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JRC.G.2 projects 2016-2020

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Contents

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Abstract

This report presents the projects as part of the Collaboration Agreement No. 34351 between the JRC and CEA running from 2016 to 2020. The activities focused on scientific and technological activities co-ordinated by JRC.G.2 within the nuclear fields of interest common to JRC and CEA: nuclear data for nuclear science and technology, development of innovative detectors and measurement technique, production of reference materials, emergency preparedness and education and training. The majority of projects were defined in project sheets and each project was assigned a lead researcher from both institutes. The umbrella of the collaboration agreement made it easy for scientists to visit the other institute and use the facilities there available. Based on the success of this collaboration, the management of JRC and CEA decided to renew this collaboration and new projects are already running or in the process of being defined.

1 Introduction

The French Alternative Energies and Atomic Energy Commission (CEA – Commissariat à l'énergie atomique et aux énergies alternatives) is a French public government-funded research organization in the areas of energy, defence and security, information technologies and health technologies. The CEA maintains a cross-disciplinary culture of engineers and researchers, building on the synergies between fundamental and technological research. It conducts fundamental and applied research into many areas, including the design of nuclear reactors, the manufacturing of integrated circuits, the use of radionuclides for curing illnesses, seismology and tsunami propagation, the safety of computerized systems, etc...

As the science and knowledge service of the European Commission, the mission of the Joint Research Centre (JRC) is to support European Union (EU) policies with independent evidence throughout the whole policy cycle. Through its Directorate for Nuclear Safety and Security located in Geel (Belgium), Ispra (Italy), Karlsruhe (Germany), and Petten (the Netherlands), the JRC conducts research in the fields of nuclear reactor and fuel safety, radioactive waste and spent fuel management, nuclear data for reactor and other applications, nuclear safeguards and security, emergency preparedness; radioprotection; dosimetry, decommissioning and nuclear science applications. JRC structures its collaboration with relevant nuclear research organisations in Member States (MS) under appropriate collaboration instruments, in order to ensure that JRC's research and training activities are aligned as appropriate with the national ones. Bringing scattered cooperation or joint projects under wider scope, more comprehensive frameworks allows for higher efficiency, easier follow-up, and appropriate visibility.

The Collaboration Agreement No 34351 between the JRC and CEA entered into force on 12 October 2016 for 5 years. The scope of cooperation covers scientific research and education and training in the field of nuclear safety of current and Generation IV systems. This report summarizes the activities and main outcomes of the Collaboration Agreement No 34351 contributed by the collaboration of JRC.G.2 and CEA.

2 Approved project sheets

Twenty projects were approved and carried out during the period 2016 – 2020. The projects together with the CEA directorate are given in Table 1. A status of the project sheets is given in sections 2.1 – 2.12.

Table 1. List of approved project sheets for the period 2016 - 2020

Research area Project	CEA division	Status
Nuclear data for nuclear science and technology		
Capture cross section measurements of fissile nuclides	CEA/DEN Cadarache	Ongoing
Fission cross section measurement of ^{235}U	CEA/DEN Cadarache	Ongoing
Integral measurements at GELINA	CEA/DEN Cadarache	Ongoing
Transmission measurements of MINERVE samples at GELINA	CEA/DEN Cadarache	Finalised
Measurements with VESPA to improve and validate the FIFRELIN code	CEA/DEN Cadarache	Finalised
Delayed Neutron Data Measurements at MONNET	CEA/DEN Cadarache	Delayed
Development of innovative detectors and measurement techniques		
Fission fragment spectrometers	CEA/DSM Saclay	Ongoing
Magnet system for alpha spectrometry	CEA/LNHB Saclay	Finalised
Production of nuclear reference materials		
Production and characaterisation of $^{235,238}U$ and Pu thin target layers	CEA/DAM Bruyères-le-Châtel	Ongoing
Production of a molecular plating cell		Finalised
Emergency preparedness		
Reference value for PT of environmental monitoring laboratories	CEA/LNHB Saclay	Finalised
Education & Training		
Training in low-level gamma-ray spectrometry	CEA/LNHB Saclay	Finalised

2.1 Capture cross section measurements of fissile nuclides

Scientific/technical contacts

JRC : P. Schillebeeckx (JRC.G.2)

CEA : O. Serot (CEA/DEN Cadarache)

Background

Neutron capture cross sections $\sigma_{n\gamma}$ of fissile nuclides are of high interest for the design of advanced reactors, safety assessment of critical systems and management of nuclear fuel. The most common method to measure $\sigma_{n\gamma}$ is based on the detection of prompt γ-rays emitted after a (n,γ) reaction. In case of a fissile nucleus such measurements are complicated by the presence of prompt fission γ-rays. Hence, a separation between the contribution due to prompt capture and fission γ-rays is required. In this project a detection system based on a fission tagging detector combined with the total energy detection principle will be developed for future measurements at the GELINA neutron Time-Of-Flight (TOF) facility of JRC-Geel.

Summary

The development of a detection system based on a fission tagging detector combined with the total energy detection principle did not start due to problems related with a PhD student (see comment).

An alternative measurement technique was proposed and applied to determine spectrum averaged cross section data for the ^{235}U(n,γ) reaction. This technique, which is based on a combination of neutron activation and atom counting of the reaction products using Accelerator Mass Spectrometry (AMS), was applied for measurements at a cold neutron beam of the ILL Grenoble and FRM II Munich reactors and at the thermal neutron field in the BR1 reactor at SCK CEN. By combining measurements at facilities with different neutron spectra the energy dependence of the cross section can be obtained.

The experiments are finalised:

- samples were prepared at JRC-Geel
- irradiation of ^{235}U samples and ^{197}Au foils were carried out at the BR1, ILL and FRM II reactors
- irradiated ^{235}U samples together with additional reference materials from JRC Geel to calibrate the mass spectrometers were sent to the University of Vienna for an AMS analysis.

The analysis of the AMS data is ongoing

Comment

These activities were scheduled to be part of the PhD work of Mr. A. Belkache supervised by Dr. O. Serot of CEA. However, early in his contract, Mr. A. Belkache decided to stop his PhD activities. Unfortunately, there were not enough resources to continue the work at GELINA. However, we intend to finalise the work on the spectrum averaged capture cross section measurements at the BR1, ILL and FRM II facilities.

2.2 Fission cross section measurement of ^{235}U

Scientific/technical contacts

JRC : P. Schillebeeckx (JRC.G.2)

CEA : O. Serot (CEA/DEN Cadarache)

Background

^{235}U is the most common fissile nuclide used worldwide. Neutron-induced fission cross sections σ(n,f) of ^{235}U has a strong influence on the results of numerical simulations. The ^{235}U fission cross section σ_{nf} at 2200 m/s, the cross section integral between 7.8 eV and 11 eV and the point-wise cross section above a neutron energy of 150 keV are used as a reference or neutron standard for measuring cross sections of other reactions. Unfortunately, experimental data in the resonance region to determine a standard for the resonance integral are rather scarce. This work aims at extending the data base to establish such a standard with a reduced uncertainty.

Summary

Fission cross section measurements were carried out at the TOF facility GELINA. The measurements were performed at a 9 m station of flight path 2 using a double Frisch-Gridded ionisation chamber with a common aluminium cathode with a thin layer of ^{235}U and ^{10}B deposited on opposite sites. To cover the full resolved resonance range, including the thermal energy region, two experimental campaigns were organised with the accelerator operating at 50 Hz and 400 Hz. The 50 Hz campaign lasted about 3 months and the 400 Hz campaign 1 week. The TOF and the pulse height of detected events were recorded in list mode using a data acquisition system developed at JRC-Geel. The data reduction and analysis is in progress.

Comment

These activities were scheduled to be part of the PhD work of Mr. A. Belkache supervised by Dr. O. Serot of CEA. However, early in his contract, Mr. A. Belkache decided to stop his PhD activities. Therefore, the expected time schedule could not be followed. Nevertheless, we intend to proceed with the analysis of the data, produce data for the EXFOR data library and report the results in a journal paper.

2.3 Integral measurements at GELINA

Scientific/technical contacts

JRC : A. Plompen (JRC.G.2)

CEA : P. Leconte (CEA/DEN Cadarache)

Background

Results of shielding experiments are valuable input data to validate evaluated cross section data, in particular cross sections for neutron elastic and inelastic reactions. In this project the possibility to perform for the first time neutron transport/shielding experiments in the target hall of the GELINA facility is investigated and verified by experiments using a thick slab of depleted uranium.

Summary

The possibility to perform shielding experiments in the target hall of GELINA was investigated. The work included:

- a feasibility study based on Monte Carlo simulations
- first experiments using slabs of depleted uranium
- improve experimental conditions based on the results of the first experiments
- design and construction of an improved set-up for new experiments.

The main objective is to design an experiment which clearly brings out the sensitivity of neutron transport to the inelastic scattering cross section of ^{238}U.

Results of Monte Carlo simulations with TRIPOLI and MCNP6 showed that GELINA has the potential to perform integral experiments:

- the total neutron emission rate is equivalent to the one used in the other experiments such as those at the CALIBAN critical facility in Valduc (FR).
- The depleted uranium disks available at JRC-Geel have suitable characteristics for such experiments.

The results of these calculations were used to design a first experiment which was carried out in 2017. Five metallic depleted uranium disks (33 mm thickness) and one 5-mm thick disk, all canned in Al, were stacked together to have a total uranium thickness of 155 mm. The employed neutron dosimetry reactions were ^{103}Rh(n,n'g), ^{115}In(n,n'g), ^{58}Ni(n,p), ^{27}Al(n,a), ^{47}Ti(n,p), ^{56}Fe(n,p), ^{54}Fe(n,p), ^{24}Mg(n,p), ^{59}Co(n,a), $^{235+238}$U(n,f), ^{46}Ti(n,p), ^{48}Ti(n,p). The primary experimental result is the reaction rate at a given depth divided by the reaction rate at the front of the block. The observed reaction rates were compared to detailed Monte Carlo calculations using the code TRIPOLI4. A study was made to improve the integral experiment with an effective shield against room return. Shield parameters were determined at CEA and an improved set-up following the design specifications of CEA was constructed by JRC.

The project continues as part of the INTEGRAAL/2 project which was accepted by the EUFRAT User Selection Committee (USC). In addition, the results of this project will benefit from another open access proposal, i.e. URANIUM_NRTA, for which the measurements at GELINA started in 2020. This proposal aims at characterizing the depleted uranium discs by Neutron Resonance Transmission Analysis (NRTA) for the presence of high neutron absorbing elements.

Publications

Contributions to conference proceedings and workshops

Leconte et al., "On the feasibility to perform integral transmission experiments in the GELINA target hall at IRMM", EPJ Web of Conferences 153 (2017) 01023

Technical reports

Nyman et al., "Integral Experiments in the GELINA Target Hall – ^{238}U and ^{nat}Cu", JRC Technical Reports, JRC104092, EUR28241 EN (2016)

Plompen et al., "Towards neutron benchmark experiments with GELINA", JRC Technical Reports, JRC109785 (2017)

2.4 Transmission measurements of MINERVE samples at GELINA

Scientific/technical contacts

JRC : S. Kopecky (JRC.G.2)

CEA : G. Noguere (CEA/DEN Cadarche)

This work is part of the PhD thesis of of Lino Šalamon (CEA/DEN Cadarache)

Background

Various UO_2 samples containing different nuclides (fission products and actinides) were used for oscillation measurements in the MINERVE reactor (CEA Cadarache) in the frame of the Burn-Up Credit (BUC) and OSMOSE experiments. A correct interpretation of these integral experiments requires an accurate knowledge of the sample composition in particular the presence of strong neutron absorbing material. In this project the use of transmission measurements at GELINA to characterise the MINERVE samples and to provide additional experimental data for an improved evaluation of resonance parameters is investigated. Part of the work was performed within the EUFRAT open access project of the JRC.G.2.

Summary

An analytical model to analyse transmission data of samples with a cylindrical geometry (like the MINERVE samples) was developed. For such samples the basic Lambert-Beer law cannot be applied. The model was validated experimentally by transmission experiments using samples containing natural silver. To avoid bias effects in the interpretation of the data, the resonance parameters of ^{107}Ag and ^{109}Ag isotopes were first reviewed and improved based on dedicated transmission and capture cross section measurements at GELINA. This resulted in a new evaluation of resonance parameters for neutron interactions with these Ag isotopes.

To validate the analytical model NRTA experiments were carried out at a 10 m transmission station of GELINA that was especially designed for such applications. NRTA was applied to determine the nuclide composition of UO_2, AL_2O_3 and liquid samples doped with natural silver. Applying the new analytical model the volume number densities of ^{238}U, ^{107}Ag and ^{109}Ag were within 2% fully consistent with the values quoted by the manufacturer. In addition, the NRTA data revealed a tungsten contamination which was not reported by the provider. Finally, transmission measurements on a cylindrical holder containing ten UO_2 pellets doped with ^{99}Tc were carried out. This sample is one of the samples which were especially designed for pile-oscillation measurements at the MINERVE reactor. The results of these measurements were used to produce an improved set of resolved and average resonance parameters for neutron interactions with ^{99}Tc.

The parameters for ^{107,109}Ag and ^{99}Tc are the basis of new evaluated data files to be adopted in the JEFF library. Most of the experimental data were delivered to the EXFOR library. The project continues as part of the MINERVE_UO2GD project which was accepted by the EUFRAT USC.

Publications

Journal papers

Šalamon et al., "^{107}Ag and ^{109}Ag resonance parameters for neutron induced reactions below 1 keV",
Nuclear Instruments and Methods B446 (2019) 19

Šalamon et al., "Neutron resonance transmission analysis of cylindrical samples used for reactivity worth measurements",
Journal of Radioanalytical and Nuclear Chemistry 321 (2019) 519

Ma Fei et al., "Non-destructive analysis of samples with a complex geometry by NRTA",
Journal of Archaeological Science, 33 (2020) 10521

Noguere et al., "Average neutron cross sections of ^{99}Tc",
Physical Review C102 (2020) 015807

Contributions to conference proceedings and workshops

Šalamon et al., "Neutron resonance transmission analysis of cylindrical samples used for reactivity worth measurements",
EPJ Web of Conferences 239 (2020) 102521

Technical Reports

Šalamon et al., "Results of TOF transmission measurements for ^{nat}Ag at a 10 m station of GELINA",
INDC International Nuclear Data Committee, INDC(EUR)-0036 (2020)

2.5 Measurement with VESPA to improve and validate the FIFRELIN code

Scientific/technical contacts

JRC : S. Oberstedt (JRC.G.2)

CEA : O. Litaize (CEA/DN Cadarache)

This work is part of the PhD thesis of V. Piau (CEA/DEN Cadarache)

Background

The goal is to produce high-quality prompt fission gamma-ray spectral data as input to support the development of FIFRELIN, which is a Monte Carlo code developed by CEA to model the fission process. The aim of this code is to simulate fission observables including prompt fission neutrons (PFNs) and gamma rays (PFGs). Four free input parameters govern the excitation energy and spin/parity entry zone of the primary fragments. These parameters are chosen to reproduce fission observables: e.g. average number of prompt fission neutrons and gamma-rays, average total gamma-ray energy.

The experimental work was performed at the MONNET laboratory of the JRC-Geel using the VESPA spectrometer.

Summary

With the VESPA spectrometer the prompt fission γ-ray (PFG) and neutron (PFN) correlations with fission-fragment mass (A*) and total kinetic energy (TKE) were measured for the spontaneous fission of ^{252}Cf. A position-sensitive twin Frisch-grid ionization chamber and several neutron detectors complemented the VESPA spectrometer. The experimental work was performed at the MONNET laboratory of JRC-Geel.

The data analysis focused on the following topics:

- Average prompt fission γ-ray quantities were measured to validate the set-up and to determine the detectors' response matrices using the GEANT4 code.
- Mass-pair resolved prompt fission γ-ray spectra were obtained. Those spectra await comparison with FIFRELIN-generated data.
- Mass- and energy-dependent average PFG multiplicity were measured, unequivocally proving the saw-tooth like dependence of average number of PFGs as a function of fragment mass hitherto debated within the community. The measured energy dependence confirms the only results existing in literature.
- Time dependence of γ-ray emission up to 30 μs.
- Investigation of fission-fragment isomer decay measuring level life-times and isomeric ratios.

Pre-neutron mass and kinetic energy yields measured with VESPA are of fundamental importance for the FIFRELIN code to initialize the de-excitation process. The measured fission-fragment isomeric state life times and yields will be used to complement the information related to level schemes coming from the RIPL-3 database. The recently measured average number of PFGs as a function of fragment mass allowed to determine, which primary fission fragment spin distribution model is the best to describe the shape of this observable. Ongoing calculations based on microscopic level densities and photon strength functions seem to reproduce even better the experimental data (to be published) especially in the heavy mass range.

Presently, the VESPA spectrometer is upgraded with an array of $CeBr_3$ detectors to increase the efficiency. Additionally, we are working on a new technique to produce spectroscopic actinide targets. Then, the PFGS and PFNS measurements on spontaneous fissioning ^{246}Cm and ^{248}Cm actinides will be pursued

Publications

Journal papers

Chebboubi et al., “Kinetic energy dependence of fission fragment isomeric ratios for spherical nuclei Sn-132”, Physics Letters B 175, (2017) 190

Gupta et al., “Fission fragment yield distribution in the heavy-mass region from the ^{239}Pu(n_{th},f) reaction”, Physical Review C96 (2017) 014608

Oberstedt et al., “Predictions of characteristics of prompt-fission γ-ray spectra from the n + ^{238}U reaction up to En = 20 MeV”, Physical Review C96 (2017) 034612

Choudhury et al., “High-Precision Prompt Fission Gamma-Ray Studies For Nuclear Reactor Safety”, Journal Nuclear Research and Development 14 (2017) 3

Thulliez et al., “Neutron and γ multiplicities as a function of neutron energy for the ^{237}Np(n,f) reaction”, Physical Review C 100 (2019) 044616

Almazán et al., “Improved STEREO simulation with a new gamma ray spectrum of excited gadolinium isotopes using FIFRELIN”, European Physical Journal A55 (2019) 183

Travar et al., “Experimental information on mass- and TKE-dependence of the prompt fission γ-ray multiplicity”, Physics Letters B 817 (2021) 136293

Contributions to conference proceedings and workshops

Choudhury et al., “Recent results from prompt fission gamma-ray measurements”, AIP Conference Proceedings 2076, 060002 (2019)

Serot et al., “Calculation of the Fission Observables in the Resolved Resonance energy Region of the ^{235}U(n,f) reaction”, EPJ Web of Conference. 239 (2020) 05002

2.6 Delayed neutron measurements at MONNET

Scientific/technical contacts

JRC : A. Plompen (JRC.G.2)

CEA : P. Leconte (CEA/DEN Cadarache)

Background

The objective of this project was to measure the yield of delayed neutrons for neutron induced fission of the main actinides, i.e. ^{235}U, ^{238}U, ^{239}Pu and ^{241}Pu, and for minor actinides of importance for transmutation studies. The aim is to improve the accuracy and to expand the traditional 6 group structure to a 8 group structure.

The basic requirements for such an experiment are:

- a target of high purity (to be provided by CEA)
- well-defined neutron fields with different energy spectra: the MONNET facility at JRC-Geel is suitable to cover energy ranges from less than 1 MeV to more than 10 MeV
- a 4π neutron counter with constant efficiency as a function of neutron energy, in order to remove the dependence to the delayed neutron spectrum associated to each precursor: These conditions are fulfilled by the LOENIE detector of CEA, which was used for prompt neutron multiplicity measurements at ILL. It consists of two rings of ^{3}He tubes inserted in an octagonal polyethylene block, shielded with neutron absorbers. The eighteen ^{3}He tubes have a special arrangement which was optimized to ensure an energy independent efficiency.

Summary

The project did not start due to a delay in the licencing of the MONNET facility. A new time schedule and distribution of tasks has to be discussed in view of the staff reduction within JRC.G.2.

2.7 Fission fragment spectrometers

Scientific/technical contacts

JRC : S. Oberstedt (JRC.G.2)

CEA : D. Doré (CEA/DSM Saclay)

This work is part of the PhD thesis of L. Thuillez (CEA/DSM Saclay)

Summary

Some years ago, CEA and JRC.G.2 started a technical exchange to optimize the different components of their 2v-2E spectrometers: FALSTAFF and VERDI, respectively. The goal of these setups is to provide fission fragment yields and correlated average neutron multiplicity for different major and minor actinides in the neutron energy domain below the threshold for the second-chance fission. In addition, FALSTAFF will allow studying the evolution of the post-neutron fission-fragment mass distribution over a large energy domain, from some hundreds of keV up to 30 MeV. All data will serve as input to nuclear fission models to improve the data libraries needed for new reactor concepts, which are developed to create a carbon-free and sustainable energy supply.

The VERDI spectrometer is based on the combination of Micro-Channel Plate (MCP) detectors and an array of silicon detectors for TOF and kinetic energy measurements. FALSTAFF uses Secondary Electron Detectors (SEDs) for the TOF measurement and axial ionisation chambers to measure the fragment residual kinetic energy, placed behind the stop detector. Both systems achieve timing resolution close to 100 ps (1 standard deviation) and an energy resolution of 1% or better.

The activities proposed in this collaboration are ongoing and were included in the PATRICIA project within the Horizon 2020 EU Framework Programme.

Summary

FALSTAFF

The first arm of the FALSTAFF spectrometer was tested in 2018 with a thermal neutron beam at the Orphée reactor at Saclay (FR). These tests revealed that there FALSTAFF can be used for studies with a neutron beam. In 2019 a new ToF detector was installed and more tests with a ^{252}Cf source were performed. With the previous detector, a high threshold was necessary to cut the noise which implies a cut in the heavy fragment mass distribution. The 2019 detector restored the proportion of light and heavy fragments. Recently another new TOF detector has been delivered and is under tests. The DAQ system has also been updated.

In parallel to the experimental work, the energy loss correction has been investigated. Indeed, the energy loss of fission fragments in the different layers of the FALSTAFF setup has to be calculated and data have to be corrected. To verify the stopping powers for such heavy ions, an experimental campaign was achieved in 2019. Results showed that the DPASS library was more appropriate than the well-known SRIM calculations for the fission fragments in the energy range of interest. This library has been implemented in our version of GEANT4 and in the analysis code.

In 2020, the Programme Advisory Committee (PAC) of GANIL accepted a CEA proposal for an experiment at the Neutrons For Science (NFS) facility with a ^{235}U target. JRC.G.2 will participate to the experiment and provide the ^{235}U target. In addition, FALSTAFF has recently welcomed new collaborators from GANIL. It has been decided to move FALSTAFF at GANIL in Fall 2021. A test experiment will be performed (beginning 2022) combining FALSTAFF with the VAMOS spectrometer in order to investigate the charge determination thanks to the energy loss profile in the ionization chamber.

VERDI

The VERDI spectrometer is operational as a two-arm TOF spectrometer. Its time and energy resolution was tested with the spontaneous fission of ^{252}Cf leading to satisfactory results for the pre-neutron mass distribution. The post-neutron mass distribution showed the effect of a limited signal-to-noise ratio. Further data analysis led to the mass-dependent average neutron multiplicity, deduced from the event-wise difference of the pre- and post-neutron masses. The correlation of the average neutron multiplicity with the fragments total kinetic energy showed the wrong slope and revealed the impact of prompt neutron emission on the fragment velocity, which is in first-order assumed to be unchanged after prompt neutron emission, a key assumption to obtain pre-neutron masses from a double-velocity measurement. A first order correction was suggested and successfully implemented.

The time resolution turned out to be worse than expected due to the Plasma-Delay Time (PDT) occurring in silicon detectors, when detecting high-charge particles. This quantity is now being measured with the ILL LOHENGRIN spectrometer in conjunction with a MCP start detector. The velocity of selected fragment masses with well-defined kinetic energies is measured. The difference of measured and calculated velocity allows determining the PDT as a function of mass and nuclear charge of the fragment. The expected improvement in time and mass resolution, will be verified in an upcoming measurement campaign with a ^{252}Cf spontaneous fission source, which is tentatively scheduled for the second half of 2022.

Publications

Contributions to conference proceedings and workshops

Jansson et al., “The new double energy-velocity spectrometer VERDI”,
EPJ Web of Conferences, 146 (2017) 04016

Al-Adili et al., “Studying fission neutrons with 2E-2v and 2E”,
EPJ Web of Conferences, 169 (2018) 00002

Doré et al., “Performance validation of the first arm of FALSTAFF: ^{252}Cf and ^{235}U fission fragment characterisation”,
EPJ Web of Conferences, 211 (2019) 04002

2.8 Magnet system for alpha spectrometry

Scientific/technical contacts

JRC : J. Paepen (JRC.G.2)

CEA : S. Pierre (CEA/LNHB Saclay)

Background

Some alpha-particle emission intensities are known with large uncertainties. These intensities can be calculated from spectra measured with silicon detectors and for accurate results, it is necessary to have a large number of pulses in the alpha peaks. If the emission intensity is low, there is a big advantage to increase the detection solid angle, thus to place the detector close to the source. However, this also increases the probability to detect alpha particles in coincidence with conversion electrons, leading to a distortion of the spectrum. The resulting effects are peak shape deformation, summing-out of the low-energy peaks, summing-in of the high-energy peaks and as a consequence erroneous peak fitting and emission probability assignments. An effective way to mitigate these effects is the application of a magnetic field to bend away the conversion electrons from their path towards the detector, as demonstrated by Paepen et al. (Applied Radiation and Isotopes 87 (2014) 320). The determination of some low-intensity alpha peaks can be time-consuming and so it is interesting to share the work and to compare the results obtained in different laboratories.

The design and production of tailor-made magnet systems that accommodate the alpha spectrometry measurement setups of CEA/LNHB is the subject of this project. The design should maximise the magnetic field in order to deflect as much as possible the electrons, but should minimise the deflection on the alpha particles, and should physically fit into the measurement setups.

Summary

Based on previous experience (Paepen et al., Applied Radiation and Isotopes 87 (2014) 320), JRC.G.2 designed and produced a magnet systems taking into account the constraints determined by CEA (conversion electron energy to deflect, alpha energy, dimensions of chamber and source, etc.). The constraints were discussed at a meeting on 23/06/2016 at JRC-Geel, attended by Sylvie Pierre and Benoit Sabot (CEA) and Jan Paepen and Maria Marouli (JRC). From 02/08/2018 until 04/08/2018, Maria Marouli (JRC) visited LNHB and provided training on the use of the magnet systems and the optimisation of alpha spectrometry measurements in general. The magnet system, the technical drawings and safety instructions were provided to CEA. The technical drawings of the magnet system together with safety instructions were delivered.

2.9 Production and characterisation of ^{235,238}U and Pu thin target layers

Scientific/technical contacts

JRC : G. Sibbens (JRC.G.2)

CEA : J. Taieb (CEA/DAM Bruyères-le-Châtel)

Background

CEA developed a fission chamber for measurements of the characteristics of prompt fission neutron emitted after neutron induced fission of ^{235}U, ^{238}U and ^{239}Pu. The chamber was used in 2017 at LANSCE for measurements of prompt fission neutron spectra emitted after a ^{239}Pu(n,f) reaction. For these measurements 22 thin target layers were prepared by JRC.G.2 as part of the EU CHANDA project. The targets were prepared by molecular plating. Similar ^{235,238}U and ^{239}Pu samples are needed for measurements of neutrons emitted after (n,f) and (n,xn) reactions. For these experiments a new detector was designed and constructed. The measurements will be carried out at the NFS facility at GANIL (FR).

Summary

A set of 22 ^{235}U and 22 ^{238}U thin target layers were prepared and characterized at the TARGET laboratory of JRC.G.2. The targets were prepared by molecular plating on a 25 μm thick Al foil mounted on a ring with inner and outer diameter of 64 mm and 74 mm, respectively. The diameter of the deposit is 33 mm. They were characterized by defined low solid-angle alpha-particle counting. The total average areal density of the ^{235}U and ^{238}U deposits is 262 and 258 μg/cm^2 respectively. The isotopic composition of the U material was determined by mass spectrometry. The ^{235}U and ^{238}U targets were provided to CEA.

The production of the ^{239}Pu deposits with a nominal areal density of 100 μg/cm^2 is scheduled for the first half of 2022. For the production of other targets, i.e. ^{238,240,241,242}Pu, the characteristics are required.

2.10 Production of a molecular plating cell

Scientific/technical contacts

JRC : G. Sibbens (JRC.G.2)

CEA : J. Taieb (CEA/DAM Bruyères-le-Châtel)

Background

JRC.G.2 prepared 22 ^{239}Pu deposits through an EUFRAT project for prompt fission neutron spectra measurements at LANSCE/WNR (Los Alamos, USA) (Marini et al., Physical Review C 101, (2020) 044614). These deposits were used in a dedicated fission chamber developed by the CEA group, in charge of the experiments at LANSCE. A dedicated molecular plating cell was prepared to deposit the ^{239}Pu layers on a frame developed by CEA. The CEA group intends to produce ^{252}Cf deposits on the same frame at there laboratories. Therefore, a similar molecular plating cell is needed.

Summary

Based on the design of the molecular plating cell that was used for the preparation of the ^{239}Pu deposits on the CEA frames, JRC.G.2 produced and tested a similar cell for CEA. The molecular plating cell including the anode motor and work instructions were provided to CEA. The project is closed.

2.11 Reference value for PT of environmental monitoring laboratories

Scientific/technical contacts

JRC : K. Sobiech-Matura (JRC.G.2)

CEA : T. Branger (CEA/LNHB Saclay)

Background

This project aims to provide Proficiency Testing (PT) of radionuclide measurements in environmental matrices and foodstuff for Member States' laboratories which monitor radionuclides in the environment and food. Periodical participation in such tests improve the comparability and reliability of measurement results reported to the Commission by the Member States as laid down in Commission Recommendation COM/2000/473 and Articles 35 and 36 of the Euratom Treaty.

Summary

JRC.G.2 prepared PT samples from maize. It was spiked with ^{131}I, ^{134}Cs and ^{137}Cs. The estimated activity level were 0.2-0.5 Bq/g per radionuclide. In the second half of May 2017 the material was prepared, homogenized and packed in amber glass bottles (~100 g each) and shipped to CEA for gamma-ray measurements together with a template of a report on the measurement results. CEA provided JRC with results and other relevant information as described in the template report.

2.12 Training in low-level gamma-ray spectrometry

Scientific/technical contacts

JRC : M. Hult (JRC.G.2)

CEA : M.-C. Lépy (CEA/LNHB Saclay)

Background

CEA organised a training course on gamma-ray spectrometry at their premises from 12 June to 14 June 2018. This course was suggested by the ICRM-GS WG (International Committee for radionuclide metrology – Gamma-ray Spectrometry Working Group) with the goal to reach people already knowing gamma ray spectrometry, wishing to get more detailed information on corrective terms, to improve the quality of results.

Summary

Mikael Hult (JRC.G.2) gave three lectures in the training course on gamma-ray spectrometry organised by CEA in Paris. There were 30 participants of whom 4 were from outside Europe, 2 from associated EU-countries and 24 from EU-countries. The other lecturers were Marie-Christine Lépy (CEA), Philippe Cassette (CEA) and Octavian Sima (Bucharest Univ.).

At Day-3 of the event the ICRM (International Committee for Radionuclide Metrology) Gamma-ray Spectrometry Working Group meeting was organised. At this meeting: (1) the ongoing actions (involving both CEA and JRC) were presented and discussed: e.g. comparison of Monte Carlo codes for coincidence summing corrections. (2) New developments were presented: e.g. MH presented the work JRC conducted with SCK CEN and U. Hasselt on studies of deadlayer thicknesses in HPGe-detectors. (3) New actions were discussed: e.g. implementation of automatic optimisation of computer models for HPGe-detectors.

3 Other projects

Besides the activities defined in the project sheets other collaborative projects between JRC.G.2 and CEA were carried out covering three application areas:

- production of nuclear data
- development of innovative detectors and measurement techniques
- production and characterisation of reference materials

3.1 Production of nuclear data

Improved evaluated data files for neutron induced interactions with ^{175}Lu and ^{241}Am in the resonance region were produced. The improved data rely on results of experiments at GELINA and integral experiments at the MINERVE reactor. They were carried out in a collaborative effort with CEA/DEN Cadarache and CEA/DAM Bruyères-le-Châtel. The results of these evaluations were published in journal papers and adopted in the JEFF-3.3 library.

Publications

Journal papers

Noguere et al., "s-wave average neutron resonance parameters of ^{175}Lu + n",
Physical Review C 100 (2019) 065806

Plompen et al., "The Joint Evaluated Fission and Fusion Nuclear Data Library, JEFF-3.3",
European Physics Journal A 56 (2020) 181

Contributions to conferences and workshops

Geslot et al., "Americium-241 integral radiative capture cross section in over-moderated neutron spectrum from pile oscillator measurements in the MINERVE reactor",
EPJ Journal Web of Conferences 146 (2017) 06016

Reports

Harada et al., "Improving Nuclear Data Accuracy of the ^{241}Am Capture Cross-section",
Nuclear Energy Agency, Nuclear Science, NEA/NSC/R (2020) 2

3.2 Development of innovative detectors and measurement techniques

The GELINA facility was used to test the performance of two innovative detection systems that were developed at CEA for use at the n_TOF facility at CERN:

- a segmented MICROMEGAS based on the microbulk technology with an embedded XY structure
- an ionisation chamber used as fission tag detector for fission and capture cross sections of actinides

The testing of the ionisation chamber was part of the PhD thesis of M. Bacak (CEA/DSM Saclay).

A joint research project from CEA/DSM Saclay and JRC.G.2 in response to a call for proposals by the Agence Nationale de la Recherche (ANR) in France was accepted. The proposal entitled "Temporal and spatial detection of charged particles by neutron-induced reactions" aims at developing a neutron-transparent detector based on the MICROMEGAS technology, capable of providing time, position and angular information. The proposal was submitted in the category "Projet de Recherche Collaborative (PRC)" for which the success rate was 15%. The project strongly relies on a collaboration with the JRC and in particular on experimental activities at the GELINA facility and the target preparation laboratory.

Publications

Journal papers

Diakaki et al., "Development of a novel segmented mesh MICROMEGAS detector for neutron beam profiling",
Nuclear Instruments and Methods A 903 (2018) 46

Bacak et al., "A compact fission detector for fission-tagging neutron capture experiments with radioactive fissile isotopes",
Nuclear Instruments and Methods A 969 (2020) 163981

Contributions to conferences and workshops

Bacak et al., “Preliminary results on the ^{233}U α-ratio measurement at n_TOF”,
EPJ Journal Web of Conferences 146 (2017) 03027

3.3 Production and characterisation of reference materials

JRC.G.2 produced and certified a reference material including ^{60}Co for nuclear decommissioning. CEA/LHNB assisted in the characterisation of the disks and reviewed the certification procedure.

A set of 14 thin ^{233}U layers were produced and characterised at the TARGET laboratory of the JRC.G.2. These layers were used for neutron induced capture and fission cross section measurements at the n_TOF facility at CERN.

In the open access project URANIUM_NRTA the composition of the uranium disks used in the INTEGRAAL project was verified by neutron transmission measurements at the GELINA facility. The experiments are finished and the data analysis is in progress.

4 Output

The output in terms of number of publications with co-authors from JRC.G.2 and CEA and theses supported by the two institutes are given in Table 2. Details about common publications in journal papers, contributions to conference proceedings or workshops and reports are given in Table 3, Table 4 and Table 5, respectively.

Table 2. Output produced as part of the projects

Output	Number
Papers in peer reviewed journals	34
Contributions to conference proceedings or workshops	12
Technical Reports	5
PhD Theses	3

Table 3. Papers published in peer reviewed journals during the period 2016-2020

Author	Title	Reference
Tzilka et al.	"^{60}Co in cast steel matrix: A European interlaboratory comparison for the characterisation of new activity standards for calibration of gamma-ray specrometers in metallurgy"	Applied Radiation and Isotopes, 114 (2016) 167
Kim et al.	"Neutron capture cross section measurements for ^{238}U in the resonance region at GELINA"	European Physics Journal A, 52 (2016) 170
Pommé et al.	"Evidence against solar influence on nuclear decay constants"	Physics Letters B, 761 (2016) 281
Vidmar et al.	"Equivalence of computer codes for calculation of coincidence summing correction factors – Part II"	Applied Radiation and Isotopes, 109 (2016) 482
Pommé et al.	"On decay constants and orbital distance to the sun – part I: alpha decay"	Metrologia, 54 (2017) 1
Pommé et al.	"On decay constants and orbital distance to the sun – part II: beta minus decay"	Metrologia, 54 (2017) 19
Pommé et al.	"On decay constants and orbital distance to the sun – part III: beta plus and electron capture decay"	Metrologia, 54 (2017) 36
Marouli et al.	"Direct measurement of alpha emission probabilities in the decay of ^{226}Ra"	Applied Radiation and Isotopes, 125 (2017) 196
Lépy et al.	"Photon emission intensities in the decay of U-235"	Applied Radiation and Isotopes, 126 (2017) 150
Wilson et al.	"Anomalies in the Charge Yields of Fission Fragments from the ^{238}U(n,f) Reaction"	Physical Review Letters, 118 (2017) 222501
Wilson et al.,	"Production and study of neutron-rich nuclei using the LICORNE directional neutron source"	Acta Physica Polonica B, 48 (2017) 395
Maringer et al.,	"Advancements in NORM metrology - Results and impact of the European joint research project MetroNORM"	Applied Radiation and Isotopes, 126 (2017) 273
Mingrone et al.	"Neutron capture cross section measurement of ^{238}U at the CERN n_TOF facility in the energy region from 1 eV to 700 keV"	Physical Review C 95 (2017) 034604
Wright et al.	"Measurement of the ^{238}U(n,γ) cross section up to 80 keV with the Total Absorption Calorimeter at the CERN n_TOF facility"	Physical Review C 96 (2017) 064601
Laborie et al.	"First experimental prompt γ-ray spectra in fast-neutron-induced fission of ^{238}U"	Physical Review C 98 (2018) 054604

Ledoux et al.	"The neutrons for science facility at SPIRAL-2"	Radiation Protection Dosimetry, 180 (2018) 115
Cassette et al.	"Results of the CCRI(II)-S12.H-3 supplementary comparison: Comparison of methods for the calculation of the activity and standard uncertainty of a tritiated-water source"	Applied Radiation and Isotopes, 134 (2018) 257
Bélier et al.	"High-precision spontaneous fission branching-ratio measurements for ^{240,242}Pu and ^{252}Cf isotopes"	Physical Review C, 98 (2018) 34612
Diakaki et al.	"Development of a novel segmented mesh MicroMegas detector for neutron beam profiling"	Nuclear Instruments and Methods A 903 (2108) 46
García-Toraño et al.	"The half-life of ^{129}I"	Applied Radiation and Isotopes, 140 (2018) 157
Marouli et al.	"Measurement of absolute γ-ray emission probabilities in the decay of ^{227}Ac in equilibrium with its progeny"	Applied Radiation and Isotopes, 144 (2019) 34
Crozet et al.	"Contribution of an interlaboratory comparison to the certification of the STAM/IRMM-0243 ^{243}Am reference material"	Journal Radioanalytical and Nuclear Chemistry 319 (2019) 717
Šalamon et al.,	"^{107}Ag and ^{109}Ag resonance parameters for neutron induced reactions below 1 keV"	Nuclear Instruments and Methods B 446 (2019) 19
Šalamon et al.,	"Neutron resonance transmission analysis of cylindrical samples used for reactivity worth measurements"	Journal Radioanalytical and Nuclear Chemistry 321 (2019) 519
Noguere et al.,	"s-wave average neutron resonance parameters of ^{175}Lu + n"	Physical Review C 100 (2019) 065806
Jerome et al.	"Half-life determination and comparison of activity standards of ^{231}Pa"	Applied Radiation and Isotopes, 326 (2020) 1785
Rudigier et al.	"Multi-quasiparticle sub-nanosecond isomers in ^{178}W"	Physics Letters B !à& (2020) 135140
Bacak et al.	"A compact fission detector for fission-tagging neutron capture experiments with radioactive fissile isotopes"	Nuclear Instruments and Methods A 969 (2020) 163981
Ma Fei et al.	"Non-destructive analysis of samples with a complex geometry by NRTA"	Journal of Archaeological Science 33 (2020) 102521
Noguere et al.,	"Average neutron cross sections of ^{99}Tc"	Physical Review C 100 (2020) 015807
Canavan et al.,	"Half-life measurements in ^{164,166}Dy using γ-γ fast-timing spectroscopy with the ν-Ball spectrometer"	Physical Review C 101 (2020) 024313
Gerst et al.,	"Prompt and delayed spectroscopy of the neutron-rich ^{94}Kr and observation of a new isomer"	Physical Review C 102 (2020) 064323
Marouli et al.	"Absolute and relative measurement of the ^{243}Am half-life"	Journal Radioanalytical and Nuclear Chemistry 321 (2020) 519
Plompen et al.	"The Joint Evaluated Fission and Fusion Nuclear Data Library, JEFF-3.3"	European Physics Journal A 56 (2020) 181

Table 4. Contributions to conference proceedings and workshops during the period 2016-2020

Author	Title	Reference
Leal et al.	"Evaluation of the ^{235}U resonance parameters to fit the standard recommended values"	Eur. Phys. J. Web of Conferences 146 (2017) 02021
Noguere et al.	"On the use of the generalized SPRT method in the equivalent hard sphere approximation for nuclear data evaluation"	Eur. Phys. J. Web of Conferences 146 (2017) 02036
Bacak et al.	"A compact multi-plate fission chamber for the simultaneous measurement of ^{233}U capture and fission cross-sections"	Eur. Phys. J. Web of Conferences 146 (2017) 03027
Laborie et al.	"First experimental prompt γ-ray spectra in fast neutron-induced fission of ^{238}U"	Eur. Phys. J. Web of Conferences 146 (2017) 04032
Geslot et al.	"Americium-241 integral radiative capture cross section in over-moderated neutron spectrum from pile oscillator measurements in the Minerve reactor"	Eur. Phys. J. Web of Conferences 146 (2017) 06016
Leconte et al.	"On the feasibility to perform integral transmission experiments in the GELINA target hall at IRMM"	Eur. Phys. J. Web of Conferences 153 (2018) 01023
Qi et al.	"Prompt fission gamma-ray emission spectral data for ^{239}Pu(n,f) using fast directional neutrons from the LICORNE neutron source"	Eur. Phys. J. Web of Conferences 169 (2018) 00018
Wilson et al.	"Studies of fission fragment yields via high-resolution gamma-ray spectroscopy"	Eur. Phys. J. Web of Conferences 169 (2018) 00030
Bélier et al.	"Use of active scintillation targets in nuclear physics experiments – Measurement of spontaneous fission"	Eur. Phys. J. Web of Conferences 193 (2018) 04001
Oprea et al.	"Neutron capture cross section measurements of ^{241}Am at the n_TOF facility"	Eur. Phys. J. Web of Conferences 239 (2020) 01009
Šalamon et al.	"Neutron resonance transmission analysis of cylindrical samples used for reactivity worth measurements"	Eur. Phys. J. Web of Conferences 239 (2020) 01022
Bacak et al.	"Preliminary results on the ^{233}U α-ratio measurement at n_TOF"	Eur. Phys. J. Web of Conferences 239 (2020) 01043

Table 5. Reports published during the period 2016-2020

Author	Title	Reference
Nyman et al.	"Integral Experiments in the GELINA Target Hall – 238U and natCu: Description of the first two integral experiments in the GELINA target hall"	JRC Technical Reports, EUR 28240 EN (2016)
Plompen et al.,	"Towards neutron benchmark experiments with GELINA"	JRC Technical Reports, JRC109785 (2017)
Harada et al.	"Improving Nuclear Data Accuracy of ^{241}Am Capture Cross-sections"	Nuclear Energy Agency, Nuclear Science NEA/NSC/R(2020)2
Šalamon et al.	"Results of time-of-flight transmission measurements for ^{nat}Ag at a 10 m station of GELINA"	INDC International Nuclear Data Committee, INDC(EUR)-0036 (2020)
Sabot et al.	"Method for the traceable calibration of radon (^{222}Rn) measurement instruments at low activity concentrations (100 Bq/m3 to 300 Bq/m3) with relative uncertainties ≤ 5 % (k = 1)"	JRC Technical Reports, JRC120057 (2020)

5 Scientific visits

CEA staff who visited JRC-Geel are listed in Table 6. Students from CEA making use of the nuclear infrastructure at JRC-Geel to prepare their PhD thesis are listed in Table 7

Table 6. CEA staff visiting JRC-Geel

Name	Devision	JRC-Geel infrastructure
Gilbert Bélier	CEA/DAM-DIF Arpajon	TARGET laboratories
Benoit Geslot	CEA/DEN Cadarache	GELINA
Benoit Laurent	CEA/DAM Bruyères-le-Châtel	TARGET laboratories
Eric Berthoumieux	CEA/DSM Saclay	GELINA, TARGET laboratories
Maria Diakaki	CEA/DEN Cadarache	GELINA
Diane Doré	CEA/DSM Saclay	GELINA, MONNET, HADES, RADMET
Emmeric Dupont	CEA/DSM Saclay	GELINA
Frank Gunsing	CEA/DSM Saclay	GELINA
Robert Jacqmin	CEA/DEN Cadarache	GELINA, MONNET
Pierre Leconte	CEA/DEN Cadarache	GELINA
Valerie Lourenco	CEA/LNHB Saclay	RADMET
Gilles Noguere	CEA/DEN Cadarache	GELINA
Sylvie Pierre	CEA/LNHB Saclay	RADMET
Benoit Sabot	CEA/LNHB Saclay	RADMET
Olivier Serot	CEA/DEN Cadarache	GELINA, MONNET
Julien Taieb	CEA/DAM Bruyères-le-Châtel	TARGET Laboratories

Table 7. PhD students supported by CEA performing experiments at JRC-Geel

Name	Devision	JRC-Geel infrastructure
Michael Bacak	CEA/DSM Saclay	GELINA
Valentin Piau	CEA/DEN Cadarache	MONNET
Lino Šalamon	CEA/DEN Cadarache	GELINA

6 Summary and conclusions

Projects in the field of nuclear safety co-ordinated by JRC.G.2 as part of the Collaboration Agreement No. 34351 between the JRC and CEA running from 2016 to 2020 were summarised. The majority of projects were defined in project sheets and each project was assigned a lead researcher from both institutes. The umbrella of the collaboration agreement made easier for researchers from both institutes to reach out to each other and we believe that the awareness of availabilities in know-how and infrastructure at both parties has increased.

The projects covered scientific research and education and training, in the following areas:

- Nuclear data for nuclear science and technology
- Development of innovative detectors and measurement techniques
- Production of nuclear reference materials
- Emergency preparedness

They demonstrate the complementary nature of the competences and nuclear infrastructure of JRC.G.2 and CEA.

Based on the success of this collaboration, the management of JRC and CEA decided to renew the collaboration agreement and new projects are already in the process of being defined.

List of abbreviations and definitions

AMS	Accelerator mass spectrometry
ANR	Agence national de la recherche
BR1	Belgian reactor 1
BUC	Burnup credit
CALIBAN	Highly enriched uranium reactor core
CBNM	Central bureau for nuclear measurements
CCRI	Consultative committee for ionizing radiation
CEA	Commissariat à l'énergie atomique et aux énergies alternatives
CERN	European council for nuclear research
CHANDA	Solving challenges in nuclear data
DAM	Direction des applications militaires
DEN	Direction de l'énergie nucleaire
DPASS	Library of stopping powers
DSM	Direction de physique nucleaire (Physical sciences division)
EC	European Commission
ENDF	Evaluated nuclear data file
EU	European Union
EUFRAT	European Facility for innovative Reactor and Transmutation Data
EXFOR	Exchange format for experimental numerical nuclear reaction data
FALSTAFF	Four arm clover for het study of actinice fission fragment
FIFRELIN	Monte Carlo simulation of the fission fragment deexcitation process
FRM II	Forschungs-Nuetronenquell Heinz Maier-Leibnitz
GELINA	Geel electron linear accelerator
ICRM	Institute for certified reference materials
ILL	Institut Laue Langevin
INDC	International nuclear data committee
JEFF	Joint Evaluated Fission and Fusion file
JENDL	Japan Evaluated Nuclear Data Library
JRC	Joint Research Centre
LANSCE	Los Alamos neutron science center
LICORNE	Directional fast neutron source
LOENIE	Long counter consisting of 16 ^{3}He detectors
MCNP	Monte Carlo n-particle code
MCP	Microchannel plate
MICROMEGAS	Micro mesh gas detector
MINERVE	Zero power reactor at CEA Cadarache
MONNET	Mono-energetic Neutron Tower
NEA	Nuclear energy agency
NORM	Naturally occurring radiative material
NFS	Neutrons for science
NRTA	Neutron resonance transmission analysis
OECD	Organisation for economic co-operation and development
OSMOSE	Oscillation in MINERVE of isotopes in ''Eupraxic'' spectra
PATRICIA	Partitioning and transmuter research initiative in a collaborative innovation action
PRC	Projet de recherche collaborative

PT	Proficiency test
SANDA	Solving challenges in nuclear data for the safety of European nuclear facilities
SCK CEN	Belgian Nuclear Research Centre
SRIM	Code to simulate interactions of ions with matter- stopping and range of ions in matter
TKE	Total kinetic energy
TOF	Time-of-flight
TRIPOLI	Monte Carlo radiation transport code
USC	User selection committee
VAMOS	Variable mode spectrometer
VERDI	Velocity for direct particle identification
VESPA	Versatile gamma spectrometer array
WNR	Weapons neutron research
WP	Work packager

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