U.S. Remote Monitoring Operational Experience

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Abstract

Under international partnerships and bilateral agreements with the U.S. Department of Energy, Sandia National Laboratories, other national laboratories, and international partner organizations have emplaced remote monitoring systems in nuclear facilities and laboratories in various parts of the world for the purpose of conducting field trials of remote monitoring. The purpose of the present report is to review the results from these field trials and draw general conclusions regarding the trials. Many thousands of hours of sensor and system operation have been logged, and data have been retrieved from many locations. In virtually all cases the system components have functioned as intended and data have been successfully collected and transmitted for review. Comparisons between front-end-triggered video and time-lapse video have shown that the triggered record has captured all relevant monitored operations at the various nuclear facilities included in the field trials. We believe the utility and functional reliability of remote monitoring for international safeguards has been shown. However, it should be kept in mind that openness and transparency, including some form of short-notice inspections, are likely to be prerequisites to the safeguards implementation of remote monitoring in any State.

1. Introduction

Under the sponsorship of the U.S. Department of Energy, and through international partnerships and bilateral agreements, Sandia National Laboratories (SNL), other national laboratories, and partner organizations have emplaced remote monitoring systems in nuclear facilities and laboratories in various parts of the world. This work has been supported by DOE/NN-44 and by various organizations in the host countries. The technical basis for these systems, and the operational environments under which they have been emplaced, have been described elsewhere.¹

Prior to this report there has been some limited analysis of the data retrieved from the individual remote monitoring sites regarding practical use of the fielded systems for safeguards purposes.²


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The purpose of the present document is to bring the separate results together, update them, and draw general conclusions regarding the remote monitoring field trials with which SNL has been involved to this point. It is important to keep in mind that the remote monitoring systems discussed here were field trials, not operational safeguards systems. The system configurations and sensor selections were not necessarily optimized for the applications involved.

The sites considered in the present assessment are shown in Table 1. Except for a few minor interruptions related to upgrades or facility operations, all but one of these remote monitoring systems have operated continuously since installation (the field trial in Sweden was discontinued in 1996). These systems are characterized by integration of the sensors and video components, coordinated data storage, and off-site data communication. All off-site communication from these sites has been via commercial telephone lines. The video data acquisition associated with the systems in all cases is front-end triggered; i.e., images are collected only in response to a stimulus, and time-lapse video is not used in the system.

Data from these systems have been collected periodically by SNL and by others during the operational lifetime of the field trials. Not all of the data have been collected or are available in one place or on a single machine, in part because the formats have changed as software upgrades have been implemented. The following comments and conclusions are based on results obtained and data analyzed by different personnel at the various participating organizations.

2. Instrument Results

Table 2 lists the major components of the remote monitoring systems and the approximate cumulative instrument hours of operation at all of the sites considered here. Results of operational use of some of the sensor types and components of the trial remote monitoring systems are presented in this section.

AIMS. During the approximately 1.5 Mhrs of operational experience with the Authorized Item Monitoring System (AIMS) motion sensors in the DOE remote monitoring field trials there has been no failure of any sensor apart from battery expiration. There have been a significant number of AIMS missing state of health messages observed at the various installations containing these sensors. In most but not all cases, these were single, isolated events. A single missing state of health is not usually a cause for alarm. In Argentina, batteries in the AIMS units were replaced in May 1996, and one of the AIMS units subsequently failed to report to the RPU and had

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Table 1. Remote Monitoring Field Trials

<table>
<thead>
<tr>
<th>Country</th>
<th>Facility Name</th>
<th>Date of Installation</th>
<th>Hours of Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>Australian High-Flux Test Reactor, Lucas Heights</td>
<td>February 1994</td>
<td>25k</td>
</tr>
<tr>
<td>Sweden</td>
<td>Barsebek Light Water Reactor, Malmo</td>
<td>August 1994</td>
<td>17k</td>
</tr>
<tr>
<td>Japan</td>
<td>JAERI Safeguards Laboratory, Tokai-mura</td>
<td>December 1994</td>
<td>17k</td>
</tr>
<tr>
<td>Russia</td>
<td>Kurchatov Institute, Moscow</td>
<td>March 1995</td>
<td>16k</td>
</tr>
<tr>
<td>U.S.</td>
<td>Argonne National Laboratory-West, Idaho</td>
<td>March 1995</td>
<td>16k</td>
</tr>
<tr>
<td>Argentina</td>
<td>Embalse Nuclear Power Plant, Cordoba Province</td>
<td>March 1995</td>
<td>15k</td>
</tr>
<tr>
<td>U.S./IAEA</td>
<td>Y-12, Oak Ridge</td>
<td>July 1996</td>
<td>5k</td>
</tr>
<tr>
<td>Japan</td>
<td>PNC, Joyo Breeder Reactor, O-arai</td>
<td>October 1996</td>
<td>4k</td>
</tr>
</tbody>
</table>

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AIMS transmitters used in the remote monitoring field trials were supplied by Inovonics Corp. The RPUs were fabricated by Sandia from commercial components. All AIMS software was developed by Sandia.

*Approximate hours of operation through December 31, 1996.
The AIMS transmitters used in the remote monitoring field trials were supplied by Inovonics Corp. The RPUs were fabricated by Sandia from commercial components. All AIMS software was developed by Sandia.
to be repaired. There have been no identified false alarms (a false alarm is an alarm that occurs in the absence of any actual activity) from the AIMS units although there have been numerous nuisance alarms (a nuisance alarm is an alarm that occurs because of activity that is not related to the monitoring function of the detector).

Table 2. Summary of Instrument Experience

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Location</th>
<th>Instrument Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIMS motion sensor</td>
<td>Australia, KI, ANL-W, Argentina, Y-12</td>
<td>1520 khrs</td>
</tr>
<tr>
<td>AFOSS</td>
<td>Argentina, KI, ANL-W, Argentina, Y-12</td>
<td>310 khrs</td>
</tr>
<tr>
<td>VACOSSTM seals</td>
<td>Y-12</td>
<td>4 khrs</td>
</tr>
<tr>
<td>Microwave motion sensors</td>
<td>Australia, Sweden, JAERI, Joyo, KI, ANL-W</td>
<td>183 khrs</td>
</tr>
<tr>
<td>Balanced magnetic switch</td>
<td>KI, ANL-W</td>
<td>31 khrs</td>
</tr>
<tr>
<td>Radiation sensors</td>
<td>Argentina, Joyo, Argentina, Y-12</td>
<td>38 khrs</td>
</tr>
<tr>
<td>RadSiPSTM</td>
<td>Y-12</td>
<td>50 khrs</td>
</tr>
<tr>
<td>RadCoupleSTM</td>
<td>Y-12</td>
<td>100 khrs</td>
</tr>
<tr>
<td>Ludlum He3 neutron</td>
<td>Joyo</td>
<td>0.7 khrs</td>
</tr>
<tr>
<td>Camera, analog</td>
<td>Australia, Sweden, JAERI, KI, ANL-W</td>
<td>106 khrs</td>
</tr>
<tr>
<td>Camera, digital</td>
<td>Y-12, Joyo</td>
<td>4 khrs</td>
</tr>
<tr>
<td>Photoelectric beam break</td>
<td>KI, ANL-W</td>
<td>31 khrs</td>
</tr>
<tr>
<td>Laser beam break</td>
<td>Joyo</td>
<td>8 khrs</td>
</tr>
<tr>
<td>Infrared motion sensor</td>
<td>KI, ANL-W</td>
<td>47 khrs</td>
</tr>
<tr>
<td>Facility power monitor</td>
<td>Sweden, Y-12, KI, ANL-W</td>
<td>53 khrs</td>
</tr>
<tr>
<td>Power status alarm node</td>
<td>Sweden</td>
<td>17 khrs</td>
</tr>
<tr>
<td>Lamp node</td>
<td>Y-12, KI</td>
<td>21 khrs</td>
</tr>
<tr>
<td>Echelon network and components: NeutronSTM chips Models 3120 and 3150</td>
<td>Australia, Sweden, JAERI, Y-12, Joyo, KI, ANL-W</td>
<td>823 khrs</td>
</tr>
</tbody>
</table>

Active Seals. The AIMS Fiber Optic Seal (AFOS) component of the AIMS system has functioned as designed throughout the IRMP trials. Tests involving repeatedly disconnecting and reconnecting the fibers have shown no problems in achieving reliable connections. There have been no false or nuisance alarms received from the seals during the trials as long as the seals were not manually shaken. Intermittent, deliberate triggers caused by intentional disconnection of the fiber optic loops have been successfully recorded, and routine tests on the seals have been performed successfully.

Motion Sensors. A commercial microwave motion sensor manufactured by AM Sensors has been used by Sandia in several applications. The adjustable sensitivity and fan angle of these sensors allow them to be tailored for particular applications. In the DOE remote monitoring field trials, the sensitivities and fan angles of the microwave motion sensors have been adjusted to accomplish specific purposes, such as triggering on the motion of large objects but not on the motion of small objects. In some cases the fan angle of the interrogated volume has been adjusted to detect crane or boom movement while ignoring activity on the floor below. Successful adjustments for such specialized applications have been found to be straightforward, and the units have reliably retained their new settings.

No microwave motion sensor has failed during the IRMP field trials. However, early in the field trial at their facility, Kurchatov reported numerous false alarms from the microwave sensors. In a three month period, in 1995, they reported 1128 false alarms. The source of these false alarms was not known at the time of reporting but were attributed to "external

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5 Removed in May 1996.

6 This actually relates to solid angle subtended by the object. A large object at a great distance is equivalent to a small object at a short distance.

interferences.” Subsequent analysis revealed that certain power fluctuations had caused the false alarms, and the source of the problem has been corrected.*

Balanced Magnetic Switch. Balanced magnetic switches (Sentrol Model 2707A) have been used to identify the opening and closing of doors in some of the monitored facilities. These are inexpensive sensors commonly used in industrial and other applications. The major requirement for their effective use is to provide proper locations for the sensors and secure attachment of the components of the sensor to the door and door jam. During the field trials there have been no failures and no false alarms from these sensors.

Radiation sensors. Several different types of radiation sensors have been used in connection with the remote monitoring field trials. In Argentina these have included two Geiger-Muller tubes, manufactured by Ludlum Electronics, and two silicon solid state sensors, manufactured by Oak Ridge National Laboratory. The four detectors were placed in the instrumentation tubes of different CANDU spent fuel storage silos.† No failure of these radiation sensors was observed, although several problems associated with the sensors were encountered.

The outputs of the GM tubes were set to the low range of the AIMS system A/D, and it was discovered after some period of use that the digital output was temperature sensitive. This was corrected by a temporary software change that adjusted the A/D output to the correct dose rate given the temperature reading. This problem was fixed in May 1996 during the scheduled battery replacement by the simple expedient of adjusting the gain on the detector electronics to ensure performance at the mid- or upper-range of the A/D.

The silicon sensors suffered cumulative radiation damage, as expected, and showed a continuing loss of sensitivity. It was originally intended to include radiation shields for these detectors; however, because of mechanical problems with the shields, the sensors were installed without protection. It is well known that this type of sensor is inappropriate for long-exposure, high-dose-rate applications. The silicon sensors were replaced by ion chambers, also provided by Oak Ridge, in May 1996.

At Joyo, two Ludlum G-M gamma sensors and one Ludlum/Reuter-Stokes 3He neutron sensor are in use. Each of these sensors has functioned as designed since installation. There have been no failures or problems with the measurements, although one flask containing a small number of fuel rods passed the gamma monitoring point without being detected. This is a sensitivity problem, not a problem with the system operation.

Digital cameras. During 1996 the network used in the field trials was reconfigured to include digital cameras. Image Compression and Authentication Modules (ICAM) have been included in two field trial systems. The time for video transmission over the network depends on the traffic load, but typically requires several seconds. Early in the ICAM operation a number of problems occurred with the video systems. These problems required several software modifications. Since the software upgrade, images have been successfully triggered and the cameras have experienced no failures or other problems.

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*Mark Sazhnev, personal communication, 1997.

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"All cameras are analog. Typically a "digital" camera is a charge-coupled device for which the pixel signals are digitized within the camera unit. A "digital" video camera is one in which the analog signal is digitized within the camera housing. A certain liberty has been taken in terming the ICAM camera "digital" since the signal is digitized outside the camera housing proper. However, the digitizing component is co-located with the camera, in the same tamper-indicating enclosure, and the distinction is not important for present purposes."
Echelon Network Components. In Table 2 the Echelon component operational experience has been calculated on the basis of the number of Neuron™ chips in each system. There have been no failures or problems with the Echelon network components used in the IRMP field trials, including Neuron™ chips, software, and communication protocol. All messages have been transmitted successfully when the network was correctly configured, or “bound,” and all data authentication, delivery confirmation, and other options activated in the trials have functioned as designed.

Data Acquisition and Review Components. From the beginning of the remote monitoring field trials, no emphasis has been placed on the rapid acquisition of data from the site. Remote monitoring in a safeguards context will require an open and cooperative environment that is fundamentally different from that of a physical security application. That is, the monitoring agency will not have a means of responding rapidly to discrepancies in the data, and will not have the wherewithal to invest major effort in resolving minor anomalies. Thus there appears to be no requirement for immediate access to the communication link of an on-site monitoring system, and no requirement for extremely rapid data transfer, or for extreme reliability in the data transfer link. An occasional inability to connect with the site on the first try, or an occasional loss of the connection during data downloading are not considered serious problems. On the other hand, practical considerations require that communications costs remain reasonable, and thus that the data download be completed in a reasonable period of time. Similarly, connection with the site should be possible within a reasonable period of time, and within a reasonable number of tries.

The computer software for the field trials was provided by Sandia and was a combination of commercial and custom software. The software used in the field trials has undergone continuous upgrading during the period of the field trials, and several of the versions that are currently in place use Windows-based data display. From a user perspective, these Windows-based systems are much improved over the original DOS-based design. The Joyo and Y-12 sites included another level of improvement in the software by making use of the Windows NT operating system.

3. System Functional Assessment

While data on the individual components of a remote monitoring system provide a basis for the evaluation of these components, they do not provide a basis for judging the performance of the system as a whole. The remote monitoring field trials discussed here addressed a variety of safeguards issues and, in order to obtain maximum benefit from the program, the effectiveness of the complete system at each site should be judged as a functional whole as well as being judged in detail.

The remote monitoring systems used in the field trials under discussion are integrated systems in which data can be transferred between any components over a communication network. The Echelon LONworks™ network technology was used for this communication link. Unlike a polled network protocol, in which a control computer must remain operational and initiate all communications with the sensor nodes, the Echelon network protocol allows communication to be initiated by any node on the network at any time. Thus both the nodes and the data computer can be placed in sleep mode, minimizing the power consumption yet allowing the sensors to remain ready to respond to any stimulus, whether from a detection event, a state-of-health requirement, or a signal from another node. Despite the fact that democratic message initiation on the network may result in slight delays for some messages, depending on the traffic on the network, we believe the resulting monitoring system architecture has been shown to be functionally efficient and effective for remote monitoring.

The concept of front-end triggering of video is not new. The present field trials used triggered video at seven sites, three of which included independent time-lapse video. Extensive comparisons of the triggered results with the operator data, and with the time-lapse video records, have shown that the triggered video

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11 Charles S. Johnson, et al., “Data Analysis on the Australian Field Trials,” Sandia National Laboratories, Albuquerque,
captured all necessary video information to support and assess the relevant site activities.

With the triggered video, lock-out times have been used to prevent the accumulation of many redundant images. Lock-out refers to a method of programming the video node such that the frequency of image collection is limited to some minimum. After the collection of a triggered image in such a system, no subsequent image will be recorded for the lock-out period, even if the sensors are still producing readings that would otherwise trigger the video collection. If, after the lock-out period, the sensors are still sending, or resume sending signals that trigger the video collection, another image is collected. By this technique, a minimum interval between video collections is maintained, the interval being adjustable according to the application; but within this constraint, images are still collected as long as the activity that triggered the image continues.

4. Conclusions

The experience gained from the DOE field trials of remote monitoring systems has shown the viability of the concept of using integrated monitoring systems with front-end triggered video, and of providing off-site data communication through commercial telephone lines. The field trial systems have been found to be reliable, and to have functioned as designed.

The sites at which the remote monitoring field trials have been conducted include a variety of nuclear and laboratory facilities. The particular facilities, and the functions of the remote monitoring systems at those facilities, were chosen deliberately to represent a wide range of possible safeguards applications. Most of the applications were to static storage of nuclear materials, but two applications, those at Barseback and Joyo, addressed the issue of monitoring the movement of spent fuel. Whether used in static or dynamic situations, the field trial systems have provided confidence in the methodology of unattended systems with remote data access, and the program is continuing to expand into increasingly sophisticated areas of application.

Since the effort of evaluating remote monitoring in safeguards-relevant applications was begun in 1994, numerous organizations in the U.S. and around the world have been working on or testing remote monitoring technology. Notably, this includes the recent installation and use of remote monitoring by the International Atomic Energy Agency. The technology is advancing rapidly, and significant improvements and cost reductions can safely be expected in the future. We believe the implementation of the remote monitoring system design used in these field trials will continue for the near future. Further improvements in the technology and the software, with resulting cost reductions through standardization, are expected and should make the concept of the integrated collection of safeguards data with remote access to the data even more useful for safeguards purposes than at present.

We believe the utility and functional reliability of remote monitoring for international safeguards has been shown. However, it should be kept in mind that openness and transparency, including some form of short-notice inspections, are likely to be prerequisites to the safeguards implementation of remote monitoring in any State.