PEACE RESEARCH INSTITUTE FRANKFURT

Annette Schaper

Principles of the verification for a future Fissile Material Cutoff Treaty (FMCT)

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Summary

This report addresses specifically the verification of a Fissile Material Cutoff Treaty (FMCT). Although it is not clear what will be the scope of the Treaty, e. g. whether nuclear materials produced prior to entry into force will be included and to what extent, many elements of the verification can be negotiated independently of the verification.
The report starts with an overview of general principles underlying the verification. An important principle of verification is its *credibility*. Even in case of a very limited scope, the verification must create assurance that all nuclear materials produced after entry into force are being used for known and non-proscribed purposes. The other principle is non-discrimination. All rights and obligations for verification must apply equally to all member states. During the negotiations, two questions will arise: firstly, whether the verification obligations of the non-nuclear weapon states are already met by the NPT verification, and secondly, how close the two verification systems will come. The verification tasks for both treaties are very similar and large differences in the verification systems would be interpreted as discrimination.
The next chapter outlines which terms need to be defined more specifically. Several materials and material categories must be distinguished, and in most cases, it is useful to apply already existing IAEA definitions. Especially, it will be necessary to clarify what must be understood by the terms "production" or "fissile materials". Also the levels of assurance that will be considered satisfactory must be defined. These definitions will have implications on the intrusiveness of the verification.
In the following chapter, the verification tasks at different facilities are illustrated. During the negotiations, it will have to be decided not only which materials should be covered but also which kinds of facilities with which verification activities must be included in these tasks. Facilities that are discussed in more detail in this chapter are reprocessing facilities, uranium enrichment facilities, and nuclear reactors.
The next chapter explains in some detail major methods of verification. Methods are well developed because they are being used by the IAEA for the verification of the NPT. They include declarations on status, design information, and material accountancy; containment and surveillance techniques, inspections, and methods for the detection of undeclared activities as are being implemented by the recent IAEA safeguards reform.
Many variations of which facilities should be included in the verification and which measures are considered appropriate are possible. In the following chapter, three scenarios with varying intrusiveness are presented and discussed. The first scenario includes only facilities capable of reprocessing and enrichment. The second scenario additionally includes nuclear reactors and all kinds of direct-use material. In this scenario, the clandestine production of spent fuel would be detected. Several categories of reactors are distinguished according to their sensitivity. In the third scenario, also the verification of the production of low enriched uranium would be included. The benefit would be the creation of higher assurance that clandestine production of highly enriched uranium would be detected.
In the next chapter, some special problems are being discussed: The FMCT verification will also take place in states possessing nuclear weapons who might wish to protect sensitive information. Some of these states possess facilities that have never been subject to

full-scope safeguards, and some of them might want to go on with the production of HEU for military naval reactors which will cause additional problems for verification.
Finally, it is recommended to task the IAEA with the verification.

Contents

1 Introduction: Aim of the paper

This paper addresses specifically the verification of a Fissile Material Cutoff Treaty (FMCT). Although it is not clear what will be the scope of the Treaty, e. g. whether nuclear materials produced prior to entry into force (EIF) will be included and to what extent, many elements of the verification can be negotiated independently of the verification.
The minimum scope will be *the ban of the production of fissile material for nuclear weapons or other nuclear explosive devices*. This will necessitate various verification elements. In case of a broader scope, more elements would be added. In this working paper, it will be assumed that only the production after EIF will be included in the scope. However, this working assumption must not be mistaken as a recommendation, instead it should be understood as a minimum common denominator that could be extended. For the same practical reasons, the name FMCT is used and must neither be understood as a recommendation.
The aim of the paper is to work out what can be said about the verification without knowing the future scope. It will start with an overview of general principles underlying the verification. Next, it will outline which terms need to be defined more specifically, especially what must be understood by "production" or by "fissile materials". These definitions will determine the extent of the verification. In the next section, an overview is given on facilities that could potentially be declared and submitted to verification, followed by an overview on typical verification measures for such facilities. There are many variations which facilities can be covered by the verification, not the least depending on the definition of the materials to be covered. In the following section, three different examples for verification scenarios are presented with different degrees of credibility. There are several verification problems specific to the FMCT and untypical for the existing safeguards in non-nuclear weapon states under the NPT (NNWS). They are addressed in the following section. The last part gives a short overview on organisational elements.

2 General principles of verification: credibility and non-discrimination

An FMCT is an essential contribution to both nuclear non-proliferation and nuclear disarmament. Four principles are of particular importance to the German Government which has been expressed in a previous working paper:[1] They are non-discrimination, universality, irreversibility, and transparency.
In addition to these principles, the principle of *credibility* of the verification is especially important for the success of the Treaty. The minimum element of the scope will be the ban on the production of fissile material for nuclear weapons or other nuclear explosive devices. The task of the verification will be therefore to create confidence that all treaty members comply with this obligation, e. g. that all nuclear materials produced after entry into force are being used for known and non-proscribed purposes. In the Shannon-Mandate, the task of the verification is expressed as to negotiate an "effectively verifiable treaty". The credibility of the treaty will depend to a large extent on the credibility of the verification. An important principle of verification is therefore its *credibility*.

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[1] Negotiations on the prohibition of the production of fissile material for nuclear weapons or other nuclear explosive devices (Cut-off negotiations) at the Geneva CD, Working Paper, Bonn, 22 January 1999.

In a working paper, the IAEA assesses the requirements for a credible verification as follows: "From the technical perspective, applying verification arrangements to anything less than a State's entire fuel cycle could not give the same level of assurance of non-production of fissile material for nuclear weapons purposes or for use in other nuclear explosive devices as it is provided by the IAEA by implementing comprehensive safeguards agreements in NNWS."[2] However, there are indications that some negotiating partners will not accept such a comprehensive system. Although on the long term, the goal must be to establish universally the same safeguards system for the civilian fuel cycles, it must be considered whether for the FMCT, some requirements could be reduced to a certain extent. But care must be taken that no loopholes will be created and that the principle of credibility will be observes.

Another principle has also been stated in the Shannon mandate: the treaty is intended to be *non-discriminatory*. This means that all rights and obligations for verification must apply equally to all member states. In other words, no material, at least that being produced after EIF, must be diverted to nuclear weapon use, equally for all treaty members. The measures to verify this ban therefore must be the same for everybody. However, NNWS are already subject to a similar obligation and corresponding verification by the IAEA, defined by INFCIRC/153 and INFCIRC/540, the latter being currently implemented. During the negotiations, two questions will arise: firstly, whether the verification obligations of the NNWS are already met by the NPT verification, and secondly, how close the two verification systems will come. It must be kept in mind that the verification tasks for both treaties are very similar and that large differences in the verification systems would be interpreted as discrimination. Literally, INFCIRC/153 defines the task as: "the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or other nuclear explosive devices or for purpose unknown, and deterrence of such diversion by the risk of early detection." Differences in the verification systems of both treaties therefore should stem only from different scopes of the treaties.

The high level of assurance that is possible in NNWS is based on nuclear material accounting supplemented by containment and surveillance. Primarily on the basis of information provided by the State, the IAEA establishes the quantities of nuclear material in a State and records changes to the quantities of the inventory. The IAEA performs inspections to examine information provided by the State and makes independent verification of nuclear material based on the States declaration. In INFCIRC/540, these measures have been reinforced and complemented. For example, as consequence, states are obliged to extended reporting on facilities containing special fissionable material, and the IAEA has additional rights with provisions of managed access. The FMCT verification must be consistent with this approach and should at least be rooted in INFCIRC/153 and INFCIRC/540, in order to create as much compatibility as possible.

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2 IAEA, A Cut-off Treaty and associated costs – An IAEA Secretariat Working Paper on Different Alternatives for the Verification of a Fissile Material Production Cut-Off Treaty and Preliminary Cost Estimates Required for the Verification of these Alternatives, presented at the Workshop on a Cut-Off Treaty, Toronto, Canada, 17-18 January 1995.

3 Definitions

In the treaty text and in the verification provisions, several definitions will be needed. It should be avoided as far as possible to invent definitions contradicting or additional to those used for the existing IAEA safeguards, which have proven useful during many years of experience. This would undermine their credibility and thereby weaken the nonproliferation regime.
The Shannon-Mandate reads simply: "banning the production of fissile material for nuclear weapons or other nuclear explosive devices". In the Treaty, it will be necessary to define the precise meaning of "*fissile material for nuclear weapons or other nuclear explosive devices*". In many contributions inside and outside the CD, the term "fissile material" in the context of the FMCT is understood *as highly enriched uranium (HEU) and plutonium (Pu)*. The IAEA definition of HEU is uranium enriched to 20 % U-235 or more. Plutonium contains varying percentages of several different isotopes. The IAEA does not make any legal distinction between different Pu isotopic compositions, except the special case of Pu containing 80% Pu-238 or more. It is widely accepted that all other plutonium isotopic compositions could in principle be used to ignite a nuclear explosion, despite the fact that the technical difficulties that must be overcome for the construction of a nuclear warhead are varying. Therefore, in the NPT context, no legal distinction is being made between different plutonium categories, e.g. "*reactor-grade"* and "*weapon-grade"*, or "*weapons usable*" and "*weapon grade*" plutonium.
In the FMCT text, the same definitions of HEU and Pu as in the NPT context and the IAEA verification should be used. This means that any negotiations on the enrichment of HEU should be avoided. Instead, HEU should be understood as enriched to 20% or more, as usual. Equally, there should be no attempt to classify different categories of plutonium. Both materials and chemical compounds and mixtures containing them are classified as "*direct-use material*" (See list of IAEA Definitions in the Appendix). A distinction can be made between *unirradiated* and *irradiated* direct-use material. According to this definition, spent fuel would be classified as irradiated direct-use material because it contains plutonium.
Another category of materials is defined in the IAEA Statute and in INFCIRC/153 as "*special fissionable material*". In addition to direct use material, the category of special fissionable material also includes low enriched uranium (LEU), e.g. uranium that is enriched to less than 20%. LEU is not weapons usable, nevertheless in NNWS, all special fissionable material is subject to IAEA safeguards. There are several reasons: LEU is fuel for nuclear reactors whose operation results in plutonium generation. The technical efforts to further enrich LEU to HEU are much less in comparison to enrichment starting at the natural uranium level. This means that a much smaller enrichment facility would be needed. Material accountancy of only HEU without LEU misses large U-235 inventories and therefore is too unprecise. For these reasons, the production of LEU is an important step towards the production of direct-use materials. For the verification of the absence of the production of direct-use materials for other than declared needs, it makes sense to additionally monitor the production and the use of LEU. This holds not only for the NPT but equally for the FMCT.
At the time being, negotiations at the IAEA are underway on the proposal to submit additional materials to international safeguards that are said to be weapons usable. These mate-

rials are americium-241 (Am-241) and neptunium-237 (Np-237). Although the negotiations are not yet completed, it must be expected that new control regulations concerning both or one of these materials will be implemented. One option is to change the definition of special fissionable material, more likely, however, is a more informal solution with special reporting and flow sheet verification for those facilities that are able to separate these materials. In the FMCT, similar provisions on the same materials as now being negotiated in Vienna should be adopted.
Another material whose production ban or control is also discussed in the framework of an FMCT is *tritium*. Tritium in its nuclear applications undergoes not *fission* but *fusion*. In the IAEA classification, it does not count as nuclear material and is not submitted to safeguards. It is used in modern warheads and in civilian fusion research. Since tritium decays with a half life of about 12 years, it must be replaced from time to time. As long as they still maintain arsenals, the NWS are therefore unlikely to accept a production ban. Tritium therefore should not be included in the verification, however, it must be assured that the verification is able to distinguish tritium production from plutonium production.
Table 1 gives an overview on several materials, their categories according to the IAEA, and their technical roles for nuclear explosives.
A term that must also be defined in the FMCT is "*production*". In case the scope will cover only an understanding that "production" means just enrichment and reprocessing, consequently the treaty text should formulate the "ban of the production of unirradiated direct-use material..." which would exclude spent fuel. In case "production" is understood as also meaning irradiation in reactors, the scope should be expressed as the "ban of the production of direct-use material...". In the NPT context and IAEA safeguards, the term "production" is understood in the broader sense, e.g. it also includes the generation of plutonium in reactors which then will be a component of spent fuel. It is highly recommendable to adopt a similar understanding in the FMCT.
There is no official IAEA definition of this term, instead there is a definition of the term "*inventory change*" which defines the entry and exit of nuclear material to and from safeguards (INFCIRC/153, para. 107, see Appendix). There are several ways how the inventory of the material subject to safeguards can change, including production, but also export and import, loss, or transformation into an unrecoverable state. At least all material produced after EIF will be subject to FMCT verification. Therefore, the starting point and termination of verification measures must be fixed in the treaty text. They are closely related to the understanding of "production".

Table 1: Materials, their IAEA categories, and their role for nuclear explosives

<table>
<tr><th>Material</th><th colspan="4">IAEA Categories</th><th>Role for nuclear explosives</th></tr>
<tr><td>"Weapon grade Pu": high content of isotope Pu-239</td><td rowspan="2">nuclear material</td><td rowspan="2">"plutonium" with no legal distinction</td><td rowspan="2">direct-use material</td><td rowspan="2">special fissionable material</td><td>explosive can be made from it</td></tr>
<tr><td>"Reactor grade Pu": Pu-239 + substantial fractions of other isotopes (Pu-240, Pu-241 ...)</td><td>explosive can be made from it, but with some technical disadvantages</td></tr>
<tr><td>Pu-238 mixtures (> 80%)</td><td colspan="4">none</td><td>none</td></tr>
<tr><td>"Weapon grade" HEU : content of U-235 very high (> 90 %)</td><td rowspan="13">n u c l e a r m a t e r i a l</td><td rowspan="2">HEU with no legal distinction</td><td rowspan="2">direct-use material</td><td rowspan="3">special fissionable material</td><td>explosive can be made from it</td></tr>
<tr><td>lower grades of HEU</td><td>explosive can be made from it, but this is more difficult that with 90% HEU</td></tr>
<tr><td>LEU: U-235 enriched to < 20%</td><td colspan="2"></td><td rowspan="3">enrichment necessary to make HEU, or neutron irradiation for transmutation into Pu</td></tr>
<tr><td>natural U: U-238 with U-235 content = 0.7 %</td><td colspan="3" rowspan="2">source material</td></tr>
<tr><td>depleted U: U-235 content < 0.7 %</td></tr>
<tr><td>U-233</td><td colspan="2" rowspan="2">direct-use material</td><td rowspan="2">special fissiona ble material</td><td>explosive can be made from it</td></tr>
<tr><td>mixtures containing U-233</td><td>first separation from other mixture components to get U-233</td></tr>
<tr><td>Thorium (Th-232)</td><td colspan="3">source material</td><td>Neutron irradiation to produce U-233</td></tr>
<tr><td>Neptunium (Np-237)</td><td colspan="3" rowspan="2">being negotiated</td><td>explosive can be made from it</td></tr>
<tr><td>Americium (Am-241)</td><td>explosive can be made from it, but only with extreme technical sophistication</td></tr>
<tr><td>MOX: mixture of U and Pu</td><td rowspan="3">direct-use material</td><td rowspan="2">unirradiated</td><td rowspan="3">special fissionable material</td><td>Pu must first be chemically separated</td></tr>
<tr><td>Fresh spent fuel: U-238 + U235 + Pu + highly radioactive isotopes....</td><td>first reprocessing to gain Pu</td></tr>
<tr><td>Older spent fuel (> 10-20 years): U-238 + U235 + Pu + less radioactive isotopes....</td><td>irradia ted</td><td>reprocessing and handling is easier</td></tr>
<tr><td>ore, ore residue (e.g. yellow cake)</td><td colspan="4">none</td><td>natural U is made from it</td></tr>
<tr><td>Tritium</td><td colspan="4">none</td><td>for fusion processes during a nuclear explosion</td></tr>
</table>

Also the verification tasks will have to be defined. Under the assumption that the scope covers only production after EIF, the verification tasks will be:

1. Provide assurance that shut-down production facilities remain shut-down.
2. Provide assurance that material produced at declared facilities will not be diverted to purposes unknown.
3. Provide assurance that no undeclared production at declared facilities takes place.
4. Provide assurance that no material will be diverted from inventories of material produced after EIF.
5. Provide assurance that no undeclared production facilities exist.

Therefore, it must be defined which levels of assurance will be considered satisfactory. Such definitions should be expressed as probabilities for detecting violations. The probability should be the higher, the more sensitive the diversion is, e.g. LEU is less sensitive than HEU. In INFCIRC/153, the verification goal is termed as "the *timely detection* of diversion of *significant quantities* of nuclear material". Both terms "timely detection" and "significant quantity" are defined as in the following table **(**Table 2**):**

Table 2: Significant quantities of nuclear materials and timeliness goals

Category	**Type**	**Significant Quantities**	**Timeliness Goals**
Direct-use material	Plutonium*	8 kg plutonium	1 month
	High-enriched uranium	25 kg uranium-235	1 month (fresh)
	Plutonium in spent fuel	8 kg plutonium	3 months (spent)
	Uranium-233	8 kg uranium-233	3 months
Indirect-use material	Low-enriched uranium**	75 kg uranium-235	12 months
	Thorium	20 t thorium	12 months

* for plutonium containing less than 80% plutonium-238
**less than 20% uranium-235; includes natural and depleted uranium

During the negotiations, it must be decided whether similar or other quantities of fissile material are considered significant to be detected, and which time interval between production and detection should be chosen. In INFCIRC/153 type safeguards, a lot of regular and frequent routine inspections take place in order to meet the timeliness goals. It might be considered whether alternatively, more random and less routine inspections should be envisaged (cf. chapter 6). In this case, it might be practical to define a term like "*detection probability within a time interval*". Time intervals could be assigned similarly as in Table 2, while additionally detection probabilities could be agreed upon. From such a definition, the average frequency of random inspections can be derived. However, care must be taken to meet the principle of credibility.
The Treaty must also fix provisions which body according to which procedure may change definitions.

4 Verification tasks at different facilities

During the negotiations, it will have to be decided not only which materials should be covered but also which kind of facilities with which verification activities must be included in these tasks. The following figure (Fig. 1) shows a schematic overview on facilities and material flows of many elements of nuclear fuel cycles with U-235 and Pu-239.

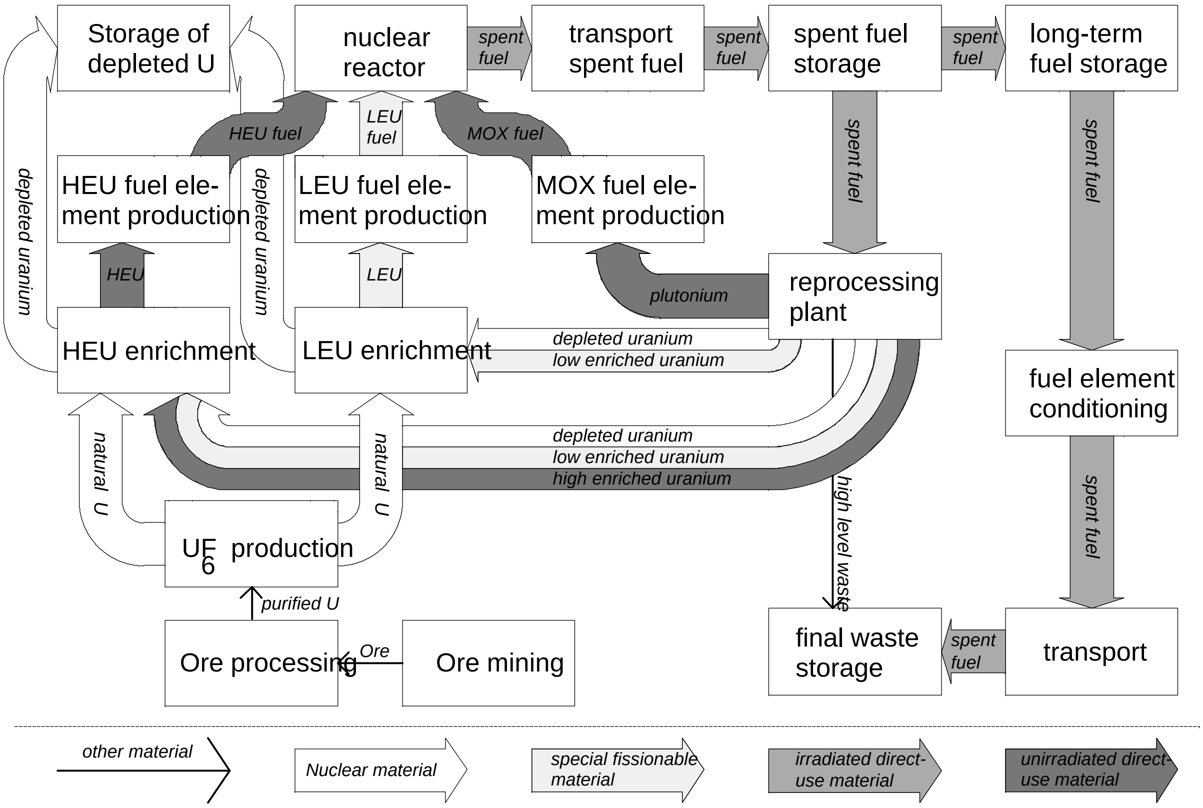

Fig. 1: Facilities and material flows in nuclear fuel cycles

It illustrates which facilities produce, use, or store which materials. There are other fuel cycles not depicted in this figure, involving thorium-232, classified as *nuclear material*, and U-233, classified as *direct-use material*. Facilities involving these materials should be treated according to this classification. In this section, an overview on verification tasks and technical methods typical for several facilities will be given.

4.1 Reprocessing facilities

Plutonium does not occur naturally but is produced in reactors by nuclear reactions between neutrons and U-238. Pu-239 can react with more neutrons to form the heavier isotopes Pu-240, Pu-241, and Pu-242. The longer a fuel element stays in a reactor, the larger is the ratio of the higher isotopes which is less favourable though still not useless for nuclear explosives. Spent fuel contains plutonium, highly radioactive fission products and their decay products, and unaffected uranium. The plutonium can be separated from the spent fuel by chemical means which is called *reprocessing*. The most efficient reprocessing process is the PUREX process (plutonium and uranium recovery by extraction). Because of the high radioactivity of spent fuel, the process takes place under radiation protection. A small radiation protection device is a hot cell which can be used for the separation of small Pu quantities.

Inspections at declared reprocessing plants are more complex and more expensive than at any other facility.[3] The reasons are firstly that reprocessing requires the dealing with very high radioactivity, and a plant consequently contains a lot of special equipment for its containment, and secondly, this process involves many material streams of different compositions in shielded pipes, tanks, and reservoirs whose material compositions and plutonium contents must be measured. Any illegal diversion from these flows must be detected. Such measurements have a certain inaccuracy which depends on the intrusiveness of the inspections and on the type of the facility, e.g. whether during its construction, it has already been designed to be submitted to safeguards, and whether its instrumentation is reliable or not. There are variations whether a reprocessing plant is used only for plutonium separation or also for separation of americium and neptunium.

The basic safeguards approach is material accountancy that verifies a detailed report by the owners, supplemented by containment and surveillance techniques.[4] Flows are measured at predetermined locations known as "key measurement points", and samples can be taken from various areas. There are several technical stages of reprocessing. In the first stage, the spent fuel is chopped and then dissolved, converting the material from discrete into bulk form. Then the fission products are removed and further processed, and finally, uranium and plutonium are separated from each other. Many of the process flows are highly radioactive, so measurements take place behind radiation shielding, and direct access is difficult. The large number of shieldings and the radiation protection measures make it difficult to maintain the overview on all potential diversion risks. In NNWS, the implementing of safeguards is taken into account already in the planning stage of a plant, and design verification can take place already during construction. This makes it much more difficult to pursue unmonitored diversion paths. Understanding the plant design is therefore a key element in the safeguardability of a plant. Similarly, the detailed knowledge of the operating history of a plant is of crucial importance in order to interpret measurement results. These methods serve mainly for verifying that no additional undeclared operations take place in operating declared facilities, and that no Pu is diverted from declared inventories. There are technical problems that add some uncertainties in results. Errors in calculated plutonium contents can at times exceed a significant quantity. They stem from biases in solution measurements, difficulties to determine the exact Pu content in spent fuel, time delays of sample analyses, and measurement limitations because of radioactivity. Safeguarding a reprocessing plant that has not formerly been under safeguards is more difficult. The first step of implementation is a thorough design analysis and reconstruction of operation history.

The verification that already shut-down facilities remain so is comparably easy by on-site inspections. Technical methods are seals, temperature and other signals measuring, and analysis of environmental samples. The analysis of Pu samples at reprocessing plants provides an unambiguous indicator of the age of the sample.

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3 T. Shea, Reconciling IAEA Safeguards Requirements in a Treaty Banning the Production of Fissile Material for Use in Nuclear Weapons or other Nuclear Explosive Devices, Disarmament Forum, UNIDIR, p. 57, Vol. 2, 1999.

4 Under full-scope IAEA safeguards, a "*State System of Accounting for and Control of its Nuclear Material*" (SSAC) must be created that is responsible for the implementation of effective arrangements according to agreed standards and for reporting.

The other verification task is the detection of undeclared production facilities. Reprocessing releases several characteristic effluents that can be detected and monitored from outside. They include particulates and gaseous fission products, especially noble gases that are not bound chemically. Reprocessing produces far more emissions than the operation of a reactor or enrichment and a clear evidence is likely. Even with shielding, a principle risk of being detected exists for undeclared reprocessing.

4.2 Uranium enrichment facilities

For HEU production, feed material, e.g. natural, depleted or low enriched uranium, and an enrichment facility are necessary. Uranium enrichment technology separates between the isotopes U-235 and U-238 Also uranium enrichment plants deal with bulk material.[3] In case, all special fissionable material production is included into the verification, it must create assurance that the enrichment level and the amounts produced are as high as declared, and that none of the material is diverted from product, feed, or tails streams. In other, less comprehensive scenarios, the task would be reduced to verify that no clandestine HEU production does take place.
There are several different enrichment technologies with different process characteristics. They include *gaseous diffusion*, *gaseous centrifuge plants*, *aerodynamic enrichment*, *electromagnetic separation*, *chemical isotope separation*, *atomic vapour laser isotope separation (AVLIS)*, and *molecular isotope separation (MLIS)*. Because of different process characteristics, the technical details of verification will vary substantially. The levels of experience the IAEA has collected in safeguarding these technologies vary, as does the extent to which such facilities are operated commercially or on an experimental level. The verification is complicated because enrichment technologies are proliferation sensitive, and therefore the access of inspectors to technological details is restricted. Therefore, special managed-access arrangements are necessary.
An enrichment plant consists of many stages of separation elements connected by pipes. The numbers and the arrangement depend on the technology, the enrichment level to be achieved, and the total production. The verification must ensure that this arrangements is the same as declared. The analysis of samples of the various material streams is another routine safeguards measure in enrichment plants. For this purpose, measuring equipment must be installed at various points to control the isotopic composition of the streams. In plants not designed to be subject to safeguards from the beginning, such installations must be added in the aftermath**.** INFCIRC/540 has additionally implemented the option of taking environmental samples to ensure that no additional undeclared HEU production has taken place. However, this method works only in LEU facilities where no previous HEU production has ever taken place. It would cause false alarms in former military facilities that have been converted to LEU production. In such plants, the major verification tool is material accountancy.
The operation of an enrichment plant releases several characteristic signals and effluents which can be used for the detection of undeclared HEU production:[5] Examples are

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5 See also: U.S. Congress, Office of Technology Assessment, Environmental Monitoring for Nuclear Safeguards, OTA-BP-ISS-168, September 1995.

uranium hexafluoride (UF_6) that reacts with water and air and therefore diffuses into the environment where it can be detected and even its enrichment level be analysed, heat that can be detected by infrared measurement equipment outside, e.g. on satellites or on aeroplanes, or electric power whose lines can be detected unless the supply is built underground. A new enrichment technology is laser isotope separation (AVLIS) whose operation, in contrast to other enrichment methods, has a much lower detection probability. However, there is no commercial use of this technology and proliferation is unlikely because the level of technical sophistication is very high. New safeguards technologies must be developed for laser isotope separation. The detection probability of construction is much lower than that of operation, however, satellite monitoring, technology transfer observation, or information gathering offer a certain chance for detection.
Noteworthy is the Hexapartite Enrichment Project, whereby 6 countries (Germany, Netherlands, Japan, USA, UK, Australia) agreed to place all civil centrifuge plants under permanent IAEA safeguards. The HSP was initiated in 1989 and was concerned primarily with devising a safeguards strategy to cover the new gas centrifuge enrichment facilities which began springing up in Western Europe and Japan during the 1970s. Thus the Capenhurst plants in the UK are permanently designated by the IAEA. This project also entailed the development of special verification techniques which enabled the implementation of satisfactory measures and an agreement between the IAEA and Euratom. One interesting option would be to widen this agreement to include Russia and China.[6]

4.3 Reactors

The verification goal at reactors is to provide assurance that there is no diversion of fresh or spent fuel.[7] Depending on the type of the reactor, the fresh fuel can consist LEU, MOX, HEU, or natural uranium. The verification is much easier than at reprocessing or enrichment plants, because all nuclear material consists of countable items. Material accountancy and its verification for fresh fuel is therefore done by item counting and identification, non-destructive measurements and examination to verify the continued integrity of the item, assuming that the fuel is received from an IAEA safeguarded facility. However, in the case where fresh MOX or HEU fuel is received from unsafeguarded facilities, additional measurements must be performed and the fuel must be maintained under seal or surveillance. Consequently, seal verification and/or surveillance evaluation must also be carried out.
Similarly, the fuel in the core must be verified. Methods can be item counting and serial number identification following refuelling and before the reactor vessel is closed. In INFCIRC/153 safeguards, any refuelling necessitates the presence of inspectors. It might be considered whether inspections can be reduced by randomising some of these visits and by automating the monitoring and surveillance the fuel reloading and the unchanged state of the core in the aftermath. Also the spent fuel pond must be verified. Methods are obser-

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6 W. Walker, personal communication.

7 N. Harms and P. Rodriguez, Safeguards at light-water reactors – Current practices, future directions, IAEA-Bulletin Vol. 38, No. 4, 1996, IAEA Web Site: http://www.iaea.org/worldatom/inforesource/bulletin/bull384/harms.html.

vation, measurements of the Cerenkov radiation (a physical effect due to radioactive decay under water), and the surveillance of the sealed transfer gate.

4.4 Other facilities

The verification tasks and methods at other facilities depend on the technical characteristics and the form and categories of the fuel involved. In fuel fabrication factories, nuclear material is processed 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 verification and financial reasons is to keep the wastes and losses to the lowest levels possible and to keep a precise material accountancy. In case the input bulk material comes from verified facilities, e.g. enrichment or reprocessing plants, it will be in form of sealed containers, which can be counted and identified and whose integrity can be measured. In case the material comes from other sources, e.g. unverified stores, the quantities must be measured independently. The output of fuel factories are countable items whose verification is easier.

5 Methods of verification

5.1 Declarations on status, design information, and material accountancy

As a start, member states will have to declare all facilities that the treaty defines as subject to verification. Such a declaration must first of all include the status of a facility, e.g. whether it is under construction, closed-down, decommissioned, or operating. Detailed design information of a facility must also be declared which is then verified. This can be used to draw conclusions about the production capabilities of the facility. Also, states must establish accountancy records of inventories and production at these facilities, and report about them to the verification agency. Standard criteria affecting the extent and quality of information to be provided by states must be defined in the treaty. Many variations are possible. In INFCIRC/153-type arrangements, as a start an initial inventory is taken, based on declarations and verification of the agency, and even information of past production. Further reporting will then cover all inputs, withdrawals, and production. All this information taken together allows to draw conclusions about the consistency and enhances the level of assurance that the information on the production is correct.
However, in case the Treaty will cover only future production, it is unlikely that states will accept an obligation to report on past production. In the most minimalist scenario, only accountancy of the material leaving the plant will be established, without considering inputs and inventories. The level of assurance in this case would be very low. Yet, as these materials must be followed downstream, more other facilities will have to be affected by verification measures. Even in case the Treaty scope covers only the production of unirradiated direct-use material – e.g. reprocessing and enrichment and some downstream plants, terminating the verification at the irradiation in nuclear reactors– it is still strongly recommended to include inventories and inputs into the material accountancy at these facilities. In case also the production of irradiated direct use material is subject to verification, automatically also inputs and inventories of reprocessing plants will be accounted. At reactors, this task is easier if also the entry of fresh fuel elements is part of the accountancy.

Material accountancy is much easier in case the material in a facility consists entirely of countable items, e.g. fresh or spent fuel elements as in reactors. It is much more difficult in case of bulk material, e.g. powders, liquids, or gases as in reprocessing and enrichment plants. Accordingly, most of the costs of material accountancy arise in the latter. However, such facilities are at the centre of the verification and must be included in every scenario. States will have to set up national bodies whose task is to set up national material accountancy and to report to the verification body. This body would also be responsible for the technical and for the national legal implementation. In case of NNWS, there are already the *State's Systems of Accounting for and Control of nuclear material* (SSAC) that serve for this task within the NPT verification.[8] They would fulfil the same task for the FMCT. It is recommendable to agree to a similar standard for the FMCT verification. INFCIRC/153-type SSACs are based on a structure of *material balance areas*, on each of which the inventory must be accounted for. The inventory and all entries and removals must be measured physically with defined precision for each balance areas. Procedures must be agreed with the Agency how to verify the inventories. However, in some states, INFCIRC/153-type SSACs do not exist, and some facilities in these states have never been designed for measuring physical inventories of defined areas within the facility. Setting them up is a technical, legal, and financial effort, therefore intermediate compromises are necessary for a defined transition period (See section 7.2). It must be kept in mind, however, that such bodies are beneficial for many additional reasons.

5.2 Containment and surveillance techniques

The next component of the verification are technical equipment that the verification authority will install in the facilities, so-called containment and surveillance techniques. It includes seals, detectors, monitors and cameras recording any action occurring in a particular area of a nuclear installation. They allow to detect undeclared movements of nuclear material, and potential tampering with containment and/or surveillance devices. In light water reactors, as an example, cores are usually not opened more than once per year. Therefore, it is often possible to seal the reactor pressure vessel head. The more sophisticated such an instalment is and the more automatisation it incorporates, the less on-site inspections are necessary for the same level of assurance that no material has disappeared. Automated data transfers to the verification agency adds to the reduction on necessary on-site inspections.

5.3 Inspections

The verification is completed by inspections. The goal is to provide assurance that all declarations are correct, e.g. that the operational status and design of facilities is as declared. There are several variations of the operational status of a facility. In case a facility is *decommissioned*, the frequency of inspections can be kept comparatively low. It will depend whether operation can be resumed and which estimated time would be necessary for it. Often, inspections can be replaced by satellite imagery. In a *decommissioning*

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[8] EU member states do not have national SSACs, instead their common SSAC is Euratom.

facility, the verification task is the simpler, the more has already been dismantled and the longer the time for the resumption of operations. A *stand-by* facility theoretically can resume the operation very quickly. However, as long as it is not running, inspections are much easier than in an *operating* facility, which must provide assurance that it is working as declared, e.g. that LEU enrichment facilities do not produce HEU, or that operating installations at reprocessing plants are as declared.
Also, containment and surveillance equipment must be checked. Particularly, the material accountancy must be verified, e.g. physical inventories and streams of nuclear materials must be confirmed. The methods to achieve the inspection goals depend on the type of the facility. The details of activities during an inspection depend on the plant and will include combinations of the following:

1. observations, measurements and tests whether the design information is correct;
2. installation of containment and surveillance technologies;
3. installation of detection technologies for proscribed activities;
4. auditing of accounting records and comparison with reports to the Agency;
5. measurements for the control of accountancy, which include volume and concentration and enrichment measurements of nuclear materials in streams, tracking the movement of solutions, and taking samples in case of bulk facilities, or in case the material is in the form of countable items as in a reactor, counting, identifying, and examining them by non-destructive means to verify their continued integrity;
6. additionally, environmental samples may be taken, as a means to detect additional undeclared operations.

Samples taken must be shipped to a laboratory, e.g. the IAEA Safeguards Analytical Laboratory, located in Seibersdorf, Austria, and analysed. Measurement data taken from inspections and from laboratory analyses are used to establish an independent material accountancy which is compared to the operators declaration.
In INFCIRC/153, *ad-hoc inspections*, *routine inspections*, and *special inspections* are provided for. Ad-hoc inspections are conducted in case an initial report must be verified or in case of transfers, routine inspections take place on a regular basis with frequencies depending on the amount and kind of nuclear material in a facility, and special inspections take place only when the Agency considers information as not adequate. INFCIRC/540 allows access beyond nuclear sites, using the existing right to access on "short notice" or "no notice" during routine inspections. As a result of very formal definitions of the frequency of routine inspections, most of them take place in countries where confidence is high anyway, e.g. Canada, Japan, or Germany. However, costs could be substantially reduced if routine inspections would be replaced by a random system. The goal of verification is the deterrence of non-compliance by creating a certain risk of detection. Unannounced random inspections that would take place with a certain probability would serve the same goal. The facility operator needs to be prepared for an unannounced inspection at any time. The benefit is that an assurance about the absence of undeclared activities at the facility at the time of the inspection implies that this has been the case with certain probability over the whole time interval since the last on-site inspection.
In case a *random inspection* regime will be implemented for the FMCT verification instead of a rigid routine inspection regime, the probability for an inspection to take place must then be defined in the Treaty. It should firstly be dependent on the amount and kind of

material involved, e.g. inspections would be more frequent at reprocessing plants producing unirradiated direct-use material than at a light-water reactor producing spent fuel elements. Different categories of reactors can also be distinguished (see section 6.2 *Verification scenario 2: verification of all direct-use material production*). Secondly, there should be provisions for special inspections in case of suspicions and for the detection of undeclared activities (see next section 5.4).
Since the most expensive component of the verification are the costs for inspectors, a random inspection regime could substantially reduce the overall costs. Nevertheless, it should be kept in mind that on the long term, the verification systems of the FMCT and the NPT should merge to one system on all civilian nuclear material, independently whether it is in a NWS or NNWS.

5.4 Detection of undeclared activities

The proliferation cases of Iraq and North Korea triggered the safeguards reform INFCIRC/540 which has enhanced the IAEA's capability to detect undeclared activities. The protocol contains several elements: they include access beyond nuclear sites, using the existing right to access on "short notice" or "no notice" during routine inspections, so-called "expanded declarations" that ask for information about activities and equipment functionally related to fuel cycle operations and not only, as before, information on all nuclear material and nuclear facilities. This includes technologies that constitute important elements in the nuclear fuel cycle infrastructure, such as components of centrifuge enrichment technology. Also exports and imports of such technologies must be declared, as well as ongoing research. Another component of the reform is taking environmental samples not only at an inspected facility which is already legal but also in the vicinity under certain circumstances. The agency has established a computerized system to store and retrieve safeguards-relevant information from open sources to assist in interpreting the expanded data and in depicting a proliferation or nonproliferation profile of a state. Another new element is expanded access, e.g. to sites contained in the expanded declaration, to decommissioned sites, and also to other sites than those identified in the expanded declaration in order to gather specific information or to take environmental samples. The reforms go further by including enhanced safeguards training, improving the efficiency of the safeguards system, increased cooperation with national or regional systems of accounting and control such as Euratom. Some of these elements will be implemented in NWS anyway, especially the expanded reporting on fuel cycle technology transfers. The reason is that they do not only aim at detecting receivers of sensitive technologies but also exporters. Many of these elements are useful for FMCT verification. In addition to material accountancy without loopholes, they are particularly *environmental sampling, special inspections,* and *information gathering*.
Material accountancy without loopholes means that all inputs, all exits, and all inventories of the whole fuel cycle are accounted for as is the case in NNWS. As consequence, there would be problems to acquire feed material for a clandestine plant without detection. For this reason, in INFCIRC/540 even reporting on uranium mining, ore processing, and uranium refining and conversion has been introduced which was not necessary when there was only INFCIRC/153. However, it is unlikely that the NWS and the states outside the

NPT will accept such thorough obligations. Furthermore, in case the scope covers only material produced after EIF, states outside the NPT and NWS would always be able to use previously fabricated and unverified materials as feeds for clandestine facilities. Nevertheless, in facilities included in the verification, accountancy and its verification is only credible if the complete material balance is included. Otherwise it cannot be verified that no illegal diversion has taken place.
Environmental samples can be taken on a random basis from the atmosphere or as part of inspections at suspicious locations or from their vicinity. As has been explained in the previous chapter, operating clandestine facilities, e.g. reprocessing and enrichment plants, reactors, fuel fabrication plants and others release characteristic effluents whose chemical and isotopic compositions can be analyzed. The results allow to establish well defined suspicions. The Treaty therefore should allow to take samples from the atmosphere, from the vicinity of inspected facility and of suspicious locations.
Special inspections must take place on a short-notice or no-notice basis, once a suspicion is constituted. These procedures will be complicated by the fact that facilities might be part of large, sensitive, possibly military sites. Also sometimes, commercial secrets must be protected. Therefore, *managed access* arrangements are necessary that on the one hand protect too sensitive information but on the other hand allow enough access to demonstrate compliance with the Treaty. Such arrangements are negotiated individually between facility operators and the verification authority. Examples for measures are coverage of certain sensitive equipment, shutting down of computers, or the use of measuring equipment with defined and limited technical capabilities.
Information gathering should allow to include information from many sources. As in other arms control treaties, additional information must be allowed to be used to establish triggers of special inspections. This information can be *national technical means* (NTM), e.g. all activities that are not regulated by an international organisation and that is passed on by States to the verification authority. Satellite images are useful for the detection of power and effluents of clandestine enrichment and reprocessing facilities, and reactors.[9] It would be desirable to organise as much data gathering as possible in an internationally organised way, e.g. the verification authority could make use of commercially available satellite images. Also, the IAEA database on safeguards-relevant information should be used and extended.

6 Three examples for verification scenarios

Many variations of which facilities should be included in the verification and which measures are considered appropriate are possible. In the following, three scenarios will be presented and discussed. They are summarized in 10 Appendix: Table 3 – Comparison of several examples of verification scenarios.

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[9] Wolfgang Fischer, Wolf-Dieter Lauppe, Bernd Richter, Gotthard Stein, Bhupendra Jasani, The Role of Satellites and Remote Data Transmission in a Future Safeguards Regime, Proceedings of the Symposium on International Nuclear Safeguards, Vol. I (Vienna: International Atomic Energy Agency, March 14-18, 1994), p. 411; Hui Zhang, F. von Hippel, The application of Commercial Observation Satellite Imagery for the Verification of Declared and Undeclared Plutonium Production Reactors, Pu/CEES Report No. 319, Princeton, August 1999.

6.1 Verification scenario 1: verification of unirradiated direct-use material production

In an example of a minimalist scenario, only facilities capable of reprocessing and enrichment, e.g. producing unirradiated direct-use material, would be included. In the figure (Fig. 1), these facilities are those whose product is unirradiated direct use material, depicted by dark shade arrows ( ). They can be categorised as former military reprocessing and enrichment plants, civilian commercial plants, pilot plants, and research installations such as hot cells. The output of HEU enrichment plants would be subject to verification. Verification of LEU enrichment plants would be limited to design verification which means to create assurance that no HEU is produced. The separated direct-use materials produced at these plants must then be followed downstream until the defined termination of verification measures. As consequence, all facilities that store, process or use them after EIF must be included. Facilities that process HEU, Pu, or U-233 are fuel fabrication and conversion plants, e.g. for MOX or research reactor fuel that contains HEU, or plants that are used in case some of this material is disposed of in another form, e.g. vitrification. Plants that use the material are mainly nuclear reactors. In a minimum approach, the verification would end upon irradiation of the material, in which case it must be determined at which level of irradiation, e.g. at which burn-up, the verification would cease. A disadvantage of such a minimalist approach would be that in such spent fuel there will be still a large fraction of plutonium or HEU which can be recovered by reprocessing. As long as there is confidence that all reprocessing and enrichment activities are declared, this might be considered sufficient, as the material would reenter the verification upon reprocessing.
However, this view omits completely the possibility of clandestine production at declared facilities. The level of assurance that none of this material is being used for banned purposes while not under safeguards is considerably smaller than that which is provided by full-scope safeguards in NNWS. Full scope safeguards are being applied in all nuclear facilities, including normal power reactors. There is hardly any possibility to detect undeclared reprocessing or enrichment at declared plants without material accountancy that includes spent fuel. If the principle of credibility of verification is to be taken seriously, the minimalist scenario is not sufficient. Even full-scope IAEA safeguards were deemed not sufficient for detecting undeclared production when Iraq's clandestine nuclear weapon program was discovered. The result was a substantial reform, namely the additional protocol INFCIRC/540. Table 3 in the appendix gives an overview on measures are attached to facility in full-scope safeguards, in this minimalist scenario, and the other scenarios which will be discussed in the following.

6.2 Verification scenario 2: verification of all direct-use material production

An example of a more thorough verification regime is one that would cover not only reprocessing and HEU enrichment plants but also nuclear reactors, and it would include not only separated but all direct-use material produced after EIF. In the above figure, these facilities are those whose product is unirradiated and irradiated direct use material, depicted by dark and lighter shade arrows (and). The verification therefore would be able to detect clandestine production of irradiated direct-use material, e.g. spent fuel from reactors. The materials must be followed downstream until the termination point of verification. In order to create a risk that diversion is detected, this termination point should be the moment when the material is practically irrecoverable, similarly as in NPT full-scope safeguards (INFCIRC/153: § 11), yet, the Agency is still provided with information (INFCIRC/540: § 2 (xiii)). As consequence, not only nuclear reactors but also storage sites, fuel conditioning and the input into reprocessing plants must be verified.

Similarly as in NPT full-scope safeguards, material accountancy will also be one of the most important elements of the verification of an FMCT. Therefore it is highly recommendable to design it in way that does not leave too many loopholes. This means that spent fuel produced after EIF should be included into the material accountancy. Otherwise, an untransparent reservoir could be created, and the verification regime would not be credible. However, opposition against this proposal has already been voiced and justified by too high costs. Frequent and regular visits of all light water reactors are indeed very costly. On-site inspections are the most expensive part of the verification. If all reactors in NWS would be inspected with the same frequency as in NNWS, the IAEA budget must raise substantially. As of January 1996, there were 226 power reactors under IAEA safeguards in NNWS and 211 power reactors not under IAEA safeguards in NWS.[10] Therefore, it should be considered whether a random inspection regime is feasible. Depending on the sensitivity of a reactor, different detection probabilities within a time interval should be assigned, and as consequence, inspections would take place with different frequencies. This would save costs and would still allow a relatively high detection probability.

Several categories of nuclear reactors must be distinguished according to their sensitivity:

7. Reactors that had been dedicated for the production of nuclear weapons and will now be used for civilian purposes,
8. reactors that had been dedicated for the production of nuclear weapons and that are now shut-down,
9. commercially used reactors that so far had not been submitted to safeguards. For them sub-categories must be determined according to the kind of fuel. As an example, research reactors using HEU might need more attention than ordinary light water reactors. It must also be decided whether there should be a power limit below which reactors are excluded or whether all reactors including critical facilities should be included.

The number of reactors of category 1 is about 7 to 10. They would require strong verification, e.g. an inspection regime on a regular basis. This would not be very expensive because of the small number of those reactors. The verification that reactors of category 2 are indeed shut-down is inexpensive. Reactors of category 3 could be verified with random inspections.

Nevertheless, material accountancy based on reports of all spent fuel produced after EIF should be established by the verification authority and followed downstream until the defined termination point of verification. Material accountancy will have to be implemented anyway nationally by each state. The new obligation for NWS and states outside the NPT would be to pass information on to the verification body. For this purpose, they must create SSACs similar to those in NNWS.

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[10] Harms/Rodriguez, footnote 7.

6.3 Verification scenario 3: verification of special fissionable material production

In an even more thorough and credible scenario, also verification of LEU production would be included. The major element would be material accountancy also of the LEU produced after EIF. In the above figure, these facilities are those whose product is all direct use material (and), and in addition those producing or using LEU (). States would declare all inventories produced after EIF. This means that at LEU enrichment facilities, not only design information would be verified, but also the complete material balance would be verified. An advantage would be the ability to detect diversion at LEU enrichment plants. The verification would follow the produced materials to storage, fuel fabrication and into reactors. As consequence, firstly the assurance against undeclared HEU production in a declared enrichment facility would be higher than in scenarios 1 or 2, secondly, the verification of the material balances at reactors can be completed because material accountancy will cover not only the output at reactors as in scenario 2. Instead, the consistency would be higher as also the input would be known. What is still lacking in comparison to full scope safeguards is high assurance against the diversion of source material, e.g. natural or depleted uranium, or thorium, in the figure illustrated by white arrows ().

7 Problematic facilities

The verification of an FMCT poses some specific problems because it will also take place in states possessing nuclear weapons. The problems stem from the fact that these states will wish to protect sensitive information that might arise as long as they do not completely disarm the nuclear arsenal. Also, some of these states might wish to protect information on their past activities. Secondly, as some of these states have never been subject to full-scope safeguards, some of their facilities have never been designed for them. Thirdly, some states might want to go on with the production of HEU for military naval reactors, and might want to protect sensitive information on these reactors.

7.1 Sensitive information at nuclear weapon facilities and secrecy on past activities

In military facilities, the problem can arise that the owners are reluctant to submit them to too intrusive a verification because too much sensitive information can be revealed. Such facilities could be former military production sites, maintenance facilities still in use, or dismantlement facilities for nuclear warheads. Maintenance facilities serve for refabrication of aged warheads, repair, technical evaluation and stockpile stewardship, and removal of tritium in aged plutonium. While closed facilities pose less problems for verification, verification inside maintenance and dismantlement facilities is unlikely to be acceptable for NWS. Some of these activities release indicators and traces that might look similar to clandestine production, e. g. purification of plutonium for refabricated warheads. It is understandable that many technical details of these activities cannot be revealed.
The sensitive information can be the following:

10. **The isotopic composition of nuclear materials:** In some NWS, this is still regarded as highly classified information. However, in case this information would be revealed, no additional proliferation danger would be created, because it is already generally known

that NWS prefer a high Pu-239 content for their weapons plutonium and a high U-235 content for their weapons uranium.

11. **The amount of material needed for one warhead:** it is also possible that at such sites material pieces or tools can be found that reveal the size of nuclear weapon components. This information is regarded as far too sensitive. An urgent task at such a facility is therefore the removal of such parts and tools as soon as possible in order to prepare it for the start of safeguards. This work, if necessary, is urgent anyway in order to minimise proliferation dangers.
12. **Design information of warheads:** in case a fissile material production facility or storage site is collocated with a warhead factory, even machinery for pit fabrication and conventional explosive ignition technology could be around. This kind of information is highly proliferation relevant and must therefore be accordingly protected. An urgent task for the owning state is therefore the physical separation of fissile material production, storage sites (at least those for future civilian material) and weapon manufacture sites, in order to prepare for future inspections.

It would be helpful if those states reconsider their classification policies, as there are large differences. However, this would be beyond the scope of FMCT negotiations, and that fact that there are limits must be accepted.

The first task when safeguards are initiated is verifying the design information of a facility. Too close integration of different illegal or sensitive legal activities might pose initial problems, but a timetable can be implemented until when the separation should be completed. This applies especially to former production facilities. Therefore, special managed access arrangements will be still necessary that protect the sensitive parts. Problems with such collocation in France and Britain do not exist because of the Euratom safeguards, but maintenance, americium removal from weapons plutonium or future dismantlement of warheads could cause similar problems.

Also transports of weapons and components to and from weapon dismantlement or refabrication facilities cannot be submitted to inspections. Although it is recommendable and probably possible to verify to a certain extent the dismantlement of warheads, this should be negotiated independently from the FMCT. The absence of illegal enrichment or reprocessing could still be verified to a certain degree of confidence from outside by environmental monitoring of effluents.

Therefore, the Treaty will need a provision for the exemption of such facilities from the general verification procedures and to replace them by special verification provisions which reduce the intrusiveness of on-site inspections and enhances the significance of containment and surveillance techniques with additional managed access provisions. Following categories could be distinguished:

13. Ordinary facilities included in the normal procedures as defined (cf. section 6: Three examples for verification scenarios).
14. Former military facilities now used for civilian production at which sensitive information can still be found: On-site inspections at such facilities might take place with less intrusiveness and special managed access provisions. As consequence, material accountancy in the interior might not be possible for a certain period. This period must be limited and declared in order to remove the sensitive information. But all exiting

materials must be accounted for and verified, and, depending on the extent of the verification agreed for other facilities, also all ingoing materials.

15. Former military facilities now closed at which sensitive information can still be found: The verification that no nuclear materials are being produced might be possible with containment and surveillance and additional observation from the outside for a limited period. It must be investigated how much managed access could be possible in case of strong suspicions. For this kind of facilities, design information and knowledge about past production is not necessary as long as the verification needs only to assure that no production takes place after EIF. This provision might be helpful to accede to the Treaty for those states that do not want to reveal past production.
16. Sites that store nuclear weapon materials produced prior to EIF. It is possible to verify from the outside by environmental monitoring that no production takes place.
17. Military nuclear weapon facilities not used for the production of nuclear materials such as refabrication or dismantlement factories: In NNWS, such facilities do not exist. Any verification activity inside of nuclear weapon factories will be very problematic and probably not possible. However, it is technically possible to monitor fences and verify their integrity. Environmental samples at the vicinity might help to create some assurance that no production of nuclear materials takes place. It is also desirable to implement some verification at the entrance and exit that the total amount of fissile materials transported, e.g. as warheads or warhead components, sums up to zero. [11] Details of such verification arrangements, however, probably lie beyond the limits of what is possible within the FMCT and must be subject to future nuclear arms control and disarmament negotiations.

The Treaty must contain a provision which allows states to declare all problematic facilities according to categories similar to the ones explained above. For each of them, verification arrangements and time scales must be negotiated individually, e.g. between the state and the verification body. However, some general limits and guidelines can be agreed upon before. There should be a provision for regular reviews and improvements of these arrangements. Interesting lessons can be learned from the *Trilateral Initiative* of the U.S., Russia, and the IAEA concerning the application of IAEA verification of weapon origin fissile materials.[12]

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11 There exist already some studies showing the principal possibility of verified warhead dismantlement without revealing intolerable design details: S. Fetter, V. A. Frolov, M. Miller, R. Mozley, O. Prilutsky, S. N. Rodionov, and R. Sagdeev, Detecting Nuclear Warheads, Science & Global Security, Vol. 1, p. 225-302, 1990. A report on an experiment on the verified dismantlement of nuclear warheads, undertaken by the United States Arms Control and Disarmament Agency in 1969, has recently been partly declassified: ACDA, Final Report: Field Test FT-34, Demonstrated Destruction of Nuclear Weapons (U), Jan. 1969. For a short summary of the results see: F. v. Hippel, The 1969 ACDA Study on Warhead Dismantlement, Science & Global Security, Vol. 2, p. 103- 108, 1991.

12 See contributions to Session 13: Verification Approaches For Released Weapon Material, IAEA Symposium On International Safeguards, Vienna, Austria, 13-17 October 1997.

7.2 Facilities not designed for safeguards

Special technical problems will be posed by facilities that had never been designed to take up safeguards. They do not have equipment that facilitates the taking of samples, e.g. measuring points that allow easy access, and it might happen that material balance areas are technically difficult to implement. Bookkeeping might have happened in very different ways than in NNWS, especially the necessity for taking physical inventories was not strong because there never was the need for international justification. Technically, it is much more difficult to implement such equipment and installations afterwards than to implement them already while the facility is designed and constructed. In addition, there are states that do not have legal bodies comparable to SSACs of IAEA standards.

Steps that must be taken include the implementation of regulations containing technical, organisational, and reporting requirements for material control and accountancy, implementing the interaction between the tasks in a facility and the SSAC, measurement systems at facilities, preparing the implementation of the according regulations, training of personnel, and the transition from the old to the new system. There are many problems that must be overcome, not only the well known financial shortages but also those of organisational nature. However, the necessity for these steps are not disputed, and the work has begun already independently from the FMCT.

Because of these problems, it must be expected that certain time scales after entry into force will be necessary for the implementation of the verification. In the Treaty text, states should be able to declare such facilities. It must be expected that material accountancy and its verification according to the agreed standards might not be possible for a while. Measures acceptable for a start and time tables for improvement must be agreed individually.

However, it is strongly recommendable to specify the timetables. Treaty language like the rather vague "as soon as practicable" could delay success indefinitely. It would be more advisable to negotiate a protocol for timetables for specific steps, perhaps combined with technical collaboration programs between states, the IAEA, Euratom or other SSAC agencies. This is a challenge but not an insurmountable obstacle.[13] A similar though smaller effort was necessary for the implementation of full-scope safeguards in South Africa. Britain brought a large reprocessing plant (B205) under Euratom safeguards some 20 years after it was designed. Although the safeguards applied there might not meet IAEA criteria, Euratom is satisfied that it can verify non-diversion from the plant. It would be worth a study how the UK brought B205 under safeguards and draw conclusions for other problematic facilities.[14]

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[13] The IAEA assesses itself well prepared for this task. Thorstensen, Fissile Material and Verification – IAEA Capability and Infrastructure for Verification of Fissile Material, Presentation at the Cut-Off Convention Workshop, Toronto, Canada, 17-18 January 1995.

[14] Communication with W. Walker.

7.3 Naval fuel

Another problem can arise when some states want to keep the option to produce HEU for naval fuel. It should be considered whether the large stocks of HEU already existing would not be sufficient for this purpose, or whether it is not possible to convert naval reactors to lower enriched fuel, similar as is currently being done with civilian research reactors.
Also NNWS are allowed to possess military HEU for nonexplosive purposes without safeguards as long as it is not used for nuclear explosives although this has not happened so far. In INFCIRC/153 (§14b), it is foreseen that verification of fuel in a "non-proscribed military activity" is renounced as long as the nuclear material is in such an activity. The Agency and the State shall make an arrangement that identifies "to the extent possible, the period or circumstances during which safeguards will not be applied". This implies that it is not clearly defined so far under which conditions safeguards of fuel are interrupted. The interruption could be limited only to fuel in the reactor, or it could also be applied to specific naval fuel storage sites. "In any event, the safeguards provided for in the Agreement shall again apply as soon as the nuclear material is reintroduced into a peaceful nuclear activity."
In case the option for the production of new HEU naval fuel will be kept open, starting and termination points of verification should be defined more precisely than in INFCIRC/153. Facilities and locations involved are the enrichment plants, fuel fabrication plants, transports, storage, and the reactors themselves. The fuel elements seem to be a highly classified secret. Nevertheless, the verification should follow the HEU until the insertion into the reactor. At the fuel factories, the fuel storage sites, and the transports, special managed access provisions should be worked out, e.g. using containers, tags, and seals.

8 Organisation

For many typical facilities, it is possible to work out standard criteria affecting the extent and quality of information to be provided by states, design information verification activities, specific requirements related to inspection frequencies, inspection activities, and outcome of such activities. But as there will be many different categories of facilities and many technical variations, the negotiations would be overburdened if all details were to be negotiated for the Treaty text.
In any case, there should be a provision to allow for the inclusion of technical improvements, similarly as in IAEA safeguards. The IAEA has an advisory group, the Standing Advisory Group on Safeguards Implementation (SAGSI), that has developed and updates fixed safeguards criteria. A similar or the same group should also be implemented for the FMCT.
However, the treaty will have to deal with unique facilities that will pose special problems. The technical equipment for these facilities must be worked out individually, and compromises will be necessary.
Because of the many technical similarities and its unique expertise and experience, the IAEA should be tasked with the verification.

The preparation of the verification should start as fast as possible. A very urgent task is to study the costs of the verification in detail. So far, there have been a few costs studies,[15] that have been used in FMCT discussions. The IAEA should be tasked to work out an elaborate study that includes several cost saving options, e.g. random inspections or work sharing with regional verification organisations such as Euratom.
A second urgent task is the technical study of verification difficulties specific to the FMCT, e. g. procedures at the problematic facilities described in section 7. Therefore it is recommended to set up an expert group composed of IAEA safeguards specialists and experts from the facilities affected. This expert group could work parallel to the negotiations. Care should be taken that a frequent exchange between the group and the CD takes place.
Similar as in the case of the CTBT, it is recommendable to implement a Preparatory Commission (PrepCom). This PrepCom should be set up within the IAEA. Its tasks should be to work out the organisational framework and technical details, to study specific problems and to assist states in implementing legal, organisational, and technical prerequisites. The goal should be to be prepared so that after EIF, the verification could resume its work as soon as possible.

[15] see footnote 2; and Piet de Klerk, Verification: Technical Dimensions and Costs, Presentation at the seminar on "Breaking ground on a Fissile Material Cut-Off Treaty", Munich, 23-25 July 1999.

9 Appendix: IAEA definitions

Direct-use material: *Nuclear material that can be used for the manufacture of nuclear explosives components without transmutation or further enrichment, such as Pu containing less than 80% Pu-238, HEU and U-233. Chemical compounds, mixtures of direct-use materials (e.g. MOX) and plutonium contained in spent nuclear fuel also fall into this category. Unirradiated direct-use material would require less processing time and effort than irradiated direct-use material (contained in spent fuel).* (from the IAEA Safeguards Glossary 1987)

Special fissionable material: *"Pu-239, U-233, uranium enriched in the isotopes 253 or 233; any material containing one or more of the foregoing; and such other fissionable material as the Board of Governors shall from time to time determine; but the term `special fissionable material does not include source material."* (Statute of the IAEA, Art. XX.1)

"Inventory change" means an increase or decrease, in terms of batches, of nuclear material in a material balance area; such a change shall involve one of the following:

(a) Increases:

(i). Import;

(ii). Domestic receipt: receipts from other material balance areas, receipts from a non-safeguarded (non-peaceful) activity or receipts at the starting point of safeguards;

(iii). Nuclear production: production of special fissionable material in a reactor; and

(iv). De-exemption: reapplication of safeguards on nuclear material previously exempted therefrom on account of its use or quantity.

(b) Decreases:

(i). Export;

(ii). Domestic shipment: shipments to other material balance areas or shipments for a non-safeguarded (non-peaceful) activity;

(iii). Nuclear loss: loss of nuclear material due to its transformation into other element(s) or isotope(s) as a result of nuclear reactions;

(iv). Measured discard: nuclear material which has been measured, or estimated on the basis of measurements, and disposed of in such a way that it is not suitable for further nuclear use;

(v). Retained waste: nuclear material generated from processing or from an operational accident, which is deemed to be unrecoverable for the time being but which is stored;

(vi). Exemption: exemption of nuclear material from safeguards on account of its use or quantity; and (vii). Other loss: for example, accidental loss (that is, irretrievable and inadvertent loss of nuclear material as the result of an operational accident) or theft.

(INFCIRC/153, 107)

"M*aterial balance area* " means an area in or outside of a facility such that:

a) The quantity of nuclear material in each transfer into or out of each "material balance area" can be determined; and

b) The physical inventory of nuclear material in each material balance area" can be determined when necessary, in accordance with specified procedures, in order that the material balance for Agency safeguards purposes can be established .

(INFCIRC/153, 110)

Design information made available to the Agencyshall be used for the following purposes: ...To determine material balance areas to be used for Agency accounting purposes and to select those strategic points which are key measurement points and which will be used to determine the nuclear material flows and inventories; in determining such material balance areal the Agency shall, inter alia, use the following criteria:

(i). The size of the material balance area should be related to the accuracy with which the material balance can be established;

(ii). In determining the mater al balance area advantage should be taken of any opportunity to use containment and surveillance to help ensure the completeness of flow measurements and thereby simplify the application of safeguards and concentrate measurement efforts at key measurement points;

(iii). A number of material balance areal in use at a facility or at distinct sites may be combined in one material balance area to be used for Agency accounting purposes when the Agency determines that this is consistent with its verification requirements; and

(iv). If the State so requests, a special material balance area around a process step involving commercially sensitive information may be established;

(INFCIRC/153, 46(b))

10 Appendix: Table 3 – Comparison of several examples of verification scenarios

Type of facility, activity	**Potential roles for nuclear weapons acquisition**	**IAEA Safeguards under NPT**	**Verification scenarios under FMCT**		
			Scenario 1: include only separated direct-use material production	Scenario 2: include all direct-use material production	Scenario 3: include also all special fissionable material
U mining and ore processing	Results in uranium concentrates, *first step* leading to fuel or HEU production; U ore can be found in many sites all over the world	INFCIRC/153: none, exports and imports reported (§ 33) 93+2: General reports to the IAEA	None		
U refining and conversion	Purification, conversion into UF6 as feed material for enrichment (second step)	INFCIRC/153: safeguards start, when the process is finished (§ 34) 93+2: General reports to the IAEA	None		
U enrichment to LEU	Potential for fabrication of HEU from less enriched U, but mostly used for fabrication of LEU for reactors, further enrichment of LEU is easier than starting with natural U, *diversion risks*	Infcirc/153: The extent of safeguards, e.g. the actual number, intensity, duration, timing and mode of routine inspections and other measures depend on the inventory, chemical and isotopic composition and annual throughput of nuclear material. 93+2: enhanced reporting, environmental samples, complementary access, managed access ...	Verification limited to design verification which means to create assurance that no HEU production takes place		Design verification + all other verification measures including material accountancy
Reconversion	Chemical process to fabricate ceramic U-Oxide from enriched UF_6 , *diversion risks*		None		
LEU fuel fabrication	Fuel elements from U-Oxide for nuclear reactors, many variations, *diversion risks*		None		
U enrichment to HEU	Production of HEU, directly weapons usable, *diversion risks*	INFCIRC/153: More intrusive than in case of lacking direct use material. The extent depends on the inventory and annual throughput. 93+2: enhanced reporting, environmental samples, complementary access, managed access ...	All verification measures, including material accountancy		
Reconversion	Chemical process to fabricate ceramic U-Oxide from enriched UF_6 , *diversion risks*				
HEU fuel fabrication	Directly weapons usable fuel, *diversion risks*				

<table>
<tr><th rowspan="2">Type of facility, activity</th><th rowspan="2">Potential roles for nuclear weapons acquisition</th><th rowspan="2">IAEA Safeguards under NPT</th><th colspan="3">Verification scenarios under FMCT</th></tr>
<tr><th>Scenario 1: include only separated direct-use material production</th><th>Scenario 2: include all direct-use material production</th><th>Scenario 3: include also all special fissionable material</th></tr>
<tr><td>Irradiation in nuclear reactors</td><td>Produces spent fuel containing: rests of unfissioned *U, Pu*, fission products; risk of *additional undeclared production and diversion*
In fast breeders, *weapon grade Pu* production</td><td rowspan="4">Infcirc/153: The extent of safeguards, e.g. the actual number, intensity, duration, timing and mode of routine inspections and other measures depend on the inventory, chemical and isotopic composition and annual throughput of nuclear material.

93+2: enhanced reporting, environmental samples, complementary access, managed access ...</td><td>Termination point of verification</td><td colspan="2" rowspan="4">Verification, including material accountancy and random inspections</td></tr>
<tr><td>At-reactor spent fuel storage</td><td>*Diversion risks*</td><td rowspan="3">None</td></tr>
<tr><td>Away-from-reactor spent fuel storage</td><td>*Diversion risk*s</td></tr>
<tr><td>Conditioning of spent fuel</td><td>After about 50 years cooling, e.g. decay of many fission products, preparation for final disposal, *diversion risks higher* because of lower radioactivity</td></tr>
<tr><td>Final disposal of spent fuel</td><td>At present, no operating final repository, but several under study. *Diversion risks* would be much *smaller*.</td><td>INFCIRC/153: safeguards cease when the material is practicably irrecoverable (§ 11, 35)
93+2: provision of information</td><td>None</td><td colspan="2">Termination of verification</td></tr>
<tr><td>Heavy water production</td><td>Heavy water reactors can be fueled with natural U, thereby rendering unnecessary the enrichment technology for the production of spent fuel (for *Pu acquisition*) which otherwise would be a prerequisite.</td><td>INFCIRC/153: none
93+2: provide the Agency with information</td><td colspan="3">None</td></tr>
<tr><td>Other: R&D, equipment, …</td><td>Research and development, technical components and plants without nuclear material, locations outside facilities, closed down or decommissioned facilities
Potential preparation for acquisition</td><td>INFCIRC/153: none
93+2: provide the Agency with information or make any reasonable effort to do so</td><td colspan="3">None</td></tr>
</table>

Type of facility, activity	**Potential roles for nuclear weapons acquisition**	**IAEA Safeguards under NPT**	**Verification scenarios under FMCT**		
			Scenario 1: include only separated direct-use material production	Scenario 2: include all direct-use material production	Scenario 3: include also all special fissionable material
Spent fuel reprocessing	Alternative to final disposal: separate the Pu and unfissioned U from spent fuel (by chemical methods in combination with radiation protection technologies). Results in separated *Pu = direct use material*. *Diversion risks*	INFCIRC/153: More intrusive than in case of lacking direct use material. The extent depends on the inventory and annual throughput. 93+2: enhanced reporting, environmental samples, complementary access, managed access ...	Starting point of FMCT verification, all verification measures, including material accountancy and random inspections	All verification measures, including material accountancy and random inspections, additionally consistency control accountancy from the reactors at which the spent fuel has been produced	
MOX fuel fabrication	Fuel in which some of the fissile U-235 in U is replaced by fissile Pu. As long as not irradiated, this counts as unirradiated direct-use material. Contents depending on reactor type. *Diversion risks*		All verification measures, including material accountancy		
Irradiation of MOX in nuclear reactor	Irradiated direct-use material, must be reprocessed to get the plutonium. *Diversion risks*		Termination of verification	All verification measures including material accountancy of spent fuel produced	

11 Appendix: Abbreviations

AVLIS	atomic vapour laser isotope separation
CD	Conference on Disarmament
CTBT	Comprehensive Test Ban Treaty
EIF	entry into force
EMIS	electromagnetic isotope separation
EU	European Union
Euratom	European Atomic Energy Community
FMCT	Fissile Material Cutoff Treaty
HEU	highly enriched uranium
IAEA	International Atomic Energy Agency
INFCIRC	Information Circular of the IAEA
INFCIRC/66	model agreement between NWSs and the IAEA for voluntary safeguards
INFCIRC/153	model agreement between NNWSs and the IAEA for full scope safeguards
INFCIRC/193	agreement between Euratom, NNWSs, and the IAEA for full scope safeguards
MLIS	molecular isotope separation
MOX	mixed oxide fuel
NNWS	non-nuclear weapon state that is member of the NPT
NPA	New Partnership Approach between Euratom and the IAEA (1992)
NPT	Nuclear Nonproliferation Treaty
NTM	national technical means
NWS	nuclear weapon state as defined in the NPT
Pu	plutonium
PUREX	plutonium and uranium recovery by extraction
SAGSI	Standing Advisory Group on Safeguards Implementation
SSAC	State’s System of Accounting for and Control of nuclear material