How to Safeguard Uranium in the Cradle and in the Grave?

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ABSTRACT

The front-end and the back-end of the fuel cycle are challenging for the IAEA safeguards since the nuclear materials are inaccessible in the geological media and thus not verifiable by the inspectors. The current IAEA safeguards objectives cover in addition to the accountancy verification, the detection of possible misuse of materials and activities. Therefore, the IAEA is assessing States and their nuclear capabilities, e.g., using the IAEA physical model and Acquisition Path Analysis. Whereas the national approach is based on multi-authority governance, making social and environmental permitting essential. Typically, the mining-oriented applicant or operator is not familiar with nuclear framework including international safeguards, therefore communication and cooperation, i.e., Safeguards-by-Design is needed between all the stakeholders.

The possible diversion scenarios have been addressed be the IAEA within the cooperation of MSSPs. At the front-end, the capability to access the uranium resources depends on the mining capabilities in the country, the main focus must be on the assessment of the motivation and financing. Uranium is present almost everywhere in the lithosphere, so a clandestine uranium extraction from multi-metallic ores is challenging to be detected. Whereas, in the back-end the motivation and financing to access hazardous waste is minimal at a licensed depository, and the detectability is more obvious. However, at both cases the responsibility for physical protection, non-proliferation and peaceful use of uranium is a national obligation that requires institutional cooperation and national control of nuclear-related activities.

The construction and licensing of facilities in the front-end and the back-end of the fuel cycle takes years. However, during the development period safeguards measures are to be applied to exclude undeclared activities already during the pre-operational phases. In the presentation, experiences from the preparation for the commercial and licensed uranium extraction and disposal in Finland will be discussed.

1. INTRODUCTION

The construction and licensing of facilities in the front-end of the nuclear fuel cycle takes years. The progress from exploration to an operating mine often takes more than a decennium. This has experienced in Finland with the Nickel mine in Sotkamo with the 30 years' time from the ore discovery in the past to the metals production that became commercial in 2008. The presence of uranium was reported to the IAEA in the OECD/NEA Red Book already in 1981. At the same time, the development of the geological repository was launched in 1983 and consequently R&D work to develop methods to carry out new type of site investigations to locate solid bedrock suitable for disposal was initiated for the site selection that was done in 1996 for Olkiluoto. At present, May 2023, neither of the stakeholder are holders of nuclear materials yet, but the sites have been considered as MBAs for more than 10 years. The national requirement to provide BTCs to the European Commission is essential to establishes safeguards awareness at the companies and to launch Safeguards-by-Design process that also facilitates the IAEA access to the sites and people.

The mining company announced its plan to also extract uranium in its ore processing factory in 2010 while the main products from the multi-metal sulphide deposit are nickel and zinc During the almost 15 year-long operational period, the ownership of the mine has changed, the environmental permits and mining licences have been appealed, in particular, for environmental and economic reasons. The plans for the extraction of uranium brought in the Finnish nuclear energy legislation, and safeguards in 2012, but the first licence was cancelled with the bank rupture in 2015. The MBA code was maintained for possible future need; and it became valid again when the licensing of uranium recovery was re-initiated in 2017. The current nuclear licence for uranium extraction was endorsed in June 2021, and the production is expected to be launched in 2024 making Finland a remarkable yellow-cake producer in Europe (see e.g., Peri, 2022 for the background). During this preparatory time, small-scale pilot tests were licensed to define the details needed in the hydrometallurgical ore processing techniques and to store the uranium extracts under safeguards. The inclusion to nuclear fuel cycle facilities is a cultural challenge for the mining and milling industry as a newcomer. The future safeguards procedures are still to be defined as the for the completion of the uranium extraction unit is still under design. The anticipated challenges to detect possible misuse or clandestine uranium production at the mine and ore processing factory (mill) are also discussed in the paper.

At the geological repository site, the 1996 decision to continue research activities only in the Olkiluoto area in western Finland by constructing an underground rock characterisation facility since 2003 has given a possibility to develop and test the site-specific safeguards procedures to be applied in the repository phase. This R&D was initiated with people having nuclear background but even though, the safeguards-by-design process became troublesome in the pre-nuclear phase since the status of the installations was understood differently at that time. The national authority's role was important to facilitate the site visits of the safeguards inspectorates at that pre-nuclear time. The waste management company Posiva finally submitted the application to construct the nuclear disposal facility at Olkiluoto to the Finnish government at the end of 2012. The preliminary versions of the BTCs were reviewed by the European Commission and IAEA and after a few consultative negotiations in 2013 and 2014 the need for safeguards instruments for the encapsulation process were agreed. The spent fuel shall be verified and kept under containment and surveillance i.e., C/S from the current location at the power plants through the whole encapsulation process as described by Park et al (2014). The emplacement of the capsules, i.e., disposal canisters in the rock cavers deep in the bedrock initiated the safeguards challenge as the cannot be revisited and accounted for. Therefore, Baldwin et. at proposed that the traditional Material Balance Area (MBA) should be replaced by the Material Disposal Area MDA for what only C/S measures would be applied. The future safeguards procedures are to be defined before the operations begin approximately in 2025. The safeguards challenges to detect possible misuse or clandestine spent fuel reprocessing at the repository have been reviewed by the SAGOR-group (IAEA 1997) and are also discussed by Richter et al. (2005)

In addition to verification of the declared activities the IAEA is assessing the state's capabilities for undeclared activities. Therefore, during the development and construction period of new installations safeguards should be applied also to exclude undeclared activities during the pre-operational phase. This task is possible only with assistance by the national regulatory system. Similarly, after the closure, the national safeguards authorities are the important contacts to facilitate IAEA visits or inspections to these locations.

2. SAFEGUARDS TASKS FOR THE NATIONAL REGULATORY SYSTEM

The commercial use of land needs authorisations from the authorities both in the front-end and back-end of fuel cycle as well in the middle. The role of the regulatory body varies from country to country owing to the mining and nuclear history of the country. Typically, the mine operator needs to apply for several licenses for environmental permits, exploration or/and mining licences, land-use permission, ownership of minerals, usage on dangerous chemicals and explosives, environmental management, radiological protection etc. The peaceful use and nuclear non-proliferation of end products are prerequisites for a national licence and social acceptance. The IAEA guidance to license a nuclear installation (IAEA, 2002) defines that a regulatory body can be a set of regulators, responsible for different aspects. The licensing process may stepwise and commonly in the mining licensing there are separate licences for exploration, mine development, operation, and closure as proposed by the IAEA (1996). Radiation protection and nuclear material control may be assessed in concordance with the mining licensing steps or kept as separate issue according to the national experience and practices. In the back-end the mining regulations cover mine closure with requirement to preserve geological information. The methodology is applicable for the civil construction of a disposal facility because there are similarities in the exploration, rock investigations, plant design, operation using dangerous goods, and finally closure and remediation of the installation. The social licence implies the environmental impact assessments and acceptance by the local council. Typically, there will be environmental restrictions or threshold values for e.g., noise, dust, pollution including radiation.

At both ends of fuel cycle, the business itself is revenue driven. There is a long-time perspective for cost-effective utilization of the rock mass for optimal way for the commercial use of ore body or host intact host rock for disposal. In practice, the operating companies, the licensees, give contracts to local subcontractors to excavate source rocks or geological material according to the licence conditions that also cover safeguards reporting and facilitation of international inspections.

The safeguards-by-design process is beneficial and could be applied to educate mining engineers to become operators of a nuclear fuel cycle facility. The experience so far is, that valid licences, decisions for investments and nominations for responsible personnel and financial stability are needed to advance safeguards culture in the newcomer organization. This challenge is obvious in the mining industry, as industrial scale focuses on quick mass flow and production rate. Therefore, the mining culture is hardly seen to change. In the more traditional nuclear field of building the disposal facility, the financial and operational stability is easier to maintain.

The land-use authorities are responsible to maintain the old operating records for future generations. In the mining business it obvious that the owners consider mines and miners as asset that may by sold profitably or closed down or even abandoned to wait for more promising times. The national register in Finland covers mining sites in the Finnish territory for more than 450 years. At the geological repository the information conservation is considered as challenge for future generations. It obvious that as long as there the institutional control of land-use, there mines and repositories can be dealt almost identically. It more obvious that the old mines may re-accessed more frequently to investigate their commercial profitability than a waste repository. Land-use restriction are evitable to protect people’s health and safety. Safeguards inspectorates will have the challenge to find hosts to facilitate access the restricted or closed sites with no operating personnel present. It is evident that the national safeguards authority will have its duty to facilitate the international inspectors’ visits and inform about licence applications concerning closed sites. The national physical protection measures will be applied according to the updates in the design basis threat.

3. DETECTION OF POSSIBLE CLANDESTINE ACTIVITIES AT THE FRONT-END

Nuclear safety, including understanding of peaceful use of nuclear energy and non-proliferation is not main task for the mining industry. As natural uranium is not highly radioactive, the dangerous chemicals needed in ore processing and the valuable products create the main safety and security concerns. Typically, nuclear issues are dealt with once these become as requirements for the economic production and basis to ensure the secure markets. The commitment of personnel is also based on the foreseen stable future. In commercial mining industry, the fluctuation of market prices affects the operations and motivation much more than in the nuclear energy industry. However, it is important to raise awareness about nuclear regulations at the newcomer to facilitate the implementation the future safeguards including non-proliferation.

In practice, the mining companies give contract to local subcontractors to excavate source rocks or geological material. The possible uranium-content is usually of no interest, and thus it is difficult to differentiate between uranium-bearing materials. In many countries, like in Finland, the social licensing is an essential part of mining, the land-use is made public, and any mining is licensed after environmental impact assessment. The only applicable way for clandestine uranium production is misleading information about the target's geological properties in the applications. In mining and ore processing the mass flow is often enormous, and therefore even low-grade uranium can be accumulated significantly. It is well-know that uranium is present in almost all geological media, even in sea water, so the motivation and financing are the drivers to be analysed. Typically, mining is outsourced to mining companies that may be, foreign or domestic, private-owned or state-controlled, but the licensing procedures and environmental issues are common for all types of mining enterprises.

Asa an example, the pilot test at Sotkamo mill were carried out in a standard container. The chemical tests need expertise and licence to access to dangerous goods and chemical chemicals needed in the hydrometallurgical processes. The test runs were done in a small-scale laboratory in a few months, a critical time for the processing of a significant quantity would not be too time consuming once the process is running constantly. The R&D needed for a possible clandestine pathway is question of motivation and resourcing according to the customer's needs. As long as the owner's, i.e., customer's need is to have purified products for international markets, the quality assurance procedures will be essential to optimize the usage of the raw materials to have uranium ore concentrate. It may even be in the interest of the metals factory not to analyse the uranium residuals that end in the non-commercial waste section. Thus, the example shows, how difficult is the detection of extraction of uranium from natural rocks. In the hypothetical case, the container(s) for small-scale production might be located anywhere, within an industrial area or hidden in remote but accessible place where pre-processed uranium containing material is available. This may be associated with other metal industry where uranium is present in the ore concentrates. In case that these environmental and economic prerequisites are neglected, the assumption will be that the lead-time is very short, in a hypothetical state-controlled system uranium extracts and other products may be available at any time.

The current IAEA safeguards objectives cover in addition to the accountancy verification, the detection of possible misuse of materials and activities. The possible scenarios for clandestine production were be addressed by the MSSPs to the IAEA under the auspices of an umbrella task "Technical Assistance on Methodology and Guidance for Implementation of Safeguards at the State-Level" applying Acquisition Path Analysis and the Physical Model. APA is an analytical methodology to assess and identify the technically plausible paths by which a State could hypothetically acquire weapons useable nuclear material and assess a State's capability of completing the nuclear fuel cycle path and its associated technical requirements. Timeline estimate, the lead time, is a function of a State's overall industrial capability along with its existing nuclear fuel cycle capability and any mining and milling (ore processing) specific related capability. In these analyses, the State's capacity is not financially limited.

This methodology is challenging to be applied as the State's capability to access the uranium resources depends on the local mining and milling capabilities using commercial technology, i.e., no dual-use items or sensitive technology are needed in open pits, underground mines, mineral processing, or in-situ leaching. The granular material from excavations need to grinded and leached, whereas in-situ leaching produces fluids to the hydrometallurgy. Economics play major role in the selection the mining and ore processing techniques needed to produce a significant quantity of uranium from an ore body.

The declarations about mining activities and exports and import of uranium according to the AP facilitate the IAEA to assess the coherency of its picture about nuclear activities and capabilities in the State. However, to assess proliferation risks the focus shall remain on the phases towards fuel fabrication after mining and milling, i.e., on conversion and enrichment where sensitive technology is essential; and the acquisition path analysis is more applicable.

4. DETECTION OF POSSIBLE CLANDESTINE ACTIVITIES AT THE BACK-END

Detection of diversion has been the main safeguards concern in the back-end of the fuel cycle. STUK has actively been participating in the work of the IAEA expert group SAGOR to develop safeguards to be applied at a geological repository and during the disposal process itself. The assurance about the content and integrity of the disposal canister during the transfers in the repository is essential for safety, security, and safeguards. The expert group focused on German concept to be applied in salt domes, but Fritzell et al. (2008) suggested that the emplacement vehicle could be equipped with positioning and radiation monitoring system to detect any replacement activities as the circumstances in the Swedish and Finnish repositories in crystalline rock are suitable for this kind of devices. The current plan (by M.Murtezi et al, this Annual INMM meeting) considers this kind of surveillance until the final emplacement in the repository. After backfilling the emplacement holes and tunnels the canisters become inaccessible.

The need to know the exact location of the spent fuel canister in the repository is not considered relevant in the generic safeguards approaches for geological repositories as the fuel becomes inaccessible in the geological medium. Therefore, the safeguards conclusions can be based only on the effective containment and surveillance measures instead of traditional item counting and reverification with timelines (Stein 1987). However, the records about the location and the nuclear content of disposed canisters shall be maintained under institutional control as long as possible. The main responsible authority is the one responsible for the future land-use.

The most challenging safeguards question concerning the licensing of the disposal of spent fuel is the termination of safeguards and the consequent economic liabilities to be set for the waste producers. The spent fuel disposed in a geological repository will be subject to safeguards as long as the safeguards agreement remains in force. The safeguards applied should provide a credible assurance of non-diversion. The cost estimate for these future safeguards needs will remain as an unsolved question. As the societal requirement for any permanent repository is the safe and secure storage of spent fuel in inaccessible repository in a way that isolates the spent fuel from the biosphere and prevents human access, there should not be any safeguards concerns in the Member States of Joint Conventions for waste management, and physical protection of nuclear materials. As long there is societal control over the disposal site, the IAEA safeguards measures might be reduced to a minimal according to the state-level approach, in member states with the AP in force (Richter et al 2015).

The disposal concept has been proven not to be harmful to the environment or people so that that no monitoring after the closure of the repository shall be expected. However, Stein et. al (1987) and Fattah Khlebnikov (1990) raised a few hardly foreseeable factors, one of these been the alterations in the institutional and social system. Another factor is the possible change in the attractiveness of the current waste in the future. Therefore, the future safeguards approaches should take in account these society-specific features and adjust the international safeguards measures as appropriate. During the period since 1987 Europe has experienced several major administrative changes, even the host countries for nuclear power plant have changed, but at most cases the safeguardability of NPPs and their waste facilities has remained in spite of government changes; and the IAEA has been able to verify the Continuity-of-Knowledge of nuclear materials at the facilities. This would not have been possible without strong national commitment to non-proliferation in those countries.

5. CONCLUSIONS

The Finnish experience demonstrates that preparation for uranium extraction at the operating Sotkamo mine and ore processing factory has lasted over 10 years, and that for disposal facility at Olkiluoto more than 25 years. These preparatory times have given good opportunity for bench marking the Finnish regulatory system for the new type of nuclear fuel cycle facility. There have been obvious needs to develop practices at the ministry, regulators i.e., the regulatory body or system and the operator in cooperation with the international safeguards inspectorates. At present, both examples of new kinds of nuclear operators in Finland are waiting for their operating licences to launch their business in 2024 and 2025 and finalisation their Safeguards-by-Design processes before that.

There are several common safeguards tasks in the front-end and back-end of the fuel cycle that can be addressed mainly by the national regulatory body which typically consists of several authorities responsible for at least land-use, environment, radiation protection and nuclear safety and safeguards. The licensing of land-use, and the competence and transparency of the national regulatory system are important state-specific factors to be encountered by the IAEA in its state-level approach. The acquisition path analysis applied for the mining industry, described in this paper, shows that if only motivation is considered and the environmental and economical precautions are neglected, the IAEA is easily overestimating its independent technical verification needs. The experience from mining practices shows, that the national registers with commercial geological data have already been maintained for centuries despite major administrative and political changes in the hosting countries. The same can be expected for geological repositories as long as there is local institutional control of land-use.

Typically, nuclear issues are dealt with once these become as requirements for the business in concern and basis to ensure the secure markets. In commercial mining industry, the fluctuation of market prices affects the operations and motivation much more than in the nuclear energy industry. In the back-end, the nuclear safety, and the safety case are extreme important for the social acceptance of the whole disposal concept for highly radioactive waste. The economy in the waste management is rather stable to facilitate personnel’s commitment to nuclear safety, security and safeguards. However, during the pre- and post-operational times the role of the national safeguards authority is essential to promote safeguards at the stakeholders and to facilitate cooperation with international inspectorates.

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