Safeguards at LEU facilities: Current practices, future directions

An overview of the IAEA's verification activities for low-enriched uranium facilities and steps toward greater co-operation with operators

by Anita Nilsson

Low-enriched uranium, or LEU, fuel cycle facilities comprise an important product of the nuclear industry, and are intimately related to nuclear power production. Such facilities include those for production of uranium hexafluoride, enrichment of uranium (to less than 20% uranium-235), conversion to uranium oxide powder, and the production of nuclear fuel assemblies for subsequent use in reactors. They also normally include facilities (excluding reprocessing plants) for encapsulation and deposition of spent fuel, which contains plutonium. This article primarily deals with fuel cycle facilities using LEU, and only briefly touches upon safeguards for spent fuel to be deposited in geological repositories.

In all LEU facilities, the presence of uranium is the reason for IAEA safeguards under agreements concluded pursuant to the Treaty on the Non-Proliferation of Nuclear Weapons (NPT). Natural or low-enriched uranium is nuclear material that only can be indirectly used for nuclear weapons production. Further enrichment of uranium in the isotope uranium-235, to a level above 20%, is necessary to obtain material that can be utilized in a nuclear explosive device.

This fact is central to the implementation of IAEA safeguards on LEU. The Agency has an obligation to draw independent conclusions that the nuclear material subject to safeguards has not been diverted from peaceful uses, i.e. to nuclear explosives or for purposes unknown. The safeguards approaches and criteria used by the IAEA to obtain that goal are defined with due consideration to the potential use of the nuclear material for nuclear weapons. The enrichment in the isotope uranium-235 that would be required for turning natural or low-enriched uranium to weapons usable material is an expensive and time-consuming process, in particular if it is concealed. It has been estimated through technical analysis that a State could have the material enriched to the desired degree for weapons production in about one year's time. Recent reviews within the Agency, however, have shown that while the establishment of an enrichment facility, in particular if is concealed, is a costly and lengthy process, the subsequent enrichment of LEU, once the enrichment facilities have been established, could be achieved in less than one year.

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Current safeguards for LEU facilities

The application of IAEA safeguards on LEU is based on a number of criteria, specifying *inspection goals* whereby the *significant quantity* is an amount of uranium containing 75 kilograms of uranium-235, and the *timeliness goal* is one year. This means that the Agency, when implementing its safeguards system, shall be able to detect a diversion of at least 75 kilograms of uranium-235 contained in LEU during a time period of one year.

An LEU fuel cycle facility processes nuclear material in bulk form. During the industrial process, nuclear materials used as feedstock may be changed isotopically, chemically, and physically. In the process, some nuclear materials also become waste products and minute quantities are discarded in waste water or otherwise discharged. A common objective for both safeguards and financial reasons is to keep the wastes and losses to the lowest levels possible.

To reach its safeguards goals for an industrial process where bulk nuclear material is handled in various forms, the IAEA establishes a safeguards approach enabling its annual evaluation and independent verification of the facility's *material balance* over specific periods of time.

The IAEA must reach its conclusions independently from both operators and Member States. The activities to reach those conclusions, however, can be performed jointly with a State System of Accountancy and Control (SSAC) or Regional System of Accountancy and Control (RSAC). To reach the conclusions, the quantities of safeguarded material must be verified with a certain degree of confidence.

According to the present safeguards criteria, both nuclear material in flow throughout the facility and in the facility's inventory should be independently verified. For an LEU fuel fabrication plant, the verification is to cover at least 20% of the nuclear material *in flow,* and, once a year, the operator's complete physical inventory of all nuclear material at the facility; this is done when the material balance is closed for accounting purposes.

The Agency uses statistical methods for cost-effective verification, based on its knowledge of the facility's industrial process, and the accuracy and precision of nuclear material measurements performed by both the operator and the IAEA. Information regarding the process and measurement system applied at the facility is included in the *design information* provided to the Agency.

The information on which the Agency bases its activities is provided by the State, through the SSAC or the RSAC. Formal State reports on inventory changes are given periodically, often monthly, reflecting changes in the previous month.

Inspections and verification activities. During routine inspections, the Agency verifies the operator's declarations of material accountancy, i.e. the accountancy records and supporting source documents, and compares, often at headquarters, the result with the formal Inventory Change Reports submitted by the SSAC or RSAC. According to the IAEA safeguards criteria now applied, routine inspections are performed to meet the inspection goals. For an LEU fuel fabrication plant, normally five inspections should be performed for flow verification, and one for physical inventory verification during a material balance period. At an enrichment plant, monthly inspections are performed, primarily to confirm the declared enrichment (absence of enrichment above 20% uranium-235). The inspection planning is based on operational information given semi-annually and advance notifications of receipts and shipments of nuclear material. Verification of nuclear material in flow is performed by weighing and sampling for subsequent chemical analysis, as well as by non-destructive assay (NDA) for enrichment control. The importance of performing "flow inspections" becomes clear when considering that fuel cycle facilities handling nuclear material in bulk form are designed to have a large throughput and a relatively small inventory of nuclear material.

The verification of the physical inventory builds on the application of statistical methods. When comparing the inventory as registered (book inventory) with the measured inventory (physical inventory) for a facility handling nuclear material in bulk form, there is always a difference. This difference is called material unaccounted for (MUF). The statistical evaluation of the material balance leads to a conclusion whether or not the MUF is within acceptable limits. Although a large value of the MUF *can* indicate a possible diversion, the overall assessment of a possible diversion of nuclear material must be made in the broader context of a State's nuclear material declarations and the IAEA's independent verification of these declarations.

Under the present safeguards system, the SSAC or RSAC always receives advance notification of inspections. Historically, this has been deemed necessary in order for the State and operator to prepare the nuclear material declaration and other documentation required for the inspection.

Accountancy and control. The safeguards system requires the operator to keep an updated register (general ledger) of the nuclear material according to agreed standards and recommendations. However, it is likely that nuclear material accountancy would be performed even if there were no safeguards requirements or system in place. Nuclear material is expensive, and accounts for a significant part of the operating cost of a nuclear reactor. It is thus in the interest of the nucleaer material's owner that the losses are kept to a minimum, and that the highest possible level of quality control is maintained.

Nuclear material accountancy is one way for the operator to keep track of the nuclear material processed, as part of the operator's responsibilities to the owner of the material. In addition, nuclear safety and reactivity calculations require precise enrichment specifications. Unknown spikes in the enrichment of pellets in a fuel rod may cause burnout, and subsequent leakage of fission products to the cooling system, with entailing losses in the production of electricity. Even at a low level, such leakage could contribute to the general public's exposure to sources of radioactivity. For the same reason, operators of a fuel cycle facility minimize and control releases of nuclear material to the environment, as is also shown by the measurement and accountancy system.

To maintain high quality in production, the operator of a nuclear fuel cycle facility uses advanced instruments. Rod scanners are used for enrichment control, and precision scales are used for weight determinations. In some facilities, routines have been established by which the Agency can use equipment owned by the operator. In such cases, in order to maintain independence, the Agency keeps, under seal at the facility, sources or nuclear material standards for calibration purposes. Such co-operative schemes improve efficiency during inspections, and maintain or improve the effectiveness of safeguards.

One other reason for the operator to maintain a control system is the requirement in bilateral or multilateral agreements related to nuclear non-proliferation. Nuclear supplier States require that safeguards are maintained and that nuclear material is accounted for according to specified standards. In other words, nuclear material accountancy and IAEA safeguards are prerequisites for nuclear trade, and it has been recognized that without a safeguards system of high quality, trade would be severely hampered, if not impossible.

Possible new elements of safeguards

Recent events have pointed out the need for improved safeguards, whereby the IAEA's system should not only verify the correctness and completeness of States' declarations of nuclear material but also provide credible assurances of the absence of undeclared nuclear activities. A strengthened safeguards system has been proposed under the IAEA programme known as "93+2". Part 1 of the programme is being implemented under comprehensive safeguards agreements, while the new measures comprising Part 2 require additional legal authority for the IAEA. In June 1995, the IAEA Board of Governors agreed that the Agency should start implementing Part 1, and in June 1996, a Board Committee was established to work on a Protocol to complement existing comprehensive safeguards agreements. The Protocol would give the Agency the additional tools required to implement the entire strengthened safeguards system envisaged.

For LEU fuel cycle facilities, Part 1 includes increased physical access and increased co-operation with the SSAC or RSAC, as applicable. Increased physical access includes unannounced inspections, i.e. inspections where the State is not notified in advance. Unannounced inspections can provide effectiveness and efficiency benefits when near-real-time declarations on material flows and facility operations are available. With increased access, all buildings at a *nuclear site* will be accessible for the inspector. Also important for strengthened safeguards is the *optimal use of the present system.* Enhanced information from SSACs, given by the States, provides for increased co-operation between the Agency and the national or regional authority. Increased co-operation can encompass sharing of measurement instruments, early submission to the IAEA of data available to the national or regional authority, and joint activities, provided the IAEA's independent control function can be maintained. Through greater co-operation, inconsistencies or questions could be solved in a timely manner.

Field trials. Field tests of strengthened safeguards systems have been performed in Canada, Finland, and Sweden. They provided good examples of how the strengthened safeguards system could work in practice.

Tests in Canada. Tests in Canada showed that unannounced access could be gained to locations that are not normally accessible for safeguards purposes at a wide range of fuel cycle facilities. The facilities involved included a uranium conversion facility, a fuel fabrication facility, two multi-unit power reactor facilities, a partially decommissioned research reactor, and a nuclear research and development complex. The tests also demonstrated (as communicated by the Atomic Energy Control Board) enhanced co-operation between the Canadian SSAC and the Agency in several respects: the site-specific procedures for unannounced access developed by the operators and the SSAC were shared with the IAEA so that they would be taken into account in the development of the inspection arrangements. Specifically, the tests ranged from broad access requested during a scheduled inspection to unannounced access outside normal working hours; the measures used included environmental sampling, design information verification, visual observation, and non-destructive analysis. In every case, access was granted without delay and the IAEA was able to carry out the required activities. In a broad sense, the tests showed that procedural arrangements can be made by the SSAC, the operator, and the IAEA that will result in the successful implementation of unannounced and short-notice access to any location at nuclear facilities in Canada.

Tests in Finland. Field tests in Finland were focused on environmental sampling and increased co-operation with the SSAC. In-field environmental monitoring techniques were evaluated and, as a result, commercially available instrumentation was described that could be used in the environmental monitoring of LEU facilities without extensive development work. Also successfully demonstrated was the applicability of autoradiography for screening environmental swipe samples. The Finnish laboratories analyzed different types of samples collected during the field trials in various countries and provided valuable analytical results. A satellite navigation and desktop mapping system was developed for determining and recording environmental sampling locations in the field. This computerized mapping and navigation system was demonstrated to be very useful in environmental sampling outside facilities.

Increased co-operation with the SSAC was tested by submitting the SSAC questionnaire and expanded declaration to the IAEA and by performing unannounced inspections at LWRs and at a research reactor. As a result, experience was gained in carrying out such inspections with broader access to information and sites. Procedures for unannounced inspections were developed and a new improved safeguards approach for WWER-type reactor facilities was worked out.

Tests in Sweden. The tests in Sweden were related to environmental monitoring and increased co-operation with the SSAC, including the submission of additional information to the IAEA with near-real-time accountancy reports, unannounced inspections, SSAC information, and an expanded declaration.

More specific parts of the tests in Sweden focused on the implementation of unannounced inspections at an LEU fuel fabrication plant. A scheme of unannounced, randomized inspections was implemented in such a way that there was a non-zero probability of inspection at any day and any time during the period. The scheme required, *inter alia*, that information was provided on a weekly basis on the operational forecast of the facility. The information was provided electronically, by a secured link to the Agency. Before the test, procedures had been agreed regarding inspector visas, entry at the facility, escorts of inspectors by facility staff, and access to data in the operator's computerized nuclear material accountancy system. The results of the unannounced inspections, together with a physical inventory verification that completed the test, provided a firm basis for evaluating the approach.

The overall test results pointed to positive effects of a strengthened safeguards system for the IAEA, the national authority, and the operator. In short, due to the randomness of the unannounced inspections, the verification results obtained in these inspections could be projected to *all* the material involved in production during the material balance period. This meant a significant increase in effectiveness, from partial to full coverage of the nuclear material in flow. The increased access for inspectors allowed the performance of activities to assure the absence of undeclared activities at the facility site.

In summary, the tested approach was shown to provide more cost-effective safeguards: the system was signficantly strengthened while the inspection effort remained at the same level. The routines applied were less intrusive for ongoing facility operations than inspections within the normal "classical" system because they were directed towards the process rather than the product. These advances compensated well for the additional work that was imposed on the operator in providing a weekly operational forecast and the establishment of routines to allow unannounced inspections at the plant to take place.

Within the Agency, a task force has recently been established to evaluate the possible safeguards approaches for LEU fuel fabrication plants, taking into consideration the applicability of different approaches in different facilities and States.

Future directions

Elements in a strengthened system. Further measures for strengthening safeguards being considered by the IAEA Board build on broader access to information on the State's nuclear programme, increased physical access of Agency inspectors to nuclear facilities and other nuclear sites, and the use of new techniques, primarily environmental sampling and the optimization of the present system. The objective will be *both* to verify that no diversion of nuclear material has taken place *and* the absence of undeclared nuclear activities. The total effect on a country of a strengthened safeguards system depends on its nuclear programme. The system would provide for the allocation of efforts to sensitive nuclear facilities, where high-enriched uranium or plutonium is handled, and provide for less effort on less sensitive material such as low-enriched uranium, depending on assurances obtained about undeclared nuclear activities. As noted earlier, unannounced inspections can provide greater assurance of non-diversion of nuclear material, and, at the same time, provide confidence of the absence of undeclared nuclear activities. The possibility of taking environmental samples will be important for the latter. If environmental samples are taken during regular inspections, there will be no need for separate inspections with the attendant costs for both the IAEA and the operator.

The increased information to be provided by the State will constitute the basis for the Agency's evaluation of information. The gradually increasing confidence as to the absence of undeclared activities may provide justification for a reduction in the intensity of safeguards on declared nuclear material. Spent nuclear power fuel may be taken as an example. Although spent fuel contains plutonium, the enhanced assurance of the absence of clandestine reprocessing in a State will influence the safeguards approach.

In some States, spent fuel will be encapsulated for permanent disposal in deep geological repositories without changes to the integrity of the fuel. In an advisory group meeting convened by the IAEA, representatives of participating States agreed that safeguards cannot be terminated for spent nuclear power fuel that is aimed to be, or has already been, deposited in a geological repository. However, it was also agreed that the measures applied should build on "continuity of knowledge", and take account of developments in the safeguards regime. Although a geological repository would contain large quantities of plutonium, safeguards measures for the site could be both effective and highly efficient — for example by applying containment and surveillance measures at the site and maintaining information about the deposited material — given the assurances provided with the strengthened safeguards system about the absence of undeclared reprocessing.

In a broad joint effort through an IAEA Safeguards Support Programme, a number of States are engaged in work related to the safeguards approach for spent fuel to be deposited in geological repositories. A joint report is due to be prepared before the next scheduled advisory group meeting that will address the matter of safeguards for the back-end of the fuel cycle.

The application of modern techniques could mark a significant change in the safeguarding of LEU fuel cycle facilities. Electronic, near-real-time transmission of accountancy and operational data could provide for both increased efficiency and effectiveness. Encryption techniques and specific transmission protocols would provide for secure transmission of data. Remote electronic transmission of authenticated measurement data would open the same opportunities for LEU facilities as remote surveillance would for nuclear reactors. Available measurement techniques provide, increasingly, the result in digital format, which is necessary for remote transmission of measurement results. The application of new techniques can, therefore, further reduce the actual inspection frequency at facilities, while maintaining or increasing the level of confidence.

Towards enhanced co-operation. For LEU fuel cycle facilities, the strengthened safeguards system is likely to provide a change in the relationship of the State (through the SSAC or RSAC) and the operator with the IAEA. It envisages greater co-operation through the provision of more timely information of selected operational events and the acceptance of unannounced inspections in the interests of enhancing the effectiveness and efficiency of safeguards.

During this evolutionary phase of safeguards development, it is worth considering that on-site inspections provide a value over and beyond their role in verifying the non-diversion of nuclear material. When the inspectors meet the operator at the facility, matters of concern can be discussed and inconsistencies or questions resolved. In all inspections or control regimes, the confidence between the parties is important.

The IAEA's safeguards inspectors are basically there to provide a service: the assurances required by the international community that the nuclear material at the facility is used according to the non-proliferation undertakings of the State. With these assurances, the facility can maintain its credibility with the public that it is only engaged in peaceful activities, and contributes, with its industrial production, to the welfare of society. The evolving safeguards system requires, and promotes, increased co-operation between the IAEA, national or regional authorities, and the operator. In the end, its effective and efficient application is a credit to facility operators, as well as to the State and the international community. ❐