Final Publishable JRP Summary for JRP ENG08 MetroFission
Metrology for new generation nuclear power plants

Overview

Society demands energy supplies that are secure, sustainable and of high quality. In the next decade, Europe is facing potential energy shortages as oil and gas supplies run down and nuclear power facilities age. Pressure to reduce the greenhouse gas emissions has led to a requirement for the development of a new generation of nuclear power plants in Europe. This project developed the necessary metrology infrastructure to enable measurement of key parameters associated with new generation nuclear power plants in order to ensure that energy suppliers and regulators develop a safe and secure nuclear energy supply.

There are several designs (typically six) for the proposed Generation IV nuclear reactors. The main differences between current nuclear reactors and Generation IV nuclear reactors are the type of fuel, the higher energy of neutrons required to fission e.g. Uranium-238 and a closed fuel cycle design that enables the fuel to be recycled leading to more efficient use of natural resources, minimisation of waste and maintained proliferation resistance. Generation IV reactors also operate at high temperatures and are capable of utilising industrial process heat to improve their efficiency and economy. In these reactors the temperatures will be much higher (i.e. above 1000 °C) than conventional reactors (i.e. 500 °C).

Need for the project

Therefore, generation IV reactors pose the following metrological problems, which this project aimed to answer: How can the temperatures be accurately measured, as existing thermocouple-based methods cannot be used at these temperatures and in this environment? What materials could be used in these reactors and how do we determine the thermal properties of these potential reactor materials? What nuclear data and radiation measurement techniques are needed to support the safe and effective operation of Generation IV reactors?

Scientific and technical objectives

Therefore the key aims of the project were to:

- **Develop improved temperature measurement for nuclear power plant applications** by providing metrology for measurements at the higher temperatures required for operating the next generation of nuclear power plants.
- **Characterise thermal properties of advanced materials for nuclear design** in order to assist with construction of the new generation of nuclear power plants. Understanding the behaviour of nuclear fuels, coolant and materials used for the reactor enclosure is vital to the design and safe operation of nuclear reactors. This includes developing models of the thermodynamic behaviour and the ability to measure and characterise thermal physical properties of relevant materials (specific heat capacity, thermal diffusivity, thermal expansion, and emissivity). In some cases, these properties can already be measured at high temperatures; however these measurements often lack traceability to the SI above 800 °C. Therefore, reference metrological methods need to be implemented or improved for measurements up to 2000 °C (1500 °C in the case of specific heat of solids).
- **Develop improved metrology for determination of high-energy neutron cross sections**. New fast reactor designs will involve materials exposed to higher energy neutron fields. The current nuclear databases concentrate on thermal energies, so much work is needed on nuclear data at higher energies. Advantage will be taken of NMI experience in neutron metrology, particularly fluence measurements, to improve cross section measurements of interest to new generation power

The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union

plants and fuel cycles. In this respect, an important objective of the project was to establish an easy-to-use secondary fluence standard and to demonstrate its potential for the determination of cross sections of actual interest and the improvement of nuclear data standards in the form of reduced measurement uncertainties. The last point is particularly in line with the "*Uncertainty and target accuracy assessment for innovative systems using recent covariance data evaluation*s" published by a working party of the OECD Nuclear Energy Agency in 2008.

- **Produce nuclear data for the fuel cycle of new nuclear power plants and to provide important data regarding the thermal energy released in the reactor core from minor actinides present in the fuel.** The heavier actinides and their decay products have generated increased interest in recent years because of their role in the foreseen development and adoption of nuclear power plants in whose fuels they will be present in controlled amounts. Uranium-238 (^{238}U) is the dominant fissile material in the fuel of new reactors and is a nuclide that has been highlighted in a recent review by the IAEA[1] as an actinide that requires new and improved nuclear data. Furthermore, the decay heat produced by fission products, amounting to 8 % of the energy generated during the fission process, needs to be well characterised for safe operations (reactor shutdown, post irradiation handling of nuclear fuels). This decay heat corresponds to the radiant energy (beta, gamma) emitted by the natural decay of these nuclides, which is imparted to surrounding medium. Therefore the second part of this objective was to improve knowledge of beta spectra.
- **Develop improved measurement techniques for radioactivity for safe and efficient operation of new nuclear power plants.** The TDCR (Triple-to-Double-Coincidence-Ratio) method is the only available detection method for beta particles (emitted from e.g. ^{3}H and ^{241}Pu) that can deliver a result without preceding calibration. It also has the potential to reduce uncertainties by a factor of two. By miniaturising this instrument it can be used in nuclear power plants, bringing benefits to activity measurements *in-situ*.

Results

Improved temperature measurement for nuclear power plant applications

New temperature sensors and methods for *in-situ* measurements in nuclear power plants have been investigated and developed with an emphasis on extending the measurement range to higher temperatures and characterising, limiting, or completely eliminating the sensor drift in a high-temperature, high-neutron-flux environments. A new reference temperature fixed point at 1153.8 ^{o}C (above the existing copper point) was developed and is available for post-irradiation studies of thermocouples or as a calibration service. A thermocouple from the Mo/Nb family was identified as potentially suitable for the nuclear environment. It was constructed by the company Thermocoax and tested by project partners in terms of its reference functions, stability, and thermoelectric homogeneity. However the studies showed rather disappointing stability results and will require further investigation in the future. Self-validation methods for thermocouples as a means to reduce or eliminate in-situ drift related problems have been developed that are suitable for use in the nuclear industry. In addition, practical primary acoustic thermometry, an inherently drift-less technique, has been tested through the construction of a demonstrator. This so far successful method could be used to assess the drift performance of more conventional sensors or as an in-situ temperature sensing method in its own right.

Thermal properties of advanced materials for nuclear design

Thermodynamic models have been developed and parameterised for a range of major and minor actinide containing systems relevant to nuclear fuels (both in reactors and during reprocessing) and coolants. These models have allowed the project to make predictions related to high-temperature phase equilibria (e.g. phase transformation temperatures) of these materials, which was validated partly by comparison with experimental observations (outside of the MetroFission project). Data was critically assessed to represent the potential interaction between the sodium coolant and the MOX nuclear fuel, taken to be based on $(U,Pu)O_2$, and incorporating minor actinides such as neptunium and americium. Data for the fission products and containment materials have also been reviewed and new data assessed to represent the interaction between them, the sodium coolant and the environment, in order to permit the calculation of phase and chemical

[1] A.L. Nichols, IAEA, Actinide Decay Data: Measurement requirements identified to date (IAEA – October 2008)

equilibria for severe accident scenarios. These validated models will support the selection of the most appropriate materials for fuel and coolants of Generation IV Reactors.

Reference facilities for the measurement of thermophysical properties (thermal diffusivity, normal spectral emissivity, thermal expansion and specific heat) of solid materials up to 1500 °C or 2000 °C (depending on which thermal property) have been developed. They have been applied to the thermal characterization of materials at high temperatures and enabled an improvement in the traceability of the thermal properties measurements performed at high temperature by nuclear research laboratories. Suitable candidate materials to serve as “transfer reference materials” for high temperature thermal properties measurements have been identified and characterised. The thermophysical properties of high purity 4N tungsten produced by *Plansee*, isostatic graphite grade R6650P5 from SGL Carbon group, magnesium oxide (powder) and nickel and zirconium dioxide (homogeneous solid materials) were selected because they are non-radioactive, stable at the temperatures of interest, and because of their relevance to thermal property measurements on nuclear materials. The next stage of validation of ISO graphite as a suitable reference material is scheduled for June 2015. Two of the project partners have been invited to participate in an APMP T-S.9 TCT thermal diffusivity supplementary comparison led by NMIJ (Japan), which will include NMI participants from NPL, LNE, KRISS (Korea), NIM (China), CMS/ITRI (Taiwan).

Improved metrology for neutron cross section measurements

An easy-to-use calibrated neutron fluence standard was developed and its potential for the determination of cross sections of interest was demonstrated by a number of neutron induced fission cross section measurements on ^{240}Pu and ^{242}Pu with mono-energetic neutron beams produced at two different NMIs, i.e. at the Van de Graaff accelerator and the cyclotron of PTB and at the Van de Graaff accelerator of NPL. The measurements were performed using gas filled detectors, consisting of a Frisch-gridded ionisation chamber containing the plutonium sample, mounted back to back to a parallel plate chamber containing a ^{238}U sample. The neutron fluence was successfully measured in parallel with the ^{238}U parallel plate chamber and with the fixed neutron fluence monitors available at the respective institutes. The availability of this transfer instrument for neutron fluence measurements will improve future nuclear data in the form of reduced measurement uncertainties[2].

Development of nuclear data

Alpha-particle emission probabilities of ^{238}U with certified isotopic composition have been determined and spectrometric measurements completed. The accuracy of the alpha particle emission probabilities of ^{238}U was improved by one order of magnitude compared to previously recommended values. Furthermore, a unique, state-of-the-art cryogenic detector was used as a means to determine the shape of beta spectra of ^{63}Ni (a pure beta transmitter). This is innovative approach that offers exceptional characteristics in terms of energy resolution and detection efficiency over a wide energy range. The experimental determination of beta spectrum shapes is essential for verifying and/or modifying existing theoretical models. The measurements of the beta-spectrum of ^{63}Ni have been made available in scientific literature and will be part of future international evaluation of nuclear data.

Improved measurement techniques for radionuclides

The measurement techniques that have been developed were aimed at providing an ability to perform on-site radioactivity measurements, by the development of a portable Triple to Double Coincidence Ratio (TDCR) system. Four prototypes of the portable TDCR system have been completed and validated against the international reference system for a range of beta-emitters. An improved digital acquisition system was developed for the portable TDCR. The digital electronics were also tested on other detector systems in order to assess whether they can allow for pulse-shape discrimination (which can be used for discrimination between different types of radiation) and measurement at higher count-rates (which would be applicable to the nuclear industry). The digital systems developed are state of the art systems with hardware that can acquire data at sampling rates of 10^9 s^{-1} and can be implemented on two channels (coincidence counting) or three channels (TDCR) detector systems. The overall system has been made available for applications on-site in nuclear power plants.

---

[2] See“Uncertainty and target accuracy assessment for innovative systems using recent covariance data evaluations“ published by a working party of the OECD Nuclear Energy Agency in 2008.

Actual and potential impact

In terms of dissemination of the project results, the project coordinator was invited as a keynote speaker at the IMEKO2011 conference in Dubrovnik in June 2011 and at the ANIMMA conference in Marseille June 2013. The project also had a special session at the same conference and seven papers have been accepted for publication. Contributions has been made to the SNETP (Strategic Nuclear Energy Technology Platform) Newsletter and several trade magasines (e.g. Materials Worls and Nuclear Future). This SNETP is a very important European platform for political decisions regarding future nuclear power in Europe and the project was presented at the SNETP General Assembly in November 2011. In total, more than 36 peer-reviewed papers describing MetroFission scientific achievements have been submitted to peer-reviewed journals and more than sixty presentations has been given at conferences and workshops such as Metrologie, ITS, ICRM, Tempmeko and ANIMMA. The work was presented at an SP/EDF Workshop in Paris. During these conference contacts were made with major stakeholders e.g. IRSN, CEA-DEN and AREVA.

The project held an open meeting to users and stakeholders, in Rome, 9-10 February 2012. Representatives from the SNETP, the ITER Fusion project and Digital Electronics providers attended the meeting. In October 2012, project partners went to the Generation IV project ASTRID in Cadarache, France, to disseminate the results of the project to CEA, France (which are building the test reactor Jules Horowitz in Cadarache). Finally, in June 2013, the project held a workshop dedicated to Nuclear Data, the INDD 2013, where stakeholders were presented with the improved nuclear data from this project. The workshop was organised by IFIN-HH and SMU together with the JRC.

Furthermore, national representatives have been identified for the three major standard committees related to the scientific developments in this project; ISO, IEC and IAEA and input has been provided, with a technical note that presents project results and suggested changes to current standards.

At the end of the project there are many examples of the outputs being taken on by the relevant communities:

- Stakeholders such as the CEA-Cadarache, University of Marseille and IRSN were interested in collaborating and taking the developed temperature measurement capabilities one step closer to implementation in nuclear power plants and testing in reactors.
- Discussions have taken place with Elsevier to include the data produced by thermo chemical modelling within a revised version of “Thermochemical data for reactor materials and fission products”, last published in 1990. This is the key reference data source and will therefore make the new data developed by the project directly available to users the nuclear industry.
- The IAEA and the NEA/OECD have provided continued support for the development of neutron cross sections, of which the transfer instrument for neutron fluence measurements is an essential part.
- The nuclear decay data have been made available for evaluation by the Decay Data Evaluation Project (DDEP), the IAEA and the OECD/NEA nuclear data working groups.
- A digital electronics manufacturer has showed interest in further development and collaboration regarding the coincidence counting system (TCDR) developed in MetroFission as well as a continued collaboration with the European Networks (European Reference Network for Critical Infrastructure Protection).
- The digital electronics development also had a direct impact on the development of a new standard for nuclear instrumentation. One of the project partners has been asked to lead a task within the newly established ERNCIP (European Reference Network for Critical Infrastructure Protection) Thematic Group on the Protection of Critical Infrastructure from Radiological and Nuclear Threats, which is pursuing the development of such a standard for list-mode data sets in radionuclide metrology. Further proposals are presently being drafted to both CENELEC and IEC Technical Committee 45 on nuclear instrumentation. Support has also been received from the International Committee for Radionuclide Metrology (ICRM) Working Group on Radionuclide Metrology Techniques.

- The portable TDCR system has been taken up in another project, working on the development of a mobile laboratory for measurements of radioactivity at Sellafield Ltd. (UK).

The uptake of project outputs will lead to environmental, social and financial impacts. The environmental impact of this project comes from nuclear data and thermo-chemical modelling of proposed reactor fuels, as this will entail a closed fuel cycle, minimising waste and maximising efficient use of the fuel. The project will enable improved monitoring of radioactivity released into the environment during operation and waste management by improved measurements of radionuclides. Furthermore, the project has provided thermo-chemical and thermo-physical data for the safe design of new generation reactors as well as improved and new direct methods for temperature measurements.

The social impact of the project comes from improved metrology for safe construction and operation of the new generation reactors, that will contribute to an enhanced quality of life for European citizens. The financial benefits from the project will be from the development of better temperature measurement in reactors which allows the production and use of high temperature reactors, capable of heat supply to improve efficiency and economy in a variety of industrial processes. The project has produced better and more reliable temperature measurements and sensors in reactors that will enable more efficient process control, reduced calibration and maintenance costs of temperature sensors and reduced costs for downtime. Previous experience of working with nuclear power plants has shown that there is a demand for on-site measurements as this significantly improves the efficiency and reduces the costs of the plant operation.

List of publications

Bobin C., J. Bouchard, S. Pierre, C. Thiam, Overview of a FPGA-based nuclear instrumentation dedicated to primary activity measurements, Applied Radiation and Isotopes, Volume 70, Issue 9, September 2012, Pages 2012-2017.

Bobin C., J. Bouchard, C. Thiam, Y. Ménesguen, Digital pulse processing and optimization of the front-end electronics for nuclear instrumentation, Applied Radiation and Isotopes, Vol. 87 (2014) 195-199.

Marco Capogni, Andrei Antohe, Construction and implementation of a TDCR system at ENEA, Applied Radiation and Isotopes, Vol. 87 (2014) 260-264.

Capogni M, De Felice P., Loreti S., 2013, Metrofission project: an overview of the ENEA contribution, Energy Procedia 41, 11-25.

Capogni M., De Felice P., 2014, A prototype of a portable TDCR system at ENEA, Appl. Radiat. Isot. DOI: 10.1016/j.apradiso.2014.03.021

Cassette, P. ; Capogni, M. ; Johansson, L. ; Kossert, K. ; Nahle, O. ; Sephton, J. ; De Felice, P., Development of portable Liquid Scintillation counters for on-site primary measurement of radionuclides using the Triple-To-Double Coincidence Ratio method, 3rd International Conference on Advancements in Nuclear Instrumentation Measurement Methods and their Applications (ANIMMA), 2013.

Dinsdale, A. ; Gisby, J. ; Davies, H. ; Konings, R. ; Benes, O., Thermodynamic data to model the interaction between coolant and fuel in gen IV sodium cooled fast reactors, 3rd International Conference on Advancements in Nuclear Instrumentation Measurement Methods and their Applications (ANIMMA), 2013.

Elliott, C. J., Pearce, J. V., Failleau, G., Deuzé, T., Briaudeau, S., Sadli, M., and Machin, G., “Fe-C eutectic fixed-point cells for contact thermometry: an investigation and comparison”, Metrologia 49, 88-94 (2012).

Failleau, G., Deuzé, T., Pearce, J. V., Elliott, C. J., Machin, G., Briaudeau, S., and Sadli, M., “Development of an Fe-C Eutectic Fixed-Point for the Calibration and In-Situ Monitoring of Thermocouples”, in Proceedings of 2nd IMEKO TC 11 International Symposium Metrological Infrastructure: Cavtat, Croatia, 2011, pp. 77-80.

Guillaume Failleau, Thierry Deuzé, Mohamed Sadli, Sid-Ali Mokdad et Stephan Briaudeau, Méthodes d’Auto-Validation Pour Thermocouples à Haute Température, 16th International Congress of Metrology, 15002 (2013).

Hay, B. ; Anhalt, K. ; Chapman, L. ; Boboridis, K. ; Hameury, J. ; Krenek, S. ; Vlahovic, L. ; Fleurence, N. ; Benes, O., Traceability improvement of high temperature thermal property measurements of materials for new fission reactors, 3rd International Conference on Advancements in Nuclear Instrumentation Measurement Methods and their Applications (ANIMMA), 2013.

Heyse, J. ; Anastasiou, M. ; Eykens, R. ; Moens, A. ; Plompen, A.J.M. ; Schillebeeckx, P. ; Wynants, R., Development of a secondary neutron fluence standard at GELINA, 3rd International Conference on Advancements in Nuclear Instrumentation Measurement Methods and their Applications (ANIMMA), 2013.

Heyse Jan, Anastasiou M., Eykens Roger, Moens Andre, Plompen Arjan, Schillebeeckx Peter, Sibbens Goedele, Vanleeuw David, Wynants Ruud, Characterization of 235U targets for the development of a secondary neutron fluence standard, JOURNAL OF RADIOANALYTICAL AND NUCLEAR CHEMISTRY vol. 299 no. 2 p. 1055-1059, 2014.

Jobbagy Viktor, Crespo M. T., Van Ammel Raf, Marouli Maria, Moens Andre, Pommé Stefaan, Garcia-Torano Eduardo, Preparation of high-resolution 238U alpha-sources by electrodeposition: a comprehensive study, JOURNAL OF RADIOANALYTICAL AND NUCLEAR CHEMISTRY vol. 298 no. 1 p. 345-352, 2013.

Johansson, L., Filtz, J. R., De Felice, P., Sadli, M., Plompen, A., Hay, B., Dinsdale, A., Pommé, S., Cassette, P., and Keightley, J., “Advanced Metrology for New Generation Nuclear Power Plants”, in proceedings of 2nd IMEKO TC 11 International Symposium Metrological Infrastructure: Cavtat, Croatia, 2011, pp. 15-17.

Lena Johansson, Eleanor Bakhshandeiar, Andy Pearce, Sean Collins, Pascal Orlandini, John Sephton, A miniature TDCR system dedicated to in-situ activity assay, Applied Radiation and Isotopes, Vol. 87 (2014) 287-291.

Johansson, L. ; Filtz, J.-R. ; DeFelice, P. ; Sadli, M. ; Plompen, A. ; Heyse, J. ; Hay, B. ; Dinsdale, A. ; Pomme, S. ; Cassette, P. ; Keightley, J., Metrology for new generation nuclear power plants – MetroFission, 3rd International Conference on Advancements in Nuclear Instrumentation Measurement Methods and their Applications (ANIMMA), 2013.

Johansson, Lena, Developing European metrology for new generation nuclear power, *Nuclear Future* Mar/Apr 2013, http://content.yudu.com/A23bye/NucFutMarApr13/resources/45.htm

Keightley, J. ; Bobin, C. ; Bouchard, J. ; Capogni, M. ; Loreti, S. ; Roteta, M., Recent advances in digital coincidence counting for Radionuclide Metrology, 3rd International Conference on Advancements in Nuclear Instrumentation Measurement Methods and their Applications (ANIMMA), 2013.

Karsten Kossert, Marco Capogni, Ole J. Nähle, Bilateral comparison between PTB and ENEA to check the performance of a commercial TDCR system for activity measurements, Applied Radiation and Isotopes, In Press, Corrected Proof, Available online 30 January 2014.

K. Kossert, Ph. Cassette, A. Grau Carles, G. Jörg, Christroph Lierse V. Gostomski, O. Nähle, Ch. Wolf, Extension of the TDCR model to compute counting efficiencies for radionuclides with complex decay schemes, Applied Radiation and Isotopes, Vol. 87 (2014) 242-248.

C. Le-Bret, M. Loidl, M. Rodrigues, X. Mougeot, J. Bouchard, Study of the Influence of the Source Quality on the Determination of the Shape Factor of Beta Spectra, Journal of Low Temperature Physics, June 2012, Volume 167, Issue 5-6, pp 985-990.

M. Loidl, M. Rodrigues, C. Le-Bret, X. Mougeot, Beta spectrometry with metallic magnetic calorimeters, Applied Radiation and Isotopes, Vol. 87 (2014) 302-305.

M. Marouli, S. Pommé, V. Jobbágy, R. Van Ammel, J. Paepen, H. Stroh, L. Benedik, Alpha-particle emission probabilities of 236U obtained by alpha spectrometry, Applied Radiation and Isotopes, Vol. 87 (2014) 292-296.

Giuliano Mini, Francesco Pepe, Carlo Tintori, Marco Capogni, A full digital approach to the TDCR method, Applied Radiation and Isotopes, Vol. 87 (2014) 166-170.

Ole Nähle, Qi Zhao, Carsten Wanke, Mathias Weierganz, Karsten Kossert, A portable TDCR system, Applied Radiation and Isotopes, Vol. 87 (2014) 249-253.

J. Paepen, A. Dirican, M. Marouli, S. Pommé, R. Van Ammel, H. Stroh, A magnet system for the suppression of conversion electrons in alpha spectrometry, Applied Radiation and Isotopes, Vol. 87 (2014) 320-324.

Jonathan Pearce, Michael de Podesta, Claire Elliott and Graham Machin, Improving temperature sensing for new reactors, Nuclear Engineering International, 7 December 2011.
http://www.neimagazine.com/features/featureimproving-temperature-sensing-for-new-reactors/

Pearce, J. V.; de Podesta, M.; Elliott, C. J.; et al., Improving Temperature Sensing in Nuclear Environments, MEASUREMENT & CONTROL, 45/2(2012)60-62.

de Podesta, M, Sutton, G, Underwood, R J, Legg, S, Steinitz, A Practical acoustic thermometry with acoustic waveguides, Int. J. Thermophysics, 2010, 31, (8-9), 1554-1566.

S. Pommé, E. García-Toraño, M. Marouli, M.T. Crespo, V. Jobbágy, R. Van Ammel, J. Paepen, H. Stroh, High-resolution alpha-particle spectrometry of ^{238}U, Applied Radiation and Isotopes, Vol. 87 (2014) 315-319.

Pomme, S. ; Loidl, M. ; Garcia-Torano, E. ; Marouli, M. ; Le-Bret, C. ; Crespo, M.T. ; Paepen, J. ; Mougeot, X. ; Jobbagy, V. ; Rodrigues, M. ; Van Ammel, R. ; Stroh, H. ; Luca, A., Lessons learned from nuclear decay data measurements in the European metrology research programme 'MetroFission', 3rd International Conference on Advancements in Nuclear Instrumentation Measurement Methods and their Applications (ANIMMA), 2013.

Sadli, M. ; de Podesta, M. ; del Campo, D. ; Deuze, T. ; Edwards, G. ; Elliott, C.J. ; Failleau, G. ; Fourrez, S. ; Garcia Izquierdo, C. ; Laurie, M. ; Mokdad, S.A. ; Pearce, J.V. ; Sutton, G., New temperature references and sensors for the next generation of nuclear power plants, 3rd International Conference on Advancements in Nuclear Instrumentation Measurement Methods and their Applications (ANIMMA), 2013.

Sadli, M., Del Campo, D., De Podesta, M., Failleau, G., Fourrez, S., Garcia, C., Pearce, J., Rae, C., and Scervini, M., "Improving high temperature measurements for the nuclear industry at the European level", in electronic proceedings of 15th International Congress of Metrology: Métrologie, 2011.

Sadli, M.; del Campo, D.; de Podesta, M.; et al., MetroFission: New high-temperature references and sensors for the nuclear industry, Ninth International Temperature Symposium Location: Los Angeles, CA, USA Date: 19-23 March 2012, AIP Conference Proceedings 1552(2013)1003-8.

Scervini, M.; Rae, C., Low drift type N thermocouples for nuclear applications, 3rd International Conference on Advancements in Nuclear Instrumentation Measurement Methods and their Applications (ANIMMA), 2013.

Scervini, M. ; Rae, C. ; Lindley, B., Transmutation of thermocouples in thermal and fast nuclear reactors 3rd International Conference on Advancements in Nuclear Instrumentation Measurement Methods and their Applications (ANIMMA), 2013.

Carsten Wanke, Karsten Kossert, Ole J. Nähle, Investigations on TDCR measurements with the HIDEX 300 SL using a free parameter model, Applied Radiation and Isotopes, Volume 70, Issue 9, September 2012, Pages 2176-2183.

JRP start date and duration:	01 September 2010, for 3 years
JRP-Coordinator: Dr. Lena Johansson Tel: +44 (0)20 8943 8587 E-mail: Lena.JOHANSSON@npl.co.uk JRP website address: http://projects.npl.co.uk/metrofission/	
JRP-Partners: JRP-Partner 1 NPL, United Kingdom JRP-Partner 2 CEA, France JRP-Partner 3 CEM, Spain JRP-Partner 4 CIEMAT, Spain JRP-Partner 5 CMI, Czech Republic JRP-Partner 6 CNAM, France JRP-Partner 7 ENEA, Italy	 JRP-Partner 8 IFIN-HH, Romania JRP-Partner 9 JRC, EC JRP-Partner 10 LNE, France JRP-Partner 11 PTB, Germany JRP-Partner 12 SMU, Slovakia
REG-Researcher (associated Home Organisation):	Michele Scervini, Italy UCAM, United Kingdom
RMG1 (associated Employing Organisation):	Matej Krivosik, Slovakia SMU, Slovakia
RMG2 (associated Employing Organisation):	Andrei Antohe, Romania IFIN-HH, Romania

The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union