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The Potential Use of Domestic Safeguards Interior Monitors in International Safeguards‡

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Abstract

An important future element of International Safeguards instrumentation is expected to be the merging of containment/surveillance and nondestructive assay equipment with domestic physical protection equipment into integrated systems, coupled with remote monitoring. Instrumentation would include interior monitoring and assessment and entry/exit monitoring. Of particular importance is the application of interior monitors in spaces of declared inactivity; for example, in nuclear material storage locations that are entered infrequently. The use of modern interior monitors in International Safeguards offers potential for improving effectiveness and efficiency. Within the context of increased cooperation, one can readily envision increased interaction between International Safeguards and Domestic Safeguards, including increased joint use of State System of Accounting and Control data.

Introduction

An important element of safeguards instrumentation is expected to be the merging of containment/surveillance, nondestructive assay, and domestic physical protection equipment into integrated systems, coupled with remote monitoring. Of special interest is the application of these interior monitors in locations of declared inactivity; for example, in nuclear material storage locations that are entered infrequently. New domestic safeguards technologies with potential application to International Safeguards are emerging. However, in order to use the existing and emerging technologies, some effort will be required to achieve proper system integration and operation with minimal false alarms. Of course, any consideration of the use of Domestic Safeguards elements in International Safeguards will require avoidance of all issues related to sensitive data. Nevertheless, it is distinctly possible that many elements of Domestic Safeguards could find dual use in International Atomic Energy Agency (IAEA) Safeguards. Such use, coupled with remote monitoring, could significantly increase the effectiveness and efficiency of IAEA Safeguards.

Interior monitors for Domestic Safeguards use include motion sensors designed to detect the motion of an intruder within a confined interior protected region. These instruments may utilize ultrasonic, microwave, infrared, audio, electric-field, active sonic, light-level, and video motion phenomena. Boundary penetration sensors are designed to detect penetration of the boundary of a protected region. These include vibration, capacitance proximity, passive audio, ultrasonic, wire grid, metal foil, glass-break, continuity, infrasonic, light-beam, magnetic switch (balanced and simple), passive sonic, passive ultrasonic, seismic, and door and window sensors. Point sensors include capacitance monitors, proximity instruments, pressure switches, and strain gauges. Basic detection phenomena for these sensors include portal opening; breaking through an exterior boundary such as a wall, floor, or ceiling; radial or traverse

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motion; and physical contact with a monitored item. Much technology is available to support the use of interior monitoring equipment, and extensive experience has been accumulated in its use.

Effective utilization of this technology is not just an "out-of-the-box" operation. In Domestic Safeguards, the integration of individual sensors into an interior sensor system must consider the skill level of the intruder, the design goals, and the effects of environmental conditions, as well as the interaction of the interior system with a balanced and integrated physical protection system. Prior to implementing any equipment a small team of experts should conduct facility evaluations and produce system designs that lead to optimal utilization of the interior monitoring systems. When applying this equipment to International Safeguards, the IAEA should consider the use of such teams, possibly through the various support programs. Additional synergy between Domestic and International Safeguards might include the evaluation and certification of domestic measurement equipment for IAEA use, the authentication of Domestic Safeguards data for IAEA use, and the international monitoring agencies assuming responsibility for domestic inventory verification to lengthen inspection intervals.

Interior Intrusion Sensors

Sensors that monitor intrusions into buildings or enclosed structures have been available for many years. Significant improvements in the performance characteristics of these sensors, as well as test techniques and application understanding, have recently been made. An example interior layout is illustrated in Figure 1.

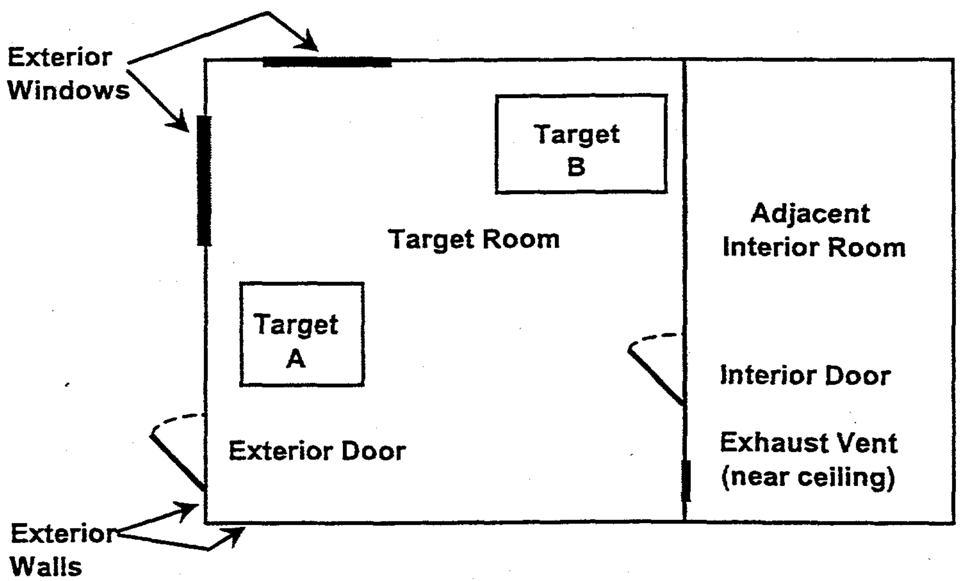

Figure 1. Example interior layout

Intrusion sensor performance is described by three fundamental characteristics: probability of detection (P_D), nuisance alarm rate, and vulnerability to defeat.

Probability of Detection–P_D. For the ideal sensor, the P_D of an intrusion is 1.0. That is, it has a 100 percent P_D. However, no sensor is ideal, and the P_D is always less than 1.0. The probability of detection for interior sensors depends primarily upon:

- target to be detected
- sensor hardware design
- installation and placement conditions
- sensitivity adjustment
- condition of the equipment

Because all of these conditions can vary, P_D is a conditional probability. Thus, despite some sensor manufacturers' claims, a specific P_D cannot be assigned to a component of sensor hardware.

Nuisance Alarm Rate. A nuisance alarm is any alarm that is not caused by an intrusion. In an ideal sensor system, the nuisance alarm rate would be 0.0. However, in the real world, all sensors interact with their environment, and in some cases they cannot discriminate between intrusions and other events in their detection zone. Hence, alarm assessment is a critical element in detection systems: not all sensor alarms are caused by intrusions.

Vulnerability to Defeat. An ideal sensor could not be defeated; however, in reality all sensors can be defeated. The objective of the physical protection system designer is to make the system very difficult to defeat. There are two general ways to defeat the system:

- Bypass—All intrusion sensors have a limited detection zone. Any sensor can be defeated by going around its detection volume.

- Spoof—Spoofing is any technique that allows the target to pass through the sensor's normal detection zone without generating or reporting an alarm.

Sensors may be grouped by their application in the physical detection space. Some sensors may be applied in several ways. There are three application classes: 1) boundary-penetration sensors, which detect penetration of the boundary to an interior location; 2) interior motion sensors, which detect motion of an intruder within a confined interior volume; and 3) point sensors, which detect an intruder in the location immediately on or adjacent to an object in an interior region.

Boundary-Penetration Sensors. This class of sensors includes vibration, electromechanical, infrasonic, capacitance proximity, and passive sonic sensors. The portion of the building best protected by boundary penetration sensors is the shell: walls, floor, ceiling doors, windows.

Vibration Sensors. Vibration sensors detect the movement of the surface to which they are fastened. A human blow or other sudden impact on a surface will cause that surface to vibrate at a specific frequency determined by its construction. The vibration frequencies are determined to a lesser extent by the impacting tool.

The primary application advantage of vibration sensors is that they provide early warning of a forced entry. When applying vibration sensors, the designer must be aware that the detector might generate nuisance alarms if mounted on the walls or structures that are exposed to external vibrations. If the structures are subject to severe vibrations caused by external sources such as rotating machinery, vibration sensors should not be used. If the structures are subject only to occasional impacts, vibration sensors with a pulse accumulator or count circuit might be effective.

Electromechanical Sensors. The most common type of electromechanical sensor is a relatively simple switch generally used on doors and windows. The most common of these switches is the magnetic switch, consisting of two units: a switch unit and a magnetic unit.

Balanced magnetic switches provide a higher level of protection for doors and windows than either magnetically or mechanically activated contacts or tilt switches. The protection, however, is only as good as the penetration resistance of the door or window. These sensors are only adequate if the intruder opens the door or window for entry.

Infrasonic Sensors. Infrasonic sensors operate by sensing pressure changes in the volume where they are installed. For example, a slight pressure change occurs whenever a door leading into a closed room is opened or closed. The sound pressure waves thus generated have frequencies below 2 Hz. The sensors are passive sensors that can be centrally located in a building some distance from exit doors. Air blowing into the closed volume can cause nuisance alarms with an infrasonic sensor.

Capacitance Proximity Sensors. Capacitance proximity sensors establish a resonant electrical circuit between a protected metal object and a control unit. The capacitance between the protected metal object and ground becomes a part of the total capacitance of a tuned circuit in an oscillator. The tuned circuit may have a fixed frequency of oscillation, or the oscillator frequency may vary. This type of sensor is used to detect boundary penetration through existing openings such as grills and ventilation ducts or metal window frames and doors.

Passive Sonic Sensors. Passive sonic sensors use a microphone to detect sounds generated within their range. It is one of the simplest intrusion detectors.

Active Infrared Sensors. Active infrared sensors establish a beam of infrared light using an infrared light source or sources (mated with appropriate lenses) as the transmitters and photodetectors for receivers. Several transmitters and receivers are normally used to provide a system with multiple beams, and the beams are usually configured into a vertical infrared fence. A pulsed synchronous technique may be used to reduce interference and the possibility of defeat by other sources of light. Infrared sensors are susceptible to several nuisance alarm sources.

Interior Motion Sensors. Interior motion sensors may use several different types of technology.

Microwave Sensors. Microwave sensors establish an energy field using energy in the electromagnetic spectrum, usually at frequencies on the order of 10 GHz. Interior microwave motion sensors are nearly always in the monostatic configuration with a single antenna being used to both transmit and receive. Intrusion detection is based on the frequency shift between the transmitted and received signal caused by the Doppler effect from a moving object in the beam. The shape of the detection zone is governed by the design of the antenna and is approximately a prolate spheroid.

The fact that microwave energy can penetrate walls has both advantages and disadvantages. An advantage occurs when an intruder is detected by the microwave energy penetrating partitions within a protected volume; but detecting someone or something moving outside the protected volume, or even outside the building, is then a disadvantage and would cause a nuisance alarm. Because microwave energy is difficult to contain, special care should be taken when locating and directing the energy within the volume requiring protection.

Ultrasonic Sensors. Ultrasonic sensors establish a detection field using energy in the acoustic spectrum typically in the frequency range of 19 and 40 kHz. Ultrasonic sensors may be monostatic, and as is the case with monostatic microwave sensors, detection is based on the frequency shift between the transmitted and received signal caused by the Doppler effect from an object moving in the beam. The magnitude and range of the frequency shift depend on the moving target's size, velocity, and direction. The shape of the detection zone is similar to the monostatic microwave sensor detection zone, but the effective shape can be changed by the installation of deflectors.

Mechanically produced stimuli such as air turbulence or miscellaneous acoustic energy sources within the protected zone can cause nuisance alarms. Acoustic energy generated by ringing bells and hissing noises, such as the noises produced by leaking radiators or compressed air, contains frequency components in the operating frequency band of ultrasonic sensors. These sources of ultrasonic energy sometime produce signals similar to an intruder that can confuse the signal processor and cause nuisance alarms. Another environmental condition that can affect ultrasonic sensor performance is the climate within the protected zone.

Active Sonic Sensors. Sonic sensors establish a detection field using energy in the acoustic spectrum at frequencies between 500 and 1000 Hz. These units can be used in monostatic, bistatic, or multistatic modes of operation. Since a frequency well below the ultrasonic is used, good reflections are obtained, and standing waves will be established in the protected volume even in the monostatic configuration. For proper operation, it is necessary to establish standing waves to prevent drastic reduction of the detection range.

Passive Infrared Sensors. Passive infrared sensors respond to the energy emitted by a human intruder, which is approximately 50 W. They also detect changes in the background thermal energy caused by someone moving through the detector field of view and shadowing the energy emanating from the objects in the background. These systems typically employ special optical and electronic techniques that limit their detection primarily to an energy source in motion.

Infrared sensors should be located away from any heat sources that could produce thermal gradients in front of the sensor lens. These sensors should be removed or directed away from any intermittent hot spots in the detector field of view. For instance, an infrared detector should never be mounted over or near radiators, heaters, or hot pipes. Radiant energy from these sources can produce thermal gradients in the detector lens view that might change the background energy pattern. Depending on the intensity of the heat source, the thermal gradients might cause nuisance alarms. An unshielded incandescent light that is within 3–5 m of the sensor might also cause an alarm if it is turned on or off or burns out.

Dual-Technology Sensors. These sensors strive to achieve absolute alarm confirmation while maintaining a high P_D. Ideally, absolute alarm confirmation is achieved by combining two technologies that individually have a high P_D and no common nuisance alarm-producing stimuli. Currently available dual-channel motion detectors combine either an active ultrasonic or microwave sensor with a passive sensor. When used in combination, alarms from either the active ultrasonic or microwave sensor are logically combined with the alarms from the infrared sensor in an AND gate logic configuration. The AND gate logic requires nearly simultaneous alarms from both the active and passive sensors to produce a valid alarm.

Dual-technology sensors usually have a lower nuisance alarm rate than single-technology sensors if the detectors are properly applied. Of course, each sensor must separately have a low nuisance alarm rate. However, when two sensors are logically combined using AND, the P_D by the combined detectors will be less than the P_D by the individual detectors.

Point Sensors. Capacitance and pressure sensors are two useful point sensors.

Capacitance Proximity Sensors. Capacitance proximity sensors can detect intruders either approaching or touching metal items or containers that the sensors are protecting. These sensors operate on the same principle as electrical capacitors. A capacitor is an electronic component that consists of two conductor plates separated by a dielectric medium. A change in the electrical charge or dielectric medium results in a change in the capacitance between the two plates. In the case of the capacitance proximity sensor, one plate is the metal item being protected, and the second plate is an electrical reference ground plate under or around the protected item. The metal item in this application is isolated from grounding by insulating blocks. This leaves only air around and between the metal object and ground. Therefore, air is the dielectric medium.

Pressure Sensors. Pressure sensors, often in the form of mats, can be placed around or underneath an object. These sensors are passive, covert, and line detectors. Pressure mats comprise a series of ribbon switches positioned parallel to each other along the length of the mat. Ribbon switches are constructed from two strips of metal in the form of a ribbon separated by an insulating material. When an adequate amount of pressure, depending on the application, is exerted anywhere along the ribbon, the metal strips make electrical contact and initiate an alarm.

Sensor Research. Research is underway in the field of microsensors. Such sensors are inexpensive, reliable, and extremely low power. Microsensors, when produced in quantity, may be considered "throw-away" and be used in both temporary and quasi-permanent applications. Their small size and low power requirements may make them amenable to high levels of redundancy. This could greatly increase coverage of both interior monitor systems and item monitoring. Microsensors can be used for chemical detection, which could assist future IAEA activities in environmental monitoring. Small, inexpensive radiation sensors are under development and might be useful for a variety of IAEA applications. Microsensor research is in its infancy. Opportunities abound for microsensors to reduce the cost of sensors used for safeguards applications, while concurrently increasing their lifetime and reliability.

Sensor Selection

Generally, optimal sensor performance can be obtained by matching sensor attributes to the environment in question. Interior location environments are normally controlled and, therefore, more predictable and measurable. However, correct sensor choice requires that the particular nuisance alarm stimuli to which it is susceptible be known, in addition to whether these stimuli are actually present in the environment in question. This is particularly true of the motion detectors, all of which can be installed to provide acceptable detection coverage and which typically experience nuisance alarms from different stimuli. A possible arrangement of these interior sensors is illustrated in Figure 2 as applied to the example layout previously shown in Figure 1.

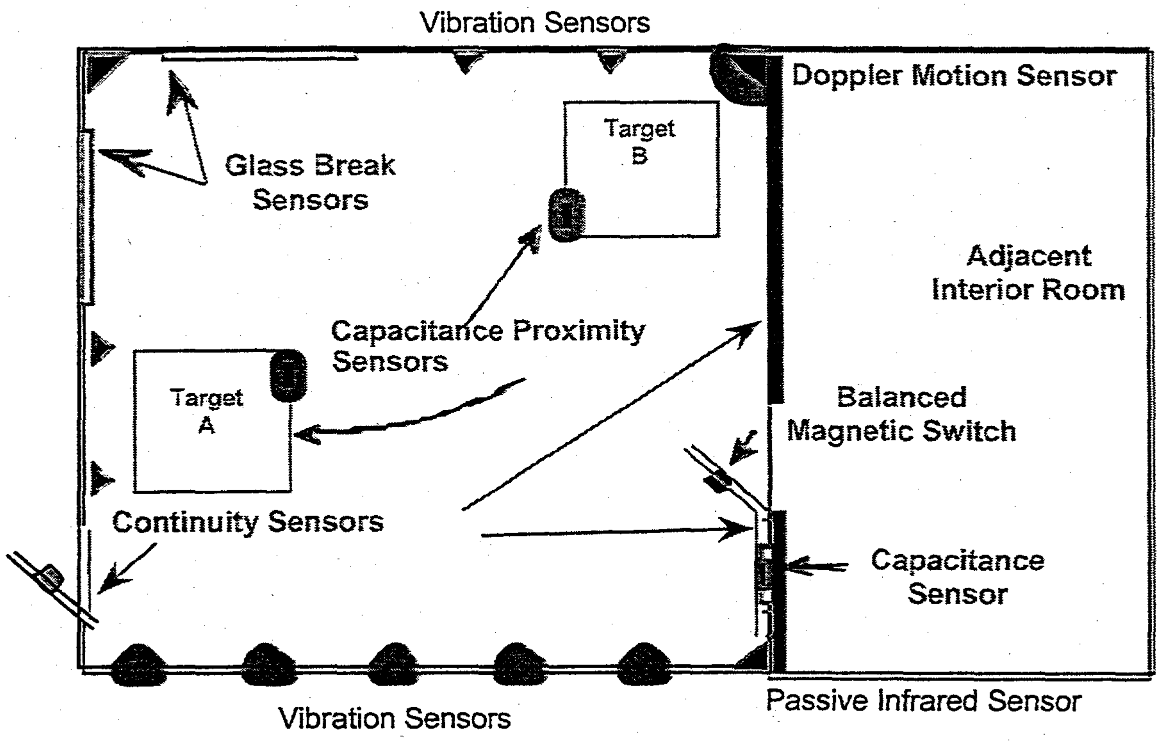

Figure 2. Possible arrangement of interior sensors for example layout

The major characteristics of several types of interior sensors suitable for fixed-site applications are shown in Figure 3.

Application	Operating Principle	Detection: Portal Opening	Detection: Breaking Through Wall/Floor/Ceiling	Detection: Radial Motion	Detection: Transverse Motion	Detection: Touching Object	Conditions Causing Unreliable Detection	Typical Defeat Methods	Nuisance Alarms: Air Humidity/Temp/Velocity (wind)	Nuisance Alarms: Localized Heating (sunlight)	Nuisance Alarms: Movement Greater Than 0.025 meter/sec	Nuisance Alarms: Movement Outside Area (vibration)	Nuisance Alarms: Fluorescent Lights	Nuisance Alarms: Loose-Fitting Doors	Nuisance Alarms: Mount Vibration	Nuisance Alarms: Ambient Acoustic Noise (lightning/thunder)	Nuisance Alarms: Animals	Nuisance Alarms: RFI (radio transmitter)
Boundary-Penetration	Balanced Magnetic	X					Improper installation	Stay behind intruder or enter through unprotected area						X				
	Vibration		X									X			X			
	Continuity		X															
	Infrasonic	X	X						X					X				
Motion	Sonic	X		X	X		Accoustic background	Disable electronics	X		X				X	X	X	
	Ultrasonic	X		X			Air movement	Cover when sensor is in access	X		X				X	X	X	
	Microwave	X		X			RF				X	X	X		X		X	X
	Infrared				X		Unstable thermal background			X					X		X	X
Proximity	Capacitance					X	Gross changes in relative humidity, tempera-ture, or pressure	Disable electronics	X								X	
	Strain					X											X	
	Pressure Pad					X											X	

Figure 3. Characteristics of interior sensors suitable for fixed-site application

Summary

The merging of containment/surveillance and nondestructive assay equipment with domestic physical protection equipment into integrated systems, coupled with remote monitoring, is expected to be an important future element of International Safeguards instrumentation. This merging would include interior monitoring with assessment (usually video), entry/exit monitoring, item monitoring and tracking, tamper indication devices (seals), and radiation detectors. These instruments are fundamental elements of domestic physical protection. Optimal performance of a physical protection monitoring system can be achieved by an appropriate combination of sensors and sensor technologies. Of particular importance is the application of interior monitors in spaces of declared inactivity; for example, in nuclear material storage locations that are entered infrequently. The use of modern interior monitors in International Safeguards offers potential for improving effectiveness and efficiency.

A particularly important feature in the potential combination of Domestic and International Safeguards is the use of remote monitoring. By retrieving data from an integrated system from remote sites, full advantage of the combination can be realized. Through the use of controlled access it would be possible for the facility operator, the State monitoring agency, and the IAEA to access the same database. Sharing relevant data in the open, cooperative environment envisaged through the Strengthened Safeguards System could result in combining monitoring equipment and inspection personnel in a highly efficient manner. Branching the data flow into multiple databases is also possible, with restricted, remote access to each of these databases by relevant organizations. Material control and accounting data obtained for the State System of Accounting and Control could ultimately augment the instrument database and increase efficiency for all parties.

Within the context of increased cooperation, one can readily envision increased interaction between International Safeguards and Domestic Safeguards. This, in fact, is the specific subject of a potential INMM workshop in 1999.

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