Abstract

Despite repeated international calls for the early conclusion of a Fissile Material Cutoff Treaty (FMCT), negotiations have not yet begun. Nonetheless, informal discussions have identified a number of key issues that will need to be resolved during negotiations. One of the key issues is the scope of verification under the Treaty. The United States has proposed a focused approach to FMCT verification, and this paper lays out the implications of that approach in defining the scope of IAEA verification. In general, this approach would apply routine monitoring to all production and downstream use of unirradiated fissile material (HEU, Pu-239 and U-233) after entry into force. Monitoring would begin at enrichment and reprocessing facilities and would end once a suitable level of irradiation is achieved. Other measures, including non-routine inspections at undeclared locations, would also be necessary in order to ensure the absence of undeclared production.

This paper will explore the issues involved in effective verification at the starting and ending points of routine monitoring. At the starting point the verification objective is to ensure that all newly produced fissile material is declared and accounted for. As with safeguards under an INFCIRC/153-type agreement, material accountancy would be a fundamental verification measure. The verification approach will depend on the type of facility and on specific design features relevant to material accountancy. At the ending point the verification objective would be to ensure that the material subject to monitoring has been suitably transformed, for example that reactor fuel containing plutonium has been irradiated to a suitable level. The irradiation level necessary to fulfill the objectives of the FMCT would depend on the context established by other relevant agreements and the effectiveness of measures to detect undeclared production.
1. Introduction

In 1993 the United Nations General Assembly passed a resolution calling for negotiation a non-discriminatory, multilateral, and internationally and effectively verifiable treaty to ban production of fissile material for nuclear weapons or other nuclear explosive devices. After extensive consultations, the CD agreed in 1995 on a mandate for negotiations of a Fissile Material Cutoff Treaty (FMCT). Yet FMCT negotiations have yet to take place because of the lack of consensus on the overall CD work program.

Anticipating that FMCT negotiations would take place, some countries have devoted substantial effort to developing proposals for FMCT scope and verification. In particular, the United States and others support a "focused approach" to FMCT verification, which would focus verification resources on enrichment and reprocessing plants and newly-produced plutonium and high-enriched uranium (HEU). This paper describes the focused approach and some of the considerations in ensuring the effectiveness of this approach.

2. The Focused Approach

The focused approach is based on the premise that the scope of the treaty should match the scope of verification. An FMCT would focus on fissile material, which is understood to mean fissionable material that can be used to make the fission components of nuclear weapons.\(^1\) To a first approximation, this corresponds to the IAEA category of unirradiated direct use material, which consists of high-enriched uranium (HEU), plutonium, and U-233. Enrichment and reprocessing are the critical "choke points" in the production process necessary to obtain such material, and the focused approach concentrates on those steps. Civil reprocessing would not be precluded but would be subject to verification to ensure that newly produced material is not used in nuclear weapons.

There have been proposals for a more comprehensive approach to FMCT verification, similar to comprehensive safeguards agreements under the NPT. Presumably such an approach would exclude existing stocks of separated HEU and plutonium, but it would include natural uranium.

\(^1\) There is a different, more technical definition of fissile material - material that has a large cross-section for fission by low energy neutrons - but that is not relevant in this context.
reactors, spent fuel, etc. Such an approach would significantly increase the cost of verification with relatively little added benefit. The countries directly affected by an FMCT are precisely those that currently have unsafeguarded enrichment or reprocessing plants, and the key benefit of an FMCT would be to cut off those critical "choke points" to acquiring weapon-usable material.

The IAEA knows well how to verify fissile material through its experience in applying safeguards to nuclear material. The focused approach includes the following basic elements, which would be based on this experience:

- Verification of all fissile material production activities. Production would encompass enrichment -- isotopic separation processes involving fissile isotopes -- and reprocessing -- separation of fissile material and fission products in irradiated nuclear material.

- Verification of all enrichment and reprocessing facilities. These would defined in terms of objective criteria, based on their designed capability to carry out isotopic separation or to separate fissile material and fission products, and would have to be declared.

- Verification of all newly-produced fissile material -- material produced after the cut-off date.

- Verification of all facilities that store, use or process newly-produced fissile material.

- Measures to detect undeclared enrichment and reprocessing and undeclared enrichment and reprocessing facilities. These would include inspections at undeclared locations.

These items are listed separately, despite the similarity and the seeming duplication, because verification focused on materials, facilities, and activities often have distinct objectives.

For example, a key objective of verification at a shut-down reprocessing facility will be to verify that the facility is not operating. Another paper in this session will focus on proposed measures for verification of shut-down facilities. This paper focuses on verification of actual production activities and on newly-produced fissile material, in particular on the scope of the
measures necessary to account properly for that material. This paper does not attempt to define the verification measures or criteria in quantitative detail, but rather presents the basic objectives of those measures and criteria and identify some of the technical problems that need to be resolved.

3. Starting and Ending Points of FMCT Verification

The focused approach is based on the fact that enrichment and reprocessing are the essential choke points for producing weapon-useable material. A simplified view would therefore be that verification of fissile material would begin when that material is enriched or reprocessed, and would end when the material reaches a state, for example as a result of downblending or irradiation, where enrichment or reprocessing is required once again to convert it to a weapon-useable form. While this is a useful shorthand, it is oversimplified at both the starting and ending points, as can be seen by focusing on the objectives of verification at each point.

3.1. Starting Point

To provide assurance that newly-produced fissile material is not diverted for use in nuclear weapons, the verification objective for new production should be to ensure that all newly-produced fissile material is accurately accounted for. The means for achieving this objective depend on the specific facility in question.

3.1.1 Reprocessing

For a modern reprocessing facility, designed with safeguards in mind, these objectives can be achieved through a combination of traditional material accountancy, process monitoring and design verification measures. Material accountancy by itself cannot provide sufficient measurement accuracy to detect diversion of a significant quantity of fissile material. The design verification measures, including containment and surveillance at key flow points, should be sufficient to ensure that there are no undeclared inputs to or outputs from the facility that could contain fissile material, or undeclared separation processes. This combination of qualitative and quantitative measures can provide confidence of non-diversion.

Meeting this verification objective at older reprocessing plants is much harder, since these facilities are unlikely to have been designed to for safeguards, and key
portions of the facility are highly radioactive and therefore inaccessible for design verification. In addition to accounting for declared separation, it is critical to ensure that there is no undeclared separation. Monitoring the dissolver and the input accountancy tank (assuming there is one) will be central, but it is also necessary to verify that there are no undeclared outputs or inputs. Perimeter monitoring is neither feasible nor affordable, but it would be important to monitor potential sources of undeclared inputs and avenues for undeclared outputs, such as the spent fuel pond at the facility input or the high-level waste storage and processing areas. Developing an effective and affordable verification approach incorporating this type of verification concept will be one of the key challenges for FMCT verification.

3.1.2. Enrichment

The same verification objectives apply to enrichment facilities, but the practical implications will depend on the particular facility or facility type. Gaseous diffusion enrichment plants can take months to reach equilibrium or to change outputs in response to changing inputs. They are also difficult to reconfigure without creating criticality risks. These factors make it relatively simple to verify the design and configuration, reducing the need for frequent reverification. Therefore, for a plant producing only LEU, verification that there is no HEU production should be relatively simple. If HEU production is taking place, it will be important to monitor all locations where HEU could be extracted.

Centrifuge enrichment plants have very different characteristics: they equilibrate quickly and are relatively easy to reconfigure. It could be possible, for example, to segregate a subset of the centrifuges into a small isolated cascade, with undeclared LEU feed and HEU product lines. The hexapartite approach to safeguards at centrifuge plants was designed in large part to provide an assurance against undeclared HEU production, and may provide a model for FMCT verification at such plants. For large facilities and for facilities with more flexible cascade configurations, it may be necessary to rethink this approach.

Other enrichment technologies could also present unique considerations, including laser isotope separation if such a plant is ever built.
For both enrichment and reprocessing, the starting point of FMCT verification is not the point where fissile material is first separated. Rather, verification must address the possibility of undeclared activities at the production facility, and therefore should encompass as much of the facility and the associated site as necessary to meet this objective.

3.2. Ending Point

Let me turn to the ending point of FMCT verification. Focusing on enrichment and reprocessing as the choke points for fissile material production, one might conclude that verification should end for material that requires enrichment or reprocessing before it could be used in a nuclear weapon. As with the starting point, however, verification must also address the possibility of undeclared activities. Specifically, the objective should be to verify that the fissile material is transformed into a form where it cannot readily be transformed into a weapon usable form without high risk of detection by the verification regime. The main processes that lead to such transformation are the reverse of enrichment and reprocessing, namely downblending and irradiation. It would seem inconsistent with to continue verifying material once it has become essentially indistinguishable from other that would not be covered, such as fresh or spent LEU fuel.

3.2.1. Downblending

Downblending of HEU involves mixing it with depleted, natural, or low-enriched uranium produce LEU, presumably for use as reactor fuel. Such downblending has become the method of choice for disposing of HEU from defense programs that has been declared excess to defense needs. The United States has downblended over 15 tons out of roughly 175 tons of declared excess HEU. The Russian Federation has downblended over 125 tons of HEU under a purchase agreement with the United States to downblend at least 500 tons of HEU over a 20-year period.

It is difficult to imagine why a state would enrich uranium to HEU only to downblend it later to LEU. Nonetheless, states may change their plans, for example converting a reactor to use LEU fuel after producing HEU fuel, and the FMCT should provide for this possibility. It would seem inconsistent to continue verifying LEU that results from downblending if LEU output from an enrichment plant is not covered. Once measurements confirm that the enrichment has been reduced below 20%,
the focused approach envisions that verification would end.

3.2.2. Irradiation

One way to process fissile material so that reprocessing is required before it can be used in nuclear weapons is through irradiation. This was one method identified for the disposition of excess weapon-origin plutonium under the Plutonium Management and Disposition Agreement (PMDA) between the United States and the Russian Federation, a program that is currently under review. To the extent that civil reprocessing continues, irradiation of mixed oxide (MOX) fuel containing newly produced plutonium would be a common practice. Therefore, it is an important practical question how the FMCT verification regime would address this situation.

Starting with the assumption that verification of fissile material would end at after irradiation, let us consider what the appropriate irradiation threshold should be. For this purpose, it is useful to examine how irradiated material is treated differently from unirradiated material in other contexts.

3.2.2.1. Precedent

The Convention on the Physical Protection of Nuclear Materials, and the Guidelines for the Physical Protection of Nuclear Material establish international standards for physical protection that distinguish between irradiated and unirradiated material. These standards are based in part on the notion that the intense radiation field from spent fuel makes that material "self-protecting." The threshold is therefore set in terms of the radiation field: material is treated as irradiated if the unshielded radiation field is 100 rads/hr at 1 meter. Because of the logistical difficulties of handling highly radioactive material, theft is intrinsically more difficult and protective measures can be less rigorous. Nonetheless, irradiated material must still be protected; both the Convention and the Guidelines call for some degree of protection for such material.

IAEA safeguards practice also distinguishes in its treatment of irradiated and unirradiated direct use material, primarily in terms of timeliness goals. The timeliness goal for irradiated direct use material is set at three months, compared to one month for unirradiated
direct use material.\textsuperscript{2} This difference is based in part on
the logistical difficulties in handling irradiated
material, but more importantly on the need for
reprocessing. Both factors contribute to the longer
conversion time required to process irradiated material
into a weapon-usable form. As with physical protection,
the intensity of the verification measures for irradiated
material is reduced but the basic verification
obligations remain.

The Standing Advisory Group on Safeguards Implementation
has been asked for its advice on how to define this
threshold. In addition to the radiation field, SAGSI has
considered other measures, such as the quantity of
material required for separation of one significant
quantity or the rate of radioactive decay (e.g.
disintegrations per gram per second). By either measure,
irradiated material will eventually cool enough through
radioactive decay that would be treated as unirradiated.
If this cooling means that the conversion time is reduced
significantly, such treatment is clearly appropriate,
even though it could lead to a substantial increase over
time in the level of safeguards effort applied to spent
fuel.

The most recent standard for distinguishing between
irradiated and unirradiated material is the threshold in
the Plutonium Management and Disposition Agreement. This
threshold was derived taking into account various studies
of "spent fuel standards"; roughly speaking, material
that meets this standard should be no easier to convert
to a weapon-usable form than spent fuel. Setting a more
stringent standard would have little added benefit since
both the United States and the Russian Federation have
thousands of tons of unsafeguarded spent fuel in their
civil nuclear power programs. Thus, the threshold of
20,000 MWD/MTHM\textsuperscript{3} for LWR fuel is comparable to civil spent
fuel. In contrast to the standard in safeguards
practice, once material meets this threshold its status
is fundamentally changed; the verification obligations
are substantially reduced, although specific verification
measures remain to be determined.

\footnote{Although the IAEA is considering changing these goals in the
context of integrated safeguards, the goal for irradiated material
would remain longer than for unirradiated material.}

\footnote{The units are Megawatt-days of thermal energy production per metric
ton of heavy metal (uranium and plutonium). The PMDA also provides a
standard for disposition of plutonium if the BN-600 reactor, namely
the fission of 9\% of heavy atoms.}
Each of these standards -- in safeguards, physical protection, and plutonium disposition -- results in a change in how, but not whether the material in question is covered under the corresponding regime. This is different from the approach described above, according to which FMCT verification would end altogether (at least until the material is reprocessed). The standard for irradiation would play a much more important role under an FMCT than in other circumstances and warrants careful consideration.

3.2.2.2. Considerations

One way of defining the threshold would be to ask how much irradiation is necessary before fissile material requires reprocessing before it can be made into a nuclear weapon. That is a question for weapon designers, and this paper does not attempt to answer it. The use of irradiated fissile material in nuclear weapons raises a number of practical challenges, for example regarding shielding and the aging of materials. As a practical matter, therefore, it may be reasonable to assume that this irradiation threshold would be quite low. Nonetheless, a healthy respect for the talents of weapon designers would argue that we should be careful not to set the threshold too low.

Another consideration in setting the threshold is on the basis of whether the material is "too hot to handle" without heavy shielding, such as in a reprocessing plant or a hot cell. This is similar to the considerations in the safeguards context, but with an important practical difference. In safeguards implementation, the main issue has been the effect on conversion time, which presumably is not reduced greatly by the use of less heavily shielded facilities. Under FMCT the key question is whether the facility is of a type that would have to be declared. Hot cells equipped for reprocessing would have to be declared as reprocessing facilities. If the material in question were no longer subject to a verification obligation, the effectiveness of the verification regime would depend on measures to detect undeclared activities involving facilities (e.g. glove boxes or small and thinly shielded hot cells) and materials that did not themselves need to be declared.

Yet another consideration in establishing an irradiation threshold is the quantity of input material required for the separation of a significant quantity of fissile material or, correspondingly, the quantity of waste that would result from the separation. Handling large
quantities of waste implies a large-scale operation, with corresponding opportunities for detection. For MOX, the plutonium concentration is typically a few percent, so that separating 8 kilograms of plutonium from low-burnup MOX leads to a waste stream containing a few hundred kilogram of heavy metal dissolved in liquid waste solvent and separation chemicals. The situation is quite different for HEU from research reactors. For low-burnup research reactor fuel, the enrichment will remain essentially unchanged and the quantity of heavy metal in the waste stream would be much lower than in the separated HEU. Even for relatively high-burnup fuel the product will be HEU and ratio of waste to product will be low. The same considerations would apply for reactors using fuel that is predominantly plutonium.

Any standard for irradiation that is used as a basis for ending verification should be expressed in terms of an irrevocable threshold: Once material exceeds that threshold it should not fall below the threshold through radioactive decay. This suggests a threshold expressed in terms of burnup, rather than in terms of the radiation field or rate of radioactive decay. However, standard burnup measures in terms of MWD/MTHM may understate the degree of irradiation required for research reactor fuels with a high density of fissile isotopes. An alternate measure of burnup that may be appropriate in this case would be the to normalize not by the mass of heavy metal in the fuel but by the mass of fissile isotopes. Thus, LEU enriched to 5% for use in LWRs where it may reach a burnup of 40,000 MWD/MTTHM would be described by this measure as reaching a burnup of roughly 800,000 MWD/MTFI, where MTFI stands for "metric tons of fissile isotopes," in this case U-235. The irradiation threshold established in the PMDA would be somewhat lower, perhaps but at least several hundred MWD/MTFI, depending on the concentration of plutonium in MOX. Even for HEU-fueled research reactors that reach a comparable irradiation level, the small input and waste streams might still argue for maintaining verification on the spent fuel.

Finally, whatever threshold is chosen, it should be one that can be confirmed readily. In any case, as stated above, it would be inconsistent to continue verification of material that is essentially indistinguishable from other spent fuel -- e.g. spent LEU -- in terms of the difficulty and detectability of separating plutonium.
4. Conclusion

The measures at the starting and ending points of FMCT verification require careful consideration, particularly in order to address the possibility of undeclared activities. At the starting point the key challenge is to ensure that all the fissile material produced is accurately accounted for. There are some technical challenges, particularly for older facilities, but the concepts are familiar from safeguards.

New concepts may be needed for the ending point of verification, and should be given careful consideration. Termination after downblending is relatively straightforward, but termination after irradiation raises a number of issues, in particular the degree to which the verification regime should rely on the ability to detect undeclared activities. A new measure of burnup is proposed, which may be appropriate for this context, assuming that ending verification on irradiated material is an accepted approach.