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Enhancement of Environmental Sampling through an Improved Air Monitoring Technique

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Abstract

Environmental sampling (ES) is a key component of International Atomic Energy Agency (IAEA) safeguarding approaches throughout the world. Performance of ES (e.g. air, water, vegetation, sediments, soil and biota) supports the IAEA's mission of drawing conclusions concerning the absence of undeclared nuclear material or nuclear activities in a State and has been available since the introduction of safeguards strengthening measures approved by the IAEA Board of Governors (1992-1997). A recent step-change improvement in the gathering and analysis of air samples at uranium/plutonium bulk handling facilities is an important addition to the international nuclear safeguards inspector's toolkit. Utilizing commonly used equipment throughout the IAEA network of analytical laboratories for particle analysis, researchers are developing the next generation of ES equipment for air grab and constant samples. Isotopic analysis of collected particles from an Aerosol Contaminant Extractor (ACE) silicon substrate has been performed with excellent results in determining attribute and isotopic composition of chemical elements present in an actual test-bed sample. The new collection equipment will allow IAEA nuclear safeguards inspectors to develop enhanced safeguarding approaches for complicated facilities. This paper will explore the use of air monitoring to establish a baseline environmental signature of a particular facility that could be used for comparison of consistencies in declared operations. The implementation of air monitoring will be contrasted against the use of smear ES when used during unannounced inspections, design information verification, limited frequency unannounced access, and complementary access visits at bulk handling facilities. Technical aspects of the air monitoring device and the analysis of its environmental samples will demonstrate the essential parameters required for successful application of the system.

Experience

An unparalleled information gathering campaign was conducted by the International Atomic Energy Agency (IAEA) in Iraq during the early 1990s, after the discovery of the Iraqi clandestine nuclear weapons development program. Collection of environmental samples played a key role during this operation in determining nuclear activities and identifying nuclear materials within Iraq that were to be used in the production of a clandestine weapon of mass destruction. After being approved by the IAEA Board of Governors in 1995 for routine use, environmental sampling (ES) became an important component of an IAEA inspector's safeguards toolbox.

Using an ultra clean 10cm by 10cm cotton cloth swipe to smear an area of interest is the most commonly used method by the IAEA for gathering environmental samples. Thousands of

swipe samples from hundreds of facilities are taken by qualified international nuclear safeguards inspectors around the globe each year. Swipe sample analysis results from the IAEA's Network of Analytical Laboratories (NWAL) are reported back to the IAEA headquarters in Vienna, Austria and used to assist State Officers in drawing a conclusion with regards to undeclared nuclear activities or materials by any member of the Nuclear Nonproliferation Treaty.

Environmental samples taken by the IAEA through water, vegetation and air samples—gathered by various methods—provide a fingerprint of nuclear activities left in nature by potential proliferators. ES methods also include 'location specific' air monitoring, used when deemed appropriate for a particular facility, and 'large area' air monitoring, which is used by the IAEA outside of facilities only after approval of the IAEA Board of Governors. Air handling unit filters in large uranium bulk handling facilities (i.e. conversion, enrichment, fuel fabrication) have also been used in the past to locate and identify holdup.

Air Sampling Combined with Swipe Sampling

In uranium enrichment plants, swipe samples are used to confirm the absence of the production of high enriched uranium (HEU) or of uranium enriched to levels not declared by the facility (Article 6(c) of INFCIRC/153). Confirmation of no undeclared activities in conversion plants and fuel fabrication plants is also accomplished by gathering environmental samples of infinitesimal leakage from plant systems, structures and components using cotton swipes. However, advanced safeguards approaches now being developed for some bulk handling facilities lower the number of inspections per material balance period—reducing the available opportunities for inspectors to take these swipe samples.

The HEU detection timeliness goal is one month for bulk handling facilities, unless that facility is under an advanced safeguards approach (Additional Protocol INFCIRC/540). Swipe samples have many barriers to meeting this goal. Contributors to not reaching the timeliness goal would include manufacturing, release and settling of highly enriched particles on a surface accessible to IAEA inspectors in a negative-pressure containment or handling building. In this particular case, air sampling of the atmosphere would capture HEU particles before they settle on surfaces which can be decontaminated, are taken into existing duct work and filtered by plant ventilation, or escape via alternate pathways (i.e. drains, doors).

Augmenting swipe samples with an air monitoring system, which could either grab samples or continuously draw samples from the atmosphere of uranium handling areas of bulk facilities, would improve the probability of diversion detection. Presence of an air sampler in enrichment facilities, for example, near the feed and take-off areas and cascade hall equipment mezzanines would allow constant monitoring of the uranium process area. Attempted undeclared design changes in enrichment plants such as quick connections, hot taping into piping, and valve or portable compressor leakage could be detected by a constant air monitoring system and provide IAEA inspectors with additional confidence in their conclusions of the absence of HEU production.

Ensuring continuity of knowledge over air monitoring collection components requires that all air samples be handled in the same manner as environmental swipe samples are managed by the IAEA today. Each sample would be sealed in clean plastic bags and sent for analysis to the Safeguards Analytical Laboratory (SAL) and/or the IAEA NWAL under an IAEA seal. Results would be evaluated and reported per the existing NWAL system of sample processing.

New Air Monitoring Technology

Advancing safeguards strengthening measures remains a key project in support of international safeguarding goals and objectives under the IAEA 2020 vision. Further endorsement of the air monitoring approach occurred in 2009 when air collection and analysis techniques for use in international safeguards were investigated by a joint team from Savannah River National Laboratory (SRNL) and Lawrence Livermore National Laboratory (LLNL) with the support and cooperation of Urenco UK, Ltd. (Capenhurst). This proof-of-concept work was supported by the U.S. DOE/NNSA Office of Nonproliferation and Verification Research and Development. Feasibility was established for a concerted effort to evaluate the applicability of air monitoring in uranium bulk handling facilities.

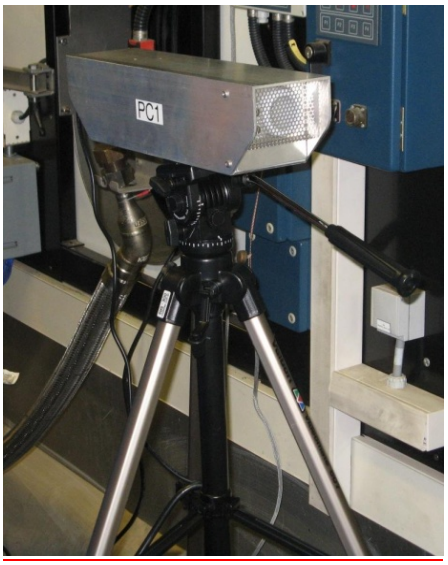

Figure 1. ACE Sampler in the Field

During the field trial, active and passive samplers were positioned throughout areas of interest inside the uranium gas centrifuge enrichment plant (GCEP) located near Capenhurst, UK and air samples were collected over a designated time period. The ACE (Aerosol Contaminant Extractor), shown in Figure 1, was deployed at locations approved by facility operators.

The collection substrates were gathered and shipped for analysis following established IAEA ES procedures. Scanning Electron Microscopy (SEM), Energy-Dispersive X-ray Spectroscopy, Thermal Ionization Mass Spectrometry (TIMS), and Secondary Ion Mass Spectrometry (SIMS) instruments were used to analyze the collected samples.

The ACE device is unique in that it deposits airborne particulates onto a solid substrate as shown in Figure 2.

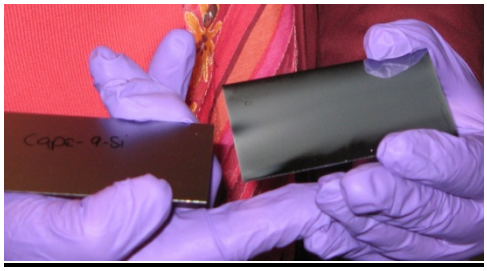

Figure 2. ACE Substrate with Collected Material

Isotopic analysis of collected materials from the silicon substrates provided excellent results in determining isotopic composition of chemical elements present in the air samples gathered at the facility. Validity of air samples from active collection in this test-bed case was confirmed when compared to operator declared values of uranium hexafluoride gas being processed through the GCEP during that period and from past declarations. Passive samples were also confirmed, but this paper will discuss the active collection because of its versatility and tamper proofing potential.

Unlike cotton swipe samples that must be processed for many days through a rigorous battery of procedures to finally allow the particles to be isolated and analyzed, the ACE silicon substrate analysis may be completed in several days. This research area may provide a complimentary technique to be used by the IAEA for fast determination of isotopic composition. Note, however, that the precision of the direct measurement technique has yet to be evaluated for this type of sample and will likely not be as high as methods currently in use for analysis of individual particles. Quick turnarounds for air sample analyses improve effectiveness of a comprehensive safeguards approach for a facility, site or location outside a facility (LOF) and provide prompt completion of State Evaluation Reports, because of their improved efficiency. Additionally, the minimally destructive nature of this technique would allow for analysis of the collected materials using standard protocol once the direct measurements have been completed.

Detecting Undeclared Activities

Identifying typical ES signatures at bulk handling facilities using air monitoring in addition to swipe samples from process systems, structures and components associated with the feed, product and tails will provide nuclear safeguards inspectors the advantage of deterring proliferation, by the constant threat of discovery. Establishing a baseline environmental signature for bulk facilities within a State that operates nuclear fuel cycle facilities is essential when trying to predict expected particle results from an air sampling device. Comparisons of samples gathered by either grab or continuous monitoring should be consistent with declared uranium isotopics and chemical composition of a particular facility and sources of unexplained particles determined.

Possible uranium/plutonium diversion pathways at bulk handling facilities could be identified by proliferation indicators supplied through environmental samples gathered while using an air sampling device. Since the early 1990s assurances of the absence of undeclared nuclear activities or nuclear materials at uranium bulk handling facilities have been confirmed using a comprehensive safeguards approach which includes nuclear material accountancy, containment and surveillance, and ES.

In some instances, transit UF_6 cylinders passing through a facility or previously used process equipment provided by substitute vendors may create an unusual burden of proof from a State in order to reestablish international acceptance of their operations. Inadvertent false positive conclusions caused by cross-contamination of ambiguous uranium enrichment particles might create anomalies that require laborious resolutions. Baseline ES results and consistent confirmation of those results by a frequent air monitoring campaign will narrow those uncertainties and reestablish confidence in the State's peaceful fuel cycle activities.

Location specific ES using an air monitoring campaign and swipes for design information verification will assist nuclear safeguards inspectors in drawing accurate conclusions concerning operation or modifications of a facility that could change production parameters beyond declared values. It would be a great advantage to the IAEA to have an air sampling device that could be remotely triggered from headquarters in Vienna to take a grab sample from the atmosphere at any time. (Figure 3) The ACE sampler described herein is amenable to being remotely controlled for either pre-determined collection periods or grab samples as needed.

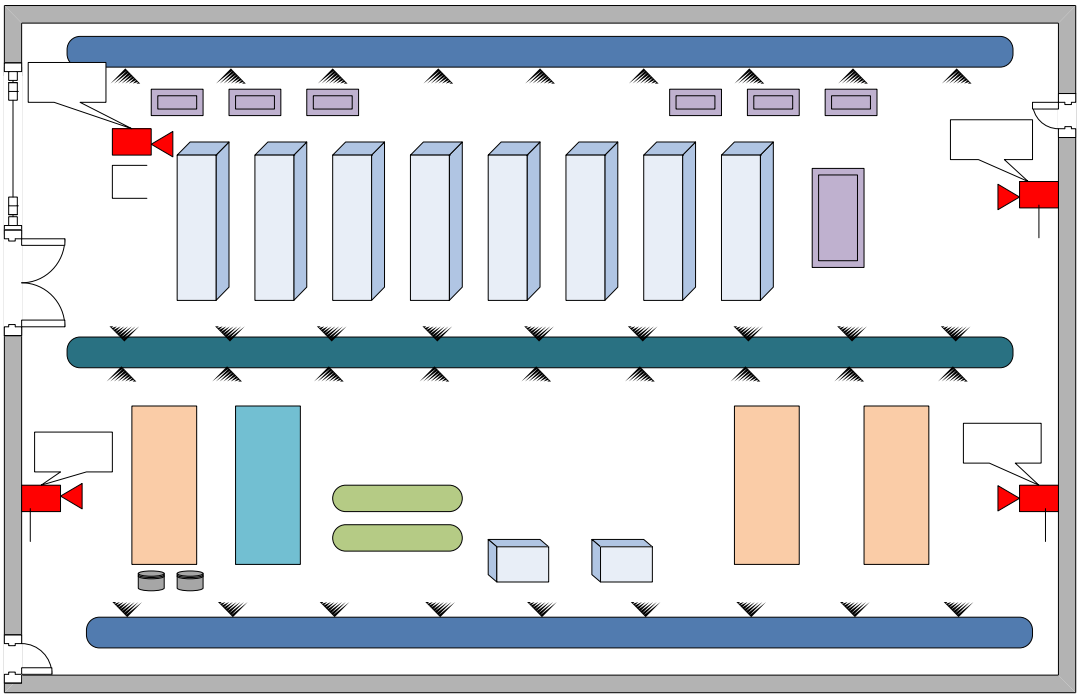

Figure 3: Enhancement of Environmental Sampling with Local Air Monitoring

Grab samples triggered from IAEA headquarters will assist in performance of an unannounced inspection (UI or LFUA) or short notice random inspection (SNRI) by surveying the atmosphere prior to and after a notification letter has been sent. Comparisons of particles collected after an official announcement letter of the eminent arrival of a nuclear safeguards inspector would provide evidence of possible equipment tampering between the time of notification and arrival.

A handheld air sampling device should be included in an international nuclear safeguards inspector's complementary access sampling kit—in addition to cotton swipes. Location specific ES using grab air samples during a complementary access (CA) would provide assurances of the absence of undeclared nuclear material and activities, resolve questions related to correctness and completeness of State provided information, and decommissioned status of a bulk handling facility or LOF.

Conclusion

Development of advanced safeguarding techniques demands that progressive ES instrumentation such as an air monitoring system be designed and tested in various settings around the globe. ES obligations under a comprehensive safeguards agreement could be met by acquisition of air samples at bulk handling facilities in the absence of IAEA nuclear safeguards inspectors. The ACE (Aerosol Contaminant Extractor) silicon substrate air sampling unit developed by Savannah River National Laboratory, supported by U.S. DOE/NNSA Office of Nonproliferation and Verification Research and Development programs, provides excellent results in determining isotopic composition of chemical elements present at a facility or LOF from air samples. ACE air sampling units which meet the progressive ES requirements of international safeguards would be installed as stand-alone, in-line with plant ventilation or handheld as described by facility and State comprehensive safeguards approaches in bulk handling facilities.

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