The application of modern methods and techniques in safeguards operations

by A. von Baeckmann*

The objective of international non-proliferation policy is to prevent the further spread of nuclear weapons. To this end a comprehensive system of international agreements and treaties has been established during the last 25 years, which incorporates an international system for verifying a state's compliance with its undertakings and for ensuring that nuclear energy is not diverted from peaceful activities to the manufacture of nuclear weapons or other nuclear explosive devices. From its formation in 1957, the IAEA has been entrusted with the task of setting up and operating this system which is now called the IAEA Safeguards System. This article describes the application of modern measurement and containment/surveillance techniques to IAEA safeguards operations.

To produce nuclear weapons or other nuclear explosives, certain quantities of U-233, U-235 or plutonium are required together with some relevant technology. Since it is practically impossible to control technical developments, the Agencv's safeguards system is mainly based on the rigorous supervision of nuclear materials. The fundamental safeguards instrument is a comprehensive system of nuclear material accountancy and containment/surveillance measures. Nuclear material accountancy is based on reports from the operators of nuclear facilities and on national systems for nuclear material accountancy and control. An integral part of this system is the independent verification of these accounts by IAEA inspections.

In order to verify independently reports on the quantity and composition of nuclear materials, the Agency's inspectors must be able to perform certain measurements. This is normally done either by taking a representative sample, which is then sent to an analytical laboratory, or by non-destructive analysis on the spot. Both procedures have their problems and require sophisticated instruments and expertise.

Chemical analysis

Chemical analyses usually lead to very accurate and precise results, but they are expensive, the samples have to be transported, and the results are only available after 3–5 weeks. Non-destructive analyses are often less accurate and less reliable but in many cases the results are available immediately. Fig.1 shows an analytical laboratory designed and equipped for chemical analysis of materials containing plutonium. Special precautions are applied to prevent the plutonium from escaping from the glove-boxes. The work in those areas requires highly trained and responsible staff. If the plutonium is accompanied by highly radioactive fission products, lead-shielded boxes equipped with manipulators are required. After separation from the fission products, the isotopic composition of very small samples is analysed.

Fig.2 shows a fully-automated thermal-ionization mass-spectrometer used for the analysis of uranium and plutonium in samples from inspections. This instrument is only one example of how modern electronic and computer technology can be applied in analytical chemistry. All operational parameters like pressure, temperature, magnetic field, electric field, etc. are controlled by pre-programmed processors and the final results – including the measurement uncertainties – are calculated by processing thousands of data-points in a minicomputer. A well-planned and executed quality assurance programme ensures reliable results. Chemical analysis provides nearly all our quantitative information on safeguarded nuclear material because chemical analysis is either used directly to obtain the results or it is used to calibrate the standards required for the non-destructive assay techniques.

Non-destructive assay

In many situations sampling and chemical analysis are not possible because the nuclear material is contained in cans, rods, pins, fuel assemblies, UF_6 cylinders or other containers, from which a sample cannot readily be taken without destroying the integrity of the container. Of course one cannot ruin a fuel assembly worth some $100 000 to find out whether the declared nuclear material is actually present in the assembly. Consequently non-destructive assay (NDA) techniques are required to enable the inspector to check the type and quantity of the contained nuclear material. For this kind of measurement it is an advantage that uranium and plutonium are radioactive elements. The process of continuous radioactive decay coupled with the emission of characteristic radiation cannot, in practice, be interfered with; and it enables the type and quantity of the radioactive material to be determined.

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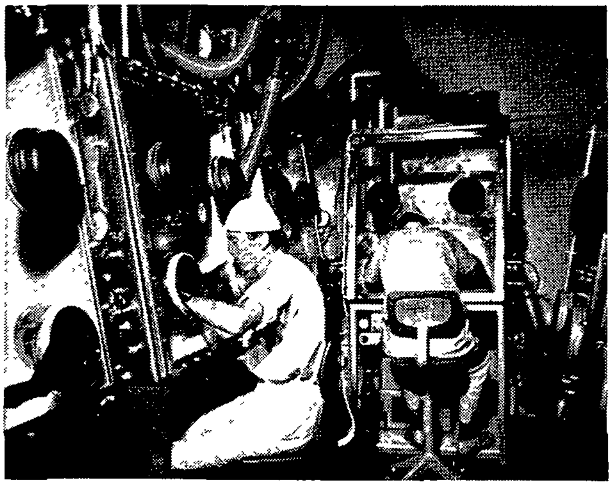


Figure 1. A laboratory designed and equipped for the chemical analysis of materials containing plutonium.

The most common NDA safeguards techniques are based on the measurement of γ-radiation interacting with the material of a detector. Electric impulses caused by this interaction are sorted into special computer memory registers according to their energies. Instruments which perform this task are called multi-channel analysers. The type of material is identified by the energy of the observed lines; its quantity by the lines' intensity.

Fig.3 shows a sophisticated 1000-channel analyser which allows the nuclear material to be identified and its quantity measured. With this instrument it is possible to display the γ-spectrum on a cathode-ray tube and to record it on magnetic tape. The display allows immediate identification and semi-quantitative determination of the nuclear material. By processing the information recorded on the magnetic tape in the Agency's central computer, the isotopic composition and quantity of uranium and plutonium can be calculated. The multi-channel analyser shown in the picture is combined with a high-resolution γ-detector which requires cooling by liquid nitrogen during measurements. The detector is made from pure Germanium.

Like all other electronic devices NDA instrumentation has benefitted enormously from the availability of highly reliable, inexpensive, and very compact solid-state components. With more advanced solid-state components, NDA instruments may be further improved to incorporate automatic quality control of measurements, full data analysis capability and even a certain degree of dialogue with the inspector. Although it is not possible to measure the uranium or plutonium content of highly radioactive irradiated fuel elements directly with this technique, the fission product γ-ray spectra – which gives the fuel's burn-up – can be measured; and the uranium and plutonium loading of the spent fuel elements can be calculated from the burn-up.

Another type of instrument which is used by IAEA inspectors for quantitative determination of nuclear material – particularly of plutonium – is the high-level neutron coincidence counter (HLNCC) shown in

Figure 2. A fully-automated thermal-ionization mass-spectrometer used for the analysis of uranium and plutonium in samples from inspections.

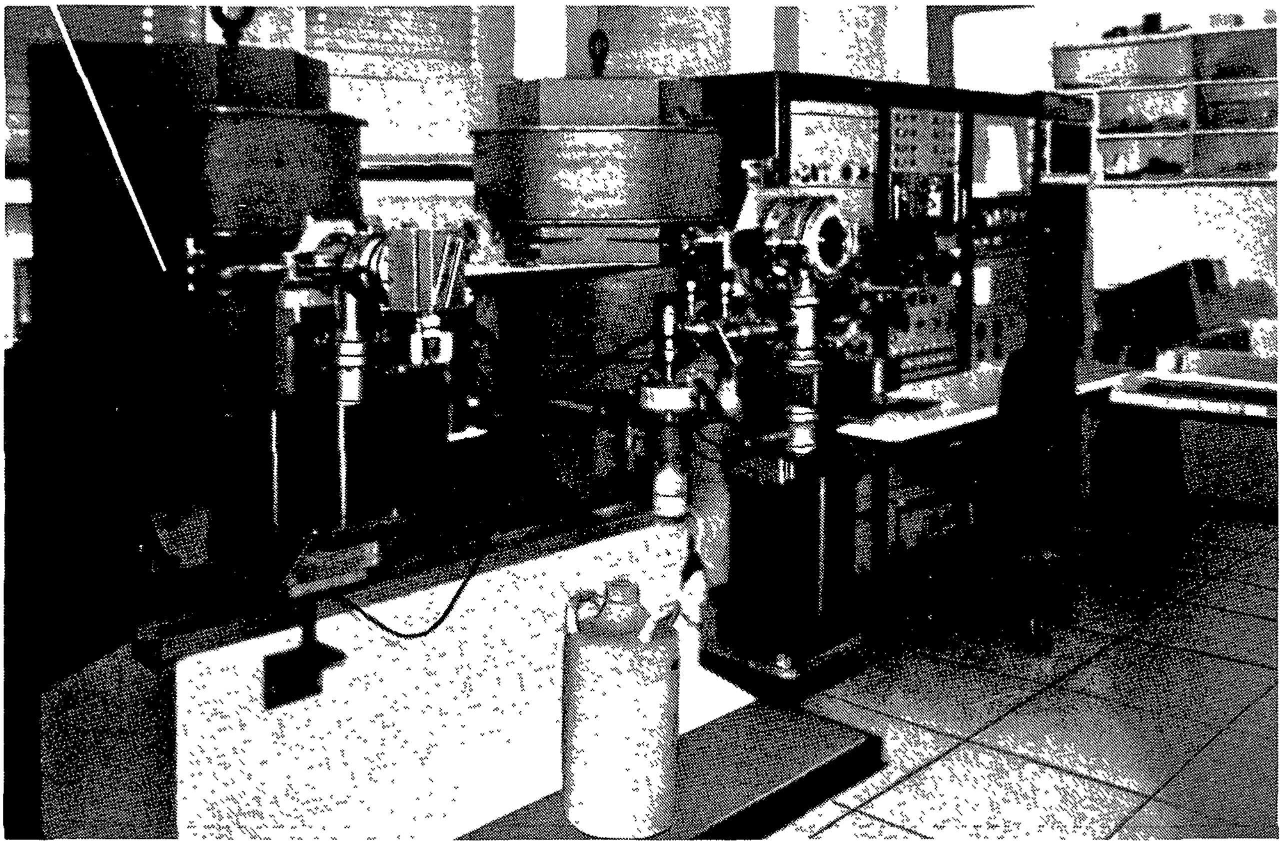


Fig.4. This instrument measures the neutrons emanating from the spontaneous fission of certain isotopes of plutonium or from the induced fission of uranium-235 or uranium-233. When an atom splits, usually 2 to 3 neutrons are emitted at the same moment. Because they arrive in the detector simultaneously, the neutrons from an atom's fission can be distinguished from "background" neutrons which are not correlated in time. The words "high-level" are included in the name because the counting and sorting electronics have been very carefully designed to perform at a very high rate, such as 100 000 single neutron counts per second. High counting rates are necessary when kilogram quantities of plutonium with high Pu-240 content are present. The HLNCC is connected directly to a small programmable calculator (HP 97). The system has been used to analyse well-characterized plutonium pins and coupons in the field with results that agreed to better than 2% with the production data.

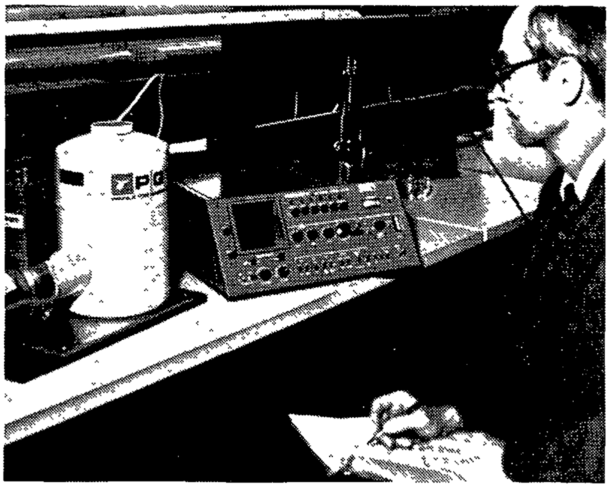


Figure 3. A 1000-channel analyser for use by IAEA inspectors.

One very simple technique for verifying the fuel content of a research reactor core has recently been further developed to give more sensitive and semi-quantitative results. The technique uses the well-known Cerenkov radiation effect. When a swimming-pool research reactor is operating an intense Cerenkov glow can be seen coming from the core. This intense light indicates that the reactor is operating, thereby verifying that the minimum critical quantity of nuclear fuel must be present. In many situations this is sufficient proof that quantity of nuclear material required to produce at least one explosive nuclear device has not been diverted.

The Cerenkov glow fades significantly once the reactor is shut down, and 3–5 months after the fuel has been removed from the core the Cerenkov glow is hardly visible with the naked eye. By using special light intensifiers or night-vision devices the Cerenkov glow can be seen and photographed, even after a cooling period of ten years or more. Fig.5 shows a very sensitive version of the light intensifier which allows photographing. This technique is particularly useful for verifying the irradiated character of spent fuel in storage Cerenkov glow devices which will allow semi-quantitative measurements are being developed. Although the quantity of uranium and plutonium in spent fuel cannot

Figure 4. A high-level neutron coincidence counter connected to a small programmable calculator.

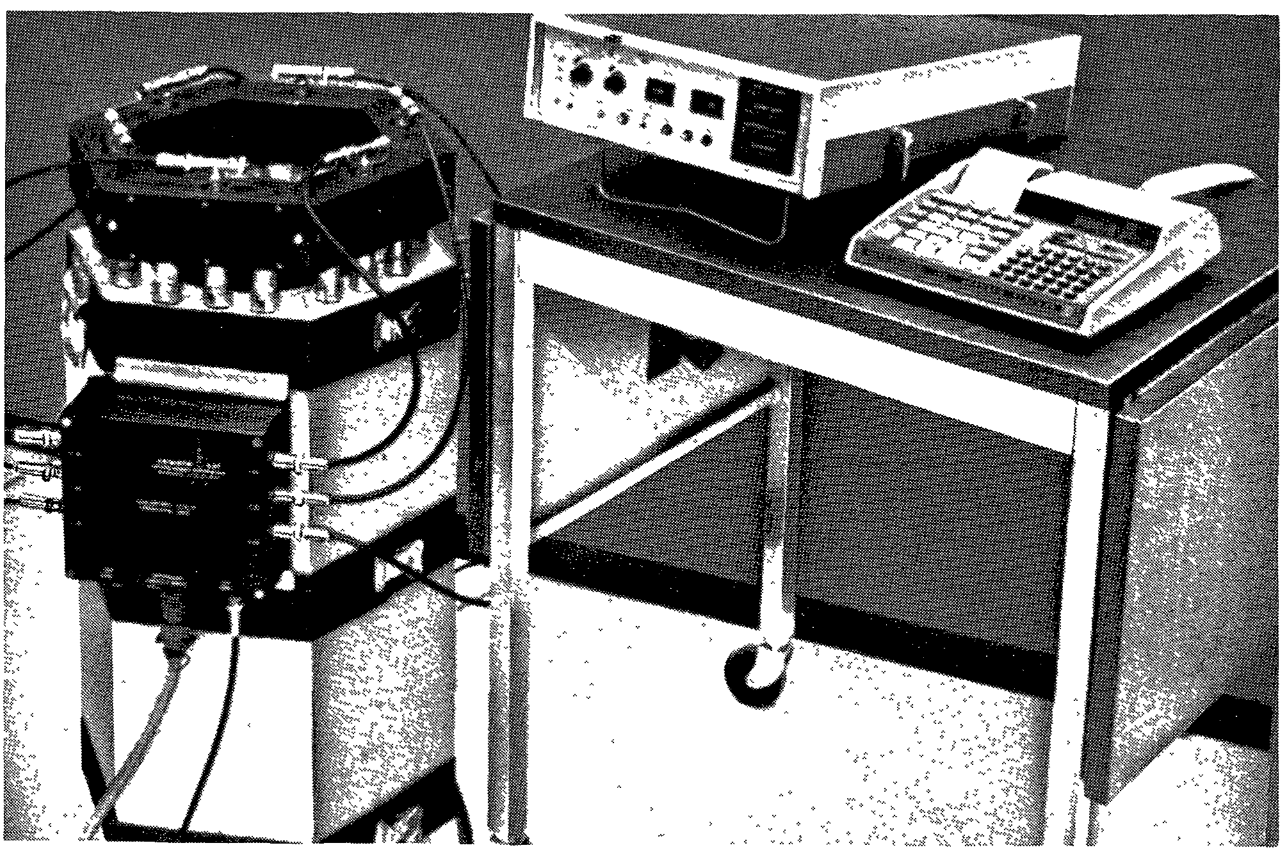
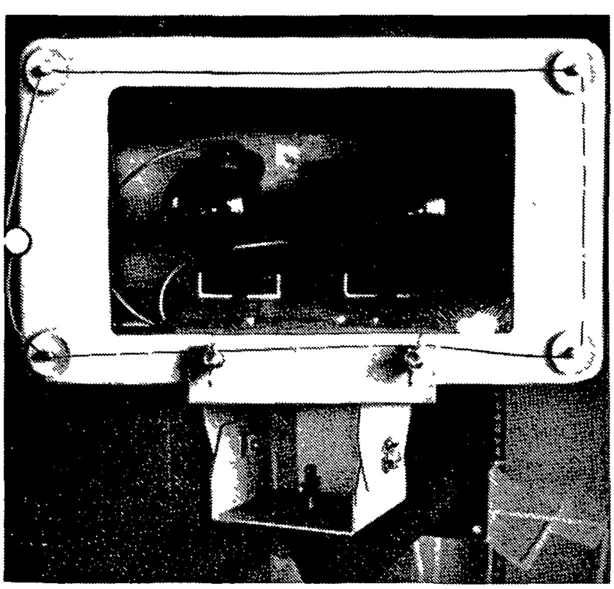


Figure 5. A light intensifier which can be used to take photographs of the Cerenkov glow of spent fuel elements.

be determined using this technique, the number of fuel rods present and the radiation level of the individual assemblies can be verified.

Reporting of all these developments and progress should not lead to the wrong impression that Non-Destructive Assay techniques offer an easy way of verifying nuclear materials. The individual techniques normally verify one specific feature of the material. Only by combining several non-destructive techniques and by calibrating them can one credibly assess the type and quantity of the nuclear material. The ideal non-destructive assay instrument would allow the reliable, simple and easy verification of type and quantity of nuclear material in a fuel assambly, a UF_6 cylinder, or any other container, or in a spent fuel storage bay. It will continue to be our goal for many more years to come.

Figure 6. The standard IAEA double camera system for containment surveillance.



Containment and surveillance measures

In order to avoid the unnecessary and expensive re-measurement of nuclear material which is enclosed in a containment, the Agency employs containment/surveillance measures. A seal, for example, is a very simple way of ensuring that the material stored in a container has remained unchanged since the seal was applied. Only the integrity of the containment and the seal needs to be checked, which is usually much cheaper and easier than re-verification of the material.

The principal general-purpose seal presently used by the IAEA is the Type-E metallic seal. About 8 000 of these seals are used by IAEA inspectors every year. In the past two years considerable efforts have been made to improve type-E seals and reduce their vulnerability to tampering. These seals are inexpensive, small and easy to apply, and are now relatively resistant to tampering. One important disadvantage is that their integrity cannot be checked on the spot. New general-purpose seals under investigation include ultrasonically *in-situ* verifiable seals, fiber optic seals, and electronic seals.

Film cameras or closed circuit television (CCTV) systems operating in a time-lapse mode are frequently used by the Agency to survey fuel movements out of spent-fuel storage bays in reactor stations or reprocessing plants. To remove spent fuel from such a storage pond, a heavy container to shield the spent fuel assembly's intense radiation has to be brought into the room and lowered into the pool. One or several fuel assemblies can then be loaded into the container which is closed and then taken out of the bay and away from the facility. This is a difficult and time-consuming activity which can easily be detected by reviewing the surveillance films, taken in a time-lapse mode in 10–20 minute intervals.

Fig.6 shows the standard IAEA double camera system which consists of two Minolta XL 401 Super 8 mm film cameras, each with its own quartz timer, a tamper-resistant sealable enclosure and a mounting bracket that allows the proper positioning of the cameras. Twin units are used for reliability. With special thin MFX films this system has a 7200 frames capacity – enough for 100 days of operation with one frame taken every 20 minutes. Approximately 150 of these systems are currently installed in facilities for IAEA safeguards purposes. They are completely self-contained, do not need electrical power from the facility and are relatively inexpensive, costing approximately $1500 per system. The use of the special thin film has, however, caused some reliability problems. Recent environmental tests have demonstrated that in high humidity the film is likely to jam. The Agency is currently retrofitting all film camera systems with special sealing materials and dessicants.

Several improvements can be made to this system. They include the use of a new 60 mm film cartridge with a capacity of 14 400 frames, automated annotation of date and time on each frame, film exposure time control to compensate for widely varying light conditions; increased reliablity, improved enclosure design which provides easier inspector access as well as increased tamper resistance, and test features. Many of these improvements are being included in a film camera system based on the Polaroid "instant movie" concept. Such features would be particularly useful where the inspector is not allowed to remove the film from the facility or the State for development and review.

To be a credible safeguards technique, optical surveillance data requires careful review by the inspectors, in most cases at Agency Headquarters. This is a particularly laborious job beset with uncertainties, and the workload has become enormous. IAEA cameras are now taking pictures at an aggregate rate of more than ten per minute. Within the past year, the Agency has brought into use a special semi-automatic Super 8 mm film scanner. In this device the film is projected into a video camera, and the video signal is analysed by a motion detector. Only those frames that show motion are recorded on a video disc and later carefully reviewed on a monitor screen by the inspectors. By using the scanner the surveillance films can be reviewed more quickly and more accurately.

Closed circuit television (CCTV) systems are sometimes used instead of film cameras when continuous surveillance is required, when the level of radiation at the camera is high and would spoil the film, or where the recording has to be reviewed on-the-spot. The CCTV system currently used by the Agency operates in much the same manner as the film camera system. Frames are recorded periodically on a video tape recorder and played back through a monitor for review; the tape can also be removed for later review at Headquarters. These pioneering systems were relatively unreliable at first but better maintenance over the past year has significantly reduced the failure rate. Some components of the older systems, particularly the video tape recorders, are wearing out. At the present time there are 12 CCTV units operating in IAEA safeguarded facilities.

New microprocessor-controlled CCTV systems are currently being evaluated for Agency use. These systems have been designed for improved reliability, and simplified set up and operator controls. The microprocessor control is programmed to provide a basic surveillance capability even if an inspector makes an operational mistake.

Another technique that can result in the more reliable use of containment/surveillance instrumentation is to monitor remotely the operational status of the equipment. This technique is under investigation in a programme called RECOVER. (REmote COntinual VERification). The RECOVER system consists of monitor units which are connected directly to the containment/surveillance device; on-site multiplexes which periodically interrogate the monitor units and upon request send the status data to IAEA Headquarters; and the resident verification units at IAEA Headquarters, or regional offices, which interrogate the on-site multiplexes and analyse and store the transmitted data. Abnormal data would cause an alarm so that IAEA personnel could investigate. The status data are encrypted before being sent through conventional telephone lines. The results of the interrogations can be immediately displayed on the remote verification unit's television monitor or recalled at a later time from its memory. Thus malfunctions or tampering with the containment/surveillance devices can be detected automatically at a site remote from the device. A first version of the RECOVER system is currently being tested at facilities in Australia, Austria, Bulgaria, Canada, the Federal Republic of Germany, Japan, the United Kingdom and the United States of America.

International co-operation

For the development of safeguards devices and techniques the Agency depends heavily on the co-operation of Member States. Unlike Euratom, NRC or similar safeguards authorities, the Agency does not operate its own Research and Development facilities. Its staff monitors and co-ordinates the safeguards research and development of Member States. The USA, Canada and the Federal Republic of Germany have established comprehensive support programmes to IAEA safeguards, and other States such as the UK, the USSR, Australia, Japan and Euratom have announced their readiness to provide additional support. Japan, France and the USA have invited the Agency to participate in the TASTEX programme, which is aimed at improving national and international safeguards at reprocessing facilities. The IAEA has also been invited to participate together with Euratom, UK, the Netherlands, the Federal Republic of Germany, USA, Japan and Australia in a development project, the objective of which is to facilitate the application of international safeguards at uranium enrichment plants of the gas centrifuge type. The Agency is very grateful for this support which has already contributed significantly to improving the effectiveness of IAEA safeguards.