IMPLEMENTATION OF THE ADDITIONAL PROTOCOL: VERIFICATION ACTIVITIES AT URANIUM MINES AND MILLS

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Abstract
Under classical safeguards uranium production was considered to be "before the starting point of safeguards". Verifying production at a uranium mine on any rigorous basis would require continuous inspector presence. Since any diverted ore or source material would have to pass through many downstream processes, each of which offers some opportunity for detection, before attaining a form suitable for nuclear explosive use, it was not considered cost-effective to extend safeguards to uranium mines. During the development of strengthened safeguards, however, it was considered that the possibility of verification of uranium production was worthwhile as a complement to conventional safeguards, and the Model Additional Protocol provides for broad reporting requirements and complementary access at mines. Although accountancy-type measures are not practicable, appropriate verification measures could identify questions or inconsistencies indicating the need for a wider investigation in the State concerned. At one extreme is the discovery of totally undeclared production, i.e. an undeclared mine, or a mine incorrectly declared to be closed down. Perhaps a more plausible scenario is the understatement of production. The Australian Safeguards Support Program is assisting the IAEA in developing verification approaches and techniques that could identify such a situation, including use of satellite imagery and environmental sampling to date production and determine the origin of material samples.

1. INTRODUCTION
The mining and milling of uranium is the first in a long chain of processes required to produce nuclear materials in a form suitable for use in nuclear weapons. Undeclared production of uranium could be just a starting point of a clandestine nuclear fuel cycle aimed at nuclear weapons manufacture. Misuse of a declared uranium mining/milling facility, in the form of understatement of production, would be hard to detect with the same high level of confidence as afforded by classical safeguards on other parts of the nuclear fuel cycle. For these reasons, it would not be cost-effective to apply verification techniques based on classical safeguards concepts to a mining/milling facility in order to derive assurance of the absence of undeclared nuclear material and/or activities at mining/milling operations has the potential to absorb substantial IAEA and SSAC resources. With this in mind, the authors advocate that in the normal course the Agency should look to other options, rather than complementary access, in order to derive assurance that declared mining/milling operations are not misused. Such options include the interpretation and analysis of information available to the IAEA from States' declarations, import/export data, open source reports, commercial satellite imagery, aerial photographs, and information from other States. The extent to which the IAEA can have confidence in the declared production will depend on the availability of independent information to corroborate declared production figures. While independent evidence may
not be sufficient to verify production, it can provide an additional level of assurance that the information contained in States' declarations is reasonably accurate and complete.

2. URANIUM MINING IN AUSTRALIA AND ASSOCIATED IAEA ACTIVITIES

Australia has around 26% of the world's low cost uranium reserves, and is a major uranium exporter. Uranium mining is carried out for the purpose of exporting uranium ore concentrates (UOC). There is no further processing of UOC in Australia, and, except for a quantity of locally produced natural UO₂ powder, all uranium in other forms used in Australia is imported. The three mines in operation at present are:

- The Ranger open-cut uranium mine and associated uranium mill with a current capacity of about 4,500 tonnes U₃O₈ per year are operated by Energy Resources of Australia Ltd (ERA), in the Northern Territory about 230km east of Darwin. It was proposed that mining operations would be moved from Ranger to a nearby (20km away) deposit known as Jabiluka, but the development of Jabiluka has been deferred indefinitely. All sales from Ranger are to utilities in Japan, South Korea, UK, France, Germany, Spain, Sweden and the United States.

- The Olympic Dam copper and uranium mine is operated by the Western Mining Corporation Ltd (WMC) in South Australia 560km north of Adelaide. The deposit is some 350m underground, and is the largest known uranium ore body in the world. Last year (FY2000-01) the plant produced about 4,800 tonnes U₃O₈, essentially as a by-product of copper mining. Plans have been announced to expand production further to 5,600 tonnes U₃O₈ per year. Sales of uranium are made under long-term contracts to utilities in Canada, USA, Japan, South Korea, Finland, Sweden, Belgium, France and the UK.

- The Beverley in situ leach mine is operated by Heathgate Resources Pty Ltd in South Australia 520km north of Adelaide. Production, eventually reaching around 1,000 tonnes UO₄ per year, began in November 2000, though no production was reported for FY2000-01. Sales contracts have been negotiated with utilities in USA.

In addition, a new mine now approaching operational status – Honeymoon, South Australia – will use in situ leaching to extract uranium. The Honeymoon Uranium Project of Southern Cross Resources Australia Pty Ltd is at the pilot plant stage. At the time of writing the project is awaiting final environmental approvals. Production is planned to be around 1,000 tonnes UO₄ per year.

Australia has six uranium mines that have been closed: Radium Hill, Rum Jungle, Mary Kathleen, Moline, Rockhole, and Nabarlek.

As mentioned above, under the classical safeguards system uranium production was before the starting point of safeguards. Thus the IAEA was not applying any verification activities at mines per se. However, the Australian mines have been always supervised by Australian State/Territory and Federal authorities to ensure production is correctly stated. There is also an export approval process under which exports are correlated with declared production. In addition, physical protection measures are in place to ensure there is no unauthorised removal of product. The Australian Safeguards and Non-Proliferation Office (ASNO) provides the IAEA with semi-annual production figures, and the IAEA is also advised of each export of UOC at the time it occurs.

In January 2001 the IAEA commenced the implementation of integrated safeguards in Australia. Amongst other verification activities, the new safeguards approach provides for up to six complementary accesses each year across the country, mainly at the nuclear site operated by the Australian Nuclear Science and Technology Organisation, but also encompassing other locations including uranium mines.

Realising that the effort to comprehensively verify the absence of undeclared nuclear material and/or activities at mining/milling operations has the potential to absorb substantial IAEA and SSAC resources, a few years ago, at the IAEA's request, ASNO started a Support Program task to consider all the options that are available to the IAEA for deriving assurance that declared mining/milling operations are not misused. Originally this task sought to determine: (1) the circumstances under which the IAEA might undertake complementary access to a uranium mining/milling site, (2) what
verification activities would be applicable, and (3) how open-source and official information (provided, for example, in a State's Declaration pursuant to the Additional Protocol) could be used in safeguards evaluation. The preliminary results of the ASSP studies, which are still in progress, are discussed below.

3. INFORMATION ANALYSIS AT IAEA HEADQUARTERS

The purpose of the analysis of information bearing on declared uranium mining/milling operations, and complementary access at these, is to derive some assurance that mines are not being misused. The forms of misuse of prime interest are the understatement of production and the presence of undeclared nuclear material or activities (ie the conduct of other fuel-cycle steps) at the location. Understatement of production would allow the State to acquire source material unknown to the IAEA, which could be used in clandestine nuclear activities.

There is a wide range of information, including official and semi-official publications, available about the uranium mining industry. Accordingly, the approach proposed here focuses upon the identification of questions and inconsistencies and other uncertainties first through information analysis and related non-access measures. As discussed below, the authors suggest there should be a need to undertake complementary access only on an occasional basis.

The information available to the Agency for consideration includes import/export data, open source reports, and official and semi-official publications. Commercial satellite imagery, and information provided by other States, may also be useful. Such sources would certainly have the capability to raise questions and reveal inconsistencies requiring access for their resolution, analogous to those addressed at Articles 4.a.(ii) and 4.d. of INFCIRC/540. They may also identify less serious uncertainties. Either situation could lead to an installation being selected for complementary access under Article 4.a.(i).

3.1. Analysis of Open Source and Gray Information

Under integrated safeguards the IAEA will routinely receive annual declarations of uranium production for States as a whole (Articles 2.a.(v) and 3.b. of INFCIRC/540). The Protocol provides that declarations of production by individual mines and concentration plants are to be provided only on request. In the first instance, therefore, questions and apparent inconsistencies with States' declarations might arise only with respect to aggregate production. However, if information comes to the Agency suggesting an apparent misuse of a particular mine/mill, the Agency can request an installation-specific declaration, and, if necessary, complementary access to resolve any uncertainties. Information suggesting misuse might become available from open sources and it is most likely to be installation-specific.

The extent to which the Agency can have confidence in the declared production will depend on the availability of corroborative information. Such information might not verify production per se, but would provide some assurance of the correctness and completeness of declarations. This assurance is strengthened when such information is available from several diverse sources that might include:

- Reports generated by mining companies for shareholders and stock exchanges. Such reports would normally include information on production and financial performance. While in principle the company might underestimate production in both its Annual Report and the declaration for the Agency, the report, and the public accountability and scrutiny associated with it nevertheless provide some additional assurance.

- Reports of government regulation bodies. Agencies of various levels of government (federal, state, local) monitor production levels for licensing and fiscal reasons (royalties and taxes), as well as for materials control and environmental reasons. In addition, customs authorities monitor exports.

- Societal verification. In many contemporary societies, nuclear activities are likely to attract the attention of environmental and local community organisations, which in turn are likely to involve the media. Any hint of a clandestine nuclear program would certainly provoke public outcry.

For most uranium producing States there is a substantial body of information available to corroborate declared production, much of it independently derived or subject to independent scrutiny. A strategy
of understating source material production would require the involvement of such a wide range of individuals and organisations as to render the likelihood of the operation remaining undetected quite low. In these circumstances the Agency can place comparatively high confidence in the production declared, and any complementary access under Article 4.a.(i) of the Additional Protocol need only be infrequent.

To aid the analysis of information relating to source material, it may be of value for the Agency to establish a worldwide source material tracking system, building on the transit-matching system already in operation. For States party to the Additional Protocol, the Agency will have available to it declarations of significant inventories and flows (imports/exports) of source material. The Agency could usefully collect this information into a single database and carry out simple analyses such as constructing a rough materials balance for the country as a whole. This does not constitute mechanistic or systematic verification, because the quantities involved will be only approximate, but it may help to identify questions or reveal inconsistencies.

3.2. Analysis of Satellite Imagery

Analysis of commercial satellite imagery may be able to identify inconsistencies between declarations and practice under certain circumstances. They should, for example, be able to establish whether mining is under way (especially in the case of open-cut mines) and thermal imaging should be capable of determining the operating status of the mill calciner. Satellite imagery might be able to observe the installation of new equipment (such as a new milling line), if such work were carried out in preparation for production at higher rates than declared. Where mines have been shut down for a long time (ie at the end of their useful lives), but not returned to green-field conditions, commercial satellite imagery could have a role to play in confirming the installation's continuing shut-down status.

During the January 2001 ASSP Review Meeting, it was agreed that the use of remote sensing to confirm the operational status of uranium mines is an important area to explore. As a result, the Agency has received ASSP funds to purchase satellite images of the Australian mines (including those with the in situ leach process) and to obtain guidance for satellite imagery interpretation. Given the continued interest in mines, and the Secretariat's apparent intention to proceed with regular complementary access to mines, this has a potential for inspection-effort savings. ASNO believes that assisting the IAEA with the acquisition of the required images is in Australia's interests as it helps the IAEA to maintain its conclusion about the absence of undeclared nuclear activities in Australia. As part of the agreement, the IAEA will make the purchased images available to ASSP so that Australian satellite imagery analysts can contribute to the project by providing some guidance to IAEA staff on the interpretation of satellite imagery of this kind.

4. ON-SITE VERIFICATION ACTIVITIES

4.1. Complementary Access

Article 4.a.(i) of the Additional Protocol provides for complementary access to uranium mines and associated mills on a selective basis in order to assure the absence of undeclared nuclear material and activities. The authors envisage that in most States complementary access at uranium mines and mills would be carried out selectively and probably very infrequently to derive assurance that:

- there are no undeclared nuclear materials and activities at the location (for example, conversion, fuel fabrication, enrichment or reprocessing); and that

- there are no gross inconsistencies between actual and declared production (it is assumed that notification of such complementary access would be accompanied by a request for an installation-specific statement of the current production).

Understated production may arise either because production is carried out at a time when an installation is declared shut down, or because production is carried out continuously at higher rates than declared.
Factors that can be expected to be most relevant in the selection of mines/mills for complementary access are:
- the existence of a question or inconsistency analogous to those addressed (for different types of location) at Articles 4.a.(ii) and 4.d. of INFCIRC/540; and
- lower-level uncertainties, less well able to be articulated as questions or inconsistencies, but which could be resolved through complementary access.

In either of the above cases, it would be reasonable to first give the State an opportunity to resolve the uncertainty without complementary access, analogous to Article 4.d. of INFCIRC/540. Certainly serious consideration should be given to the cost and likely effectiveness of access as a means of resolving uncertainties before access is sought. Uranium mines are typically in remote locations, and the cost of getting to them is likely to be significant. In particular cases commercial satellite imagery (for example) could provide an adequate and more cost-effective alternative.

Mining and processing techniques are diverse, and the assays arising at various points in the process vary considerably over the operating cycle of an individual installation as well as between facilities. So it is virtually impossible to confirm, or otherwise, declared production by measuring a few parameters within the mining/milling process. Inspection is only feasible at the last stages of the process where the uranium is present in a relatively pure form. Thus activities at the location would most usefully focus on confirming consistency between declarations and production inferred (to the extent that is possible) from observations at the product end of the mill, where similar equipment is used in all processes.

4.2. The First Ever Complementary Access by the IAEA at a Uranium Mine

It should be observed that the first ever complementary access by the IAEA at a uranium mine was in Australia – to the Ranger mine in June 1999 – prior to the introduction of integrated safeguards. The objective was to determine that there was no undeclared uranium production. That access was particularly important as it was the IAEA’s first opportunity to trial verification activities at a uranium mine – a difficult task, but one on which ASNO has been working closely with the Agency in the development of new safeguards concepts and approaches.

Notice of the access was given in the course of a routine inspection at Lucas Heights on 23 June 1999, for an access visit scheduled for 28 and 29 June. Ranger is quite a remote location, so even the five days notice given gave rise to some transportation difficulties for the national inspector concerned. The Agency inspectors brought with them a GPS unit to check locations, and a digital camera to record the progress of the inspection and details of inspected areas. The mining company placed no restrictions on their use of these items.

Samples were taken of the coarse ore and the fine (crushed) ore. A sample was also taken from a uranium ore concentrate (UOC) product drum. Inspectors took samples of new (current) tailings and tailings stated to be at least two years old in order to determine any difference in their properties which could be used to distinguish between old and new tailings in the future. As discussed below, the IAEA has obtained very promising results from this exercise. A visit was also made to the neighbouring Jabiluka ore body where a sample of ore was taken.

The inspectors sought a substantial amount of additional site information. The information sought included: the physical dimensions and capacities of all major components of the plant; the suppliers of these items; and weekly, monthly and yearly production records. The inspectors also took swipe samples from the walls of the calciner/packing building. This was to check for any indication of hydrogen fluoride (HF), which would suggest that conversion of UOC to uranium hexafluoride might have been undertaken.

4.3. Addressing Continuous Production at Higher than Declared Rates

As noted above, verification activities can be usefully carried out only at the product end of the installation. At the simplest level, inspectors should satisfy themselves that the product line identified to them as the uranium (or thorium) ore concentrate product line is, in fact the only such line. The
processing of other products, such as copper and precious metals, can be expected to be sufficiently different from processing of source material to be readily identified by visual examination. If that proves difficult, it should be possible to devise a simple procedure based upon radiation measurements to confirm that source material is present only in the declared source material line.

Experience with classical safeguards suggests that the consistency of production records with records of the inputs of ore (to the extent that it has been assayed accurately enough) and essential chemicals should be reviewed. It will not be possible, in general, to verify any of these records. However, this process will enhance inspectors’ understanding of the declared recent operating history of the installation, and broaden the range of information in Agency hands supporting the declaration. This information may give rise to a question or inconsistency or other uncertainty.

Specialised training, coupled with growing experience of complementary access to mines and mills should give inspectors a capability to estimate, or find out in other ways (eg from the manufacturer, if the equipment is imported), the design production capacity of the equipment incorporated into the final stages of a uranium mill. Determination of throughput capacity of the calciner and/or the product purification system at an ore concentration plant should provide inspectors with an indication of potential production capacity at a site. However, day-to-day production of uranium varies considerably depending on such factors as mineralogy variability, ore quality, and maintenance downtime. Economic and market conditions also impact on operational decisions. Therefore, inspectors would be able to confirm only approximate production levels (say within an order of magnitude).

4.4. Addressing Operation when Declared to Be Shut Down

Under certain circumstances, environmental sampling (for example, detection of gamma emitting radionuclides of uranium/thorium decay daughters, perhaps in tails) could prove a useful tool in verifying the absence of undeclared production during on-site visits, particularly when inspecting those operations which may, for example, mine for six months of the year and mill for the remainder of the year. Absence of comparatively short-lived decay products in effluents would be indicative that the daughters had not been in recent contact with the parent, and thus that the mill had not been in recent operation.

Th-234 seemed an ideal candidate to look for in determining whether a mill had been in recent operation. Processing uranium ore removes significant components of the uranium decay chain from the tails generated. Specifically, the uranium will be lost, as will the radon gas. That will disturb the equilibrium levels of the daughter products. The immediate daughter of U-238, Th-234, has a half-life of 24.1 days. Removal of the U-238 parent will result in a reduction of the Th-234 activity in the tails. This might be measured in terms of the Th-234/Th-230 ratio. Th-230 is long-lived and has a long-lived parent, so its activity will not be much affected by decay. The Th-234/Th-230 ratio in the tails will diminish as time passes since the tails were separated from the uranium, and could, at least in principle, be used to determine for how long a mill has been shut down.

This idea was put forward by ASNO in 1998. The feasibility of this proposition needed to be assessed by IAEA experts. In 1999, the advice regarding the use of Th-234 as an indicator of time since ore processing was utilised successfully by the IAEA in the analysis of five uranium samples taken from the Ranger mine and concentration plant, and one sample taken from the Jabiluka mine. The samples included unprocessed ore, coarse ore from the stockpile, final crushed ore, fresh and old tails, and fresh product (U₃O₈). All the samples were analysed by High Resolution Gamma Ray Spectrometry (HRGRS) to measure the activities of gamma emitting nuclides. X-Ray Fluorescence Spectrometry (XRF) and Isotope Dilution Mass Spectrometry (IDMS) were used to measure uranium content and isotopic composition.

Thus it has been shown by the ASSP/IAEA collaboration that HRGRS, XRF and IDMS measurement techniques could be applied to analyse samples of ore, tails and product for safeguards purposes. As this was demonstrated in the laboratory conditions for a limited number of samples taken from one Australian mine, additional validation of the proposed method is required before it could be recommended for use by inspectors in the field. The validation involves additional sampling and
measurements at three operating Australian mines (Ranger, Olympic Dam and Beverley) performed by appropriate IAEA experts.

The plan of related work being undertaken by ASSP and the IAEA (at the time of the submission of this paper – 17 September 2001) was as follows:

- At the three mines, three to six representative samples would be taken by the IAEA experts with ASNO staff assistance from: undisturbed ore, tailing ponds, and product, including possible intermediate products, for example, coarse and fine fractions.
- The IAEA experts will identify the sampling points after analysing the flow diagrams describing the principal steps of ore processing at each of the three mines.
- Where possible all samples will be measured in the field (by the IAEA experts with ASNO staff assistance) immediately after sample-taking using portable HRGRS and XRF equipment.
- After that all samples will be sent to the IAEA for further precise measurements at the Safeguards Analytical Laboratory in Vienna.

The results of this project will be published in a separate paper.

As an aside, it should be noted that environmental sampling could also prove a useful technique in providing to inspectors an additional level of assurance that undeclared nuclear activities, such as conversion or enrichment, were not being carried out clandestinely in the vicinity of the mine site.

5. CONCLUSIONS

IAEA verification activities related to uranium mines and mills should be directed at deriving a measure of assurance that there is no undeclared nuclear material or activities (ie other fuel-cycle activities) at the location and that production of source material is not understated.

The measures proposed in this paper for the derivation of assurance of no undeclared nuclear material or activities are, visual examination and environmental sampling during complementary accesses under Article 4.a.(i) of INFCIRC/540. It is suggested such complementary accesses would be carried out at on a selective basis and should occur only occasionally.

The measures proposed for the derivation of assurance of no understatement of production are, information analysis, followed by complementary access on a selective basis as discussed above.

The information available for analysis includes: open-source reporting, reports from mining companies, reports from relevant State regulatory bodies, commercial satellite imagery as appropriate to confirm the operational status of mines and/or mills and observe new construction.

An appropriate additional information analysis measure would be for the Agency to develop a database of information on production, holdings and flows of source material to facilitate reconciliation of information from various sources.

Activities at complementary access under Article 4.a.(i) of INFCIRC/540, in addition to those noted above, could include: an audit of production records, a physical examination of all production lines to ensure that only those declared to do so are producing source material, estimation of the design maximum throughput of the equipment at the product end of the mill, and where the mill is shut down, environmental sampling of the freshest possible tails to determine the length of time for which it has been shut down.

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