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# FMCT VERIFICATION: CASE STUDIES*

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## Abstract

A primary goal of an FMCT will be to have the five declared nuclear weapon states and the three that operate unsafeguarded nuclear facilities become parties. One focus in negotiating the FMCT will be verification. Most importantly, FMCT verification would focus, in the first instance, on these former military fissile material production facilities. After the FMCT enters into force, some of these facilities would continue operating to produce civil nuclear power or to produce fissile material for non-explosive military uses. However, most of these production facilities would be shut down. Thus, one important task of the FMCT verifications will be to confirm the status of these closed facilities. How to manage the trade-off between the need for transparency and the concern about the disclosure of sensitive information would be a key issue during the negotiations of FMCT verification provision. As case studies, this paper will demonstrate what verification measures might be applied to those shutdown reprocessing and enrichment plants.

## FMCT Verification: General Consideration

A universal fissile material cutoff treaty (FMCT), which bans the production of fissile material for nuclear weapons, has long been seen as a key building block in nuclear disarmament and nonproliferation. There remains strong support for the prompt negotiation and conclusion of an FMCT, as demonstrated by the 2000 NPT Review Conference's call for the CD to commence negotiations immediately with a view to their conclusion within five years [1]. A primary goal of an FMCT will be to have the five declared nuclear weapon states and the three that operate unsafeguarded nuclear facilities become parties. One focus in negotiating the FMCT will be verification. Verification measures must be seen as efficient and effective, but must also be politically acceptable.

The scope of verification will depend on the facilities and activities subject to an FMCT. In principle, all facilities and activities that could be used to produce or divert weapon-usable fissile material for weapons would be subject to FMCT verification. However, the scope of verification is open to negotiation, and many options have been proposed [2]. The proposed scope ranges from focused verification to wide verification. Focused verification would concentrate on only sensitive fissile material production facilities, i.e., reprocessing and enrichment facilities, and fissile materials produced after an FMCT enters into force along with the facilities where these materials are present. A wide-scope approach would also cover

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a variety of less sensitive civil facilities such as fuel fabrication plants and civilian power reactors. It is believed that a focused approach would be most likely feasible.

FMCT verification will have to cover the following three classes of facility: declared shutdown production facilities; declared operating fissile material production facilities; and undeclared production facilities. The verification objective for a cut-off treaty--to assure that no fissile material is being produced for weapons--is similar to the objective of existing IAEA nuclear safeguards in non-nuclear weapon states (NNWS) that have ratified the nuclear Non-Proliferation Treaty (NPT). The basic FMCT verification measures will include: safeguards at declared facilities similar to those administered by the IAEA; non-routine inspections involving managed access; environmental monitoring, and remote sensing involving satellite imagery. Appropriate verification measures should be applied in each case.

Most importantly, FMCT verification would focus, in the first instance, on those former military fissile material production facilities in the eight target states. The FMCT verification system for those former military facilities in the eight target states would have to be different from the IAEA safeguards verification for NNWS. For IAEA safeguards verification, the main target nations are NNWS, and these states have confirmed that their nuclear facilities will not produce fissile material for weapons or unsafeguarded purpose not only in the future but also in the past. Then the IAEA can mainly use on-site safeguards verification measures that could be very intrusive. In principle, these states' nuclear facilities are with very high political tolerability. However, for the eight nuclear nations, an FMCT is likely to permit their holding of undeclared stockpiles (from past production) and their using or processing of already produced fissile material for sensitive military activities (such as the assembly of nuclear weapons). These allowed sensitive production facilities and activities could be collocated with facilities (such as reprocessing and enrichment plants) requiring verification. Thus, some nuclear states could worry about potential loss of sensitive information at those defense-related nuclear processing sites. Furthermore, some nuclear facilities whose original goal are for the military production could be not established following the requirement of IAEA safeguards, so their military classified levels might be lower. Eventually, some on-site safeguards and environmental sampling might be seen as too intrusive and might not be permitted. Thus, effective but less intrusive verification measures may be needed.

## Verification of Shut-Down Reprocessing Plants

After the FMCT enters into force, all those former military production facilities should be declared. Some would continue operating to produce civil nuclear power or to produce fissile material for non-explosive military uses. For these operating facilities, the verification measures necessary for these facilities would be primarily strengthened IAEA safeguards, as currently being applied to NNWS under the NPT. And it is expected that the activities safeguarding such operating facilities will require most of the resource available for the FMCT verification. However, most former military facilities would be shut down. Thus, one important task of the FMCT verifications will be to confirm the status of these closed facilities. To provide assurance that no operations are carried out in these shutdown reprocessing plants, verification activities will include on-site inspections ,the use of seals, surveillance or monitors on critical plant equipment[3], environmental sampling and remote sensing. The application of the verification methods would depend on the status of the plant ( such as operational stand-by, or being decommissioned) and plant-specific design features.

**Remote sensing and off-site samplings.** For satellite monitoring of the status of a reprocessing plant, the most likely observable characteristics would be the activity level. When a large reprocessing plant is operating, there will be many shipments of various forms of nuclear material[4]. If the plant is closed, these activities level should be very low or absent. For example, there should be no shipments moving at the railroad cask portals (the portals for rail-mounted shipping casks from the reactor), no activity at the shipping dock (loading point for plutonium product), and no activity at the cold feed loading point (reprocessing requires a periodic feed of fresh chemicals). For these activities, transport vehicles, such as trucks, should be big enough to be detected by 1m resolution images from satellites[5]. Similarly, the activity level at a medium scale reprocessing plant should be monitorable. However, there would be too difficult to monitor the cases of using underground transport tunnel between reactors and reprocessing plants or the reactor connected with the reprocessing facilities. In addition, shipments could be made at night. Other preferred off-site verification could include: off-site sampling of nuclear and chemical effluents such as krepton-85.

**On-site verification.** However, some kinds of on-site inspections will be required to verify that the reprocessing plant is shutdown. For example, on-site visual observation would show there is no activities at the spent fuel cask portal. In some cases, sealing essential plant equipment or using sensors would detect its operation. On-site sampling would reveal the undeclared activities.

To monitor the status of a reprocessing plant, one important and effective verification means would be on-site environmental sampling[6]. The samples could be taken from gloveboxes in the plutonium product processing sectors, which could allow a determination of the burn-up of the spent fuel, plutonium isotopic composition, and the time since separation of the plutonium. Another effective approach to detect undeclared reprocessing activities would be for inspectors to take samples from high-level waste(HLW) was HLW tanks or the areas contampted by HLW, which would for recent plutonium production activities, determine the important quantities--the burn-up of spent fuel, plutonium isotopic composition ,the irradiation time and discharge time to reasonable accuracy through measurements of ratios of fission product and actinide isotopic ratios. This will help confirm the status of the plant.

However, at the same time, some target states may worry that on-site sampling analysis could disclose sensitive information about their past plutonium production activities, such as the power level at which production reactors had operated and how much plutonium they had produced, data that will probably not have to be declared under an FMCT. Could the sampling activities also reveal the quantity of plutonium produced prior to the FMCT? First, although the plutonium isotopic composition would be an important warning signal of new production of plutonium after an FMCT comes into force, plutonium isotopic composition and burn-up of spent fuel should not be considered sensitive information for target states' past production activities (However, some countries could take it as sensitive information. Such as, Russia still regards this data as highly classified[7]). This is because, it is already assumed that much of the plutonium that produced in the past was for weapons use. This is in contrast to the case of non-nuclear weapon states and all states after the conclusion of an FMCT. Furthermore, the design and size of nuclear weapons is not sensitive to the exact isotopic composition of the plutonium used[8]. Secondly, estimations of discharge time, irradiation time and Burn-up will not, by themselves, allow a determination of total plutonium produced in the past without additional information, such as the power of a reactor or the mass of the fuel in a reactor core.

Thus, the power of past production reactors and the mass of the fuel in the reactor core are sensitive information for a country that wishes to conceal the quantity of plutonium in its military stockpile. These two quantities could be concealed for shutdown production reactors. Similarly, the total quantity of Cs-137 and Sr-90 in the HLW would be considered sensitive, since knowledge of these quantities would allow estimation of total plutonium production. This means that inspectors could not be permitted to measure the total volume of HLW (whether in liquid or sludge form).

Consequently, we find that sampling analysis at reprocessing plants need not reveal sensitive information relating to past plutonium production at former military plutonium production facilities. Sampling cannot be used to discover such information as long as inspectors are not able to measure total quantities of Cs-137 and Sr-90 from HLW produced at former military plutonium production facilities. Sampling methods at reprocessing plants can therefore serve as an effective and militarily non-intrusive measure for verification of an FMCT. States that do not wish to reveal the quantities of military plutonium that they have produced need not worry about such on-site sampling analysis and should be willing to permit a verification agency to conduct it.

One major concern about the on-site verification of some former military reprocessing plants could be the issues of collocated facilities. Under the FMCT, the nuclear-weapons-related activities at some reprocessing sites, such as the processing of plutonium and HEU produced in the past into metal, the fabrication of weapons components and the finial assembly of weapons, all these sensitive activities should be permitted and continued. Some sensitive information, for example, chemical composition information from these activities might be divulged through sampling and analysis around the facilities. Therefore, it is necessary to explore whether conducting on-site sampling around reprocessing facilities could also get such sensitive information, which might depend on how far away such information is detectable from the sensitive manufacturing facilities and how close such facilities to the reprocessing plant. For such collocated sites, managed access approach will be vital to the FMCT verification.

## Verification of Shut-Down Uranium Enrichment Facilities

All known uranium enrichment plants in eight target states are either gaseous diffusion or gas centrifuge enrichment plants(CEP). However, research and development (R&D) on laser enrichment is well advanced in a number of countries. Under an FMCT, it can be expected that most military gaseous diffusion plants (GDPs) would be shut down, because they are energy inefficient and therefore much more costly to operate than uranium centrifuge enrichment plants with which they are being replaced[9].

**Satellite imaging**. A GDP cannot operate without a cooling system because it consumes huge amounts of electrical energy and more than 90 percent of the electrical energy is converted into compression heat which is dissipated by cooling towers or into a local water body via cooling water. Most GDPs, other than those in Russia, have wet cooling towers, such as the three US GDPs (at Oak Ridge, Paducah and Portsmouth) and China's GDP (at Lanzhou) use mechanical draft cooling towers. The UK's GDP at Capenhurst uses a natural draft cooling tower.

One of the telltale signature of the GDP operation should be the water-vapor plume coming from the cooling tower[10]. When the cooling tower is operating, a water-vapor plume will ordinarily be seen emerging from its top. The air is almost saturated after it passes through

wet packing at the base of the tower and cools as it rises through the tower. It is therefore slightly supersaturated when it emerges. Downwind from the tower the air mixes with cooler ambient air resulting in a mix which is more supersaturated. How far downwind the mix remains supersaturated depends upon the relative humidity of the ambient air. The plume will be easy to detect with 1m-resolution satellite images at visible band. Because of their large inventory of in-process $UF_6$, the time required for a GDP producing 90% U235 to reach equilibrium is about two to three months. A satellite revisit time of several days and 1m resolution should therefore be adequate for detection of GDP operation.

Another important signature of the GDP operating would be the hot roof of the enrichment buildings[11]. Most of the waste heat from a GDP is discharged from its cooling towers. However, since the temperature in the spaces housing the cascades must be kept much higher than that of ambient air, this is because the lowest $UF_6$ temperature in a GDP must be safely above the $UF_6$ condensation or freezing temperature. Consequently, the air temperature in the areas containing the compressors are typically much higher than the outdoor temperature[12]. Thus, the roof above can be expected to be much hotter than ambient air when the GDP is operating. Because of the large area of GDP processing buildings, the elevated temperature of their roofs would be detectable using commercial satellite thermal infrared (TIR) images. Based on our analysis of the Landsat-5 thermal infrared satellite images of US Portsmouth GDP, indeed the hot roof of the reprocessing buildings can be detected by the TIR[13].We also found that the new satellite TIR such as Landsat-7 and ASTER satellite should be able to detect the hot roof of the medium GDPs, such as China's GDP at Lanzhou, United Kingdom's Capenhurst and France's Pierrelatte GDPs once they are operating. In short, the shutdown status of the GDPs should be able to be monitored effectively using satellite images at visible band and thermal infrared band. This approach would be the least intrusive. It should be easily accept by the target countries.

Monitoring a small CEP, such as that operated by Pakistan at Kahuta, would, however, be much more difficult. There are few observable operating signatures for VNIR images. Because of their small size and relatively low energy intensity, these plants do not require special cooling systems such as cooling towers. A recently released 1m resolution IKONOS image of the Khuhuta CEP provides much more detail than the 10m resolution SPOT images did[14]. The enrichment buildings at south and north production area are clearly seen. But there is no visible operational evidence in the image. Also the TIR imaging system on current generation commercial satellites could not measure the roof temperature increase associated with their operation. Verification of the shutdown status of these nuclear facilities with few visible and thermal signatures would most likely require other less- intrusively monitoring measures.

**On-site inspections.** To further confirm the shutdown status of the GDP, some on-site inspections would be required, including 1) site visual observation, such as no plume from the cooling towers, no treatment of cooling water, no electrical service for the enrichments, not hot and not noisy inside the enrichment building. 2)continuous surveillance monitor and tamper-proof seal, such as, sealing the high-voltage disconnect switches; sealing the valves on the supply and return headers of the Recirculating Cooling Water system; sealing the inlet and outlet block valves for the cascade piping; putting vibration and or/temperature sensors on the process equipment.

The major concerns on such site would be the diffusion barrier technology information that most countries take it as industrial secrets. However, this would be easily protected by some prevent measures. Finally, environmental sampling at the site would release the composition

of the feeds, products and tails of uranium, which could provide information to further estimate the amount of HEU produced by the plant. It is not clear whether each target state would take such information sensitive. However, sampling is not needed to confirm the GDP shutdown status.

## Detection of Undeclared Nuclear Facilities

FMCT verification regime would have to be design to detect undeclared nuclear facilities, such as reprocessing or enrichment facilities. Such verification measures could include non-routine inspections including challenge inspection. However, some countries would be unwilling to see the abuse of such kind of inspections at its sensitive and non-proscribed military and nuclear activities. To protect its national security sensitivities, it is essential to have an appropriated manages access mechanism which should be able to realize the aim of FMCT verification as well as not compromising the national security interests.

To detect and identify undeclared nuclear facilities, the FMCT verification measures including satellite imagery, on-site visit, location-specific or wide-area environmental sampling could be applied. All these verification measures would be synergistic in an effective and efficient FMCT verification system. Based on analysis on recently available 1m-resolution commercial satellite images of nuclear facilities, it can be expected that the high-resolution satellite images can be used to detect and identify the undeclared nuclear facilities through their characteristic visible features[15]. Moreover, the construction activities of the undeclared nuclear facilities could be detected using satellite imagery. As a potential FMCT verification tool, commercial satellite imagery could provide the targets for on-site inspections and environmental sampling; The satellite imagery could also be used to confirm information acquired by the agency from other sources. Before conducting a challenge inspection, it is necessary to investigate and confirm such information, especially when the suspect facilities are within or near a sensitive site.

Making final decisions on the clandestine nuclear facilities will have to require some on-site inspections. If the suspected reprocessing or enrichment facilities are within collocated or other sensitive military sites, managed access approach will be vital to FMCT verification. For most cases of managed access situations, simple procedures are sufficient. For example, the undeclared facilities and activities would be detected by sampling around the site (without accessing to the inner of the buildings or the appropriated control security fences) through their signatures in the effluents such as fission products from reprocessing and HEU from enrichment activities. However, in some location, measures would have to taken to prevent overt or covert sampling. Such as, at the fissile material manufacturing facilities, chemical composition information—the sensitive information could be divulged through sampling and analysis. In some cases where it will be essential for inspectors to have access areas with classified activities, appropriated measures would have to employed to protect sensitive information. For example, at the nuclear weapons assembly facility, the sensitive information -- weapons component, or process machinery that provided design information-- might be vulnerable to the visual access. Thus it had to take measures including shrouding and masking of sensitive equipments or other obvious method to prevent the visual access.

## Conclusion

FMCT verification would focus in the first instance on the former military nuclear production facilities. The FMCT verification system for former military facilities would have to differ in some ways from traditional IAEA safeguards. Effective but less intrusive verification measures may be needed.

Verification measures including remote sensing, off-site environmental sampling and on-site inspections would be applied to monitor the shutdown status of plutonium production facilities. One effective verification measure would be on-site environmental sampling. Meanwhile some countries may worry that sample analysis could disclose sensitive information about their past plutonium production activities. However, we find that sample analysis at the reprocessing site need not reveal such information. States that do not wish to reveal the quantities of military plutonium that they have produced need not worry about such on-site sampling analysis and should be willing to permit a verification agency to conduct it.

The GDPs would be monitored effectively by satellite imagery. This approach would be the least intrusive. As one telltale operational signature of the GDP would be the water-vapor plume coming from the cooling tower, which should be easy to detect with satellite images at visible band. Also the hot roof of the enrichment building would be detectable using satellite thermal-infrared images. Furthermore, some on-site verification measures should be applied, such as visual observation, surveillance and tamper-indicating seals. In short, under the FMCT, appropriate verification measures would be able to verify the status of shutdown reprocessing and enrichment facilities without compromising national sensitive information.

Finally, FMCT verification regime would have to be designed to detect undeclared fissile material production activities and facilities. These verification measures could include something like special or challenge inspections or complementary access. There would need to be provisions to prevent the abuse of such inspections, especially at sensitive and non-proscribed military and nuclear activities. In such cases, managed access approach would be vital to FMCT verification.

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