

## Suspension of Nuclear Activities Is Not End of Diversion Risks

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### **Abstract**

A long-standing goal of diplomacy with Iran is persuading Iran to suspend its enrichment operations while it clarifies its past activities and while negotiations proceed on a more permanent resolution to the nuclear crisis. However, there is problem in using suspension of nuclear material production as a negotiating step: The technical details of suspension have never been clearly defined. In the case of suspending enrichment, the problem of determining how much material has been enriched to what particular levels is even more acute since countries agreeing to suspension probably have or have had weapons aspirations. The international community needs to be aware of the diversion risks during a suspension of enrichment activities and should mitigate these risks by including the necessary verification measures during negotiations and signing of any agreement on suspension. For that reason, inspections and monitoring of enrichment facilities where operations have been suspended should be even more intrusive than during normal operations. The containment and surveillance equipment that the IAEA uses when monitoring an operational nuclear facility (including cameras, seals, and detectors) is not necessarily sufficient to ensure that diversion of material or equipment does not occur during a suspension. The only way to ensure nondiversion during a period of suspension is to insist not only on keeping containment and surveillance equipment in place but also on the disablement and sealing of, the feed supply system, the product recovery system, and the electric supply. Verified disablement should be a standard procedure during the suspension of an enrichment facility. It is crucial for inspectors to be constantly present during the preparations and suspension period.

### **Background**

The International Atomic Energy Agency (IAEA) has been safeguarding gas centrifuge enrichment facilities for more than 25 years. Unfortunately, the measurement of the amount and the enrichment level of nuclear material in uranium enrichment facilities remains one of the principal safeguards challenges. In recent years, many states have begun new activities involving proliferation-sensitive aspects of the nuclear fuel cycle. Some of them were declared and some were not. When problems arise, diplomats reach for convincing the noncompliant state to suspend its activities for an interim period while negotiations on a longer term solution proceed.

In 2004 the IAEA declared that "Iran has decided, on a voluntary basis, to continue and extend its suspension to include all enrichment related and reprocessing activities, and specifically: the manufacture and import of gas centrifuges and their components; the assembly, installation, testing or operation of gas centrifuges; work to undertake any plutonium separation, or to construct or operate any plutonium separation installation; and all tests or production at any uranium conversion installation. The IAEA will be notified of this suspension and invited to verify and monitor it. The suspension will be implemented in time for the IAEA to confirm before the November Board that it has been put into effect. The suspension will be sustained

while negotiations proceed on a mutually acceptable agreement on long-term arrangements...”[1]

In January 2006, Iran informed the Agency that it had decided to resume “R&D activities on the peaceful nuclear energy program which had been suspended as part of its expanded voluntary and non-legally binding suspension.”[2] Iran was referring to activities that included those carried out at the Fuel Enrichment Plant (FEP) and the Pilot Fuel Enrichment Plant (PFEP) located at Natanz. Iran restarted enrichment tests at the PFEP on February 2006; The FEP was put into operation in February 2007.

Iran continues to negotiate with the IAEA and the representatives from the five weapon states plus Germany, about their request to suspend part or all the uranium enrichment activities (5% and 20% enrichment) and to shut down the operation in Fordow, an underground uranium enrichment facility near the city of Qom. The issue of suspension extends beyond Iran. The international community still hopes to convince North Korea to suspend its nuclear activities and to agree to a possible moratorium on the development of long-range missiles.

In the near future, it may be necessary to address in greater technical detail the issue of suspension of nuclear activities. The aim of this work is to give a safeguard framework in the case of suspended enrichment facilities and to suggest a policy which might reduce diversion risks of nuclear material and essential equipment.

## **Suspension**

Suspension is an intermediate status between normal operation and permanent shut down or decommissioning. It is not necessarily time limited, but suspension implies impermanence. It is voluntary; there are no established regulations that international bodies can rely upon to verify non-diversion during periods of suspension. The state cannot be obliged by the IAEA to suspend its activities. There are several past examples of ambiguity connected to safeguards and nuclear facilities under suspension. Along the years, in different occasions, North Korea declared that it holds suspend its nuclear activity. The IAEA tried to inspect and to verify that no nuclear material production has performed during the suspension without great success.

Suspension of nuclear activities is rightly seen as a diplomatic success when dealing with potential proliferators [3]. The IAEA should be the main player in ensuring that an agreement on suspension of any manufacturing activity in a nuclear facility can be verified and is not a cover for hidden nuclear activities. Dealing with suspended facilities and any associated proliferation risks from such facilities, should continue to be of considerable interest for the coming months and years.

One of the proposals for the suspension of a nuclear enrichment facility entails what M. Bunn defined as “standby mode.” [4] In the discussion, Bunn addressed the concern about resuming regular production after the end of the suspension period. For his analysis, he drew on the case of the gaseous diffusion enrichment plant in Portsmouth, USA. By defining states of “warm standby” and “cold standby,” and applying them to gas centrifuge cascades, Bunn was attempting to find a technically feasible means of getting Iran to comply with the demand in

2006, to suspend its enrichment activities at Natanz. According to the negotiators' demand, Iran was left with a limited ability to restart the enrichment operation again in the future. However, although the "warm standby" and "cold standby" options move in the right direction of providing a technical basis for overcoming a diplomatic impasse, it does not give a complete response to nonproliferation risks and to the possible diversion paths of nuclear material and vital equipment.

In recent years the IAEA has invested extensive effort and resources in strengthening the safeguard regime for nuclear facilities. One example of the outcome of these efforts is the new policy that was implemented for inspection of uranium conversion facilities. At the same time a lot of work is still underway to further develop equipment, methods, and techniques to enhance containment and surveillance capabilities [5] [6]. Scientists from different countries are trying to assist the IAEA in developing new methods as a response to one of the known weaknesses which is the measurement methods and accuracy of the equipment used by inspectors during their visits enrichment facilities. These improvements may also address the need for preventing possible diversion of nuclear material from enrichment facilities whose activities were suspended.

### **Weaknesses in the current system**

Assume that a country voluntarily decides to suspend its nuclear enrichment activities. This means that the enrichment process is shut down and nuclear materials are removed, including the removal of feed, product, and tails of  $UF_6$ . Routine inspections might be stopped. There is currently no clear definition or guidelines for which steps should be performed in this situation by the country to verify non-diversion. The IAEA has not formulated any framework, methodology, or policy that should be applied in the case of suspension of different activities in production facilities.

In the case of suspension in an enrichment facility, the capability to restart the isotopic separation process may still exist. M. Bunn has defined enrichment suspension as a standby situation and distinguished in his article between cold and warm standby. A cold standby scenario would involve shutting down the enrichment activities, stopping the flow of material and most utilities, causing the centrifuges to stop spinning. However, the possibility remains of restarting the production systems and the operations, relatively quickly.

During a warm standby most of the utility systems continue to operate. In this case inert gas will substitute the uranium hexafluoride ( $UF_6$ ). It will allow to the centrifuges to continue spinning. In this case, it will not take a long time to restart the enrichment activities following the decision to do so.

In both cases, cold or warm standby, the IAEA continues to be responsible for verification activities for implementing these modes, under the conventional safeguard procedures and tools, and the new diversion risks are added to potential diversion routes in a facility that continues to produce. Therefore, constructing a more appropriate policy and safeguards framework for the case of enrichment suspension should start with an understanding of the possible diversion scenarios.

The diverter could easily take the advantage of the weaknesses in the existing safeguards approach, inaccuracy in measurements, combined with the special characteristics of the uranium enrichment facility (UEF). UEFs are not very large facilities but they contain a lot of long pipe lines for different uses, hundreds and thousands of valves and meters which make it very hard for IAEA inspectors to detect possible modifications. This could lead, for example, to the introduction and processing of undeclared feed of UF<sub>6</sub>. Accurate and reliable measurement of UF<sub>6</sub> in different isotopic ratios is considered one of the major safeguard challenges of the IAEA. A lot of resources are being invested to develop a new methods and equipment that will allow decreasing measurement errors. A difficulty in verification along with the unique characteristic of UEF still leaves open several diversion scenarios.

The enrichment facility, the same as any other nuclear or chemical plant is characterized by the presence of “holdup” material after shutdown. After suspending the activities in a UEF, when the flow of material is paused or stopped, a significant amount of material still could be found in different locations [7]. The need to estimate the amount of material remaining in the facility’s pipes which could be accumulated in different locations, has significance, primarily for radiation safety reasons and reduce criticality risks. Second, certain aspects of safeguards are very important. Nuclear material can be found in the cascade pipes, connections, traps, and filters. Most probably, UF<sub>6</sub> could also be found around the loading area and weighing area for the feed, and the pipes that are connected to the collection of the tail, the depleted uranium, and the enriched UF<sub>6</sub>.

This holdup [8] is usually declared as an in-process inventory when material balance is performed. Because traces of material can be found in many locations in the facility it is very hard to use the standard detection equipment in order to estimate the exact amount of material and its isotopic ratio. In addition, the high percentage measurement error and the insufficient accuracy of the existing equipment of the IAEA inspectors should be a source of concern. Potential risks of diversion and theft of highly valuable nuclear material exist, especially, from a suspended facility, by using the right to declare on the amount of holdup without the necessity of proving or demonstrating it. The potential diverter can easily cheat and falsify his records and these numbers.

According to the IAEA regulations and policy, 0.2% of the total amount of the nuclear material that was processed in the facility can be declared as Material Unaccounted For (MUF). In a large UEF, with a significant volume of production, the amount of MUF that could be accumulated with every batch and be diverted without notice is considerably high and exceeds one Significant Quantity (SQ). Thus, during the preparation procedure there is an increased chance of nuclear material diversion from a facility in which the enrichment activity is suspended.

The shortcomings of the measuring systems that are used by the IAEA inspectors in order to safeguard enrichment facilities have been extensively discussed [9]. The Cascade Header Enrichment Monitor (CHEM) is not a continuous and unattended system while the X-ray absorption of the continuous enrichment monitor (CEMO) varies with pipe diameter and wall material which very much limited the use. CHEM and CEMO are permanently installed and the measurements are not applied at random points. They are very sensitive to temperature and gas pressure changes and to the material state, if it's gas or solid. The accuracy depends much on

pipe geometry and materials of construction. The detectors are based on a source that has to be replaced every 2 years and needs to be calibrated frequently. All these issues lead to an unacceptable amount of the measurement error.

### **Diversions scenarios**

There are four main diversion paths for the acquisition of HEU by a state having a UEF with a declared maximum enrichment level of 5%-20%  $^{235}\text{U}$  [10]. The potential risk of diversion exists in an operating facility but becomes higher in the transient stage to suspension. The need to pause enrichment activities, stop feeding nuclear material, decommissioning, emptying the pipelines--all these activities could provide opportunities for diversion.

#### Diversions during the preparation for suspension

The purpose of diversion of 5-20%  $^{235}\text{U}$  will probably be the ambition to produce higher enriched uranium for military purposes. Because there is a need for only a small amount of product, the further enrichment can take place in a relatively small clandestine facility. This facility can be hidden underground or above ground in between many other chemical plants in an industrial area.

When a country is involved in an effort to divert nuclear material, one of the possible paths could be through the feed area or the area where the product (tail or enriched material) is collected. The diversion can happen during the regular operation of the UEF but it would be even easier during the preparation for suspension, or the suspension period itself. As was discussed above it is very difficult to identify and measure or even estimate the quantities of nuclear material held up in different regions in the facility. It is difficult to perform static measurements of  $\text{UF}_6$  quantities and even more complicated to measure during the flow of the material in the pipes of the cascade.

One of the recent developments in the attempt to determine the process holdup in a more accurate and reliable way is by using statistical modelling. In order to develop these statistical models which can help estimate the hold up, it is essential to collect all the data and information about the routine operation and the periodic inventory. Many parameters can influence the accuracy of the model; the estimate depends very much on the specific characteristics of the facility, its design, structure, and cleanout procedures.

In preparation for suspending the activities in a UEF, there is a need for fundamental procedures which involve a lot of cleanout processes, ventilation, and dismantling of pipe parts. There are various stages of preparation required to empty and ventilate  $\text{UF}_6$  from the piping. The inability to measure the exact amount of material accumulated in the pipelines and in various parts of the facility could allow a diverter to exploit the early stages of preparation for suspension to divert undeclared  $\text{UF}_6$ . The operators could easily report false numbers of the hold up in the systems and the possible MUF and could ship the excess material to a clandestine facility for further enrichment for military purposes.

### The introduction of undeclared feed

One of the diversion scenarios in an operating UEF could be the introduction of undeclared feed into the plant for enrichment to a level less than or equal to the declared maximum. In the case of a closed facility, due to suspension, it is more likely that this diversion path could take place. Especially, if the centrifuges continue to spin and the vacuum and cooling systems still operate.

There is also the possibility of finding extra UF<sub>6</sub> cylinders that are stored in the cascade area and if a facility is not under tight inspections and visits, at the time when the enrichment process is shut down and nuclear materials are removed, the diverter will simply bring undeclared UF<sub>6</sub> feed to the facility and will process undeclared batch of material. The product of this activity is not declared and is shipped to an undeclared enrichment plant for further enrichment to HEU. This path is known as 'excess production'.

### Undeclared production of HEU

Enrichment facilities have a vast number of valves and long pipes of different kinds. Some may be isolated and difficult to find; it might be hard to distinguish the purpose of every pipe and valve. During suspension and under the cover of maintenance work and a need for dismantling, a lot of modification and reconfiguration in the facility and cascades layout could be carried out without detection.

If cascades are reconfigured in a new and simple design, it would be relatively simple to use the same facility for enriching uranium to higher levels. Undeclared feed could be used in order to get HEU product which can be shipped to an undeclared location for storage or further processing. If declared feed is used, the missing material would have to be declared as part of MUF or shipper-receiver differences.

### Using removed essential equipment

Because of the corrosive nature of UF<sub>6</sub> a considerable and extensive amount of work is needed to dismantle pipes, units, and systems to decontaminate and clean them.

Parts of centrifuges like the rotors, units in the cooling system, special pumps and valves, measuring instrumentation, sampling systems or electric converters are very unique. Some of these parts would have been specially designed for an enrichment operation. Procurement of such elements with fraudulent end-use explanations is difficult and risky. But planning and constructing an undeclared clandestine enrichment facility would require such hard-to-procure parts. Dismantling and removing essential equipment in preparation for suspension of a declared facility could be an opportunity to transfer key parts to a clandestine UEF elsewhere, which would become operational after the installation of the missing systems.

### **Possible remedies**

Because of the sensitivity of enrichment facilities and the high risk of diversion of valuable nuclear material for military purposes, one should be aware of the potential diversion routes and possible illicit and undeclared activities.

To ensure that there is virtually no risk of diversion of material or equipment during the preparation for or period of suspension, there is no way other than a complete disablement of some parts of the process and the facility. The IAEA should conduct appropriate verification activities through the Design Information Verification (DIV) and complementary accesses to confirm the absence of undeclared activities in a facility. The appropriate verification regime would be possible only under a specific agreement or as a transparency measure accepted by the State and facility operator.

The essential equipment of a UEF offers the possibility of second hand use; it could be reused at undeclared locations. This is the reason why tracking the removed essential equipment is necessary. Specially designed equipment, including parts of the rotor and the rotor itself, should be under appropriate surveillance. Furthermore, even if it might be difficult to track dual-use equipment and components, such as the electric supply system (with high-frequency converters) and mass spectrometers, it is very important to do so, both to assure that there are no undeclared uses and to maintain confidentiality of knowledge relevant to the technical proliferation of UEF.

Improvements are needed in many aspects of inspection and measurement in UEFs. The best means of improvement would be to increase the installation of unattended monitoring systems at key positions in the facility, like the feed stations, product collection areas, and around utilities like the power supply and cooling systems. It is important to improve the sensitivity of detectors used by IAEA inspectors in Non Destructive Assay (NDA) applications for measuring special nuclear material held up in piping along with radiation monitoring. This verification technique is called *online enrichment measurement*. In addition, there is a need to enhance inspector access and video surveillance inside cascade halls and other related rooms in the facility.

The IAEA should refer to the weighting of the indicators (*Weak, Medium, and Strong*) associated with each piece of the essential equipment identified in the physical model of a UEF, and accordingly assign a priority to the tracking efforts. The IAEA may also have the opportunity to implement other appropriate measures, such as the application of immobilization seals and surveillance systems to the removed equipment, prior to and until the start of dismantlement.

At each step of decommissioning, the IAEA should verify the status of the decommissioning phase, in order to assure that the process is irreversible. It is not possible to reconstruct an operational UEF with only auxiliary systems, dual use equipment and components, or individual equipment items, but the gathering of such equipment at one location, even though that this may be perfectly legal, must be seen as strongly indicative of future aspirations for building such a plant.

Therefore, the IAEA should pay more attention if such equipment is collected in one location. Generally, the suspension process, regardless of the length of the suspension period expected, should involve the following steps:

- a. Termination of UF<sub>6</sub> gas feeding into the process, stopping the rotation of the centrifuges and ensuring the discontinuance of centrifuge operation by cutting off the electric power supply of the equipment, and dismantling of electric power supply to the high frequency converters.
- b. Flushing out the residual uranium within the equipment and piping systems with IF<sub>7</sub> or ClF<sub>3</sub> gases; confirming the shutdown phase and measuring the amount of holdup during

- ventilation and decommissioning. Containers of recovered nuclear material should be sealed by the IAEA. Normally the amount of nuclear material will be small.
- c. Separation of the connections between the feed supply system, piping systems (cascades) and the product recovery system. The IAEA applies seals and surveillance systems to the feed system of the plant and any remaining UF<sub>6</sub> cylinders. Verification of the seals and surveillance system records should be carried out periodically. The IAEA should continue to implement routine inspections to verify the amount of nuclear material at the facility and to accomplish any *timeliness goal requirements*.
  - d. Confirmation of dismantlement of special equipment and infrastructures relevant to facility operations like the vacuum and cooling water supply system to the cascades, and verification of the status of special equipment that is removed; dismantlement of the on-line enrichment measurement system including the mass spectrometers and gas circulation pipeline to the measurement system from several positions of the piping system. The IAEA inspector can easily verify the stoppage of centrifuge operation by confirming the lack of shrill sound from the cascades. When a cascade is operating, a clearly audible high frequency sound comes from each rotor. The IAEA can apply a seal to the breaker of the electric supply system of the cascades. The seal should be verified periodically.

Based on the operator's information related to the schedule and the steps of decommissioning critical equipment at the plant, the IAEA must confirm each phase of dismantlement and removal of auxiliary equipment and systems. Particular maintenance work, and every sudden request for sampling, safety, or security checks, needs the approval and inspection of the IAEA. For the confirmation, it is necessary that the IAEA and the operator to reach agreement on an appropriate arrangement for submitting and updating the timetable for dismantlement.

Under an INFCIRC/153-type safeguards agreement, the IAEA retains the right and has the obligation to carry out DIV based on the declaration of suspension status by the operator. During that period, the IAEA has also the right to conduct complementary access to verify the absence of undeclared activities and nuclear material and to use unattended and remote monitoring. Under the comprehensive safeguards agreement, one week advance notification to the state for the implementation of the DIV is necessary [11]. The IAEA may need to seek the possibility to implement DIV with shorter advance notice. Generally, a DIV with a short time advance notice is a very effective measure to detect and to deter undeclared activities.

The IAEA can continue to carry out the confirmation activities as a part of its routine inspections of the facility. It is crucial to apply all the permitted activities under complementary access under Article 5.a.(i) and 5.a.(ii), in the INFCIRC/540 including visual observation; item counting; use of radiation detection and measurement devices; application of seals and other identifying and tamper-indicating devices; examination of records relevant to the quantities, origin, and disposition of nuclear material; and a collection of environmental samples [12]. Even after removal of all nuclear material, and loss of the capability for enrichment, the plant is still considered as a facility under safeguards and inspection.

In this manner, enhancing the IAEA legal mandate is crucial, by providing a specific mandate for IAEA verification of digression including full ("any place any time") access to IAEA inspectors



and the right to verify weaponization activities. Explicitly authorizing Agency inspectors to exercise the option of interviewing all relevant personnel related to the state's nuclear activities would also be very helpful.

There is a need for modifying the auditing and clearance process of reports inside the IAEA to ensure that the Board of Governors (BOG) has in front of it timely, full, and factual reports when it conducts its deliberations. Also, establishing a factual reporting mechanism directly from the inspectors to the BOG chairperson (not only before BOG meetings) is required. Mandatory reporting requirements on any import of dual-use equipment and/or materials relevant to the production of equipment should be designed, prepared, and added to existing requirements.

There is a need for introducing a mandatory requirement of the IAEA to provide each BOG meeting with a progress report on the investigation of open issues (both unanswered questions as well as unsatisfactorily addressed ones), as well as updates on the monitoring of suspension activities.

When safeguards are applied in the case of suspension, for states with a comprehensive safeguards agreement and an additional protocol in force, efforts must be made to implement the integrated safeguards approach for depleted, natural, and low enriched uranium conversion and fabrication plants together. This approach could shed light on investigation of nuclear material absence and undeclared activities in a state.

It is necessary to enforce compliance. Violations and/or incidents involving less than full cooperation with the verification requirements and mechanism (access denial, delay, or restrictions to sites, records, or interviewees) should lead to an immediate reporting to the BOG and preferably a special session of the BOG.

The aims of these steps are to strengthen the verification mechanism for "augmenting the suspension." Taken together such measures could create the proper policy in the case of the suspension of a uranium enrichment facility and reduce the risk of nuclear material diversion and performing undeclared activities. Because of the many potential diversion paths, transition to the stage of suspension cannot mean merely a standby process. It is essential to have some intrusive actions, including dismantling critical equipment, using seals on pipelines, continued monitoring etc.

## **Summary**

In recent years, the IAEA has been forced to cope with new political and technical challenges that are connected directly to safeguard requirements. In the near future, it may be necessary to adequately address the issue of suspension of nuclear activities as part of strengthening the safeguards regime. The aim of this work was an attempt to provide a general safeguard framework in the case of suspended enrichment facilities and to suggest a policy which might reduce diversion risks of nuclear material and essential equipment. The basic conclusions are as follows: (a) guaranties are necessary to ensure and verify that a suspended facility will not continue to operate in any condition, with or without nuclear material; (b) maintenance and safety operations should be the minimum needed and under external supervision; (c) removal of materials, machinery, and equipment outside the site should not be allowed without IAEA inspection involved; (d) the shutdown process should be handled carefully, verifying each

quantity in the material balance, inspecting the feed points, and outlets, characterizing, counting, and verifying waste streams and intermediate products, which are produced during the shut down process, cleaning, and decommissioning.

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