Improving safeguards techniques: Instrumentation

by David E. Rundquist and Leonard M. Watkins

The technical objective of safeguards has frequently been defined as the timely detection of diversion of significant quantities of nuclear material in the event that such a diversion has occurred. Critics liken it to trying to put socks on an octopus, casting the Inspectorate in the front-line rôle of dresser, holding the beast down, with Development supplying the socks (equipment) and advice (approach and technique) from a safe position in the wings.

This view is not only flippant, but unduly cynical, since so far international safeguards have been successful. Nevertheless, the analogy's implication that the job is never quite finished has an element of truth in it.

Each year the number of facilities and amount of nuclear material to be safeguarded increase faster than the Inspectorate's available manpower. Moreover, the range of technology available to a potential divertor widens.

The Agency and the international safeguards community have responded to this challenge by focusing effort on increasing Agency efficiency through improving safeguards techniques.

The associated research and development (R & D) effort is extensive, involving formal support from nine Member States and the European Community and an expenditure to date of some tens of millions of US dollars.* About 200 development tasks are currently active.

In this article we describe a few representative examples from this large effort to illustrate the nature of the work and the problems the Agency faces. A glimpse of future trends also is given.

Before proceeding to these illustrations, it is worth reviewing general considerations that must be taken into account if safeguards techniques are truly to be improved.

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* See: "Research and Development Programmes in Support of IAEA Safeguards", by A. von Baeckmann, in *Nuclear Safeguards Technology 1982* (Proc. Symp. Vienna 1982), Vol.1, Paper No. IAEA-SM-260/127, IAEA Vienna (1983).

General considerations for improving techniques

Success in safeguarding a nuclear facility requires both an approach and the equipment to implement it that guarantee, with a reasonable degree of confidence, that nuclear material can be accounted for in an acceptable time interval. Most importantly, success also requires competent inspectors thoroughly trained in the techniques of using the equipment and interpreting data from it.

It is not therefore surprising that Agency and supporting Member States' R & D efforts for improving safeguards techniques primarily are concentrated on developing system approaches, associated equipment, and the methodology of use.

Safeguards approaches vary, dependent on the type of facility, but essentially all schemes employ a combination of material accountancy and containment and surveillance.

Material accountancy* primarily is concerned with keeping track of the inventory of nuclear material within the various areas of a plant. To do so typically requires such measurements as "amount", "enrichment", and "number of specific items".

Containment is the restriction of the movement of, or access to, nuclear material, either as naturally occurs in a plant for operational reasons (e.g., "reactor core"), or by measures employed by the Agency in carrying out inspection duties (e.g., sealing of a previously verified quantity of nuclear material).

Surveillance means the instrumental or human observation of the movement of nuclear material (e.g., closed circuit television, film camera).

Implementation of the selected safeguards approach, naturally then, results in the field deployment and use of an appropriate mix of measurement and containment and surveillance (C & S) equipment. Such equipment must be non-intrusive to station operation. This is a particular challenge for measurement equipment, and, in combination with "timeliness" requirements, results in extensive use of non-destructive assay (NDA)

* Complete definitions of technical terms in this article are given in *IAEA Safeguards Glossary*, IAEA/SG/INF/1.

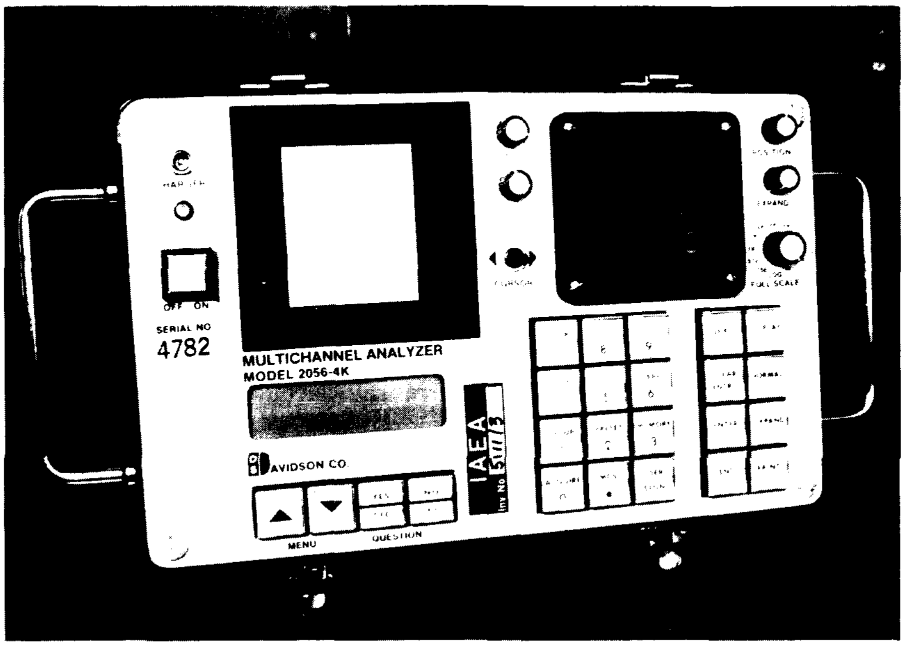


Figure 1.
Portable mini-multichannel analyser.
The three clusters of push buttons (lower left, center, and right) allow inspector to interactively set up the instrument in response to instructions appearing on the liquid crystal display (middle left). Spectra can be displayed on the CRT screen (upper right) using the controls surrounding the screen, and recorded on the cassette recorder (upper left).

instrumentation. The Agency uses the information obtained *in situ* from such equipment as an input to its judgement on the accountability of nuclear material in a given plant. In some instances, the *in situ* NDA measurement results may dictate inspector actions needed to resolve bookkeeping mistakes.

For the final Agency judgement to be credible, the approach must be sound, and the equipment used must be highly dependable. In turn, soundness and dependability can only be assured by:

- Ensuring that approach and equipment are well specified, and truly meet operational needs
- Employing the most suitable technology and procedures
- Monitoring performance and making adjustments of equipment or procedures, when necessary
- Training inspectors thoroughly in the use of equipment and the understanding of the safeguards approach.

Specifying equipment properly must not only take into account technical performance targets (e.g., high mean-time-between-failure (MTBF) and high accuracy), but also the environment in which most equipment will work.

By environment we do not merely mean such ambient conditions as temperature, humidity, and radiation. These, of course, are important, and, because of the worldwide scope of Agency safeguards, they tend to cover a broader range than those for which commercial equipment is designed.

Environment, in its broadest and most important sense, encompasses how the equipment will be used and maintained, by whom, and under what constraints. In this larger sense, there are important differences between typical industrial situations and those which typify safeguards installations. Agency development successes in the past have in large part occurred when careful attention has been paid to these differences and, conversely, failures have occurred when they have been overlooked.

These differences include:

- C & S equipment must perform reliably unattended for the two or three month interval between inspections, in a manner that does not indicate its operational state to the facility operator. Faults are only detected on the inspection visit or in the case of film cameras, back at Headquarters when films are reviewed. Such a situation leads to greater unavailability of equipment than industrial equipment of comparable reliability, since modern industrial equipment is generally designed to self-annunciate its failure to an in-house, specialized maintenance staff.

  This puts a premium on reliability and on a comprehensive preventive maintenance programme for Agency C & S equipment.
- *In situ* NDA measurements are performed under non-ideal field conditions by inspectors who are under "time-pressure" from the station staff to complete their work quickly, with minimum disruption of station operations. The inspector is, in general, not an instrument specialist, and normally has limited access to calibration standards, other than those that may come with, or be built into, the instrument.

  This requires that instruments be simple to use, that they "prompt" the inspector at each step in the measurement process and, where possible, that they be self-calibrating.

- To the facility operator, safeguards equipment and procedures are a non-commercial requirement, and the operator quite rightly requests that safeguards systems and equipment be non-intrusive, with minimum interference to his activity. Moreover, the operator gives low priority to any safeguards equipment problem that requires action on his part.

  This not only reinforces the need for reliability and ease-of-use factors mentioned earlier, but also makes it desirable that the operation of the instrument is independent of station services.

Representative examples of R & D

Portable Mini-MCA (PMCA). The PMCA is an "intelligent" portable, battery-operated multichannel analyser that can display and record gamma-ray spectra obtained from radioactive samples using appropriate detectors.

It was developed under the US Technical Support Programme by the Los Alamos National Laboratory and has gone through a number of development stages.

The key factor guiding this evolutionary development process has been feedback from inspectors on their experience with early prototypes used under field conditions.

This feedback has resulted in extreme ease-of-operation of the current commercially available version (see Figure 1). The "user-friendly" software on which the instrument design is based aids the inspector in performing measurements under a variety of environmental conditions. Simple key-stroke entries result in the instrument automatically setting itself up for a given measurement. The instrument prompts the inspector throughout the setting-up procedure.

Self-test features, such as checks of detector and instrument power supply voltages, are built-in and result in diagnostic messages on a liquid crystal display screen if the voltages are outside limits.

Other features include:

- Number of channels adjustable (up to 4096)
- Useable with sodium iodide, intrinsic germanium or germanium/lithium gamma detectors
- Cathode-ray tube display of spectrum with cursor selection of region of interest
- Magnetic tape storage of data and instrument status
- Adjustable upper- and lower-level discriminators
- Livetime check timer
- Serial output data dump to an external "listening" or recording device.

With the introduction of the PMCA, the inspector has at his disposal an instrument suitable for numerous routine gamma-ray NDA applications.

These include:

- Definitive identification of plutonium or uranium
- Determination of uranium-235 enrichment of uranium oxide bulk materials, fresh fuel assemblies and hexafluoride storage cylinders
- Determination of amount of uranium-235 in research reactor fuel elements
- Determination of spent fuel burn-up for estimating residual plutonium content.

Additionally, it may eventually be used to perform standard multi-channel analyser operations, such as isotope identification.

The software is designed so, that as future measurement applications are identified, and procedures are developed, additional routines can be incorporated as a user function.

Because of its versatility and ease of use, the PMCA is likely to become the Agency's "work horse" for gamma-ray NDA. Some grasp of the degree of initial acceptance by Agency inspectors can be gained from a recent projection that more than 40 PMCA units will be in field use by 1986.

Bundle counter for Candu on-line refuelled reactors. One requirement of Candu safeguards approaches is that discharges of irradiated fuel between the reactor and the storage bay are monitored.

A bundle counter was developed expressly for this purpose under the Canadian Support Programme by the Chalk River Nuclear Laboratories. It is currently installed, and successfully working, in a number of stations.

It consists of a number of Geiger-tube sensors (strategically placed along the normal fuel discharge path to sense presence of irradiated fuel) connected to a microprocessor-based electronics package. The package (shown in Figure 2, with associated security cabinet) interprets the Geiger signals and records, for later use by an inspector, the fuel movements that have occurred, plus the time and direction of occurrence. The information can then be used directly by the inspector to check the operator's fuel discharge records.

The bundle counter includes many features illustrative of current trends in safeguards C & S instrumentation design.

These include:

- *Microprocessor base.* This allows flexibility to make changes in design logic, without re-packaging the electronic hardware.
- *Self-monitoring.* A "watch-dog" low-activity cobalt-60 source is built into the Geiger-tube assembly, thus feeding the electronics package with a steady stream of pulses at a low rate. Any accidental or deliberate cutting of the Geiger-type wiring to the electronics package (or failure of the Geiger, or its

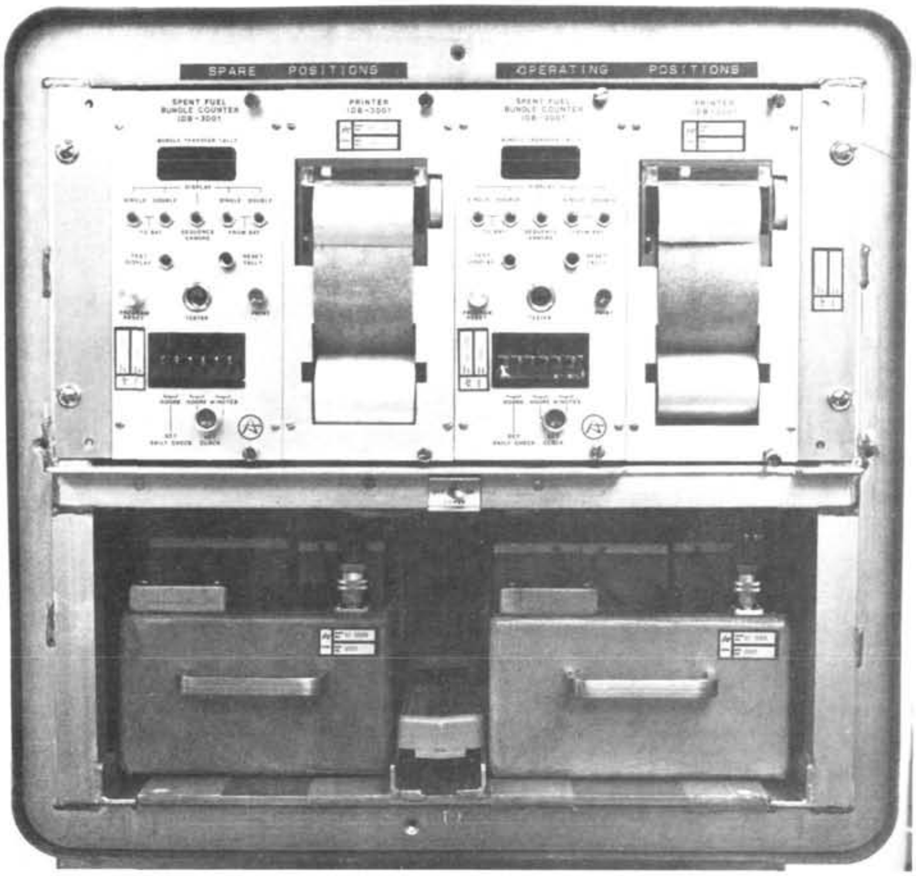


Figure 2.
Front view of Candu spent fuel bundle counter security cabinet with door off.
The complete set of spare units can be seen in the upper left corner and the built-in battery power supply below. Note also the "Maximum – Minimum" thermometer between the two battery packs. (Credit: Atomic Energy of Canada Ltd – Research Co., Chalk River, Ontario, Canada.)

high voltage supply) immediately cuts off the pulses, and this is sensed and recorded by the electronics package. In addition, the microprocessor performs periodic self-checks of its memory and associated electronics.

- *Easy maintenance.* As shown in Figure 2, a spare set of electronic modules is built into the installed security cabinet. If a unit is suspect, the inspector can unplug the faulty unit and plug in the spare, leaving the detailed trouble shooting of the replaced unit for electronic specialists off-site.
- *Tamper resistance.* These features include the location of the electronic modules in a specially designed steel box operating on their own battery-supplied power; Agency seals on the box; temperature and radiation indicators within the box to detect any attempts to cause operation errors by high temperature or radiation; and the watch-dog feature described earlier.
- *Concealment of operating state.* These design features include: the location within a steel box; use of low-power (CMOS) electronic circuits generating no detectable heat at points accessible to the diverter; and its own battery supply for operation.
- *High reliability.* Performance monitoring (see below) has established that, with timely replacement of Geiger assemblies, the bundle counter is likely to attain or exceed its mean-time-between-failure target of three years.

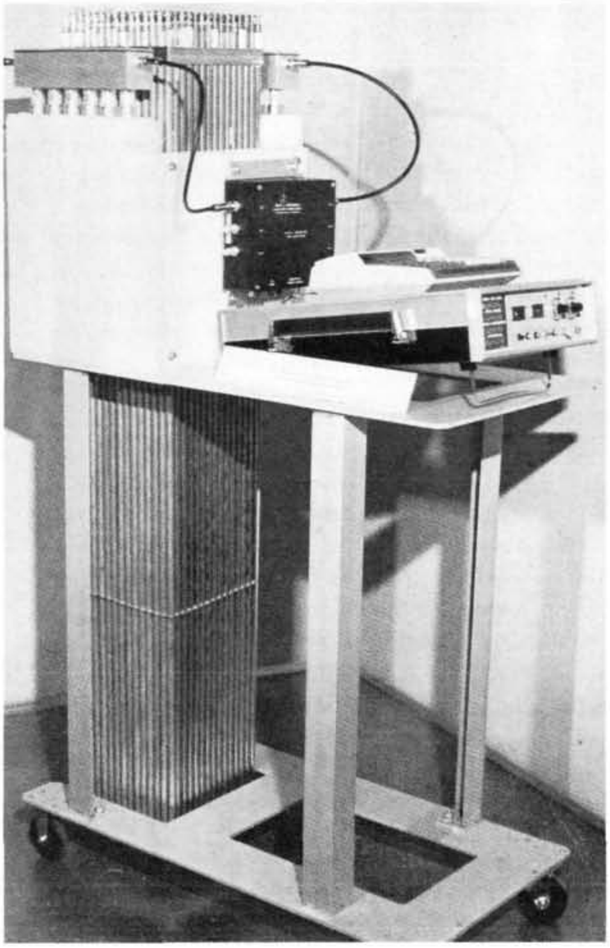
Performance monitoring: an effective programme

It has been recognized for some time that safeguards instrumentation has matured to the point where setting of practical performance targets and field monitoring of their attainment is necessary, if the Agency is to efficiently make decisions on the acceptability and optimal use of safeguards equipment.*

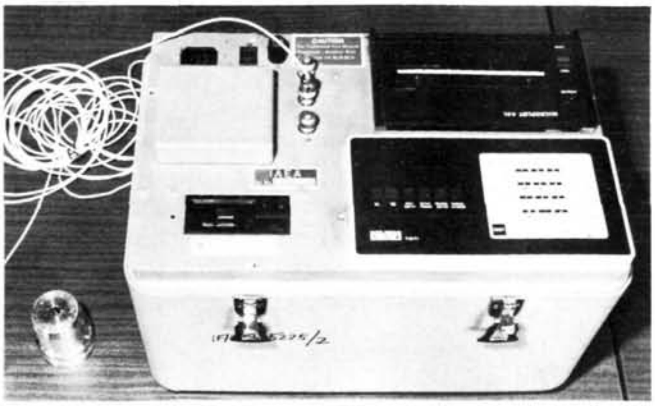
Consequently, the Agency is in the process of defining field performance monitoring programmes for all routinely deployed safeguards equipment, in both the C & S and NDA fields. The ultimate goal of these programmes is to assess, in a systematic way, whether this field-installed equipment meets its target specifications, using formalized methods of fault analysis, and to feed back information to the safeguards community on improvements or innovations needed to meet evolving requirements.

A major programme has been in force since May 1983 on safeguards equipment in four Candu 600-megawatt

* See: "IAEA Safeguards Instrumentation Development, Implementation and Control", by D. Rundquist, in Nuclear *Safeguards Technology* 1982 (Proc. Symp. Vienna 1982), Vol.2, Paper No. IAEA-SM-260/58, IAEA Vienna (1983); the *IAEA Safeguards Glossary*, IAEA/SG/INF/1; and "Practical Goals and Performance Monitoring of C & S Equipment", by D. Rundquist and L. Watkins, in Proc. Fifth Annual ESARDA Symp. on *Safeguards and Nuclear Materials Management* (April 1983) 71–5.



Uranium neutron coincidence collar



Ultrasonic seal and verifier

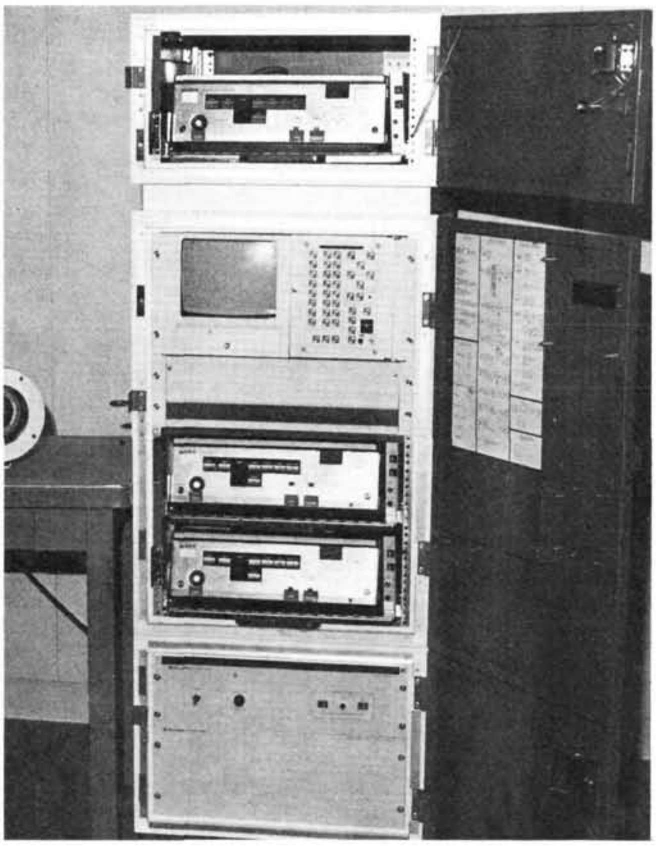
Gamma assay monitor

Cherenkov glow device

High-level neutron coincidence counter

System for plutonium isotopic analysis with multichannel analyser and detector

Advanced television surveillance system



In addition to specific techniques and equipment discussed in the accompanying article, safeguards personnel use a variety of instruments for verification purposes.

reactors, under the Canadian Support Programme. The Candu stations were selected for the first large-scale implementation of Agency performance monitoring because the Candu equipment provided a unique opportunity to establish performance monitoring on an integrated system. The associated safeguards systems were designed as part of an overall safeguards scheme, each with a well-defined rôle and target performance.

In addition, the systems involved were from the same technological generation and included trends that were appearing in modern safeguards equipment (e.g., microprocessor-control, self-diagnosing, intrusion-detection): data also was available from four stations, thus providing a larger sample size and better statistics than normally available.

The programme involved the following constituents:

- Setting up standardized equipment check-sheets and fault-reporting mechanisms
- "Hands-on" training of inspectors in the use of the equipment, plus training on its rôle
- Accompanying of inspectors by development personnel to initiate the programme, and to provide necessary help when additional testing or training was required or when equipment modifications were instituted
- Monthly exchange and review of field information between the various participating Agency sections
- Formal analysis and reporting of performance with recommendations for improvements and/or replacements.

The programme has been a success, leading to both improvements in equipment and a better understanding by inspectors of the safeguards scheme.

With the incorporation of inspector suggestions, the equipment check-sheets have proven to be an aid rather than a hindrance in the use and check of equipment. An additional major benefit has been a better appreciation by development personnel of the environment and conditions in which the inspector carries out his task.

Recently, a similar programme has been implemented on the Agency's newly deployed STAR closed-circuit television systems, developed under the US Support Programme.

Performance monitoring also will be applied to NDA instruments. However, a fundamental difference arises because the emphasis is shifted towards measurement results rather than hardware reliability. This complicates the acquisition of the performance monitoring data as well as the assessment of whether an instrument meets its target goal.

Safeguards concept for heavy-water production plants

In anticipation of safeguards application to a large, natural water-fed, heavy-water production plant, the Agency has analysed various approaches. The goal would be to provide the Agency with an effective verification capability for the reactor-grade heavy water that is produced. A capability would be needed to permit the Agency to assure itself that there were no significant unrecorded withdrawals or removals of heavy water (or enriched, deuterated compounds) with concentrations above some target figure, and to permit the approach's implementation with an effort consistent with that devoted to other safeguarded bulk-handling facilities processing indirect-use material.

Alternative approaches that have been examined include those related to material balance accounting, process monitoring, and containment and surveillance, though the best approach appears to be an optimized combination of the first two. As an example, the Agency would measure the flow and deuterium concentration of the feed and discharge ammonia streams. The flow and concentration of the heavy-water product stream would also be measured, and plant inventory changes and losses would be estimated from process monitoring data, supplemented by measurements of those parts of the inventory that are accessible. Process monitoring data would also be used to estimate the plant's extraction.

Preliminary estimates indicate this approach could achieve a detection sensitivity of better than 20 tonnes deuterium oxide equivalent through the use of commercially available instrumentation. Infrared spectrometers are planned for concentration measurements, and standard meters for flow measurements. Intermediate concentration measurements needed to establish the plant's enrichment profile, and thus help to establish inventories and losses, are planned to be carried out on the basis of densitometry, using instruments commercially available for this purpose.

In view of the large amount of data involved, a small digital acquisition system is planned to record at frequent intervals process-monitoring data relevant to safeguards.

Product storage in the form of water would be verified on the basis of a standard attributes/variables sampling plan. For this purpose, acoustic velocity measurements combined with a simple weight check would serve the purpose of the attributes test. These tests can be carried out on barrels without sampling. The variables test would involve taking a heavy-water sample and using a hand-held densitometer to determine the concentration (and/or submitting the sample to laboratory analysis by mass-spectrometry, for example).

The instrumentation for all these purposes is commercially available, but field testing will be required, as will some software and tamper-resistance development effort. In this particular case, the development of the system approach has defined the instrumentation needed to implement the approach. Often the situation is reversed and the existence of crucial instruments has preceded the formal development of the system approach.

Future trends

The noted science fiction writer, Arthur C. Clarke, once said, "This is the first age that's paid much attention to the future, which is a little ironic, since we may not have one."

Organizations like the IAEA cannot afford to be this pessimistic, and, in fact, have been set up to help ensure that we do have a future.

The examples of R & D given here reflect work immediately applicable to safeguards. It is necessary in R & D, however, to always look a few years ahead. It is becoming increasingly evident, as more nuclear stations are built, that more nuclear material will come under safeguards, more countries will enter into safeguards agreements, and the Agency's Inspectorate will face an increasingly heavy burden.

Thought is being given in R & D on how to ease this burden. One *technically* promising aid is the use of computer network technology to gather some data the inspector currently obtains.

Such an approach is fraught with political problems and may never prove to be feasible, but such remote data gathering has proven technically feasible in a host of other applications.

Consequently, an eye is being kept on what is technically applicable to safeguards. One promising initial application would be to monitor the operational status of safeguards equipment at the various installations (e.g., is the film camera working?).

We see this occurring in steps. Initially, equipment and interfaces would be designed to allow the inspector to determine on-site the operating status of safeguards equipment. This would allow automation of the performance monitoring activity described earlier, a reduction in the intrusion or increase in efficiency, and most probably, a reduction of radiation exposure for facility staff as well as inspectors.

A second phase could be transmission of this information to an Agency field office within the country of origin. The final step would be transmission of information directly to Agency Headquarters in Vienna.

To make this programme technically and economically feasible requires:

- Appropriate sensors built into equipment that unambiguously detect failures
- Design of suitable equipment interfaces to allow read-out of such failure data
- Development of cost-effective and secure network technology for remote transmission of the data.

Long range projects in these areas are underway or in planning. Once technical feasibility is assured and the benefits shown to be worth the costs, the larger problem of political acceptability will have to be addressed.

Another future trend is the replacement of film with television, since television makes on-site review of the surveillance results of an inspection period immediately available. Currently television is being used in some installations, but if it is ever to replace the Agency surveillance "work-horse", the twin Minolta film camera, it must be made more reliable, smaller, more tamper-proof and more cost-effective than it is at present. To accomplish all these goals is a major technical challenge.

International effort

The major continuing R & D effort being carried out to improve safeguards techniques is truly international in scope involving formal support from nine countries and the European Community, and the co-operation of essentially all Member States.

Such a programme is almost without precedent, and consequently is not without unique problems. The fact that, in large part, safeguards needs are being met indicates that problems are being solved and is a testimonial to the support and co-operation given by Member States.

Nevertheless, it is clear that more has to be done to improve safeguards credibility and efficiency. Improving safeguards techniques will require the continuance of this support and co-operation. We cannot afford to be complacent and assume that present solutions will work in the environment of the future.

If we are too constrained by the past we are likely to suffer the fate of Disraelis' conservative who attempted to leap a canyon in two stages.

Innovation also has its pitfalls, as illustrated by a truism that one can identify the pioneers by the protruding arrows. A blend of established technology and innovation is required that will increase both safeguards effectiveness and safeguards efficiency.

Our success will be determined by how well we strike the correct balance to achieve these often-conflicting goals.