STATUS OF SAFEGUARDS INSTRUMENTATION
William A. Higinbotham
Brookhaven National Laboratory
Upton, New York 11973

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Abstract

The International Atomic Energy Agency is performing safeguards at some nuclear power reactors, 50 bulk processing facilities, and 170 research facilities. Its verification activities require the use of instruments to measure nuclear materials and of surveillance instruments to maintain continuity of knowledge of the locations of nuclear materials. Instruments that are in use and under development to measure weight, volume, concentration, and isotopic composition of nuclear materials, and the major surveillance instruments, will be described in connection with their uses at representative nuclear facilities. The current status of safeguards instrumentation and the needs for future development are discussed.

The United States and the rest of the world have a big stake in the credibility of international safeguards. This paper presents one view of the importance of and the status of instrumentation which The International Atomic Energy Agency (IAEA) probably will need in the next few years. The developers of nuclear instrumentation have provided the devices and the techniques on which these tools are largely based. However, it is important to realize that success or failure of IAEA safeguards depends on many other political and technical factors which would require rather more words to describe than is possible in fifteen minutes. The view presented here is based on the author's survey of the IAEA's instrumentation needs from now until 1985. Other knowledgeable people could have drawn somewhat different conclusions as to details, but would probably have arrived at similar conclusions as to the important role of instrumentation and as to the approximate future costs for instruments, and for repair and maintenance.

The IAEA came into existence in 1957. During the 1960's it began to apply safeguards to research reactors, power reactors and to a few, small processing facilities. Its responsibilities have increased rapidly during the last 10 years, after the Nuclear Non-Proliferation Treaty (NPT) went into effect. There have also been substantial improvements in the design of safeguards systems, in the types and quality of safeguards instruments, and in methods to assess efficiency and effectiveness of safeguards operations. These have come about due to the efforts of the Agency and due to the advice and assistance provided by many of the member states.

The U.S., the United Kingdom and the Soviet Union have provided advice, encouragement, and technical assistance, virtually from the beginning. For the last 5 years, the U.S. Congress has specifically authorized substantial funds for technical support

of the Agency. The Department of State, ACDA, the Nuclear Regulatory Commission and the Department of Energy oversee this program, which is administered by the Department of Energy. Cost-free experts, system studies and instruments are supplied, in response to Agency requests. In addition, ACDA and the Department of Energy support R&D on instruments and techniques which, in their view, will be needed by the IAEA in the future. You will appreciate that it has not been easy for the Agency and for all of its helpers to clearly anticipate the needs, or to perform all of the steps that are necessary to get from an idea, to a prototype, to assessment, trial use and modifications, to actual use supported by training and maintenance.

In order to appreciate the role of instrumentation, it is useful to understand what the IAEA is supposed to do, how it does or would like to do this, and where and how instruments fit in.

The objectives of IAEA safeguards are described in the charter and in two other major legal documents. Nations voluntarily submit nuclear materials and facilities for inspection. Non-nuclear-weapon states that comply with the NPT, volunteer (in effect) all nuclear materials and facilities. Others, such as India, have agreed to submit some of these, but not all, for inspection. The U.S. and the U.K. have offered to place their non-military nuclear facilities under safeguards. At present, the IAEA has chosen to inspect only a few of the latter facilities, because it prefers to concentrate its limited resources on the non-nuclear-weapon states.

The primary safeguards measure is accounting for the nuclear materials. Nations are expected to require that nuclear facility operators measure transfers and inventories and maintain records. Monthly status reports are required by the IAEA. Agency inspectors independently make a number of measurements in order to verify the accuracy and validity of the operator's data. This is not the place to discuss verification strategy in detail. It will suffice to state that some highly accurate measurements are important and that many, less accurate and cheaper NDA measurements are necessary.

Containment and surveillance are listed as important complementary measures. These include the use of seals, to indicate that a previous measurement is still valid, and surveillance cameras to detect suspicious activities at a spent fuel storage pool, for example, between inspector visits.

The IAEA has adopted design goals for the detection of diversion at a facility. (It is important to note that these are goals, not absolute requirements):

TABLE I

Material Type	Goal Quantity	Timeliness Goal
U less than 20%	75 kg contained U-235	unknown
Pu contained in spent fuel	8 kg contained Pu	1 to 3 months
Pu in fresh fuels	8 kg contained Pu	1 to 3 weeks
High-enriched U, ditto	25 kg contained U-235	1 to 3 weeks

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How these goals might be achieved will be discussed with reference to specific facility types, below.

In order to suggest the general magnitude of the Agency's assignment, Table II lists the number of major facilities that were under IAEA safeguards in 1980, by geographical section, excluding those located in nuclear-weapon countries. In 10 years, the number of facilities is likely to double, and some of the bulk processing facilities will be much larger than those presently operating.

clear activity. It is, then, most important for the Agency to verify the receipts at an enrichment plant, which will be the base for all later material accounting. In order to close a material balance around an enrichment process, the Agency will need to verify the operator's measurements of the product and depleted tails cylinders, as well as the feed cylinders. It will also be important to provide assurance that no part of an enrichment facility is being used to produce more than 25 kg of undeclared high-enriched uranium. Exactly how this is to be achieved is still being studied by the IAEA and by

Table II

Approximate Number of Facilities in Non-Nuclear Weapon States under Safeguards in 1980

IAEA Section	Fuel Fabrication				Facility Type		Uranium Enrichment	Reprocessing	R&D Facilities	
	NU	LEU	HEU	MOX	LWR	Other			Small	Large
N. America	5	0	2	0	0	12	0	0	9	3
Euratom	0	6	2	3	24	4	4	4	39	13
Central & N. Europe	0	1	0	0	30	1	0	0	26	9
Far East	1	4	2	1	26	2	1	1	20	8
S.S.E.	1	0	0	0	2	3	0	1	19	14
S. America, Africa, Spain	1	1	1	0	5	1	0	2	22	6
NU=natural uranium LEU=low-enriched uranium HEU=high-enriched uranium MOX=UO ₂ /PuO ₂					LWR=light water moderated Others are mostly D ₂ O-moderated		large=reactors of 5MW or higher capacity, and fast critical facilities			

The N. America facilities are all in Canada. Euratom refers to the European Community, excluding the U.K. Central and N. Europe includes Switzerland, German Democratic Republic, Czechoslovakia, Hungary, Sweden, Norway, etc. Japan, S. Korea and Taiwan comprise the Far East. South, SE, includes the Near East, S. Asia, Australia, etc. The last section encompasses Cuba, all of S. America and Africa, and Spain. There is a heavy concentration of facilities in Europe, near IAEA headquarters, in Canada and in Japan. The Agency has established field offices in the latter two. In thinking about instrumentation, it is necessary to consider how often and how far the inspectors will need to travel.

For the purpose of illustration, 3 generic fuel cycles will be discussed: The low-enriched uranium, once-through fuel cycle, reprocessing and recycle of plutonium in fast breeder reactors, and R&D programs involving significant amounts of high-enriched uranium or plutonium.

The starting point for IAEA safeguards is when uranium is purified to the point that it is suitable for fuel fabrication, e.g. UF₆ for shipment to an enrichment facility. The end point is when the Agency agrees that the nuclear material is consumed, or so diluted as to be no longer useful for any nu-

clear activity. It is, then, most important for the Agency to verify the receipts at an enrichment plant, which will be the base for all later material accounting. In order to close a material balance around an enrichment process, the Agency will need to verify the operator's measurements of the product and depleted tails cylinders, as well as the feed cylinders. It will also be important to provide assurance that no part of an enrichment facility is being used to produce more than 25 kg of undeclared high-enriched uranium. Exactly how this is to be achieved is still being studied by the IAEA and by

the several nations that are building enrichment plants.

The techniques that will be needed to measure the feed, products, and major wastes of enrichment plants have been developed. Weight and mass spectrometry can make highly accurate measurements of the UF₆ and of enrichments. The U-235 fraction of UF₆ in cylinders or liquids or gas streams, can be measured approximately using gamma-ray spectrometry, and the U-234 fraction via the alpha-n neutrons. Since it is not easy to transport or to use large mass standards to calibrate the scales for 10-ton UF₆ cylinders, Agency inspectors have had difficulty in verifying the weights. A possibility, that is now being evaluated, is to supply the inspectors with light-weight, accurately calibrated strain-gauge weighing devices, which could be attached to the hoist with which the operator moves the cylinders.

Although it is anticipated that IAEA inspectors would be permitted essentially continuous presence at the key measurement stations, it is evident that film or TV surveillance cameras will be useful to record attachment and removal of UF₆-cylinders. Much more elaborate perimeter surveillance equipment has been developed, which may prove to be useful. The most important development project for these

facilities at this time is to produce more secure and useful seals for the large UF₆ cylinders.

Fuel fabrication facilities receive the UF₆ cylinders, convert the UF₆ to UO₂ powder, press the powder into pellets, sinter and grind the pellets, stuff them into rods and put 50 to 200 rods into an LWR fuel assembly. In the process some recoverable scrap and disposable wastes are generated. IAEA inspectors visit several times a year to verify the records for receipts, shipments and inventories. Extensive use is made of gamma-ray instruments to verify enrichments of intermediate products, and the U contained in waste discards. Selected samples are sent to the IAEA analytical lab. in Vienna, for more accurate determinations of U-content and enrichment. Until recently, the inspectors had no convenient way to verify the content of finished fuel assemblies, which is important to close a material balance around this plant and for material accounting at reactors and thereafter. Recently, Los Alamos has developed a neutron detector (polyethylene moderator and ³He counters) which will fit around a segment of a fuel assembly. In the passive mode it measures the spontaneous fission neutrons from U-238. With a modest activity isotopic neutron source, it measures the U-235 content with acceptable accuracy. Surveillance instruments are not used at these plants. For over 10 years there has been a program (Euratom) to develop acoustically readable seals which could be attached to fuel assemblies and read, under-water, even after exposure in a reactor. This would be extremely useful at reactors. However, a cost/effective, reliable system still is not available.

A large, light water moderated power reactor consumes about 30 tons of uranium each year in fresh fuel assemblies and produces about 30 tons of radioactive spent fuel containing up to 1% of plutonium. Table I indicates that detection times for diversion of LEU fresh fuel is less than one year and for plutonium in spent fuel it is 1 to 3 months. Inspectors visit when the reactor is being reloaded (about once a year) and every 2 to 3 months to check the spent fuel. Since counting spent-fuel assemblies in the pool and checking for substitutions consumes considerable time and effort, the Agency makes extensive use of surveillance cameras. The design and use of film and TV surveillance cameras is a complex subject. Suffice it to say, here, that the Agency employs about 100 dual cameras (in tamper-indicating containers) and about 12 fancy TV recording systems at LWR's. There are technical problems regarding reliability, lighting, tamper-resistance, and interpretation of the recorded snap-shots, which require, and which are receiving, attention.

Several instruments have been developed to detect substitution of spent-fuel assemblies. The instrument that is easiest to use is a commercial night-vision device which is used to observe the Cerenkov glow around rods in an assembly. Other instruments measure gamma-ray spectra and neutron emissions, which can be correlated with burnup and time since removal from a reactor. These are especially important if surveillance cameras have not been installed or fail to produce a readable record.

Reprocessing plants receive and store spent-fuel assemblies, dismantle them, dissolve the fuel, separate the fission products, uranium and plutonium from each other, store U and Pu-nitrate solutions, and transfer them to facilities that convert the ni-

trates into oxides or other useful forms for subsequent uses. The receiving-storage area involves item accounting and surveillance instrumentation, similar to that at reactor pools. The special problems for the IAEA concern verification of measurements of material entering, contained in, and removed from the chemical processes and the product storage tanks. Inputs and outputs are generally derived from the bulk volume measured in calibrated transfer vessels and on the U and Pu concentrations determined by analysis of representative samples. The amounts contained in the processing vessels can be estimated, indirectly, with an understanding of the operating characteristics of the individual equipment items, with analysis of samples taken between processes, and using process control information, if these should be available to the Agency. It is important to be able to detect an "abrupt" diversion within a week or two, and also to be as sensitive as possible to longer term diversions.

The facility operators will install the accountability vessels and analyze many samples. Inspectors will participate in calibrations, take readings of the volumes, take and analyze samples. Physical methods may prove to be useful for the latter purpose, since they are faster, cheaper, and require less skill than the chemical analysis methods. X-ray fluorescence can be used to measure the U and Pu-concentrations in the highly radioactive dissolver solutions. Gamma and alpha-ray spectrometry can be used to measure the isotopic composition of plutonium. X and gamma-ray absorptiometry are useful to measure U or Pu concentrations after removal of the fission products. The important thing is that the techniques have all been developed and used for other purposes. What remains is to determine how inspectors can use these effectively, and to engineer automated systems.

In the process and storage areas, the principal role of surveillance instrumentation, in my view, will be to insure that all materials are measured, that volume indications and samples have not been tampered with, and that no material is transferred into or out of the product tanks except when inspectors are present. Such instrumentation probably will have to be custom designed for each facility.

Passive gamma-ray and neutron instruments have been developed and demonstrated, to measure the feed, products, intermediate forms, scrap and wastes at facilities that process mixed U/Pu-oxide fuels for recycle in LWR's or for fast breeder reactors.

The fabrication of fuel for research reactors and fast critical facilities, and the facilities themselves present some different instrumentation problems. Some high-power research reactors consume significant amounts of high enriched uranium. Accurate bulk and chemical analyses are required for fabrication. The most promising NDA technique, to verify receipts, products and scrap, involves active neutron-interrogation. Calibration and use of such instruments calls for continuing effort. ISPRAs has developed seals for MTR fuel assemblies, which may prove to be very useful for accounting at these reactors. Research reactors (with 40 MW or higher ratings) could conceivably be used to breed plutonium. Since this would involve unusual fuel handling operations, optical surveillance equipment may be needed to record activity between inspector visits.

The other important class of research reactor uses natural or low enriched uranium fuel, which is not of great concern, and breeds plutonium more efficiently than the previous class. In this case, the spent fuel should be monitored as it is discharged and while in storage. This activity is similar to that discussed above for LWR spent fuel.

There are a few fast critical facilities, in developed nations, that have several hundred kilograms of Pu and HEU metal in thousands of small platelets or rods. A large fraction of the inventory may be in the critical assembly and not accessible for verification. A number of NDA and other assay techniques have been proposed and are being evaluated. Even so, taking a physical inventory is very time-consuming and may involve significant radiation exposures. A credible combination of measurement, containment and surveillance techniques has yet to be worked out.

Some important types of nuclear facility have not been mentioned. However the above summaries should serve to support the following conclusions:

1. There is little, if any need for new techniques or basic R&D.
2. Most of the important types of measurement and surveillance instruments have been developed and, to some extent, demonstrated.
3. It is extremely important to understand how and where the IAEA is or could be using instruments. The Agency will have to collect this information and to provide it to those in friendly nations that will do the engineering.
4. Reliability, tamper-resistance, and the form of data outputs are important. Inspectors have to learn how to use the instruments and how to use the data that they obtain while on inspections. In addition, it may be important to have raw data recorded in such a way that it can be reviewed at a field office and/or in Vienna.
5. The IAEA's budget and resources will always be limited. Ideally, an instrument should save man-hours and also improve safeguards effectiveness. The costs of instruments, capital and up-keep, are important considerations. It is especially important to analyze the costs for repairs, training, calibrations, replacements, etc. that will be involved for each instrument, whether it will be relatively cheap and used in large numbers, or relatively sophisticated and only used at a few special facilities.
6. Clearly there will be a need for close cooperation between the instrument designers and the ultimate users if the resources of both are to be used effectively and so that the IAEA will credibly perform its important safeguards function.

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