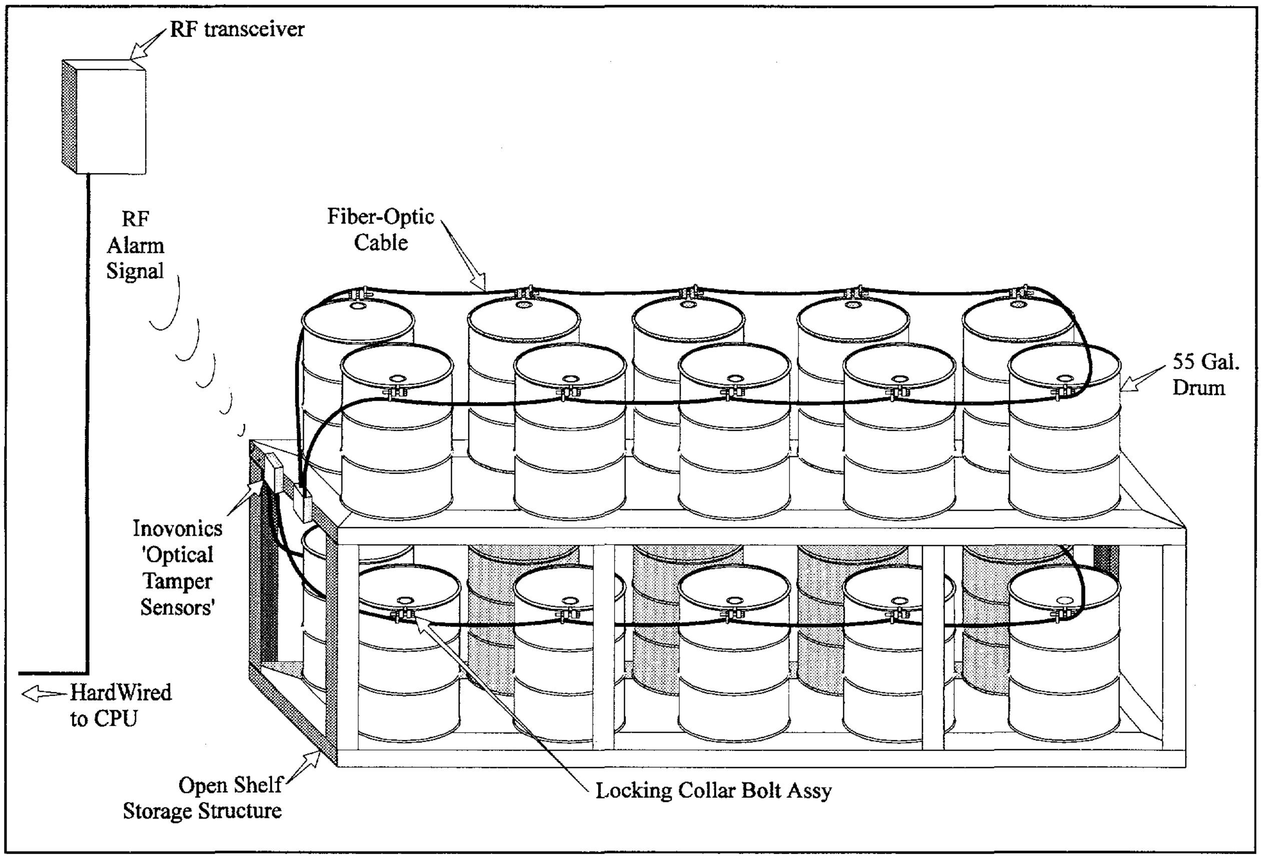

Figure 4 - Inovonics System Implementation

Table 4 illustrates the Inovonics system components and their cost. As applied in a similar fashion for the previous two systems, one zone with ten containers does not

Table 4 – Inovonics Components and Cost Elements

Zones:		1	10	20	40	60	80
Total Containers		10	100	200	400	600	800
Equipment	**Description**	**Cost**					
C209	Optic Tamper Sensor Setup Charge	$98 $258	$980 $258	$1,920 $258	$3,840 $258	$5,760 $258	$7,680 $258
Cable	100 ft. Fiber-Optic lengths	$29	$290	$580	$1,160	$1,740	$2,320
C403	RF Receiver Processing	$170 $2,000	$170 $2,000	$170 $2,000	$170 $2,000	$170 $2,000	$170 $2,000
Total System Cost		$7,386	$8,511	$9,761	$12,261	$14,761	$17,261
Cost per Container		**$739**	**$85**	**$49**	**$31**	**$25**	**$22**

5.4 Valve Security Systems, Inc. – Fiber Optic Sensor System

Valve Security Systems, Inc., (VSS) uses plastic fiber optics with hardwire power and communication links in their VSS 300B security system. Like the ITI System, the VSS unit contains in-line fiber optic connectors and a user-friendly connect/disconnect concept for removing secured property (for inventory or property transfer).

The Network Control Box (NCB) for the VSS system can be configured to accommodate up to 41 sensors (2,624 drums). It takes one single communication wire to carry the signal from the distribution box to the computer. The computer can process up to 10,000 VSS sensors while addressing each one individually.

As with the ITI and FSI systems, the fiber optic sensor electronically pulses a light source through one end of the fiber optic loop. The same pulse should be seen through the other end of the loop that is connected to a light-sensing photo detector. If the pulse is not seen, a hardwire signal is delivered to the NCB distribution box.

The VSS 300B fiber optic sensor provides an RS-485 multi-drop bus system where all the sensors can be connected in a series. Up to 60 sensors can be interconnected from this four-wire bus. The interconnection eliminates the need for separate connections between each sensor and a distribution device (a single connection terminates in the NCB). This connection may be extended up to 2,000 feet. In addition, each sensor can poll itself as often as desired to conduct self performance tests. The sensor also contains a supervised circuit that will detect a cable break as well as an LED light on the exterior body. This light indicates fiber optic continuity and whether the sensor is in monitoring mode.

Approximately 500 feet of fiber optic cable can be used with the system. Each loop can protect up to 80 drums in one zone. Figure 5 shows a wiring diagram of the VSS 300B system.

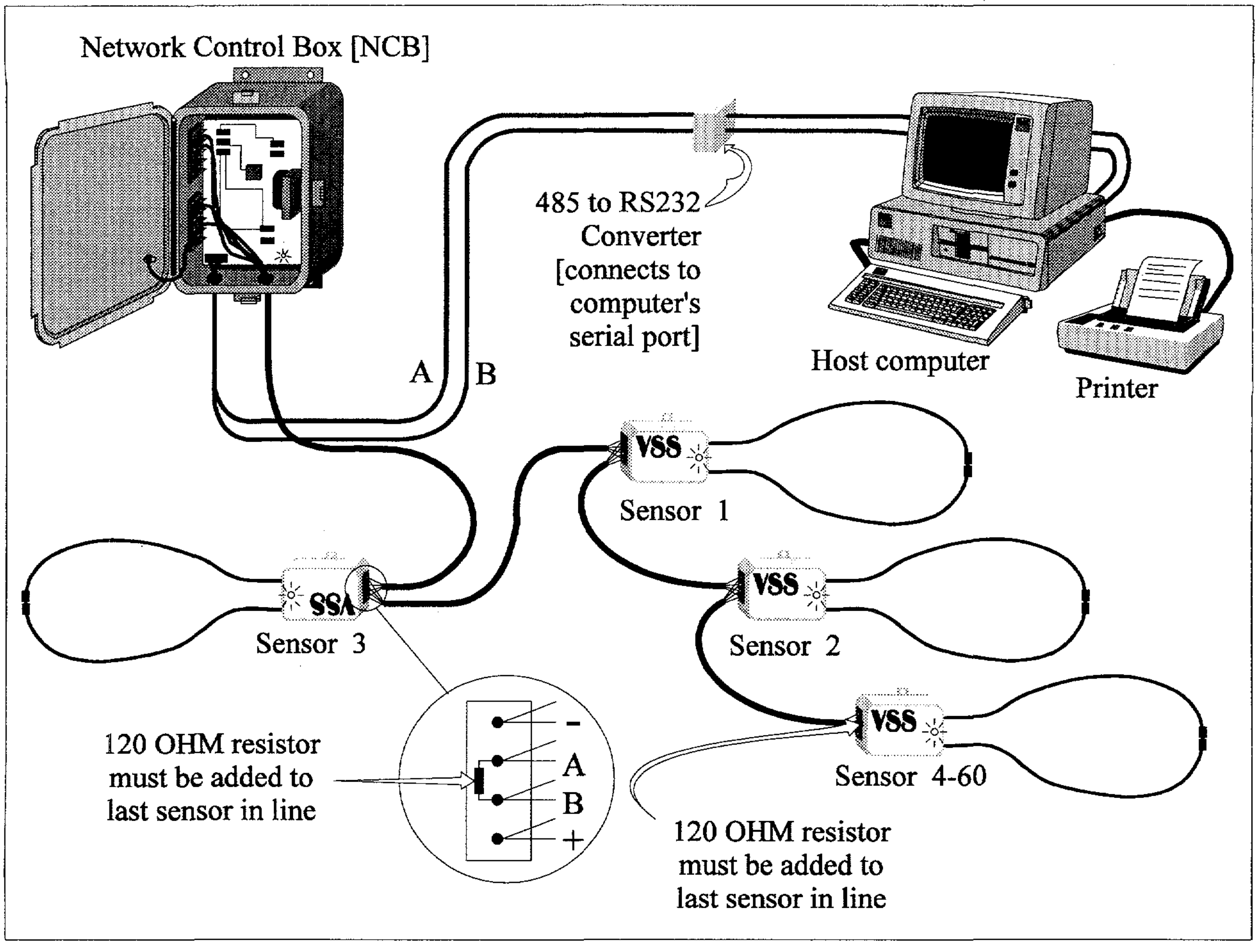

Figure 5 – VSS Wiring Diagram

Table 5 shows the VSS system components and their cost. As illustrated, one zone with 80_containers meets the $100 maximum average cost at $48 each.

Table 5 – VSS Components and Cost Elements

	Zones	1	7	10	20	80	100
	Total Containers	80	560	800	1,600	6,400	8,000
Equipment	**Description**	**Cost**					
VSS 300B	Sensor body 500 ft fiber optics	$514	$3,598	$5,140	$10,280	$41,120	$51,400
Model 3500	Network Control Box	$859	$859	$859	$859	$1,718	$1,718
	Receiver Processing Unit Software	$2,000 $500	$2,000 $500	$2,000 $500	$2,000 $500	$2,000 $500	$2,000 $500
	Total System Cost	$3,873	$6,957	$8,499	$13,639	$45,338	$55,618
	Cost per Container	**$48**	**$12**	**$11**	**$9**	**$7**	**$7**

6.0 Summary and Recommendations

Fiber optic products from four manufacturers were evaluated as tamper-indicating devices for DOE use even though the manufacturer's intended use of their product might be for some other purpose. The four products tested were:

- The Fiber SenSys, Inc. – *M105 Intrusion Detection System*, used mainly for exterior perimeter security.

- Inovonics, Inc. – *C-209 Optical Tamper Sensor*, used as a personnel tracking device in private industry.

- Interactive Technologies, Inc. – *LightGard*, used by businesses and universities to secure property (computers, etc.) for inventory and theft protection.

- Valve Security Systems – *VSS-300B Fiber Optic Sensor,* developed for hospital valve monitoring of exotic gases. The Navy is now testing the system on the *USS Kitty Hawk* for fuel ballast transfer and for ship refueling. VSS also advertises their sensors for computer anti-theft detection and inventory.

The tamper-indicating devices used are either glass fiber optics or plastic fiber optics with electronics that indicate a tamper through radio frequency and/or hardwire communications. They must meet the following specifications:

- reasonable cost
- resistance to environmental conditions (must remain functional and viable for at least 2 years subsequent to installation)
- ability to secure a variety of containers or storage cabinets
- ability to indicate attempts to tamper with the device
- relative ease and speed of application
- ability to fit a variety of containers

Table 6 compares some of the features of the four systems evaluated. All four passed the temperature and humidity tests, and we expect that all four will operate successfully for long periods of typical DOE storage radiation exposure. The electronics in the FSI and Inovonics systems are probably more susceptible to radiation-damage failure than the electronics in the other systems. In our tests, the two memory chips, Electronically Erasable Programmable Memory and the AC-11 microprocessor with on-board memory, were erased by the gamma radiation.

Table 6 – Active Seal Technologies Feature Comparison Matrix

DESCRIPTION	Interactive Technologies, Inc.	Fiber SenSys, Inc.	Inovonics Corporation	Valve Security Systems
Light Source	LED	Laser	LED	LED
Fiber Optic Motion, Vibration & Pressure Sensing Cable		X		
Fiber Optic Optical Continuity	X		X	X
Random Pulsing Light Source	X	X	X	X
Maximum Fiber Optic Cable Length Per Loop	150 ft	656 ft	100 ft	500 ft.
Uses Glass Fiber Optic Cable		X		
Uses Plastic Fiber Optic Cable	X		X	X
Signal Processing for Natural Phenomenon Disturbances		X		
Circuit Card Contact Tamper Switch / Alarm	X		X	
Number of Containers Protected to Reach $100 Cost Factor	41	187	86	39
Motion Sensor Add-On Capabilities	X	built in	X	
Hand-Held Calibrator w/ Security Key		X		
Alpha/Numeric Keys with Alpha/Numeric Display Unit	X			

Table 7 shows the ranking of the seals tested where "1" represents the best rating in that particular category. All of the seals could be defeated by the vulnerability analysts if they were allowed an unconstrained environment, but none could be readily defeated in the two-person environment.

Table 7– Active Seal Technologies Comparison

Manufacturer	Cost Factor	Climatic Test	Radiation Test	Tamper Resistance
FSI	4	1	2	1
ITI	2	1	1	2
Inovonics	3	1	2	3
VSS	1	1	1	4

It seems that the primary trade-offs to be made are between the cost and level of protection desired. The systems that provide higher tamper resistance are more sophisticated and, therefore, more expensive. Other factors may also enter into selection decisions such as 1) VSS and ITI support other types of sensors, and 2) Inovonics presently uses only short fiber loops but FSI uses very long loops.

In conclusion, we believe that any of the four systems can meet some current DOE needs and recommend that all be considered for use at DOE facilities. Which systems to use will be strongly driven by the particular storage configuration. Another major consideration is the system's ability to integrate with other elements to provide balanced, complete protection of SNM in a vault situation.

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Safeguards and Security
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PO Box 808
Livermore, CA 94550

1 Interactive Technologies, Inc.
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1 K. J. Heidemann, Director
U.S. Department of Energy/RF
Safeguards and Security Division
PO Box 928
Golden, CO 80402-0928

6 SAIC
Attn: F. D. James(1)
Attn: R. E. Kellam(1)
Attn: M. Castro(1)
Attn: G. Agurio(1)
Attn: G. Nelson(1)
Attn: D. J. Frank(1)
PO Box 928
Golden, CO 80401

1 G. P. Morgan, Director
U.S. Department of Energy
Western Area Power Administration
Division of Energy Services and Security Affairs, A0410
1667 Cole Boulevard, Bldg 18
Golden, CO 80401-0456

1 James Hartman, Assistant Manager
Site Support and Security
U.S. Department of Energy/RF
PO Box 958, Bldg 115
Golden, CO 80402-0464

1 Chief of Security Police
Air Force Space Command
Peterson Air Force Base
Colorado 80914-5001

1 James W. Atherton, SA
Federal Bureau of Investigation
Washington Field Office
10th Street and Pennsylvania Ave. NW
Washington, DC 20537

1 Raymond Brady, Director
U.S. Nuclear Regulatory Commission
Division of Security
Washington, DC 20555

1 Fred Branch, Chief - Physical Security Branch
U.S. Department of State
DS/PSD Room 804, SA6
Washington, DC 20520

1 Robert Burnett, Director
U.S. Nuclear Regulatory Commission
Div. of Fuel Cycle, Safety, & Safeguards,NMSS
Mail Stop 8-A-33 TWFN
Washington, DC 20555

1 Director, Systems Protection
OASD (C3I), DASD (I&S), CI&SP, 3C260
6000 Defense Pentagon
Washington, DC 20301-6000

1 Central Intelligence Agency
Director, Office of Security
202 Jefferson
Washington, DC 20505

1 Priscilla A. Dwyer
U.S. Nuclear Regulatory Commission
Div. of Fuel Cycle, Safety & Safeguards, NMSS
Washington, DC 20555

1 Tom Fey
U.S. Department of State
DS/PI/PRD, State Annex 1
2201 C Street NW
Washington, DC 20520

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National Aeronautics and Space Administration
Security Office (NIS)
Washington, DC 20546

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Federal Bureau of Prisons
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Washington, DC 20534

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U.S. Nuclear Regulatory Commission
Division of Inspection Programs
Washington, DC 20555

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1340 Air Force
The Pentagon
Washington, DC 20330-1340

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1340 Air Force
The Pentagon
Washington, DC 20330-1340

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1 Michael Toscano, Chairman
DoD Physical Security Equipment
Advisory Group, OUSD (A&T)
The Pentagon, Room 3B1060
Washington, DC 20301

1 Stanley W. Zack, Jr.
Federal Bureau of Investigation
Washington Field Office
10th Street and Pennsylvania Avenue NW
Washington, DC 20537

1 HEADQUARTERS, PACAF/SPPA
Attn: Director, Plans and Programs
Hickam Air Force Base, Hawaii 96853

1 B. G. Essary, General Manager
Protection Technologies of Idaho
785 DOE Place
Idaho Falls, ID 83402

1 Richard L. Green, Director
U.S. Department of Energy/ID
Safeguards and Security Division
785 DOE Place
Idaho Falls, ID 83402

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Safeguards and Security
Attn: E. L. Goldman, Manager(1)
Safeguards and Security Technical Operations
Attn: Roger O. Cook, Supervisor(1)
Security Equipment Systems
PO Box 1624
Idaho Falls, ID 83415

1 Bruce Meppen, Manager
Safeguards and Security
U.S. Department of Energy
Argonne National Laboratory, Idaho Site
PO Box 2528
Idaho Falls, ID 83403-2528

1 Charleton Bingham, Director
U.S. Department of Energy/CH
New Brunswick Laboratory
Safeguards and Security Division
Argonne, IL 60439

1 Thomas Gradle, Director
U.S. Department of Energy/CH
Safeguards and Security Division
Argonne, IL 60439

2 Argonne National Laboratory
Attn: K. W. Poupa (1)
Attn: D. G. Erick (1)
9700 South Cass Avenue
Argonne, IL 60439

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Fermi National Accelerator Laboratory - MS 102
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Boeing Petroleum Services
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Security and Emergency Management
Kansas City, MO 64141-6159

1 Commanding General
USAJFKSWCS / SOTIC
Fort Bragg, NC 28307-5000

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1st SOCOM
ODCOPS-Special Projects
Fort Bragg, NC 28307

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Department of the Army
1st Special Forces Operational, Det-Delta
Fort Bragg, NC 28307-5000

1 John Trout
U.S. Army Corps of Engineers, MROED-S
215 North 17th Street
Omaha, NE 68102

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Newark, NJ 07107

2 U.S. Department of Energy
Safeguards and Security
Central Training Academy
Attn: Stan Laktasic
Attn: Walter Strohm
PO Box 18041
Albuquerque, NM 87185

1 U.S. Department of Energy, SNSD/AL
Attn: Ms. Linda L. Mueller, Acting Director
Security and Nuclear Safeguards Directorate
PO Box 5400
Albuquerque, NM 87185

1 U.S. Department of Energy, AL
Attn: Lou Gutierrez
PO Box 5400
Albuquerque NM 87185

1 HEADQUARTERS, AFSPA/SPS
Attn: Col David M. Taylor, USAF
Director, Physical Security
8201 H Avenue SE
Kirtland Air Force Base
New Mexico 87117-5664

1 Director of Operations (SPO)
Air Force Agency Security Police
Kirtland Air Force Base
New Mexico 87117-5000

1 D. B. Smith, N-DO/SG
Los Alamos National Laboratory
Mail Stop: E550
PO Box 1663
Los Alamos, NM 87545

1 E. Wayne Adams, Director
Safeguards and Security Division
U.S. Department of Energy/NV
PO Box 98518
Las Vegas, NV 89193-8518

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Attn: Electronics Department
PO Box 93838
Las Vegas, NV 89193-3838

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1 George G. Stefani, Jr., Director
Safeguards and Security Division
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Schenectady Naval Reactors Office
PO Box 1069
Schenectady, NY 12301

2 U.S. Department of Energy
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Attn: Kris Dahms, Bldg 703 (1)
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Upton, NY 11973

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Attn: J. P. Kelly
PO Box 825
Nyack, NY 10960

1 485th EIG/EICI
Griffiss Air Force Base
New York 13441-6348

1 Daniel Baker, Security Manager
EG&G Mound
PO Box 3000
Building 99
Miamisburg, OH 45342

1 J. M. Miller, Manager
Westinghouse Materials Company of Ohio
Safeguards and Security
PO Box 898704
Cincinnati, OH 45239

1 Battelle Memorial Institute
Nuclear Services
Attn: H. Toy, Manager
Columbus, OH 43201

1 Robert L. Windus, Security Manager
U.S. Department of Energy/BP
PO Box 3621
Portland, OR 97208

1 J. A. Bullian, Director
U.S. Department of Energy/PNR
Safeguards and Security Division
PO Box 109
West Mifflin, PA 15122

1 Advantage Technology, Inc.
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PO Box 10155
Lancaster, PA 17605-0155

1 A. H. Hopfinger, Manager
Laboratory Operational Safeguards, 62M
Bettis Atomic Power Laboratory
Westinghouse Electric Corporation
Box 79
West Mifflin, PA 15122-0079

2 Westinghouse Savannah River Company
Attn: J. W. Dorrycott, Division Manager (1)
Safeguards, Security, & Emergency Preparedness
Attn: R. E. Gmitter, Manager (1)
Safeguards and Security Programs
PO Box 616
Aiken, SC 29802

4 U.S. Department of Energy/SR
Office of Safeguards and Security
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Attn: Larry Ogletree, Director (1)
Safeguards Engineering and Projects Br.
Attn: Tom Williams, Branch Chief (1)
Safeguards and Classification
Attn: Steve Shelt (1)
Information and Protection Branch
PO Box A
Aiken, SC 29802

1 W. L. Clements, Division Manager
Martin Marietta Energy Systems
Y-12 Safeguards and Security
Bldg 9706-1, MS 8212
Oak Ridge, TN 37831-8213

1 Oak Ridge National Laboratory
Attn: M. H. Ehinger
PO Box 2008
Oak Ridge, TN 37831

3 Martin Marietta Energy Systems
Y-12 Safeguards and Security
Attn: M. Fuller(1)
Attn: Cathy Key(1)
Attn: Chris Pickett (1)
Oak Ridge, TN 37831-8213

1 William G. Phelps, Director
U.S. Department of Energy/OR
Safeguards and Security Division
PO Box 2001
Oak Ridge, TN 37831-857

1 James J. Hallihan, Director,
Safeguards and Security, Pantex Plant
Mason and Hanger-Silas Mason Company, Inc.
PO Box 30020
Amarillo, TX 79177-001

1 Chief of Security Police
Air Force Intelligence Command
Kelly Air Force Base, Texas 78243-5000

1 Belvoir Research, Development, & Engr. Center
Product Manager, Physical Security Equipment
Attn: AMCPM-PSE
Fort Belvoir, VA 22060-5606

2 Belvoir Research, Development, and Engineering Center
Attn: STRBE-JI (A. Zushin)(1)
Attn: STRBE-ZM (J. M. Hale)(1)
Fort Belvoir, VA 22060-5606

1 Jerry Edwards
U.S. Army PSEMO
Attn: AMSAT-W-TP -BRDEC
Fort Belvoir, VA 22060-5606

1 William J. Witter
Defense Nuclear Agency (NOSA)
6801 Telegraph Road
Alexandria, VA 22310-3398

1 Craig Walton, Manager
Westinghouse Hanford Company
Safeguards and Security Division
PO Box 1970, Mail Stop L4-01
Richland, WA 99352

1 J. L. Spracklen, Director
U.S. Department of Energy/RL
Safeguards and Security Division
PO Box 550, Mail Stop A6-35
Richland, WA 99352

4 Pacific Northwest Lab
Attn: O. Amacker, Jr.(1)
Attn: S. Gordy(1)
Attn: J. Griggs(1)
Attn: J. Abraham(1)
PO Box 999
Richland, WA 99352

1 VSS Fiber Optic Sensors
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