THE NEW VERIFICATION APPROACH BASED ON CONTINUOUS COLLECTION AND ANALYSIS OF OPERATIONAL DATA IMPLEMENTED AT THE GEORGES BESSE II GAS CENTRIFUGE ENRICHMENT PLANT

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ABSTRACT

The Georges Besse II enrichment plant located in Pierrelatte (France) is based on the ETC gas centrifuge technology and operated by Orano. It reached its full production capacity in 2016. The facility is under Euratom safeguards and has been designated since the beginning of the project for IAEA safeguards. The initial verification approach was similar to those applied at other enrichment plants under Euratom and IAEA safeguards. Since 2008, the operator, the State authorities, Euratom and the IAEA cooperated, through the French and the EC support programmes, on the development of a new approach based on the recording and analysis of operational data.

Dedicated software tools were created to enable continuous data collection from the cylinder weighing and mass spectrometry systems. The data is immediately secured under the inspectorates' custody and can be retrieved for analysis. The software application, "Inspector Studio GBII", developed by the EC Joint Research Center Ispra in cooperation with the IAEA, allows to confirm at any time that the flow of nuclear material within the facility is balanced. It enables the verification of declared uranium content and isotopic composition in each and every tails and product cylinder produced. It also provides a robust verification of the absence of undeclared production of LEU from undeclared feed and absence of production of uranium enriched at higher levels than declared.

Nevertheless, Limited Frequency Unannounced Access (LFUA) inspections remain one of its key elements, to conduct specific activities providing confidence that the data collected when inspectors were not present, remained valid, genuine and representative of the plant operation.

The EC Server, thoroughly tested during the last five annual physical inventory verifications, is now 100% operational, including modifications that effectively address the latest cybersecurity challenges and other demands raised during tests by the inspectorates. The new safeguards approach has thus been implemented by the IAEA since November 2020. The Facility Attachment is about to be finalized as well as the Euratom Safeguard Provisions. The new GBII approach demonstrated its reliability and significantly enhances effectiveness and efficiency of the verification activities in such large throughput facility and the concept could be considered for implementation in other similar facilities.

INTRODUCTION

Uranium enrichment is one of the essential step of the fuel cycle to produce a fuel assembly applicable to light water power nuclear reactors, which use low enriched uranium. At the same time, the enrichment technology potentially allows to enrich uranium to higher level of U-235 content, which implies a major risk of nuclear proliferation. As a result, international treaties and safeguards agreements have always put enrichment plants among the short list of top nuclear proliferation concerns.

The George Besse II gas centrifuge plant (GB II) is located in Pierrelatte (France). Its enrichment process is based on the Enrichment Technology Company Ltd. (ETC) gas centrifuge technology and operated by Orano. GB II reached its full production capacity in 2016.

Applying international safeguards to GB II requires complying with international commitments, such as the Non-Proliferation Treaty [1], the Trilateral Agreement between the IAEA, France and Euratom [2] and chapter VII of the Euratom Treaty [3]: the facility is under Euratom safeguards and has been designated for IAEA safeguards in 2009. The initial verification approach was similar to those applied at other enrichment plants under Euratom and IAEA safeguards.

GB II is one of the largest gas centrifuge plant in the world. The very large-size of that bulk-handling facility represents a challenge for implementing a safeguards verification scheme that comprehends verification of all flows and inventories of the involved nuclear material. Moreover, two additional issues had to be taken into account for the design of the new safeguard verification scheme:

- The enrichment plant makes use one of the most performant centrifuges currently available, which associated technology represents a very sensitive issue in terms of industrial secret;
- The level of automation of the plant makes GB II a potential target of cyberattacks that could cause serious safety and security issues.

Since 2008, the operator Orano, the French authorities, Euratom and the IAEA cooperated, through the French and the EC support programmes, on the development of a new approach based on the recording and analysis of operational data to ensure a successful implementation of international safeguards, going one step further than the initial "traditional" approach.

In particular, the experience gathered by both IAEA and Euratom inspectors in similar large nuclear installations as well as the availability of new hardware and the development of a dedicated network (EC Server) and IT application (Inspector Studio) played an essential role in making real the "new approach".

VERIFICATION FEATURES OF THE EC SERVER

<u>Data types and acquisition:</u>

For (cyber)security reasons, the data from the three installations of the GB II plant (GB II North, GB II South and REC II - the blending unit) are collected separately. Currently, only the information from GB II North and GB II South is analyzed and interpreted by Inspector Studio. At the beginning of the project, it was decided that the data from the load cells station would be made available by the Operator at a defined and commonly accepted frequency excluding *de facto* a direct acquisition from the load cells. This limited frequency aimed to avoid revealing commercial information as well as sensitive technical information linked to the uranium enrichment technology using centrifuges.

The sharing of the load cell information via operator acquisition modules led to set up security systems to prevent that any possible malevolent pieces of code could flow "backwards", i.e. from Euratom system to the Operator's one, and cause damages and this despite the Euratom

acquisition systems are isolated from the "outside world" in dedicated rooms and that any operating system or application update is duly scrutinized on a terminal maintained by the Operator to detect any possible presence of malwares.
Since 2010's, the increasing cybersecurity concerns led to put in place more stringent data exchange systems before making the load cell data available for storage in data historians hosted on redundant Euratom servers for each GB II installation to be analyzed and interpreted by Inspector Studio (see Figure 1).
In addition to load cells data made available every 10 minutes, data is also acquired from on-line mass spectrometers, which acquisition frequency depends on the type of material (feed, product or tail) and from accountancy scales for each cylinder entering or leaving the enrichment process area.

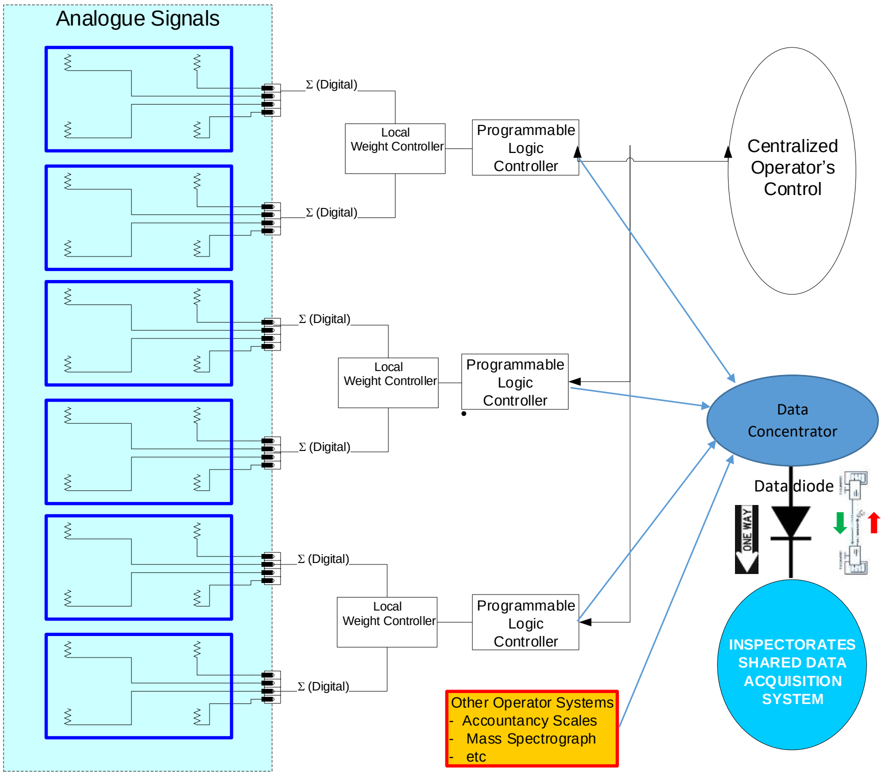

Figure 1 - Simplified schema of the new acquisition architecture

Inspector Studio:
This safeguards data evaluation tool was developed by the Joint Research Centre (JRC) of Ispra through the French and the EC support programmes to the IAEA. It aimed to support both Euratom and IAEA safeguards activities at the GBII plant while reducing undue interference in the operation of facility. Among its functionalities, we can list the possibility to display information of all the stations of any module, to make consistency checks between load cells and accountancy scale data, to calculate and evaluate the mass balances of uranium and uranium-235, to calculate uranium enrichment, to track the route of any cylinder within the process area, to perform statistical tests, to display the filling or emptying curves of any cylinder.
Of course, the application also offers the possibility to check the good working order of the acquisition system (state of the acquisition for each equipment) and the pertinence of the data. Some features are reported hereunder but for a more complete technical description of Inspector

Studio, the lecturers are invited to refer to the paper published at the occasion of the 2017 INMM conference [4].

The snapshot (see Figure 2) displays information pieces such as the gross and net weights, the cylinder identifications and the on-line status to the cascades for all stations of a selected module. Double clicking on any station will lead to the display of the emptying-filling curves during the define time window, part of the data authentication.

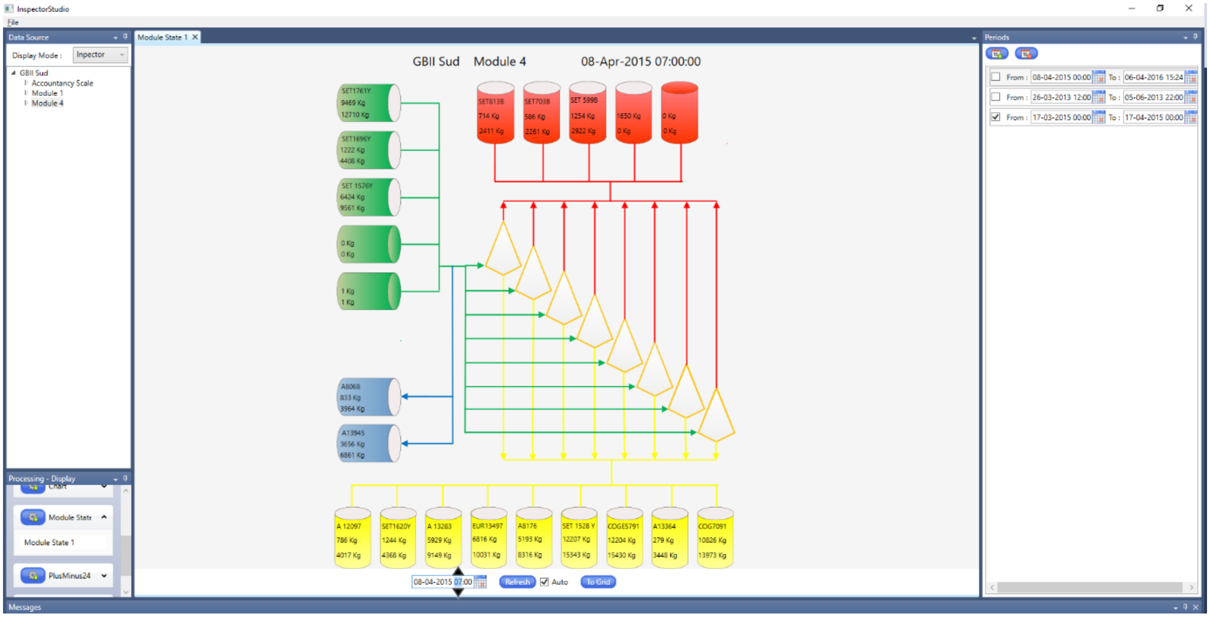

Figure 2 - Snapshot at time "t" of all stations of a module.

Mass balance

Figure 3 - Mass balance details for Feed cylinders

For a selected period (masked for confidentiality reasons), the information for all cylinders of all stations involved in the enrichment process is retrieved (for more clarity only the feed stations are shown in the Figure 3). Mass balances are then calculated using the accountancy scale (PP, *pesée précise*) data if available or the station load cell information. Consistency checks between both types of weighings are also performed according to parameters set by an application administrator.

Product or tails cylinder uranium enrichment

For a given product or tails cylinder, provided that the mass balance is respected, Inspector Studio can compute its uranium enrichment making use of the enrichment reported for the other, tails or product, withdrawal stream (see Figure 4).

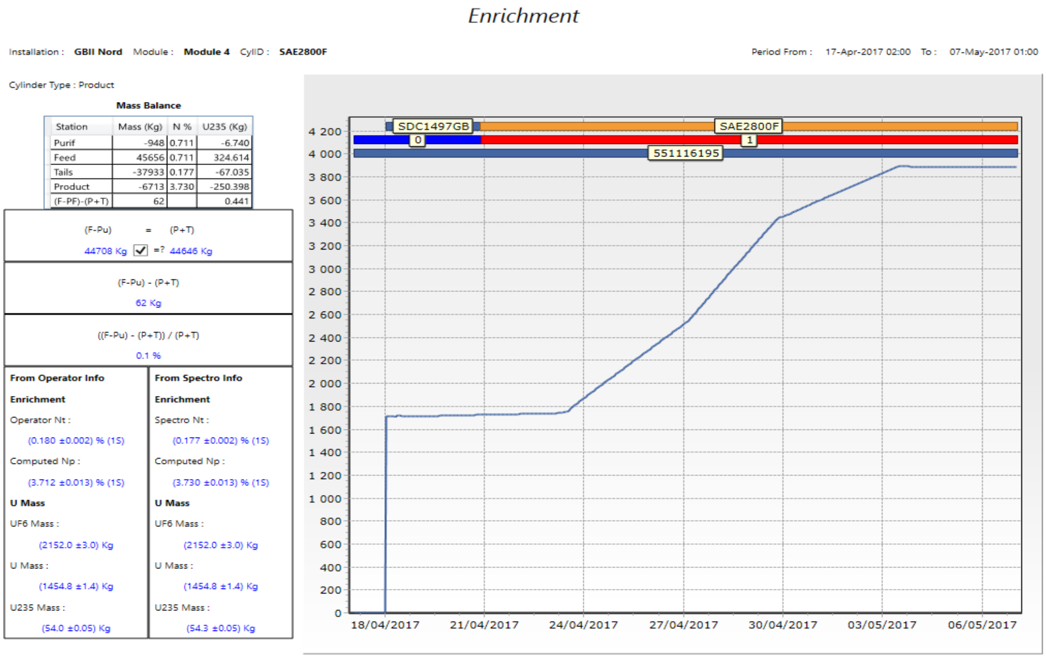

Figure 4 - Enrichment calculations for a given cylinder and its filling-up pattern

Enrichment over a time window:

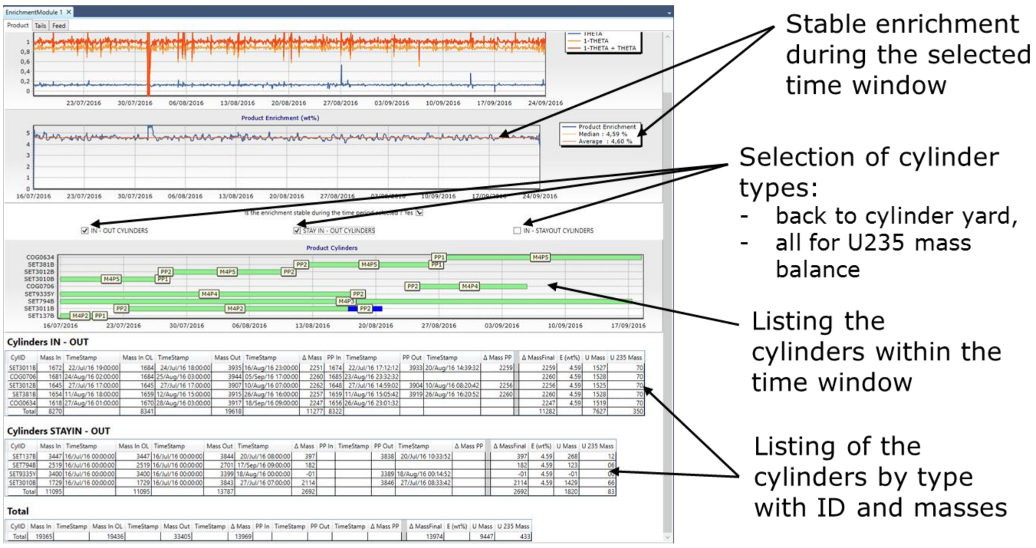

Figure 5 - Enrichment for a defined time window and listing of cylinder IDs

Inspector Studio also computes the uranium enrichment over a selected time window. If it appears to be stable during this period, the tool will list the product cylinder information for which the enrichment should be the same (see Figure 5).

NEW SAFEGUARDS APPROACH AT GBII

The safeguards objectives for GBII are based on the 2006 Model safeguards approach for Gas Centrifuge Enrichment Plants (GCEPs) [5], which includes availability for verification of all UF_6 cylinders flowing into and out of the plant, as well as the State-specific factors for France. In order to ensure 100% availability of all flow cylinders for verification, the initial approach of 2008 included monthly inspections for flow verification and the requirement for the operator to retain all cylinders received from off-site or from the process (hereafter referred to as "flow cylinders") between scheduled inspections.

Implementing, the conventional approach at the very large-sized GBII industrial site induced considerable engagement of human resources. The operator, the French authorities, Euratom and the IAEA cooperated, through the French and the EC support programmes, on the development of a new approach. Boundary requirement were that this new approach would ensure effective protection of Orano's industrial proprietary knowhow and ETC's technology in use at GBII. Moreover, due consideration had to be given to the fact that the level of automation of the plant as well as the use of one of the most performant centrifuges currently available and associated technology, makes GB II a potential target of cyberattacks that could cause serious safety and security issues.

Now implemented, this new approach utilizes data collected by the EC Server to suspend the need for scheduled monthly inspections and obligation to the operator to retain flow cylinders for verification at the facility. Data collected by the EC Server also enables a verification of in-process material during the Physical Inventory Verification (PIV) without the need to disconnect cylinders from the production process (aka ``switch over``). The main safeguards measures of the approach are:

- Annual PIV: for verification of inventory and flows;
- Design Information Verification (DIV): for verification of the declared design information;
- Interim inspections needed to support completion of the PIV. A pre-PIV inspection will be necessary during each Material Balance Period (MBP) to evaluate EC Server data related to flow of UF_6 throughout the MBP, and a post-PIV inspection will be required to evaluate the verification of in process material and complete any other follow-up activities from the PIV;
- Limited Frequency Unannounced Access (LFUA).

The previous approach relied on the principle of random selection in the population of flow cylinders for verification measurement and sampling, which was resource-intensive and variable depending on the facility throughput in a given period. By implementing the new approach based on the automatic acquisition system, the declared nuclear material flow is verified by a combination of item counting, tag checking, weighing, non-destructive assay (a reduced and fixed number of measurements to provide quality assurance of the captured data), and sampling. The EC system provides the possibility for 100% flow verification coverage of product and tails cylinder for partial defect (weighting and enrichment), as well as removal of the necessity for any physical cylinder "switch-over" operations during the PIV.

A mass balance calculation at module level is used on systematic basis as the initial step of data evaluations to confirm integrity of the data and absence of unbalance in the material flow.

The data for any nominated cylinder can be retrieved from the EC Server and retrospectively analysed. As a practical matter, every product and tails cylinder from a particular module over

a given time period has identical process flow characteristics (feed/product ratio). A report can be generated periodically by Inspector Studio, which provides verification data (weight and enrichment) for every product and tails cylinder.
The activities carried out during LFUAs, (checking feed station occupancy, header DA samples) are used to provide additional assurance of the collected data and correct operation of the EC Server. Other LFUA activities, including visual observation in cascade hall, are conducted as in the past.

BENEFITS OF THIS NEW APPROACH

Efficiency

Thanks to the new approach, the inspectors can reach satisfactory safeguards conclusions while investing an effort that in the past would have been substantially higher. Namely, the IAEA has now reduced of 60% the person-days of inspection.
Euratom has kept the same inspection effort also with the new approach so that, by visiting more often the GB II facility than the IAEA, Euratom safeguards inspectors can maintain the dedicated IT system and perform physical verifications that are then authenticated by the IAEA.
The new verification approach allows safeguards inspectors, IAEA and Euratom, with a globally reduced effort, to gather much more data and elaborate them more extensively then before, finally obtaining a considerable, deeper and tighter control on the nuclear material involved in the enrichment process.
Since the beginning of the Covid pandemic, ensuring continuity of safeguards verifications was particularly challenging because of restrictions applicable to international travels and presence of inspectors at nuclear sites. At that occasion, the new GBII approach was instrumental in effectively mitigating the impact of such restrictions and the IT application “Inspector Studio” proved to be a very valuable tool for both retrieving the data from the EC Server and providing the inspectors with accurate mass balances relative to long periods. This proves that the current verification scheme enables robust mitigation of the risk of losing continuity of knowledge also during long periods of absence of inspectors in GB II.

Effectiveness

The new safeguards approach applicable at GBII provides substantial effectiveness enhancements. The load cell data evaluated by the Inspector Studio applications supports the verification of both the mass and enrichment of UF_6 contained in all cylinders emptied and filled between inspections.
Verification of UF_6 cylinders is traditionally based on weighing and enrichment assay from either Destructive Analysis (DA) or Non-Destructive Assay (NDA) of the involved UF_6. Effectiveness of such verification assumes that the cylinder tare weights are known and that the totality of the weighed material is actually UF_6. Continuous monitoring generates data supporting confirmation that filling did occur at a takeoff station and that its filling rate was consistent with normal operation of such station. A substantial effectiveness gain therefore resides in the fact that the load cell data provides additional assurance that the weighed material in cylinders is indeed UF_6.
The initial step of the procedure for evaluation of the load cell data consists in confirming the balancing of the material flows in the process. That provides evidence that the totality of the material feed to the process is properly declared as matching quantities and assays of product and tails. Compared to the “traditional” approach, the GBII approach provides additional evidence that the material presented for verification does originate from and represents the totality of the operation of the plant.
Verification of the absence of undeclared production from undeclared feed at large facilities is always a challenge because knowledge of the content of cylinders cannot be maintained all over

the process. Verification of feed station occupancy during LFUA using a mailbox system is one of the measures traditionally used to confirm the absence of undeclared production. However, because so far UF_6 cylinders are not uniquely identified, the feed occupancy verification measure can only provide assurance that the number of cylinders attached to the production process at the LFUA time is as declared via the mailbox. Now, at GBII plants, all feed and take off stations are permanently monitored. Any presence of an undeclared feed cylinder connected to the feed stream (i. e. with its weight evolving over time) would induce records that will lead to the identification of an imbalance of the material flows. The induced effectiveness gain is that detection probability of undeclared production from undeclared feed by load cell monitoring is dramatically enhanced compared to traditional approaches.

Under the 2006 model safeguards approach for GCEPs, all new feed material and all new product and tails cylinders since the previous inspection should be made available for verification. This requirement is typically implemented by applying a 'residence time' to all flow cylinders until the inspection following the flow transaction; i.e. when a feed cylinder is received, it should be held in the feed storage area until the next scheduled interim inspection so that inspectors have the opportunity to verify it. Similarly, when a tails cylinder is detached from the process or when a product cylinder is ready for shipment, it must be held in the storage area until the next scheduled interim inspection. The Facility Attachment (FA) to the Subsidiary Arrangements of the Safeguards Agreement between France, Euratom and the IAEA provides for shorter residence times in exceptional circumstances given proper advance notification. However, continuous data collection in the custody of the EC Server enables a safeguards approach where the requirement for the operator to retain new flow is suspended.

APPLICABILITY TO OTHER PLANTS

Continuous monitoring of the operator weighing systems is particularly beneficial at large plants where UF_6 cannot practically be kept under continuity-of-knowledge (i. e. flow cylinders placed under containment/surveillance measures). Options for sharing of data collected from operator systems for safeguards verification purposes at GBII have been thoroughly evaluated at the project initiation phase back in 2008. Splitting the analog signals from the load cell sensors had been considered unrealistic and collection of the data relevant to weighing at the level of the Programmable Logic Controlers (PLC) found the optimal option.

Experience showed that cybersecurity challenges induced by extraction of the data at the closest possible location from the sensors induced considerable efforts and expenditures from involved parties, as well as adaptability to the evolving threats. Provided that shared data is placed continuously and in real-time under the inspectorates' custody, sharing of the weighing data at the level of the centralized supervision system of the plants would be adequate. Specific additional measures, including presence of inspectors, might be necessary to ensure authenticity of the shared data. However, regardless of its point of collection, the shared data could be processed with an application similar to the Inspector Studio and provide the same benefits at other enrichment facilities.

Emphasis must be placed on the fact that applying safeguards by design is the best practice to recommend for any new enrichment plant or any important change in an existing facility wishing to adopt a similar approach. The sooner the discussions between the international safeguards inspectorate(s), the national authorities and the operator begins on the safeguards control, the better and the easier it will be to implement innovative tools that will benefit both to the inspectorates and the operator.

CONCLUSION

The new safeguards approach implemented for few months at GB II is based on a combination of evaluation of weighing data collected from operator systems into the EC Server, and on inspector's activity at the site. The EC Server with its associated Inspector Studio application proves to be reliable and adaptive tools. Nevertheless, longer term experience will progressively build the insight into the overall benefits of the approach. For the time, it is remarkable that the numerous challenges associated with the technology and methodological aspects of the new approach have been collectively met, including mitigation of cybersecurity risks, thanks to a constructive and quality dialogue with all the stakeholders.

Will it be inspiring for implementation of safeguards verification at other enrichment plants?

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REFERENCES

[1] Treaty on the Non-Proliferation of Nuclear Weapons (INFCIRC/140), signed in Vienna in 1968 and entered into force on 5 March 1970.

[2] Agreement of 27 July 1978 between France, the European Atomic Energy Community and the International Atomic Energy Agency for the Application of Safeguards in France (INFCIRC/290).

[3] Treaty establishing the European Atomic Energy Community, signed in Rome on 25 March 1957. Title II "Provisions for the encouragement of progress in the field of nuclear Energy", Chapter 7 "Safeguards".

[4] P. RICHIR et al., "Development and Functionalities of a Software Tool to Perform the Monitoring for Safeguards Activities of Gas Centrifuge Enrichment Plants Making Use of Load Cell, Accountancy Scale and online Mass Spectrometer Plant Data", 58th Annual Meeting of the Institute of Nuclear Materials Management (INMM), 16-20 July 2017, Indian Wells, California, USA.

[5] BUSH, W ; et al., ``Model safeguards approach for gas centrifuge enrichment plants``, IAEA-CN-148/98, Symposium on International Safeguards, Vienna, Austria, 16–20 October 2006.