Chairman of the 1970 IAEA Safeguards Committee was Mr Kurt Waldheim, now President of Austria. Director General of the IAEA at the time, Dr Sigvard Eklund, is at left.

The 1970 Safeguards Committee

In April 1970, the IAEA Board of Governors adopted a resolution calling for establishment of a Safeguards Committee to formulate guidelines for safeguards agreements in connection with the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), which had been opened for signature in 1968 and whose entry into force was imminent. The Treaty assigns to the IAEA the responsibility of applying safeguards to nuclear material in all nuclear facilities in States that become NPT parties for the exclusive purpose of verification of the fulfillment of their obligations under the Treaty. Once the NPT has entered into force for a State, it is required to start negotiations on a safeguards agreement with the IAEA within 180 days.

As Chairman of the Safeguards Committee, the Board designated Mr Kurt Waldheim of Austria, who would later become Secretary-General of the United Nations and President of Austria. Mr F.B. Straub of Hungary and Mr J.A.K. Quartey of Ghana were designated as Vice Chairmen. The Committee was open to representation to any Member State. All told, delegations from 50 Member States participated in one or more meetings of the Committee: Argentina, Australia, Austria, Belgium, Brazil, Bulgaria, Canada, Chile, China, Czechoslovakia, Denmark, Ecuador, Egypt (United Arab Republic), Finland, France, Federal Republic of Germany, Ghana, Greece, Hungary, India, Indonesia, Iran, Ireland, Israel, Italy, Japan, Republic of Korea, Mexico, Netherlands, Nigeria, Norway, Pakistan, Peru, Philippines, Poland, Portugal, Romania, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey, USSR, United Kingdom, United States, Uruguay, Venezuela, Viet Nam, and Yugoslavia. Members of State delegations included Dr Hans Blix (Sweden), who in 1981 would succeed Dr Sigvard Eklund of Sweden as Director General of the IAEA; Mr Jon Jennekens (Canada), currently the IAEA Deputy Director General for Safeguards; and Mr D.L. Siazon, Jr. (Philippines), currently Director General of the United Nations Industrial Development Organization (UNIDO).

IAEA safeguards: A look at 1970–1990 and future prospects

Political, financial, and technological developments continue to influence directions and change

by Jon Jennekens

Fears that nuclear weapons would spread to many countries have fortunately not come true. To an important degree, the application of international safeguards has furthered this reality. For the IAEA, the operation of an effective worldwide safeguards system is a great responsibility, one that has been carried out over the past quarter century.

Even after 25 years, new challenges arise: Complicated installations are built that handle large quantities of fissionable material which have to be safeguarded. Verification techniques which were once satisfactory become obsolete. Today's political developments as well — for example, the discussion of disarmament on many fronts — have opened up a much greater general readiness to accept verification than was true when the safeguards system began in the 1960s. IAEA safeguards will benefit both in cost efficiency and credibility if they are allowed to keep up with the advances made in other verification schemes.

Over the past decade, these developments, coupled with financial limitations, have seriously tested the IAEA's capability to carry out effective safeguards operations. Necessarily, the Agency has undertaken a number of steps to increase the overall effectiveness of its safeguards work. New diversion scenarios and safeguards concepts for larger and more complex nuclear facilities have been defined, for example, and safeguards at such plants have been updated. A safeguards information system has been introduced for the computerization of all safeguards data, which has greatly improved record handling and evaluation activities. Simultaneous inspection of all facilities in certain countries has been developed to the point of routine application. This procedure has resulted in improvements in safeguards effectiveness.

Other steps have been taken through safeguards support programmes of Member States. These include improvements in the reliability and performance of film cameras for surveillance of nuclear facilities. Advanced closed-circuit television systems have also been developed and tested. Additionally, there have been significant improvements in the accuracy, reliability, and ease of use of instruments for non-destructive measurement of the composition of nuclear material.

This article reviews some of the important developments influencing the evolution of the IAEA's safeguards implementation over the past 20 years, since the entry into force of the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) in 1970 which has significantly influenced safeguards activities. Areas specifically addressed include safeguards procedures, equipment, analytical measurements, and inspection reporting systems and evaluations.

Safeguards agreements and procedures

In 1970, the IAEA's "Safeguards Committee" was established to elaborate guidelines for use by the Director General in concluding safeguards agreements envisaged in Article III of the NPT. (*See box.)* Before then, the safeguards "system" was largely based on the acceptance of safeguards by States receiving nuclear material or equipment from other States for specific projects. Prior to 1970, the scope of safeguards implementation was largely limited to individual nuclear installations involving specific quantities of nuclear material and materials and equipment especially designed or adapted for use in nuclear research, development, and industrial activities.

In contrast, the safeguards required by the NPT apply to all source or special fissionable material in all peaceful nuclear activities in non-nuclear-weapon States. The entry into force of the NPT thus brought about an important change in the demands placed upon the Agency.

Other changes also affected the Agency's safeguards activities. Before 1970, the nuclear materials subject to IAEA safeguards were either highly enriched uranium (HEU) in the form of fuel elements for research reactors, or relatively small quantities of natural uranium intended for use in research and development facilities and "pilot" production facilities. Other than a dozen or

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so industrialized States with fledgling nuclear power programmes, there were only 10 or 12 developing countries pursuing nuclear research and development programmes. As a result, there were only isolated instances of international traffic in nuclear materials and equipment. The optimism of the participants of the first Geneva Conference in 1955 on the peaceful uses of nuclear energy had long since been tempered by the hard realities of economics and, more generally, geopolitics.

The Safeguards Committee's report entitled "The Structure and Content of Agreements between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons (NPT)", documented as INFCIRC/153, recommended the incorporation of provisions in safeguards agreements which were largely but not entirely acceptable to both industrialized and developing States. The recommendations were intended to provide the Agency with the verification possibilities required by the NPT and, at the same time, to avoid undue interference in nuclear industry or research activities.

The Committee's recommendations constituted significant progress in the evolutionary development of the legal and technical aspects of the Agency's safeguards policies, practices, and procedures. According to the Committee, the primary objectives of IAEA safeguards are the timely detection of the diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons, other nuclear explosive devices or for unknown purposes, plus the deterrence of such diversion by the risk of early detection. These objectives are to be achieved by means of nuclear material accountancy, with containment and surveillance (C/S) as important complementary measures.

The proposed conditions under which safeguards inspections were to be conducted suggested that the Agency would check nuclear material only at strategic points jointly defined by the State and the Agency in the installations in which safeguards were to be applied. The Committee emphasized the need for taking into account several factors: material accountancy control systems already existing in States or to be established; the interdependence with other States; and the characteristics of nuclear material, fuel cycle capabilities, and evolving safeguards technologies.

The Committee recommended the maximum inspection effort in "person-days" to be applied in each of three classes of facilities: reactors and sealed storage facilities; facilities handling plutonium or uranium enriched to more than 5% uranium-235, including conversion, fabrication, and reprocessing plants; all other facilities handling material of lesser enrichment, including conversion and fabrication plants processing natural or slightly enriched uranium.

It was also recommended that the Agency not require more than the minimum information needed for safeguards implementation and that it scrupulously respect the confidentiality of this and other sensitive information it might receive. Emphasis was placed on the importance of national accounting and control systems and their role between the Agency and plant operators as a means of expediting and simplifying the application of safeguards.

The expectation at the time of the 18 Nation Disarmament Committee which drafted the NPT was that most States would ratify the NPT and therefore enter into INFCIRC/153-type safeguards agreements with the Agency. This expectation has been largely realized, although a handful of States with significant nuclear research, development, and industrial programmes have declined to ratify the Treaty for a variety of reasons.

Facility attachments. The first facility attachments negotiated in accordance with the terms of INFCIRC/153-type safeguards agreements included provisions relating to plant location, design information, and record and report systems only. Later versions were expanded to include provisions concerning verification of physical inventories. Since the facilities in the early 1970s were basically "item" facilities, (i.e. power and research reactors), the provisions guiding the implementation of safeguards at them were quite simple in comparison with present day, very complex facilities. The inspection activities conducted in 1970 included examination of records, verification of their consistency with reports, application of C/S measures, and verification of the fresh fuel items by item counting, identification of serial numbers, and simple non-destructive assay (NDA) methods (normally using portable instruments).

In the early 1970s, the implementation of safeguards at reactors concentrated on examination of operational records and of burnup calculations. High-resolution systems with magnetic cassette data recording capabilities were introduced to confirm the declared plutonium production. The application of seals was quite limited. Reactor operating records were examined to obtain an understanding of their operating history and to schedule subsequent inspections. Eventually, experience obtained in safeguarding reactors was extended to the safeguarding of facilities in which nuclear materials were processed.

Today, following the IAEA's development of technical manuals and guidelines in response to the recommendations of consultants and advisers, safeguards inspectors are guided by a set of comprehensive instructions in a multi-volume document called the Safeguards Manual.

Instruments and equipment

Non-destructive measurements. In the early 1970s, the equipment used for NDA during safeguards inspections was limited to a small number of mostly portable instruments. These were capable of making approximate measurements of gamma radiation to establish the presence of uranium and its enrichment, and measurements of neutron emissions which were characteristic of various plutonium compounds.

The instruments were later replaced by more sophisticated models with which it was possible to perform more comprehensive and accurate qualitative and semi-quantitative measurements.

In 1990, the Department of Safeguards has more than 300 individual portable and semi-portable NDA instruments and devices which represent the most advanced and practical measuring systems for routine and special inspection purposes. They include:

● Gamma-ray measurement instruments for attribute tests of radioactive materials (e.g. determination of uranium enrichment and spectrometry of fission products in spent fuel by means of portable multi-channel analysers (PMCAs)).

● High-resolution gamma-ray spectrometers for plutonium isotopic and spent fuel measurements.

● Coincident neutron emission detectors for quantitative measurements of plutonium and, with active interrogation, uranium-235.

● Cerenkov-glow viewing devices for non-intrusive attribute measurements of spent-fuel assemblies.

● Load-cell based weighing systems and ultrasonic thickness gauges used together with PMCAs for verifying the contents of uranium hexafluoride transport cylinders and uranium dioxide processing equipment.

● Ion chamber/fission chamber spent-fuel monitors for attribute measurements of spent-fuel assemblies.

● Portable computers (over 200) used in connection with many NDA instruments for data acquisition and analysis.

Containment and surveillance equipment. The first photo-surveillance system for routine inspection work was installed in 1970. It was a 35-mm photo camera with an enlarged film cassette providing a capacity for 200 pictures. Servicing such cameras was a relatively lengthy and tedious operation. The process of loading film into the camera was awkward compared with the much simpler cassette exchange of the 8-mm "home movie" cameras which were introduced for the first time in 1972. These film cameras had a picture capacity of 3600, which was increased to 7200 in 1974 with the introduction of a thinner film material. These 8-mm film cameras are still the workhorse for safeguards surveillance purposes. About 290 "Twin Minolta" systems are presently installed. Thanks to continuing technical development these systems have matured to a high level of reliability.

Production using 8-mm film has been discontinued worldwide and video systems now serve the requirements of the amateur movie maker. The Agency will have to replace all "Twin Minolta" systems by video equipment, i.e. closed-circuit television (CCTV). A replacement programme for safeguards surveillance units was initiated in 1988 and installation of video replacement units is now being done.

The IAEA first introduced CCTV systems in 1976. The advantages of CCTV systems as compared to film camera systems are higher picture quality, higher light sensitivity, date and time annotation, and a lower sensitivity to radiation. Also, the direct review of the recorded information on-site without film processing is possible.

The "Modular Integrated Video System" (MIVS) was developed under the Support Programme of the United States. Its production started in late 1989 and installation is under way. (*See a separate article in this edition on the MIVS project.*) The "Compact Surveillance and Monitoring System (COSMOS) is being developed under the Support programme of Japan and is expected to be available for installation in the latter part of 1991.

Also available for use by inspectors are reactor power monitors; ultrasonic seals and seal verifiers; electronic seals; cap metallic seals; adhesive/paper seals; and thermal luminescent dosimeters (TLDs).

Microprocessors. Microprocessors have enabled the Agency to raise the level of technical performance to an entirely new, higher level. Microprocessors in tandem with PMCAs are used for measurement of isotopic composition, error diagnosis, and data evaluation.

Similarly, the use of portable computers is boosting the Agency's capability to perform verification of plutonium samples in the field by running sophisticated programmes which previously could only be run at IAEA headquarters.

New technical methods to store and encode information have greatly improved the performance of C/S equipment. The recording of surveillance data on film has now been replaced by electromagnetic storage media (video tapes). Electronic seals have been developed which can be verified by inspectors in the field.

New types of radiation detectors have been introduced to improve the Agency's analytical capabilities. High purity germanium detectors are quite widely used, allowing for high performance in the field which could only be achieved previously in the laboratory. Miniature cadmium-tellurium detectors have enabled the design of small, shielded probes which can be placed next to closely packed nuclear fuel assemblies rather than requiring their isolation for verification.

Some examples may demonstrate how newly developed safeguards NDA and C/S equipment have contributed to the improvement of safeguards practices:

● Several measurement devices consisting of "high level" neutron coincidence detectors with associated electronics and computers were installed in a large automated mixed-oxide (MOX) fuel fabrication plant recently. The system is used to verify different types of plutonium compounds without the presence of an inspector. The design incorporates features to authenticate the measurement data and software and to collect, review, and facilitate data evaluation by inspectors. The software is considered to be "user friendly" by inspectors.

● Operator-installed equipment, such as an X-ray Fluorescence Spectrometer (XFS) and Thermal Quadrapole Mass Spectrometer (THQ), has been reviewed, tested, and accepted for routine use in the field. The procedures and software enable authentication and an unambiguous evaluation of the measured data.

● In 1970 there were very few reprocessing plants. The largest one in which safeguarded nuclear material was reprocessed had a total capacity of 400 tonnes of irradiated fuel per year. The associated spent-fuel storage facility had a capacity of 250 tonnes, or 750 fuel assemblies. Today the throughput of modern, large-scale reprocessing plants is of the order of 800 tonnes per year. Storage ponds have capacities of about 10 000 tonnes. Such facilities receive irradiated fuel from reactors in different regions of the world and the frequency of unloading is about 12 fuel assemblies per day. To safeguard such plants, the Agency had to develop new techniques to avoid a large increase in the number of inspectors, and at the same time to improve the quality of safeguards and reduce the impact of safeguards activities on the operator. One system developed under the safeguards support programme of a Member State is an unattended, tamper-resistant surveillance system, which allows verification of spent fuel by NDA upon receipt. Instead of a regime of continuous inspection, the Agency will be able to reduce the inspection effort required.

● Ultrasonic seals are used to seal stacks of irradiated fuel in on-load reactor storage pools. They permit on-site verification, thereby improving the timeliness aspect of safeguards for such reactors. COBRA fibre-optic seals are used to seal irradiated fuel canisters for dry storage. They also permit on-site verification, thus improving conditions of work for inspectors, especially during winter. Another recent development is the use of underwater television for irradiated fuel verification.

● Two new types of Cerenkov Viewing Devices (Mark-IV and UV-II) are used exclusively for verification of irradiated fuel for light-water reactors (LWRs). New methods are being developed which complement the use of these viewing devices in cases where the spent fuel has a long cooling time and/or a low burnup. New procedures, together with specialized training of inspectors, has resulted in a reliable tool for achieving some of the safeguards goals for LWR reactors.

Safeguards analytical measurements

The idea of the IAEA's Safeguards Analytical Services was conceived in the early 1970s. It foresaw that the IAEA would establish and operate a fully equipped Safeguards Analytical Laboratory (SAL). The analytical capability of SAL was to be such that "samples taken from any key measurement point of the fuel cycle could be analysed and that the data from these analyses would suffice for safeguards accounting verification requirements". However, to accommodate the large number of samples anticipated to be taken annually, a worldwide Network of Analytical Laboratories (NWAL) was established. At the request of the IAEA, analytical laboratories were nominated for this purpose by a number of Member States. The NWAL began to operate in 1975 and still functions actively in providing measurement services as well as support in the development of analytical techniques.

Even prior to 1970, Agency inspectors took samples of safeguarded nuclear material for chemical and/or isotopic analysis to determine the fissile material content. These measurements have become an important part of the Agency's independent verification system, in particular in support of quantitative conclusions. From a few dozens of samples taken in 1970, the annual number has increased to about 1300 samples.

The use of destructive analysis for verification measurements involves several steps, such as sampling, packaging, shipping from facilities to SAL, and finally the actual analytical measurement. Improvements have helped to reduce the considerable delays which occurred in the earlier years. For example, the average time for shipping samples of input solution from reprocessing facilities in 1979 was 75 days, compared to 16 days in 1989. Similarly, the average time interval required for analysis of a sample in 1979 was 80 days, compared to 17 days in 1989.

The main analytical techniques used at SAL and NWAL are potentiometric titrations, mass spectrometry, and radiometry. These techniques are subject to continuous modification to improve measurements to the latest state of practice. In these activities the contributions of Member State Support Programmes will continue to be essential. The monitoring of the measurement quality is achieved by a strict quality control programme.

The analytical results reported by SAL and NWAL are stored in a central database, together with the corresponding facility declarations. This data is routinely evaluated and the results are used in inspection conclusions. They also provide the basis for a continuous monitoring of the actual verification measurement quality.

In the 1990s, it is expected that at large bulk-handling facilities, on-site destructive analytical measurement capabilities will be needed to meet the Agency's goals for timely verification. This is a new challenge for the Safeguards Analytical Services and success will depend on collaboration with facility operators and support programmes.

Inspection reporting and evaluation

In 1970, the reporting of safeguards inspections was done in a relatively simple format that summarized inspection activities and their results. Details of the activities and the "depth" of the inspection were reflected in the inspection report filed by the individual inspector.

In later years, inspection report forms were improved in the interests of consistency, completeness, and reduction of the narrative component. Today's form, commonly called a "logsheet", records all information required for computerized inspection reports.

Since 1977, the Agency has issued an annual Safeguards Implementation Report (SIR) which contains data and conclusions drawn on the effectiveness and efficiency of the safeguards programme. The growing number and types of facilities, and the introduction of new and more effective verification methods, have influenced both the scope and depth of the report.

The compilation and evaluation of safeguards data have also improved considerably. The processing and handling of inspection data is for the most part computerized. Significant progress has also been made in the development of criteria for the evaluation of inspection goal attainment.

Facilities in non-nuclear-weapon States where nuclear material was subject to safeguards in 1970 and 1990

	1970	1990
Power reactors	9	195
Research reactors and critical assemblies	63	177
Conversion plants	—	8
Fuel fabrication plants (including pilot plants)	5	43
Reprocessing plants (including pilot plants)	3	6
Enrichment plants	—	6
Separate storage facilities	—	41
Other facilities	19	51
Subtotal	99	527
— Other locations	57	405
— Non-nuclear installations	—	2
Totals	156	934

Future prospects

Since the inception of IAEA safeguards activities, the Agency has constantly recognized the importance of ensuring that technological changes in the nuclear field would be immediately addressed in the evolution of new safeguards procedures and techniques. During the 1960s and early 1970s, a number of advisory groups were established to examine specific issues which had arisen in the development of safeguards approaches. In 1975, the Director General decided, in consultation with Member States particularly involved in safeguards matters, to establish the Standing Advisory Group on Safeguards Implementation (SAGSI) to provide overall guidance on the Agency's safeguards programme. SAGSI has fulfilled its senior level responsibilities in a manner which has gained the endorsement of Member States and the Secretariat.

In accordance with SAGSI's advice on long-term guidelines which should govern the Agency's safeguards programme, the IAEA is developing safeguards implementation and evaluation criteria which are intended to take into account expected technological advances and to provide a more comprehensive basis for planning, implementing, and evaluating safeguards activities. Support and co-operation from Member States in the application of these criteria will be highly important to maintaining the effectiveness of the safeguards system.

Most certainly, the Agency's technical capabilities will need to continue to improve in tune with technological advances being made in nuclear materials measurement and accounting systems. Equally, the trend to computerized nuclear materials handling, processing, and storage systems — with a consequently reduced accessibility to these materials for verification purposes — will force further changes in the interfaces between the IAEA's Inspectorate, the national regulatory authorities of Member States, and the operators of nuclear facilities. A greater interconnectivity between national nuclear materials accountancy systems and IAEA safeguards means that more emphasis will have to be placed on the authentication of data derived from measurement systems that are jointly operated by the IAEA and facility operators, and particularly of data supplied solely by systems owned and run by facility operators.

Nuclear materials subject to safeguards in non-nuclear-weapon States in 1970 and 1990 (amounts in tonnes)

	1970	1990
Plutonium in irradiated fuel	<1 tonne	245
Separated plutonium		11
Enriched uranium	243	29 000
Natural and depleted uranium and thorium	1146	43 000

The safeguards support programmes of Member States will assume even greater importance in enabling the IAEA to benefit from the technological advances being pursued in nuclear engineering and related fields. At the IAEA, the likelihood of the continued imposition of a "zero-real-growth" budget policy is very high and it is evident that without the many and varied contributions of Member States the IAEA's safeguards programme will be progressively impaired.

Possibilities stand on the horizon that could broaden the scope of the IAEA's safeguards programme:

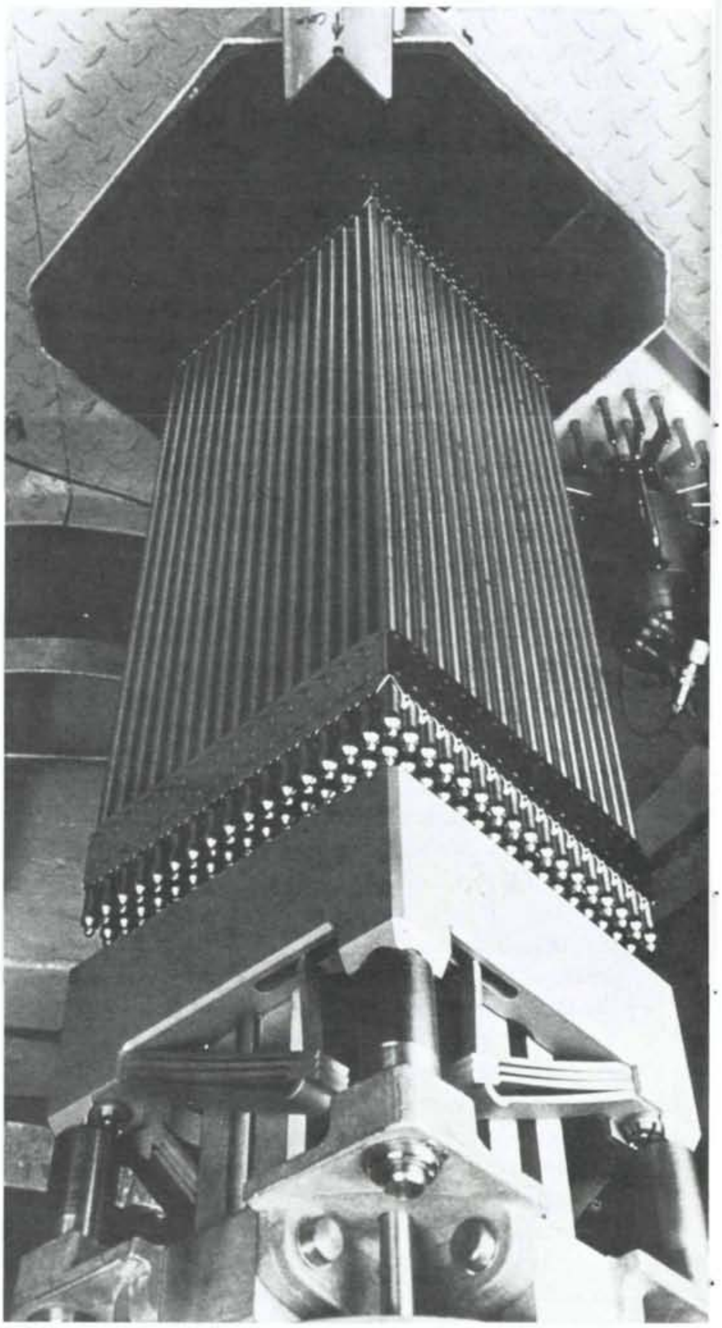
- The negotiation and entry into force of safeguards agreements by countries which have not yet placed their entire nuclear programmes under IAEA safeguards;

● An extension of IAEA safeguards in nuclear-weapon States to cover the entire civilian nuclear programmes of such States; and

● The continuing expansion of nuclear programmes in countries which have already placed their entire nuclear programmes under IAEA safeguards.

What effect might these possibilities have, if realized? Estimates based upon published but unconfirmed information indicate that if more countries were to place their entire nuclear programmes under IAEA safeguards, this would increase the IAEA's safeguards coverage by about 5-10%. If safeguards were extended to the entire civilian nuclear programmes in nuclear-weapon States, an IAEA "best guess" estimate suggests that the total operational safeguards workload would be nearly tripled. The continuing expansion of the nuclear programmes in countries which already have placed their entire programmes under IAEA safeguards is likely to result in a 20–25% increase in the IAEA's safeguards workload over the next 5 years.

Thus, the future prospects for IAEA safeguards are quite bright, albeit with a not unexpected degree of uncertainty. The continuing importance of IAEA safeguards as a bulwark of the nuclear non-proliferation efforts of the world community is beyond question. States which have undertaken comprehensive safeguards obligations firmly believe that IAEA safeguards provide the only broadly international and therefore credible means of verifying the peaceful nature of their nuclear activities. Those States which have chosen not to undertake such comprehensive safeguards obligations are not asked to forego the many humanitarian benefits of nuclear energy and ionizing radiation, but only to strengthen the already wide-reaching safeguards programme of the IAEA. The two decades of the 1970s and 1980s have provided striking evidence of the near universal belief in the value of IAEA safeguards. Hopefully, the decade of the 1990s will see the joining together of all States in a truly universal undertaking of a system of verifying the non-diversion of nuclear materials to non-peaceful purposes. Or, stated in a more positive way, a system of verification which will provide the necessary confirmation of the solely peaceful use of nuclear materials.



Fuel assembly for nuclear plant. (Credit: French Nuclear Newsletter)