SCK•CEN ACADEMY
FOR NUCLEAR SCIENCE AND TECHNOLOGY

Book of abstracts

Day of the PhD's

October 27, 2016

SCK•CEN
Boeretang 200
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Day of the PhD's

October 27, 2016

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Programme

Oral presentations

Morning Session
Chair: Prof. Thomas Pardoen, President of the Scientific Council SCK•CEN

08:45-09:00	Registration and welcome coffee	
09:00-09:10	Welcome & introduction	Michèle Coeck, Head SCK•CEN Academy for Nuclear Science and Technology Prof. Thomas Pardoen, President Scientific Council SCK•CEN
09:10-09:35	Investigation of the influence of thermo-mechanical treatments on microstructure and mechanical properties of Ti stabilized 15Cr-15Ni austenitic stainless steel	**Niels Cautaerts** SCK•CEN mentors: Rémi Delville & Marc Verwerft University promoter: Dominique Schryvers, UAntwerpen Start date: October 1st, 2015
09:35-10:00	Towards the development of novel cladding materials based on nanolaminated ternary carbides (MAX phases) for different nuclear systems	**Tunca Bensu** SCK•CEN mentors: Konstantza Lambrinou & Rémi Delville University promoters: Jef Vleugels, KU Leuven & Joke Haderman, UAntwerpen Start date: October 1st, 2015
10:00-10:25	Study of low Prandtl number heat transfer in the E-SCAPE liquid-metal pool facility	**Edoardo Cascioli** SCK•CEN mentors: Katrien Van Tichelen & Steven Keijers University promoter: Sasa Kenjeres, TU Delft Start date: October 1st, 2015
10:25-11:15	Break + poster presentations	

11:15-11:40	Modeling of nucleation and growth of oxides in LBE by CFD for the design of LBE filtering systems	**Kristof Gladinez** SCK•CEN mentors: Kris Rosseel & Jun Lim University promoter: Geraldine Heynderickx, UGent Start date: October 1st, 2015
11:40-12:45	Presentation of the best master thesis award	Prof. Dr. Eric van Walle, Director-General SCK•CEN
12:45-13:45	Sandwich lunch + poster presentations	

Afternoon Session
Chair: Prof. em. Michel Giot, Honorary President of the Scientific Council SCK•CEN

13:45-14:10	Space dosimetry with luminescent detectors	**Alessio Parisi** SCK•CEN mentors: Olivier Van Hoey & Filip Vanhavere University promoter: Patrice Mégret, UMons Start date: October 1st, 2015
14:10-14:35	Implementation and validation of a simulation framework for optimization studies in chest radiography	**Sunay Rodriguez Perez** SCK•CEN mentors: Lara Struelens & Filip Vanhavere University promoter: Hilde Bosmans, KU Leuven Start date: December 15, 2014
14:35-15:00	Uncertainty quantification of atmospheric transport and dispersion modelling of radioxenon in support of the CTBT	**Pieter De Meutter** SCK•CEN mentor: Johan Camps University promoter: Piet Termonia, UGent Mentor RMI: Andy Delcloo Start date: January 1st, 2015
15:00-15:30	Break + poster presentations	
15:30-15:55	Medium resolution gamma rays spectroscopy for safeguards applications	**Yaroslav Meleshenkovskiy** SCK•CEN mentors: Alessandro Borella & Michel Bruggeman University promoter: Nicolas Pauly, ULB Start date: September 1st, 2015
15:55-16:20	Growth and recovery of rice plants exposed to gamma radiation: oxidative stress response and expression of miRNAs	**Jackline Mwihaki Kariuki** SCK•CEN mentors: Nele Horemans & Eline Saenen University promoter: Ann Cuypers, UHasselt Start date: October 1st, 2015
16:20-16:45	Dental pediatric imaging: an investigation towards low dose radiation induced risks	**Niels Belmans** SCK•CEN mentors: Marjan Moreels & Sarah Baatout University promoters: Ivo Lambrichts, UHasselt & Stéphane Lucas (UNamur) Start date: October 1st, 2015
16:45-17:00	Closure	Prof. em. Michel Giot, Honorary President of the Scientific Council SCK•CEN
17:00	Drink	

Poster presentations

Within the Institute Advanced Nuclear Systems (ANS)

Ultrasonic measurement techniques in heavy liquid metals	**Marc Dierckx** SCK•CEN mentor: Ludo Vermeeren University promoter: Walter Bogaerts, KU Leuven Start date: January 1st, 2015
Solid state ionic devices for lead alloys cooled nuclear systems	**Gabriele Manfredi** SCK•CEN mentors: Jun Lim & Kris Rosseel University promoter: Claudine Buess-Herman, ULB Start date: December 1st, 2012

Within the Institute Environment, Health and Safety (EHS)

Dissection of novel resistance mechanisms in *Cupriavidus metallidurans*	**Muntasir Md Ali** SCK•CEN mentor: Rob Van Houdt University promoter: Daniel Charlier, VUB Start date: October 1st, 2015
Effects of ionizing radiation on mitochondrial function in human endothelial cells	**Bjorn Baselet** SCK•CEN mentor: An Aerts University promoter: Pierre Sonveaux, UCL Start date: September 1st, 2013
Physiology of *Cupriavidus metallidurans* CH34 in the presence of basalt, a lunar-like rock, on Earth and in Space	**Bo Byloos** SCK•CEN mentors: Natalie Leys & Rob Van Houdt University promoter: Nico Boon, UGent Start date: October 1st, 2013
Spatially distributed recharge in groundwater models: bridging the gap between the soil profile and the catchment scale	**Antoine Di Ciacca** SCK•CEN mentors: Bertrand Leterme & Eric Laloy University promoter: Jan Vanderborght, KU Leuven Start date: November 14, 2015
An advanced mineralogical study of the clay mineral fractions of the Boom Clay	**Lander Frederickx** SCK•CEN mentors: Mieke De Craen & Honty Miroslav University promoter: Jan Elsen, KU Leuven Start date: November 16, 2015
Development of practical eye lens dosimetry for interventional procedures in hospitals	**Edilaine Honorio da Silva** SCK•CEN mentors: Filip Vanhavere & Lara Struelens University promoter: Nico Buls, VUB Start date: December 6, 2013

Effect of variations in clay/silt content on the diffusive properties of the Boom Clay	**Elke Jacops** SCK•CEN mentor: Christophe Bruggeman University promoters: Rudy Swennen, KU Leuven & Ralf Littke, RWTH Aachen university Start date: October 1st, 2013
Mechanistic analysis of radiation-induced microcephaly and cognitive impairment in mice	**André Claude Mbouombouo Mfossa** SCK•CEN mentor: Roel Quintens & Rafi Benotmane University promoter: Danny Huylebroeck, KU Leuven Start date: October 1st, 2015
Microbiological analysis of spent nuclear fuel pools: towards the identification of radiation-resistant bacteria	**Valérie Van Eesbeeck** SCK•CEN mentors: Pieter Monsieurs & Natalie Leys University promoter: Jacques Mahillon, UCL Start date: October 1st, 2015
Mechanisms of radiation resistance in Arthrospira sp. PCC 8005	**Anu Yadav** SCK•CEN mentors: Paul Janssen & Natalie Leys University promoter: Ann Cuypers, UHasselt Start date: October 1st, 2015

Within the Institute Nuclear Materials Science (NMS)

Microstructural study of plastic deformation of tungsten	**Andrii Dubinko** SCK•CEN mentors: Dmitry Terentyev & Lorenzo Malerba University promoter: Jean-Marie Noterdaeme, UGent Start date: October 7, 2013
Microstructural characterization of complex oxide scales formed on DIN1.4970 reference MYRRHA cladding tubes in static LBE at targeted oxygen concentrations	**Evangelia Charalampopoulou** SCK•CEN mentors: Rémi Delville & Konstantza Lambrinou University promoter: Dominique Schryvers, UAntwerpen Start date: April 15, 2015
Nanostructure evolution of high-chromium ferritic/martensitic alloys under neutron and ion irradiation: an object kinetic Monte Carlo model	**Monica Chiapetto** SCK•CEN mentors: Lorenzo Malerba & Nicolas Castin University promoter: Charlotte Becquart, ULille Start date: October 1st, 2013

Retention of plasma components in tungsten under high flux plasma in presence of neutron irradiation: multi-scale modelling approach	**Petr Grigorev** SCK•CEN mentor: Dmitry Terentyev University promoter: Jean-Marie Noterdaeme & Guido Van Oost, UGent Start date: November 12, 2011
MAX phase-based materials for the MYRRHA pump impeller	**Thomas Lapauw** SCK•CEN mentor: Konstantza Lambrinou University promoter: Jef Vleugels, KU Leuven Start date: October 1^{st}, 2013
Purification of medical ^{153}Sm using radiation-resistant ionic liquids	**Michiel Van de Voorde** SCK•CEN mentors: Thomas Cardinaels, Patrick Goethals & Karen Van Hecke University promoter: Koen Binnemans, KU Leuven Start date: October 1^{st}, 2015
The effects of precipitation and calcination characteristics on oxalate derived ThO_2 pellets	**Tadeas Wangle** SCK•CEN mentors: Marc Verwerft & Thomas Cardinaels University promoter: Jef Vleugels, KU Leuven Start date: October 1st, 2015
Finite element modelling of mechanical properties of tungsten under neutron irradiation	**Aleksandr Zinovev** SCK•CEN mentors: Dmitry Terentyev & Lorenzo Malerba University promoter: Laurent Delannay, UCL Start date: October 1st, 2015
Seperation of minor actinides by solvent extraction with [A336][NO_3] ionic liquidbased solvent	**Peter Zsabka** SCK•CEN mentors: Thomas Cardinaels, Marc Verwerft & Karen Van Hecke University promoter: Koen Binnemans, KU Leuven Start date: October 1st, 2015

Oral presentations

Investigation of the influence of thermo-mechanical treatments on microstructure and mechanical properties of Ti stabilized 15Cr-15Ni austenitic stainless steel

Niels Cautaerts
Institute Nuclear Materials Science
Expert Group on Structural Materials, Structural Materials Research and Fuel Materials Unit

SCK•CEN mentors: Remi Delville & Marc Verwerft
University promoter: Dominique Schryvers (UAntwerpen)
Start date as PhD: October 1st, 2015

Abstract

With renewed interest in fast spectrum reactors, research in swelling resistant stabilized austenitic stainless steels for use as fuel cladding is being revived after years of standstill. Despite the vast amounts of experimental work conducted in the 1970s on the microstructure and mechanical properties of these steels, many questions remain that can be addressed with modern characterization techniques.

For the fuel cladding of the MYRRHA reactor in development here at SCK•CEN, a new heat of cold worked DIN 1.4970 (X10 CrNiMoTiB 15 15) steel was recently produced at Sandvik [1]. In this steel, under certain thermal and irradiation conditions, TiC nanoprecipitates form on dislocations. These precipitates stabilize the dislocation network, which improves the creep resistance, and provide vacancy-interstitial recombination centers, which reduces irradiation swelling [2]. The low operating temperatures (~400°C) envisaged for the MYRRHA reactor, may inhibit precipitation of TiC [3]. Therefore, a thermal ageing heat treatment at elevated temperature is required. However, during such heat treatment, undesirable processes such as recrystallization and partial or complete recovery of the cold work may also take place.

In this work, 24% cold worked DIN 1.4970 steel was subjected to different ageing heat treatments at 600 and 800 °C. The resultant microstructure was investigated with SEM, EBSD and TEM to elucidate recrystallization and recovery behavior. Size, distribution and orientation of precipitates were studied in thin foils using HRTEM and STEM EELS and compared with a bulk dissolution separation technique.

References

[1] Delville, R., et al., 22nd International Conference on Nuclear Engineering ICONE22. 2014. Prague, Czech Republic ASME.
[2] Bergmann, H. J., et al., 2003, FZK and Interatom/Siemens-KWU.
[3] Padilha, A.F., et al., Journal of Nuclear Materials, 1982. 105(1): p

Towards the development of novel cladding materials based on nanolaminated ternary carbides (MAX phases) for different nuclear systems

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SCK•CEN mentors : Konstantza Lambrinou & Rémi Delville
University promoters: Jef Vleugels (KU Leuven) & Joke Hadermann (UAntwerpen)
Start date as PhD: October 1st, 2015

Abstract

MAX phases are nanolaminated carbides or nitrides which show both metallic properties such as good thermal/electrical conductivity, thermal shock resistance, good machinability, damage tolerance and also ceramic properties like good mechanical properties at high temperature, high oxidation and corrosion resistance. Among MAX phase family Ti-Al-C based phases have been extensively studied in literature and one of their outstanding properties is their oxidation resistance due to the formation of protective Al_2O_3 layers. Zr-Al-C based MAX phases: Zr_3AlC_2 and Zr_2AlC are some of the new members of the expanding MAX phase family and their features are yet to be explored. Their particular importance lies in the lower neutron absorption cross-section of Zr, making these MAX phases especially promising for future nuclear applications. To satisfy both the requirements of next generation (GENIII+) nuclear reactor designs and also the safety requirements to prevent material failure accidents, new accident tolerant cladding materials should be developed. These materials should have high resistance to oxidation and corrosion and should also withstand high temperatures and radiation doses for prolonged exposures. One of the methods to fine-tune the properties of MAX phases is by creating solid solutions with different M, A or X element. Studies have shown that solid solutions can have better properties than their end members.

Focus of this PhD study during the first year was synthesis and characterization of Zr-Ti-Al-C MAX phases. Solid solution MAX phases $(Zr_{1-x}Ti_x)_3AlC_2$ (312) and $(Zr_{1-y}Ti_y)_2AlC$ (211) with x and y changing from 0.1 to 0.9 were synthesized by reactive hot pressing of ZrH_2, TiH_2, Al and C powders at temperatures between 1350 and 1600°C. Rietveld refinement of powder X-ray diffraction measurements showed that changes in the MAX phase lattice parameters follow the Vegard's law of solid solution. While minor intermetallics (Al_2Zr, Al_3Zr_2) were found in some of the samples hot pressed at low temperatures, (Zr,Ti)C ternary carbides were always present in the system. Microstructural examinations and Rietveld refinement results confirms that these ternary carbides were found in only Zr and/or Ti rich forms throughout the full range of Zr-Ti ratios, due to decomposition of mixed carbides. HRSTEM studies were performed to show the 211 and 312 MAX phase stackings in Zr-Ti-Al-C. Regions with mixed stackings and areas with local 413 and 523 were also observed.

Study of low Prandtl number heat transfer in the E-SCAPE liquid metal pool facility

Edoardo Cascioli
Institute Advanced Nuclear Systems
Expert Group on Nuclear Systems Research, LBE Components and Experiments and Primary System Design Unit

SCK•CEN mentors: Katrien Van Tichelen & Steven Keijers
University promoter: Sasa Kenjeres (TU Delft)
Start date as PhD: October 1st, 2015

Abstract

Liquid metal-cooled fast reactors can contribute to the future of nuclear energy production thanks to the possibility of using more efficiently the natural resources and reducing the amount and lifetime of nuclear waste. At SCK•CEN, the Multi-purpose hYbrid Research Reactor for High-tech Applications (MYRRHA) is being designed to be a pool-type fast reactor prototype cooled by Lead-Bismuth Eutetic.

Thermal hydraulics is recognized as a key aspect in the design phases and safety analyses. Three-dimensional flows of liquid metal in natural and forced convection regimes need to be carefully investigated, modelled and tested for pool-type systems.

In the solution of the Reynolds Averaged Navier-Stokes (RANS) equations for fluid flow, current engineering computational fluid dynamics tools apply statistical turbulence closure, adopting the concept of a turbulent Prandtl number based on the Reynolds analogy. The main assumption is here that the turbulent heat flux in the time-averaged energy equation can be modelled analogous to the Reynolds stresses in the time-averaged momentum equation. This hypothesis is valid mainly for forced convection flows and fluids with a molecular Prandtl number of the order of unity. Because of their high thermal conductivity, liquid metals are characterized by significantly lower values of the molecular Prandtl number.

Hence, the goal of the PhD is the development of an innovative RANS turbulent heat transfer model for low Prandtl number fluids for industrial use with particular reference to fast pool-type reactors cooled by liquid metals.

Parametric studies have been performed for wall and free shear flows setting different molecular and turbulent Prandtl numbers in order to estimate and physically understand the sensitivity of the standard RANS approach to these properties of the fluid and flow respectively.

Large-eddy simulations are also being performed for the same fundamental test cases. This numerical database will be complemented with experimental data from the operation of a wind tunnel with a mixture of low Prandtl number noble gases under construction at The von Karman Institute for Fluid Dynamics.

These achievements will represent the basis to select and improve the current low Prandtl number heat transfer correlations and models, suitable only for few specific flow regimes. The developed turbulent heat transfer model will be finally tested and optimized with experimental data from the European SCAled Pool Experiment (E-SCAPE) facility, a thermal-hydraulic 1/6-scale model of the MYRRHA reactor built and operated by SCK•CEN.

Modeling of nucleation and growth of oxides in LBE by CFD for the design of LBE filtering systems

Kristof Gladinez
Institute Advanced Nuclear Systems
Expert Group on Nuclear Systems Research, Conditioning and Chemistry Programme Unit

SCK•CEN mentors: Kris Rosseel & Jun Lim
University promoter: Geraldine Heynderickx (UGent)
Start date as PhD: October 1st, 2015

Abstract

The Belgian Nuclear Research Centre (SCK•CEN) is a worldwide pioneer in the development of MYRRHA, the first research Accelerator Driven System (ADS). A unique feature of MYRRHA is the use of liquid lead-bismuth eutectic (LBE) as the primary coolant. Use of LBE has many technical and safety advantages. However it is well-known that accurate control of LBE chemistry is a key issue for the design of reliable LBE cooled systems. In the presented research topic the formation, transport and deposition of solid impurity particles during operation of LBE cooled systems are studied as these can result in e.g. clogging of pipes. This fouling problem needs to be mastered for safe operation of MYRRHA and accurate design of filtering systems.

Part of the research covers the development of a kinetic model for formation of solid oxides. The kinetics for lead oxide formation are selected as a suitable test case, as model validation is possible with data obtained using experimental facilities already present at SCK•CEN. A point-kinetic model for the formation of lead oxide in LBE is developed starting from the Classical Nucleation Theory (CNT). CNT predicts the rate of formation of solid nuclei in a liquid phase. Growth of these nuclei is, for the moment, assumed to be mass transfer limited. The point-kinetic model is extended to account for concentration and temperature inhomogeneities by coupling the chemical kinetics of oxide formation to a Computational Fluid Dynamics (CFD) code, Ansys Fluent. CFD simulations are performed to determine the hydrodynamics of LBE in regions where oxide formation is present. Reynolds Averaged Navier-Stokes (RANS) modeling is used in all computations. Single phase calculations were carried out in simplified geometries with the solid species modeled as a passive scalar with an effective diffusion coefficient in LBE. The performed calculations show the expected nucleation of critical nuclei but do not include particle growth and dissolution. The effect of particle sizes on the distribution in complex flow structures is not simulated. To mitigate this limitation the model has been extended to a two-phase Eulerian-Eulerian calculation. The solid oxide particles are modeled as a pseudo-continuous phase, using the 'Kinetic Theory of Granular Flow' (KTGF) to account for particle-flow interaction. The particle size distribution is accounted for using Population Balance Equations/ Models (PBE/PBM).

The point-kinetic model of lead oxide formation and dissolution has been tested in the HELIOS III experimental facility. The theoretical CNT model is corrected based on measurements in stagnant LBE. Using the corrected model, a good agreement between predicted and measured oxygen concentration during formation and dissolution of lead oxide in mixed LBE is observed. An experimental campaign is conducted in the MEXICO LBE loop at SCK•CEN to validate the obtained results of the kinetic model coupled with CFD calculations. Results indicate that the nucleation and growth of large amounts of sub-micron particles of lead-oxide is indeed the dominant mechanism of lead-oxide formation. Qualitative agreement between the model and experimental measurements is obtained by comparison of the oxygen concentration and filter pressure drop.

This work is financially supported by AVN.

Space dosimetry with luminescent detectors

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University promoter: Patrice Mégret (UMONS)
Start date as PhD: October 1st, 2015

Abstract

Dose mapping in space, individual monitoring of astronauts and space biological experiments require passive, small, safe and light detectors which are able to measure doses for the whole range of particles and energies. For this, a combination of luminescent detectors and track etch detectors is currently used on spacecrafts to respectively measure the low and the high LET part of the radiation spectrum. However, the dose assessment process with track etch detectors is very time consuming, requires specialized equipment and personnel and cannot be performed directly in space.

Aiming to explore the possibility of determining total radiation doses in space with luminescent detectors only, ^{6}LiF:Mg,Ti, ^{7}LiF:Mg,Ti, ^{6}LiF:Mg,Cu,P and ^{7}LiF:Mg,Cu,P detectors were exposed to protons, helium and carbon ions to investigate the relative efficiency LET dependence of the different peaks composing their glow curves. In order to resolve the different peak contributions, computer assisted deconvolution of the glow curves was performed. A general decrease of the relative efficiency with the increase of the LET was found for both LiF:Mg,Ti and LiF:Mg,Cu,P detectors. Exceptions to this trend are represented by the high temperature peaks of LiF:Mg,Ti detectors which appear to be enhanced by high LET radiation.

Consequently, an analysis of the glow curve peak structure was performed using the high temperature ratio (HTR) method. This method uses the different LET dependence of LiF:Mg,Ti main and high temperature peaks for the determination of the average LET of the incident particles. The goal of this study was to investigate if the use of deconvolution software could improve the performances of the HTR method. It was found that it was possible to obtain two parameters (called advanced high temperature ratios, A-HTR) using the ratio between the deconvoluted high temperature peaks 6 or 7 over the main peak 5. For detectors irradiated with the same radiation quality, these two A-HTR parameters are characterized by typically 2-3 times lower dispersion in comparison with the classical HTR method.

The classical HTR and newer A-HTR, together with a LiF:Mg,Ti/LiF:Mg,Cu,P main peak ratio method, were then applied to measurements performed on the International Space Station (ISS) to assess detector efficiencies at different locations inside the spacecraft.

Implementation and validation of a simulation framework for optimization studies in chest radiography

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University promoter: Hilde Bosmans (KU Leuven)
Start date as PhD: December 15th, 2014

Abstract

Optimization in diagnostic radiology is intended to ensure an image quality adequate to perform the clinical task, while keeping the patient exposure as low as possible. Establishing a good image quality in chest radiography is a complex subject due to the wide range of organs and the many clinical tasks involved. Achieving this image quality requires the generation of images with the correct acquisition parameters (i.e. tube voltage, mAs, filtration, anti-scatter method and automatic exposure), which have a direct influence on the dose delivered to the patient. The acquisition parameters currently used in digital systems are those recommended by the European Commission Guidelines, despite they have been published in 1996 explicitly for screen-film systems. Optimization of the acquisition settings becomes indispensable, since digital detectors have proved to have better image quality per patient dose compared with analogue technology detectors.

When performing optimization it is crucial to establish the link between clinical and physical measures of image quality. Computer simulations have proved to be useful for this, since they constitute a flexible way to test large systems configurations, making them an efficient alternative to the time consuming observer analysis. This work describes the first steps that have been taken towards the creation of a simulation framework for optimizing chest X-ray. A methodology for simulating the imaging chain was developed and validated in terms of image quality and dose. Radiographic images were generated from primary and scatter projections obtained separately in order to reduce the computation time. High resolution primary projections were generated using a ray tracing software, while low resolution scatter images were generated by means of Monte Carlo modelling. Detailed detector imaging characteristics, given by presampling modulation transfer function (MTF) and the noise power spectrum (NPS) were measured and used to apply realistic degrees of sharpness and noise to the simulated images. The methodology was validated in terms of image quality by measuring signal difference to noise ratio (SDNR) and contrast in the simulated and real images. It was found that both parameters decrease with the increasing of tube voltage, while increasing tube load at a fixed kVp reduced the SDNR but left contrast unchanged, as expected. The difference between measurement and simulation increased as the x-ray energy was reduced, with a maximum deviation of 7.2% as tube voltage was changed from 80 to 125 kVp. SDNR was generally underestimated in the simulated images compared to the real images.

Future work includes task specific optimization of chest radiography for a specific task, together with the modelling of anti-scatter devices and the creation of more realistic detector models.

Uncertainty quantification of atmospheric transport and dispersion modelling of radioxenon in support of the CTBT

Pieter De Meutter
Institute Environment, Health and Safety
Expert Group on Society and Policy support, Crisis Management and Decision Support Unit

SCK•CEN mentor: Johan Camps
Mentor RMI: Andy Delcloo
University promoter: Piet Termonia (UGent)
Start date as PhD: January 1st, 2015

Abstract

The Comprehensive nuclear Test-Ban-Treaty (CTBT) bans nuclear explosions by everyone, everywhere. Observations from the International Monitoring System are used to verify compliance with the Treaty. The International Monitoring System measures hydroacoustic, infrasound and seismic waves, together with airborne radionuclides. Observations of such airborne radionuclides can be used by Atmospheric Transport Models (ATM) to backtrack a radionuclide plume to a possible source.

ATM can also be used to simulate the future movement of a radionuclide plume. This is for instance of interest in the case of an accidental radionuclide release such as the Fukushima Daiichi nuclear disaster.

In both cases, an uncertainty quantification of the ATM output is desirable. We quantify uncertainty by using the ensemble method (the ensemble method will be discussed in the presentation).

We validate the model simulations and the corresponding uncertainty prediction by making use of the global radionuclide detection network of the International Monitoring System and an emission database of the most relevant civil sources.

The presentation will give an overview of the radioxenon background study that was done for Europe, and will highlight some of the work done in response to the announced nuclear tests of the Democratic People's Republic of Korea this year.

Medium resolution gamma-rays spectroscopy for safeguards applications

Yaroslav Meleshenkovskiy
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Expert Group on Society and Policy Support, Nuclear Science and Technology Studies Unit

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University promoter: Nicolas Pauly (ULB)
Start date as PhD: September 1st, 2015

Abstract

Nowadays, there is interest in developing gamma-ray measuring devices based on the room temperature operated medium resolution detectors such as semicoductor detectors of the type CdZnTe and scintillators of the type $LaBr_3$. This is true also for safeguards applications and the International Atomic Energy Agency has launched a project devoted to assessment of medium resolution gamma-rays spectroscopy for the verification of the isotopic composition of U and Pu bearing samples. This project is carried out within the European Safeguards Research and Development Association (ESARDA) Non-Destructive Assay Working Group.

This PhD is focused on the development of a specialized spectra processing algorithm for the room temperature detectors of the type CdZnTe and LaBr3 and is meant to complement and extend the work carried out within the ESARDA. It includes a detector characterisation stage with investigation of the proper response function that corresponds to the detector physics and best describes its peak shape.

A first objective of this PhD work is to carry out an assessment of the detector characterization procedure. The assessment will be based on the experimental results of measurements obtained on the 500 mm3 CdZnTe detector using different sources – point sources, U and Pu standards, as well as the information available in the literature on the developed spectra processing codes, and carrying our own assessment by Monte Carlo simulations of the detector response using the PHITS code.

The first year of the PhD was devoted to the following objectives: an extensive measurement campaign, carried out at the JRC-Geel; quantitative and qualitative analysis of the obtained spectra; literature study; quantitative analysis of the peak fitting approaches based on the existing codes for CdZnTe detectors described in literature. Peak fitting assessment has been made based upon the literature study of the existing CdZnTe response models. Selected approaches were quantitatively compared between each other to determine their limits and characteristics, such as fitting parameters covariance and correlation, residuals distribution, net peak area uncertainty and goodness of fit.

Growth and recovery of rice plants exposed to gamma radiation: oxidative stress response and expression of miRNAs

Jackline Mwihaki Kariuki
Institute Environment, Health and Safety
Expert Group on Radiological Impact and Performance Assessment, Biosphere Impact Studies Unit

SCK•CEN mentors: Nele Horemans & Eline Saenen
University promoter: Ann Cuypers (UHasselt)
Start date as PhD: October 1st, 2015

Abstract

With regard to chronic low dose radiation, it is difficult to extrapolate the effects observed at cellular level to those observed in higher levels of organization because the mechanisms behind them are not fully understood. To develop more robust and reliable frameworks for radiation protection of non-human biota, it is imperative to first understand how these effects are propagated from cellular to higher levels of organization. The overall objective of this PhD project is to determine the effect of chronic radiation in plants. Experiments conducted so far have focused on determining the effect of radiation in rice (*Oryza sativa cv. Nipponbare*) by irradiating 7-day old seedlings with 4 gamma dose rates: (30, 50, 100 and 400 mGy/h) for two weeks. Control plants were not irradiated. Most of the plants were harvested immediately after exposure whereas 24 plants per condition were placed in a climate chamber for an additional two weeks to allow for recovery. Endpoints measured in both sets of plants were growth (length and fresh weight), capacity of antioxidative stress enzymes and the expression of primary miRNAs (pri-miRNAs). For the analyses of antioxidative stress enzymes and pri-miRNAs plants were divided into two groups. First group consisted of plants that had their leaves harvested according to the leaf age i.e. leaves of different plants but same physiological age bulked together, otherwise referred to as pooled plants. Second group comprised of leaves from the same plant (different physiological age) bulked together i.e. non-pooled plants. Roots were harvested without any grouping.

Growth measurements revealed no difference in fresh weight immediately after irradiation but there was a significant decreased fresh weight in recovery plants. This indicates that exposure to gamma radiation induces stress in *Oryza sativa* plants, although this was not visible immediately after harvesting.

Antioxidative enzymes generally had decreased activity in response to gamma radiation in the non-pooled leaves and roots. Ascorbate peroxidase and superoxide dismutase were more responsive in the leaves whereas guiacol peroxidase and syringaldazine peroxidase were more responsive in the roots. In addition, expression profile of pri-miRNAs (selected based on a literature review) revealed no difference in exposed plants compared to controls immediately after radiation exposure. However, following recovery of these plants, the change in expression of these pri-miRNAs in non-pooled leaves is a first indication that they play a role in gene regulation. In pooled leaves, the enzymatic response to gamma radiation was seen to be dependent on the physiological age of the leaves thus this should be taken into account in future analyses.

Future work will test the expression profile of more miRNA genes shown to be involved in oxidative stress response in rice. Responsive miRNAs will also be tested in *Arabidopsis* for further comparison of both species. Transcriptomic profiling and miRNA specific microarrays will be conducted to investigate further changes that occur during gene expression and the mechanistic pathways induced. Comparisons of observations made in rice and *Arabidopsis* will give us an insight into the difference in radiosensitivity between these two plant species and will enable us to get a general overview of the molecular response of plants to radiation.

Dental pediatric imaging: an investigation towards low dose radiation induced risks

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Start date as PhD: October 1st, 2015

Abstract

Cone Beam Computed Tomography (CBCT) is a multipurpose radiographic tool for diagnosis, treatment planning, follow-up and research in dental practice, mostly in the field of pediatric orthodontics. Like conventional CT, CBCT uses X-rays to generate anatomical images. Although CBCT is considered a low dose imaging modality, it is uncertain that using CBCT is completely without risk. Investigating these low dose effects is of particular interest in pediatric CBCT examinations, since children are known to be more radiosensitive than adults.

To investigate the potential biological effects of CBCT both *in vitro* and *ex vivo* samples are analysed. The main focus is placed on pediatric patients, but adult samples are included to check for age-dependent differences. In the *in vitro* part low dose X-radiation-induced (0, 5, 10, 20, 50 and 100 mGy) effects are studied in dental stem cells (stem cells from the apical papilla, dental pulp stem cells and dental follicle stem cells) from three pediatric donors. DNA damage repair and repair kinetics are analysed by microscopical visualization of DNA double strand markers (γH2AX/53BP1) 30 minutes, 1 hour, 4 hours and 24 hours after irradiation. For the *ex vivo* study oral mucosal cells and saliva samples are collected from consenting patients. DNA damage and repair kinetics are analyzed by microscopical visualization of DNA double strand markers (γH2AX/53BP1) in exfoliated oral mucosal cells collected just before and after (30 minutes and 24 hours) CBCT exposure. Saliva is used in a pilot study to detect local changes in oxidative stress levels in the oropharyngeal region and salivary glands induced by CBCT. Sample collection occurs just before and 30 minutes after CBCT exposure.

Preliminary *in vitro* data show that there is a dose dependent increase in the amount of DNA damage 30 minutes and 1 hour post-irradition for doses higher than 20 mGy. This damage is resolved 24 hours post-irradiation. These results are similar in three different stem cell types originating from one of the pediatric donors. DNA damage analysis in oral mucosal cells from adult patients reveals that no significant increases in the amount of DNA damage can be detected after CBCT examination. Finally, saliva data from adult patients shows that oxidative stress levels do significantly increase after CBCT examination.

In conclusion, preliminary data indicate that low dose X-rays induce increases in DNA damage *in vitro*, but CBCT examination does not lead to increased DNA damage in oral mucosal cells in adult patients. Finally, adults show increased salivary oxidative stress levels after CBCT examination.

Poster presentations

Ultrasonic measurement techniques in heavy liquid metals

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Start date as PhD: January 1st, 2015

Abstract

The Belgian Nuclear Research Centre SCK•CEN is in the process of developing MYRRHA, a new generation IV fast flux research reactor to replace the aging BR2. MYRRHA is conceptualized as an accelerator driven system cooled with lead bismuth eutectic mixture (LBE). As LBE is opaque to visual light, ultrasonic measurement techniques are employed as the main technology to provide feedback where needed. This poster we will give an overview of the R&D at SCK•CEN with respect to ultrasonic instrumentation in heavy liquid metals.

We will discuss the main acoustic properties of LBE and their consequence on optimal sensor design for application in heavy liquid metal cooled reactors. We will present the results of experimental validation campaign in pool of LBE at 200°C, where submerged objects are visualized by means of ultrasonic techniques. Furthermore, we present two dedicated ultrasonic systems that are envisaged to be deployed in the MYRRHA reactor: the "Ultrasonic Fuel Identification System" and the "Lost Fuel Localization System".

Solid state ionic devices for lead alloys cooled nuclear systems

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Abstract

Liquid lead-bismuth eutectic (LBE) is the candidate coolant and spallation target for advanced nuclear reactors such as MYRRHA (Multi-purpose hYbrid Research Reactor for High-tech Applications), currently under development at the Belgian nuclear research centre SCK•CEN.
One of the challenges using LBE is the corrosion of the structural steel in contact with the lead alloy, occurring mainly by dissolution processes. To minimize the corrosion rate, the content of oxygen in LBE should be high enough to guarantee the formation of a protective oxide layer on the steel surfaces and low enough to avoid the formation of lead oxide precipitates that could clog reactor components.
Therefore, oxygen sensors and an oxygen control system able to add/ remove oxygen from LBE must be implemented in MYRRHA.
Although potentiometric oxygen sensors based on yttria partially stabilized zirconia (YPSZ) as solid electrolyte (SE) and Bi/Bi_2O_3 or air/Pt as reference electrode are commonly used to monitor the oxygen content in LBE, their operation temperature limit is respectively of 280 and 350 °C. MYRRHA will operate between 200 and 400 °C, therefore the development of novel oxygen sensors operating as low as 200 °C is required.
A poor electrocatalytic activity and limited reaction surface of platinum towards oxygen reduction reaction (triple phase boundaries, TPBs) may explain the temperature limit of air/Pt sensors while the solidification of bismuth (about 270 °C) may limit the performance of Bi/Bi_2O_3 sensors.
Reason why different reference electrode systems were tested, while using YPSZ as solid electrolyte.
Gas reference electrode systems with perovskite oxides such as Lanthanum Strontium Manganite (LSM) performed well down to 200 °C, confirming the assumption made for air/Pt sensors.
Liquid metal-metal oxide reference electrodes with lower melting point than bismuth measured properly down to 200 °C.
Moreover, among solid metal-metal oxide reference electrodes a mixture of Cu/Cu_2O was selected for operation in LBE down to 200 °C.
An electrochemical oxygen pumping (EPO) system based on the properties of solid ionic conductors was for the first time designed and implemented to control the oxygen content in LBE.
Firstly, the feasibility of an electrochemical pump based on YPSZ and air/LSM electrode has been proven in a small scale facility.
Therefore, based on the results achieved, the EPO system was implemented in a large scale facility at SCK•CEN (MEXICO facility) obtaining a highly accurate and reliable oxygen control.

Dissection of novel resistance mechanisms in *Cupriavidus metallidurans*

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Abstract

Cupriavidus metallidurans strains, which belong to the *Burkholderiaceae* family, are characterized by multiple metal resistances and have been mostly isolated from industrial sites linked to mining, metallurgic and chemical industries. Studies at SCK•CEN underscored the rapid evolution of *C. metallidurans* strains towards significantly increased metal resistance. Surprisingly, the canonical mechanisms did not participate in this adaptive evolution. In contrast, a novel and unique resistance mechanism, involving an uncharacterized small periplasmic protein, was discovered.

In this work, we investigated silver resistance. Different *C. metallidurans* strains including type strain CH34, its plasmidless derivative AE104 and strain NA4, which was isolated form the silver-sanitized drinking water of International Space Station (ISS), were grown in toxic concentration of silver to obtain silver-resistant mutants. Since silver-resistant mutants were even found in the plasmidless AE104 strain, the dominant silver-resistant mechanism does not include the canonical efflux mechanisms encoded by the megaplasmids. Whole-genome expression profiling was used to compare the up- and downregulated genes of the silver-resistant mutants with their respective parents. Only eight genes were commonly upregulated genes in all silver-resistant mutants and no commonly downregulated genes were observed. Deletion mutants were constructed for these genes and showed that deletion of the two-component system *agrRS* and a *copQ*-like gene coding for a small periplasmic protein render susceptibility to silver. Furthermore, plasmid-based complementation restored resistance to silver. Further investigation is ongoing with the other differentially expressed genes and to validate the DNA-binding properties of AgrR.

Altogether, our data indicate that *C. metallidurans* is able to adapt rapidly to toxic silver concentrations without mediation of its known silver efflux pumps. Although the mechanism that confers increased silver resistance is still not fully understood, these results indicate differential regulation via a two-component regulatory system and the involvement of a family of small periplasmic proteins.

Effects of ionizing radiation on mitochondrial function in human endothelial cells

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Abstract

Background
Mitochondria are often regarded as the powerhouses of the cell because they supply most of the cellular energy, meanwhile however generating substantial amounts of reactive oxygen species. Yet, mitochondria are also involved in other tasks such as oxidative stress signalling, calcium regulation and apoptotic control. Deregulation of mitochondrial functions can result in the promotion of apoptosis and senescence, and in an increased inflammatory status. All of these adverse events are observed in the onset and progression of atherosclerosis, the main cause of cardiovascular disease (CVD).

Objective
To assess the effect of ionizing radiation exposure on the mitochondrial function and related pathways in endothelial cells.

Methods
Assays for mitochondrial DNA, cellular metabolism, senescence and cytokine quantification were used to compare sham- and X-ray-irradiated endothelial cells over time.

Results
We could demonstrate a differential response in the amount of mitochondrial DNA after exposure to medium and high dose ionizing radiation. This observation was accompanied with a glycolytic switch, consisting of a decreased mitochondrial respiration rate and an increased glycolytic activity. Moreover, every dose of ionizing radiation induced premature endothelial cell senescence, which could be partly explained by the inflammatory reaction occurring after exposure to ionizing radiation at the medium and high dose range.

Conclusion
Our results indicate that mitochondrial function is changed after exposure to ionizing radiation and could explain in part the endothelial cell dysfunction observed after radiation exposure. This observation indicates that mitochondria are an interesting cellular target for cardiovascular risk-reducing strategies, aimed to prevent radiation-induced CVD.

Acknowledgements
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Physiology of *Cupriavidus metallidurans* CH34 in the presence of basalt, a lunar-like rock, on Earth and in Space

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Abstract

In order to maintain a persistent human presence in space, materials must either be provided from Earth or generated from material already present in space, in a process referred to as '*in situ* resource utilization (ISRU)'. Microorganisms can bio-mine useful elements from extra-terrestrial materials for use as nutrients in a life support system Therefore, this research is aimed to identify the interaction of bacteria with basalt, a volcanic lunar-like analogue and look at the impact of micro-gravity and space radiation on these interactions.

The physiology and interaction of the soil bacterium *Cupriavidus metallidurans* CH34 in the presence of basalt was analyzed trough growth and survival experiments. Survival of CH34 was monitored, with and without basalt, in mineral water. After 3 months, cell physiology was analyzed (by flow cytometry), as well as cultivability, element release and biofilm formation (by scanning electron microscopy). To study the influence of micro-gravity on these interactions the survival setup was also send as a flight experiment onboard the Russian FOTON M4 capsule, launched in July 2014. For growth, cells were grown in medium with and without essential elements in the presence and absence of basalt and followed up with flow cytometry, plate counting and OD measurements.

CH34 cells survived relatively well in mineral water at ambient conditions for 3 months on ground. Storage in mineral water did have a significant impact on cell physiology and energy status: 61% of cells of the stored cell suspensions had lost their cell membrane potential and only 7% were still active. These stored cells also contained less ATP and more PHB, compared to the cells at the start. These changes impacted cultivability as viable cell counts dropped one log indicating a transition into a more 'dormant' state. Both basalt and flight conditions counteract some of these effects and cells in the presence of basalt exposed to flight conditions showed less changes in physiology, with only 2% of the cells which lost its cell membrane potential and 34% of the cells which were still active leading to a higher cultivability. Microbe-mineral interaction and biofilm formation were slightly influenced by spaceflight as less biofilm was present on the basalt from the flight conditions.
For the growth experiments, it was seen that CH34 was able to grow in the presence of basalt and basalt could be a source for essential elements supporting its growth. In contrast, results obtained in another setup (different type of basalt,…) showed significant growth limitation of CH34 in these conditions and additional growth experiments will be performed to look at the impact of different kinds of basalt and setups on growth.

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Spatially distributed recharge in groundwater models: bridging the gap between the soil profile and the catchment scale

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Abstract

Flow and transport in aquifers are influenced by recharge processes, which are the downward fluxes from precipitation to groundwater. These fluxes are the net result of fluxes and processes in the atmosphere, vegetation and the vadose zone (soil). In lowland areas, these fluxes are also strongly non-linearly coupled to groundwater levels and flow processes in the shallow groundwater and to transfers towards surface waters via surface and subsurface drainage networks. Moreover these processes are highly variable at different temporal (mainly due to weather and climatic variability) and spatial scales (due to soil, land cover, groundwater depth variability, distance and connection to surface waters). At the small scale (point scale to plot scale ~0.001-0.01 km^2), the parameters determining vertical flow in the groundwater-vadose zone- vegetation-atmosphere system can be measured/estimated and the water flow can be relatively well described. At a larger scale (catchment scale, ~100-1000 km^2), the accurate representation of vadose zone processes and lateral transfers towards surface water is limited by the above-mentioned variability and computational requirements. In this context, model abstraction is of paramount importance. Up to now, this is mainly achieved by simplifying the spatio-temporal variability of the parameters, boundary conditions and/or processes. These simplifications are however questionable given the non-linearity and interconnection of the processes. Furthermore, to assess the effect of spatial variability of recharge on the spreading and movement of solute (e.g. radionuclides) plumes in shallow aquifer, an accurate representation of this variability is required. Therefore, an upscaling approach that leads to a more consistent representation of recharge variability in large scale groundwater models resulting from spatial variability of processes and parameters at smaller scales needs to be developed. This poster presents such an approach. It builds on small scale existing modelling knowledge and measurements, to go to the catchment scale by performing model abstraction and using available catchment scale spatialized data (e.g soil map, land use/cover map) and transfer functions. The proposed methodology will be tested on the Kleine Nete catchment (Flanders, Belgium). This catchment has been chosen as a case study because a lot of hydrogeological data are already available. Moreover hydrological modelling on this catchment is of particular importance because of the foreseen installation of surface waste disposal (cAt). To complete the hydrogeological data and in order to develop and test the modelling methodology a monitoring network is being installed and is presented in this poster in its current state.

An advanced mineralogical study of the clay mineral fraction of the Boom Clay

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Abstract

The Belgian Boom Clay Formation is studied as a potential host rock for the geological disposal of radioactive waste. The clay minerals within the Boom Clay have a significant influence on the retardation of radionuclides from within a repository to the geosphere and biosphere due to their sorption capacity. The sorption behaviour can be attributed to cation exchange in the interlayer of (swelling) clay minerals such as smectite and surface complexation on the broken edges of clay platelets. Due to these processes, clay minerals also dictate to a high extent the pore water chemistry of argillaceous rocks.

The detailed study of the clay mineral characteristics is therefore fundamental in the understanding of the Boom Clay composition and geochemical processes and forms the base for further experimental work and modelling. The objectives of this PhD are to study the clay mineral characteristics of various Boom Clay samples, both qualitatively and quantitatively, and to couple this information to geochemical parameters and processes. This study will be performed on bulk rock samples, as well as on different size fractions of the Boom Clay. To characterise the mineralogy, X-ray diffraction will be performed. Additionally, the use of Fourier transform infrared spectroscopy (FTIR) will be investigated as an alternative, qualitative characterisation method. In order to assess the sorption behaviour of the clay minerals, several geochemical parameters will be tested. The cation exchange capacity will be measured with index cations, such as Co-hexamine and Cu-trien, the specific surface area will be studied through the N_2 adsorption technique and the layer charge will be studied by using cationic dyes such as alkylammonium.

The coupling of a detailed mineralogical characterisation to geochemical parameters and associated processes, will allow for a better prediction of the retention properties of the Boom Clay, starting from baseline mineralogical information.

Development of practical eye lens dosimetry for interventional procedures in hospitals

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Start date PhD: December 6th, 2013

Abstract

Recent studies have shown that the lens of the eyes is more radiosensitive than previously considered. In view of these studies, a new dose limit of 20 mSv/year has been recommended by ICRP since 2011, for occupationally exposed individuals, and was included in the International Basic Safety Standards in 2014. Hospital based workers that perform interventional radiology/cardiology are at risk of reaching this new dose limit. These workers are exposed to the radiation scattered by the patient, which creates a complex radiation field, as several beam projections are usually employed during the same procedure. Furthermore, the use of protective devices, such as ceiling suspended shields and lead glasses, contributes to the creation of a challenging environment to properly assess the dose received by the eye lens. Although several eye lens dosemeters are available nowadays, they are usually big in size and were not developed to be used together with lead glasses, which leads to high uncertainties when the eye lens dose under the shielding of the glasses is intended to be evaluated. In view of improving eye lens dose assessment when lead glasses are used, the purpose of this project is to develop a practical eye lens dosemeter, which can be worn together with lead glasses, without hindering the user, and that assess the eye lens dose without important over/underestimation. On this PhD day, results from the optimization of the angular dependence of the dosemeter chosen for this project and the best position where to place it on the lead glasses will be presented and discussed.

Effect of variations in clay/silt content on the diffusive properties of Boom Clay

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Start date as PhD: October 1st, 2013

Abstract

Boom Clay is currently considered as a potential host rock for the disposal of high-level, long-lived radioactive waste in Belgium. Due to a low hydraulic conductivity and a low hydraulic gradient over the formation, transport is dominated by diffusion. Therefore, diffusive transport parameters are important input data for safety calculations. In 2008, SCK•CEN developed a new technique to measure diffusive parameters for dissolved gases with high precision (Jacops et al., 2013).
Boom Clay consists of different lithological sub-units consisting of a rhythmic alteration of silty and more clay-rich layers, with the presence of organic-rich and carbonate-rich layers. From previous work, it is well known that variations in clay and silt content lead to changes in transport parameters such as hydraulic conductivity (Wemaere et al., 2008). Variations in diffusive parameters for unretarded tracers have in the past only been studied for tritiated water (HTO) and results indicate some variation over the formation (Aertsens et al., 2005; Bruggeman et al., 2009). In order to extend our knowledge on the effect of variations in clay/silt content on the diffusive parameters, diffusion experiments with He, CH_4 and HTO on samples with variable clay/silt contents were performed. Hereafter, samples were fully characterised regarding their grain size characteristics and mineralogy and a petrographical analyses of thin sections was carried out.
The diffusion coefficients obtained for He, CH_4 and HTO show little variation. However, when looking at the geometric factor (a factor which indicates how diffusion is influenced by pore structure, geometry and connectivity, $G = \eta \times D_0/D_{eff}$), more variation can be observed. Correlations are noted between the geometric factor and the content of 2:1 clay minerals as well as the silt content. Petrographic analyses of thin sections of the samples showed a clear difference between the "clayey" and the "silty" samples. For the clayey samples, the quartz grains are homogeneously distributed over the clay matrix, whereas for the silty samples, clusters of quartz grains with interparticle porosity are characteristic features. These results support the hypothesis that the lithological variations influence to a certain degree the diffusive pathways of dissolved species through the formation.

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Mechanistic analysis of radiation-induced microcephaly and cognitive impairment in mice

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Abstract

Exposure to high doses of ionizing radiation during brain development at the neurogenesis period has been shown both in humans and mice to result in microcephaly (reduced brain size) and cognitive defects later in life. Previous experimental studies have shown that changes in gene expression in the embryonic mouse brain at an early time point after radiation exposure were very similar to those observed in several genetic mouse models of microcephaly. This suggests that early radiation-induced changes in gene expression in the embryonic brain might be responsible for these developmental defects. Most of these early transcriptional changes were found to be mediated by the tumor suppressor p53, a transcription factor known to activate genes involved in cell cycle arrest, DNA repair and apoptosis in response to DNA damage. Among these p53-regulated genes, novel p53 targets were identified, some of which are not yet fully characterized.

The purpose of this project is to gain more insight in the role of p53 and one of its currently uncharacterized target genes, *D630023F18Rik*, in brain development and the response to ionizing radiation. To reach this objective, we generated mice in which the p53 gene is specifically knocked out at the stage of early neurogenesis in the dorsal forebrain (cKO mice) using the Cre-LoxP recombination system. These mice will be used to evaluate morphological and functional effects of prenatal radiation exposure in comparison with wild-type mice. Concerning the functional characterization of *D630023F18Rik*, we have identified different splice variants which are highly enriched during brain development and neuron differentiation in vitro, suggesting that this gene could play a key role in these processes. Furthermore, several short variants of this gene were found to be responsive to radiation.

To futher investigate the functions of *D630023F18Rik*, different expression vectors have been constructed. These will be used for overexpression of the different splice variants in Neuro-2a neuroblastoma cells, a cell line which differentiates to neurons in a p53-dependent manner after radiation exposure.

Acknowledgements
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Microbiological analysis of spent nuclear fuel pools: towards the identification of radiation-resistant bacteria

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Abstract

After being used as energy source inside power plants, spent nuclear fuel must be stored underwater in so-called "spent nuclear fuel pools" (SNFPs) in order to cool down before being safely disposed. Interestingly, despite the highly oligotrophic and radioactive nature of the water, microbial growth is not fully prevented. Microorganisms identified in such environments provide a unique opportunity to acquire new insights into radiation-resistance mechanisms. A detailed characterization of highly resistant strains might result in identifying good candidates to be used in bioremediation processes for radionuclide-contaminated environments.

The objective of our project is to inventory and monitor the bacterial communities present in SNFPs of French and Belgian reactors over time. Furthermore, this project also aims at a phenotypical characterization of the most abundant species.
In this work, we present the inventory of the bacterial communities we analyzed in one SNFP as well as a secondary pool surrounding the reactor vessel. Since a culture-independent approach focusing on characterizing the entire microbial population is currently lacking, we chose to inventory the communities present in those pools using a 16S rRNA amplicon sequencing approach. First results highlighted the presence of bacteria mainly belonging to the Alpha- and Betaproteobacteria. For the phenotypic characterization, we isolated and cultured the most abundant strains, which were then tested for their resistance towards radiation using a gamma irradiation facility. Preliminary results showed that all strains tolerated a dose of 300 Gy, but only a single strain from the SNFP was able to cope with a dose of 2100 Gy.

Next to bacteria in planktonic form, biofilms present on the walls and the fuel rods stored in the SNFP will also be analyzed in the near future. This will be done using a combination of culture-based and culture-independent (16S rRNA amplicon sequencing) methods.

Mechanisms of radiation resistance in Arthrospira sp. PCC 8005

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Abstract

This project aims to provide a better insight on how certain genetic mechanisms or biochemical pathways allow the cyanobacterium *Arthrospira* to withstand extreme high doses of ionizing radiation (IR). Our main interest goes to strain PCC 8005 which is used as an oxygen producer and a nutritional endproduct in the lifesupport system MELiSSA[1] and which is intensively studied by the MIC group of SCK•CEN. A first approach is to establish a catalogue of bacterial genes and proteins/enzymes known from literature to be involved in extreme radioresistance and perform bioinformatic analyses to identify genes and pathways relevant to IR-resistance in *Arthrospira*. This will also allow me to become familiar with the range of mechanisms for IR-resistance in other microbes. In addition, we will zoom in into particular protein sequences of strain PCC 8005 (e.g. ClpX, RecA, PriA, ..) to find clues for the *Arthrospira* sp. PCC 8005 IR-resistant phenotype on the molecular level. A second approach is to test IR-resistance in a wide set of *Arthrospira* strains. Through comparison of PCC 8005 genome data with genome data of IR-sensitive *Arthrospira* we hope to find additional genes and pathways potentially related to IR resistance. Throughout these studies, particular interest will be given to DNA repair systems and the avoidance and detoxification of reactive oxygen species (ROS), as well as transcriptionally regulatory systems, including those that involve ncRNA's. In a third approach, *Arthrospira* sp. PCC 8005 cells will be subjected to high doses of gamma radiation and global gene expression levels will be measured by RNAseq technologies during at least one cycle of photosynthetic growth (i.e. in the presence of light, where previous gene expression experiments were only performed in the dark). Other gene expression experiments may be devised to address specific questions related to IR-resistance in strain PCC 8005. In general, irradiated cells will also be studied for DNA damage, protein modification, ROS abundance, and pigment and antioxidant composition. Novel antioxidants will be characterized and further investigated. A last aspect of the PhD project is to develop a genetic system for *Arthrospira*. Although *Arthrospira* has prominent defenses against incoming DNA this not only would allow the generation of gene-specific mutants of strain PCC 8005 to verify or test for an IR-sensitive phenotype but would also give an important impetus to further genetic studies of *Arthrospira*.

[1] http://www.esa.int/Our_Activities/Space_Engineering_Technology/Melissa

Microstructural study of plastic deformation of tungsten

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Start date as PhD: October 7th, 2013

Abstract

Tungsten (W) is the divertor material selected for ITER and a prime candidate for plasma-facing materials (PFMs) in DEMO. The mechanical and microstuctural properties play a key role in the performance of tungsten as armor material protecting the functional components from the plasma heat. Under plasma exposure of tungsten at ITER relevant conditions deuterium (D) retention with subsequent growth of D bubbles alongside thermo-mechanical stresses lead to the accumulation of plastic deformation and eventually to the nucleation of micro-cracks on the surface, with the risk of crack propagation towards the bulk. Thus, understanding of precise mechanisms of deformation is an important issue in the assessment of safety exploitation of the structural and functional materials to be utilized as PFMs. In this work, transmission electron microscopy (TEM) and Nano-indentation testing (NIT) are applied to investigate the influence of plastic deformation and annealing on mechanical properties and microstructure of recrystallized and ITER-relevant specification tungsten grades.

Microstructural characterization of complex oxide scales formed on DIN 1.4970 reference MYRRHA cladding tubes in static LBE at targeted oxygen concentrations

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Abstract

MYRRHA is an experimental liquid lead bismuth (LBE)-cooled fast reactor project developed at SCK•CEN. The candidate MYRRHA driver fuel (mixed plutonium-uranium oxide fuel pellets) is encapsulated in cladding tubes made of austenitic stainless steel DIN 1.4970. Fuel cladding is the first barrier that separates the radioactive fuel from the rest of the reactor system so its failure must be avoided. Therefore, it is crucial to study the oxidation and dissolution mechanisms operating in these steels due to their contact with liquid LBE. Thermodynamics but also reaction kinetics will determine the threshold temperature for a given oxygen concentration at which the cladding can be kept safely in the reactor core. The main liquid metal corrosion (LMC) mechanisms are oxidation, dissolution and erosion. For this study, the focus is on oxidation, which occurs when the steel is exposed to a high amount of oxygen dissolved in the liquid LBE ($[O]>10^{-8}$ mass%) at low temperatures (T<450 °C). Whereas, in oxygen-poor liquid LBE ($[O]<10^{-8}$ mass%) at high temperatures (T>450 °C), dissolution corrosion occurs.
The objective of this study was to characterize the oxide scale that forms on the surface of the DIN 1.4970 steel after its exposure to static LBE and to correlate the oxide scale configuration and properties to the specific exposure conditions. For this work, the effects of relatively high oxygen potentials for different temperatures were studied.
The specimens exposed to LBE were DIN 1.4970 cladding tubes 24% cold worked. The temperature and LBE oxygen concentration during this test were monitored by a thermocouple and an electrochemical oxygen sensor (air/Lanthanum Strontium Manganese oxide (LSM) reference electrode). An automatic oxygen control system, developed at SCK•CEN, maintained the amount of dissolved oxygen in the liquid LBE constant throughout the experiment. This work presents results from the steel characterization by means of light optical microscopy (LOM), scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDS) and transmission electron microscopy (TEM).
The formed oxide layers did not consist of well-defined, homogeneous layers; inner Fe-Cr spinel ($Fe_xCr_{2-x}O_4$), outer magnetite (Fe_3O_4) as often described in literature, but had a more complex structure and elemental distribution. The formation and growth of the oxides was strongly dependant on the temperature at which the steel was exposed. It was also observed that the oxide scales were not protective as they did not prevent the dissolution corrosion of the steel.

Nanostructure evolution of high-chromium ferritic/martensitic alloys under neutron and ion irradiation: an object kinetic Monte Carlo model

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Abstract

High-chromium ferritic/martensitic steels are canditate materials for fuel cladding and other core components in commercial GenIV reactors, as well as for the breeding blanket of fusion systems. However, despite exhibiting an optimal resistance to radiation-induced swelling, the structural integrity, service lifetime and mechanical properties of these materials are threatened, among others, by low-temperature hardening and subsequent embrittlement caused by neutron irradiation damage. To mitigate this problem it is important to understand which radiation-induced nanofeatures are responsible for it, by exposing these materials to irradiation and performing adequate characterization.

The limited availability of suitable neutron irradiation facilities, as well as costs and time expenditure of neutron irradiation experiments, have given rise to a continuously increasing interest in alternative irradiation sources, e.g. ion irradiation. Yet, drawbacks associated with ion irradiation experiments do exist. Important ones are the small (of the order of a few microns) depth of penetration of ions into the material, the proximity of surfaces, the existence of strong damage gradients in defect concentrations throughout the specimen thickness, and the injection of an excess of interstials with respect to vacancies. Moreover, the displacement rate is several orders of magnitude larger in ion than in neutron irradiation and this effect is likely to be exacerbated by the use of pulsed versus continuous irradiation.

As part of a multiscale modeling approach, in this work we use an object kinetic Monte Carlo model to study the response of ferritic/martensitic Fe-Cr-C model alloys to different dose-rates. The effect of pulsed versus continuous ion irradiation at the operational temperature of light water reactors, ~300 °C, is investigated, reproducing the effect of ion beam scanning and finding that the presence of Cr is key to explain the material nanostructure response to the two different irradiation regimes. Finally, irradiation temperatures from values relevant for the water-cooled design of the fusion DEMO (i.e. ~250°C) to temperatures of the order of ~400°C, closer to those envisaged for Gen-IV applications, are also explored.

Retention of plasma components in tungsten under high flux plasma in presence of neutron irradiation: multi-scale modelling approach

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Abstract

Currently I am at the stage of finalization of my PhD thesis so in this poster presentation I would like to summarize the results achieved during these four years.

The main focus of the project was a study of physical mechanisms of H retention in tungsten by means of computer simulations. The results can be divided in three groups (corresponding to three chapters of the thesis): first principle calculations and construction of the physical model of H retention in tungsten, molecular dynamics simulations at finite temperature and implementation of the model in rate theory simulation tool and its application for analysis of experimental results. Scientific output in terms of publications and conference presentations will be also presented on the poster.

MAX phase-based materials for the MYRRHA pump impeller

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Start date as PhD: October 1st, 2013

Abstract

The development of new materials with enhanced properties is of utmost importance for the nuclear industry. The lack of qualified materials which can stand the extreme conditions in the next generation nuclear power plants is one of the main limiting factors in the realization of these new reactor concepts. Recently, MAX phases are considered as a promising material group for the nuclear field. These ternary ceramics combine unique mechanical and thermal properties with a good corrosion and irradiation resistance. This study reports on the development of novel MAX phase materials with the potential use in lead fast reactors (LFRs). The synthesis route of the promising Zr-Nb-Al-C MAX phase system was explored starting from ZrH_2, $NbH_{0.89}$, Al and C. The ceramics were successfully produced by reactive hot pressing and some new ternary compounds such as Zr_3AlC_2 and Zr_2AlC were discovered. The interchangeability of Nb and Zr on the M-sites was determined using the Rietveld refinement. Furthermore, the mechanical properties (i.e., stiffness, flexural strength and fracture toughness) of Nb_4AlC_3 and $(Nb_{0.85},Zr_{0.15})_4AlC_3)$ were evaluated. The high-temperature stability of these materials was assessed based on the temperature dependence of both dynamic elastic properties and 4-point bending strength. Finally the chemical stability of these carbides were evaluated in contact with stagnant lead bismuth eutectic (LBE) at 500°C with low oxygen content

Purification of medical ^{153}Sm using radiation-resistant ionic liquids

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Abstract

^{153}Sm can be used as a medical radiopharmaceutical for treatment of different types of bone cancer because of its favourable physical decay properties ($t_{1/2}$ = 46.284 h, β^- emitting radioisotope). ^{153}Sm can also be used in bone imaging using γ-ray detectors because of γ-photons emission. ^{153}Sm is usually produced via neutron irradiation of an enriched ^{152}Sm target, i.e. $^{152}Sm(n,\gamma)^{153}Sm$. However, ^{154}Eu ($t_{1/2}$ = 8.593 y) is also formed in the targets by neutron capture of ^{153}Eu (decay product of ^{153}Sm). By keeping the irradiation time rather short, the amounts of this impurity can be kept relatively low compared to the ^{153}Sm activity, allowing the ^{153}Sm to be used without purification from Eu. This is, however, associated with the drawback of a rather short shelf-life of the ^{153}Sm product since the ratio of $^{153}Sm/^{154}Eu$ decreases significantly with time. To increase the availability and decrease the prize of the product, it would be beneficial if the shelf-life could be increased and/or the irradiation time could be prolonged. Therefore, the ^{154}Eu has to be removed from the ^{153}Sm. This, however, is not straightforward because of the very similar chemical properties of both neighbouring lanthanides and the low concentration of europium compared to samarium. Moreover, a separation method based on solvent extraction technology that could be automatized would be beneficial to minimize the dose rate for the operators.

The irradiated solid target is usually first dissolved in acidic environment. Afterwards, the unwanted by-products can be removed by different separation methods. In this study, the use of radiation resistant ionic liquids (ILs) for the separation of the aforementioned radiolanthanide pair is investigated. ILs are solvents that consist entirely of ions and they are a very interesting alternative for the molecular organic phase in solvent extraction processes. To prevent high losses of the IL, hydrophobicity of the IL is very important. Since the use of fluorinated ILs have to be prevented, both for radiolysis and waste treatment reasons (CHON principle), hydrophobicity was achieved by using a cation with long alkyl chains. An aromatic group was added to increase the radiation resistivity. To meet the requirements, the IL cation benzyltrioctylammonium was chosen in combination with a nitrate anion.

Europium has the ability of being relatively stable for a short period of time when being selectively reduced to its divalent state by a strong reducing agent (e.g. by Zn^0). This reduction changes the chemical properties of europium, leading to the possibility to separate europium from the other lanthanides, including neighbouring samarium. Different extraction conditions using stabile isotopes and different aqueous feed solutions, containing various chloride or nitrate concentrations were investigated. Also the use of a crown ether dissolved in the IL to enhance Eu^{2+} entrapment was investigated.

The effects of precipitation and calcination characteristics on oxalate derived ThO_2 pellets

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Abstract

Oxalate precipitation remains the reference route for the production of thorium dioxide, but milling is required to achieve good pellet densities with industrially produced powders. In this first part of the thesis we explored precipitation and calcination conditions of this reference route (i.e. oxalate-derived ThO2 powder) and their effect on pressing and sintering while avoiding any milling step. Different precipitation strategies - adding oxalic acid to thorium nitrate ("direct strike"), with and without the application of ultrasound after precipitation and adding thorium nitrate to oxalic acid ("reverse strike") - were compared for ease of production (filtering, crushing) and final characteristics (specific surface area, green pellet density and stability, sintered pellet density). Of these, reverse strike proved superior for production and pellet characteristics and was further optimized by applying different calcination temperatures. It was found that higher calcination temperatures decrease densification during sintering, but increase the green densities that can be achieved after pressing. An optimum calcination temperature is thus intimately linked with the chosen fabrication strategy, i.e. both pressing and sintering are to be taken into account.

Finite element modeling of mechanical properties of tungsten under neutron irradiation

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Abstract

Tungsten and tungsten-based composites are considered as main candidates for plasma-facing material in nuclear fusion reactors ITER and DEMO. The armour material requires high crack-resistance due to envisaged exposure to cyclic heat loads during operation. Hence, the qualification of material is needed, which can be assisted with the help of a finite element (FE) model. The model must be capable to simulate mechanical response of polycrystalline tungsten under tensile testing, accounting for the effect of temperature and irradiation induced defects. Such experiments as tensile tests and measurement of fracture toughness provide constitutive law for the model, and crystal plasticity (CP) models give understanding of texture influence on the deformation behaviour.

So far the work was to develop a macroscopic constitutive law to be applied in FE simulations. The obtained law is based on a Kocks-Mecking type CP model, used in our laboratory. The averaging of stresses and strains over all the possible slip systems was applied in order to obtain the macroscopic constitutive law. The tensile tests of non-irradiated annealed IGP tungsten with equiaxial microstructure served as the data source. Therefore the macroscopic model assumes the material to be isotropic and having no texture; its advantage is the accelerated simulations. However, the simulated and experimental curves diverge as the strain increases above 10%, what can be explained by the presence of hardening mechanisms other than Kocks-Mecking one. For instance, the formation of dislocation cells, acting as low-angle boundaries, impedes the mobile dislocation movement to a greater extent than the forest dislocations. It shows the need for improvement of the model at large strain.

Separation of minor actinides by solvent extraction with [A336][NO_3] ionic liquid-based solvent

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Abstract

The presence of minor actinides in spent nuclear fuel poses a major obstacle for both open and closed fuel cycles. Several long-lived isotopes of Am and Cm are responsible for the main heat production and high radiotoxicity of the nuclear waste. These isotopes make both reprocessing as well as final disposal complicated and costly. In the framework of the Belgian MYRRHA-project, a GenIV prototype accelerator-driven fast reactor is foreseen to be built, in which these long-lived minor actinide isotopes can be efficiently burnt.
If we consider a closed fuel cycle (and thus reprocessing), U and Pu are separated from spent fuel via the so-called PUREX process, leaving a PUREX-raffinate containing the fission products and minor actinides. In order to separate a small amount of trivalent actinide elements from the PUREX-raffinate, several sophisticated methods have been elaborated (TALSPEAK, DIAMEX, SANEX or GANEX, etc.), all of which are based on the use of an aliphatic diluents such as dodecane or kerosene. These diluents however all have common shortcomings, namely they are volatile, flammable and sensitive to radiation-induced degradation that reduces their process lifetime. By the application of are non-volatile and non-flammable and radiation-resistant diluent medium for the minor actinide separation, secondary waste production can be reduced.
[Aliquat-336][NO_3] ionic liquid as diluent and TODGA as extractant ligand was used for the liquid-liquid extraction of lanthanides and actinides from nitric acid solutions. Batch extractions using stabile lanthanide isotopes together with tracers of ^{152}Eu, ^{241}Am and ^{244}Cm isotopes were conducted to determine the distribution ratios, separation factors, and kinetics of the extraction, and also the loading effect on the phase behavior of the ionic liquids. The actinide and lanthanide ions are extracted via a neutral solvation mechanism and fast kinetics with TODGA. From a slope analysis of $\log D_{Am(III)}$ vs. log [TODGA] plot the number of extracting molecules participating in the metal-ligand complex was determined. The possibility of directly separating the chemically similar trivalent actinides from trivalent lanthanides was also studied using actinide-selective soft-donor $CyMe_4$BTPhen and $CyMe_4$BTBP ligands.
These initial experiments are being followed by radiation stability studies on the ionic liquid to simulate realistic extraction circumstances. Degradation effects will be analysed by NMR and ESI-MS studies and in addition, the effect of radiation on the extraction system will be evaluated (effect on distribution ratios and separation factors).