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BASIC ASPECTS OF A SAFEGUARDS APPROACH FOR A GASEOUS DIFFUSION ENRICHMENT PLANT

M. MARZO, A. BIAGGIO
ABACC - Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials

ABSTRACT

Safeguards-relevant aspects of the gaseous diffusion enrichment process and the main characteristics of a gaseous diffusion plant are described. The principal differences with the centrifuge process are indicated. In addition, basic safeguards' objectives for diffusion plants are presented and a concise diversion analysis is made. Also, the difficulties for carrying out some activities, such as a physical inventory verification that includes the in-process inventory determination, are summarized and possible solutions are outlined. Finally the paper presents a summary of the main control elements. It is noted that in spite of the fact that these studies where carried out for a small capacity gaseous diffusion plant most of the concepts can also be applied to larger plants.

1. INTRODUCTION

Since ABACC Secretariat started its operation, in the middle of 1992, a major concern was how to apply safeguards in two small enrichment facilities, one based on a diffusion process and the other on centrifuge.

Preliminary analysis, looking for ideas and guidelines in use in other parts of the world, showed that for centrifuge plants there was a significant amount of information on safeguards approach, safeguards activities and diversion scenarios [1,2,3,4], while the information on diffusion plants was scarce. ABACC, with the collaboration of the Argentinean Nuclear Regulatory Authority and other organizations, in particular for dealing with some specific PIV problems, has been studying how to apply safeguards to a diffusion enrichment plant and this paper summarizes these studies.

From the beginning, the studies clearly indicated that as the characteristics of a diffusion plant are quite different from those of a centrifuge plant, a simple extrapolation of the safeguards practices followed for centrifuge to the case of diffusion was not possible. Furthermore, the differences are such that some control elements used in the case of centrifuge plants would have no meaning in the context of a diffusion one.

2. BASIC INFORMATION

The basic separation element of the gaseous diffusion enrichment process is the diffuser. An enrichment stage is composed by diffuser, compressor, motor, cooling devices and linking pipework. The stages are connected in series to form a cascade. The UF_6 gas enters a stage and a portion of the gas passes through a membrane or barrier resulting in a slight separation of the U^{235} and U^{238} streams (theoretical separation factor about 1.004). The enrichment capacity of one diffusion stage is quite small; several stages are connected in series to build an enrichment module (that also have a small enrichment capacity) and several modules are connected in serie to form a plant. The diffusion process operates at relatively high temperature and pressure.

The main characteristics of the gaseous diffusion plant that have strong influence on the safeguard's analysis are:

(i) the high throughput and inventory: the throughput is some kg of UF_6 per minute and the in-process inventory is significant (typically 10% of the throughput); a small-scale gaseous diffusion plant has an in-process inventory of at least some tons of total Uranium.
(ii) the long time needed to reach operating equilibrium conditions: even for low enriched Uranium (LEU), it takes in the order of months to build up the desired U235 concentration profile.
(iii) the diffusion plant is huge, due to the number and size of the stages, even for producing LEU.
(iv) the stages are connected in series and therefore a LEU diffusion plant only could produce high enriched Uranium (HEU) by recycling batch-wise the enriched UF_6. (In the case of gas centrifuge, the parallel cascades could be connected in series.).
(v) when a gaseous diffusion plant designed for producing LEU is filled with LEU to produce HEU, the equilibrium time could exceed a year.

3. SAFEGUARDS IMPORTANCE: A COMPARISON WITH THE CENTRIFUGE PROCESS

Table I summarizes some important safeguards-relevant differences between the gaseous diffusion and gas centrifuge processes.

The number of stages required to produce LEU is about 30 times larger in the diffusion plant than in the centrifuge plant.

The corresponding equilibrium time is significantly longer in diffusion plants (months) as compared to centrifuge plants (hours). This effect, more intensive when the diffusion plant processes Uranium with higher enrichments, makes difficult and time consuming any significant change of the modus operandi of a gaseous diffusion plant.

The large in-process inventory in the diffusion plant (a few tons in a small-scale diffusion plant) indicates the importance of closing the Uranium balance in this facility. On the other hand, for centrifuge plants, the small equilibrium time, small in-process inventory and the flexibility to change the cascade design (parallel to series) determine the importance of verifying that the plant is operating as declared.

For safeguards' purposes, an important consequence arises from the differences between the two processes:

- In centrifuge plants the safeguard's approach should have as a key element unannounced inspections or equivalent tools to re-verify the design and confirm the operation of the plant;

- For diffusion plants the safeguard's approach should be mainly based on announced inspection to verify the material balance. In both cases complementary surveillance measures could be used for verification of the nuclear material flow between the storage and the process areas.

4. SAFEGUARDS OBJECTIVES AND DIVERSION SCENARIOS

The basic safeguards' objectives are to detect the diversion of significant quantities of nuclear material and to verify that the facility is operating as stated. In general, for enrichment facilities, the safeguards' objectives are:

(a) to verify that the inventory, flow of nuclear material and the facility operation are as declared; and
(b) to verify that the facility is not been used for producing undeclared LEU or HEU.

The possible diversion or misuse strategies that could be associated with gaseous diffusion plants are summarized in Table II.

The production of undeclared LEU seems to be the scenario to be considered and this implies that the safeguards' commitment has been violated at other facility. The strategies would be:

- the underestimation of the operating capacity, using the additional separative work capacity to process undeclared material or
- the operation during a declared shut-down.

However in diffusion plants, unlike centrifuge plants, it is difficult to conceal or modify the capacity and it easy to recognize the plant's operation because of the noise and temperature.

The scenario of HEU production can be considered as automatically controlled when the previous one has been covered because the production of HEU shall require to fill the cascade with LEU (some tons) and to reach a new equilibrium (about one year). Further, neither batch recycling (at least three times) nor reflux for the HEU production constitute a credible diversion scenario due to the very long timescales involved [5].

Diversion into the material unaccounted for (MUF) is limited by the MUF value, that in a small-scale diffusion plant should not be relevant.

5. SAFEGUARDS APPROACH FOR A SMALL-SCALE DIFFUSION PLANT

A safeguards approach for a small-scale diffusion plant embraces nuclear material accountancy, containment and surveillance, and inspection activities, including some design information verification.

The safeguards' goals for a gaseous diffusion plant designed to produce LEU are:

(a) to detect an abrupt diversion of about 75 kg of U-235 contained in LEU in 1 year[1], and

[1] Usually 30 kg of U^{235} contained in LEU is the safeguards goal for centrifuge plants

(b) to detect along a year the protracted diversion of about 75 kg of U-235 contained in LEU.

As was indicated, the production of HEU would require to operate the plant during more than a year using LEU as feed, a situation that would be detected when covering the other goals.

Considering these goals, a frequency of announced inspections to the facility can be established, consisting of a physical inventory verification per year and a few interim inspections. It should be noted that neither the operating conditions of the facility can be easily modified as to accommodate the process before an announced inspection takes place nor the operation can be easily restarted after a shut-down.

These activities could be supported by a C/S System, aimed at confirming that only verified feed cylinders are connected to the F/W station.

Samples could be taken from the feed, product and tail streams to confirm that the enrichment is within the declared range or confirmation that the level of enrichment has not been exceeded could be obtained through go/no go measurements. With the same purpose, swipe sampling could be taken; although in this case the results are available with a remarkable delay. The continuity of the pipelines between the feed/withdraw station and the cascade area should be verified and the size (number of modules) of the plant reconfirmed.

5.1. Nuclear material accountancy and MBA

Usually, an enrichment facility has two material balance areas (MBA): MBA 1 is the storage of UF_6 cylinders, that accounts for all the transfers from/to the facility; MBA 2 is the process area that includes the feed and withdraw (F/W) station, the cascade and could also include equipment cleaning and other laboratories.

As usual, a basic condition should be that feed cylinders shall not be connected to the process before they are made available for verification and product and tails cylinders shall not be shipped out or blended before they are made available for verification.

Because of the large in-process inventory, the inventory changes should be informed as unified Uranium; so the operator's total Uranium and U^{235} mass balances can be easily verified.

5.2. Inspections

5.2.1. Physical inventory verification (PIV)

The PIV should be performed simultaneously to, or shortly after, the facility Physical Inventory Taking (PIT). During the PIT/PIV, the process operation is not interrupted. Natural and depleted UF_6 cylinders should be verified for gross and partial defects and the LEU UF_6 cylinders also for bias defects.

As the in-process inventory is a major component of the overall nuclear material inventory, a relevant activity in relation to the PIV is its verification and a special NDA method for diffusion plants has been developed [6,7]. The Uranium involved in the enrichment process contains a gaseous and a solid phase. The solid phase mainly comprises material retained in the membranes and internal surfaces. The overall gas:solid ratio is about 3:1. The NDA method is based on the relationship between the mass of U235 contained in a diffuser and the count rate produced in a NaI(Tl) detector, by the absorption of the 185.7 keV gamma-ray, emitted by that nuclide, measured using a multi-channel analyzer coupled to the detector. Results of the application of this method show that with an adequate sampling plan, the inspectors can verify the declared hold-up inventory with about 3% uncertainty [8]. This figure seems to be quite adequate for closing satisfactorily the material balance.

5.2.2. Interim inspection for flow verification

Interim inspections should be performed periodically to verify the transfers from/to the facility and the nuclear material flow between the storage and the process areas. In such inspections the accounting and operating records are audited and feed, product and tail cylinders should be verified.

5.3. Containment and surveillance

Containment and surveillance measures could be applied at the feed/withdraw station to assure that only previously verified UF_6 feed cylinders are connected. A solution that integrates cameras and active seals seems to be the best approach considering both the cost and the state of the art in the area of integrated monitoring. ABACC is studying this system for its application in centrifuge and gaseous diffusion plants.

When verifying the feed cylinder, the inspectors would place an active seal on it (the indication of seal connected should be automatically recorded at that time). Later, the operator, under surveillance, would make the “lecture” of the seal and detach it. Both signals, first of reading of the seals as connected to confirm its “health” and second the signal of seal opened should be recorded, and constitute an input to the surveillance system. The cameras themselves should be able to assure that no cylinder is connected without detection and the combination of active seals and cameras should be able to confirm that only verified cylinders have been connected as feed during the time period.

6. CONCLUSIONS

A safeguards approach for a small-scale gaseous diffusion enrichment facility can be satisfactorily developed. The detection of LEU diversion is important in diffusion plants, due to the uncertainty in the material balance. However in a small-scale diffusion plant, it is possible to meet the safeguards' goal by applying a NDA method to determine the in-process inventory. The main element of such safeguards' approach is the performance of announced inspection for verification of nuclear material transfers from/to the facility and between the storage and the process areas, and for physical inventory verification.

Measures of containment and surveillance to the Feed/Withdraw Station could be applied to assure that the plant is fed only by pre-verified nuclear material.

Although a small-scale diffusion plant seems to be not suitable for the production of high enriched Uranium, the detection of HEU production could be achieved indirectly by controlling the plant feeding, and directly by sampling the feed, tail and product streams. Application of a go/no go system could be used for additional confirmation that the enrichment is within the declared range. Swipe sampling could also be used for this purpose, although in this case the conclusion of the activity would have a remarkable delay.

As result of these studies it was not identified any credible diversion scenario that requires to carry out unannounced inspections. Finally, it is noted that in the context of the new technologies, if an unattended system is installed, unannounced inspections could play a role for confirming that such a system is working properly.

8. REFERENCES

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Table I. Comparison between gaseous diffusion and gas centrifuge enrichment processes

	GASEOUS DIFFUSION	GAS CENTRIFUGE
Nuclear material	UF6	UF6
Separation factor	~ 1.004	1.2 - 1.6
In-process inventory	order of tons (~10% throughput)	order of kg (~0.02% throughput)
Specific inventory (kg U/SWU/y)	0.1 - 0.3	~ 0.0005
Throughput	high	low
Specific energy consumption (kWh/SWU)	2300 - 3000	100 - 300
Parallel Module	no	yes
Stage reflux mechanism	none	yes
- Number of stages (ideal cascade) to produce 3%	~1400	~50

enrichment Uranium from natural Uranium with 0.2% tails; - equilibrium time	 months	 hours
- Number of stages (ideal cascade) to produce 20% enrichment Uranium from 3% enriched Uranium with 1% tails - equilibrium time	~1600 ~ 1 year	~60 hours

Table II. Analysis of the diversion/misuse scenarios and proposed safeguards measures for a small-scale diffusion enrichment plant.

DIVERSION/MISUSE SCENARIO	CONCEALMENT METHODS	SAFEGUARDS MEASURES
1.- Abrupt or protracted diversion of declared Uranium	- Removal and substitution with natural Uranium, depleted Uranium or dummy; - Diversion into the MUF;	- Verification of feed, product and tail UF_6 cylinders; - Closing the U and U-235 mass balance during the PIV.
2.- Undeclared production of LEU; feeding with declared Uranium	- Substitution of material with falsification of accounting and operating data; - Overestimation of the in-process inventory;	- Same as in (1) - Containment and Surveillance at F/W station; - Matching among feed, product and tail and operation time.
3.- Undeclared production of LEU; feeding with undeclared Uranium	- Underestimation of the operating capacity; - Operation during declared shut-down	- Matching among feed, product and tail and operational data. - Access to the cascade area to confirm the operational status of the facility. - Containment and Surveillance at F/W station;
4.- Production of HEU	- Feeding with LEU - Batch recycle; - Reflux operation - Undeclared separative capacity	- Same as in (3) - Sampling of feed, product and tail streams; - Use of a NDA system go/no-go; - Swipe sampling;