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The Role of Remote Monitoring under Integrated Safeguards

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Abstract

One of the aims of integrated safeguards is to use the "optimum" combination of available methods for the IAEA to independently derive assurance that a State's declarations are both correct and complete. The "optimum" is determined on grounds of both safeguards effectiveness and cost efficiency.

Since the early nineties a great deal of effort has been put into the application of remote monitoring (RM) techniques to safeguards. However the use of RM remains relatively limited, particularly outside EU countries, and a number of concerns continue to be held about RM, principally relating to the manner in which the remotely collected data can be used as part of safeguards evaluation, and the overall cost and reliability of RM techniques. In the context of integrated safeguards there is scope to reexamine these issues. The situations where RM techniques are likely to have the greatest impact include: where containment and surveillance measures are used; where inspector presence is used to maintain continuity of knowledge; and to address diversion scenarios that may not be adequately addressed by existing measures.

This paper will review situations in which RM techniques can be used as part of integrated safeguards approaches and will examine means of ensuring that the RM derived data are appropriately coordinated with other safeguards measures to ensure that all realistic diversion scenarios are addressed in an efficient and cost effective way.

1. INTRODUCTION

The International Atomic Energy Agency administers a system of safeguards that has historically relied on labour-intensive and time-consuming inspections of nuclear facilities to verify the inventory declarations made by States, with containment and surveillance (C/S) measures used to maintain continuity of knowledge and to limit the reverification of previously verified material where possible. The growth in the amount of nuclear material under safeguards, and in the volume of data that must be analysed, means that unless changes are made to the way safeguards are practised, the task of safeguarding nuclear material will become more difficult and expensive each year.

Given that the Agency has a zero-growth budget, enhancing the Agency's technical capabilities has to play a major role in enabling the increasing safeguards workload to be managed within resource constraints. This will require greater reliance on technology and less reliance on inspectors in the field. One way this might be achieved is via the use of remote monitoring systems (RMS) and automated systems for the evaluation of collected data. RMS will permit a more efficient use of inspection resources and, in some circumstances, better coverage of facilities under safeguards. RMS may, therefore, be seen as a tool both to *complement* traditional safeguards techniques and to provide an *optimal* approach to the changing requirements of *integrated safeguards*.

One major difference between RMS and other new technologies being embraced by the Agency (such as information analysis and the use of commercial satellite imagery) is that RMS focus primarily on *declared* activities of member States, whereas the other new methods tend to deal with the State more broadly (including possible undeclared activities). The generally accepted objectives for the installation of RMS are as follows:

(i) To provide confidence building measures in relation to material under safeguards through continuous, improved openness and transparency;

(ii) To strengthen safeguards implementation and increase its effectiveness;

(iii) To lower the cost of safeguards processes and improve their efficiency;

(iv) To reduce personnel radiation exposure; and

(v) To be less intrusive on facility operations.[1]

In this paper, we review situations in which RM techniques can be used as part of the Agency's integrated safeguards program and consider how to ensure that the RM derived data are coordinated with other safeguards measures so that realistic diversion scenarios are addressed in an effective and cost-efficient way.

2. RM TECHNIQUES AS PART OF INTEGRATED SAFEGUARDS APPROACHES

Integrated safeguards (IS) bring together the optimum combination of available methods for the IAEA to independently derive assurance that a State's declarations are both correct and complete. The basis of IS is that the measures available under classical and strengthened safeguards are mutually reinforcing and, to a certain extent, redundant (i.e. the same diversion scenario being addressed by two or more independent measures). Since strengthened safeguards are designed to establish a credible assurance of the absence of undeclared nuclear activities, a reduction in the intensity of the classical safeguards effort is justifiable in appropriate circumstances.

RM first became the subject of interest under "classical" safeguards when it was seen that RM had the potential to realize substantial savings in inspection resources. With the introduction of IS, however, <u>some</u> of the safeguards measures that were demanding of inspection effort, or made use of continuous surveillance, are being discontinued—this can be illustrated by reference to light water reactors (LWRs), where the timeliness goal for spent fuel has been changed from three months to 12 months, and quarterly interim inspections and continuous surveillance of spent fuel ponds are no longer required. As a consequence, it <u>might</u> be thought that under IS the opportunities for a useful contribution from RM will be relatively limited. This is not the case, however—there will continue to be some facilities at which it will be necessary to maintain safeguards coverage at a level comparable to that under classical safeguards. For example, this will be true for all facilities in which there are greater than one Significant Quantity (SQ) of unirradiated direct-use material (of which LWRs with MOX are considered a special case under IS).

Accordingly, there will still be situations in which C/S measures supplemented by inspections will remain central to the application of safeguards. In all situations in which C/S measures are required under IS, consideration should be given to a C/S system that can be remotely monitored. There will be many situations where RM will offer advantages in terms of improving timeliness, improving effectiveness, reducing inspection effort, reducing unnecessary intrusiveness, and so on.

RM techniques have an important role to play in IS implementation and operation in that many safeguards tasks can be performed by utilising a suitably designed remote monitoring system in a way that provides both greater safeguards effectiveness and cost efficiency. Other types of sensors can be included in the RMS and can be arranged to detect events such as motion, removal of material, instrument tampering, replacement of equipment, etc. RMS can also be set to record and transmit images of sensor triggered events.

The principal diversion scenarios of interest from a RM perspective are:

1. Diversion of fresh or slightly irradiated fuel containing Unirradiated Direct Use Material (UDU);
2. Diversion of spent or irradiated fuel containing Irradiated Direct Use Material (IDU); and
3. Clandestine production of fissile material.

Each of these scenarios has its own tell-tale signs and signatures, many of which would be detectable by suitably designed and strategically placed remote sensors.[2] The possible application of RM techniques should be considered for each of these scenarios in the context of the re-examination of safeguards approaches that is inherent in establishing an IS regime for a given State.

The digital and information revolutions have opened a veritable cornucopia of technical resources that are now available for the purposes of providing credible and transparent safeguards coverage of nuclear materials and facilities. It needs to be emphasised, however, that the placement of RMS will not usually remove the requirement for Agency inspections of nuclear facilities, though it may provide a partial justification for the replacement of scheduled inspections with either a lower frequency of inspection or, in some cases, with unannounced inspections. RM has the potential to form a part of the Agency's IS approach for any given State.

3. FACILITY TYPES AT WHICH RM WOULD STILL BE NEEDED UNDER IS

Research reactors and critical assemblies (RRCAs) with greater than one SQ of fresh fuel are one class of facilities in which, at this stage, no substantial relaxation of safeguards coverage under IS is anticipated. Such facilities are currently inspected monthly, specifically because the State has access to material that could be used in a "crash-though" diversion scenario (i.e. the State takes the fresh fuel with the intention of making a weapon from it directly before the next inspection). A safeguards approach for such a facility under IS can either continue with monthly inspections or make use of alternative approaches to achieve the same end. One possible way to achieve this is to construct a RMS that ensures that, in practice, the State cannot have access to quantities of UDU near or exceeding one SQ of UDU without the Agency being aware of this in a timely fashion. Depending on the characteristics of the facility, this might be achieved by the use of a RMS system that makes use of seals that can be remotely verified, a video surveillance system and, potentially other sensors (door monitors, weight sensors, radiation sensors etc.).

If such measures reduced the inspection effort from twelve inspections per year (one PIV plus 11 interim inspections) to an average of two inspections per year (one PIV plus an average of one unannounced inspection to maintain the integrity of the surveillance system) the Agency would potentially be able to save a substantial number of Person Days of Inspection effort (PDI). Of course, increasing the average number of unannounced inspections would have a corresponding effect on the savings possible from using RM.

Frequency of data transmission and frequency of data evaluation are issues that need careful evaluation in the context of RM under IS. If an event is detected which requires investigation, the time-frame within which this can occur must have a suitable relationship to the type of material under safeguards, e.g. UDU data would need to be transmitted with a frequency that matches its importance, and reviewed as soon as possible (both economic and physical protection concerns would generally prevent real time transmission of images).[3] Since RM allows monitoring at close to real-time, this means that much shorter timeliness targets can be attained than through inspection alone.

Under IS, the Agency's conclusion of the absence of undeclared nuclear material and activities in a State permits the relaxation of the timeliness goals for irradiated fuel to one year and to three months for fresh MOX fuel assemblies. If fresh MOX fuel assemblies were under C/S from receipt at a reactor site until loading into the reactor core, the timeliness goal could be achieved by quarterly evaluation of RM data without the need for quarterly inspections. Continuity of knowledge of the core fuel of LWRs, both with and without MOX, can be maintained by RM surveillance during refuelling and by the use of core seals between refuelling.[4] Continuity of knowledge is often maintained over receipts of UDU material (such as fresh MOX fuel at LWRs) by inspectors being present at the facility during the receipt and maintaining visual observation of the assemblies from the time that they are removed from the receipt C/S measures until they are placed under storage C/S measures—appropriately designed receipt and storage C/S measures supplemented by an RMS can be used to replace inspector presence for such receipts.

On-load refuelled reactors (OLR) could incorporate the continuous use of remotely monitored flow meters for core fuel discharges and, potentially, a selection of other RM measures (e.g. underwater cameras, Cerenkov radiation detectors) could be placed to monitor spent fuel ponds. Current safeguards approaches for OLRs sometimes experience loss of continuity of knowledge due to failures in data collection systems designed to record the flow of material through the facility. The use of RMS with appropriate levels of redundancy could be used to ensure that inspectors are aware of any difficulties before the safeguards coverage of the fuel inventory at the OLR is compromised.

The loading of spent fuel casks for shipment to a dry storage facility at OLRs uses considerable Agency inspection resources under current safeguards approaches because continuity of knowledge is generally maintained via continuous inspector presence. IS approaches that make use of RMS to cover the loading of spent fuel casks have the potential to save the Agency substantial PDI, especially in States in which OLRs are the dominant reactor class. Such a move to RM under IS becomes possible because it is possible for the Agency to accept a less complete (though more timely) form of coverage of spent fuel when it has a significant (though non-quantifiable) possibility of detecting undeclared activities via other IS measures.

Remote transmission of measurement data could provide improved coverage of the flow of material for LEU fuel fabrication facilities. Current Agency criteria require five inspections for flow verification and one inspection for physical inventory verification during a material balance period at an LEU fuel fabrication plant.[5] The use of RMS appropriate for each type of facility would allow the numbers of these inspections to be decreased. There would be an accompanying reduction (in the long term) of the cost of conducting Agency inspections. Once well-designed and reliable RMS become extensively used, the current concept of timeliness is likely to decrease in practical importance. However, assurance of the long-term integrity of RMS may be maintained by Agency inspectors making random, short-notice visits to nuclear facilities that are subject to RM.

4. REMOTE MONITORING SYSTEMS AND TECHNIQUES

RM techniques are potentially able to involve the full range of safeguards data collection systems (ionising radiation, microwave, infrared, seismic, binary switches, electronic seals, flow meters, thermal sensors, mass measuring systems and video). The locations of sensors and their thresholds within a given site would need to be carefully selected to optimize their sensitivity to events of interest (while limiting the risk of sensor/scalar overload and radiation damage).

There are distinct advantages to having such data remotely transmitted to Agency Headquarters (or to a local field office) rather than merely stored on-site. After an initial period of investment in product development and manufacture, longer term improvements in the efficiency of safeguards inspections and reductions in cost for the Agency are to be expected. RM also provides additional, timely assurance that no undeclared activities have taken place.

The extent to which a RM system can be effectively used at a given site will depend on the site's physical layout, and the number and type of facilities present on the site, i.e. some elements of RMS may need to be designed on a case-by-case basis to take into account the specifics of the facilities and the nuclear material present. It is clear that the placement of any RM system will require the cooperation of both the facility operators and the State System of Accounting and Control (SSAC). The installation of specific RM devices may also depend on the outcome of cost-benefit analyses.[6]

There are many practical advantages to placing facilities under RM. A review of surveillance data prior to inspection would tell inspectors whether the surveillance was conclusive or not. Inspectors would then be prepared to perform any additional verification activities prior to departing for a facility. This can reduce the need for follow-up visits. Unannounced inspections could be scheduled as required on the basis of RM derived data. Subject to the practicalities of access to particular sites, the State and the facility operator need only be informed of an inspection after Agency inspectors arrive in country.[7]

Recent advances in sensor technology have produced digital devices that are more dependable than the older analogue systems and the technical problems that have plagued most surveillance systems can be expected to reduce in frequency as the technology continues to improve. In the event of a sensor going off-line, the state-of-health component records when and which sensor is affected and can transmit the status off-site. Consequently inspectors can be informed of the need for maintenance/replacement of components before travelling to the site. They can bring spare parts and any technical personnel necessary to conduct repairs immediately, instead of scheduling additional visits.

5. COORDINATION OF RM DERIVED DATA WITH OTHER SAFEGUARDS MEASURES

The coordination of RM derived data with other safeguards measures will be a major challenge for the Agency to meet in implementing large scale applications of RMS. One of the main obstacles to be overcome in meeting this challenge is how the Agency will manage the huge amounts of data that will result from an extensive deployment of remotely monitored instrumentation. It will be necessary for the Agency to develop both new hardware and software tools to deal with this massive flow of information.

One potential advance would be to make the main component of an intelligent safeguards monitoring system (ISMS) an *Expert System* using a knowledge base built on human expertise (i.e. a set of heuristics) to evaluate the data from sensor arrays. The degree to which such a system is capable of independently evaluating data is a function of the quality of the data and the rules obtained from human experts. Information from a variety of sources can be used to provide comprehensive monitoring as the *Expert System* processes the states of all sensors and correlates the data with events and its programmed procedures. This automatically identifies anomalies and provides diagnostic conclusions. The RM system's interface would also allow inspectors to monitor facility information directly so that assessment of the RM system's conclusions can be made in short order, additional analysis performed and/or other suitable actions undertaken.[8]

The Agency's strengthened safeguards system incorporates a number of important features over and above the system of classical safeguards. Under strengthened safeguards, the Agency receives more information on nuclear and nuclear-related activities, including information provided through a "Protocol Declaration" by each State. Agency inspectors have substantially increased access rights to anywhere on a nuclear site, locations included in the Protocol Declaration and locations elsewhere in the State to carry out verification measures. The Agency also is collecting additional information from open sources, governments and individuals, commercial satellite imagery and through its own environmental sampling and non-destructive assay (NDA) capabilities. How can these new sources of information and access rights be best utilised in conjunction with RM derived data?

Information fed into an ISMS need not be restricted to the data from RM sensors and the system's programmed knowledge base. The totality of information collected and otherwise received by the Agency under the provisions of Strengthened Safeguards should be made available to such an ISMS and not just used separately in the evaluation of State's compliance with its Safeguards Agreement. The software tools available to the Agency's ISMS should include a suitable modified, commercially available, *Link Analysis* program. *Link Analysis* is an investigative tool that compiles large amounts of independent and apparently unrelated data in order to reveal the structure and content in a body of information so that connections between disparate facts can be established and reported by the system.

What actions should follow from an analysis of RM derived data and ISMS conclusions? It was discussed above how a review of RM data would inform inspectors of surveillance discrepancies, possible tampering, and the state-of-health of an RMS. Action following such a review might include the investigation of irregularities, confirming/rejecting system conclusions, instigating alternative verification activities, and despatching inquiry/repair teams, depending on the specifics of the system conclusion and subsequent review of information. Whenever an Agency ISMS indicates that a problem exists at a particular facility, a decision will have to be made within the Department of Safeguards as to what follow-up action is most appropriate. Agency procedures and guidelines will need to be developed to address how inspectors methodically deal with adverse system conclusions about a facility. Once prepared and endorsed by the Agency, these procedures will provide a means of addressing realistic diversion scenarios as they occur and in a more effective and cost-efficient way than is currently available.

6. CONCLUSIONS

The growth in the amount of nuclear material under safeguards will require greater reliance on automated techniques and remote monitoring for the collection and evaluation of safeguards data. In order to achieve this goal, the Agency should develop intelligent monitoring systems which incorporate digital technology for data acquisition, transmission and storage. The central processing unit of an intelligent monitoring system should integrate both an heuristics-driven *Expert System* and specially prepared *Link Analysis* software. Such systems would provide better coverage of facilities than is currently available, allow for more efficient use of inspection resources, and would indicate when other safeguards measures are necessary. Agency procedures and guidelines will need to be developed to address how inspectors methodically deal with adverse intelligent monitoring system conclusions about a specific facility. System conclusions and appropriate Agency procedures will provide a means of addressing realistic diversion scenarios as they occur.

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