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Title: Status Report on the Passive Neutron Enrichment Meter (PNEM) for UF6 Cylinder Assay

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Status Report on the Passive Neutron Enrichment Meter (PNEM) for UF_6 Cylinder Assay

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State-of-the-Art NDA Methods Applicable to UF_6 Cylinder Assay: Phase II
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I. PNEM STATUS REPORT

I.A. Background

The Passive Neutron Enrichment Meter (PNEM) is a nondestructive assay (NDA) system being developed at Los Alamos National Laboratory (LANL). It was designed to determine ^{235}U mass and enrichment of uranium hexafluoride (UF_6) in product, feed, and tails cylinders (i.e., 30B and 48Y cylinders). These cylinders are found in the nuclear fuel cycle at uranium conversion, enrichment, and fuel fabrication facilities. The PNEM is a ^3He-based neutron detection system that consists of two briefcase-sized detector pods. A photograph of the system during characterization at LANL is shown in Fig. 1.

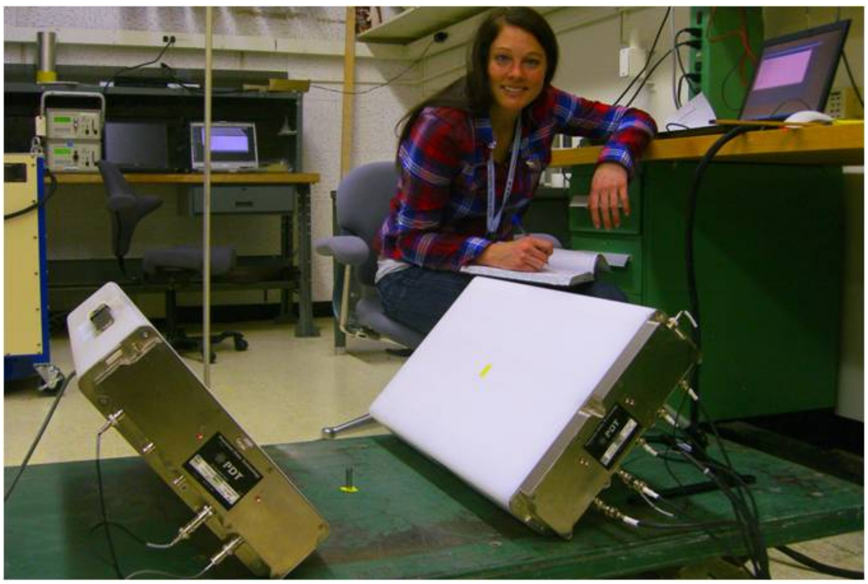

Fig. 1. The PNEM was designed to determine ^{235}U mass and enrichment of UF_6 in 30B and 48Y cylinders. It consists of two ^3He-based briefcase-sized detector pods. The system is shown here during characterization measurements LANL.

Several signatures are currently being studied to determine the most effective measurement and data reduction technique for unfolding ^{235}U mass and enrichment. The system collects total neutron and coincidence data for both bare and cadmium-covered detector pods. The measurement concept grew out of the success of the Uranium Cylinder Assay System (UCAS), which is an operator system at Rokkasho Enrichment Plant (REP) that uses total neutron counting to determine ^{235}U mass in UF_6 cylinders.[1] The PNEM system was designed with higher efficiency than the UCAS in order to add coincidence counting functionality for the enrichment determination. A photograph of the UCAS with a 48Y cylinder at REP is shown in Fig. 2, and the calibration measurement data for 30B product and 48Y feed and tails cylinders is shown in Fig. 3. The data was collected in a low-background environment, meaning there is very little scatter in the data.

Fig. 2. The PNEM measurement concept grew out of the success of the Uranium Cylinder Assay System (UCAS). The UCAS is shown here with a 48Y cylinder at Rokkasho Enrichment Plant (REP) in Japan.

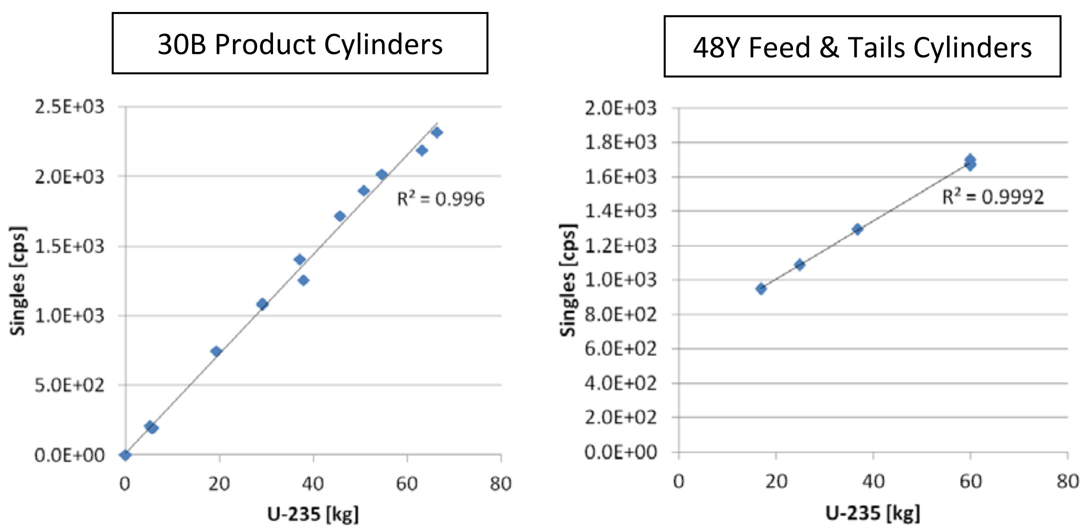

Fig. 3. The UCAS calibration data for 30B product cylinders (left) and 48Y feed and tails cylinders (right) at REP. The PNEM system was designed with more efficiency than the UCAS in order to add coincidence counting functionality for enrichment determination.

The PNEM measurement concept was first presented at the 2010 Institute of Nuclear Materials Management (INMM) Annual Meeting.[2] The physics design and uncertainty analysis were presented at the 2010 International Atomic Energy Agency (IAEA) Safeguards Symposium,[3] and the mechanical and electrical designs and characterization measurements were published in the *ESARDA Bulletin* in 2011.[4]

I.B. Rokkasho Enrichment Plant Field Trial

The first field trial of the PNEM system occurred in 2011 at REP. REP is a gas centrifuge enrichment plant owned by Japan Nuclear Fuel Limited (JNFL). JNFL was generous enough to host LANL personnel for two weeks (October 17-28, 2011) at the company's expense. They provided an enormous amount of assistance in taking the measurements and accommodated all requests for information. In addition to LANL and JNFL, there were personnel from Japan's Nuclear Material Control Center (NMCC) present throughout the entire measurement campaign, and we had an observer from the Japan Safeguards Office (JSGO) for one day. Michael Farnitano from the IAEA's Tokyo office was present for two days of measurements. Mr. Farnitano provided useful feedback regarding the feasibility of a PNEM system from an IAEA Operations standpoint.

Overall, it was a very successful test of the system, and it demonstrated the viability of the measurement technique. During the two-week field trial, the team measured total of 36 cylinders. This included 26 product cylinders, 5 feed cylinders, and 5 tails cylinders. All of the measurements were taken in the cylinder storage area at REP as shown in Fig. 4 (unlike some other enrichment plants, the storage area at REP is located indoors). The measurement location represents what might be expected in an attended measurement scenario where an operator does not move the cylinders to an isolated, low background measurement location as in the UCAS setup, which would be more representative of an unattended cylinder verification station.

Fig. 4. LANL personnel in the cylinder storage area at REP with the PNEM measuring a 30B cylinder.

The preliminary results show that the PNEM performed as expected. For each cylinder, we we collected the Singles and Doubles count rates, both with and without a cadmium cover on the cover on the detector pods. Again, the measurement objective is to determine uranium mass and mass and enrichment using some combination of these signatures. Although the extra cadmium cadmium measurement is not vital to unfolding mass and enrichment in UF_6 cylinders, it may

may mitigate background effects that can arise in attended measurement scenarios. The detector detector pods were positioned on the floor on both sides of the cylinder for the assay measurements. Photographs of the measurement positioning for 30B cylinders are shown in

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Fig. 9 and Fig. 10. Fig. 7 shows the measurement position for a 48Y cylinder.

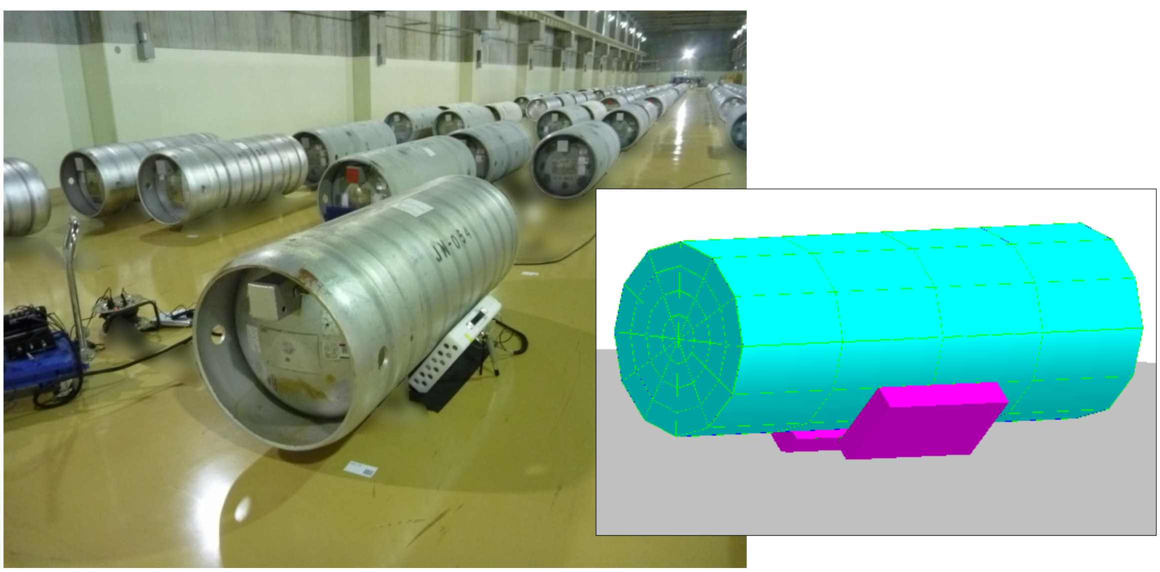

Fig. 5. Side view of the PNEM with a 30B cylinder, actual and conceptual measurement position.

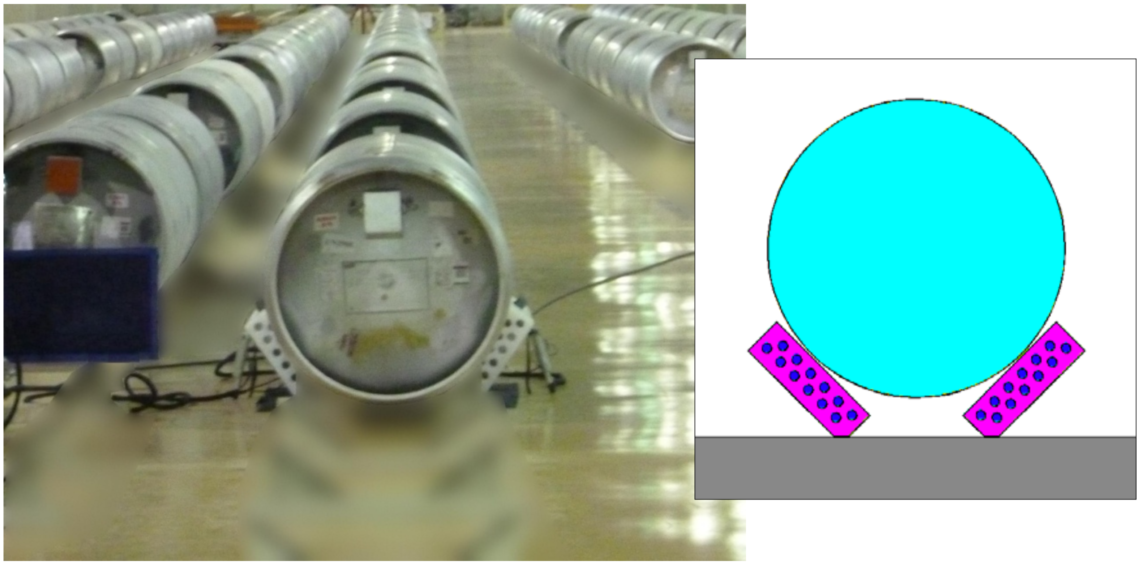

Fig. 6. Head-on view of the PNEM with a 30B cylinder, actual and conceptual measurement position.

Fig. 7. PNEM with a 48Y cylinder at REP.

We also took an additional measurement with one of the detector pods positioned on top of the cylinder to study how the distribution of UF_6 varies between cylinders. The ratio of Singles count rates between the top to bottom detector pods provides a signature for the UF_6 filling profile. We found little variation in the filling profile between cylinders of the same type, which is consistent with our observations of the UCAS calibration measurements. As more field trials of the PNEM are conducted in different facilities, this type of data collection will help us constrain the systematic uncertainty associated with the distribution of UF_6 inside 30B and 48Y cylinders.

The consistency and predictability of ^{234}U content in UF_6 as a function of enrichment is another potential source of systematic uncertainty for passive neutron measurements of UF_6. The sensitivity of the PNEM measurement technique to variations in ^{234}U content has not been studied. JNFL provided LANL with a set of data containing uranium isotopics from mass spectrometry of about 1,700 samples of UF_6 from REP. The data shows that the ^{234}U content can easily and reliably be predicted. We believe that the REP data should be consistent with most commercial gas centrifuge enrichment plants, except in a few special circumstances (e.g., reprocessed UF_6, re-enriched tails, HEU downblending, etc.). It is also important to note that there are two ASTM standards for product and feed UF_6 with limits on the isotopics.

I.C. Westinghouse Fuel Fabrication Plant Field Trial

The second field trial occurred in March 2012 at Westinghouse Fuel Fabrication Plant (WFFP) in Columbia, South Carolina. LANL partnered with Savannah River National Laboratory (SRNL) for this project. The ultimate goal is to combine an accountancy scale installed at SRNL with the PNEM detector pods in a field trial at the WFFP. The scale is the centerpiece of a UF_6 cylinder monitoring test bed setup at SRNL that incorporates key components used by the IAEA in safeguards applications including instrument racks, computers, and data transfer devices. The scale, shown in Fig. 8 with an empty 30B cylinder, is contained inside a tamper-indicating enclosure developed at SRNL. In the March 2012 field trial at WFFP, the PNEM detector pods were mounted on the existing accountancy scale at the facility. Photographs from the field trial are shown in Fig. 9. Later, WFFP plans to construct a portal to house the SRNL scale, which will be combined with the PNEM detector pods for a second field trial.

Fig. 8. This photograph shows SRNL's UF_6 cylinder measurement test bed, which includes an accountancy scale inside a tamper-indicating enclosure (photograph provided by SRNL).

Fig. 9. The measurement configuration for the March 2012 PNEM field trial at WFFP that combined the neutron detection system with the existing scale at WFFP.

One focus area of the joint LANL-SRNL effort is on the concept of "cross-check verification," where consistency is checked among multiple sensors. In many safeguards applications, multiple sensor types can be used to determine a certain attribute of the nuclear material under consideration such as uranium mass or enrichment in UF_6. Typically, one sensor provides a much more precise measure of that attribute, which is used as the accountancy value, while a complementary sensor provides an independent consistency check of that value. There are numerous benefits to cross-check verification—it can be used to indicate when systematic effects are outside the calibrated range, it provides a redundant measurement in the case of an instrument failure, and it makes spoofing attempts by a potential proliferator significantly more difficult. To illustrate, an accountancy scale and the PNEM system both provide a measure of uranium mass, and the scale's mass measurement is likely more precise than the PNEM. However, the PNEM measurement may flag a systematic effect such as an erroneous cylinder tare weight or bias in the scale created by environmental factors. The PNEM complements an accountancy scale measurement by providing assurance that the material in the cylinder is, in fact, nuclear material. Likewise, the scale can be used to flag systematic effects in the PNEM measurement such as the assumed ^{234}U content or distribution of material inside the cylinder. The same benefits can be extended to the enrichment determination made by the PNEM if the information is combined with gamma-ray measurements from an On-Line Enrichment Monitor (OLEM).

During the March 2012 field trial, we measured 30 cylinders in three days covering the range of 0.71% to 4.97% enriched UF_6, all in 30B cylinders. The cylinders were from both centrifuge and gaseous diffusion enrichment plants (mainly URENCO and USEC). The measurement staging area was on the WFFP scale, which was located approximately thirty meters from the outdoor storage area. Because of this, the background rate in the PNEM detector pods was an order of magnitude smaller than it was in Japan, and it was a constant for each cylinder measurement. WFFP provided LANL with the minor uranium isotopics for each cylinder. Preliminary analysis of the limited data set shows that the ^{234}U content as a function of enrichment is more predictable for UF_6 enriched in a centrifuge enrichment process compared to gaseous diffusion. The results show that the system performed very well, especially for the cylinders enriched via centrifuge. As in the REP field trial, we took an additional measurement of each cylinder with a detector pod placed on top of the cylinder to study the UF_6 filling profile. Despite the fact that the cylinders are stored outside at WFFP, we found a relatively consistent filling profile in the cylinders.

I.D. Euratom Field Trial

Another PNEM field trial is being planned for 2012 under the bilateral agreements between the U.S. Department of Energy and Euratom. The facility for this field trial has not yet been determined, but the objective will be to compare the performance of the PNEM system and Pacific Northwest National Laboratory's (PNNL's) Hybrid Enrichment Verification Array (HEVA).[5] The HEVA system combines the traditional gamma-ray measurement of the 186-keV peak from ^{235}U with the neutron-induced high-energy gamma signal from the cylinder wall to predict enrichment in UF_6 cylinders. As the IAEA develops new concepts and approaches to meet the safeguards demands of modern enrichment plants, it will be important to understand the performance of traditional and emerging cylinder NDA techniques under the same measurement conditions. The choice of NDA equipment for a particular plant will likely come down to a number of competing factors such as accuracy, stability, cost, sensitivity to systematic effects, feasibility of unattended use, count time, availability of ^3He or a suitable alternative, etc., and this study will help quantify some of the performance parameters associated with the PNEM and HEVA systems.

I.E. Related Projects

Two extensions of the PNEM measurement technique have been explored. In addition to the large 30B and 48Y cylinders, enrichment plants may also have 1.5-in. and 5-in. diameter cylinders (i.e., 1S and 5A cylinders). These smaller cylinders are rated to hold UF_6 enriched to 100% ^{235}U. The Mini-Epithermal Neutron Multiplicity Counter (Mini-ENMC) was used to measure 1S cylinders at LANL's Sigma Facility (Fig. 10). The Mini-ENMC is a four-ring passive well counter with 104 10-atmosphere ^3He tubes. Its high efficiency and short die-away time make it well suited for neutron multiplicity counting. The measurements were used to demonstrate the extension of the PNEM measurement technique for 30B and 48Y cylinders to smaller cylinders with higher enrichment values (up to 70% ^{235}U). The results were presented at the 2011 Annual INMM Meeting.[6]

Fig. 10. Extension of the PNEM measurement technique to small UF_6 cylinders using the Mini-Epithermal Neutron Multiplicity Counter (Mini-ENMC) at LANL's Sigma Facility.

The second extension was a Monte Carlo feasibility study of an active neutron assay technique for UF_6 cylinder assay based on the PNEM design.[7] Active NDA methods have a long history in safeguards applications such as the Active Well Coincidence Counter (AWCC), the Neutron Coincidence Collar for fresh fuel assay, and the Advanced Experimental Fuel Counter (AEFC) for research reactor spent fuel assay. In the feasibility study, we showed the improvement in performance gained by using a correlated ^{252}Cf source as the active driver as opposed to the traditional AmLi random driver. The active method is a direct measure of induced fission in ^{235}U, and the passive signal from F(α,n) and spontaneous fission are subtracted out of the signal (or the passive signal becomes negligible, depending on the interrogation source strength). This means that the method is independent of variations in ^{234}U content, prior reactor history (meaning it can be used with reprocessed UF_6), and uncertainties in F(α,n) yields. Furthermore, it is not sensitive to high background rates, and the total count time for both the passive and active measurement is on the order of about one minute. The feasibility study will hopefully be followed on with an optimization of the active configuration. A field trial could be performed using the existing PNEM detector pods.

II. CONCLUSIONS

In conclusion, passive neutron measurements are proving to be a reliable and effective means for UF_6 cylinder assay. Over the past few years, we have developed the Uranium Cylinder Assay System and the Passive Neutron Enrichment Meter for assay of 30B and

48Y cylinders, deployed the Mini-ENMC for assay of the smaller 1S cylinders, and accrued a large amount of practical field experience taking cylinder measurements in various nuclear facilities. The PNEM system has evolved considerably since Phase I of this task. It has gone from a Monte Carlo design to a field-tested piece of hardware, and we hope to build a second prototype of the system next year. Some of our ongoing and future work in the area of UF_6 cylinder assay includes:

- Continued field trials of the PNEM and Mini-ENMC with UF_6 cylinders;
- Integration of the PNEM with an accountancy scale;
- Development of a data reduction methodology for the PNEM;
- Assessment of systematic factors encountered in the field and their impact on neutron assay techniques;
- Analysis of field trial data to unfold F(α,n) yields from uranium isotopes;
- Further exploration of active neutron techniques; and
- Development of new gamma-ray-based cylinder assay techniques.

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