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ENVIRONMENTAL SAMPLING: ISSUES FOR THE CUT-OFF REGIME

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Introduction

The fissile material cut-off treaty (FMCT) initiative under the Conference on Disarmament mandate is envisioned to include certain aspects of environmental sampling and monitoring. One of the intents of this treaty is to bring certain non-NPT signatories (*e.g.*, threshold states) under this treaty agreement along with the nuclear weapon states (NWSs). Because this treaty includes NWSs which have had a significant history of weapons-grade materials production, background problems must be considered. Similar problems may come into play for some non-nuclear weapon state (NNWSs) non-NPT signatories.

This paper provides a brief overview of some of the relevant issues that may be involved in the implementation and use of environmental monitoring for 1) verification of the cut-off regime declarations, 2) the detection of undeclared activities, and 3) application in non-routine inspections. The intent is to provide backstopping information important for treaty negotiators.

Specific issues addressed within this paper include signature sampling, differences in the proposed detection regime, potential signature integrators, specific examples and spoofing concerns. Many of these issues must be carefully considered and weighed in order to create a credibly verifiable inspection regime. Importantly, the cut-off treaty must enable nondiscriminatory implementation, while carefully assuring that nonproliferation treaty requirements are maintained (*i.e.*, preventing unintentional release of critical weapons design information — potentially through environmental sampling and analysis).

Environmental Monitoring

The technical feasibility of environmental monitoring (EM) for the detection of and confirmation of nuclear-related activities has been demonstrated by the International Atomic Energy Agency (IAEA) under “programme 93+2.” Several US facilities and several countries participated in the field trials, providing facility field sampling access or field training. The potential value of EM for confirmation of Signatories’ activities and detection of undeclared activities or facilities is tremendous. The impact of EM is not only due to the enhanced detection probabilities, but also the concomitant increase in confidence among other signatories in each other’s declarations through this independent confirmation technique.

However, within both the NPT and the FMCT regimes, environmental monitoring only increases the probability of detection of undeclared activities at declared, undeclared or clandestine facilities. It must be remembered that although EM is a powerful analysis tool, other tools are necessary (*e.g.*, safeguards or other technical means). In addition, specific signatures that may be detected are rarely a “smoking gun.” Thus, to attain a high confidence necessary to warrant either “special inspections”

[NPT signatories] or “non-routine inspections” [as envisioned under the FMCT], additional multiple confirmatory tools are required.

Environmental Sampling

One of the keys to environmental monitoring is the extensive history of sampling methodology development. The actual implementation of environmental sampling is quite important to the analysis of the site samples. This methodology involves specific “clean” handling procedures designed to assure sample integrity and to ensure against sample contamination (critical elements within any EM program implementation).

Sampling locations can range from “intrusive” (IAEA-type safeguards) to on-site (*e.g.*, building interior/exterior) to perimeter (“at fence”) to remote. For each sampling location, the level of detection sensitivity and confidence generally scales with distance (*i.e.*, the closer the sampling, the greater the probability of detection and, hence, the greater the confidence of declarations). Note that for some signature sources, for example, gaseous releases, that the optimal detection distance can vary significantly depending upon specific atmospheric conditions.

Environmental sampling can include swipes, soils or sediments, waters (*e.g.*, drainage, holding ponds, waterways), vegetation (such as, leaves, pine needles or tree cores), particulates, noble gases, organic volatiles and others. Each of these sample-types have different specific characteristics which can lend themselves to different types of analysis and signatures.

Some signatures of interest and their most relevant nuclear activity indicator include (see previous signature paper within this volume for additional details);

- noble gases (radioactive and non-radioactive) ⇒ reprocessing, reactors
- radionuclides (short- / long-lived) ⇒ reprocessing, reactors
- volatile gases (organics / radiolytic decomposition) ⇒ reprocessing, fabrication
- plutonium / uranium / americium (abundance and isotopics) ⇒ enrichment, reprocessing, fabrication
- elemental composition ⇒ reprocessing, fabrication

Environmental monitoring detection technologies have advanced significantly over the last few decades and have been developed for a variety of applications. Instrumental measurement technologies range from portable to remote to laboratory-based, each of which can be established in a continuous monitoring mode. Some of the demonstrated techniques include a variety of mass spectrometric methods, gas and liquid chromatography, nuclear nondestructive analysis and optical sensors. Details on many of these measurement technologies can be found, for example, within the *Chemical and Radiological Signatures of Nuclear Weapons Production Report PNL-NST-0383 (SRD)* and references therein.

NEW Detection Regime

One of the most relevant issues impacting the verification ability of environmental monitoring is that — NWSs are not NNWSs. Although this statement may seem obvious, it is less obvious how

this fact impacts environmental sampling for detection of undeclared activities. As stated earlier, because NWSs have a history of weapons-grade materials production, significant backgrounds will exist. Similar difficulties may also be pertinent for some of the threshold states. If environmental monitoring is to be credible for verification of declared activities and for detection of undeclared activities (either at declared, undeclared or clandestine sites), prior background measurements may be required. Such a requirement will be particularly critical for the detection of “small” perturbations on “large” backgrounds. In addition, because of the necessity to detect such small changes, improved analytical precision should also be anticipated. Obviously, concerns about masking and spoofing could also reduce the probability of detection (see below).

Specific suggestions to mitigate such problems might be a site baseline assessment, particularly where the detection of incremental changes is desired. This assessment could include such attributes as source term analysis, migration pathways, geochemical considerations and optimized sampling methodologies. Despite the apparent “intrusiveness” of such EM baseline analysis, such analysis may in fact reduce the amount of future inspections through the use of subsequent EM sampling for declaration verification. In addition, early in the FMCT such analyses could provide an excellent opportunity for “confidence building” through non-confrontational verification.

A particular concern related during the *FMCT Non-Routine Inspection Workshop* was the potential cost implications. A suggestion put forth referred to a sample archival program where samples might only be analyzed in cases of unusual or suspect activities. Such archival will require separate sample splits (*i.e.*, aliquots) to maximize confidence. This sort of protocol could substantially reduce implementation costs.

Finally, another related issue must be addressed which could lead to false accusations, and, hence, could have substantial political consequences. This issue has to do with the facility declarations. Because environmental monitoring can be extremely sensitive and, in turn, can detect many past activities, it will be essential that declared facilities disclose as fully as possible all previous activities prior to entry into force. This particular concern is exacerbated by the non-time dependent character of many EM signatures.

Signature Integrators

Environmental signatures originate from a variety of sources and accumulate in surrounding media in numerous ways. The potential to carefully analyze different time scales of signatures based upon their environmental accumulators may offer an alternative or supportive analysis tool. This tool could provide a mechanism whereby current or recent activities could be distinguished from past activities.

This ability arises because different environmental media may “store” signature information relevant to different time scales. For example, some water and sediment media can have quite long residence times (*i.e.*, years to decades), while vegetative media will typically have only seasonal residence times. Further, “instantaneous” signatures such as noble gases and short-lived radionuclides have distinct short-term activity attribution, albeit often with only near-site sensitivities. Although signature integrators are attractive for the discrimination between current and past facility activities, this analysis method has not been fully optimized or demonstrated.

Detection Examples

Although environmental sampling and monitoring have been used sporadically over the last several decades, only within the last several years has the power of this technology been widely recognized. Most recently, this has been proven to be technically feasible to the international community under the IAEA "93+2" initiative. Below are described just a few demonstrated pertinent examples relevant to potential declared facilities (*i.e.*, enrichment, reprocessing and, possibly, reactors) under the FMCT negotiations.

Although the magnitude of emission from an enrichment plant can be quite minimal, the signatures can be quite telling. Specifically, through the use of high sensitivity mass spectrometric techniques, detailed isotopic patterns can reveal a wealth of information. For example, the existence of ^{236}U indicates that the material experienced a neutron field (*e.g.*, reactors) sometime during its lifetime. In addition, the ^{234}U content can be indicative of the specific mine sources. Finally, if sufficient sampling is performed, a detailed analysis can reveal the pertinent material isotopic extremes of the nuclear site activities (*e.g.*, natural, HEU, LEU, depleted, material sources and neutron history). Clearly the detail and spread of discernibles depends on the overall history of the facility, and the number and extent of various campaigns at the site. Explicit examples of these signature attributes are shown in the attached presentation figures 1-2, which represent sample analyses from a DOE fabrication site.

Another complementary set of signatures relates to the production and separation of plutonium (*i.e.*, reactor production and reprocessing). For example, by measuring the relative abundance of the ^{239}Pu isotope, the detection of weapons-grade material separation is clear. The level of the plutonium decay product ^{241}Am (from ^{241}Pu) can provide timing information related to plutonium separation or purification. Figures 3-5 illustrate the type of isotopic information obtainable by distinguishing between fallout, "modern" plutonium and pre-1960 plutonium. Specifically, the first shows fallout isotopics found up-wind of a site, while the second is from on-site, and the last from another site where some early operations occurred.

Overall elemental composition of, for example, sediment can also point to unusual activities related to fuel fabrication (*e.g.*, cladding), reactor operations (*e.g.*, neutron flux field shaping), special enrichment equipment fabrication, and reprocessing. Finally, ^{14}C measurements from tree-ring cores have been shown to provide a time-history of facility or site operations.

Spoofing Concerns

The potential for spoofing environmental monitoring within the FMCT may be quite high. First of all, environmental monitoring should typically be viewed as a qualitative tool (*i.e.*, as a "yes/no" indicator) and not as a quantitative tool (although in some case, rough estimates can be made). This is primarily due to the fact that incremental undeclared changes (*i.e.*, a few significant quantities of materials) on a weapons or threshold state production facility will be very difficult to detect (especially if a site baseline assessment is lacking). This is simply because of the significant historical chronicle of production for NWSs, as well as for some potential threshold states. Further, there is a possibility that a relatively small undeclared or clandestine facility could be co-located with a declared production

facility. Such a situation would significantly obscure and mask activities. Another concern is the intentional masking of undeclared activities by the intentional release of certain signature analogues.

Finally, because of increased world-wide concerns related to nuclear health and safety, many filtering and trapping technologies are now available, many commercially, which can easily reduce nuclear emission by several factors of ten. Such simply facility enhancements will increase the difficulties for detection of clandestine or undeclared nuclear activities.

Summary

The importance of the fissile material cut-off treaty (FMCT) initiative is clear, having potentially far-reaching influence on world stability by improving control of weapons-grade nuclear material and by favorably impacting the longevity on the NPT. However, as in any new treaty negotiation, it is critical that the negotiators be as familiar as possible to all relevant technical issues. This paper has focused upon certain aspects of environmental sampling and monitoring. Several key environmental monitoring and sampling conclusions can be drawn. These can be summarized as follows: 1) NWSs are not NNWSs (implying a new analysis regime), 2) large backgrounds may limit detection probabilities and mandate background assessment, 3) masking and co-location can significantly complicate detection, 4) small-scale or short-term activities may be extremely difficult to detect, and 5) "full" declarations will minimize uncertainties and false accusations.

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