Technological developments and safeguards instrumentation: Responding to new challenges

From a variety of directions, advances in technology are influencing safeguards operations and support

by K. Naito and D.E. Rundquist

Entering the 1990s, technological tools that were in the research and development stage not so long ago are changing the way inspectors are able to verify nuclear materials at many facilities around the world.

Many new instruments — ranging from advanced video monitoring systems to miniature detectors and analysers — already are in place. In some cases, they have been custom-made for specific safeguards tasks, or for placement in locations, such as underwater storage pools for spent reactor fuel, where inspectors cannot go.

Standing behind the development of many of these new safeguards instruments are a number of factors. They include:

- ***Technological advances in computer-related fields, such as microprocessing and electronics, and specific areas of instrumentation.*** The IAEA's safeguards activities — through an international network of support programmes with more than 10 countries and Euratom — benefit from the expertise of some of the world's top instrumentation laboratories. In some cases, rapid changes in instrument technology have dictated changes, making some equipment obsolete, or making it difficult to ensure availability of spare parts.
- ***Technical developments in the nuclear industry.*** These include more modern fabrication of fuel assemblies for power reactors, and the increasing use of automation and remote handling methods in nuclear fuel cycle facilities, particularly in spent-fuel reprocessing and fuel element fabrication plants. In the process, nuclear material can become less accessible for verification, requiring new safeguards procedures and techniques for verifying inventories.
- ***Efficiency improvements and efforts to reduce the costs of safeguards implementation.*** The IAEA's financial situation has heightened interest in the development of more cost-effective safeguards measures and techniques, particularly with respect to specific types of nuclear facilities.

When considered from a broad perspective, technological developments have substantially improved safeguards instrumentation capabilities. Of course, concomitant with the improvements, new requirements relating to instrument support and training also have risen.

Today, no major gap exists between a specific requirement for an instrument application and the availability of an instrument that, in principle, can accommodate that requirement. In some circumstances, the quality of the instrument is state-of-the-art. Even so, in most situations, the instrument's sophistication or capability has to be compromised to improve its reliability when utilized under industrial conditions.

On the other end of the spectrum, situations remain where the readily available instrument is just barely adequate.

In most cases, safeguards requirements demand stringent specifications that cannot be met by off-the-shelf equipment. Consequently, most Agency safeguards equipment must be custom-designed. This generally insures that technical objectives are met. But it does not insure that the strategy for implementing the new equipment is optimum or that the support infrastructure can readily accommodate it.

In this respect, technological developments have raised an important problem that the IAEA now is addressing: how best to integrate high-technology equipment within the Agency's

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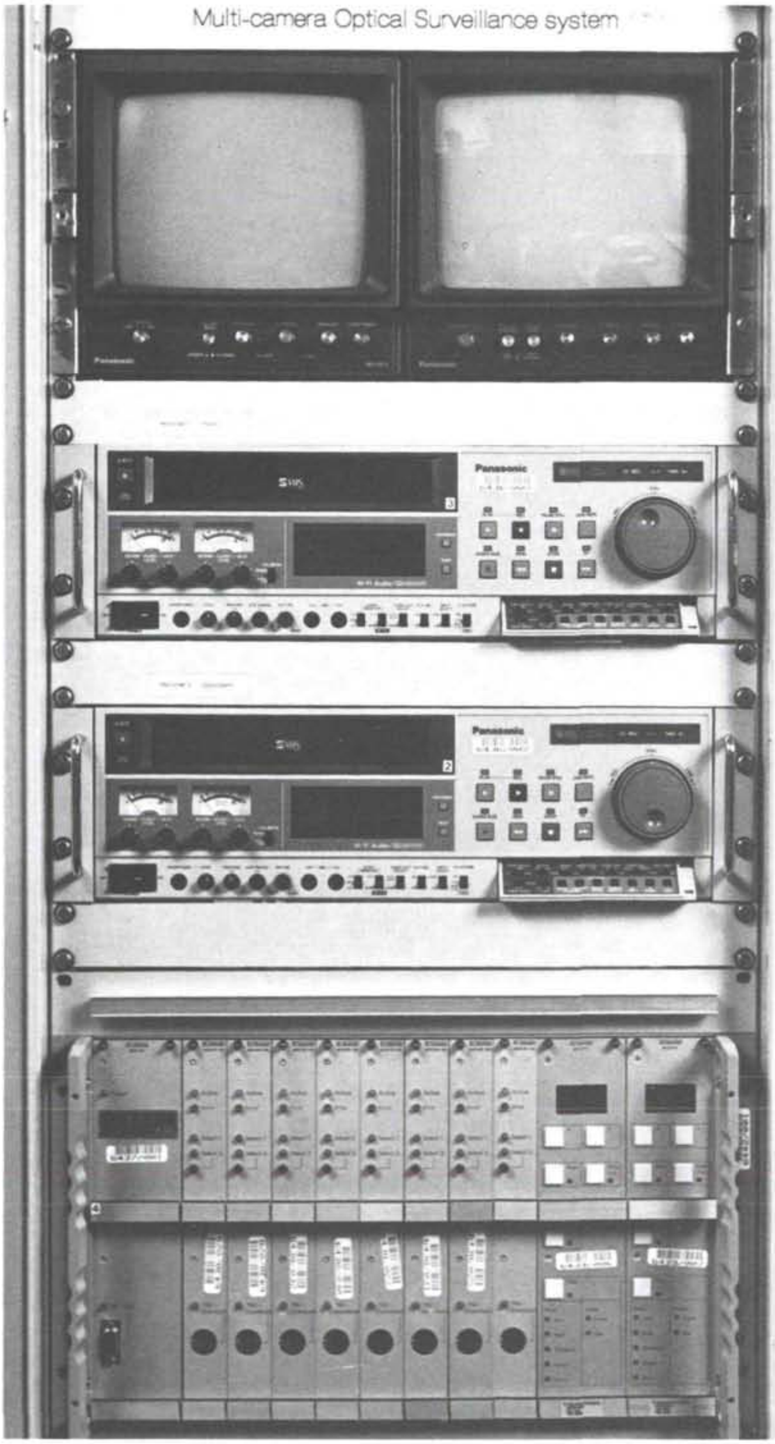
limited implementation and support capabilities for safeguards.

This article briefly reviews how safeguards equipment currently is being developed within the context of technological developments and presents selected technical details of a representative set of the latest safeguards instrumentation systems.

Multi-camera optical surveillance system.



Developing instruments and equipment

Success in safeguarding a facility requires both an approach and the resources to implement it.

The approaches vary, depending on the type of facility, but essentially all schemes employ a combination of material accountancy and containment/surveillance (C/S). Accountancy mainly 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, or by safeguards measures, such as applying IAEA seals to a previously verified quantity of nuclear material. Surveillance means the instrumental or human observation of the movement of nuclear material, such as by closed circuit television or film camera.

Resources include financial support, inspectors, and equipment. For the success of a given safeguards approach, inspectors must be thoroughly trained in the techniques of using the required equipment and interpreting data from it.

In general, the IAEA's safeguards equipment can be subdivided into two general categories:

- Bulky, *in-situ* type of equipment that may be employed for reliable surveillance/monitoring applications or for accurate non-destructive assay (NDA) measurements.
- Portable, miniaturized equipment carried by the inspector to the facility to make attribute (indicative rather than quantitative) types of measurements or to perform simple C/S functions.

This categorization scheme is arbitrary but useful in visualizing the implementation of the instrument.

Typical instruments in the first category include neutron coincidence counters for quantitatively measuring unirradiated plutonium in a variety of chemical forms. The instrument itself may or may not be fixed in the facility. Under good conditions (with well-characterized material and representative standards) neutron coincidence counters can achieve accuracies on the order of 1%. Another example is the core discharge monitor (CDM), which is described in the following section.

In the second category, instruments include the portable multi-channel analyzer (PMCA) and the Cerenkov viewing device for observing irradiated spent fuel.

For both categories, the development process generally is similar but different in detail. The basic need is defined by a statement of the user requirements that ultimately is translated into functional specifications that then lead to the instrument's technical design.

Functional specifications are crucial milestones in an instrument development programme. A complete development programme includes technical design specifications, safety evaluation, acceptance and field testing, documentation, maintenance, and training. A minimum set of criteria must be met before an instrument can be authorized for inspection use.

To date some 65 instruments or instrumental systems are approved for inspection use; another 24 are under evaluation. To a certain extent, the number of instruments is representative of the multitude of applications that are encountered by Agency inspectors in the course of performing their duties. On the other hand, they pose substantial organizational challenges because appropriate support must be provided reliably and cost effectively in such areas as documentation, training, maintenance, inventory control, and shipping.

Overview of selected instruments

Recently a number of new instruments have been approved for use or have entered the final stage of development. They include:

Core discharge monitor (CDM). The CDM is located inside the containment area (inaccessible area) of a power reactor that is fuelled on-load, and provides continuous unattended monitoring of the core fuel. It was developed with the assistance of support programmes with Canada and the United States for multi-unit Candu (or other on-load fuelled) reactors.

The CDM detects fuel discharged from the reactor face, with its signal recorded as a function of time. The inspector later reviews the data and is able to verify that a specific number of irradiated fuel bundles were discharged from the reactor core.

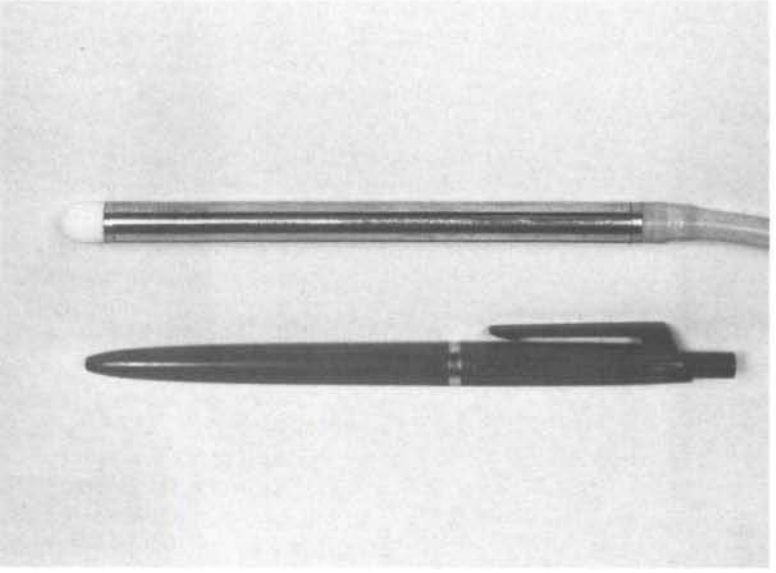
The system was designed to be "fail-safe". Sufficient redundancy is built in to accommodate individual component failures without compromising the CDM's operation. The detection monitors are designed to last the lifetime of the reactor, since their location inside an inaccessible area limits possibilities for maintenance and repair. Automatic perfomance monitoring and failure announcement are other features that have been incorporated.

Since it has been in use, the system has performed well. Of particular interest has been its detection of discharged irradiated fuel bundles even after the reactor was shut down for a long period.

Miniaturized gamma detector probes (CdTe). The verification of nuclear material by NDA or destructive assay is a key element of an effective international safeguards system. In most cases, nuclear material is verified by measuring its neutron and gamma radiation.

Cadmium-telluride (CdTe) detectors have been found most useful in providing solutions for verification measurements using gamma rays, particularly when the accessibility is limited or a high degree of portability is needed. Through the Russian Federation support programme, a miniaturized CdTe detector probe has been developed that opens up new practical applications. It is coupled to a hybrid chip forming the first stage of a charge sensitive preamplifier. The head end of the detection system is housed in a miniature probe with a diameter of only 8.2 mm and length of 100 mm. This probe can be located up to 2 metres away from the small portable multichannel analyzer.

Miniaturized gamma detector probe (CdTe).



The development of these miniaturized probes has made practical a number of measurement applications. They range from underwater verification of irradiated fuel to the internal verification of fresh fuel assemblies (by inserting the detector probe into the cooling channel).

Spent fuel attribute tester (SFAT). Inventories of spent fuel stored underwater are the largest single source of direct-use material covered by safeguards. Typically this material is verified by observing the Cerenkov glow.

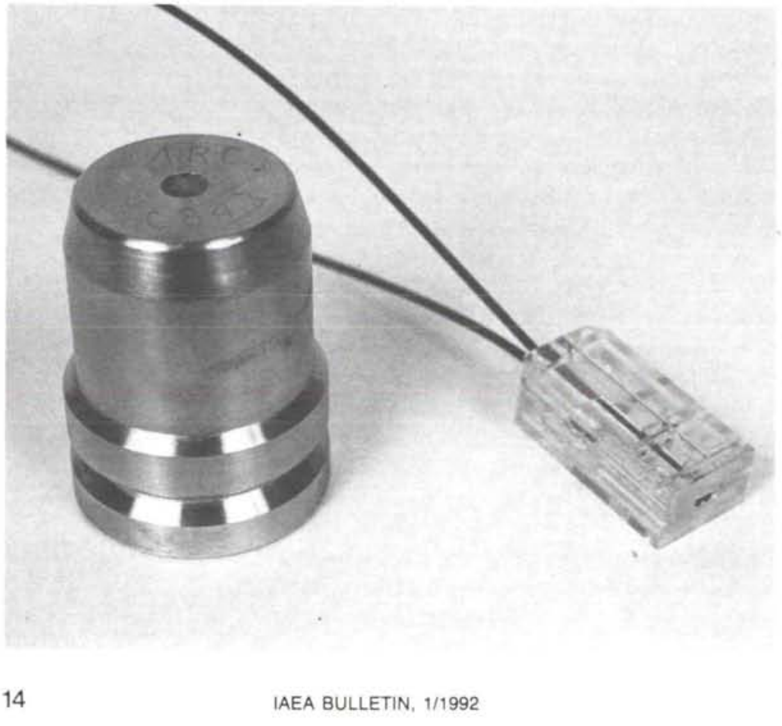
More and more often, however, situations are encountered where the Cerenkov radiation is too weak to be utilized for safeguards purposes. Existing NDA techniques (e.g., ion fork detector) require lifting the spent fuel assemblies for verification.

A new, less intrusive technique has been developed that more definitively detects an attribute (fission product gamma rays) of irradiated fuel even when the radiation signal is relatively weak, which can be the case when the fuel has been cooled for a long time, for example. The concept behind SFAT is simple: the detection of gamma rays utilizing a collimated spectrometer. SFAT systems built for specific facilities currently are in routine use, following successful field testing. The work has been supported through research contracts and support programmes, especially those with Germany, Sweden, and Finland.

High count-rate gamma spectroscopy system (HCRS). The determination of plutonium isotopic content of measurement samples is an established field technique using high resolution gamma ray spectrometry. Until recently, the time required for isotopic measurement was significantly longer than the required time to make the neutron coincidence count of total plutonium contained in the sample.

Through a support programme with Italy, a new self-contained system was developed for routinely determining plutonium isotopic ratios in far less time. Measurement times are three-to-five times shorter than previously realized by inspectors in the field. The system's main components are a recently developed pulse processor coupled with carefully specified high-purity germanium detectors. Measurements are designed to be performed under industrial conditions in the field. The HCRS recently was authorized for inspection use.

Two verifiable seals, known as COBRA and ARC.



Multi-camera optical surveillance system (MOS). Another key element of international safeguards systems is the use of optical surveillance. It serves as a complementary measure to nuclear material accountancy and provides continuity of information on the location and integrity of nuclear material. The Agency has deployed such systems for many years beginning with film cameras and continuing on to closed circuit television (CCTV) systems.

The latest and most sophisticated system, MOS, supports up to 16 camera channels; it was developed under a support programme with Germany. Main components include the cameras, transmitter, and receiver units (for each camera channel), solid-state memory device for intermediate storage of images, network controller, and the video tape recorder. Each channel can be desynchronized and set for different time intervals between 0.5 and 99 minutes. It can also be triggered by external sources such as infrared sensors or video motion detectors. Video signal multiplexing is performed through software control on an individual basis for each channel. The system further has the capacity to record data on the history of the inspection period, the number of scenes recorded, and the number of tamper events which have occurred. MOS has been accepted for routine inspection use.

Generic review station (GRS). With the increased capacity of CCTV systems, the review of surveillance data is becoming more of a burden for the inspector to do efficiently. Experience has shown that approximately 5% or less of the recorded data has any safeguards significance (i.e., indicates a possible movement of nuclear material).

Besides reviewing the safeguards significance of surveillance data, inspectors must be assured that the system functioned when it was supposed to (i.e., no missing scenes) and that any tamper signals are properly acknowledged. With tapes containing 30 000 scenes, this can be a considerable chore.

To relieve the inspector's burden, the concept of a generic review station was proposed for processing video surveillance tapes recorded by different CCTV systems, including MOS and a number of other types. The GRS was conceived as a single entity to simplify inspector training, maintainence, and other support costs. Two proposals have been generated that technically meet requirements.

Functionally, the GRS will reduce the inspectors' total review time by 75% or more. Its main features are tamper alarms, and automatic identification of scenes of significance to safeguards, including missing scenes. The first GRS prototypes are expected to be completed by mid-1992.

In-situ verifiable seals (COBRA, ARC). Two sealing systems capable of *in-situ* verification are in advanced stages of development. The COBRA seal was developed through the USA support programme. Designed and extensively tested, it is presently authorized for inspection use with a photographic verifier. An automated verifier, which is necessary for widespread usage, is under development through the Japanese support programme. Seal identification is performed by comparing the random pattern of a partially cut fiber optic cable.

The ARC seal is an underwater seal developed through the Canadian support programme that has been in routine use for several years. A new ultrasonic verification system is under development through a joint programme involving Canada, Euratom, and the United States. (The system also will be able to verify the Euratom-developed VAK-III seal, also an underwater ultrasonic seal.)

Also being developed under this joint programme is a database to automatically process the seal data. Ultimately it will relieve the present system, which manually processes data from approximately 20 000 seals per year.

Future directions

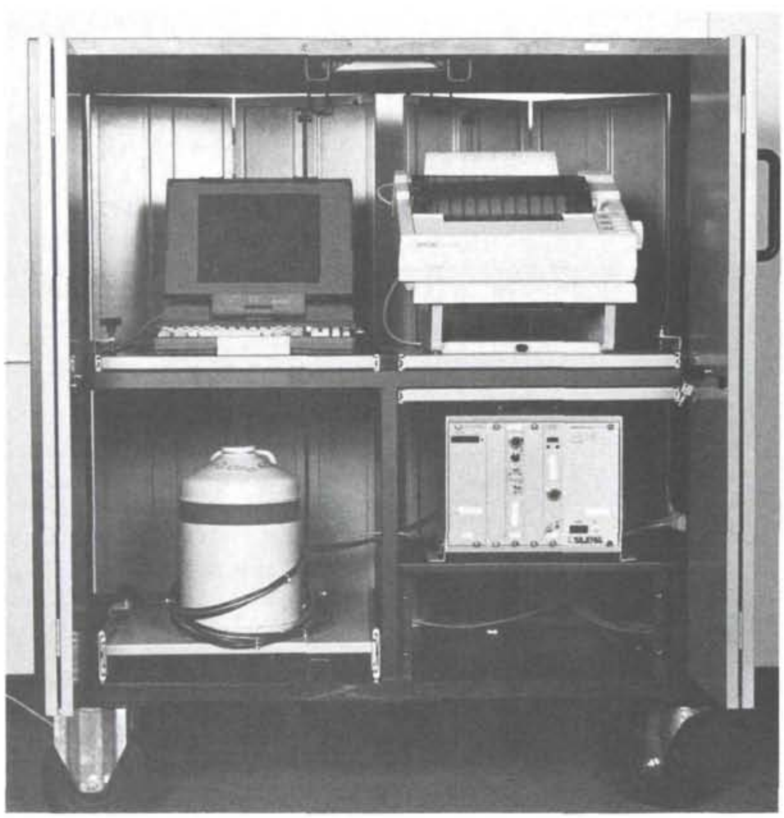
In a variety of ways, technological advances continue to be a major factor in the development of the IAEA's safeguards system. Today, equipment and procedures exist for most applications encountered by Agency inspectors. To meet highly specific requirements, customized equipment is normally employed. The IAEA's limited resources, however, are stretched to provide the necessary infrastructure to support the wide variety of instrumentation.

In recent years, technological developments have opened up new possibilities for equipment development and management, particularly in the area of standardization. Virtually all safeguards instrumentation systems utilize modern technologies, such as computers and microprocessors. They have a basic similarity, even though the particular type of sensor, or the instrument's specific function, may vary substantially. A typical system consists of a sensor, data processor, data storage unit, and review unit. The sensor could be a TV camera, radiation detector, or some other measurement device coupled to the control, storage, and review units. By standardizing components and techniques, for instance, equipment activities could be more readily optimized and resource requirements could be reduced.

In the face of continuing financial constraints, technical and economic factors are becoming stronger incentives to consider Agency safeguards equipment from a different perspective, one that takes into account instrumentation development, implementation, support, and training. Efforts to consolidate all these areas have begun. At a meeting in November 1991 at which a proposed programme was outlined, the IAEA received valuable advice from Member States involved in safeguards supports programmes.

The application of such a programme will be evolutionary rather than abrupt. Initially, the use of appropriate standards will be studied to facilitate communication, data authentication, software and hardware development, maintenance, and training. A long-term goal will be the integration of standard components to meet applications that are specific to a particular facility.

In years ahead, such an integrated approach should help the IAEA safeguards system to realize even greater efficiency gains than in the past, while strengthening its level of effectiveness.



High count-rate gamma spectroscopy system.