

TABLE 7b – Uranium and Plutonium Mass by Neutron (NDA)

Method/measurement system (including software): [AWCC](#)

Application: [Measurement of LEU/HEU fresh fuel plates and assemblies](#)

Short Description of the method/measurement system and typical measurement conditions (shielding, measurement time, etc.)
The Active Well Coincidence Counter (AWCC) is a Safeguards verification NDA measurement system coupled with a multiplicity shift register (JSR-15). It can perform active neutron interrogation of LEU/HEU fresh fuel plates and assemblies to derive the fissile (^{235}U) content of the measured item(s). The counter is made of a main High-Density Polyethylene (HDPE) hollowed body. Two HDPE ‘plug’ can be inserted and secured at the bottom and top of the hollowed body to form a measurement cavity in the central part of the counter. Each plug has an inserts to hold one (α, n) neutron interrogation sources, such as $^{241}\text{AmLi}$. Sources with neutron output typically between 3×10^4 and 5×10^4 neutrons per second. Forty-two CO_2 quenched, 4 atmospheres pressurized, 20’’ long, 1’’ diameter ^3He proportional counters are embedded in the cavity walls, forming 2 concentric rings. Charge collection resulting from neutron interaction in the ^3He gas is performed through a wire anode and initial stage amplification of the collected signals are performed through AMPTEK A111 pre-amplifiers mounted within an electronics enclosure located above the counter main HDPE body. [1] For the measurement of fresh fuel plates and assemblies, the AWCC cavity is tilted into a horizontal position and specific HDPE inserts, embedding the two $^{241}\text{AmLi}$ sources, are used rather than the bottom and top plugs. Cadmium liners can be placed around the measurement cavity wall, although reducing the overall detection efficiency of the counter. That results into an harden neutron interrogation flux, thus improving the depth of penetration the neutrons, limiting self-shielding in denser samples like metallic fuel plates [2]. ^{235}U quantification is performed by interpreting the measured doubles neutron rate registered in the multiplicity shift register. Although randomly time correlated (α, n) neutron detections are vetoed by the shift register, their presence impacts the overall precision of the measurements. AWCC measurements are therefore only well suited for the measurement of ^{235}U masses above 50 grams. Because they mainly release neutrons below the ^{238}U fission energy threshold ($\approx 1 \text{ MeV}$), the use of $^{241}\text{AmLi}$ interrogation sources limits the dependency of the measurement results to the enrichment of the measured item. Although empirical calibrations have been performed, calibration of the AWCC is also mainly performed by using benchmarked Monte Carlo calculations. Typical measurement times range from 600 to 1000 s.
Factors affecting the method performance
The positioning of the fuel plates/assemblies in the measurement insert/cavity needs to be reproducible and similar to the one used during calibration/modelling. Calibrations established for HEU material tend to show some biases when measuring LEU fuels. This is mainly due to changes in the material composition, density and to a lesser extend enrichment.

Method references

1. H.O Menlove, "Description and Operation Manual for the Active Well Coincidence Counter", Los Alamos Scientific Laboratory, LA-7823-M, Manual ISPO-66, May 1979.
2. H.O Menlove, G. E. Bosler, "Application of the Active Well Coincidence Counter (AWCC) to High Enrichment Uranium Metal", Los Alamos National Laboratory, LA-8621-MS, ISPO-121, August 1981.

Prepared by: Ludovic Bourva

Method/measurement System (including software): ENMC**Application:** Measurement of Pu in oxide and MOX

Short Description of the method/measurement system and typical measurement conditions (shielding, measurement time etc.)
The method for the Epithermal Neutron Multiplicity Counter is the same as described for the PSMC (q.v.). The ENMC [1,2] has 121 polyethylene-moderated 10-atmosphere ^3He tubes and 27 preamplifiers giving a neutron detection efficiency of 64%. The detection efficiency includes a contribution from epithermal neutrons because of the high pressure of the tubes. The high pressure and close separation of the tubes gives a short dieaway time of 19 μs, which improves the statistical precision. The measurement time is typically 600 seconds. The isotopic composition used in the analysis is obtained from mass spectrometry.
Factors affecting the method performance
The data is typically processed with point model equations with a multiplication bias correction for large multiplication items [3]. One assumption is that the (α, n) neutron energy is the same as the spontaneous fission neutron energy. This is a very good approximation for (α, n) neutrons from oxygen, but less good for other potential (α, n) emitters. The counting statistics on the Triples become poor at higher counting rates and for items with high “alpha” values ($\alpha > 10$).
Method Reference
1. J. E. Stewart, H. O. Menlove, D. Mayo, K. Kroncke, F.A. Duran “Epithermal Neutron Multiplicity Counter (ENMC): Faster Plutonium Assays by Factors up to 20” Nuclear Materials Management XXVII July 1999 and Los Alamos National Laboratory Report LA-UR-99-3791 (1999). 2. H. O. Menlove, C. D. Rael, K. E. Kroncke and K. J. DeAquero “Manual for the Epithermal Neutron Multiplicity Detector (ENMC) for Measurement of Impure (MOX) and Plutonium Samples” Los Alamos National Laboratory Report LA-14088 (2004) 3. W. Geist, J. Longo, M. Krick and W. Harker “INCC Software Users Manual” Los Alamos Report LA-UR-01-6761 (2009)
Source of bottom-up value (only for prospective ITV not based on historical data)
n/a

Prepared by: Martyn Swinhoe

Method/measurement system (including software): FNCL

Application: ^{235}U measurement in LWR fresh fuel assemblies with/without burnable poisons

Short Description of the method/measurement system and typical measurement conditions (shielding, measurement time, etc.)

The verification of the fissile mass of ^{235}U in fresh fuel assemblies with the Fast Neutron Coincidence Collar (FNCL) is performed by measuring both passive and active neutron coincidence rates with the fuel assembly centered within the FNCL measurement cavity. Typically, 4 min and 11 min are used for the respective passive and active measurements. Neutron interrogation by epi-cadmium (Fast Mode) neutrons is provided by ^{241}Am -Lithium sources with total neutron output around 1×10^5 neutrons per second. The FNCL uses 12 fast neutron liquid scintillation detectors to perform both neutron and gamma-ray detection.

A dedicated FNCL assay software supports the operation of the equipment and provides analytical results. Data acquisition is performed using 500 MHz digitizers and the net coincidence rates are derived within the FNCL software after several data filtering steps, including gamma-neutron pulse shape discrimination, pile up rejection and neutron energy filtering.

The standard FNCL can be used to assay all commercial LWR fuel types, including PWR, BWR, VVERs. The FNCL measures the ^{235}U mass/cm of the fuel assembly. An active length verification (for example with an HM5) is necessary to verify the active length of the fuel assembly.

Factors affecting the method performance

The FNCL relies on the detection of fast neutrons above 0.5 MeV induced from epi-cadmium interrogation neutrons. The measured neutron coincidence rates from the FNCL therefore show little to no dependency on the neutron poison loading of the fresh fuel assemblies. No neutron poison correction based on operator declared data is therefore used in the FNCL evaluation of the assembly fissile mass, unlike assays conducted with the UNCL in thermal mode.

Method references

1. Beaumont J., et al. "A fast-neutron coincidence collar using liquid scintillators for fresh fuel verification" Journal of Radioanalytical and Nuclear Chemistry 314.2 (2017): 803-812.
2. Tomanin A., et al. "Inter-Comparison Exercise for the Safeguards Verification of PWR Fresh Fuel Assemblies using Fast and Thermal Neutron Coincidence Collars" Proceedings of ESARDA 41st Annual Meeting Symposium on Safeguards and Nuclear Material Management, 14-16 May, 2019 Stresa (VB), Italy pp. 378-388.
3. Beaumont J., et al. "Field testing of a fast-neutron coincidence collar for fresh uranium fuel verification." Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 962 (2020): 163682.

Source of bottom-up value (only for prospective ITV not based on historical data)

The reported ITV values originate from a limited set of field measurements performed in conditions similar to those encountered in the field. These estimated performance values have been propagated to generate paired data with operator values assumed to carry only small systematic and random uncertainties as LWR assemblies are manufactured to very high level of quality controls.

Method/measurement system (including software): GBAS/SBAS/HBAS**Application:** Plutonium hold-up in glove-box and process equipment

Short Description of the method/measurement system and typical measurement conditions (shielding, measurement time, etc.)
The GBAS (Glove Box Assay System), and iterative instrument developments such as SBAS (Super Glove Box Assay System) and HBAS (Hopper Glove Box Assay System) are neutron counting system used to evaluate the plutonium hold-up in glove boxes [1]. These systems use relatively large neutron moderator slabs with ^3He proportional counters to measure Doubles neutron count rates when positioned around the glove box. The full glove box sides are scanned using pairs or up to four slabs (mSBAS) [2] to record the Doubles neutron rate at several heights along the faces of glove boxes. A mathematical model based on solid angle calculations are used to infer the normalized rates, accounting for effects like neutron reflection from the floor.
Factors affecting the method performance
Plutonium hold-up determinations by Doubles neutron counting are challenging measurements, for the recorded count rates depend on the relative position of the source/detectors and the importance of the neutron scattering in any given measurement situation (glove box surrounding, internal structure of the glove box/hopper, position of the source material...). The technique therefore represents a semi-quantitative approach based on extensive characterization of the detector response for any specific measurements case.
Method references
1. T. Asano, H. Kobayashi, S. Takahashi <i>et al.</i>, "Development of improved hold up measurement system at plutonium fuel production facility", Proceeding of the 38th INMM annual meeting, Phoenix AZ, 1997. 2. H. Tanaka, H. Nakamura, T. Hosoma, "Design of geometrical detector arrangement for extensive hold up measurement", Proceedings of the Symposium on International Safeguards, Vienna, Austria, 29 Oct. 02 Nov. 2001, IAEA-SM-367/14/08.
Source of bottom-up value (<u>only for prospective ITV not based on historical data</u>)
The reported ITV values originate mainly from operator measurement.

Prepared by: Ludovic Bourva

Method/measurement system (including software): HEPC**Application:** Measurement of Large LEU/NU items

Short Description of the method/measurement system and typical measurement conditions (shielding, measurement time, etc.)

The High Efficiency Passive Counters (HEPC) are neutron coincidence counters design to measure large items (from 1 to 15 kg) of uranium oxide powder canisters placed within the counter cavity. The units developed for measurements at fuel fabrication plants within the European Union (EU) rely on the detection of coincident neutrons emitted from spontaneous fission events in ^{238}U . The neutron measurement is coupled with a separate gamma-ray measurement to provide an evaluation of the measured mass of uranium compound. The counters are operated in standard neutron coincidence mode (4.5 μs pre-delay / 64 μs Gate Width) and achieved a ^{252}Cf neutron detection efficiency of the order of 53 %. The counters operate a large number of proportional ^3He tubes (148) pressurized to 4 atmospheres and arranged in three 'rings' on each of the 6 sides of the prism. Standard coincidence electronics (JSR-12/JSR-15) are used with the measurement system.

Standard measurement times for the verifications are 1000-s, which should be consistent with measurement precision of the order of 1-%.

Reports on the design, qualification and calibration of these counters can be found in the literatures [1, 2].

Factors affecting the method performance

As for any standard passive neutron counter the HEPC calibration accuracy is subject to measuring pure oxide material similar to the one used to establish the counter calibration. Dependence of the measurement to ^{235}U enrichment was minimized by lining the internal wall of the cavity with Cadmium to limit the effect of thermalized albedo neutrons into the measured sample. Measurement of items in a physical form other than the one used for calibration (i.e. pellet vs. powder) or enrichment close to the upper LEU limit (i.e. 20 wt.%) show systematic biases due to alternative neutron multiplication in the items.

Variation in the sample fill height and central positioning within the counter cavity have also been reported to create small relative measurement biases of the order of 1 to 3 %.

Method references

1. Peerani, P.; Jaime, R.; Looman, M.; Ravazzani, A.; "Implementation of a Verification Procedure for large LEU Samples based on Passive Neutron Assay"; Proceedings. 25th Annual Meeting. Symposium on Safeguards and Nuclear Materials Management (ESARDA).
2. Peerani, P *et. al*; "Development of high-efficiency passive counters (HEPC) for the verification of large LEU samples"; Nuclear Instruments and Methods in Physics Research Section A Accelerators Spectrometers Detectors and Associated Equipment 601(3) 326-332.

Source of bottom-up value (only for prospective ITV not based on historical data)

The reported ITV values originate mainly from relatively small set of verification results performed mainly with LEU powder samples covering the ^{235}U enrichment range between 2.5 and 5 wt.%.

Prepared by: Ludovic Bourva

Method/measurement System (including software): HLNC

Application: Measurement of Pu in plutonium oxide and MOX

Short Description of the method/measurement system and typical measurement conditions (shielding, measurement time etc.)
The $^{240}\text{Pu}_{\text{eff}}$* content of an item is determined from the total (Singles) and coincidence (Doubles) counting rates of the High-Level Neutron Coincidence counter (HLNC) [1], using a shift register to extract the correlated rate. The HLNC uses 18 4-atmosphere ^3He tubes in a polyethylene moderator to detect the neutrons. The neutron detection efficiency is $\sim 17\%$. Two analysis methods are used in Passive Neutron Coincidence Counting (PNCC). 1. A passive calibration curve ("PCC") using only the Doubles rate and 2. A method ("known alpha") that combines both Singles and Doubles rates and uses a calculated ratio of (α, n) to spontaneous fission neutrons ("alpha") to correct for item self-multiplication. The data is typically collected and analyzed using the International Neutron Coincidence Counting code [2]. The isotopic composition is needed to convert from $^{240}\text{Pu}_{\text{eff}}$ to total Pu and to calculate "alpha" and is obtained from mass spectrometry. (The uncertainty contribution from the mass spectrometry results is negligible). The measurement time is 300 s. A good measurement of the background counting rates is important for the known alpha technique. These methods are used for many kinds of items that fit in the cavity (17.5 cm diameter and 41 cm tall). * The $^{240}\text{Pu}_{\text{eff}}$ of an item is the weighted sum of the even Pu isotopes.
Factors affecting the method performance
The passive calibration curve method is valid for items that are similar to those used to make the relevant calibration. The results for items with different neutron multiplication (for example, from different shapes or density) will be biased. This method is not very sensitive to small amounts of impurities, especially when the neutron multiplication is small. The known alpha method contains an intrinsic correction for neutron multiplication and so is not sensitive to the size and shape (density) of the item. The result is sensitive to the value used for the (α, n) rate, which is usually calculated from the isotopic composition and chemical composition of the sample assuming it is pure. A good quality control check is to compare the results from the two analysis methods and to understand the reason for the difference between them (if any).
Method References
1. H. O. Menlove and J. E. Swansen "A high performance Neutron Time Correlation Counter," Nuclear Technology 71 497-505 (1985). 2. W. Geist, J. Longo, M. Krick and W. Harker "INCC Software Users Manual" Los Alamos Report LA-UR-01-6761 (2009)
Source of bottom-up value (only for prospective ITV not based on historical data)
n/a

Prepared by: Martyn Swinhoe

Method/measurement System (including software): INVS**Application: Measurement of Pu in small samples of plutonium oxide and MOX**

Short Description of the method/measurement system and typical measurement conditions (shielding, measurement time etc.)
The Inventory Verification Sample counter (INVS) [1] uses the passive calibration curve method - the same as the PCC method in the HLNC (q.v.), but the masses of the measured items are small, around 1g for PuO₂ and 1-5 g for MOX. The detector uses 18 6-atmosphere, polyethylene moderated ³He detectors, giving a neutron detection efficiency of 43%. The cavity size is 4.9 cm in diameter and 15 cm tall. The calibration curve is made with well-characterized reference material. The conventional counting time is 600 s. (The most precise values were obtained when the measurement time was chosen to reach 0.2% statistical error on the Doubles counting rate and this varied from 2 to 30 hours [2].) The data is collected and analyzed using the International Neutron Coincidence Counting code [3]. The analysis uses the plutonium isotopic composition obtained from mass spectrometry.
Factors affecting the method performance
The best results are obtained by defining separate sample types (for example, PuO₂ powder, LWR-MOX powder, FBR-MOX powder and FBR-MOX pellets) and keeping sample sizes consistent. Quantitative corrections are made for sample-to-sample variations such as mass, density, “alpha” and Pu content (and also ²³⁵U enrichment if applicable) using the MCNP® code [4]. (“alpha” is the ratio of (α,n) to spontaneous fission neutron emission)
Method references
1. J.K. Sprinkle, H.O. Menlove, M.C. Miller and P.A. Russo “An Evaluation of the INVS Model IV Neutron Counter” Los Alamos National Laboratory Report LA-12496-MS 1993 2. H. Ottmar, A. Schubert, T. R. Wenz, H. O. Menlove, G. W. Eccleston, U. Blohm-Hieber and M. T. Swinhoe “A Consistent Calibration Approach for Neutron Coincidence Counting of Small PuO₂ and MOX Samples.” Proc. 19th ESARDA Annual Meeting Montpelier, France May 1997 3. W. Geist, J. Longo, M. Krick and W. Harker “INCC Software Users Manual” Los Alamos Report LA-UR-01-6761 (2009) 4. See mcnp.lanl.gov
Source of bottom-up value (only for prospective ITV not based on historical data)
n/a

Prepared by: Martyn Swinhoe

Method/measurement System (including software): PCAS**Application:** Measurement of plutonium in MOX

Short Description of the method/measurement system and typical measurement conditions (shielding, measurement time etc.)
There are several implementations of the PFPF*-Canister Assay System (PCAS) measurement system, which are similar [1]. All use the passive coincidence counting method described under the HLNC detector (q.v.). The PCAS-3 has 16 polyethylene-moderated 4-atmosphere ^3He tubes with 8 preamplifiers, giving an efficiency of 13% and a dieaway time of 52 μs. PCAS are used for the measurement of canisters containing large masses of MOX (up to 12 kg of Pu) resulting in high counting rates. Deadtime corrections are important. The PCAS has a uniform detection efficiency profile over the height of the material in the canister. The isotopic composition used in the analysis is obtained from mass spectrometry. The data is collected in unattended mode [2] and analyzed with INCC [3]. *PFPF Plutonium Fuel Production Facility in Tokai, Japan.
Factors affecting the method performance
The performance of the instruments is helped by the fact that the production material measured in the facility is very homogenous with little variation in isotopic composition.
Method References
1. H. O. Menlove, J. Baca, K. E. Kroncke, M. C. Miller S. Takahashi, S. Seki, S. Inose, and T. Yamamoto "PFPF Canister Counter for Foreign Plutonium (PCAS-3) Hardware Operations and Procedures Manual" Los Alamos National Laboratory Report LA-12485-M (1992) 2. D. G. Pelowitz "MIC- Multi Instrument Collect" Los Alamos National Laboratory Report LA-UR-001182 (2000) 3. W. Geist, J. Longo, M. Krick and W. Harker "INCC Software Users Manual" Los Alamos Report LA-UR-01-6761 (2009)
Source of bottom-up value (only for prospective ITV not based on historical data)
n/a

Prepared by: Martyn Swinhoe

Method/measurement System (including software): PNCL**Application:** Measurement of Pu in LWR MOX Fuel Assemblies

Short Description of the method/measurement system and typical measurement conditions (shielding, measurement time etc.)
The verification of the plutonium mass of LWR MOX assemblies can be done using the passive analysis methods of the HLNC (q.v.) with a detector that looks like the UNCL (q.v.) [1]. The original UNCL-I was configurable for active measurements of both BWR and PWR fuel, but also had an additional detector side that could make 4-sided passive detector for passive measurement of MOX assemblies [2]. Other detectors have been specifically built for this application. A typical total measurement time of 10 minutes. The data is typically collected and analyzed using the International Neutron Coincidence Counting code [3] (or in unattended mode). The PNCL measures the Pu mass/cm of the fuel assembly. An active length verification (for example with an HM5) is necessary to verify the active length of the fuel assembly.
Factors affecting the method performance
The performance of the method is helped by the uniformity of the items- production MOX assemblies. The amount of Pu in a typical MOX assembly is large and leads to very high counting rates in the collar. This requires careful determination of deadtime correction coefficients.
Method References
1. H. O. Menlove "Passive/Active Coincidence Collar for Total Plutonium Measurement of MOX Fuel Assemblies" Los Alamos Laboratory Report LA-9288 1982 2. H. O. Menlove, J. E. Stewart, S. Z. Qiao, T.R. Wenz and G. P. D. Verrecchia "Neutron Collar Calibration and Evaluation for assay of LWR Fuel Assemblies Containing Burnable Neutron Absorbers" Los Alamos Laboratory Report LA-11965-MS 1990 3. W. Geist, J. Longo, M. Krick and W. Harker "INCC Software Users Manual" Los Alamos Report LA-UR-01-6761 (2009)
Source of bottom-up value (only for prospective ITV not based on historical data)
n/a

Prepared by: Martyn Swinhoe

Method/measurement System (including software): PSMC**Application:** Measurement of Pu mass in oxide and MOX

Short Description of the method/measurement system and typical measurement conditions (shielding, measurement time etc.)
The methods described under HLNC (q.v.) have limitations for impure and inhomogeneous materials such as scrap and waste. The passive neutron multiplicity counting technique (PNMC) [1] expands the experimental information provided by passive coincidence counting to give three measured quantities: Singles, Doubles and Triples. This allows quantitative information on spontaneous fission rate ($^{240}\text{Pu}_{\text{eff}}^*$), neutron multiplication and (α, n) rate to be extracted from the measurement data. In this way systematic measurement uncertainties can be greatly reduced, thus making the plutonium assay by PNMC much more reliable and accurate, particularly for poorly characterized and impure materials with a large induced fission component. The method does not require reference materials for calibration, but does require high efficiency detectors. Even so, typical measurement times are longer than for passive coincidence counting to obtain good statistics on Triples (~600 s). One detector used for this method is the Plutonium Scrap Multiplicity Counter (PSMC) [2], which has an efficiency of 55% using 80 polyethylene-moderated, 4-atmosphere ^3He tubes and 19 preamplifiers. The dieaway time is 47 μs. The data is typically collected and analyzed using the International Neutron Coincidence Counting code [3]. The isotopic composition used in the analysis is obtained from mass spectrometry. * The $^{240}\text{Pu}_{\text{eff}}$ of an item is the weighted sum of the even Pu isotopes.
Factors affecting the method performance
The data is typically processed with point model equations with a multiplication bias correction for large multiplication items. One assumption is that the (α, n) neutron energy is the same as the spontaneous fission neutron energy. This is a very good approximation for (α, n) neutrons from oxygen, but less good for other potential (α, n) emitters. The counting statistics on the Triples become poor at higher counting rates and for items with high "alpha" values ($\alpha > 10$).
Method References
1. N. Ensslin et al., "Application Guide to Neutron Multiplicity Counting", Los Alamos National Laboratory Report LA-13422-M (1998). 2. H. O. Menlove, J. Baca, M. S. Krick, K. E. Kroncke and D. G. Langner "Plutonium Scrap Multiplicity Counter Operation Manual" Los Alamos National Laboratory Report LA-12479-M (1992) 3. W. Geist, J. Longo, M. Krick and W. Harker "INCC Software Users Manual" Los Alamos Report LA-UR-01-6761 (2009)
Source of bottom-up value (only for prospective ITV not based on historical data)
n/a

Prepared by: Martyn Swinhoe

Method/measurement System (including software): UNCL thermal mode**Application: Measurement of ^{235}U in LWR Fuel Assemblies with/without burnable poisons**

Short Description of the method/measurement system and typical measurement conditions (shielding, measurement time etc.)
The verification of the mass of ^{235}U in fresh fuel assemblies with the UNCL [1] is performed by measuring both passive neutron and active neutron coincidence rates with the fuel centered in the UNCL cavity. The active measurement uses a single AmLi with source strength typically 4×10^4 n/s to induce fissions in the fuel. The instrument has with 18 4-atmosphere polyethylene moderated ^3He detectors. Two UNCL-II detector sizes exist, one for PWR fuel and one for the smaller BWR fuel, although an earlier design, UNCL-I, could be configured to measure both types. Because of the difficulty of making individual detector calibrations (the lack of availability of partially made fuel assemblies) the calibration of these detectors is made as a family – all detectors are related back to one initial collar calibration for PWR and one for BWR fuel assemblies. A typical total measurement time is 10 minutes. The data is usually collected and analyzed using the International Neutron Coincidence Counting code [2]. The UNCL measures the ^{235}U mass/cm of the fuel assembly. An active length verification (for example with an HM5) is necessary to verify the active length of the fuel assembly.
Factors affecting the method performance
The measurement in thermal mode is affected by the amount of Gd, or other burnable poison in the fresh fuel assembly. The correction for Gd is significant for large Gd loadings (20% for 12 rods at 5.2% Gd_2O_3 in a PWR assembly) and relies on the operator's declaration. Variability of BWR fuel designs (non-symmetrical pin lattice, variable pin types and enrichments) makes the use of a single mass calibration and neutron poison correction more susceptible to biases. (The effect of Gd is much less when collars are used in fast mode (q.v.). The poison amount can be verified with a measurement in fast mode [1], although this can be prohibitive in terms of effort and measurement time.) The results are biased if the fuel assembly is not centered in the detector cavity.
Method References
1. H. O. Menlove, J. E. Stewart, S. Z. Qiao, T.R. Wenz and G. P. D. Verrecchia "Neutron Collar Calibration and Evaluation for assay of LWR Fuel Assemblies Containing Burnable Neutron Absorbers" Los Alamos Laboratory Report LA-11965-MS 1990 2. W. Geist, J. Longo, M. Krick and W. Harker "INCC Software Users Manual" Los Alamos Report LA-UR-01-6761 (2009)
Source of bottom-up value (only for prospective ITV not based on historical data)
n/a

Prepared by: Martyn Swinhoe

Method/measurement System (including software): UNCL fast mode

Application: Measurement of ^{235}U in LWR Fuel Assemblies with/without burnable poisons

Short Description of the method/measurement system and typical measurement conditions (shielding, measurement time etc.)

The verification of the mass of ^{235}U in fresh fuel assemblies with the UNCL [1] is performed by measuring both passive neutron and active neutron coincidence rates with the fuel centered in the UNCL cavity (similar to the UNCL thermal mode q.v.). The active measurement uses a single AmLi with source strength typically 4×10^4 n/s to induce fissions in the fuel. In fast mode a cadmium liner is used to prevent the return of thermal neutrons into the fuel assembly and so the interrogation is done with epi-cadmium neutrons which significantly reduces the effect of burnable poisons on the results.

Fast mode measurements were originally foreseen on the origin collar designs, using removable cadmium liners. Two UNCL-II detector sizes exist, one for PWR fuel and one for the smaller BWR fuel, although an earlier design UNCL-I could be configured to measure both types. However, the counting time required to obtain adequate statistical precision with these detectors in fast mode was at least one hour, making inspection use difficult.

A new design of fast interrogation collars (EFCP/EFCB) [2] with 33 polyethylene moderated 10 atmosphere ^3He detectors for the PWR type and 25 ^3He detectors for the BWR type and a permanently installed cadmium liner allow a total measurement time of 20 minutes.

The data is typically collected and analyzed using the International Neutron Coincidence Counting code [3]. The UNCL measures the ^{235}U mass/cm of the fuel assembly. An active length verification (for example with an HM5) is necessary to verify the active length of the fuel assembly.

Factors affecting the method performance

The correction for Gd relies on the operator's declaration. However, the effect of burnable neutron poison in 17 x 17 PWR fuel for 12 Gd rods at 5% wt Gd_2O_3 is significantly reduced in the fast mode (3.2% compared to 20% for the UNCL in thermal mode). For 9x9 BWR fuel the effect of 6 Gd rods at 5 wt.% Gd_2O_3 is 3.8% in fast mode, compared to 33% in thermal mode. Nevertheless, K_3 corrections should be applied within their calibration range and may be impacted by specific fuel designs.

Method References

1. H. O. Menlove, J. E. Stewart, S. Z. Qiao, T.R. Wenz and G. P. D. Verrecchia "Neutron Collar Calibration and Evaluation for assay of LWR Fuel Assemblies Containing Burnable Neutron Absorbers" Los Alamos Laboratory Report LA-11965-MS 1990
2. L. G. Evans, M. T. Swinhoe, H. O. Menlove, P. Schwalbach, P. De Baere and M. C. Browne "A new fast collar for safeguards inspection measurements of fresh low enriched uranium fuel assemblies containing burnable poison rods" Nuclear Instruments and Methods in Physics Research A 729 (2013) 740-746.
3. W. Geist, J. Longo, M. Krick and W. Harker "INCC Software Users Manual" Los Alamos Report LA-UR-01-6761 (2009)
4. M. T. Swinhoe, H. O. Menlove, P. De Baere, D. Lodi, P. Schwalbach, C. D. Rael, M. Root, A. Tomanin and A. Favalli "A new generation of uranium coincidence fast neutron collars for assay of LWR fresh fuel assemblies" Nuclear Instruments and Methods in Physics Research, A 1009 (2021) 165453

Source of bottom-up value (only for prospective ITV not based on historical data)

The EFCP/EFCB uncertainty estimates come from a limited number of measurements described in a paper [4] describing initial field tests of the BWR and PWR versions of the Euratom fast collar.

Prepared by: Martyn Swinhoe

Method/measurement system (including software): WDAS

Application: Measurement of 200-l/55-Gal Pu Solid Waste Drums

Short Description of the method/measurement system and typical measurement conditions (shielding, measurement time, etc.)

The WDAS (Waste Drum Assay System) measurement systems represent a category of large Passive Neutron Coincidence Counters applied to the quantification of plutonium in solid waste contained in 200-l/55-Gal drums [1]. The passive detection of fission events (either spontaneous or induced) is performed in these counters using a relatively large number (>100) of ^3He proportional neutron counters, usually pressurized to 4 atmospheres. Neutron detection efficiency varies depending on the actual design but values between 18 % and 35 % are common [2, 3, 4]. Signals generated from local pre-amplifiers connected to banks of several ^3He tubes are fed into either shift register or neutron multiplicity electronics to generate coincident or multiplicity count rates (Singles, Double, Triples). Empirical calibration of the system is performed by deriving a Weighted Volume Average (VWA) response of the counter to ^{252}Cf or Pu spontaneous neutrons emitted in air. This is done by measuring a known neutron source at several vertical/radial positions within the volume of the waste container. Derivation of the waste matrix corrections to be applied for different types of waste material is performed by repeating this counter response characterization for a number of waste measurement scenarios (e.g. combustible, metallic, plastics, earth, concrete...). Derivation of these correction effects for 'unknown' waste matrix measurement is usually performed by an 'Add-a-Source' (AAS) interrogation measurement [2, 5]. This entails evaluating the decay corrected counter response of a reference ^{252}Cf source exposed in the vicinity of the waste drum, and comparing this measurement to a reference Reals rate established for an empty drum. Characterizing this AAS perturbation for an equivalent number of waste measurement scenarios allows to establish an AAS matrix calibration. In the case of a waste item with unknown matrix absorption/moderation properties, the measured AAS perturbation can be evaluated and interpreted using the AAS matrix calibration to derive the waste matrix correction to be applied to the passive Doubles rate.

Quantification of the $^{240}\text{Pu}_{\text{Eff}}$ mass present in the item has to be complemented by isotopic information to derive the total plutonium content. These counters can measure from a few milligram quantities up to several 100's grams of plutonium in 200-l drums. Measurement times are usually between 20 and 30 min per assay, including a 3 to 5 min AAS measurement.

Factors affecting the method performance

As for any waste assay system, the mass calibration used to interpret the measured rates is based on a number of assumptions (i.e. Single efficiency, source uniformity, matrix homogeneity...). Real waste items are bound to break some of these assumptions and thus generating biases. AAS or other matrix correction factors introduced in WDAS system correct the raw measured rates, but the accuracy of these corrections can also be affected by effect such as matrix heterogeneity coupled with source non-uniformity.

Method references
1. Menlove, H O, Baca, J; Harker, W; Kroncke, K E; Miller, M C; Takahashi, S; Kobayashi, H; Seki, S; Matsuyama, K; Kobayashi, S; "WDAS operation manual including the add-a-source function", Los Alamos National Laboratory, Report LA-12292-M, April 1992. 2. Menlove, H O, et al.; "HENC Performance evaluation and Plutonium Calibration"; Los Alamos National Laboratory, Report LA-13362-MS, October 1997. 3. Menlove, H O, Beddingfield, D. H; Pickrell, M M; Davidson, D R; Mc Elroy, R D; Brochu, D B; "The Design of a High-efficiency neutron counter for waste drums to provide optimized sensitivity for plutonium assay", Proceedings for the Nondestructive Assay and Nondestructive Examination Waste Characterization Conference, Salt Lake City, January 14-16, 1997. 4. Whitehouse, K R; Rackham, J W, Sharpe, R J and Wilson M; "TRU-D: Waste Drum Assay System – The use of passive neutron technologies to accurately categorize between PCM/TRU and Low-Level Waste"; Proceedings of the 25th Annual ESARDA symposium, Stockholm, 13-15 May 2003. 5. Mayo, D R, Menlove, H O, Pecos, J M; "Nondestructive Assay Tests of High-Efficiency Neutron Counter (HENC) for Waste Assay and Possible Diversion Scenario" Los Alamos National Laboratory, Report LA-13418-MS, May 1998.
Source of bottom-up value (<u>only for prospective ITV not based on historical data</u>)
n/a

Prepared by: Ludovic Bourva