Nuclear Science
October 2019

www.oecd-nea.org

Fourth International Workshop on Technology and Components of Accelerator-Driven Systems

Antwerp, Belgium
14–17 October 2019

Programme and
Book of Abstracts

OECD
BETTER POLICIES FOR BETTER LIVES

NEA
NUCLEAR ENERGY AGENCY

Fourth International Workshop on Technology and Components of Accelerator-Driven Systems

Antwerp, Belgium

14-17 October 2019

Programme and Book of Abstracts

NUCLEAR ENERGY AGENCY

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

The OECD is a unique forum where the governments of 36 democracies work together to address the economic, social and environmental challenges of globalisation. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The Organisation provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

The OECD member countries are: Australia, Austria, Belgium, Canada, Chile, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission takes part in the work of the OECD.

OECD Publishing disseminates widely the results of the Organisation's statistics gathering and research on economic, social and environmental issues, as well as the conventions, guidelines and standards agreed by its members.

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1 February 1958. Current NEA membership consists of 33 countries: Argentina, Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, Norway, Poland, Portugal, Romania, Russia, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission also takes part in the work of the Agency.

The mission of the NEA is:

- to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally sound and economical use of nuclear energy for peaceful purposes;
- to provide authoritative assessments and to forge common understandings on key issues as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development of low-carbon economies.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

Contents

Programme

Monday 14 October 2019		
08:00	09:00	Registration
09:00	09:10	**Welcome address from SCK•CEN** G. Van den Eynde
09:10	09:20	**Welcome address from NEA** S. Cornet

SESSION 1: International and National Programmes
Chairs: S. Cornet & M. Tarantino

09:20	09:50	**The current status of the MYRRHA Project** G. Van den Eynde (SCK•CEN, Belgium)
09:50	10:20	**ADS activities in China 2019** W. Zhan (CAS, China)
10:20	10:50	**ADS activities of the International Thorium Energy Committee** M. Bourquin (iThEC, Switzerland)
10:50	11:20	**The current R&D status in JAEA** K. Tsujimoto (JAEA, Japan)
11:20	11:40	*Coffee*
11:40	12:10	**An R&D programme for accelerator-based transmutation system for LLFP** H. Sakurai (Riken, Japan)
12:10	12:40	**Lessons learned from designing, constructing and commissioning KIPT ADS facility** Y. Gohar (ANL, US)
12:40	13:10	**Development of molten lead-bismuth as a target material for accelerator-driven systems at Los Alamos** K. Woloshun (LANL, US)
13:10	14:10	*Lunch*

SESSION 2: ADS Accelerators Systems
Chairs: A. Mueller & Y. Celik

14:10	14:30	**The MYRRHA Phase 1 accelerator: design and integrated prototyping** D. Vandeplassche (SCK•CEN, Belgium)
14:30	14:50	**The MYRRHA superconducting LINAC: Fault-tolerant design and developments** F. Bouly (CNRS, France)
14:50	15:10	**MYRRHA LEBT recommissioning and high speed modelling with neural networks** M. Debongnie (CNRS, France)
15:10	15:30	**Cryogenic system for the SC LINAC MINERVA Project (MYRRHA phase 1)** O. Kochebina (Accelerators and Cryogenic Systems, France)
15:30	15:50	**17 MeV MYRRHA beam dump design** D. Lamberts (SCK•CEN, Belgium), on behalf of Yurdunaz Celik
15:50	16:10	*Coffee*
16:10	16:30	**Stability and reliability study on the China ADS front-end superconducting demo LINAC (CAFe)** Y. He (CAS, China)
16:30	16:50	**Operating status of the RF cavities in the J-PARC LINAC** T. Morishita (JAEA, Japan)
16:50	17:10	**Almost everything about backward wave acceleration (Third method of particles linear acceleration)** A. Bogomolov (IPPE, Russia)
17:10	17:30	Coffee

SESSION 3: Neutron Sources
Chairs: L. Popescu & Y. Gohar

17:30	17:50	**J-PARC LBE Spallation target for ADS development** T. Sasa (JAEA, Japan)
17:50	18:10	**The proton target facility to be constructed in the first phase of MYRRHA** L.-A. Popescu (SCK•CEN, Belgium)
18:10	18:30	**Accelerator and target for transmutation of long-lived fission products of nuclear waste** H. Okuno (Riken, Japan)

Tuesday 15 October 2019

SESSION 4: Design and Technology of Subcritical Systems
Session 4a Design
Chairs: K. Van Tichelen & A. Rineiski

09:00	09:20	**The preliminary conceptual design for the subcritical reactor of China initiative accelerator driven** L. Gu (IMPCAS, China)
09:20	09:40	**Leak-Before-Break (LBB) Design for Accelerator-Driven Systems (ADS) Steam Generators** J. Lee (UNIST, Korea)
09:40	10:00	**Analysis of MYRRHA 600 MeV Proton Beam Line shielding** A. Stankovskiy (SCK•CEN, Belgium) on behalf of Yurdunaz Celik
10:00	10:20	*Coffee*

Session 4b R&D
Chairs: T. Sasa & N. Watanabe

10:20	10:40	**Overview of research on LBE corrosion and oxygen control technique in IMP** C. Yao (IMPCAS, China)
10:40	11:00	**The LBE coolant chemistry R&D programme for the MYRRHA ADS** A. Aerts (SCK•CEN, Belgium)
11:00	11:20	**Oxygen transfer and oxidation of LBE at the LBE-cover gas interface** K. Rosseel (SCK•CEN, Belgium)
11:20	11:40	**Release and deposition of volatile radionuclides in lead-bismuth cooled ADS** J. Neuhausen (PSI, Switzerland)
11:40	12:00	**Development of analysis code for spallation products behaviour in LBE coolant system in ADS** S. Miyahara (Uni. of Fukui, Japan)
12:00	12:20	**Nuclear data production system in RAON** S.-W. Hong (Sungkyunkwan Uni., Korea)
12:20	13:20	*Lunch*

Session 4b: R&D
Chairs: T. Sasa & N. Watanabe

13:20	13:40	**Experimental activities on liquid-metal thermal hydraulics at SCK•CEN in support of MYRRHA** K. Van Tichelen (SCK•CEN, Belgium)
13:40	14:00	**Fuel bundle experimental characterisation in heavy liquid metal** M. Tarantino (ENEA, Italy)

14:00	14:20	**RELAP5 simulations of the CIRCE-HERO facility for PLOFA scenarios** F. Galleni (Uni. Pisa, Italy)
14:20	14:40	**Multiscale simulation of the CIRCE-HERO facility by a STH/CFD coupling tool** D. Martelli (ENEA, Italy)
14:40	15:00	**HERO - Steam generator bayonet tube experimental validation in CIRCE Facility** M. Tarantino (ENEA, Italy), on behalf of Pierdomenico Lorusso
15:00	15:20	*Coffee*
15:20	15:40	**Numerical thermal-hydraulic simulation of LBE target mock-up loop "IMMORTAL" by using RELAP5-3D** N. Watanabe (JAEA, Japan)
15:40	16:00	**Mechanical properties of austenitic and martensitic steels in contact with liquid lead and LBE** I. Proriol Serre (Uni. Lille, UMET, France)

SESSION 5: Current ADS Experiments
Chairs: Y. He & O. Kochebina

16:00	16:20	**Study on applicability of subcriticality measurement method to LBE cooled accelerator-driven system** R. Katano (JAEA, Japan)
16:20	16:40	**Interpretation of reactivity measurements performed for some subcritical configurations at KUCA** V. Fabrizio (ENEA, Italy), on behalf of Mario Carta
16:40	17:00	**LBE spallation target handling technologies in JAEA** H. Obayashi (JAEA, Japan)
19:00		Workshop Dinner (12th Floor Lindner Hotel)

Wednesday 16 October 2019

SESSION 5: Current ADS Experiments
Chairs: Y. He & O. Kochebina

09:00	09:20	**Validation of subcriticality monitoring techniques for the MYRRHA ADS** A. Kotchetkov (SCK•CEN, Belgium)
09:20	09:40	**Beam interruption experiments in a deep subcritical ADS within the MYRACL Programme** J.-L. Lecouey (ENSICAEN/LPC Caen, France)
09:40	10:00	**Experimental verification of the threshold spectral index measurement as a relative method for k_{eff} monitoring in a fast subcritical reactor** A. Krasa (SCK•CEN, Belgium)

10:00	10:20	**Neutron noise experiments in a lead-bismuth core within the MYRTE project** V. Becares-Palacios (CIEMAT, Spain)
10:20	10:40	*Coffee*
		SESSION 6: ADS Data and Simulations **Chairs: G. Van den Eynde & I. Proriol-Serre**
10:40	11:00	**3-D simulation of fuel assembly blockage in MYRRHA** X.-N. Chen (KIT, Germany)
11:00	11:20	**A control oriented model for the simulation of the accelerator-driven systems** S. Lorenzi (POLIMI, Italy)
11:20	11:40	**PSi project for accelerator-driven systems** K. Nishihara (JAEA, Japan)
11:40	12:00	**Exploration and quantification of the main differences on ADS nuclear fuel cycle simulators** A. Hernandez-Solis (SCK•CEN, Belgium)
12:00	12:20	**Calculating swing reactivity of accelerator-driven systems (ADS) subcritical reactor** S. Sudarmono (BATAN, Indonesia)
12:00	13:00	*Lunch*
		SESSION 6: ADS Data and Simulations **Chairs: G. Van den Eynde & I. Proriol-Serre**
13:00	13:20	**Development of nuclear data for performance assessment and safety analysis of MYRRHA** A. Plompen (JRC, EU) on behalf of Peter Schillebeeckx
13:20	13:40	**Investigation of nuclear data accuracy for commercial grade accelerator-driven system to transmute minor actinides** T. Sugawara (JAEA, Japan)
13:40	14:00	**Cross-section measurements for LLFP nuclei at RIBF** H. Otsu (Riken, Japan)
14:00	14:20	**Measurement of displacement cross-section and residual nuclide cross-section by spallation reaction** S.-I. Meigo (JAEA, Japan)
14:20	14:40	**Neutronic characterisation of a TRIGA reactor in a subcritical configuration** F. Panza (ENEA, Italy)

14:40	15:00	*Coffee*
		Summary Session
15:00	15:30	Summary by sessions chairs
15:30	15:45	Summary **K. Tsujimoto**

Thursday 17 October 2019

Tour of SCK•CEN facilities

Session 1: International and National Programmes

ADS activities in China in 2019

W. Zhan et al.
Institute of Modern Physics, Chinese Academy of Sciences, China

Abstract

The Chinese Initial Accelerator Driven System (CIADS) is designed as a 10 MW system, which consists of ~500 MeV & 5 mA super-conductor linear (SCL), >2.5 MW spallation target and subcritical blanket. It was assessed in 2018 and the project will start in HuiZhou of Chana in 2019.

The key R&D components of CIADS had been performed intensively in last 7 years. The prototype of SCL injector had been extracted with CW Beam at >25MeV&0.25mA before the end of 2017. Then, the beam was performed at >16 MeV&2mA for 100 hr with CW beam and reached more than 89%. It is planned to reach 100 kW CW beam after updating the shielding. The granular target, coolant test benches and GPU supercomputing design subsystem passed the evaluation tests over the last years. The civil intrastation of CIADS stared last year.

The proposal of the massive medical isotopes production based on ADS will result in a more efficient application of ADS.

ADS activities of the International Thorium Energy Committee

M. Bourquin[a] and S. Sidorkin[b]
[a]International Thorium Energy Committee, Switzerland
[b]Institute for Nuclear Research, Russian Academy of Sciences, Russia

Abstract

Nuclear fission is the only present-day zero-carbon technology with the demonstrated ability to meet most of the energy demands of a modern economy and achieve significant climate mitigation. However, a variety of social, economic, and institutional challenges make substantial deployment unlikely. The international Thorium Energy Committee supports the development of a new generation of nuclear technologies that are safer, cheaper, and could responsibly manage the large amount of spent nuclear matter. The proposed design of an accelerator-driven system with thorium fuel includes a proton cyclotron, a lead-bismuth liquid target and a lead-cooled fast neutron subcritical core. The implementation of this scheme includes simulations, a series of experimental tests to be performed at the Institute for Nuclear Research of the Russian Academy of Sciences in Moscow, making use of an existing facility, and a search for private investment for developing a system demonstrator in view of industrialisation.

The current R&D status in JAEA

K. Tsujimoto
Japan Atomic Energy Agency, Japan

Abstract

The Government of Japan periodically formulates the Basic Energy Plan in accordance with an article in the Basic Act on Energy Policy that entered into force in 2002. The latest version, called the Strategic Energy Plan, was issued in July 2018. The Plan focuses on the importance of activities to resolve the challenge of how to manage and dispose of spent fuel, as well as the previous version issued in 2014. As for the P&T technology, the Government will promote technology development on volume reduction and mitigation of degree of harmfulness of radioactive waste. Specifically, development of technologies for decreasing the radiation dose remaining in radioactive waste over a long period of time and enhancing the safety of processing and disposal of radioactive waste, including nuclear transmutation technology using fast reactors and accelerators, will be promoted by utilising global networks for co-operation.

Based on this new Strategic Energy Plan, research and development (R&D) on P&T are being accelerated in Japan. The Japan Atomic Energy Agency (JAEA) has been continuously implementing R&D on P&T technology to reduce the burden of the backend of the nuclear fuel cycle. The R&D on P&T in JAEA are based on two kinds of concepts: one is the homogeneous recycling of minor actinide (MA) in fast reactors and the other is the dedicated MA transmutation, the so-called “double-strata” strategy, using an accelerator-driven system (ADS). This work presents recent R&D activities based on these policies.

An R&D programme for accelerator-based transmutation system for LLFP

H. Sakurai
RIKEN Nishina Center for Accelerator-Based Science, Japan

Abstract

This paper gives an overview of the R&D programme for accelerator-based transmutation system for LLFP in Japan, entitled "Reduction and Resource Recycling of High-level Radioactive Wastes through Nuclear Transmutation" [1]. In 2014, the programme was approved within the framework of ImPACT R&D budget organised by the government and was completed in March 2019.

In parallel to the JAEA ADS programme for minor actinides, the ImPACT programme was dedicated to P&T developments for long-lived fission products and was organised by researchers in domestic universities, institutes and industries. The programme consists of several R&D projects, and many new achievements were made.

Special focus has been placed on R&D activities for the transmutation system as a strong neutron source in terms of nuclear reaction data and accelerator and target developments for intense beams. This paper presents the guiding principles of the programme, the concepts in designing the transmutation system and R&D highlights. The future of the P&T activities will also be discussed.

This work was funded by ImPACT Programme of Council for Science, Technology and Innovation (Cabinet Office, Government of Japan).

Reference

[1] http://www.jst.go.jp/impact/en/program/08.html.

Lessons learned from designing, constructing, and commissioning KIPT ADS facility

Yo. Gohar
Argonne National Laboratory, US

Abstract

Argonne National Laboratory (ANL) of US and Kharkiv Institute of Physics & Technology (KIPT) of Ukraine have been collaborating on designing, constructing, and operating an accelerator-driven system (ADS) supported by the Russian Research Reactor Fuel Return (RRRFR) programme of the United States Department of Energy. This ADS facility uses a low-enriched uranium fuel and it is driven with an electron accelerator. The target design was optimised to maximise the neutron yield from the interaction of the 100 KW-100 MeV electron beam with the tungsten or the natural uranium material. The subcritical assembly design was also optimised to maximise the neutron flux intensity with an effective neutron multiplication factor of <0.98 and provide passive safety features. Biological dose analyses defined the required facility shielding for normal and abnormal operating conditions. Safety, reliability, and environmental considerations defined the facility design details. In addition, it has unique features relative to the other ADS facilities and it is suitable for studying accelerator-driven systems. Several horizontal neutron channels for performing basic research including cold neutron source are built in. The facility is designed to produce medical isotopes, train young nuclear professionals, support the Ukraine nuclear industry, and provide capability for performing reactor physics, material research, and basic science experiments. This presentation highlights the lessons learned from designing, constructing, and commissioning the facility and the facility safety features.

Development of molten lead-bismuth as a target material for accelerator-driven systems at Los Alamos National Laboratory

K. Woloshun*
Los Alamos National Laboratory, US

Abstract

Los Alamos National Laboratory (LANL) began consideration of lead or lead-bismuth as an accelerator target material in 1994 for the ADTT (Accelerator Driven Transmutation Technology) project, one of several investigations into transmutation of nuclear waste technology development. Following that, an ISTC project between LANL and IPPE in Obninsk, Russia, designed and built a LBE target specifically for the high current test area at LANSCE. This MW sized target was tested out of beam but never saw the intended proton irradiation. The LBE material test loop, DELTA, was then built at LANL. Commissioned in 2001, DELTA was in service until 2016. Materials were tested at up to 550°C and at velocities up to 3.5 m/s in an oxygen controlled environment. At that time, LANL was an active partner in the MEGAPIE project, the only LBE target to operate in beam. The neutronics performance of MEGAPIE was even better than predicted. Later, the Materials Test Station (MTS) project at LANL intended to use LBE not as the target but as a coolant for a tungsten target. This allowed for high temperature operation and higher heat transfer rate than possible with gas. Most recently, LANL is supporting technology development at the Niowave corporation using LBE to convert electron beam to fast flux neutrons for materials testing. This project is developing a windowless target configuration. This paper presents the LANL development of LBE over the past 25 years.

.

Session 2: ADS Accelerator Systems

The MYRRHA Phase 1 accelerator: Design and integrated prototyping

D. Vandeplassche[a], J. Belmans[a], F. Pompon[a], F. Davin[a], W. De Cock[a], A. Ponton[a], A. Gatera[a], P. Della Faille[a], F. Douce [a], F. Bouly[b], D. Bondoux[b], Y. Gomez[b], C. Joly[c], G. Olry[c], H. Saugnac[c], H. Podlech[d], U. Ratzinger [d]
[a]SCK•CEN, Belgium
[b]LPSC, Université Grenoble-Alpes, CNRS/IN2P3, France
[c]IPNO, CNRS/IN2P3, Université Paris-Sud, France
[d]IAP, Goethe Universität, Germany

Abstract

The MYRRHA project by SCK•CEN, Mol, is approached in a phased manner: a first phase will consist of a 100 MeV, 4 mA CW proton LINAC feeding in parallel an ISOL-type installation and a target dedicated to studies for fusion materials. The 100 MeV LINAC consists of a 4-rod RFQ, a 17 MeV normal conducting injector followed by a superconducting section made of 60 identical single spoke cavities.

The principal aim of the 100 MeV LINAC project is to demonstrate a fault tolerance capability of the design, which is in accordance with the MYRRHA goals, and especially the beam-MTBF of 250 hours. This paper highlights the most relevant reliability related items of the accelerator, as well as the integrated prototyping activities that support its design. The commissioning results of the LEBT and of the RFQ will also be reported.

The MYRRHA superconducting LINAC: fault-tolerant design and developments

F. Bouly*[a], N. Gandolfo [b], C. JOLY [b], L.Perrot[b], H. Saugnac[b],
D. Uriot[c], A. Gatera[d], D. Vandeplassche[d], M. Dominiczak[e]
[a]LPSC, Université Grenoble-Alpes, CNRS/IN2P3, France
[b]IPN Orsay, CNRS/IN2P3, Orsay, France
[c]CEA-Saclay DSM/IRFU, Gif-sur-Yvette, France
[d]SCK•CEN, Mol, Belgium
[e]Accelerators and Cryogenic Systems, Orsay, France

Abstract

The MYRRHA facility requires a 600 MeV accelerator delivering a maximum proton current of 4 mA in a continuous wave operation. Driven by SCK•CEN and supported by the Belgium Government, the phase I (MINERVA) of the project consists of the construction of the accelerator first part, up to 100 MeV. Such a continuous wave beam will be delivered by a superconducting LINAC, which must fulfill very stringent reliability requirements to ensure the safe ADS operation with a high-level availability. For this purpose, the accelerator design is based on a redundant and fault-tolerant scheme to enable rapid failures mitigations.

The design updates of the superconducting LINAC, at 100 MeV (Phase I) and 600 MeV (ADS operation) will be exposed and discussed. Then beam dynamics studies on the fault tolerance capability of the MYRRHA superconducting LINAC will be presented. The results will be focussed on cavity failure compensation scenarios. The impact on the R&D − especially for the Spoke 352 MHz cryomodule − to enable fast retuning procedures will also be discussed.

MYRRHA LEBT recommissioning and high speed modelling with neural networks

M. Debongnie*[a,b], F. Bouly[a], T. Junquera[b], D. Vandeplassche[c]
[a]LPSC, Université Grenoble-Alpes, CNRS/IN2P3France
[b]Accelerators and Cryogenic Systems, Orsay, France
[c]SCK•CEN, Mol, Belgium

Abstract

The MYRRHA facility requires a 600 MeV accelerator delivering a maximum proton current of 4 mA in a continuous wave operation. Driven by SCK•CEN and supported by the Belgian Government, the phase I (MINERVA) of the project consists of the construction of the accelerator first part, up to 100 MeV. The Low Energy Beam Transport (LEBT) section of the LINAC has been recently rebuilt at the Université Catholique de Louvain in Louvain-la-Neuve, Belgium, after its transport from the Laboratoire de Physique Subatomique et de Cosmologie in Grenoble, France. The role of LEBT is to extract and shape the proton beam from an ion source in order to ensure a good injection into a radio-frequency quadrupole, the first accelerating and bunching element of the MYRRHA injector.

The recommissioning of the LEBT will be exposed. Then, the training of a high-speed model of the LEBT using artificial neural networks and machine learning will be discussed. Finally, the training of potential "on-line tuner" neural networks using the aforementioned model will be examined.

Cryogenic system for the SC LINAC MINERVA Project (MYRRHA phase 1)

O. Kochebina*[a], T. Junquera[a], F. Dieudegard[a] and D. Vandeplassche[b] *
olga.kochebina@acsfrance.com
[a]Accelerators and Cryogenic Systems, France
[b]SCK•CEN, Mol, Belgium

Abstract

The MYRRHA project aims to construct an accelerator-driven system (ADS) demonstrator for the transmutation of long-lived radioactive waste. It will include a subcritical reactor of 100 MW thermal power and a Continuous Wave (CW) proton LINAC accelerator with superconducting (SC) cavities. It will provide a 600 MeV proton beam of 4 mA intensity that will hit a spallation target in order to obtain neutrons to feed the reactor. The main challenge of this LINAC is an extremely high reliability performance to limit stresses and long restart procedures of the reactor. Indeed, beam interruptions could cause high-thermal stresses and fatigue on the reactor structures.

The first phase of the MYRRHA project includes the construction of a SC LINAC proton accelerator with a final energy of 100 MeV: the MINERVA SC LINAC. It will be composed of 30 cryomodules housing 60 single-spoke SC cavities. The cavities will operate at 352 MHz in a superfluid helium bath at 2 K. One major goal of the MINERVA project is to test the reliability of such a LINAC, and the operational results with a Cryogenic System are essential to check the technical feasibility of SC LINAC accelerators for ADS applications. This article presents the preliminary studies in this subject including the analysis of high-thermal loads induced by the CW mode operation of cavities (950 W@2K for 30 cryomodules). A cryogenic refrigerator with an equivalent power capacity of 2645 W @4.5 K (3970 W with 1.5 overcapacity factor) is proposed. The constraints for the He distribution in the LINAC tunnel are also discussed.

17 MeV MYYRHA beam dump design

Y. Çelik*, D. Lamberts, G. Van den Eynde and G. Vittiglio
SCK•CEN, Belgium

Abstract

The initial part of the MYRRHA accelerator consists of two ion sources, both of them followed by a separate beam line up to the proton energy of 17 MeV. A beam dump is required for each. The planned peak power at this stage is 70 kW. The beam dump receives a proton beam current intensity of 4 mA and safely convert the energy into heat evacuated in the water cooling. The conceptual design of the beam dump consists of a series of aluminium disks welded in a cone-like shape (≈300 mm in length and an opening of Ø150 mm). The design can reasonably minimise the waste mass and activity. Dump robustness and ease of operation are also considered. In order to provide safe and efficient operation including cooling conditions for the maintenance, prompt and residual dose rates, radioactivity of the beam dump materials and shielding were calculated with MCNPX Monte Carlo code and ALEPH2 depletion code.

Stability and reliability study on the China ADS front-end superconducting demo LINAC (CAFe)

Y. He, T. Jiang, Z. Gao, W. Yue, R. Huang, Z. Wang, G. Zhang,
S. Zhang, X. Liu, W. Chen, Z. Zhou, J. Wu, L. Sun
Institute of Modern Physics, Chinese Academy of Sciences, China

Abstract

The Chinese Initiative Accelerator Driven System (CiADS) has been approved and will start in 2019. A demo project to build injectors started in 2011. This project was used to demonstrate the SRF technology in low-energy session and investigate the feasibility and the reliability for the CiADS. The project named CAFe (the Chines ADS Front-end superconducting demo LINAC) is a 10-mA continuous-wave (CW) proton beam in low-energy superconducting accelerator structure for accelerator-driven system. It operated the first 25 MeV beam in June 2017. Recently, the 2 mA, 16 MeV CW beam has been achieved and operated more than 110 hours. During the operation, the availability was 89%, the MTBF was 99 min, and the MTTR was 12 min. All the sources of trips are traced and two main reasons caused the frequent trips are analysed. The field emission in the superconducting HWR cavity led to discharging in the pick-up and the further the open the loop of RF control. It is a special phenomenon in the compact coaxial superconducting resonators. The experiments show the relations between the field strength and the trips. The frequency and phase shift due to beam loading is another main reason for trips and will exit the pondermotive oscillation.

Operating status of the RF cavities in the J-PARC LINAC

T. Morishita[a*], J. Tamura[a], Y. Kondo[a], K. Hirano[a], T. Ito[a], H. Oguri[a], K. Nanmo[b], T. Sugimura[b], F. Naito[b], and K. Hasegawa[a]
[a]Japan Atomic Energy Agency (JAEA), Japan
[b]High Energy Accelerator Research Organization (KEK), Japan

Abstract

The J-PARC accelerator comprises an injector LINAC, a 3 GeV Rapid-Cycling Synchrotron (RCS) and a main ring synchrotron. Accelerator components in the LINAC contain a negative hydrogen ion source, a radio-frequency quadrupole (RFQ) LINAC, drift tube LINACs (DTLs), separated-type DTLs, and annular-ring coupled structure (ACS) LINACs. The beam commissioning started in November 2006 and beam delivery to the users started in 2009. The ACS cavities were installed to increase the energy to the original design of 400 MeV. The new front-end (ion source, RFQ, and chopping system) was installed in 2014 to increase the peak beam current from 30 to 50 mA. Currently, a peak current of 50-mA beam is delivered to the RCS with a beam pulse width of 0.27 ms for neutron and muon experiments and 0.1 ms for particle and nuclear experiments with the repetition of 25 Hz. This paper presents the progress and the operating stability of the RF cavities and measures to maintain the performance.

Almost everything about backward wave acceleration (third method of charged particles linear acceleration)

A. S. Bogomolov*[a], T. S. Bakirov[b]
*[a]retired from JSC "SSC RF - IPPE", Russia
[b]Energozapas, Russia

Abstract

Focus has been paced on the demonstration of potential opportunities that could be achieved with the method of backward wave linear acceleration of charged particles (ions), as well as computer simulation results of LINACs layouts and their parameters for optional industrial applications. The results of developing acceleration method with Ez-component of the backward spatial harmonic of the flux of the electromagnetic field, propagating towards the accelerated particles with a current of I_{imp}= 300 mA in the Backward Wave Linear Accelerators of Protons (BWLAP) were summarised in some publications in Russian journals in 2012, and in the Japan proceedings (TCADS3, Mito, Japan, 2016). This paper presents the results of computer simulation of the BWLAP LINAC with I_{imp} = 1200 mA on accelerating structures (AS) with negative dispersion (modified interdigital structures) at room temperature, and with removal of RF heat losses in the AS by the water flow (T~ 300K). The calculated values of the electronic efficiency of the AS - η_e > 92%, and the overall efficiency of the accelerator (complex) - η_Σ > 40% (f_{RF} =1300 MHz), as well as no particle losses and compact design. The expected cost of the compact 1 GeV "warm" BWLAP (BTW) LINAC with a proton beam average power of 30 MW could be about $150M.

Session 3: Neutron Sources

J-PARC LBE spallation target for ADS development

T. Sasa*[a], S. Saito[a], H. Obayashi[a], G. Ariyoshi[a], T. Wan[a],
N. Okubo[a], N. Odaira[b], K. Yamaki[a], S. Kita[a] and H. Yoshimoto[a]
[a]J-PARC Center, Japan Atomic Energy Agency, (JAEA) Japan
[b]Research Institute of Nuclear Engineering, University of Fukui, Japan

Abstract

Japan Atomic Energy Agency (JAEA) proposes reducing minor actinides by partitioning and transmutation technology using accelerator-driven system (ADS). To realise ADS, JAEA plans to locate lead-bismuth eutectic alloy (LBE) spallation target within the framework of J-PARC project. For the JAEA-proposed ADS, LBE is adopted as both a coolant for subcritical core and a spallation target. J-PARC LBE spallation target will be used to solve technical issues for ADS design by preparing irradiation database. The target will locate at the end of LINAC and share the proton beam with other existing experimental facilities in J-PARC. The repetition of proton beam will be doubled up to 50 Hz, then the 400 MeV-250 kW proton beam can be used for ADS studies with no power degradation to other facilities. Various applications of the irradiation facility are planned such as fission/fusion/spallation materials irradiation, semiconductor development and highly reliable accelerator systems development. The hot cells to prepare the samples for post-irradiation examination are also planned in the same building for efficient irradiation data preparation. The spallation target is optimised by thermal-hydraulic analysis and structural analysis to increase proton/neutron irradiation of ADS materials by sharply focused proton beam injection. The studies for elemental technologies such as a fully-remote target exchange procedure and freeze-sealed drain valve system are also performed and integrated into the design of LBE target. This paper presents the latest design of the J-PARC LBE spallation target system.

The proton target facility to be constructed in the first phase of MYRRHA

L. Popescu
SCK•CEN, Belgium

Abstract

The production of high-purity radioactive ion beams (RIB) through the isotope separation online (ISOL) method makes possible unique research programmes in several fields of science. The demand for beam time continues to be high, while the study of more and more exotic isotopes, difficult to produce in sufficient quantities, is of primary interest for many of the currently defined research projects. At the same time, the growing interest from the medical field cannot pass unnoticed, the ISOL technique giving access to the most innovative medical isotopes, with extremely high specific activity. Increasing the RIBs intensity is therefore of primary interest, and it is carefully addressed through several R&D programmes worldwide. ISOL targets implemented at accelerator facilities can be operated through direct-proton irradiation or in converter-mode. In the latter case, the particle beam is shot on a spallation target for the production of neutrons which, in turn, irradiate an ISOL target. This results in a more selective production of particular isotopes of high interest for the ISOL physics community.

The development of the accelerator-driven system MYRRHA, at SCK•CEN, allowed elaborating the idea of a high-power ISOL facility capable to operate in parallel to the accelerator-driven system (ADS) and making use of the same proton accelerator. In the operation scheme, about 5% of the CW proton beam of the 600-MeV 4-mA LINAC would be diverted towards the ISOL@MYRRHA facility with a frequency up to 250 Hz.

A phased implementation of the MYRRHA project was decided in 2015. Phase 1 involves the construction of the first part of the LINAC, providing 100 MeV proton beams to a Proton Target Facility (PTF) and a high-power beam dump used for testing the requested high reliability of the accelerator. After a detailed analysis of potential applications of the 100-MeV proton beam, ISOL@MYRRHA was selected to be implemented at PTF. In phase 1, this will be a major user of the up to 4-mA proton beam and the ISOL technology will be pushed to the maximum power level achievable. The R&D programme, which started already in 2016, encompasses both the development of the technical-design solutions for the future facility and the implementation of a physics-research programme available at 100 MeV.

The presentation provides information on the project and the ISOL-facility. The special case of ISOL targets operated in converter mode will be also addressed.

Accelerator and target for transmutation of long-lived fission products of nuclear waste

H. Okuno*[a], H. Sakurai[a] and Y. Mori[b]
[a]RIKEN, Nishina Center for Accelerator-based Science, Japan
[b]Institute for Integrated Radiation and Nuclear Science, Kyoto University, Japan

Abstract

Accelerator and target for transmutation of long-lived fission products of nuclear waste were conceptually designed.

A linear accelerator was designed, which consists of single-cell cavities with magnetic elements, in order to accept a 1 A beam with a large bore. The single-cell LINAC has the following advantages for acceleration of high-intensity beams:

- low-frequency RF cavities with a large bore can be used to mitigate strong space charge forces;
- number of couplers for the RF input per cavity can be significantly reduced to two or three;
- voltage and phase can be independently selected to compensate for the space charge effects.

The conceptual design of the target has adopted a “tornado” type structure using liquid metal, to enhance irradiation area without losing its compactness to transmute the LLFPs efficiently. This structure can also avoid boiling of liquid metal in the heated area by high power beam due to centrifugal forces.

Acknowledgements

This work was supported and funded by ImPACT Programme of Council for Science, Technology, and Innovation (Cabinet Office, Government of Japan).

Session 4: Design and Technology of Subcritical Systems

Session 4a: Design

The preliminary conceptual design for the subcritical reactor of China Initiative Accelerator-driven System Project

G. Long*[a,b], L.-J.-Yang[a,b] , W.-D.-Wei[a,b], P. T.-Ji[a,b] and Z. Lu[a,b]
[a]Institute of Modern Physics, Chinese Academy of Sciences, China
[b]School of Nuclear Science and Technology, University of Chinese Academy of Sciences, China

Abstract

The Chinese Government has already approved the China Initiative Accelerator-driven System (CiADS) Project, which will construct the first prototype of ADS facility in China to demonstrate the minor actinides transmutation principle from the viewpoint of industrial scale. This paper gives an overview of the technical roadmap for the CiADS project. There are two steps to achieve the final goal of the CiADS project. The first step will be to establish a smaller MW scale prototype ADS facility to test and verify the key technology for subcritical reactors. The second step will be to construct a 10 MW scale facility. Within the CiADS project lead-bismuth eutectic has been chosen as a coolant for subcritical reactors. High-level subcriticality has been chosen in this design to receive permissions in an easier way from the national nuclear safety agency. This paper presents the design of subcritical reactors within the CiADS project.

Leak-before-break (LBB) design for accelerator-driven systems (ADS) steam generators

J. Lee*, J. H. Kim and I.-S. Hwang
Ulsan National Institute of Science and Technology (UNIST), Korea

Abstract

Majority of ADS design utilises lead-bismuth eutectic (LBE) as spallation target and/or cooling fluid for its fast neutron transparency, good thermal-hydraulic characteristics, chemical inertness, high-boiling point and low-melting point. Potential release of radiotoxic polonium-210 and risks with core void injection, however, present enormous challenge in licensing, operation, inspection and maintenance operations. These issues can be drastically alleviated by assuring the Leak-Before Break (LBB) nature of high-pressure tube in steam generators. To this end, Online-Monitored Double-Wall Once-Through Steam Generator (OMDWOTSG) designs have been developed for emerging nuclear systems cooled by LBE, including ADS. Leak detection sensitivities required in LBB qualifications for preventing excessive defect growth to unstable rupture conditions have been computed conservatively by linear elastic fracture mechanics. This paper presents various leak detection sensor designs being developed for LBB qualification and validation testing in large-scale LBE mock-ups, including HELIOS and PILLAR. For OMDWOTSG designs, both periodic inspections and predictive maintenance strategies are explored and potential benefits in safety licensing will be discussed, based on LBB principles.

Analysis of MYRRHA 600 MeV proton beam line shielding

Y. Çelik*, A. Stankovskiy and G. Van den Eynde
SCK•CEN, Belgium

Abstract

The MYRRHA accelerator-driven system will use a proton linear accelerator up to the energy of 600 MeV. This paper provides an estimate of the minimal lateral shielding required for the beam line of the 600 MeV horizontal section. MCNPX Monte Carlo simulations using advanced variance reduction techniques complemented with analytical formulas were performed to calculate spatial and energy distributions of protons, photons and neutrons. The corresponding dose rates were determined considering different shielding materials. A large impact was observed for the elemental composition of soil as a last shielding layer.

Various factors have impact on the required shielding thicknesses such as the amount of continuous losses, concentration of shielding materials, source spatial distribution, nuclear physics model used for the calculations and self-shielding of the materials. The effects of all these factors were thoroughly investigated. Continuous linear beam losses of 10 W/m were modelled with point, cone, line and pencil shaped sources. Modelling the point source distribution turned to be too simplistic, leading to excessively large dose rates and consequently too thick shielding estimates. The line source distribution is deemed to be more realistic for the MYRRHA accelerator. A rather small effect on the shielding thickness was observed in the case of the choice of high-energy particle physics models and additional structural materials around the beam line. Modelling a simple geometry was found to be preferential (less CPU consuming and conservative) compared to a detailed complex geometry.

Session 4: Design and Technology of Subcritical Systems

Session 4b: R&D

Overview of research on LBE corrosion and oxygen control technique in IMP

C. Yao, Z. Wang, H. Zhang, H. Chong, Z. Ma
[a]Institute of Modern Physics (IMP), Chinese Academy of Sciences (CAS), China

Abstract

Lead-bismuth eutectic (LBE) is selected as a core coolant for subcritical reactors within the China Initial Accelerator-driven System (CiADS) due to its several advantages, low melting point, chemically inert, good neutronic characteristic and natural circulation, etc. [1]. However, one of the major challenges for deploying LBE in future reactors is its corrosion towards structural components and self-oxidation (PbO). In general, corrosion phenomena involve material loss either by dissolution of materials' alloying elements or by surface oxidation [2,3]. The loss of materials implies wall thinning of a component and reduction of load-bearing capability. The PbO products formed in reactor core might cause blockage accidents. The structural materials corrosion can be mitigated and PbO production can be avoided through the control of oxygen potential in the liquid metal. The LBE corrosion and the oxygen control technique are very important issues that need to be addressed for the R&D of CiADS. Over the past few years, a series of LBE testing facilities (both corrosion and oxygen control) have been designed and established at the Institute of Modern Physics (IMP), Chinese Academy of Sciences (CAS). A number of LBE corrosion tests have been conducted on selected steels for CiADS: 316L, 15-15Ti, T91 and SIMP (a newly developed martensitic steel with 1.5% Si addition) under different conditions.

This work gives an overview of the testing facilities and the latest progress on gas phase oxygen control and corrosion tests. Some results on the synergistic effect of LBE corrosion and irradiation will be discussed.

References

[1] Hushan Xu, Yuan He, Peng Luo (2015), China's Accelerator Driven Sub-critical System (ADS), Association of Asia pacific Physical Societies, 25(2015)30-35.

[2] NEA (2007), Handbook on Lead-bismuth Eutectic Alloy and Lead Properties, Materials Compatibility, Thermal-hydraulics and Technologies, 2007 Edition, Nuclear Energy Agency, OECD 2007, NEA No. 6195.

[3] Damien Féron (2012), Nuclear corrosion science and engineering, Woodhead Publishing series in Energy, No. 22.

The LBE coolant chemistry R&D programme for the MYRRHA ADS

A. Aerts, C. Corazza, K. Gladinez, B. Gonzalez Prieto, J. Lim, A. Marino and K. Rosseel
Chemistry and Condition Programme, SCK•CEN, Belgium

Abstract

Compatibility with structural materials and activation are major challenges for the use of heavy liquid metal spallation targets and coolants such as lead-bismuth eutectic (LBE).

Steel exposed to LBE is prone to corrosion, which results in the release of steel elements in the LBE coolant. A commonly accepted strategy to reduce corrosion rates is to maintain a sufficiently elevated dissolved oxygen concentration in order to stabilise a protective oxide layer on the steel surface in contact with LBE. This paper presents an overview of the oxygen sensing and control technology for LBE, developed for the MYRRHA ADS, and demonstrates its performance on a large scale in the MEXICO chemistry loop.

On the other hand, oxygen concentrations must be sufficiently low to avoid formation of solid lead oxide (PbO) in the primary circuit. When designing an ADS, accidents should be taken into account, which may lead to an increase of the oxygen concentrations in the LBE with a potential formation of PbO and its consequences. In this context, the formation of lead oxide from oxygen-oversaturated LBE was studied and the metastable limit for PbO nucleation was determined. Experiments in various installations suggested that this limit is universally applicable. These studies also form the basis for the development of cold trap technology for LBE.

Corrosion products that are released in the LBE interact with dissolved oxygen to form corrosion product oxides. Experimental results provide evidence for the precipitation and dissolution of oxides of iron and nickel impurities in LBE. A thermochemical model was developed, capturing the experimental observations in a wide range of conditions. This model was coupled to computational fluid dynamics codes to assess these chemical processes in the complex temperature and flow fields of an LBE-cooled system.

A similar approach was adopted for simulating the chemistry of spallation and other activation products in the LBE of MYRRHA. Simulations allow the prediction of released fraction, vapour composition and precipitation/dissolution phenomena in the LBE, as a function of the dissolved oxygen concentration and of the oxygen and humidity content of the cover gas. Simulations of the chemical behaviour of several critical coolant activation products, such as polonium, are discussed and compared with experimental results. The recently started research on LBE aerosol formation will be briefly discussed.

Oxygen transfer and oxidation of LBE at the LBE-cover gas interface

K. Rosseel*, K. Gladinez, B. Gonzalez Prieto, J. Lim, A. Marino and A. Aerts
Chemistry and Condition Programme, SCK•CEN, Belgium

Abstract

Besides compatibility with structural materials and activation, coolant oxidation is another major concern in the use of lead-bismuth eutectic (LBE) as spallation target and primary coolant for accelerator-driven systems (ADS) such as MYRRHA. Accidents or conditions need to be taken into account that may lead to the formation of solid lead-oxide (PbO) in the primary circuit. In the framework of the long-term safe state conditions, LBE was exposed at 200°C and 350°C to argon gas containing 200-5000 ppm of oxygen, via the cover gas space of the HELIOS3 stirred tank reactor. The evolution of the dissolved oxygen content in the LBE as well as that of the O_2 content in the exit stream were measured. It was concluded that for stagnant LBE, the O_2 in the inlet stream is mostly consumed in the formation of the oxide layer, as the increase of the dissolved oxygen content is limited by mass transfer effects.

Release and deposition of volatile radionuclides in lead-bismuth cooled ADS

I. I. Danilov[a,b], Erik Karlsson[a,b], Robert Eichler[a] and Jörg Neuhausen*[a]
[a]Paul Scherrer Institut, Switzerland
[b]University of Bern, Switzerland

Abstract

The release of volatile radionuclides from the liquid metal coolant of lead-bismuth eutectic (LBE) cooled ADS constitutes a significant safety issue for such facilities. For reliable safety analyses, the release behaviour has to be well understood. In the last decade, considerable effort was devoted to studying the release and deposition of the highly radiotoxic α-emitting volatile element polonium formed by activation of bismuth in the coolant. In these studies, the formation of particularly volatile polonium species in presence of moisture was confirmed. However, the mechanism leading to the formation of these volatile species and its relevance for ADS remains to be verified. Furthermore, detailed studies on the evaporation and deposition of fission products, formed by particle-induced reactions in the liquid LBE or ingressed from failed fuel elements into the coolant, are lacking. To answer the most urgent questions regarding the behaviour of these volatile radionuclides in chemical environments potentially occuring in LBE-cooled ADS, a corresponding work package was included in the HORIZON 2020 project MYRTE launched in 2015 in support of the development of the MYRRHA reactor. This paper presents the results of studies performed in our laboratory within the MYRTE project on the release of iodine, caesium, and polonium from LBE and their deposition on different surfaces under various chemical conditions relevant for the operation of ADS.

Development of analysis code for spallation products behaviour in LBE coolant system of ADS

S. Miyahara*[a], N. Odaira[a], Y. Arita[a], F. Maekawa[b] and T. Sasa[b]
*[a]Research Institute of Nuclear Engineering, University of Fukui, Japan
[b]J-PARC Center, JAEA, Japan

Abstract

It is important to evaluate the release and transport behaviour of the spallation products (SPs) including polonium-210 in the lead-bismuth eutectic (LBE) coolant system of accelerator-driven systems (ADS) from the viewpoints of the radiological hazard both in the cases of normal operation and accident. Especially, the transport and deposition inside the coolant circulation system and the evaporation from the coolant to the cover gas are dominant mechanisms to evaluate the release and transport behaviour of SPs. The University of Fukui and Japan Atomic Energy Agency (JAEA) have been developing a computer analysis code, which predicts the time dependent behaviour of SPs within the LBE coolant system of ADS for a wide range of operational events. This code deals with the SPs transport and deposition behaviour mechanistically taking into account a variety of physicochemical compositions of SPs due to the physical and chemical properties such as the solubility in LBE and the volatility, depending on the composition. The SPs behaviour modelled in the code is based on the generalised flow network model including pipe and tank components. The flow network model is constituted from mass conservation equations, considering the SPs mass changes due to coolant flow effect, deposition or adsorption of SPs onto the structure surfaces, and transport into the cover gas due to evaporation. The source term of both radioactive and stable SPs in the LBE coolant is given as input and the radioactive decay chain model for the radioactive SPs is implemented in the code to evaluate the effect of precursors on the SPs mobility. This paper presents the recent advancement status of the code development.

Nuclear data production system in RAON

S.-W. Hong
RAON User Liaison Centre, IBS, Korea,
and Sungkyunkwan University, Korea

Abstract

The Institute for Basic Science (IBS), located in Daejeon, Korea, was established in 2011 by the Korean Government. The IBS is constructing a new accelerator complex named RAON, which stands for **R**are isotope **A**ccelerator complex for **ON**-line experiments. The name of the project constructing RAON is RISP (**R**are **I**sotope **S**cience **P**roject). The purpose of RAON is to produce a variety of stable and rare isotope beams, which can be used in a variety of basic scientific research and applications. RAON can deliver ions from protons to uranium. Proton and uranium beams can be accelerated up to 600 MeV and 200 MeV/u, respectively. RAON will produce isotopes by using both in-flight (IF) fragmentation and isotope separation on-line (ISOL) methods. The IF system uses a driver LINAC, which consists of superconducting ECR ion sources, a low-energy beam transport (LEBT) section, a 500 keV/u RFQ, a superconducting (SC) LINAC, a medium-energy beam transport (MEBT) section for a 400 kW in-flight fragmentation facility. The ISOL system uses a proton cyclotron as a driver, which can accelerate protons to 70 MeV at ~1 mA for the ISOL facility. The ISOL facility uses a SC LINAC for post-acceleration of rare isotopes up to about 18.5 MeV/u, while the SC LINAC of IF facility is capable of accelerating uranium beams up to 200 MeV/u at 8 pμA.

There are seven experimental systems for RAON, which include KOBRA, LAMPS, MMS, CLS, μSR, NDPS and BIS. The NDPS (Nuclear Data Production System) is an experimental system that can be used to measure nuclear data related to the development of fast reactor systems. The NDPS consists of a neutron generation target, collimators, neutron monitoring and detection systems and beam dumps. Both are mono-energetic and white neutron sources. The NDPS aims to produce nuclear data for various reactions such as (n, xn), (n, α), etc and fission at high energies. The NDPS can also be used with light or heavy ion beams. Recently, the RAON User Liaison Center has been established to facilitate the communication between the RISP and the outside users who will use the seven experimental systems. The organisation called the “RAON Users Association” promotes the use of the RAON among the users. This paper presents the current status of RAON and its experimental systems.

Experimental activities on liquid-metal thermal hydraulics at SCK•CEN in support of MYRRHA

K. Van Tichelen, G. Kennedy, D. Rozzia and Y.-H. Shin
SCK•CEN, Belgium

Abstract

SCK•CEN is at the forefront of heavy liquid metal (HLM) nuclear technology worldwide with the development of the MYRRHA accelerator-driven system. MYRRHA is a flexible fast-spectrum pool-type research reactor cooled by lead-bismuth eutectic and was identified as the European Technology Pilot Plant for the lead-cooled fast reactor.

In support of the MYRRHA design and licensing, the LBE-components and experiments research unit at SCK•CEN has developed an experimental programme focusing on LBE thermal hydraulics. Research activities evolve around two large-scale LBE-cooled facilities: the European SCAled Pool Experiment (E-SCAPE), a 1/6 scale model of the primary pool system of MYRRHA for integral system analysis, and the COMPLOT loop for thermal hydraulic characterisation of key components in MYRRHA at real scale. These components include the fuel assembly, control and safety rod, primary heat exchanger etc.

This paper presents the main objectives and characteristics of E-SCAPE and COMPLOT, gives an overview of the experimental results already obtained from these facilities and introduces the current steps and future plans.

Fuel bundle experimental characterisation in heavy liquid metal

M. Tarantino*[a], D. Martelli[a], I. Di Piazza[a], P. Lorusso[b], R. Marinari[c], M. Angelucci[c] and A. Del Nevo[a]
[a]ENEA FSN-ING, Brasimone Research Centre, Italy
[b]DIAEE – Nuclear Section, "Sapienza" University of Rome, Italy
[c]DICI-University of Pisa, Italy

Abstract

Since heavy liquid metal fast reactors (i.e. ADSs, LFRs) have been conceptualised within the international framework, great interest has focused on the development and testing of new technologies related to pool-type nuclear reactors. A detailed investigation of maximum core temperatures occurring under several postulated scenarios is considered as a key point in the safety assessment of the innovative reactor concept. Numerical simulations present several challenging aspects for the design phase due to fuel assemblies complex geometries and the low Prandtl number of heavy liquid metal coolants. Furthermore, the validation of implemented numerical models for turbulent transport of momentum and heat is still an on-going activity. Thus, reliable experimental data are needed to support the validation of numerical tools.

In this frame, a series of comprehensive heat transfer tests in fuel pin bundle simulators were performed at ENEA Brasimone Research Centre (Italy). Both grid (CIRCE pool facility) and wire spacer geometries (NACIE-UP loop facility) were experimentally investigated in a wide range of operating conditions (temperature, flow velocity and power density) and under natural or forced-convective flow regimes.

Several experimental campaigns were designed to investigate the coolability of the fuel bundles under different accidental scenarios such as Protected Loos of Flow Accident (PLOFA) or flow blockage regimes.

This paper presents the main outcomes achieved concerning heat transfer phenomena in grid and wire spaced bundles in terms of Nu number vs Peclet numbers, both in forced and natural circulation regimes and flow blockage effects in terms of thermal-hydraulic of the coolant and clad temperatures modification near blocked subchannels and of the whole fuel assemblies.

RELAP5 simulations of the CIRCE-HERO facility for PLOFA scenarios

F. Galleni*[a], A. Pucciarelli[a], N. Forgione[a], D. Martelli[b]
[a]DICI, University of Pisa, Italy
[b]ENEA, FSN-ING, Brasimone Research Centre, Italy

Abstract

This paper presents the simulations carried out with the system thermal hydraulics (STH) code RELAP5/Mod3.3 at the University of Pisa to support the characterisation of the components and experiments conducted on the CIRCE-HERO facility, operated at the ENEA Brasimone Research Centre. CIRCE facility is an integral effect pool type facility dedicated to the study of innovative nuclear systems cooled by heavy liquid heavy metal. The HX-HERO (Heat eXchanger-Heavy liquid mEtal pRessurised water cOoled) test section is hosted inside the CIRCE facility and consists of seven double wall bayonet tubes that represent seven tubes full scale of the Advanced Lead Fast Reactor European Demonstrator (ALFRED) Steam Generator.

As part of the H2020 project MYRTE, a series of experiments were performed with the CIRCE-HERO facility, both for nominal steady-state settings and for accidental scenarios. In this context, the University of Pisa performed numerical calculations using a modified version of the RELAP5 code to simulate the experimental tests that were focused on the assessment of the heat losses of the facility and on the analysis of the thermal hydraulics phenomena occurring during the postulated Protected Loss Of Flow Accident (PLOFA) scenario. The modifications to the source of the RELAP5 code made by the University of Pisa were carried out to include updated thermo-physical properties and convective heat transfer correlations suitable for heavy liquid metals.

First, a RELAP5 nodalisation of the complete facility was realised. Second, different simulations were performed to reproduce the experimental test cases characterising heat losses. A suitable value for the heat transfer coefficient towards the environment was found and, furthermore, the thermal conductivity of the powder inside the bayonet tubes of the HERO-HX was estimated. The information received in the first phase of the work was assumed for the simulations performed for the PLOFA scenarios. Several simulations were carried out considering different argon flow rate time trends (promoting gas enhanced forced circulation), used as boundary conditions. It was shown that in the first phase of the transient from forced to natural circulation, the LBE flow rate trend is strongly dependent on the injected argon flow time trend. Nevertheless, the numerical results are in good agreement with the experimental data, even if further investigations should be required to better understand the LBE reversed flow not observed experimentally.

Multiscale simulation of the CIRCE-HERO facility by a STH/CFD coupling tool

D. Martelli*[a], F. Galleni[b], M. Tarantino[a] and N. Forgione[b]
[a]ENEA FSN-ING, Brasimone Research Centre, Italy
[b]DICI, University of Pisa, Italy

Abstract

This paper presents the application of a coupling methodology between CFD and System Thermal Hydraulic (STH) codes developed at the DICI (Department of Civil and Industrial Engineering) of the University of Pisa. The methodology was applied to the LBE-water heat exchanger HERO (Heavy liquid mEtal pRessurised water cOoled) installed inside the vessel of the CIRCE facility, and operated at the ENEA Brasimone Research Centre. This device consists of seven double wall bayonet tubes that represent a mock-up (seven full scale tubes) of the ALFRED (Advanced Lead Fast Reactor European Demonstrator) SG tubes. In the proposed methodology, the LBE side of the HX-HERO is simulated by the CFD code fluent, while the secondary side (two-phase flow, water-vapour) is reproduced by the STH code RELAP5. The coupling procedure was tested against the experimental data provided by ENEA and represented a protected loss of flow with a partial loss of heat sink. The experimental test was numerically simulated by the coupling tool and the predicted temperatures were compared with the experimental ones, both for the primary and the secondary side. The numerical results provided an overall good prediction of the axial trend of the temperatures at full power, reduced power steady states during the simulation of the postulated accidental transient. The comparison with experimental data shows a general under-prediction of the temperature along the primary circuit of the test section; this discrepancy might be due to several reasons such as the simplified computational geometry or the incorrect estimation of the properties of the material composing the bayonet tubes. However, given the uncertainties of the experimental measurements, the error can be considered small. The use of multi-scale approaches, such as STH/CFD coupled calculation proved to be a useful instrument for the analysis of the integral system, where a portion of the domain is characterised both by 3D and two-phase phenomena that affect the overall system behaviour. The coupling procedure can be a solution in many cases to overcome the limitations related to the selective use of a unique approach (STH standalone or CFD alone) and to exploit the advantages from both the codes.

HERO – Steam generator bayonet tube experimental validation in CIRCE Facility

P. Lorusso*[a], M. Tarantino[b], D. Martelli[b], G. Caruso[a], A. Del Nevo[b]
[a]DIAEE – Nuclear Section, "Sapienza" University of Rome, Italy
[b]ENEA FSN-ING, Brasimone Research Centre, Italy

Abstract

This paper presents the results achieved during the experimental campaign carried out at the CR ENEA Brasimone, which aimed to investigate the thermal-hydraulic behaviour of an innovative steam generator (SG) based on double wall bayonet tubes concept. For this purpose, a dedicated test section named HERO (Heavy liquid mEtal pRessurised water cOoled tubes) has been developed to refurbish the pre-existent pool integral effect facility CIRCE (CIRcolazione Eutettico), using LBE (Lead-Bismuth Eutectic) as primary coolant.

The HERO steam generator consists of seven double wall bayonet tubes, with an active length of about 6 m, arranged in a hexagonal shroud. A once-through secondary circuit has been realised to feed the HERO unit with demineralised water and both the primary and secondary systems have been instrumented. In this configuration, the CIRCE-HERO facility has been involved in a set of experimental tests at low water pressure secondary side (~16 bar) within the framework of the HORIZON2020 MYRTE (MYRRHA Research and Transmutation Endeavour) European project, providing support to the development of MYRRHA (Multi-purpose hYbrid Research Reactor for High-tech Applications) and acquiring thermo-dynamic feedbacks on the Primary Heat eXchanger (PHX) behaviour.

This paper discusses the outcomes of the performed experimental tests and the main results achieved, investigates the thermal-hydraulic performances of the HERO SG in operating conditions consistent with the MYRRHA PHX, and describes the system behaviour in terms of primary LBE mass flow rate, temperatures and pressure. The experimental activity realised improves the knowledge and the experience in terms of design and operations for lead-cooled fast reactor (LFR) and accelerator-driven system (ADS) and provides a database for STH codes validation.

Numerical thermal-hydraulic simulation of LBE target mock-up loop "IMMORTAL" by using RELAP5-3D

N. Watanabe, * H. Obayashi and K. Nishihara
Japan Atomic Energy Agency, Japan

Abstract

JAEA investigates lead-bismuth eutectic alloy (LBE) as a candidate of coolant and spallation target of accelerator-driven systems (ADS). The construction of an experimental facility for LBE spallation target is planned within the J-PARC project for feasibility study of ADS's beam window, which is exposed to high-temperature LBE flow and strong proton and neutron irradiation environment. As a demonstration, an LBE target mock-up loop "IMMORTAL" was constructed to confirm the operation of a primary cooling system and to implement the integration tests to develop the components of LBE technologies.

The thermal-hydraulic characteristic of LBE is very important, however, studies are still limited compared with that of light water. Therefore, in this research, a calculation model of IMMORTAL's primary loop was performed and the thermal-hydraulic behaviour was numerically simulated by using the RELAP5-3D code. Then, simulation results and experimental data were compared to validate heat transfer coefficient correlations and the properties of LBE.

Mechanical properties of austenitic and martensitic steels in contact with liquid lead bismuth eutectic and liquid lead: Influence of dissolved oxygen in liquid metal and of strain rate

I. Proriol Serre*, J.-B. Vogt
Unité Matériaux et Transformations, Univ. Lille, CNRS, INRA, ENSCL, UMR 8207 – UMET, France

Abstract

The mechanical behaviour assessment of structural alloys is crucial for the durability and safety of ADS. Moreover, it is well-known that the presence of a liquid metal may compromise the good performances of a metallic alloy due to liquid metal corrosion or liquid metal assisted mechanical damage. Tough and ductile metallic alloys are selected, they may become brittle when stressed in liquid metal, exhibiting the so-called Liquid Metal Embrittlement (LME).

This paper summarises the results obtained in our lab on the mechanical behaviour of martensitic and austenitic steels in liquid lead and in liquid lead-bismuth (LBE) eutectic. Focus has been placed on the influence of two parameters: the oxygen content in the liquid metal and the strain rate. Indeed, the chemistry of the liquid metal, especially oxygen content affects the interface between the steel and the liquid metal forming an oxide layer (high oxygen) or decreasing the possibility of protective oxide layer to form (low oxygen). Furthermore, variation in oxygen content or chemistry of the liquid metal (Pb, Pb-Bi) could lead to a modification of adsorption or absorption mechanisms. The mechanical properties in inert environment depend on the strain rate as the effect of liquid metal depends on the time immersion in the liquid metal. The strain rate could be considered as an important parameter concerning the mechanical behaviour of the steel in contact with lead and LBE.

The mechanical behaviour of martensitic steel and austenitic steels were investigated in a temperature range from 200°C to 500°C by performing monotonic tests (Small Punch Tests and tensile tests) and low-cycle fatigue tests in air and in liquid LBE or/and liquid lead. After tests, cracking and fracture surfaces were analysed by SEM, EDX-SEM, EBSD or ToF-SIMS to characterise and understand the effect of the liquid metal.

This paper presents the effect of the presence of liquid metal depending on the microstructure of the steels as well as the strain rate and chemistry of liquid metal.

Session 5: Current ADS Experiments

Study on applicability of sub-criticality measurement method to LBE cooled accelerator-driven system

R. Katano*
Japan Atomic Energy Agency (JAEA), Japan

Abstract

The Japan Atomic Energy Agency (JAEA) studied accelerator-driven systems (ADSs) to realise transmutation of minor actinides (MAs) which are produced by light water reactors (LWRs) and have extremely long lives. The ADS consists of LBE coolant, a subcritical core loaded with MA fuel, and a proton accelerator installed to generate spallation neutrons. The subcriticality indicates a safety margin from the viewpoint of criticality safety, thus subcriticality measurements are important.

The alpha-fitting method classified as one of the pulsed neutron source (PNS) method has great advantage because of its simplicity of experimental analysis and capability of reduction of the spatial higher order mode (HOM) effect by the masking technique. In addition, to improve the alpha-fitting method, a linear combination method was proposed to reduce the HOM effect by taking linear combination of neutron counts obtained by multiple neutron detectors. Therefore, the alpha-fitting method with linear combination could be a practical method for the subcriticality measurement.

To confirm the applicability of this method to ADS core, a numerical PNS analysis was conducted with a continuous energy Monte Carlo calculation code (MCNP6) and the time evolutions of neutron counts obtained by some fission rate tallies were evaluated. However, to achieve an accurate subciriticality measurement by the linear combination method is difficult due to long-lived thermal neutrons which are produced by slowing down by N-15 and small absorption cross-sections of N-15 and LBE nuclides. To improve the measurement accuracy, these thermal neutrons should be removed from the system by using coolant containing cadmium.

Interpretation of reactivity measurements performed for some subcritical configurations at Kyoto University Critical Assembly (KUCA)

M. Carta,*[a] N. Burgio[a], V. Fabrizio[a] and V. Peluso[b]
[a]ENEA – C.R. Casaccia, Rome Italy
[b]ENEA, C.R. Ezio Clementel, Bologna, Italy

Abstract

KUCA (Kyoto University Critical Assembly) is a multi-core facility used for reactor physics studies. It consists of two solid-moderated cores, named A-core and B-core, and one liquid-moderated by light water core, C-core. The A-core, loaded in subcritical configuration, has been coupled with the FFAG (Fixed-Field Alternating Gradient) proton accelerator (100 MeV) allowing several experimental campaigns on the neutronic behaviour of ADS (accelerator-driven systems). By means of the PNS (Pulsed Neutron Source) Area Method both the reactivity level and the prompt decay constant have been experimentally evaluated. This work is focused on the analysis of some experimental results using the ERANOS deterministic code. In order to set up the 3D model for the subcritical calculations particular care has been paid at cell cross-sections evaluation level, to take into account the different heterogeneities of the KUCA core. The 3D model (TGV-Variant ERANOS module) has been used both for static calculations (for the evaluations of the integral kinetics parameters ρ, βeff and Λ) and kinetic calculations for the evaluation of the subcritical level by the area method. JEFF-3.1 has been selected as a nuclear data library. The study has been performed for three kinds of neutron external sources provided by three different solid targets (W, W-Be and Pb-Bi) coupled with the FFAG proton accelerator. Results are under analysis and the output of the interpretation will be provided in the final paper.

LBE spallation target handling technologies in JAEA

H. Obayashi*, T. Wan, G. Ariyoshi, K. Yamaki, S. Kita, H. Yoshimoto, S. Saito and T. Sasa
J-PARC Center, Japan Atomic Energy Agency (JAEA), Japan

Abstract

JAEA has been promoting R&Ds for a lead-bismuth eutectic (LBE) cooled accelerator-driven system (ADS) to reduce environmental burden from long-lived radioactive nuclides such as minor actinides. In order to acquire material irradiation data under an environment with high temperature and high irradiation dose condition for the future ADS, a construction of an experimental facility is being planned to use a LBE spallation target system and a high-power (400 MeV-250 kW) pulsed proton beam from J-PARC accelerator. In the facility, LBE is used as a spallation target material and as a primary coolant. The establishment of LBE handling technology is indispensable to realise both the experimental facility and the future ADS. In order to develop the handling technology of LBE, JAEA has several experimental apparatuses such as circulation loops and testing pots. This paper describes the recent experimental results obtained by each LBE apparatuses.

"IMMORTAL" is a demonstrative test loop of the planning LBE spallation target system. The loop was manufactured to verify the overall thermal behaviour of the primary system and to perform the comprehensive functional test of each individually developed component designed based on R&Ds of LBE handling technologies. Most of the components are designed with the same performance as the planned target system. In order to verify the performance of the heat exchanger, and to acquire verification data for a safety analysis code, several temperature differential operation tests were performed under low-temperature condition (< 250˚C). During the long-term experiment, over 500 hours of continuous temperature differential operation, the problem caused by the instability of the tertiary system was solved. "OLLOCHI" is a test loop for understanding erosion/corrosion behaviour of several candidate structural materials of the future ADS under flowing high-temperature LBE condition hence its maximum operation temperature is 550˚C. A measurement test of the dissolved oxygen concentration behaviour in flowing LBE is being performed under various operation conditions. During testing pot device activities, automatic control tests of oxygen concentration were performed under stagnant LBE condition. We succeeded to keep the O_2 concentration at a target value (1×10^{-7} wt%) by a method of supplying reducing gas and carrier gas when the oxygen sensor output exceeds a threshold. In a near future, the same method will be applied to IMMORTAL and OLLOCHI test loops.

Validation of subcriticality monitoring techniques for the MYRRHA ADS

A. Kochetkov*[a], V. Bécares[b], A. Billebaud[c], S. Chabod[c], A. Krása[a], J.-L. Lecouey[d], F. R. Lecolley[d], G. Lehaut[d], N. Marie[d], N. Messaoudi[a], D. Villamarín[b], G. Vittiglio[a] and J. Wagemans[a]
[a]SCK•CEN, Belgium
[b]CIEMAT, Spain
[c]LPSC, Université Grenoble-Alpes, CNRS/IN2P3, France
[d]Normandie Univ, ENSICAEN, UNICAEN, CNRS/IN2P3, France

Abstract

In order to support the development of the MYRRHA ADS, the Belgian Nuclear Research Centre SCK•CEN initiated the GUINEVERE programme (2007-2011) within the 6th Framework programme of the European Commission. A zero-power thermal VENUS reactor was transformed into a fast VENUS-F reactor using solid lead as a coolant simulator. The following FREYA project (2011-2016, FP7) was dedicated to the coupling of the VENUS-F reactor with the GENEPI-3C accelerator (developed by the French research centre CNRS) that can be operated in a pulsed, continuous or beam trip mode (i.e. continuous beam with short, regular interruptions). Various techniques for subcriticality monitoring were extensively investigated in a large number of the VENUS-F reactor core configurations (-4$ to -18$). The source jerk method during the beam trip mode of the accelerator operation has been identified as an appropriate candidate for the subcriticality level measurement in the MYRRHA core loading/start-up phase. During the nominal operation of the MYRRHA ADS, the current-to-flux method will be continuously applied for relative monitoring of the subcriticality level and can be calibrated from time to time applying the source jerk method.

Within the ensuing MYRTE project (2016-2017, Horizon2020), the selected techniques were further refined for the application in MYRRHA by modifying the VENUS-F reactor core to be representative to the latest version of the MYRRHA design (i.e. presence of reflector and in-pile sections) and the impact of the instrumentation was investigated (detector deposit and detector positioning in the core and reflector).

Follow-up on the SCK•CEN+CNRS project (2017-2019), GENEPI-3C was operated in two special regimes. First, random beam trips were added to the regular beam time structure, which simulated short beam intensity variations (~1-100 μs) that can occur rather often with a LINAC such as the one to be used for MYRRHA. The sensitivity of the source jerk technique to such unwanted, aperiodic beam glitches was tested. Second, the accelerator worked in the beam trip mode with a very low duty cycle factor (≈2%), which is planned to be applied during the MYRRHA start-up. For this purpose, a deeply subcritical VENUS-F reactor core was loaded (-30 $), which also tested the source jerk technique reliability under limit conditions.

This paper presents some key results of 2011-2019 activity in the frame of the projects.

Beam interruption experiments in a deep subcritical ADS within the MYRACL Programme at the GUINEVERE facility

A. Bailly[a], J. L. Lecouey[a], A. Kochetkov[b], A. Krása[b], A. Billebaud[c], S. Chabod[c], F.R. Lecolley[a], G. Lehaut[a], N. Marie[a], N. Messaoudi[b], G. Vittiglio[b] and J. Wagemans[b]
[a]Normandie Univ, ENSICAEN, UNICAEN, CNRS/IN2P3, France
[b]SCK•CEN, Belgium
[c]LPSC, Université Grenoble-Alpes, CNRS/IN2P3, France

Abstract

The GUINEVERE (Generator of Uninterrupted Intense NEutrons at the lead VEnus REactor) project was launched in 2006, within the 6th Euratom Framework Programme IP-EUROTRANS, in order to study the feasibility of transmutation in ADS. The eponymous facility hosted at the SCK•CEN site in Mol (Belgium) coupled the fast subcritical lead reactor VENUS-F with an external neutron source provided by the deuteron accelerator GENEPI-3C via $T(d,n)^4He$ fusion reactions occurring at the reactor core center. The GUINEVERE facility was then used in the follow-up of the FREYA project (7th European FP), which was dedicated to experiments in support of the design and licensing of critical and subcritical configurations of MYRRHA (Multi-purpose hYbrid Research Reactor for High-tech Applications). In particular, techniques of on-line subcriticality monitoring were investigated by conducting various zero-power experiments with temporal variations of the external neutron source. Within the MYRTE H2020 European project (2016-2019), new experiments were carried out in a new VENUS-F configuration, which were more representative for the future MYRRHA subcritical reactor in operation, introducing bismuth in the core and using more threshold fission chambers as detectors. However, these experiments did not cover the particular features of an ADS at start-up. Indeed, when the ADS is being commissioned or restarted, the reactor will be largely subcritical and the linear accelerator duty cycle will be strongly reduced to limit the average power generated in the core, two features never studied in a MYRRHA-like configuration of VENUS-F. This is the reason why SCK•CEN and CNRS have collaborated within the new research programme MYRACL (MYRrha ACceLerator) to perform new experiments at the GUINEVERE facility. This paper presents some preliminary results of MYRACL beam interruption experiments in deep subcritical configurations (~-30 $) of VENUS-F with GENEPI-3C working in a very low duty cycle. The paper also discusses the consequences for the reactivity monitoring of the future MYRRHA ADS at commissioning.

Experimental verification of the threshold spectral index measurement as a relative method for k_{eff} monitoring in a fast subcritical reactor

A. Krása[a], A. Kochetkov*[a], A. Billebaud[c], S. Chabod[c], J.-L. Lecouey[b], F.R. Lecolley[b], G. Lehaut[b], N. Marie[b], N. Messaoudi[a], G. Vittiglio[a] and J. Wagemans[a]
[a]SCK•CEN, Belgium
[b]Normandie Univ, ENSICAEN, UNICAEN, CNRS/IN2P3, France
[c]LPSC, Université Grenoble-Alpes, CNRS/IN2P3, France

Abstract

A recently published theoretical assumption [1,2] claims linear dependence between the fraction of the fast neutron component in the neutron spectrum and k_{eff} of a fast reactor (for k_{eff} > 0.7). We tested this hypothesis in experiments at the VENUS-F zero power reactor coupled with the GENEPI-3C accelerator at the Belgian Nuclear Research Centre SCK•CEN. Two core configurations with largely different levels of complexity were investigated, both of them are representative for the MYRRHA ADS.

The fraction of the fast component in the total neutron spectrum was determined by measuring the fission rate ratio of ^{237}Np (with threshold of about 0.4 MeV) to ^{235}U (F37/F25 spectral index) using fission chambers located at different places (active zone, reflector). The effective multiplication factor was varied from the critical state (k_{eff} = 1) down to k_{eff} ≈0.8 (in steps of about 7000 pcm) using insertion of absorber rods (safety and control). The 14 MeV neutrons from D-T reactions (deuteron beam on the tritium target) were used as a neutron source in the centre of the subcritical VENUS-F cores.

The experimental results confirm in general the theoretical predictions. In addition to the threshold index F37/F25, the "all–energy" spectral index F49/F25 (fission rate in ^{239}Pu to ^{235}U) was measured. The F49/F25 dependence on k_{eff} has opposite trend than in the case of F37/F25. To support the analysis of the results, Monte Carlo code MCNP was used to calculate the fission rates (source-driven calculations) as well as k_{eff} (KCODE calculations) of all the measured core configurations. Additionally, the k_{eff} of each subcritical core was independently measured with the source jerk integral method.

References

[1] D. Chersola et al. (2016), An alternative observable to estimate k_{eff} in fast ADS, *Annals of Nuclear Energy* 95 (2016) 42-47.

[2] P. Saracco et al. (2017), A useful observable for estimating k_{eff} in fast subcritical system, *EPJ Web of Conferences* 153, 05017.

Neutron noise experiments in a lead-bismuth core within the MYRTE project

V. Bécares*[a], D. Villamarín[a], J. Blázquez[a], A. Kochetkov[b], A. Krása[b],
N. Messaoudi[b], G. Vittiglio[b], J. Wagemans[b]
[a]CIEMAT, Spain
[b]SCK•CEN, Belgium

Abstract

The EU's H2020 MYRTE project supports the development of MYRRHA ADS facility and includes a Work Package (WP5) devoted to reactor physics experiments. These experiments have been carried out at the VENUS-F zero power reactor facility of SCK•CEN. For the purpose of the MYRTE project, a configuration simulating the neutronic characteristics of the envisaged MYRRHA cores was implemented in the VENUS-F reactor. This configuration consists of a core made up of U_{MET} fuel, lead, bismuth and Al_2O_3 surrounded by a thick graphite reflector. The activities carried out within this Work Package include neutron noise experiments, both in the critical state and in three slightly subcritical states obtained by different insertions of the control rods. The aim of this work is to present the results of the first analysis of these experiments, including the application of the Rossi-α and Feynman-α techniques to determine the reactor kinetic parameters, the prompt neutron decay slopes and the reactivity of the subcritical states. This paper presents the analysis of the C/E results obtained with the MCNP code and the three different nuclear data libraries (ENDF-7.1, JEFF-3.2 and JENDL-4.0).

Session 6: ADS Data and Simulations

3D Simulation of fuel assembly blockage in MYRRHA

X.-N. Chen[a], A. Rineiski[a], F. Belloni[b] and G. Scheveneels[b]
[a]Karlsruhe Institute of Technology (KIT), Institute for Nuclear and Energy Technologies, Germany
[b]SCK•CEN, Belgium

Abstract

Within the framework of the KIT and SCK•CEN R&D co-operation and as a continuation of earlier studies performed for the EURATOM FP7 MAXSIMA project, accidental transients caused by a single fuel assembly (FA) blockage were simulated with the SIMMER-IV (3-D) code for the MYRRHA core, while assuming no reactor power variation during the accident. A 7-FA model that includes mesh cells for inter-wrapper gaps between FAs was applied, with the blockage of the central FA. Sensitivity analyses on the gap flow rate, fuel chunk jamming fraction, insulator pellet material were performed in order to identify a conservative case that maximises the chance of damage propagation from the blocked FA to the neighbouring ones.

All calculations with different options and parameters showed the same sequence in the blocked FA, including melting of pin cladding, fuel pellet failure, small can-wall break-up, steel particle and fuel chunk accumulation leading to additional blockages, and large canwall break-up. Finally, fuel chunks are swept out from this FA through the inter-wrapper gaps. In the calculations performed for several tens of seconds no canwall break-up in the neighbouring FAs has been observed. Nevertheless, different options for simulation of the insulator break-up led to significantly different results in the later phases of calculations. If the insulator pellet breaks up when the cladding is lost, a fuel/steel blockage is formed, which results in a large canwall break-up, but this blockage is dissolved as soon as the upper steel structure melts. If no insulator pellet breaks-up, the fuel/steel blockage is kept in place by the ceramic insulator, which has a very high melting temperature. This observation supports the use of an insulating material with low melting temperature; this option may prevent or reduce blockage of fuel/steel particles coming from failed pins that eventually may prevent or reduce the risk of damage propagation to the intact core.

A control-oriented model for the simulation of the accelerator-driven systems

A. Cammi, S. Lorenzi
Politecnico di Milano, Department of Energy, Nuclear Reactor Group, Italy

Abstract

Accelerator-driven systems are complex engineering systems that coupled different components as the accelerator, the subcritical nuclear reactors, the reactor pool (if present) and the cooling circuits. The presence of different components with a wide range of time constant poses a challenge from the viewpoint of control where simulation tools are required to analyse the entire system. For this purpose, this paper presents a control-oriented dynamics simulator for the simulation of the accelerator-driven systems aimed at providing a fast-running and flexible for studying the dynamics of the system and to lay the foundation for the analysis of the different possible control strategies. In this work, an object-oriented approach is adopted relying on the tested, flexible and open-source object-oriented Modelica language. A one-dimensional modelling is used for the thermal-hydraulics and the heat transfer Modelica libraries are used for the most conventional components. A particular effort has been made to develop a new component representing the coupling between the accelerator and the subcritical core. The simulator is used to analyse the 80 MWth eXperimental accelerator-driven system (XADS) facility in different transient scenarios. The results are also compared with the outcomes of a simplified, lumped and zero-dimensional model of the XADS in order to outline the impact of the different modelling approaches.

PSi project for accelerator-driven systems

K. Nishihara*, T. Sugawara and K. Tsujimoto
Japan Atomic Energy Agency, (JAEA), Japan

Abstract

The Japan Atomic Energy Agency has reorganised the past R&Ds and launched Ψ project (PSi, Proton accelerator-driven Subcritical virtual system) for R&D on ADS (accelerator-driven system). The Ψ project aims to create an efficient R&D towards industrialisation of partitioning and transmutation by accelerator-driven systems (ADSs) by constructing "virtual" ADS on computer. The project is planned for around 10 years and its final goal is to be ready for the final design and approval application of demo-scale ADS.

The project consists of four R&D fields: reactor physics and nuclear data, ADS plant and safety, lead-bismuth eutectic (LBE) and material, and, accelerator. Each field includes computation code for efficient engineering design, construction of model assembled in the code, and experiments to verify and validate the model. The experiment is a small-scale mock-up using all the existing facilities in Japan and the world.

Exploration and quantification of the main differences on nuclear fuel cycle simulators applied to ADS scenarios

A. Villacorta Skarbeli[a], I. Merino Rodriguez[b,c], F. Alvarez-Velarde[a] and A. Hernandez Solis[b]
[a]CIEMAT, Spain
[b]SCK•CEN, Belgium
[c]Universidad Católica del Maule, Chile

Abstract

Nuclear fuel cycle simulators emerged as powerful and versatile tools that can be used by experts and policy makers in order to address and analyse the key aspects of the nuclear fuel cycles. Motivated by different scientific questions, in the recent years multiple institutions have developed their own tools for studying those aspects of the fuel cycle they considered the most relevant. Consequently, nowadays several fuel cycle codes are used around the world.

Considering this background, the next question is if these codes provide the same results given a fixed set of hypotheses describing a certain nuclear fuel cycle. Additionally, since each code will make use of different interpretation of the assumptions and approaches, this is not an easy task. In this area, multiple benchmarking exercises have been done in the past, leading to the acceptance of some discrepancies in the results. In this work, the quantification of such discrepancies was addressed using a methodology that relies on the theory of uncertainty propagation.

In a first place, two different codes (namely TR_EVOL and ANICCA, developed respectively by CIEMAT and SCK•CEN) were selected for the study of an advanced and realistic nuclear fuel cycle scenario, which employs three different technologies: a PWR with UOX fuel, a PWR with MOX fuel and an ADS fleet, which is fed with a mixture of Pu and MA. Such a chosen scenario has been proposed and is currently under study by the Expert Group on Advanced Fuel Cycle Scenarios (WPFC/AFCS) co-ordinated by the OECD/NEA. The main objective of this study is to stabilise the production (and stocks) of plutonium and minor actinides (MA) while maintaining the same electricity production for up to 300 years. After a first approach where it was found that the largest source of discrepancy was the interpretation of the specifications, the scenario was iteratively readapted until the point where no differences could be explained by different interpretations of the input parameters. At this point, a maximum discrepancy in the Pu and MA's total inventories happens to be about 11% and 3% for the Pu and MA, respectively, at the end of the simulation after 300 years.

Once the scenario was finally defined, an uncertainty propagation analysis was done over the most relevant parameters of the simulation following the total Monte Carlo approach, where random sampling is performed over the input parameter space. The obtained results will be compared with the differences obtained between the two codes, in such a way that it can be established if the results coming from different codes are compatible with the system uncertainties or, on the other hand, they are larger or smaller than that.

Calculating swing reactivity of accelerator-driven systems (ADS) subcritical reactor

S. Sudarmono*[a], A. Rohanda[a,b] , A. Waris[b], S. Bakhri[a], G.R. Sunaryo[a]
*[a]National Nuclear Agency of Indonesia (BATAN) Indonesia
[b]Department of Physics, Institut Teknologi, Indonesia

Abstract

Used nuclear fuel in electricity generation yields disadvantage in form of spent fuel, which is radioactive and subjected to proliferation. The conceptual design of accelerator-driven systems (ADS) utilises power reactor's spent fuel, which is reprocessed as nuclear waste transmutation to generate clean, safe and economic energy. The use of those isotopes in fast and thermal reactor has been proposed. In addition, the ADS is one of the efforts in the utilisation of transuranic material. The configuration used in ADS aims to produce subcritical condition through the use of light water reactor's fuel, which is effective to transmute plutonium and minor actinide (MA). ADS design calculated in this research has the specifications of used fuels obtained from PWR spent fuel, i.e. UO_2 with 3.4% enrichment and k_{eff} calculation using MCNPX code to determine expected subcritical conditions of ADS system (about 0.97 – 0.98) with different percentage of U-Pu at each fuel core layer. It is estimated that the cycle of this system in subcritical condition is 720 days. It was shown that at the beginning of life (BOL), the k_{eff} of ADS design is 0.9847, and at the end of life (EOL) it is 0.9823. The presence of plutonium and major actinides makes k_{eff} get slightly lower. ADS subcritical reactor in this research produces subcritical k_{eff} during its operation. The addition of thorium-based fuel provides sufficient contribution to this subcritical k_{eff}. Therefore, swing reactivity generated is negative. During its operation, this subcritical can burn long half-life fission products. By using this ADS, the amount of that isotope can be reduced.

Development of nuclear data for performance assessment and safety analysis of MYRRHA

F. Álvarez-Velarde[a], O. Cabellos[b,c], C.J.r Díez[b], L. Fiorito[c,d], J. Heyse[e], I. Kodeli[f], N. García-Herranz[b], P. Romojaro[b], A. Stankovskiy[d], P. Schillebeeckx*[e], G. Van den Eynde[d], G. Žerovnik[e]
[a]CIEMAT, Centro de Investigaciones Científicas, Medioambientales y Tecnológicas, Spain
[b]UPM, Universidad Politécnica de Madrid, Spain
[c]OECD Nuclear Energy Agency, France
[d]SCK•CEN, Belgian Nuclear Research Centre, Belgium
[e]EC-JRC, Belgium
[f]JSI, Jožef Stefan Institute, Slovenia

Abstract

Nuclear data required for the development, safety assessment and licensing of MYRHHA were studied. In addition, recommendations to improve evaluated nuclear data libraries for the most important reactions are provided. The work is part of a workpackage of the CHANDA project and is the result of a collaborative effort of: Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas (CIEMAT), Joint Research Centre (JRC), Universidad Politecnica de Madrid (UPM), Belgian Nuclear Research Centre (SCK•CEN) and Jožef Stefan Institute (JSI).

Sensitivity profiles, i.e. sensitivity to nuclear data as a function of incoming neutron energy, were derived for both a critical and sub-critical core. They were calculated using codes that are based on different methodologies including stochastic and deterministic calculations (i.e. SCALE, MCNP and XSUN). The sensitivity analysis identified the main nuclides and reactions of interest for the MYRRHA reactor concept. These are: ^{239}Pu(n,γ) in both the resonance and fast energy region, ^{39}Pu(n,f) and corresponding prompt neutron multiplicity and emission spectrum in the fast region; ^{238}U(n,n') in the fast region, ^{238}U (n,γ) and ^{238}U(n,n) in the resonance and fast region, the prompt neutron emission for ^{240}Pu; ^{238}Pu(n,f) in both resonance and fast; ^{56}Fe(n,γ) in both resonance and fast region. Differences of less than 4% between codes were obtained for these quantities, with exceptions for the ^{238}Pu(n,f), ^{238}U(n,n) and ^{56}Fe(n,γ) reactions. Nuclear data covariance matrices of different libraries (SCALE-6, COMMARA-2 and JENDL-4.0m) were used to derive the uncertainty in k_{eff} based on the calculated sensitivities. This study reveals that the largest contributions to k_{eff} uncertainty result from the uncertainty in the average prompt neutron fission multiplicity of ^{239}Pu, in the ^{238}U inelastic scattering cross-section and ^{239}Pu fission cross-section, using the covariances from SCALE-6, COMMARA-2 and JENDL-4.0m, respectively. Data resulting from neutron transmission experiments, lead slowing down spectrometers and integral benchmark experiments were used to compare the status of nuclear data libraries for the above mentioned key nuclides.

Investigation of nuclear data accuracy for commercial grade accelerator-driven systems to transmute minor actinides

T. Sugawara*[a], T. Kashima[a], F. Gabrielli[b], A. Rineiski[b] and M. Yamanaka[c]
[a]Japan Atomic Energy Agency (JAEA), Japan
[b]Karlsruhe Institute of Technology (KIT), Germany
[c]Kyoto University Institute for Integrated Radiation and Nuclear Science (KURNS), Japan

Abstract

The nuclear data accuracy of minor actinides (MAs) is important for neutronics design of MA transmutation systems such as accelerator-driven systems (ADS). To obtain the fundamental knowledge of the current nuclear data accuracy for the ADS neutronics design, a benchmark activity was performed in the Co-ordinated Research Programme (CRP) on "accelerator-driven systems (ADS) applications and use of low-enriched uranium in ADS" held by the International Atomic Energy Agency (IAEA). A lead-bismuth cooled ADS with 800 MW thermal power proposed by JAEA was employed for the benchmark calculation.

Through the calculations performed by participants, it was confirmed that the prediction accuracy of the criticality and the transmutation amount for the ADS still had the problem. There was a large discrepancy about 1100 pcm for the criticality at the beginning of cycle between JENDL-4.0 and ENDF/B-VII.1 even if the same calculation code was used. For the transmutation performance, the transmutation amounts for MA nuclides were different with the use of different nuclear data libraries and codes.

The sensitivity/uncertainty analysis was also performed and the results presented that the uncertainties deduced by the covariance data prepared in JENDL-4.0 and ENDF/B-VII.1 were almost the same for the criticality and the coolant void reactivity. However, it was confirmed that the uncertainties might be underestimated due to the lack of the covariance data. It is required to prepare covariance data for all nuclides and reactions related to the ADS neutronics design.

Cross-section measurements for LLFP nuclei at RIBF

H. Otsu*[a], H. Wang[a,b], ImPACT-RIBF collaboration[c]
[a]RIKEN Nishina Center, Japan
[b]Department of Physics, Tokyo Institute of Technolog, Japan

Abstract

Reduction in the quantity of high-level radioactive waste in the spent fuel is one of the major issues for the use of a nuclear power plant. Research and development into the reduction and recycling of radioactive waste using partitioning and transmutation technology has been performed over recent decades. Transmutation on the long-lived fission products (LLFPs), however, has been slow. Proton- and deuteron-induced spallation reactions for the long-lived fission products ^{107}Pd were studied to bring a new invention to the nuclear transmutation on LLFP.

The experiments were performed by using advanced RI facilities at the RIKEN Radioactive Isotope Beam Factory (RIBF). The inverse kinematics was applied for a direct measurement on each reaction product from ^{107}Pd. In order to search the best energy for transmutation, the proton- and deuteron-induced spallation cross-sections were obtained, reaction energies around 50, 100 and 200 MeV/nucleon. For the 50MeV/nucleon experiment, several developments on the beam-line devices have been made.

The energy dependence of reaction has been systematically investigated for ^{107}Pd. The results were compared with several newly developed theoretical calculations, such as CCONE, DEURACS and PHITS. This paper presents the results on the reaction data for ^{107}Pd, reaction mechanism and its relation with incident energies.

Acknowledgement

This work was supported and funded by ImPACT Programme of Council for Science, Technology and Innovation (Cabinet Office, Government of Japan). ImPACT-RIBF collaboration[c] consists of over 50 members from 9 institutes who joined RIBF experiments as collaborators.

Measurement of displacement cross-section and residual nuclide cross-section by spallation reaction for the target material utilised in the neutron source of the ADS

S.-I. Meigo* H. Iwamoto and H. Matsuda
J-PARC Japan Atomic Energy Agency, Japan

Abstract

For the accelerator-driven system (ADS), the neutron source will receive a remarkably higher current of the proton on the target than the existing target of the spallation neutron source. As the increase of the proton beam power, the damage to target material is essential. For estimation of damage such as target material used at the facility, displacement per atom (DPA), calculated by the particle flux multiplied displacement cross-section based on intranuclear cascade model is widely employed as an index of the damage. Although the DPA is employed as the standard, the experimental data of displacement cross-section are scarce for a proton in the energy region above 20 MeV. A recent study reports that the displacement cross-section of tungsten has 8 times difference among the calculation models. Therefore, the experimental data of the DPA cross-section is crucial. The DPA cross-section can be obtained by observing the change of resistivity of the sample cooled by GM cooler to sustain the damage. The sample is placed in the vacuum chamber placed at upstream of the beam dump for 3-GeV synchrotron in J-PARC, where the sample can be irradiated by the proton in the energy range between 0.4 and 3 GeV. Based on the present experimental results, it was found that the calculation of PHITS code with the NRT model suggested by Norgett, Robinson, and Torrens, which is widely employed to calculate the DPA, gave a factor of 4 to the experiment. On the contrary, the calculation with the Athermal Recombination Correction (ARC) model, suggested by Nordlund et al. showed good agreement with the experiment.

In order to improve the accuracy of the nuclear aspect of the ADS, nuclear reaction cross-sections are required. Considering the handling of the target in the ADS, accurate cross-sections are mandatory. The residual nuclide cross-sections by spallation reaction have been measured in several facilities. However, they have low accuracy and precision and are not well to validate the reaction model. For the sake of the forthcoming full-time measurement of the activation cross-sections for various nuclei, we have started measurement of the cross-sections of light nuclei such as Be, Al and Fe with 0.4 to 3 GeV protons in J-PARC. It was found that more accurate data than current ones would be measured by using precise beam controls and highly accurate beam monitoring. The experimental data were compared with the evaluated data (JENDL-HE/2007), and the calculations with several intranuclear cascade models using the PHITS code.

Neutronic characterisation of a TRIGA reactor in a subcritical configuration

F. Panza[a], M. Ciotti[a], N. Cherubini[a], V. Fabrizio[a], L. Falconi[a], F. Filippi[a], L. Lepore[a], M. Carta[a], A. Dodaro[a], F. Orsitto[b], M. Osipenko[c], G. Ricco[c,d], M. Ripani[c,d], M. Salvatores[e]
[a]ENEA Casaccia, Italy
[b]CREATE Consortium, Napoli University, Italy
[c]INFN Sezione di Genova, Italy
[d]Centro Fermi, Museo Storico della Fisica e Centro Studi e Ricerche, "Enrico Fermi", Italy
[e]Senior Scientific Advisor

Abstract

This study deals with the characterisation of neutron fluxes of a TRIGA reactor configured in a zero-power subcritical mode and consequently driven by a neutron source. Some simulations have been performed by using the Monte Carlo code, MCNP6 (Monte Carlo N-Particles), in order to investigate reactor subcritical conditions with different neutron sources. Specific attention has been devoted to simulations aimed to validate the model by means of future experimental measurements using in situ detectors.

The considered TRIGA system is a thermal pool reactor, the core is fuelled with U (20%^{235}U)-ZrH alloy including four control rods (B_4C) and a graphite reflector.

The reactor has been configured in a subcritical mode by extracting some of the fuel rods from the core, starting from the first critical configuration without fuel burn-up.

Three kinds of neutron sources have been considered and virtually placed in different positions within the core and by using the radial channels: d-t neutron generator (10^8 n/s), Plutonium-Beryllium (5 x 10^6 n/s) and Californium-252 (2 x 10^9 n/s) sources. The various in-core neutron flux intensities and their relative energy distributions have been evaluated and compared in all these configurations. In particular, the presence of the d-t neutron generator could be useful in order to investigate some properties and characteristics of the “hybrid” coupling between a d-t fusion source and a subcritical thermal system (fusion driven system).

In conclusion, the aims of this work are to understand the different in-core neutron flux characteristics in all considered configurations and investigate the different kinds of measurements and detectors that could be involved in the experimental campaign to be performed in the subcritical TRIGA facility.