EUROPEAN COMMISSION

Community Research

MATISSE

Materials' Innovations for Safe and Sustainable nuclear in Europe

Support to the development of joint research actions

between national programmes on advanced nuclear materials

FP7-Fission-2013

Combination of Collaborative project (CP) and Coordination and Support Actions (CSA)

Grant agreement no: 604862

Start date: 01/11/2013 Duration: 48 Months

D.1.41

Training and education scheme

MatISSE – Contract Number: 604862

Document title	Training and education scheme
Author(s)	Janne Wallenius
Number of pages	17
Document type	Deliverable
Work Package	1
Document number	1.41
Issued by	KTH
Date of completion	16/11/2017
Dissemination level	Confidential, only for consortium members (including the Commission Services)

Summary

Safe operation of future Generation IV reactors in Europe requires adequate training and education of scientists, engineers, technicians and regulators. Within MatISSE a survey of current programs, courses and training events of relevance for Generation IV system materials and fuels has been undertaken. Gaps in these programs are identified and a training program to address these gaps is proposed, based on intended learning outcome principles and the outcome of workshops held with task participants.

The major component of the training program would be four sessions titled as

- Fabrication of steels for Gen-IV reactors
- Mechanical testing of steels for Gen-IV reactors
- Irradiation testing of steels and ceramics
- Fabrication and recycle of mixed oxide fuels

Each session would be operated by a centre of excellence consisting of a research institute/industrial site providing the adequate experimental equipment and tools, in association with an academic institution responsible for the pedagogical approach and training. A session would last two weeks and contain associated learning activities on modelling. A total of 12 ECTS (European Credit Transfer System) credits would be granted to participating MSc and PhD students.

The eight week program would accommodate 20 students per year and charge a participation fee of 11-12 k€ per student, including accommodation.

The initial cost for developing the programme, and designing building and commissioning the training laboratories, is estimated at 1.0 M€, out of which 700 k€ is for equipment.

Approval

Rev.	Date	First author	WP leader	Project Coordinator
0	10/2017	J. Wallenius, KTH 30/10/2017	A. Bohnstedt, KIT 06/11/2017	P.F. Giroux, CEA 16/11/2017

Distribution list

Name	Organisation	Comments
All beneficiaries	MatISSE	

Table of contents

1 Background

Safe operation of future Generation IV reactors in Europe requires adequate training and education of future scientists, engineers, technicians and regulators. Currently, training programmes on nuclear materials and fuels in academia and elsewhere are fragmented and do not necessarily meet needs of future industrial Generation IV systems. For this purpose, the formulation and implementation of a pan-European Intended Learning Outcome (ILO) based approach is desired.

The training programme here defined is suggested to be based on the CDIO (Conceive, Design, Implement & Operate) approach (www.cdio.org). This approach focuses on providing students with functional skills that are of direct value for addressing the complex problems they will encounter in industry [Crawley 2014]. The CDIO initiative was taken by MIT, KTH and Chalmers to address the increasing disparity between academic research/education and industrial needs that had become evident by the end of the last century. Today, it is an established approach for engineering education in more than 100 technical universities all-over the world. It is compliant with, but goes beyond the recommendation of the European parliament to adopt an ILO-based approach at the highest relevant learning taxonomy levels (see Annex 1).

Thus, the training approach taken in MatISSE is based on the understanding that intended learning outcomes must be possible to classify within the highest level of learning taxonomies, such as the one suggested by Anderson and Krathwohl (see Annex 1). This means that the aim of learning activities should be to acquire abilities to analyse, evaluate and create. Learning activities are to be aligned with these objectives. The innovation adopted by MatISSE to achieve deep learning is a mandatory combination of modelling and experiment in the training package to be defined. Implementing this important innovation is expected to enhance the capabilities of the students to analyse complex phenomena, synthesise experimental data with outcomes of modelling and thereby provide them with unique abilities to create new knowledge.

Moreover, the future training program on nuclear materials and fuels must address the unfortunate practise of using demonstration experiments as a way of teaching in the nuclear engineering field. Active and experiential learning (standard 8 within the CDIO initiative), becomes deeper if hands-on work using facilities, instruments, tools and other equipment is integrated into learning activities [Gonzales Correal 2016]. However, such nuclear engineering facilities may not necessarily be available in every university, or not even in most countries. In particular, access to liquid metal loops for training in materials test procedures and glove boxes for training in MOX fuel fabrication is highly restricted today.

Therefore, this deliverable aims at analysing existing academic curricula and extra-academic training programs in Europe, in order to identify gaps in competence building in nuclear materials and fuels for Generation IV systems. Moreover, a coherent training program is formulated to address the gaps that are identified during the aforementioned analysis. Facilities will be identified where such learning activities can be carried out. In the case such facilities are not available, recommendations for design and construction of such facilities will be made.

We limit this survey to learning activities that are directly focused on materials and fuels for fast neutron Generation IV systems, which many times are distinctly different from those used in LWRs or other thermal reactors. Hence, courses in conventional nuclear reactor materials/fuels and corresponding training sessions are not considered.

Selected Doctoral dissertations on these topics defended in Europe during 2014-2017 are listed in Annex 2.

2 Academic curricula

The academic curricula of European universities providing masters programs in nuclear engineering has been analysed with respect to concurrent use of the CDIO approach (be it explicitly stated or implicit). The conditions for being considered CDIO compliant are:

1) Explicitly stated learning objectives:
   a) Formulated as skills and competences
   b) Classified at highest level of learning taxonomies
2) Learning activities constructively aligned with learning objectives:
   a) Computational assignments, including code writing
   b) Hands-on experimental data taking and analysis
3) Formative examination:
   a) Student presentations
   b) Project report
   c) Oral exam

The curricula that have been analysed by the participants of the task are listed in Table 1. Table 2 displays individual courses in these masters programs that to a *significant part* provide training in science and technology of materials and fuels for Generation IV systems, including fuel cycle aspects.

It may be noted that only five of the programs investigated offer courses that contain elements on nuclear materials and fuels for Generation IV systems. A total of seven courses were identified that offer training on fuels, and four on structural materials. Only one example of an experimental lab project could be found: *actinide chemistry* at the Chalmers hot lab in Göteborg. High level learning objectives, such as ability to select materials and fuels for a Gen-IV reactor was only found in the syllabi of KTH, whereas formative examination has been implemented in all of the concerned universities.

One may note, in particular, that no experimental lab exercises related to the use of Generation IV materials have been implemented in a European university so far. Moreover, no courses containing practical exercises in manufacture of mixed oxide/nitride/carbide fuels were identified. These areas hold a large potential for improvement.

Table 1: Masters programmes in Nuclear Engineering analysed for the present survey.

University	Country	Web site
Universiteit Gent	Belgium	http://studiegids.ugent.be/2014/EN/FACULTY/E/MAMA/ENNUCL/ENNUCL.html
Lappeenranta University of Technology	Finland	http://www.lut.fi/web/en/admissions/masters-studies/msc-in-technology/energy-technology/energy
Czech Technical University	Czech Republic	https://www.fjfi.cvut.cz/en/education/master-s-study/fields-of-master-s-study/ing-nuclear-engineering
Grenoble INP	France	http://www.grenoble-inp.fr/masters-/master-materials-science-for-nuclear-energy-manuen--482457.kjsp#page-presentation
École Central Paris	France	http://www.ecp.fr/lang/en/home/Academics/Masters_program/thematic_field_Master_Nuclear_Energy

University	Country	Web site
École des Mines de Nantes & ENSICAEN	France	http://www.mines-nantes.fr/en/Study/Masters-of-Science-English-taught/SNEAM-NEPIA
Politecnico di Milano	Italy	http://www.polinternational.polimi.it/educational-offer/laurea-magistrale-equivalent-to-master-of-science-programmes/nuclear-engineering/
Università di Pisa	Italy	http://younuclear.ing.unipi.it/faq/faq_display.html
Kaunas University of Technology	Lithuania	http://ktu.edu/en/programme/b/nuclear-energy
Warsaw University of Technology	Poland	http://www.meil.pw.edu.pl/eng/PAE2/Education/Nuclear-Power-Engineering
Universitat politècnica de Catalunya	Spain	https://nuclearengineering.masters.upc.edu/info-general
Universidad politécnica de Madrid	Spain	http://www.etsii.upm.es/estudios/masteres/tecnologia_nuclear.es.htm
Universidad Autónoma de Madrid-CIEMAT	Spain	http://events.ciemat.es/web/mastermina/inicio
Univerza v Ljubljani	Slovenia	http://www.fmf.uni-lj.si/si/studij-fizike/podiplomski-jedrska-tehnika/
Kungliga Tekniska Högskolan	Sweden	https://www.kth.se/en/studies/master/kth/nuclear-energy-engineering/course-overview-1.268630
Chalmers Tekniska Högskola	Sweden	https://student.portal.chalmers.se/en/chalmersstudies/programme-information/Pages/SearchProgram.aspx?program_id=1197&parsergrp=1
ETH & EPFL	Switzerland	http://www.master-nuclear.ch/index
Imperial College	UK	http://www.imperial.ac.uk/engineering/departments/materials/courses/pgt/msc-nuclear/
University of Birmingham	UK	http://www.birmingham.ac.uk/postgraduate/courses/taught/physics/physics-technology-nuclear-reactors.aspx#CourseOverviewTab
Cambridge University	UK	https://www.masterstudies.com/Cambridge-Masters-in-Nuclear-Energy/United-Kingdom/CUED
University of Sheffield	UK	http://www.sheffield.ac.uk/postgraduate/taught/courses/enginee

University	Country	Web site
		ring/material/nuclear-science-technology-msc

Table 2: Courses containing elements of nuclear materials and/or fuels for Gen-IV systems

University	Course	MatiSSE relevance	Learning objectives	Learning activities	Examination
Universiteit Gent	Advanced Courses on the Nuclear Fuel Cycle	MOX and Thorium fuels	Low level	None	Formative: oral exam
École Central Paris	Nuclear spent fuel recycling	Pu and MA recycle and fuel manufacture	Low level	?	?
Kungliga Tekniska Högskolan	Generation IV reactors	Fuels and materials for Gen-IV reactors	High level: Select suitable materials/fuels	Computational home assignments	Formative: Presentations, report, oral exam
Kungliga Tekniska Högskolan	Transmutation of nuclear waste	Fuels and materials for Pu & MA recycle in PWR, FR & ADS	High level: Select suitable materials/fuels	Computational home assignments	Formative : Presentations, report, oral exam
Chalmers Tekniska Högskola	Chemistry of lanthanides, actinides and super-heavy elements	Pu and MA chemistry	Low level	Laboratory project	Summative & Formative
Universidad Autónoma de Madrid-CIEMAT	Transmutation of nuclear waste	Pu and MA fuels, materials		Computational workshop	Formative: Presentation
Universidad Autónoma de Madrid-CIEMAT	Nuclear materials	Materials for Gen-IV reactors		Home assignments	Formative: Presentation, report
Universidad Autónoma de Madrid-CIEMAT	Fuel cycle	Fuels for Gen-IV reactors	Low level	Computational workshop	Formative: Presentation, report

3 Non-academic training schemes

Non-academic training schemes on nuclear materials and fuels for Generation IV systems are provided by research institutes or as part of Euratom framework projects. The latter are training events organised on a frequent base, but are dependent on funding from a particular project. The former are sustainable, in the meaning that the corresponding events are organised by institutes rather than time-limited projects. Table 3 provides a list of European training schemes organised by research institutes, including corresponding learning activities.

Table 3: European Training Schemes

Training scheme	Organiser/ Coordinator	Web site	Learning activities
Nuclear fuel cycle: from strategy to processes	CEA/INSTN	http://www-instn.cea.fr/en/education-and-training/continuing-education/short-courses/international-school-in-nuclear-engineering-nuclear-fuel-cycle-and-reprocessing,1936949.html	Lectures and exercises.
Frederic Joliot/Otto Hahn summer school FJOHSS	CEA/KIT	http://www.fjohss.eu	Lectures.
Heavy metal summer school	SCK-CEN	http://academy.sckcen.be/en/Academic_courses/Calendar/Heavy-Metal-summer-school-2017-20170612-20170616-4f9f015f-92bc-e611-80d5-001dd8b8114f	Lectures, visits to experimental facilities, interactive sessions on best practices and selections of technologies for HLM cooled nuclear systems.
Structrural materials for Generation IV reactors	CIEMAT	http:www.ciemat.es/formacion	Lectures and exercises.

Explicit learning objectives are only provided on the web site of the heavy metal summer school. Most of these objectives may be classified on lower levels. With exception of the FJOHSS, all schemes contain aspects of active learning. None of the schemes provide hands-on training on experimental facilities.

4 Needs for E&T programme on nuclear materials and fuels for Gen-IV systems

4.1 Materials

Within the FP7 ARCADIA project, a list of competences required for implementation of the ALFRED project was prepared [Cizelj 2017]. The conclusion from the study was that among the responding partners, the main gaps were found in lead-coolant chemistry, material sciences and electrical engineering. Whereas the lack of competence within electrical engineering is a generic problem for nuclear industry, it may be noted that the deficiency in the other areas is consistent with the lack of courses in lead-coolant chemistry and materials for Generation IV reactors found in the present investigation of academic curricula in Europe. The training scheme that currently addresses this deficiency is the heavy metal summer school organised by SCK-CEN. Unfortunately the short duration of this school obviously does not allow to go into depth on these complex areas. The ambition of training schemes for nuclear materials needs to be raised in order to meet higher level learning objectives for education of future R&D staff, design/construction engineers, regulators and plant operators.

On the academic side, courses focusing explicitly on Generation IV materials technology are notably absent from current curricula. This may be considered to constitute a serious gap in the competence building for a future Generation IV industry.

4.2 Fuels

Whereas courses providing training on fuels for Generation IV reactors are given in some European universities, learning activities are most often limited to computational exercises. A notable lack of opportunities to train manufacturing procedures for mixed oxide/nitride/carbide fuels in active facilities is observed.

5 Proposal for an E&T programme on nuclear materials and fuels for Gen-IV systems

The implementation of Generation IV system demo units and the subsequent commercialisation of Generation IV technology is likely to be a multi-national venture. Moreover, current training programmes on corresponding materials and fuels technology in academia and elsewhere are fragmented and do not necessarily meet needs of the industrial initiative.

It is suggested to address the above identified deficiencies by an approach including the establishment of centres of excellence for hand on training on experimental, operational and maintenance procedures.

5.1 Centres of excelence

The training on science and technology of materials and fuels for Generation IV systems is preferably implemented as dedicated courses arranged at centres of excellence. Such centres would physically be located at the site of research institutes (or in rarer cases industries/universities) already operating experimental facilities of the kind that would be needed for competence building in the context of ESNII systems.

Examples of such research centres include SCK-CEN, CVR, ENEA, CIEMAT and KIT with a variety of lead-loops and Studsvik and Chalmers, having licenses allowing for students to work hands-on with plutonium. The training facilities, be they existing, or built on purpose for the E&T program, would be managed by the respective host organisation. The training activities are to be led by pedagogically skilled staff from academic organisations associated to the centres of excellence. University students participating in the training program, as part of the final year in their master's or bachelor's education, would receive ECTS credits through these academic organisations. A system for giving life-long-learners from industry ECVET (European Credit System for Vocational Education and Training) credits is to be elaborated.

It is foreseen that such centres could receive students for courses lasting at least two weeks, permitting the students to spend sufficient time on learning activities, to allow for sufficient teacher-student interaction and feedback, and include formative assessment sessions. The pedagogical approach to be taken is discussed further in chapter 5.2.

The operation of the centres could possibly be funded by a combination of European grants and participant fees. The programs and its teachers would be accredited by an international organisation of stakeholders, as elaborated in chapter 5.3. Besides academia and research centres, active participation from industry, regulatory bodies and technical support organisations would be essential for the functionality of this scheme.

5.2 Pedagogical approach and course design

A general consensus in modern approaches to course design is the application of the intended learning outcome (ILO) approach, which is endorsed by the CDIO initiative and recommended by the European parliament to be adopted in European programs for competence building.

Intended learning outcomes are obviously different for different categories of professions, but in the context of building competence for the development, construction, operation and maintenance of complex ESNII systems, the ILO's by necessity should be of higher sophistication. We may exemplify by noting that system designers (obviously) should learn how to design Generation IV reactors with adequate materials and fuels, that operators should be trained in assessing the integrity of materials and fuels during emergency situations, and that maintenance staff need to be able to analyse the state of materials in the reactor. In the same vein, regulators need to be able to judge the processes undertaken by utilities to recruit and train their staff. All these actions are classified at higher levels of learning taxonomies (see Annex 1).

Implementing learning activities constructively aligned with learning objectives improves the likelihood of students meeting expectations. Examples of learning activities that are aligned with high level ILO's for a training course on materials and fuels for Generation IV systems are:

- Possible learning activities to be implemented at the excellence centres may include:
- Fabricate a ferritic-martensitic steel and measure its properties
- Irradiate steel samples with ion beams, measure and analyse the degradation in mechanical properties
- Perform and analyse tensile tests of steel samples carried out under liquid lead
- Manufacture a MOX disc sample, characterise its properties, dissolve the sample and recover the plutonium

The above experimental activities would be combined, in a compulsory fashion, with modelling exercises of phenomena related to each experiment.

Continuous feedback between students, teacher and peers facilitates the learning process, and should be an integrated part of any training scheme. Peer-review of home assignments has proven to be an effective way of improving learning among both authors and peers, and with adequate instructions on how to conduct the review, the quality of the review may become as good as if the teacher does the work.

Formative assessment, such as oral exams, student presentations, debates and seminars, is known to enhance the quality of learning and is already implemented in most European nuclear engineering masters programs. However, it is yet to be established in many non-academic training schemes. In particular, it is strongly recommended to give proper attention to developing adequate modes of formative assessment for the training sessions to be carried out at the excellence centres here proposed.

Table 4 displays the syllabus of an 8 week (12 ECTS) training programme combining hands-on experimental work with computational learning activities hat could be arranged in Europe either during an academic semester period or during a summer session. The suggested hosts (potential centres of excellent sites) for the training programme have been approached by KTH to verify their interest in acting as such. Teachers for modelling activities come from associated academic institutions and would travel to the site for the duration of the course. It is foreseen that 20 students would participate in the programme each year, and that two teachers are required for each session, one for training in experimental methods and one for modelling.

Table 4: Generation IV materials and fuels training programme

Experimental/modelling activity	Host organisation/country	Academic associate
Fabricating an advanced steel/ CALPHAD modelling of metals and alloys	OCAS/Belgium	KTH
Mechanical testing in lead/ DFT modelling of liquid metal embrittlement	CVR	CNRS
Ion irradiation of steels and ceramics/ Modelling of micro-structural evolution under irradiation	HZDR/Germany	KTH
Manufacturing and recycling of MOX fuel sample Modelling of dissolution and separation processes	Studsvik/Sweden	Chalmers

5.3 Programme accreditation

To assure quality and continued relevance, on-going accreditation of the proposed E&T programme is of major importance, and this may be carried out in a variety of ways. It is necessary that teachers and trainers at the excellence centres are qualified and accredited according to the highest pedagogical standards, for which an accreditation system must be established (i.e., either borrowed from ECVET or developed on the basis of shared principles and standards), along with an organisation responsible for it.

In some countries, the accrediting function is performed by government ministries and agencies. Elsewhere it may be handled by professional or learned societies.

A third approach, which is proposed here, is to have accreditation handled by an independent organisation. This organisation could be JPNM (Joint Program on Nuclear Materials) or an industry-governed committee or task force. The former is an existing organisation including a majority of stake-holders from academia and R&D, while the latter might be more appropriate to guarantee that the proposed E&T programme meets the needs and expectations of industry. ENEN (European Nuclear Education network) might be considered as an alternative, but lacks the necessary connection to industry. Moreover, as observed in the survey of E&T within academia, there is very little activity on education and training for Generation IV system materials within European universities, which is the very reason for developing a dedicated training programme.

The accrediting organisation should operate by nominating a peer review committee or commission to evaluate the performance of the accredited faculty/department. The reviewers should have the competence and standing in the field to serve as an objective reviewer. In addition, the accrediting organisation should seek feedback from the faculty/department regarding the reviewers to assure that they are qualified to serve in this role.

5.4 Preliminary cost estimate

It is suggested that the initial costs for developing the training programme and for designing, procuring and commissioning dedicated training equipment are shared by the EC and participating member states, e.g. as a Marie Curie-Sklodowska action. Operating costs should be covered by fees from participants in the training programme. Tables 5 and 6 show cost estimates for development and operation based on known expenses for junior academic staff in Swedish universities (KTH & Chalmers) and estimated laboratory costs at a research institute or industrial nuclear site (Studsvik).

Table 5: Cost estimate for the training programme: Annual operation

Cost item	Unit	Cost/unit	Total cost
Teacher salary cost: 4 sessions	8 pm	8 k€/pm	64 k€
Host lab cost (8 weeks)	320 h	200 €/h	64 k€
Boarding (20 students)	1000 nights	70 €/night	70 k€
JPNM management	2 pm	10 k€/pm	20 k€
Total annual cost			218 k€
Fee per participant	20 students	11.4 k€/student	

The estimated fee for participation is of the order of 1 k€ per ECTS, which is in line with the cost for other advanced training courses in the nuclear engineering field.

Table 6: Cost estimate for developing the training programme

Cost item	Unit	Cost/unit	Total cost
Course design	8 pm	15 k€/pm	120 k€
Lab design & safety analysis	8 pm	15 k€/pm	120 k€
Steel manufacture lab equipment			100 k€
Mechanical test lab equipment			100 k€
Glove box lab equipment			400 k€
Ion irradiation lab equipment			100 k€
Travel for design team	20 flights/nights	500 €/flight/night	10 k€
JPNM management	2 pm	10 k€/pm	20 k€
Total cost			970 k€

Course and lab design cost rates correspond to management level staff at academia and R&D organisations. The costs for lab equipment include licensing and commissioning costs, and remain uncertain at this point.

6 Annexes

Annex 1: Learning taxonomies

Bloom's original taxonomy contained six levels of cognitive skills [Bloom 1956]. It was later extended into a two-dimensional taxonomy including a knowledge dimension [Anderson 2001]. Each co-ordinate in the two-dimensional taxonomy is represented by an action. When applying this taxonomy to formulation of intended learning outcomes an object is connected to each action. For example, a high level learning objective in the MatISSE training programme could be to "Design a fuel cladding for a gas cooled Generation IV reactor". A low level objective would be "Identify materials used in fast neutron Generation IV reactors".

Table A1: Two-dimensional taxonomy of learning objectives [ISU 2017]. Actions are ranked from the top left (higher order) to bottom right (lower order).

Knowledge level ______________ –Cognitive process	Metacognitive	Procedural	Conceptual	Factual
Create	Create	Design	Assemble	Generate
Evaluate	Reflect	Judge	Determine	Check
Analyse	Deconstruct	Integrate	Differentiate	Select
Apply	Use	Carry out	Provide	Respond
Understand	Predict	Clarify	Classify	Summarise
Remember	Identify	Recall	Recognise	List

Annex 2: Doctoral dissertation

Table A2 lists selected PhD dissertations on nuclear materials and fuels for Generation IV systems completed in Europe during the course of the MatISSE project (2014-2017). A link to the published thesis or abstract is provided when available. It may be noted that in France, most PhD theses are carried out in collaboration with CEA, while in Belgium, SCK-CEN provides supervision for most PhD theses.

Table A2: Doctoral dissertation performed during the course of MatISSE project

University	PhD student	Topic/link to thesis	Year
KTH	Zhongwen Chang	Multiscale modelling of radiation-enhanced diffusion phenomena in metals	2015
	Luca Messina	Multiscale modelling of atomic transport phenomena in ferritic steels	2015
	Jesper Ejenstam	Corrosion resistant alumina-forming alloys for lead-cooled fast reactors	2015
	Antoine Claisse	Multiscale modelling of nitride fuels	2016
Chalmers	Marcus Hedberg	Production and Characterization of ZrN and PuN Materials for Nuclear Fuel Applications	2016
Cluj-Napoca	Ancuta Balla	Conversion of sulphuric acid to sulf dioxide	2015
Gent	Alexander Bakaev	Plasticity of Fe-Ni-Cr alloys under irradiation	2014
KU Leuven	Xin Gong	Effects of an LBE environment and hold times on the fatigue properties of austenitic and ferritic-martensitic MYRRHA candidate materials	2015
TU Delft	R. Böhler	High Temperature Phase Transitions of Actinide Dioxides	2014
Aix-Marseille	Tam ngoc Pham thi	Characterization and modelling of the thermodynamic behavior of SFR fuel under irradiation	2014
	Michal Strach	In situ studies of uranium-plutonium mixed oxides : Influence of composition on phase equilibria and thermodynamic properties	2015
Grenoble	Nicholas Sallez	Recrystallization, abnormal grain growth and ultrafine microstructure of ODS ferritic steels	2014
	Romain Vauchy	Study of the O/M ratio in new nuclear fuels based on U,Pu : development and characterization of model materials U1-y PuyO2-x	2014
Lille	Emmanuel Mathe	Radiocontaminant behaviour in the cover-gas space and the containment building of a sodium-cooled fast reactor in accident conditions	2014
	Baptiste Rouxel	Development of advanced austenitic stainless steels resistant to void swelling under irradiation	2016

University	PhD student	Topic/link to thesis	Year
Limoges	Florent Lebreton	Synthesis and characterization of uranium-americium mixed oxides	2014
Lyon	Guillaume Victor	Structural modifications induced in boron carbide B4C by ion irradiation at different energy ranges	2016
Orleans	Gaëlle Raveu	Optimization of uranium carbide fabrication by carbothermic reduction with limited oxygen content	2014
Paris 6	Fatima Hajjaji Rachdi	Modeling of the mechanical behavior of austenitic stainless steels under pure fatigue and fatigue-relaxation loadings	2015
Paris 11	Thomas Schuler	Impact of vacancy-solute clusters on the aging of α-Fe solid solutions	2015
Paris ENSAM	Loys Duquesne	Thermal characterization of SiCf/SiC tubular composite structures for nuclear applications	2015
Paris ENMP	Abdellatif Karch	Study of the microstructure evolution of ferritic stainless ODS steels during hot working	2014
	Fabien Bernachy-Barbé	Characterization of the deformation mechanisms and modelling of the mechanical behaviour under multi-axial loadings of SiC/SiC composite tubes	2014

7 References

Anderson, L. W., & Krathwohl, D. R. (eds.) (2001). A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives. New York: Longman.

Bloom, B., Englehart, M. Furst, E., Hill, W., & Krathwohl, D. (1956). Taxonomy of educational objectives: The classification of educational goals. Handbook I: Cognitive domain. New York, Toronto: Longmans, Green.

L. Cizelj, editor, ARCADIA deliverable D1.2 - Gaps on the Competences for ALFRED Reactor Implementation, JSI, 11/10/2016.

Crawley, E. F., Malmqvist, J., Östlund, S., Brodeur, D. R., Edström, K. (2014). Rethinking Engineering Education: The CDIO approach, 2nd Edition. Springer: New York.

Alejandra María González Correal et al., Active Learning in Electronics Engineering at Pontificia Universidad Javeriana, in Proc. Proceedings of the 12th International CDIO Conference, Turku, Finland, June 12-16 2016.

Iowa State University, Centre for Excellence in Learning and Teaching, http://www.celt.iastate.edu/teaching/effective-teaching-practices/revised-blooms-taxonomy, retrieved 2017-05-19.