PERFORMANCE COMPARISON OF DIFFERENT ACTIVE NEUTRON INTERROGATION TECHNIQUES FOR SAFEGUARDS APPLICATIONS

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Abstract

The paper reports some performance values of different active neutron interrogation techniques for the assay of the fissile content, i.e. ^{235}U, in uranium material. The techniques discussed are the NCC, AWCC, Phonid and an advanced Phonid technique, based on a combination of emission and transmission measurements. Most of the results are based on measurements of well characterised PERLA standards and discussed in terms of in-field applications.

1. Introduction

Non-destructive Assay (NDA) can be an important tool for safeguarding of nuclear material provided that Target Values can be established for the components of the measurement uncertainty/1/. Target Values are based on "Performance Values", ideally obtained from measurements of actual process materials, carried out under industrial conditions/1/. Where the technique requires calibration, it is essential to link the assessment of uncertainty with that calibration. However, when the materials used for calibration are significantly different from the actual process samples, evaluation of the uncertainty becomes very difficult, as discussed in Ref. /2/.

As a result the safeguards community has struggled to define performance values for measurement techniques for which different process materials require different calibration materials, even though the primary parameter of interest is the same. Measurement of ^{235}U in uranium bearing materials by active neutron interrogation is possibly the best known example of this problem; the difficulty of establishing performance values, and the problems of assaying different forms of process material have been widely reported in Refs. /2/, /3/, and /4/. By contrast methods based on passive gamma measurement for the determination of Uranium enrichment and especially for Plutonium Isotopic composition /6,7/, and passive neutron methods for the determination of the amount of spontaneously fissioning isotopes/8/, demand less exacting calibration.

The authors of this paper therefore are unable to agree with the assertion made in Ref. /9/ that "Methods, application and uncertainty sources of Shift-register based instruments for active neutron coincidence counting are similar to those shown in section 2.3 (i.e. Passive Neutron Coincidence Counting Technique)". The main difference between passive and active neutron interrogation is that in the former the response depends only on the behaviour of the fission neutrons in the sample, whereas in active methods the response is strongly dependent on the behaviour of the source neutrons in the sample. This is due to the strong energy dependency of the neutron induced fission cross and the attenuation of the interrogating neutron fluence in the sample.

One consequence of this is the 1993 list of International Target Values for NDA techniques, there is much more emphasis on passive gamma and neutron methods than on active neutron techniques. Given that active methods have strong advantages for certain applications, and in particular for the assay of ^{235}U, it is appropriate to review the potential for improvement in active methods. Two options suggest themselves: to determine the uncertainties more accurately and reliably, and/or to improve the measurement techniques themselves along with the associated data analysis procedures, as proposed in Refs. /10/ and /11/. Section 2 of this paper considers the first option for the Neutron Coincidence Collar (NCC), the Active Well Coincidence Counter (AWCC), and the Photo-neutron Interrogation Device (Phonid). Section 3 demonstrates the major improvements that are possible for Phonid yielding a single calibration curve applicable to a diverse range of Uranium bearing materials.

2. Performance of Active Neutron Interrogation Devices: NCC, AWCC, and Phonid

The performance of the NCC, AWCC, and Phonid are discussed on the basis of measurement results obtained on PERLA standards/12,13/. To avoid as much as possible counting statistics uncertainties measurement times were long compared to the measurement times for in-field measurements.

2.1 Performance of NCC

The NCC is developed to measure both the ^{235}U and ^{238}U content per unit length by resp. active and passive neutron interrogation. The neutron induced and spontaneous fission neutrons are measured by

moderated ^{3}He detectors, operated in conjunction with a Shift Register. The active measurements, using a ^{241}AmLi(α,n) neutron source, can be performed in the so-called thermal and fast mode. For the latter one a Cd liner is placed inside the measurement cavity. However, in practice measurements in fast mode are rarely performed since they require long measurement times to obtain reasonable statistical uncertainties. A detailed description of the calibration procedure currently used is given in Ref. /3/. From Ref. /3/ one concludes that for a well characterised NCC device in thermal active mode the ^{235}U content per unit length is determined out of one measurement parameter, the so-called 'Reals'(R), and several correction factors, based on operator's declared values. These correction factors account for a difference in response due to a difference in characteristics of the measured assembly and the reference assemblies used to establish the calibration curve. These characteristics are e.g. the enrichment, the total Uranium content per unit length, the total number of poison rods, the relative content of neutron poison per rod. In passive mode the determination of the ^{238}U content per unit length needs, according to Ref. /3/, two correction factors due to room-background induced fission neutrons and neutron multiplication in ^{235}U. The latter one again requiring the enrichment as an input data, obtained from operator declared values. In thermal mode the largest correction factor is due to the neutron poison present in the assemblies.

Measurements were performed in PERLA with a modular NCC device, manufactured at JRC Ispra, using a well characterised PERLA mock-up assembly of the BWR type /12/. This assembly is a 9x9 array, with support rods on the 4 edges, resulting in 77 possible positions for fuel and poison rods. The fuel pins, 1.296 m long, used for the present experiment

are all 3.1 % enriched and the poison rods, 1.225 m long, are filled with the neutron absorbing material Pyrex. Although this material is different from the normal Gd_2O_3 neutron poison normally present in BWR fuel assemblies, it does not influence the general interpretation of the measurement results. In Fig. 1.a and Fig. 1.b the response as a function of the ^{235}U and ^{238}U mass per unit length is given for assemblies with different number of poison rods present, in respectively thermal active and passive mode. The ^{235}U content has been changed by removing fuel rods. The measured response has been approximated by two different calibration formulae. In the first one the shape of the calibration curve is supposed to be independent of the number of poison rods present, as in Ref. /3/ where the effect of the poison is represented as a multiplication factor, and is given by:

$$R = \frac{1}{1+bn} \frac{a_1 m}{1+a_2 m} \qquad (1)$$

with R the measured net Reals per time unit, m the ^{235}U content per unit length and n (n = 0,4,8, and 12) the number of poison rods present in the assembly. Equation (1) applies for responses based on mass (fuel pins) removal and not on a change in enrichment. The parameter b depends on the poison material and will be different for fuel assemblies with Gd_2O_3 as neutron poison. In a second representation the response is:

$$R = \frac{a_1(i)m}{1+a_2(i)m} \qquad (2)$$

with a_1 and a_2 depending on the number of poison rods present. The free parameters and the square root of the average square relative difference between the measured and declared mass per unit length, Δ_m, are summarised in Table 1.

Mode	Poison rods	Equation (1)				Equation (2)		
		a_1 (1/gs)	a_2 (1/g)	b	Δ_m (%)	$a_1(i)$ (1/gs)	$a_2(i)$ (1/g)	Δ_m (%)
Active	0	28.6 (0.2)	0.042 (0.001)	0.0325 (0.0008)	0.5	29.24 (0.22)	0.045 (0.001)	0.5
	4				1.9	22.99 (0.36)	0.028 (0.003)	1.2
	8				1.1	20.94 (0.35)	0.031 (0.002)	0.6
	12				1.7	22.73 (0.62)	0.059 (0.005)	1.2
Passive	0	6.15 (0. 04) 10^{-3}	-5.58 (0.15)10^{-4}	0.0108 (0.0003)	0.4	6.15 (0. 05) 10^{-3}	-5.52 (0.20)10^{-4}	0.4
	4				0.9	5.74 (0. 07) 10^{-3}	-6.29 (0.30)10^{-4}	0.7
	8				1.3	6.00 (0. 08) 10^{-3}	-3.85(0.42)10^{-4}	0.7
	12				1.9	5.25 (0. 08) 10^{-3}	-6.52 (0.43)10^{-4}	1.7

Table 1. The square root of the average square relative difference between the measured and declared mass per unit length, Δ_m. The table also shows the calibration parameters for the data in Fig. 1. The counting statistics uncertainty on the measured signal is about 0.4 % for both active and passive measurements. The calibration is based on mass removal and not on a change in enrichment. The poison rods are filled with Pyrex as absorbing material.
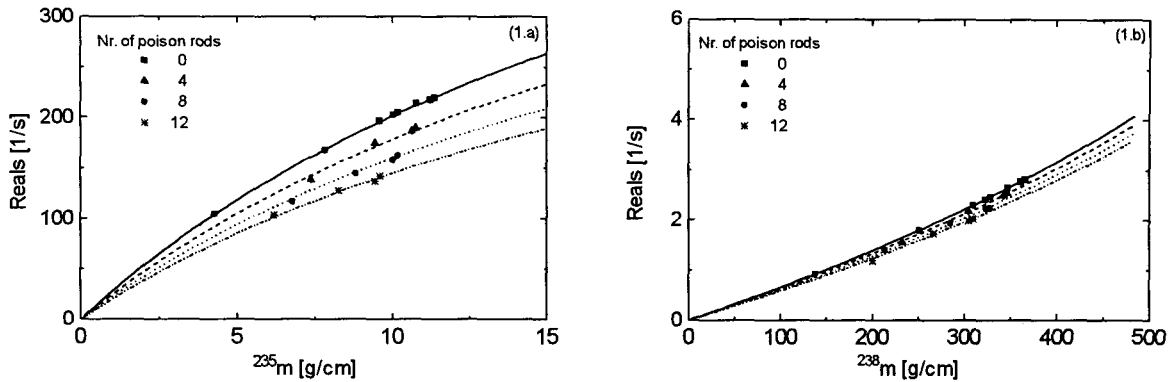
Fig. 1 The response (Reals) in thermal active (1.a) and passive mode (1.b) as a function of resp. the ^{235}U and ^{238}U (^{235}m and ^{238}m) content per unit length. The response is given for fuel assemblies with different number of poison rods (Pyrex) present. The ^{235}U and ^{238}U content has been changed by removing fuel pins.

Fig. 1 and Table 1 reveal that the measurement data can well be described by equation (1). Confirming the assumption in Ref. /3/, that the calibration formula does not need a shape parameter dependent on the number of poison rods. The response in passive mode is, although only slightly, sensitive to the presence of neutron poison. In Ref. /3/ no correction for the presence of neutron poison is introduced for passive measurements. Applying the procedure proposed in Ref. /3/ on the present data (Fig. 1.b) results in Δ_m = 1%, 1.2% and 1.7% on the ^{238}U content for resp. 4, 8 and 12 poison rods. The response in thermal active mode, however, is very sensitive to the presence of neutron poison. Based on Fig. 1.a and Ref. /3/ correction factors as high as 1.5 are needed for fuel assemblies with 12 poison rods present. One therefore has first of all to define the uncertainty in the correction for the poison rods before establishing performances values. The relative change on the mass per unit length, $\delta m/m$, due to the uncertainty on the number of poison rods, δ_n, can be deduced from the partial derivative of Eq. 1 with respect to n and is given by:

$$\frac{\delta m}{m} = \frac{b}{1+bn}(1+a_2 m)\delta n \qquad (3)$$

The relative change on the ^{235}U mass per unit length due to an uncertainty of one rod on the input of number of poison rods is given in Fig. 2. This component is certainly not negligible and it underlines the importance of knowing the true number of poison rods if the measurement result is to be credible. In Ref. /3/ a procedure is proposed to determine the number of poison rods out of a combination of a thermal and fast measurement. This could be used to make a more independent determination of the ^{235}U mass. Standard deviations for such measurements have to take into account the measurement uncertainty of the number of rods as in Eq. (3).

Another uncertainty is due to the different packing material of the fuel assemblies with respect to the calibration assemblies. For the PERLA assembly, completely filled with 3.1 % enriched pins, results in an increase of 6% and 5% in active and passive response resp. due to the presence of plastic spacers.

The present data, even including the extensive work in Ref. /3/, is to our opinion not sufficient to define reliable performance values. Similar measurements, as presented in this paper, should be performed with poison rods containing Gd_2O_3 and changing the ^{235}U and ^{238}U content by changing the enrichment. The target values in Ref. /1/ are over-optimistic and should be re-evaluated and better described with respect to specific conditions, e.g. neutron poison. The present paper only discusses the performance for the determination of the mass per unit length of a BWR type assembly. For the determination of the total mass, uncertainty components due to axial in-homogeneous distributions have also to be included.
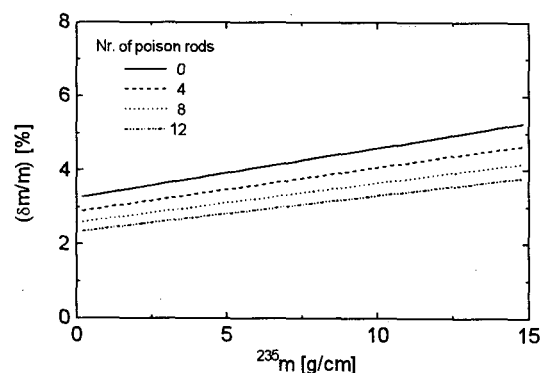

Fig. 2 The relative change of the ^{235}U mass per unit length, $\delta m/m$, due to an uncertainty of 1 poison rod (Pyrex) on the input of number of poison rods. The results are for measurements in thermal active mode.

2.2 Performance of AWCC

The Active Well Coincidence Counter (AWCC) is designed for the assay of the ^{235}U content in items such as bulk uranium samples and samples containing different types of matrix material such as scraps. The measurement principles of the AWCC are the same as those of the NCC (section 2.1). The ^{235}U content is deduced from a calibration curve out of one measurement parameter (Reals). As for the NCC, in-field use is mostly limited to the thermal mode due to long measurement times required in fast mode. Results of a calibration campaign on PERLA samples are given in Ref. /14/. In Ref. /14/ problems linked to the failure of direct proportionality (linear through the origin) between the response and the ^{235}U mass are mentioned. This non-direct proportionality is caused by e.g. the attenuation of the integrating neutron fluence, neutron multiplication, and response profiles.

A similar data set for a commercially available AWCC in thermal mode is given in Fig. 3.a. These measurement data cover 20, 35, 60 and 92 % enriched UO$_2$ samples. Fig. 3.a reveals that the ^{235}U content can only be determined by a prior knowledge of the enrichment. This is mainly due to the attenuation of the interrogating neutron fluence in the sample depending on the ^{235}U number density. In Table 2 expected average uncertainty values, based on individual calibration curves for each material type, are given. For each material type the square root of the average square relative difference between deduced and declared ^{235}U mass, Δ_m, is given for different calibration formulae involving different number of free parameters. Using the calibration formula:

$$R = a_1 m + a_2 m^{a_3} \qquad (4)$$

a value $\Delta_m = 3.0$ % can be obtained for a broad mass region. Such a performance, however, can only be reached under the strict conditions that the samples to be measured match the reference samples. In other words that enough prior knowledge of the sample (e.g. enrichment) is available to decide which calibration curve is to be used. An example of the change in the ^{235}U mass of the UO$_2$ samples due to a 5% relative uncertainty in the enrichment is shown in Fig. 4.a. Fig. 4.a is based on the partial derivative of the responses (Fig. 3.a) with respect to the enrichment. The 5% has been taken as a realistic value that can be reached for the determination of the Uranium enrichment by gamma spectroscopy methods. When performance values and target values are established such an uncertainty component has to be taken into account. The target values of Ref. /1/ seem over-optimistic. The values mentioned in Ref. /9/ seem quiet reasonable. However, more specifications are required e.g. the mass range of interest, sample size and applied calibration formulae.

For the AWCC in fast mode the change in response due to the change in enrichment is much smaller due to the harder interrogation spectrum as discussed in Ref. /15/. Measurements of scrap and waste material require (Ref. / 4/ and /16/) even more a strict categorisation of the samples. As a consequence the availability of different reference materials for the different types of materials to be assayed and precise specifications of the operator are required.

	Material	Nr. of samples	^{235}U mass range (g)	E (%)	σ_r (%)	Δ_m (%)				
						$a_1m^{a_2}$	$a_1m+a_2m^{a_3}$	$\sum\limits_{i=0}^{2} a_i m^i$	$\sum\limits_{i=1}^{3} a_i m^i$	$\sum\limits_{i=0}^{3} a_i m^i$
AWCC	UO$_2$	8	50 - 350	20	0.4	1.8	1.5	2.5	3.2	1.1
	UO$_2$	6	50 - 600	35	0.4	2.1	2.4	6.7	7.2	1.1
	UO$_2$	4	100 - 1000	60	0.4	8.0	3.0	1.1	13.4	
	UO$_2$	6	100 - 1500	92	0.3	4.7	2.3	5.4	16.4	2.0
Phonid	U$_3$O$_8$	4	10 - 80	3	1.5	1.2				
	U$_3$O$_8$	4	10 - 120	5	1.5	0.8				
	UO$_2$	11	25 - 350	20	0.7	0.8		0.5	2.0	0.5
	UO$_2$	6	50 - 600	35	0.6	0.9		0.7	1.5	0.7
	UO$_2$	8	50 - 1000	60	0.6	1.4		1.7	3.6	1.5
	UO$_2$	11	50 - 1500	92	0.5	1.3		3.4	5.6	1.9

Table 2 The uncertainty level Δ_m between measured and declared ^{235}U content, for measurements with AWCC (thermal mode) and Phonid PERLA samples (10 cm diameter). Results obtained with different calibration formulae are reported. The counting statistics uncertainty, σ_r, is given for the sample with the highest ^{235}U content. These values are obtained with 1000 and 300 s measurement times, for measurements with resp. AWCC and Phonid. For Phonid these values refer to a ^{124}Sb source with an activity of 7 10^{10} Bq.
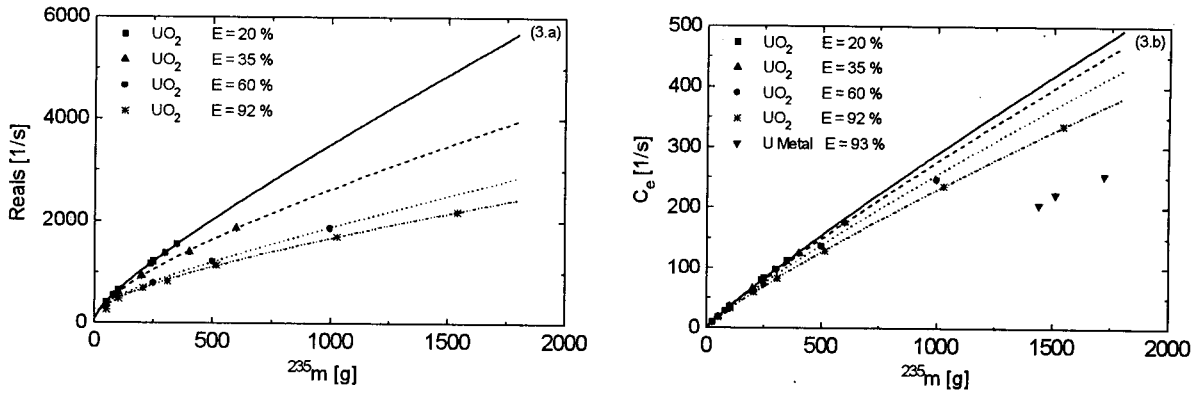
Fig. 3. The response of the AWCC and Phonid, respectively Reals (3.a) and C_e (3.b), as a function of the ^{235}U mass for a variety of PERLA samples. The full lines in Fig. 3.a are based on an individual calibration for each enrichment using Eq. (4). The full lines in Fig. 3.b represent the calibration formula Eq. (5).
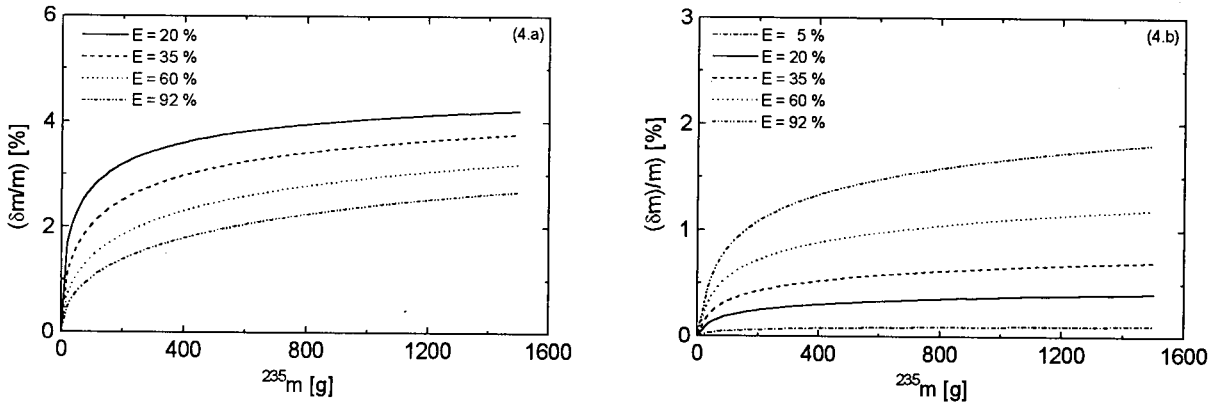

Fig. 4. The relative change in the ^{235}U mass, $\delta m/m$, due to a 5% uncertainty on the input enrichment as a function of the ^{235}U mass (for UO$_2$ samples with different enrichment). The results for measurements with AWCC and Phonid are given in resp. Fig. 4.a and 4.b.

2.3 Performance of Phonid

Phonid (PHOto Neutron Interrogation Device) is an active neutron interrogation instrument for the assay of the ^{235}U content in low and high enriched uranium of different forms /17/. A ^{124}Sb-^{9}Be Photoneutron source performs active interrogation of the sample with intermediate energy neutrons. The source neutrons induce only fission in the fissile material, in particular ^{235}U, contained in the sample. The prompt induced fission neutrons are counted by ^{4}He detectors. By using fast ^{4}He neutron detectors the fission neutrons can be separated form the source neutrons and the gamma background by energy discrimination. As for the AWCC and NCC the ^{235}U content is deduced from a calibration curve out of one measurement parameter i.e. the total net neutron count rate, C_e (corrected for background and the decay of the

interrogating neutron source). The performance of this device has been reported in e.g. Ref. /5/, /15/ and /18/. From these references one concludes that also using Phonid as an assay device a strict categorisation of the samples with respect to geometry, density and homogeneity of fissile and matrix material is required to obtain reasonable uncertainty levels. In Ref. /5/ a systematic uncertainty component of at least 2.5 % is quoted for 10 cm diameter samples when no difference is made between pure UO$_2$ and U$_3$O$_8$ powder for samples. In Fig. 3. b the response of the device to a set of HEU UO$_2$ and U-metal PERLA samples is given. The full line through the data points is a calibration formula with the enrichment, E, as an input parameter:

$$C_e = a_1 \exp(a_2 E) m^{a_3 \exp(a_4 E)} \qquad (5)$$

The square root of the average square relative difference between the ^{235}U mass obtained through this

calibration curve and the declared ^{235}U mass is $\Delta_m = 2.1\ \%$. This value is better then the 5% reported in Ref. /18/ where another calibration formula has been proposed. The response of the 93 % enriched metal samples strongly deviates from the 92 % UO_2 samples. This is due to the increase of attenuation of the interrogating neutron fluence due to an increase of the ^{235}U number density.

In Table 2 the resulting square root of the average square relative difference between the measured and declared ^{235}U mass, Δ_m, for different types of calibration formulae are compared with those obtained with the AWCC in thermal mode. From Table 2 one concludes that the measured signal obtained from Phonid shows a better direct proportionality with the ^{235}U mass as compared to the one from the AWCC in thermal mode. As a consequence, a ^{235}U mass determination with the AWCC requires more reference samples to reach the same performance values for Phonid. In addition longer counting times, about a factor 3, are needed using the AWCC. A comparison between Fig. 3.a and Fig. 3.b shows that the response of the Phonid is less dependent on the enrichment, i.e. the ^{235}U number density in general, then the response of the AWCC in thermal mode. A more prominent illustration of this statement can be found in Fig. 4. The relative change in the ^{235}U mass due to an 5% uncertainty on the input enrichment for measurements with Phonid is considerably smaller then the one for measurements with the AWCC. This uncertainty component for measurements with Phonid on LEU samples, with a 10 cm diameter, can almost be neglected. This is due to the harder spectrum of the interrogating neutrons, around 10 keV. As discussed in Ref. /15/ the AWCC in fast mode almost approaches the performance of the Phonid, however at least 10 times longer counting times are needed to reduce the counting statistics uncertainty component. The performance values for Phonid quoted in Ref. /9/, however, seem quiet overoptimistic and no underlying constraints are mentioned.

The performance of Phonid for measurements of small size scrap and waste samples, 10 cm diameter, is extensively discussed in Ref. /5/. Residues from five different production processes, of the BNFL LEU fabrication facility at Springfields (UK), were measured. Without separation of the samples, with respect to the production processes, the measurement results have huge errors. Through individual calibration curves for each production process uncertainties between 10% and 30% are obtained.

3. Improvement of Active Neutron Interrogation Techniques

The previous section shows that the results of currently available active neutron interrogation devices are all based on the detection of one measurement parameter. As a consequence the calibration curves not only depend on the ^{235}U content of the material, but are also dependent on the neutronic properties of the sample. Therefore, these devices require difficult calibration campaigns for each individual class of material. Moreover well characterised reference materials are required with similar neutronic characteristics to those of the unknown samples. These requirements are not easy to fulfil for in-field use of such devices. The main reason of these necessities are due to the absorption and moderation of the interrogating neutrons in the sample. Both physical effects are currently corrected for based on operator's declarations. To overcome these shortcomings a new measurement technique is presented in Ref. /19/. The technique described in Ref. /19/ is based on a combination of neutron emission and transmission signals. This combination enables self-characterisation of samples with respect to absorption and moderation of the source neutrons in the sample.

Active neutron interrogation is performed by a $^{124}Sb(\gamma,n)^8Be$ Photoneutron source and the induced fission neutrons are detected by ^4He fast neutron detectors, providing the emission signal, C_e. The source neutrons are detected by a ring of 11 ^3He detectors, 7 bare, 2 Boron wrapped and 2 Cd wrapped, surrounding the sample. Due to the relative low efficiency of these detectors for fission neutrons compared to the source neutrons, the ^3He detectors are almost only sensitive to the source neutrons. These detectors, therefore provide the transmission signal. The combination of the $^{124}Sb(\gamma,n)^8Be$ Photoneutron source and the ^4He fast neutron detectors, the basic concept of the Phonid discussed in section 2.3, is essential to maintain first of all the high penetrating power of the source neutrons and secondly for a clean separation between emission and transmission signal. Both conditions can not be met by using moderated ^3He detectors as fission neutron detectors. Moreover, the basic concept of Phonid, compared to e.g. AWCC, has advantages with respect to penetration power, detection limits and measurement time as discussed above and in Ref. /15/. In Ref. /19/ three from the 11 available transmission signals were used to define one so-called absorption parameter P_a and one so-called moderation parameter P_m. The limited number of signals used in Ref. /19/ is due to the difficulty of

interpreting too many signals in one multiparametric calibration formula. In Ref. /19/ the performance of the technique is demonstrated for measurements on a variety of LEU and HEU PERLA reference samples and tested on scrap material originating from the UKAEA HEU reprocessing facility at Dounreay (UK).

The PERLA samples, all 10 cm diameter containers, cover LEU U_3O_8 powder, LEU and HEU UO_2 powder, HEU metal and pellet samples. Based on the emission signal from the fast neutron detectors and the absorption parameters P_a, obtained from one bare ^3He detector, an intrinsic calibration without necessity of any prior knowledge of the samples is obtained. The relative ratio between the measured and declared ^{235}U mass as function of ^{235}U mass is shown in Fig. 5, resulting in a $\Delta_m = 2.1\%$ uncertainty level. This value is as good as the one obtained for the HEU UO_2 samples through a calibration curve, requiring the enrichment as an input parameter and without including the metal and pellet samples. The deviation of masses determined by this technique from the declared masses are almost all within the counting statistics uncertainty (1 sigma level). The largest deviation is found for two metallic samples.
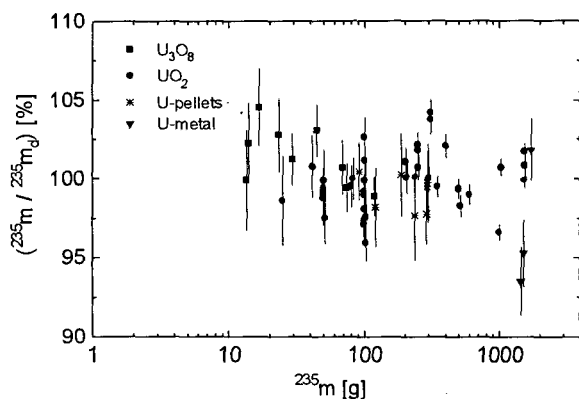

Fig. 5. The ratio, $^{235}m/^{235}m_d$, between the measured and declared ^{235}U mass determined with the advanced Phonid technique. The error bars, 1 sigma level, are only due to counting statistics.

The performance of the self-characterisation of the samples using the moderation power parameter was tested on a wide variety of scrap and waste material originating from the production stream of the UKAEA HEU reprocessing facility at Dounreay (UK). The ^{235}U mass of the HEU material was derived from a calibration curve obtained from measurements with well characterised natural Uranium samples with varying moderation power. The calibration curve applied to all data expresses the ^{235}U mass as a function of two measurement parameters: the emission

signal and the moderation power parameter. The square root of the average square relative difference between measured and declared ^{235}U mass is $\Delta_m = 15\%$. As mentioned in Ref. /19/ the performance can still be improved by a more extensive systematic study including more transmission signals into the calibration. Presently the possibility of applying a Neural Network approach, as e.g. in Ref. /20/, for the data analysis is under study. The 15 %, obtained without classifying the material, is far better then the one that could be obtained with the conventional Phonid technique. This is illustrated in Fig. 6, where the declared mass divided by the emission signal is plotted as a function of the moderation parameter. The full line in Fig. 6 represents the calibration curve obtained from measurements with natural Uranium samples. Without introduction of the moderation parameter and without any classification of the material, the ^{235}U content can deviate with a factor as high as 8 from the declared values.
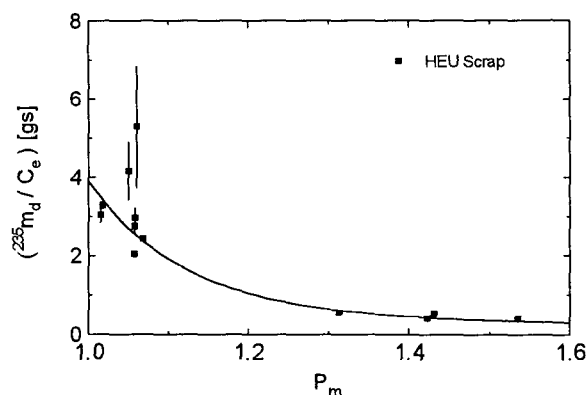

Fig. 6. The ^{235}U mass divided by the emission signal as a function of the moderation parameter, P_m. The data points are for HEU scrap and waste samples in a 10 cm diameter container. The full line represents the calibration curve obtained from measurements with natural Uranium samples. The error bars, 1 sigma level, are only due to counting statistics.

4. Conclusions

The paper reports an evaluation of performance values of active neutron interrogation techniques for the assay of nuclear materials, i.e. ^{235}U content in Uranium bearing material. The values are a result of measurements on PERLA standards and in-field measurements and experience. To often reported performance values are overoptimistic and are quoted for ideal conditions, not reflecting the in-field use. This is mainly due to the fact that quoted values are given without reference to the underlying constraints;

e.g. neutron poison present in fuel assemblies, calibration formula used, applicable mass range, matrix material conditions, packing conditions of the material, sample diameter, etc. All of these constraints are linked to the intrinsic problems associated with active neutron interrogation: that is to say mainly the behaviour of the interrogating neutrons in the material to be assayed. In addition, the definition of performance values requires a certain methodological framework /2/.

As mentioned in Ref. /1/ "the most trustworthy studies of performance values are certainly those which identify the basic metrological parameters of the measurement process..." , and therefore of the measurement techniques. Examples of such NDA techniques are passive neutron interrogation for the determination of the amount of spontaneously fissioning material in Ref. /8/ and gamma spectroscopy for the determination of the Pu-isotopic composition in Ref. /6,7/.

In section 3 an active neutron technique is discussed where besides one measurement signal, linked to the total number of fission neutrons, other measurement signals (P_a and P_m), reflecting the behaviour of the interrogating neutrons in the sample, are used to determine the ^{235}U mass. Although the basic metrological parameters (e.g. effective neutron induced fission cross section) can not be identified using these additional signals, the technique still offers a more reliable measurement of the ^{235}U mass, requires less difficult calibration campaigns, and above all is less dependent on operator's declared values. The method does not require a so strict categorisation of the material and problems linked to the mismatch between actual samples and calibration samples are avoided.

5. Acknowledgements

6. References

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