CLOSING THE SWU BALANCE ON A RANDOM BASIS

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Definition of the Problem

The safeguards' objectives for enrichment facilities encompass the detection of the diversion of declared nuclear material and facility misuse. Diversion scenarios on declared nuclear material include inflating the MUF and or concealment of diverted material introducing gross, partial or bias defect into uranium or isotopic content in some items, complemented with data falsification.

Relevant scenarios of facility misuse include the production of high-enriched uranium (HEU) or low-enriched uranium with enrichment higher than 5%; and undeclared production of low enriched uranium with enrichment lower than 5%.

While the installed separative work capacity and the throughput are small, misuse scenarios are the dominant concern from the safeguards point of view, particularly those associated with feeding the plant with undeclared LEU.

One on the main misuse scenario at centrifuge enrichment facilities is the SWU deviation. The operator declares that has used X SWU/y, but effectively he used Y<X for production of declared enriched uranium and uses the difference X-Y to enrich undeclared uranium. That means the operator can divert SWUs. Swipe environmental sampling is presently the most powerful tool to confirm the absence of unrecorded production of direct use material. The verification of the SWU balance, associated with U and U-235 mass balance, is another relevant measure to detect SWU diversion. The traditional approach for enrichment facilities foresees the closing of the SWU balance once per year, at the end of the Material Balance Period, at the Physical Inventory Verification. This has two disadvantages: the uncertainty associated with the SWU closing is relatively high because it is performed only once per year and this scheme does not introduce any deterrence into the verification.

The introduction of enrichment and flow monitors on line in the headers would be a measure to confirm the SWUs that are really used in the enrichment process. Such monitors however are under development and not yet available for safeguards purposes. As an alternative measure to the enrichment and flow monitor, a scheme of closing periodically the SWU balance at randomly selected opportunities is proposed.

Objective

The objective is to verify the facility operator's declaration on the SWUs that are used during a certain period of time on a random basis. To increase the effectiveness of the safeguards approach, the closing of the SWU balance is performed on a timely random basis, in such way

that the facility operator never knows the date of the SWU balance closing. The unpredictability introduces significant deterrence into the approach. In addition to that, as the balance is closed more frequently, the uncertainty is lower and it is more difficult to hidden potential SWU deviation.

Verifying the Facility Operator's Declaration on the Used SWUs

The conceptual idea is to request from the facility operator an advance notification on operational program using a mailbox (or similar) and to verify its declaration at point on time selected by the inspectors (during announced or unannounced inspections).

Let's assume a Material Balance Period (normally one year). The facility operator declares monthly at instants t_0 to t_{12} an operational program containing the following figures:

- The planned SWUs to be used in the next three months period;
- The real SWUs used in the last month;
- The gross weight of product, feed and tail cylinders that are connected to the process (kg of UF6) at the instant of the declaration;
- The U-235 content of the product, feed and tail cylinder (x_P, x_F and x_W) that are connected to the process at the instant of the declaration.

The facility operator should inform immediately to the inspectors any change to the operational program.

It is assumed that the facility is operating on a routine basis, i.e. the values of x_P, x_F and x_W are approximately constant.

Let's consider the inspectors select the inspection at the instant t_I to perform the SWU balance closing. At this instant the inspectors have available from the last facility operator's declaration (OD_2) the following data:

$\Delta U_{2\text{-}5}$ = Separative Work Units to be used between t_2 and t_5 (3 months)
ΔU_2 = SWUs used between t_1 and t_2 (1 month);
P_2, x_P = Weight and enrichment of product cylinder connected to the process at instant t_2
W_2, x_W = Weight and enrichment of tail cylinder connected to the process at instant t_2
F_2, x_F = Weight and enrichment of feed cylinder connected to the process at instant t_2

They also know from the past declaration (OD_1) the SWUs used between t_0 and t_1 (1 month);

At instant t_I the inspectors verify the weight of the cylinders connected to the process, as follows:

$P_2+\Delta P$, x_P

$W_2+\Delta W$, x_W

$F_2+\Delta F$, x_F

ΔP, ΔW and ΔF are the weight changes since t_2 , which can be expressed easily in [kg/d] or [kg/y];

For this purpose inspectors access to the facility load-cells is required. The inspectors can verify the load-cells using standard weights. Load-cells calibration should be performed during any announced or unannounced inspections, in the case that feed, product and tail cylinders are not connected to the process.

x_P, x_W and x_F are the U-235 concentration measured through DA from sampling of the product, tail and feed currents. The proposed methodology considers the sampling from the currents because, even in the case of high facility flexibility that allows quick cascade reconfiguration, the sampling can be performed before cascade stabilizing.

The SWUs that have been used by the facility operator between t_2 and t_I are given by:

$$\Delta U = \Delta P.V(x_P) + \Delta W.V(x_W) - \Delta F.V(x_F)$$

Where V(x) are the usual potential function, which is given by:

$$V(x) = (2x - 1)\ \ln[x/(1-x)]$$

In the case that there was change of cylinder in the period of time between t_2 and t_I, the inspectors verify the cylinders connected to the process with the following values:

P' , x_P
W', x_W
F' , x_F

The inspectors also verify the cylinders that were disconnected since the previous declaration:

$P + \Delta P$, x_P
$W + \Delta W$, x_W
$F - \Delta F$, x_F

In this case the SWUs that were used between t_2 and t_I are calculated as follows:

$\Delta U = (P'+\Delta P).V(x_P) + (W'+\Delta W).V(x_W) - (F'+\Delta F).V(x_F)$

This ΔU value will be used by the inspectors to evaluate the facility operator's declaration.

Evaluation of the SWU Balance

At the time of the inspection (t_I) the inspectors know the following data:

a) The SWUs values ΔU_1 and ΔU_2, which are really used in the intervals (t_0-t_1) and (t_1- t_2), respectively, as declared by the facility operator;
b) The determined value ΔU_1 and ΔU_2, from the verification of the cylinders disconnected between (t_0-t_2);
c) The determined value ΔU that is a fraction α of $\Delta U3$, which are the SWUs used in the interval (t_2- t_3). ΔU indicates how much of SWUs used in this interval was verified by the inspectors. That means $0<\alpha\leq 1$. In the case the inspection date is selected closer to t_3, the value of α will be closer to 1. In the case the inspection date is selected closer to t_2 , the value of will be closer to 0.

The inspectors can analyse the consistency of the facility operator's declaration through the comparison between the calculated value ΔU_1+ ΔU_2+ ΔU with the facility operator's declaration. (ΔU_1+ ΔU_2+ ΔU_3)

Final Remarks

The proposed methodology allows a quite precise continuous follow-up of the facility operation in terms of separative work capacity. As the SWU balance closing can be performed either in announced inspections or unannounced inspections – it is up to the inspectors to decide - there is an adequate flexibility to select the best opportunity to maximize the verification. Anyway, with a certain delay, a precise verification of the facility operator's declaration can be performed.

It is required from the facility operator precise operational information on a timely manner (monthly). The declaration on the separative work capacity and the used SWUs are very relevant. Any significant discrepancy between the declared and verified SWU value is considered an anomaly and should be investigated. In such cases, additional swipe sampling and unannounced inspections should be performed.

The proposed methodology can be applied for any facility, the frequency of closing the SWU balance depending on the facility capacity.

Although the methodology requires a detailed operational program from the facility operator, no access to sensitive information is required.