Position Statements
For WG3 International Safeguards
B. The integration of emerging technologies for safeguards

Title: Neutron Resonance Densitometry (NRD); Ready for Practical Use

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1. Neutron resonance densitometry

Neutron Resonance Densitometry (NRD) is an active NDA technique that has been developed for the quantification of U/Pu isotopes in particle like melted fuel (MF) debris, that is for the characterization of heterogeneous nuclear materials even in the presence of intense gamma-ray and neutron radiation. It has been studied during the last 3 years (2012-2015) as part of a collaboration between JAEA and EC-JRC. The results show that the amount of U and Pu in particle like debris of melted fuel can be determined with an accuracy of better than 3%. Such an accuracy can be reached without the need of any sample preparation or calibration measurements using samples that are representative for the material under investigation. The only constraint is the thickness of the sample which for debris of melted fuel will be limited to a a thickness of about 2 cm.

NRD is a combination of NRTA (Neutron Resonance Transmission Analysis) and NRCA (Neutron Resonance Capture Analysis) / PGA (Prompt Gamma-ray Analysis). A conceptual design of a NRD system is shown in Figure1. The function of NRTA and NRCA/PGA are summarized in Table 1.

Table 1: Overview of the techniques involved in Neutron Resonance Densitometry

Techniques	NRTA	NRCA/PGA
Roles	Quantification of U/Pu isotopes a resonance shape analysis of resonance transmission dips Measurement sample: Particle-like NM in a thin (2~3 cm thickness) disk type container	Identification of neutron absorbing materials by the detection of gamma-rays characteristic for the elements of interest Measurement samples: Particle-like NM in a small vial
Remarks	Quantification of NM by NRTA is affected by existence of neutron absorbers such as ^{10}B in the NM. The results of NRCA/PGA are used to facilitate the analysis of NRTA data.	

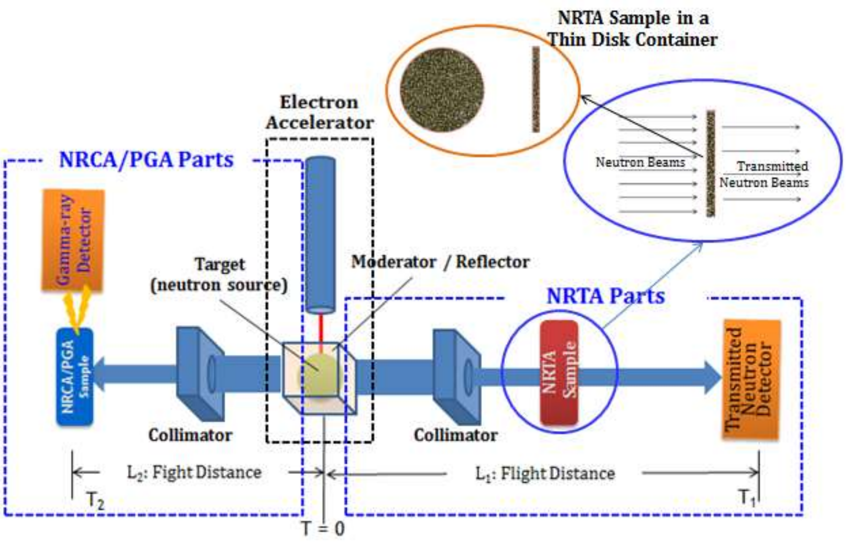

Figure 1: schematic representation of a NRD system

The results of studies on NRD as part of the JAEA/JRC collaboration are described in detail in Ref. 1. The studies concentrated mainly on the development of improved interpretation models. It involved theoretical work based on Monte Carlo simulations combined with experiments at the time of flight facility GELINA. From these studies performance values could be derived. The impact of different effects are summarized in Table 2.

Table 2: The impact of different effects on performance of Neutron Resonance Densitometry

Effects		Uncertainty	
Counting statistics		≤ 1%	Based on Monte Carlo simulations
Systematic effects	Nuclear data	≤ 1%	Depends on nuclear data. Can be reduced by improved nuclear data
	Particle size distribution	≤ 2%	Improved theoretical model confirmed by experiments at GELINA
	Temperature	≤ 1%	To be confirmed experimentally
Combined uncertainty		≤ 3%	

A more realistic NRD system is shown in Figure2. It requires an area of about 200 m^2 and costs about $6 million (except for building). Both the area and cost are similar to those for an analytical laboratory.

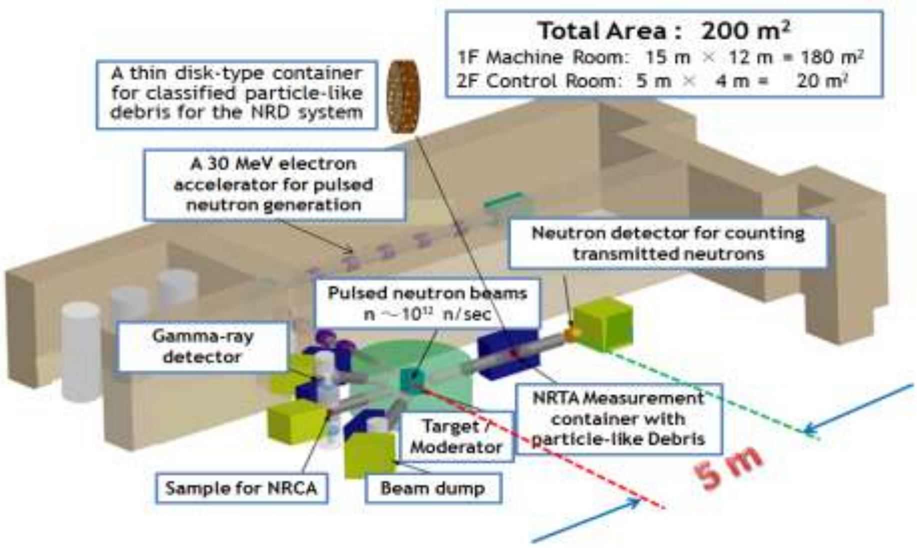

Figure 2: A realistic NRD system

2. NRD safeguards applications.

NRD is a nondestructive method that can be applied to determine the amount of U and Pu in a variety of nuclear materials. It is an absolute method that does not require any additional calibration measurements. The accuracy primarily depends on the quality of the nuclear data. An overview of possible applications is given in Table 3.

Table.3: Possible Applications of NRD

No.	Samples (NM) / Container	Remarks
1	Particle-like MF Debris / Thin (~2 cm) Disk Container	Particle size stochastically distributed
2	Spent Fuel of Pebble Bed Modular Reactor (PBMR)	Spent Fuel of PBMR (Sphere of 6 cm diameter with many small fuel particles) can be directly measured by NRD (see the Reference)

3	Solid samples of Next Generation Fuel Cycle Facilities with ~10 g of material / small sizes vial (Dia. 2-3cm, High. several cm)	These samples are taken from bulk area of next generation fuel fabrication facility, which have very high gamma-radiation

The practical NRD system should be prepared by the operator or the country which develop new type of nuclear facilities in the course of safeguards by design (SBD).

Reference:

P. Schillebeeckx, B. Becker, S. Kopecky and H. Harada, "The use of neutron resonance spectroscopy for the characterization of materials and objects", JRC Science and Policy report, Report EUR 26848 EN, (2014).