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JRC support to JAEA on the development of Neutron Resonance Densitometry

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Abstract

The activities carried out during 2013 at the Institute for Reference Materials and Measurements of the Joint Research Centre of the European Commission to support the Japan Atomic Energy Agency in the development of Neutron Resonance Densitometry are described. These activities include experiments carried out at the time-of-flight facility GELINA, development of a model to account for sample inhomogeneities, assistance in data reduction and analysis procedures, preparation of test samples, training of JAEA staff and dissemination of the results.

1 Introduction

Neutron Resonance Densitometry (NRD) is being developed as a method to characterize debris from the melted cores of the Fukushima-Daiichi nuclear power plants in terms of elemental and isotopic composition [1, 2]. More in particular to determine the amount of fissile material. NRD is based on Resonance Transmission Analysis (NRTA) and a combined use of Neutron Resonance Capture Analysis (NRCA) and prompt gamma-ray analysis (PGAA).

NRTA and NRCA are non-destructive analysis techniques which are based on the appearance of resonances in neutron induced reaction cross sections [3,4]. They both rely on well-established methods which are applied for neutron induced reaction cross section measurements in the resonance region [5].

Both NRTA and NRCA have been successfully applied at the time-of-flight facility GELINA of Institute for Reference Materials and Measurements of the Joint Research Centre of the European Commission (EC-JRC-IRMM), which is described in ref. [6]. They have been used for the characterization of reference materials used for neutron induced reaction cross section measurements and to study objects of cultural heritage interest [4]. The EC-JRC-IRMM has a worldwide recognized expertise and operational experience in neutron resonance spectroscopy. Therefore, the Japan Atomic Energy Agency (JAEA) and EC-JRC-IRMM started a collaboration to evaluate the achievable accuracy of NRD for the characterization of debris samples of the molten cores from the Fukushima-Daiichi nuclear power plants. The activities within this collaboration strongly rely on experiments at the GELINA facility of EC-JRC-IRMM.

In section 2 transmission and capture experiments carried out at the time-of-flight facility GELINA to support the development of NRD are summarized. Section 3 addresses the development of a model to take into account sample inhomogeneities in the analysis of results of NRD measurements. In section 4 the production of an alloy sample simulating melted fuel is presented. Sections 5 and 6 give an overview of dissemination and training activities related to the collaboration of EC-JRC-IRMM and JAEA. In section 7 an update of the collaboration action sheet is given.

2 Experiments at GELINA

Specific problems that arise when debris samples of melted fuel produced in a severe accident are analysed by NRD have been identified and discussed in ref. [2, 7]. From this work one concludes that the accuracy of the results is strongly affected by the specific characteristics of such samples. To support the development of models and methods to account for the characteristics of debris samples caputre and transmisison measurements have been performed at the time-of-flight facility GELINA.

2.1 Transmission experiments

Transmission measurements using Cu and W samples with different characteristics were performed at the 25 m station of flight path 2 with the accelerator operating at 800 Hz. The samples were placed at 9 m from the neutron target in a multi-position sample changer. Neutrons were detected by a 12.7 mm thick and 101.6-mm diameter Li-glass NE905 scintillator enriched to 95% in ^{6}L. The scintillator was coupled to a boron-free quartz windowed EMI9823-QKB photomultiplier (PMT). The detector was placed at 26.45 m from the face of the moderator viewing the flight path. The output signals of the detector were connected to conventional analog electronics. The anode pulse of the PMT was fed into a constant fraction discriminator to create a fast logic signal which defines the time the neutron has been detected. The signal of the 9^{th} dynode was shaped by a spectroscopic amplifier to determine the energy deposited by the ^{6}Li(n,t)α reaction in the detector. A module was included to produce a fixed dead time in the whole electronics chain directly after the detection of an event. The time-of-flight (TOF) of the detected neutron was determined by the time difference between the start signal (T_0), given at each electron burst, and the stop signal (T_s) derived from the anode pulse of the PMT. This time difference was measured with a multi-hit fast time coder with a 1 ns time resolution [8]. The TOF and pulse height of a detected event were recorded in list mode using a multi-parameter data acquisition system developed at the EC-JRC-IRMM [9].

2.1.1 Measurements using Cu samples

Transmission measurements on Cu samples, all in the form of a metal disc with a 8 cm nominal diameter and different thicknesses, were performed to assess the performance of NRTA for the determination of the areal density and effective thickness of the sample. The beam diameter at the sample position was approximately 35 mm. All measurements were performed with a ^{10}B overlap filter and fixed sulphur, bismuth and cobalt black resonance filters. A summary of the experiments that have been carried out is given in table 1. The results will be used to verify the accuracy of NRTA as a function of the resonance strength and more in particular if quantitative information can be derived from a saturated resonance profile. The measurements with the additional B_4C and ^{6}LiF samples in the beam will be used to establish a procedure to correct for the presence of ^{10}B or other neutron absorbing impurities with a total cross section without resonance structures in the low energy region. The data reduction, *i.e.* quality control of the data, data sorting from list mode data to TOF-histograms and calculation of the experimental transmission using the AGS code [10] used and developed at the EC-JRC-IRMM, was carried out at EC-JRC-IRMM in collaboratin with JAEA staff. Currently a resonance shape analysis of the data with the REFIT code [11] is being performed at JAEA. Prelimenary results have been presented at the INMM 54^{th} Annual Meeting [12].

2.1.2 Measurements using W samples

Transmission measurements on W samples have been carried out at to study the impact of the homogeneity of the samples. The measurement details are summarized in table 2. All measurements have been performed with a ^{10}B overlap filter. Both a metallic sample disc and a sample containing a mixture of tungsten and sulfur powder were used. The powder sample was prepared by the target preparation group of the EC-JRC-IRMM. The sample was made by mixing tungsten and sulfur powders with a nominal

Table 1: Summary of transmission experiments performed at a 25 m station of GELINA using different Cu samples.

Sample ID	Thickness mm	Background filters	Additional sample	Exp. completed
NP2012-12-04	20.0	S, Bi, Co		02/2013
NP2013-03-02	0.7	S, Bi, Co		02/2013
TP2012-010-01	0.25	S, Bi, Co		02/2013
TP2012-011-01	0.125	S, Bi, Co		02/2013
TP2012-011-01	0.125	S, Bi, Co	B_4C disc (TP-NP 08/42)	03/2013
NP2013-03-02	0.7	S, Bi, Co	B_4C disc (TP-NP 08/42)	03/2013
NP2013-03-02	0.7	S, Bi, Co	B_4C disc + ^{6}LiF sheet	04/2013

grain size of 50 – 250 μm and 44 μm, respectively. Both the powder and metallic sample had a diameter of 8 cm while the beam diameter at the sample position was 2 cm. In case of the powder sample, several different positions of the sample in the beam were used. Fig. 1 shows an example of sample-in and sample-out TOF spectra together with the total background and the different background components. The background was determined using the black resonance technique [5].

Transmission spectra for all measurements summarized in table 2 were produced and compared with results of calculations using REFIT [11]. The impact of the sample heterogeneity on a NRD analysis was clearly observed in particular for the strong resonances of ^{182}W and ^{183}W at 21.08 eV and 18.83 eV, respectively [13]. Assuming a homogeneous sample leads to a bad quality of the fit of the experimental transmission data and to an underestimation of the deduced areal density of W. The bias on the deduced areal density was removed and the quality of the fit improved by accounting for the radiation transport in stochastic media in the analysis. Therefore a model was implemented in REFIT (see section 3).

2.1.3 Measurements using a CBNM reference sample

A NRD measurements of an U_3O_8 reference sample has been carried out at the FP2-25 m transmission station. The sample consisted of 4.514 at% ^{235}U enriched sample (CBNM 446) of the EU nuclear reference material 171 set [14]. This sample set was originally produced as reference material for γ-ray spectroscopy. Therefore, the sample itself is not ideal for NRD. In particular the significant EPOXY content of the ultrasonic identifier in the plug of the sample container led to a strong attenuation of the incident neutron beam i.e. to a very low transmission spectrum. Nevertheless, the transmission dips due

Table 2: Summary of transmission experiments performed at FP2-25 m using metal (M) and powder (P) tungsten samples. The average areal density of tungsten $\bar{n}_W$ in samples was deduced from the total tungsten mass and the sample area.

Sample ID	M	P	$\bar{n}_W$ / (10^{-4} at/b)	Background filters	Beam position	Exp. completed
NP2013-03-01	×		9.3781 (0.0007)	S, Na	Center	05/2013
NP2013-03-01	×		9.3781 (0.0007)	S, Na, Ag, W, Co	Center	05/2013
TP2013-006-01		×	9.356 (0.007)	S, Na	Center	05/2013
TP2013-006-01		×	9.356 (0.007)	S, Na, Ag, W, Co	Center	05/2013
TP2013-006-01		×	9.356 (0.007)	S, Na	Top	05/2013
TP2013-006-01		×	9.356 (0.007)	S, Na	Bottom	05/2013

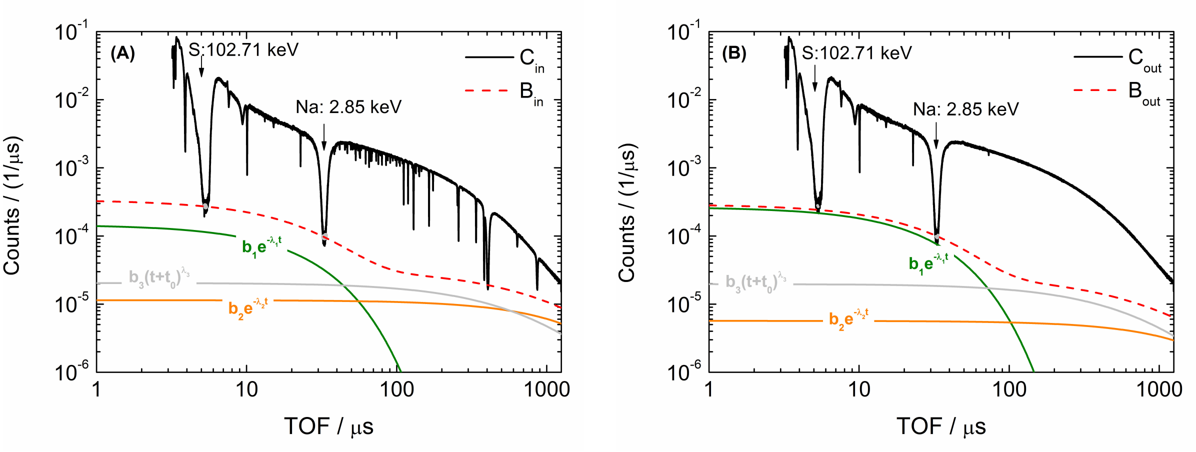

Fig. 1: (**A**): Sample-in TOF spectrum (C_{in}) together with the total background contribution (B_{in}) and different background components. (**B**): Sample-out TOF spectrum (C_{out}) together with the total background contribution (B_{out}) and different background components.

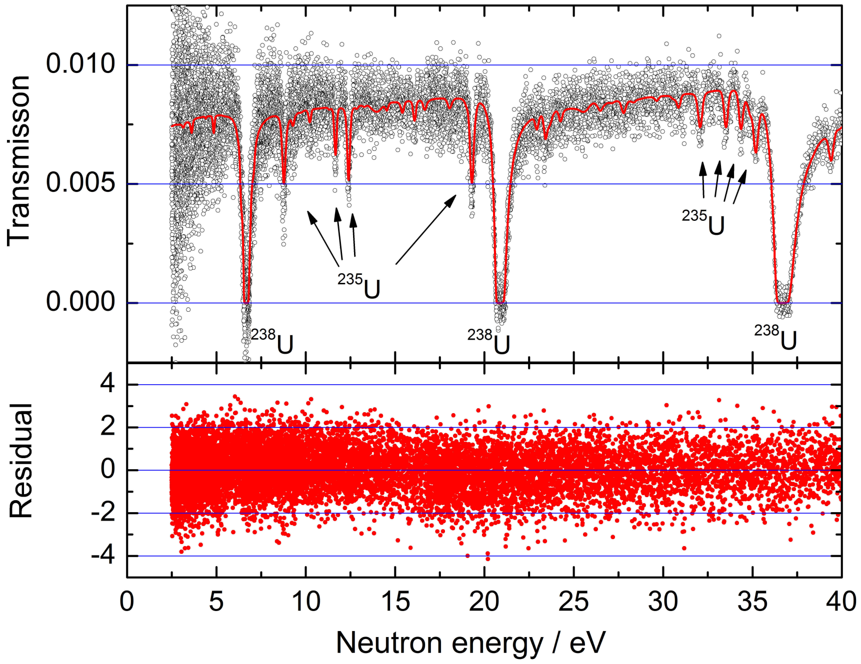

Fig. 2: NRD measurement of a CBNM 446 sample of the EU nuclear reference material 171 set and model calculation with REFIT.

to ^{238}U and ^{235}U could be clearly resolved (see figure 2). For this measurement the diameter of the last collimator was changed to 4 cm primarily to increase the count rate and to reduce effect of areal density variations. The total sample-in measurement time was 30 h. This time decreases significantly for a larger sample and a shorter flight path as planned for the JAEA application of NRD. The role of the nuclear data on the accuracy that can be reached to analyze uranium containing samples by NRD was discussed in ref. [15].

Table 3: Summary of capture experiments performed at FP15-30 m using radionuclide sources to test the performance of a $LaBr_3$ detector.

Sample	ID	Source	Background filters	Exp. completed
B_4C	TP-NP08/42		S, Na, Co	02/2013
B_4C	TP-NP08/42	^{137}Cs close to $LaBr_3$	S, Na, Co	02/2013
B_4C	TP-NP08/42	^{137}Cs close to $LaBr_3$	S, Na, Co	02/2013
B_4C	TP-NP08/42	^{137}Cs + ^{60}Co close to $LaBr_3$	S, Na, Co	02/2013

2.2 Capture experiment with a $LaBr_3$ detector

The amount of ^{10}B and structural materials such as Fe cannot be determined by an analysis of low energy resonances. These elements can be quantified by the detection of prompt γ-rays which are emitted after a neutron capture reaction [1, 18]. A special detector, consisting of a large cylindrical $LaBr_3$ crystal acting as a main detector combined with a well made out of $LaBr_3$ acting as a back-catcher. A conceptual design of such a detector is given in ref. [16]. The $LaBr_3$ detector was chosen over Ge or C_6D_6 detectors as compromise of timing and energy resolution. To test the performance of a $LaBr_3$ detector for NRCA and PGAA applications experiments have been carried out at the 30 m capture measurement station of flight path 15 of GELINA. The C_6D_6 detectors, which are routinely used for capture cross section measurements at this station, were replaced by a commercial available $LaBr_3$ detector. The detector was coupled to a conventional electroncis chain. The anode pulse of the PMT was split. One part of the signal was fed into a constant fraction discriminator to create a fast logic signal which defines the arrival time of the neutron creating the capture event in the sample. The other part was shaped by a spectroscopic amplifier to determine the energy deposited by the detected γ-rays in the detector. The processing of the time and amplitude signals for both capture and flux detection systems was based on analog electronics. The TOF of a detected event was determined with a multi-hit fast time coder with a 1 ns time resolution [8]. The TOF and pulse height of a detected event were recorded in list mode using the multi-parameter data acquisition system developed at the EC-JRC-IRMM [9].

The measurements at the neutron beam have been complemented by measurements with radioactive sources (Cs, Co, Th and a Pu-C mixture) used for the energy calibration of the $LaBr_3$ detector. A summary of the measurements that have been carried out is given in table 3. The measurements at the pulsed neutron beam were carried out with a B_4C sample in the beam to verify if a $LaBr_3$-detector can be used to determine the amount of ^{10}B in a sample. The performance of a $LaBr_3$ detector to separate the 478-keV gamma ray emitted in the $^{10}B(n,\alpha)$ reaction from the 661-keV gamma ray emitted due to the decay of ^{137}Cs was verified by placing a ^{137}Cs source at different positions from the $LaBr_3$ detector. Part of the data have already been analysed and prelimenary results have been presented at the INMM 54^{th} Annual Meeting [12, 18].

3 Sample inhomogeneity model

The attenuation of a neutron flux in a heterogeneous sample can differ significantly from the attenuation in an homogenized medium. This occurs predominately if the characteristic length of the microscopic structure of the heterogeneity is larger than the mean free path of neutrons. Assuming a homogeneous medium when analyzing the transmission spectrum using a heterogeneous sample can introduce a significant bias outcome of a resonance shape analysis. In particular, fitted areal densities are underestimated in NRTA, as shown in ref. [13]. Therefore, several analytical models which describe the flux attenuation in heterogeneous sample were studied [7, 13] and implemented in the resonance shape analysis code REFIT [11]. The implementation in REFIT is described in detail in ref. [17]. The use of the model has been demonstrated in ref. [13] using the data that was described in section 2.1.2.

4 Production of samples simulating melted fuel

Alloy samples that will be used to simulate melted fuel in a demonstration experiment have been specified. The samples will be produced by the company OCAS NV. All administrative arrangements for the production of the samples have been made. The underlying idea is to replace radioactive elements by non-radioactive elements with similar cross section structure. The composition of the alloy was based on the results of an analysis of molten fuel from the Phébus FPT1 experiment [19]. Instead of oxide an metallic alloy was considered. A first attempt to produce a W-In-Zr-Fe-Cr alloy was unsuccessful due to the high melting point of tungsten.

A set of two Ag-In-Zr-Fe-Cr alloys in the form of a disc with a 50 mm diameter and a thickness of 1 mm and 5 mm have been specified. The elemental composition of the alloys is given in table 4. The amount of Ag and In has been specified to simulate U and Pu, respectively, taking into account the difference in resonance strength. The other elements are the conventional structural materials present in a nuclear fuel assembly. After the extraction of the samples out of the cast material, the remaining material will be used to produce samples made out of broken pieces simulating debris of melted fuel.

Table 4: Elemental composition of the Ag-In-Zr-Fe-Cr alloys.

Element	Atom fraction (at%)	Weight fraction (wt%)
Ag	55.06	59.739
In	1.44	1.660
Zr	39.89	36.609
Fe	2.66	1.494
Cr	0.95	0.498

5 Dissemination

In this section activities to disseminate the progress made on the development of NRD are summarized. These activities include presentations at workshops and conferences, contributions to conference proceedings, scientific reports and papers published in refereed journals.

5.1 Contributions to workshops and meetings

The following presentations of research related to the development of NRD by JAEA and EC-JRC-IRMM were given by IRMM staff at workshops and meetings:

- P. Schillebeeckx, *R&D Activities of Neutron Resonance Densitometry*, Seminar of the Integrated Support Center for Nuclear Non-proliferation and Nuclear Security (ISCN) of Japan and hosted by the State Nuclear Regulatory Inspectorate of Ukraine (SNRIU) Seminar on the Experiences of Ukraine and Japan: Nuclear non-proliferation and overcoming from the accidents, Kiev, Ukraine, 24 – 26 September, 2013
- K. Kauwenberghs, *Implementation of an analytical model accounting for sample inhomogeneities in REFIT*, European Research Infrastructures for Nuclear Data Applications (ERINDA) 2013 Worskhop, CERN, Geneva, Switzerland, 1 – 3 October, 2013
- B. Becker, *Characterization of melted fuel by neutron resonance spectroscopy*, Meeting of the European Safeguards Research and Development Association (ESARDA) Working Group on Techniques and Standards for Non Destructive Analysis, SCK, Brussels, Belgium, November 26 – 27, 2013

5.2 Contributions to conferences with proceedings

In the following a list of contributions to conferences with proceeding for which an IRMM staff member was principle author is given:

35th Annual European Safeguards Research and Development Association (ESARDA) Symposium on International Safeguards, Bruges, Belgium, 27 – 30 May, 2013

- P. Schillebeeckx, B. Becker, A. Borella, H. Harada, K. Kauwenberghs, F. Kitatani, M. Koizumi, S. Kopecky, A. Moens, G. Sibbens, H. Tsuchiya, *Development of neutron resonance densitometry at the GELINA TOF-facility*
- B. Becker, H. Harada, K. Kauwenberghs, F. Kitatani, M. Koizumi, S. Kopecky, A. Moens, P. Schillebeeckx, G. Sibbens, H. Tsuchiya, *Particle size inhomogeneity effect on neutron resonance densitometry*

Institute of Nuclear Materials Management (INMM) 54th Annual Meeting, Palm Desert, California USA, July 14 – 18, 2013

- P. Schillebeeckx, B. Becker, F. Emiliani, S. Kopecky, K. Kauwenberghs, A. Moens, W. Mondelaers, G. Sibbens, H. Harada, F. Kitatani, M. Koizumi, M. Kureta, H. Iimura, J. Takamine, H. Tsuchiya, S. Abousahl, M. Moxon, *Contribution of the JRC to the development of neutron resonance densitometry to characterize melted fuel from severe accidents*

11th International Topical Meeting on Nuclear Application of Accelerators (AccApp), 5–8 August 2013, Bruges, Belgium

- B. Becker, S. Kopecky, P. Schillebeeckx, H. Harada, F. Kitatani, *Importance of Nuclear Data for Neutron Resonance Densitometry*

5.3 Reports

A report was produced to document changes the resonance shape analysis code REFIT:

- B. Becker, K. Kauwenberghs, S. Kopecky, H. Harada, M. Moxon, P. Schillebeeckx, *Implementation of an analytical model accounting for sample inhomogeneities in REFIT*, JRC Scientific and Policy Reports (2013)

5.4 Publications in refereed journals

The following scientific papers were submitted to refereed journals:

- P. Schillebeeckx, B. Becker, A. Borella, H. Harada, K. Kauwenberghs, F. Kitatani, M. Koizumi, S. Kopecky, A. Moens, G. Sibbens, H. Tsuchiya, *Development of neutron resonance densitometry at the GELINA TOF-facility*, accepted for publication in ESARDA bulletin **50** (2013)
- B. Becker, H. Harada, K. Kauwenberghs, F. Kitatani, M. Koizumi, S. Kopecky, A. Moens, P. Schillebeeckx, G. Sibbens, H. Tsuchiya, *Particle size inhomogeneity effect on neutron resonance densitometry*, accepted for publication in ESARDA bulletin **50** (2013)
- B. Becker, S. Kopecky, H. Harada, P. Schillebeeckx, *Measurement of the direct particle transport through stochastic media using neutron resonance transmission analysis*, submitted to Eur. Phys. J. Plus (2013)

6 Training of JAEA staff

Several staff members of JAEA were trained by IRMM staff regarding measurements at GELINA and data reduction and analysis methods and codes.

6.1 Measurements at GELINA

Four scientific staff members of JAEA were trained to perform capture and transmission measurements at GELINA. The full measurements period extended from November 2012 to April 2013. The scientific visits were:

- 26 November 2012 – 30 November 2012: H. Harada for capture experiments using $LaBr_3$;
- 26 November 2012 – 29 November 2012: M. Koizumi for capture experiments using $LaBr_3$;
- 3 December 2012 – 7 December 2012: F. Kitatani for Cu transmission experiments;
- 3 December 2012 – 7 December 2012: H. Tsuchiya for Cu transmission experiments.

6.2 Data reduction and analysis

Four scientific staff members of JAEA also received training in data reduction with the AGS code [10] and data analysis with REFIT [11]. These codes are widely used and further developed at EC-JRC-IRMM for the analysis of TOF measurements. The scientific visits were:

- 3 December 2012 – 7 December 2012: H. Tsuchiya for training with AGS and REFIT,
- 3 June 2013 – 4 June 2013: H. Harad, for training with AGS and REFIT,
- 3 June 2013 – 4 June 2013: H. Tsuchiya for training with AGS and REFIT,
- 11 November 2013 – 20 December 2013: A. Kimura for training with REFIT.

7 Update of action sheet

During the progress meeting, which was organized at the ESARDA symposium in Bruges, Belgium on the 30 May 2013, the activities of the action sheet were discussed and reviewed. On request of JAEA section 2.4 of the action sheet was adapted to accelerate the development. JAEA proposed to include:

a) the production of a report describing the feasibility and performance assessment (by April 2014), and
b) the demonstration of NRD at GELINA (begin 2015).

The updated action sheet is given in the Appendix A.

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APPENDIX A:

Action Sheet 1

Feasibility Study and Development of Neutron Resonance Densitometry for Particle-like Debris of Melted Fuel

1. Aim of this collaboration

This collaboration is aiming at quantifying nuclear materials by a non-destructive method NRD (neutron resonance densitometry) in particle-like debris of melted fuel formed in severe accidents of nuclear reactors such as Fukushima No.1 nuclear power plant.

The NRD here is a combined method of NRTA (neutron resonance transmission analysis) and NRCA (neutron resonance capture analysis) using a pulsed neutron generator and TOF (time of flight) measurement. NRCA and NRTA are two techniques which are applied at the GELINA facility of the EC-JRC-IRMM for the characterization of reference materials and objects.

2. Activities

1. Study of the methodology including the accuracy and uncertainty of the neutron transmission and capture method
   - i) Effect of particle size (◎IRMM, ○JAEA)
   - ii) Effect of sample thickness (◎JAEA, ○IRMM)
   - iii) Effect of contaminated materials (◎JAEA, ○IRMM)
   - iv) Effect of sample temperature (◎IRMM, ○JAEA)
   - v) Study of detection systems (◎JAEA, ○IRMM)
   - vi) Generalization of resonance analysis code (REFIT) (◎IRMM, ○JAEA)

2. Study of relevant nuclear data
   - i) Survey of current nuclear data (◎JAEA, ○IRMM)
   - ii) Measurement of relevant nuclear data and reference TOF-spectra (◎IRMM, ○JAEA)

3. Study of neutron source
   - i) Electron linear accelerator design (◎IRMM, ◎JAEA)
   - ii) Neutron source study (◎JAEA, ○IRMM)
   - ii) Study of resolution function (◎IRMM, ○JAEA)

4. Validation and demonstration of NRD
   - iii) Report on feasibility and expected accuracy of NRD (◎IRMM, ◎JAEA)

    ii) Preparation of measurement station at GELINA (◎IRMM, ○JAEA)
    iv) Preparation of detectors for NRD (◎JAEA, ○IRMM)
    v) NRD demonstration experiments at GELINA(◎JAEA, ◎IRMM)
    vi) Report of results (◎JAEA, ◎IRMM)

5. Report on NRD applications ((◎JAEA, ◎IRMM))

* Experimental devices etc., which would be imported / exported for the accomplishment of this study, shall not be used for activities beyond this purpose.

3. Programmatic Responsibilities

1. With best efforts basis and within funding and schedule, JRC-IRMM and JAEA personnel are responsible for performing the activities in 2.
2. JRC-IRMM will be responsible for providing JAEA with necessary information to support JAEA responsibilities and to perform the activities in 2.
3. JAEA will be responsible for providing JRC-IRMM with necessary information to support JRC-IRMM responsibilities and to perform to perform the activities in 2.
4. JAEA and JRC-IRMM will be responsible for participating in co-authorship and review of reports produced during this study.

4. Schedule

The schedule of activities shown in 1. spans April 1, 2012 through March 31, 2016.

Feasibility Study and Development of Neutron Resonance Densitometry for Particle-like Debris of Melted Fuel		**2012 JFY**				**2013 JFY**				**2014 JFY**				**2015JFY**			
Activity		**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
1	i Effect of particle size	X	X	X	X	X	X	X	X								
	ii Effect of sample thickness	X	X	X	X	X	X	X	X								
	iii Effect of contaminated materials						X	X	X	X	X	X	X	X			
	iv Effect of sample temperature						X	X	X	X	X	X	X	X			
	v Study of detection systems				X	X	X	X	X	X	X	X	X	X	X	X	
	vi Generalization of resonance analysis code				X	X	X	X	X	X	X	X	X	X	X	X	
2	i Survey of current data			X	X	X	X	X	X	X	X						
	ii Measurement of relevant data and reference TOF-spectra									X	X	X	X	X	X	X	X
3	i Electron linear accelerator design			X	X	X	X	X	X	X	X						
	ii Neutron source study			X	X	X	X	X	X	X	X	X	X	X	X		
	iii Study of resolution function									X	X	X	X	X	X	X	X

Feasibility Study and Development of Neutron Resonance Densitometry for Particle-like Debris of Melted Fuel		**2012 JFY**				**2013 JFY**				**2014 JFY**				**2015JFY**			
Activity		**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
4	i Report on feasibility and accuracy of NRD					X	X	X									
	ii Preparation of measurement station at GELINA							X	X								
	iii Preparation of detection equipment								X	X	X	X					
	iv NRD demonstration experiments at GELINA												X	X			
	v Report on results													X	X		
5	Report on NRD applications													X	X	X	X

This schedule may be changed with the appropriation of funds by the governmental authority.

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Abstract

The activities carried out during 2013 at the Institute for Reference Materials and Measurements of the Joint Research Centre of the European Commission to support the Japan Atomic Energy Agency in the development of Neutron Resonance Densitometry are described. These activities include experiments carried out at the time-of-flight facility GELINA, development of a model to account for sample inhomogeneities, assistance in data reduction and analysis procedures, preparation of test samples, training of JAEA staff and dissemination of the results.

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