Status of Accelerator Driven Systems Research and Technology Development

Tuesday, 7 February 2017 - Thursday, 9 February 2017

CERN

Book of Abstracts

Contents

Session 1: introduction / 10

Welcome session

Corresponding Author: maurizio.vretenar@cern.ch

Session 1: introduction / 11

Workshop introduction: ADS and the environment

Author: Maurice Bourquin[1]

[1] *iThEC*

Corresponding Author: maurice.bourquin@unige.ch

The energy and climate challenge can be summarized with the four statements: we live in a world where the demand for electricity is increasing, where the use of fossil fuels is threatening the environment, where the use of fossil fuels is not sustainable, and thus we need innovative technological solutions to meet the "decarbonization challenge". Innovative nuclear power should include thorium-fuelled Accelerator-Driven System Reactors, which are promoted by iThEC, the international Thorium Energy Committee.

Session 2: ADS national programs / 2

IAEA and ADS

Corresponding Author: s.monti@iaea.org

After a short introduction on the IAEA mission in seeking to accelerate and enlarge the contribution of nuclear energy to peace, health and prosperity through the world, the presentation will focus on the expected role that advanced nuclear technologies should play in the coming years in addressing some of the 17 UN Sustainable Development Goals. In the framework of the IAEA support to Member States on advanced reactor technologies and related fuel cycles, the presentation will provide a comprehensive overview of ADS-oriented activities like recently concluded and on-going Coordinated Research Projects, Technical Publications and Databases. Finally, the audience will be informed about the forthcoming 3rd IAEA International Conference on Fast Reactors and Related Fuel Cycles (FR17), which will also include a number of contributions from the ADS community.

Session 2: ADS national programs / 3

Europe ADS project MYRRHA

Corresponding Author: pbaeten@sckcen.be

MYRRHA (Multi-purpose hYbrid Research Reactor for High-tech Applications) is a multipurpose research facility being developed since 1998 at SCK•CEN, based on the Accelerator Driven System (ADS) concept where a proton accelerator, a spallation target and a lead-bismuth cooled subcritical reactor are coupled. MYRRHA will demonstrate the ADS full concept by coupling these three components at a reasonable power level to allow operation feedback, scalable to an industrial demonstrator, and allow the study of efficient transmutation of high-level nuclear waste.

The MYRRHA research facility will be able to work in both critical as subcritical modes and will allow fuel developments for innovative reactor systems, material developments for GEN IV and fusion reactors, and radioisotope production for medical and industrial applications. MYRRHA will contribute to the development of Lead Fast Reactor (LFR) technology and in critical mode it will play the role of European Technology Pilot Plant in the roadmap for LFR.
In the beginning of 2014, SCK•CEN has consolidated a coherent version of the primary system. This version 1.6 of the primary system forms the basis for the pre-licensing activities. In this paper, the implementation of MYRRHA via a phased approach will be presented.

Session 2: ADS national programs / **4**

China ADS project

Corresponding Author: wlzhan@cashq.ac.cn

ADS has been evolving as ADANES (Accelerator Driven Advanced Nuclear Energy System) after intensive R&D last 5 years in CAS (Chinese Academy of Science). ADANES consist of the recycle fuel burner and the used fuel recycle. ADANES burner is optimized as nuclear waste transmutation, fissile material breeding and energy production in situ from traditional ADS. The fast core/blanket is designed to operate in the subcritical or critical state with or without accelerator driven respectively and burn "raw"recycle fuel which contain >50% FP (Fission Products). The fuel recycle is designed to remove > 50% volatile FP by the extend "AIROX"and lanthanide FP by Rare Earth extraction from used fuel of LWR, then, form other residual as recycle fuel. Consequence, ADANES is the ideal to close fuel cycle as utilizing fissile fuel ⊠ 95% which means the fission energy could be sustainable for ˜10000 yr. and minimizing radiotoxicity <4% with live time < 500 yr. In the approaches, the accelerator play important role of the burner starter which is 10%˜15% duration of the burner operation due to the long refueling (˜30 yr.), the much simplified procedure of no water "raw"recycle fuel and the easier for storing small quantity waste (<4%) with lower decay heat by dry storage. Therefore, ADANES's nuclear power plant could use an accelerator to drive ˜10 set of the fast reactor and transmute the minor actinides about ˜50% of those transmuted by traditional ADS in same beam power.
Up to now, the key technical R&D make a significant breakthrough. Injector I is 325 MHz option with ECR+RFQ+2CM (7 spoke cavity) and Injector II is 162.5 MHz option with ECR+RFQ+2CM (6 HWR cavity). The lower frequency is the lower RF power density which is benefit to meet RAMI requirements in low energy part of LINAC. Both optional SCL injectors have extracted ˜10MeV&1.1˜2.7mA CW proton beam. 25 MeV SCL [ECR+RFQ+3CM(6HWR)+1CM(7 spoke cavity)] is assembling and plan to extract beam during first half year of 2017. The new concept of the granular target had been introduced, in which millimeter size solid grain, which is made by target material, driven by gravity, the beam bombarding the grains from top to down to produce intensive neutron and the deposited heat fluid with the grain out of target chamber, then treated off line. Therefore, the granular target power should be jump to 10˜100MW, and withstand the impact by high power CW beam trip within 10 sec. as grain is discrete medium and selectable the different material of target. The prototype of 10˜100 kW granular target has been test and preliminary results shown the agreement with design.
There are 4 phases in Chinese ADS/ADANES burner development roadmap and new research sites are starting to construct. The 1st phase close finish within half year, the key technique setups at the institutes separately, the 2nd phase will start this year and finish around 2022, the burner is 10MW scale which consists of the high average beam power ˜4 MW, 400˜600MeV&5˜10mA proton beam LINAC and the blanket.

Session 2: ADS national programs / **5**

India ADS programme

Corresponding Author: psingh@barc.gov.in

Accelerator Driven Systems have evoked considerable interest in the nuclear community the world over because of their capability to incinerate the minor actinides (MA) and LLFP (long-lived fission products) radiotoxic waste and utilization of Thorium as an alternative nuclear fuel. In the Indian context, due to our vast thorium resources, ADS is particularly important as one of the potential routes for accelerated thorium utilization and the closure of the fuel cycle. The Department of Atomic Energy, India has envisaged development of an Accelerator Driven subcritical reactor System (ADS) in connection with its Thorium utilization programme. An ADS consists of a high current proton accelerator, a spallation target and a sub-critical reactor. R&D is in progress for all the three systems.
Efforts are on in India to develop such a system, one of the main components of which is a 1 GeV, high intensity CW proton accelerator. The development is being done in phased manner and experimental facilities are set up to make ADS related studies. Initially, we have developed a 400 keV DC accelerator based neutron source (108-109 n/sec) for carrying out experiments on physics of ADS and for testing the simulations. A facility, BRAHMMA (Beryllium Oxide Reflected And High Density Polythene Moderated Multiplying Assembly), has been set up to measure flux distribution, flux spectra, total fission power, source multiplication and degree of sub-criticality. It uses 14 MeV neutrons produced through D+T reaction. It is a sub-critical assembly (keff=0.87) of natural uranium. In order to increase the neutron yield to about 1011 n/sec, a 400 keV, 1 mA RFQ for D+ ions has been built for replacing DC accelerator presently used for neutron generation. To perform these studies at higher energies, a Low Energy High Intensity (20 MeV, 30 mA) Proton Accelerator (LEHIPA) is also under development at BARC. This will also enable us to understand accelerator physics issues (space charge and beam halo) associated with high intensity beams. LEHIPA will be an intense neutron source and presently is under commissioning.
An important component of ADS is a 1 GeV proton accelerator. It is planned to build it using superconducting technology from 3 MeV onwards and it is being done in collaboration with Fermilab. Resonators/Cavities designed and built in India and processed at Fermilab, have met the specifications. R&D related to spallation target and materials is also pursued at BARC. LBE will be used for spallation target. Computational codes have been developed for thermal hydraulics for LBE target simulations. Experimental loops for validation of thermal hydraulics codes and corrosion studies on window materials have been built.
BARC has also studied details of a one way coupled reactor system which allows considerable reduction in the beam current. In this system, two sub-critical cores are used. The inner core is subcritical fast reactor with thermal neutron absorber liner surrounded by a gap and outer core is subcritical thermal reactor. The neutrons leaking from inner core can go to thermal core and get multiplied. However, neutron from thermal reactor cannot go to inner core due to absorber liner, that is why it is called one way coupled system.

In this talk, salient features of the Indian ADS programme and its present status will be presented.

Session 2: ADS national programs / 6

Japan ADS project

Corresponding Author: sugawara.takanori@jaea.go.jp

Partitioning and transmutation (P&T) technology of long lived radioactive nuclides such as minor actinides (MAs) will be a promising technology to reduce the burden of the geological disposal of the high-level radioactive waste (HLW). The Japan Atomic Energy Agency (JAEA) has been continuously performing research and development (R&D) on the P&T technology. The R&D on the P&T technology in JAEA is based on two concepts: one is the homogeneous recycling of MA in fast breeder reactors (FBRs) and the other is the dedicated MA transmutation cycle, "double-strata" strategy, using an accelerator-driven system (ADS). In this presentation, the current status of the R&D for the ADS in JAEA will be introduced.

Session 2: ADS national programs / 8

Ukraine NSC KIPT ADS project

Author: Yousry Gohar[1]

Co-authors: Igor Bolshinsky [2]; Ivan Karnaukhov [3]

[1] *Argonne National Laboratory*

[2] *Idaho National Laboratory*

[3] *National Science Center "Kharkiv Institute of Physics & Technology"*

Corresponding Author: gohar@anl.gov

Argonne National Laboratory (ANL) of USA and Kharkiv Institute of Physics & Technology (KIPT) of Ukraine are collaborating on the design, the construction, and the operation of an Accelerator Driven System (ADS) supported by the Russian Research Reactor Fuel Return (RRRFR) program of the United States Department of Energy. RRRFR is a trilateral initiative among the United States, the Russian Federation, and the International Atomic Energy Agency (IAEA) to repatriate high-enriched uranium fuels (fresh and irradiated) to Russia. The facility is planned 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 ADS facility uses a qualified proliferation-resistant low-enriched uranium (LEU) fuel and it is driven with an electron accelerator. The target design utilizes tungsten or natural uranium for neutron production through photonuclear reactions from the 100 KW electron beam using 100 MeV electrons. The neutron source intensity, spectrum, and spatial distribution studied as function of the electron beam parameters to maximize the neutron yield and satisfy different engineering requirements. Physics, thermal-hydraulics, and thermal-stresses analyses performed and iterated to minimize the maximum temperature and the thermal stresses in the target materials. The subcritical assembly design has the highest possible neutron flux intensity for such configuration with an effective neutron multiplication factor of <0.98. Different fuel designs and reflector materials considered for the subcritical assembly design. Shielding analyses defined the biological dose map around the facility during operation as a function of the heavy concrete shield thickness. Safety, reliability, and environmental considerations are included in the design. The facility configuration can accommodate future design upgrades and new missions. In addition, it has unique features relative to the other international 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. This presentation highlights the main design features and the present facility status.

Session 2: ADS national programs / 9

USA Progress on SRF Linacs Driving Subcritical GEM*STAR Reactors

Author: Rolland Johnson[1]

[1] *Muons Inc.*

Corresponding Author: rol@muonsinc.com

Scaling from the ORNL SNS 6% duty factor with 1.4 MW of beam on target to CW operation by appropriate upgrades of components, the traditionally considered Accelerator-Driven System (ADS) goal of 10 MW at 1 GeV is easily surpassed. However, studies have pointed out that even a few hundred trips of an accelerator lasting a few seconds could lead to unacceptable thermal stresses as each trip causes fission to be turned off in solid fuel structures found in conventional reactors. The newest designs based on the GEM*STAR [1] concept, however, take such trips in stride by using molten-salt fuel, where fuel pin fatigue is not an issue. Other aspects of the GEM*STAR concept, which address all historical reactor failures, include an internal spallation neutron target and high temperature molten salt fuel with continuous purging of volatile radioactive fission products such that the

reactor contains less than a critical mass and almost a million times fewer volatile radioactive fission products than conventional reactors like those at Fukushima. GEM*STAR is a reactor that without redesign will burn spent nuclear fuel, natural uranium, thorium, or surplus weapons material. It will operate without the need for a critical core, fuel enrichment, or reprocessing making it an excellent candidate for export. While conventional nuclear reactors are becoming more and more difficult to license and expensive to build, SRF technology development is on a steep learning curve and the simplicity implied by subcritical operation will lead to reductions in costs from regulatory hurdles and construction complexity. We describe the design and discuss the prospects of funding a pilot plant for the profitable disposition of surplus weapons-grade plutonium as was proposed by a consortium of US companies, national laboratories, and universities.

[1] C.D. Bowman, R.B. Vogelaar Edward G. Bilpuch, Calvin R. Howell, Anton P. Tonchev, Werner Tornow, R.L. Walter, "GEM*STAR: The Alternative Reactor Technology Comprising Graphite, Molten Salt, and Accelerators", Handbook of Nuclear Engineering, DOI 10.1007/978-0-387-98149-9_24, Springer Science and Business Media LLC, 2010.

Session 3 : Critical aspects of accelerators / 15

Overview of specifications and issues of ADS-drivers

Author: Alex Mueller[1]

[1] *ACM Consult GmbH*

Corresponding Author: mueller@orange.fr

I will recall some salient aspects of reactor physics to review pertinent requirements and main specifications for accelerators driving a hybrid nuclear system with significant thermal power.
I will try to put this into the perspective of the historical developments. Due to time constraints, the term "review"(assigned from the organizing committee), or "overview", as I have chosen for the title, is somewhat too ambitious.
The aim is to shine some light on the interplay between reactor physics (in a simplified way), spallation physics and accelerator physics (concentrating here on rather fundamental properties). I shall show the main differences between a classical critical reactor and a completely source-driven system that has at all times to exhibit subcriticality (i.e. with a safe margin).
The feature of being source-driven, however perfectly allows for fuel compositions that have too small delayed neutron fractions, e.g. for the incineration of minor actinide waste. On the other hand, it quests for extremely reliable accelerators since a beam trip corresponds to a very rapid and complete shut-down. In classical reactors that corresponds to a "scram"with the associated procedural issues for a restart and the necessity to consider the induced thermal stress.
These arguments obviously also hold true for a "breeding"ADS, e.g. when fertile Thorium fuel is used to breed 233U as in the energy amplifier.
The most efficient production method for fast neutrons is proton-induced spallation, I briefly describe this mechanism and the properties for the accelerator with respect to its required energy and intensity as function of the thermal power of the ADS and the adopted subcriticality.
From this I shall discuss the best options for the ADS-class accelerator, taken in particular into account the reliability requirement, the technical developments of recent years and the choices of the new neutron spallation sources.
The aim is to underline the importance of the required performance margins as well from a technical as a licensing standpoint.
For an efficiency considerations, I shall also show numbers in electricity production (and self-consumption) for a 1GWth ADS as one could imagine for a waste-burner suited either for accompanying nuclear phase-out or taking care of legacy waste from earlier generations in countries transitioning to GEN-IV reactor technology.

Session 3 : Critical aspects of accelerators / 29

High power single stage cyclotron

Author: Matthieu Conjat[1]

Co-author: Pierre Mandrillon [1]

[1] *AIMA Developpement*

Corresponding Author: matthieu.conjat@aima.fr

The state of the art of accelerator physics and technologies allows to cope with the challenge of a compact cyclotron driver for an ADS demonstrator aiming at providing a proton beam power in the 5 to 10 MWatt range. The Single Stage Cyclotron Driver (S2CDTM) design studies developped by the AIMA DEVELOPMENT (AD) company show that this concept could bring industrial attractive solutions in terms of reliability, maintenance, investment, running cost effectiveness and power efficiency. Some critical aspects are presented in this paper

Session 3 : Critical aspects of accelerators / 17

Proton linacs as ADS drivers

Corresponding Author: frederic.bouly@lpsc.in2p3.fr

The presentation will focus on the potential and the main critical issues for high power proton linacs to drive a subcritical reactor. As an introduction the main beam requirements for an Accelerator Driven System (ADS) will be reminded: to safely guide and accelerate a continuous wave (CW) MW class beam with a high level of performance, and thus with an extreme level of reliability. Then, the choice for using RF superconducting resonators to accelerate a CW beam will be explained. The main criteria to optimise the transition between normal conducting and superconducting accelerating structures will also be discussed. The second part of the presentation will focus on the reliability requirements to drive an ADS, and the guidelines to follow to fulfil these requirements. The concepts of Fault-Tolerance and Fast Failure Compensation will therefore be introduced. Finally, the impact of such concepts on the linac design, on the beam dynamics, as well as on the R&D –in particular for accelerating structures - will be exposed. Throughout the presentation, the arguments will be supported by examples of linacs presently operated or on-going projects such as: the Oak Ridge Spallation Neutron Source, the European Spallation Source, the Chinese ADS linac and more particularly the studies for the MYRRHA linac.

Session 3 : Critical aspects of accelerators / 18

Alternative designs for ADS drivers: FFAGs and electrons

Author: Roger Barlow[1]

[1] *University of Huddersfield (UK)*

Corresponding Author: roger.barlow@cern.ch

The talk considers alternative possibilities for ADS drivers. The energy and current required for a typical design are somewhat beyond the reach of conventional cyclotrons and
synchrotrons; linear accelerators can supply the required power but they are expensive, and their price is a barrier to the wide adoption of the ADSR concept. The Fixed Field
Alternating Gradient (FFAG) combines the best features of cyclotron and synchrotron performance: the rationale is outlined and a review given of the current state of development.
The talk also considers the proposal to use electron accelerators for ADSR, generating neutrons

through excitation of the giant dipole resonance by bremsstrahlung photons, and shows how this may have applications for low power systems.

Session 3 : Critical aspects of accelerators / 16

The Strong-Focusing Cyclotron: 800 MeV, 8 MW CW driver for ADS fission

Session 4: Targets and coupling experiments / 24

Overview of the achieved coupling experiments on zero power facilities

Author: Frederic Mellier[1]

[1] *French Alternative Energies and Atomic Energy Commission*

Corresponding Author: frederic.mellier@cea.fr

The scientific and technological challenges relative to the integration, in a nuclear power facility, of the three main components of an ADS (an accelerator delivering a high-energy particle beam, a heavy metal spallation target acting as a neutron source when bombarded by ions and a subcritical multiplying medium possibly comprising significant amounts of MA and/or LLFP) are numerous. Their resolution requires going through several stages with tests successively at low, intermediate and high power and, in a first step, to consider separately the "accelerator / target spallation" and "neutron source / subcritical multiplying medium" systems. This is the direction taken in Europe in the early 2000s after first tests at low power at CERN and in France were successfully achieved (FEAT in 1994, TARC in 1996 and MUSE-1/2/3 experiments in 1995, 1996 and 1998). The objective of presentation is to give an overview of "neutron source / subcritical multiplying medium" coupling experiments at low power that were performed since.

This talk starts with a few words about the interest of zero power reactors for ADS research and a reminder of the objectives and main lessons drawn from experiments evoked above. Then, we present a review of initiatives launched world-wide with the aim to conduct low-power experiments involving the coupling of a subcritical core with an external neutron source, mostly provided by D-D / D-T generators. We give main features of experiments that were completed (list below) before focusing a bit more on major programs (the MUSE-4/GUINEVERE/FREYA suite and the Yalina-B experiment in Europe, the ADS R&D activities at KURRI/KUCA in Japan), their most significant characteristics (neutron spectrum, characteristics of the source, experimental program content) and their main outcomes. In particular, the major accomplishments with respect to the representativity of the experiments and the key issue of the control and monitoring of subcritical levels are underlined. The overview is extended to initiatives that have not gone beyond the stage of opportunity or feasibility study (in Brazil, Czech Republic and UK). The main features of larger projects (RACE, TRADE plus, SAD) that had to stop prematurely are also reminded. Last, some highlights on possible next steps are given.

Session 4: Targets and coupling experiments / 19

The GUINEVERE facility and associated experimental programs and outputs

Session 4: Targets and coupling experiments / 22

Experimental Benchmarks on Accelerator-Driven System at Kyoto University Critical Assembly

Author: Song Hyun Kim[1]

Co-authors: Cheol Ho Pyeon [1]; Masao Yamanaka [1]

[1] *Nuclear Engineering Science Division, Research Reactor Institute, Kyoto University,*

The accelerator-driven system (ADS) has been developed for producing energy and for transmuting minor actinides and long-lived fission products. In the Kyoto University Research Reactor Institute, for the feasibility study of ADS, various experiments and numerical analyses related to ADS have been conducted with the combined use of the Kyoto University Critical Assembly (KUCA) and two types of accelerators. In this presentation, the feasibility study on ADS is introduced as follows; (1) outline and research activity of ADS in Japan; (2) specification of KUCA ADS; (3) 235U-loaded ADS experiments with 14 MeV neutron; (4) 235U-loaded ADS experiments with 100 MeV proton; (5) 232Th-loaded ADS experiments with 14 MeV neutrons or 100 MeV protons; (6) uncertainty study of solid Pb-Bi with 100 MeV protons. In addition, the future plans on the ADS experimental studies at KUCA are discussed.

Session 4: Targets and coupling experiments / 25

The zero power CLEAR-0 facility project and future programs

Author: Yican Wu[1]

Co-author: FDS team

[1] *Key Laboratory of Neutronics and Radiation Safety, Institute of Nuclear Energy Safety Technology, Chinese Academy of Sciences*

Lead-based reactor is one of the most promising nuclear energy systems for Accelerator Driven subcritical System (ADS) and Generation-IV reactors. Chinese Academy of Sciences (CAS) had launched a project to develop ADS and lead-based fast reactors technology since 2011. China LEAd-based Reactor(CLEAR) was selected as the reference reactor for ADS and fast reactor system, which was performed by Institute of Nuclear Energy Safety Technology (INEST/FDS Team), CAS. The program consists of three stages with the goal of developing 10MWth lead-based research reactor (CLEAR-I), 100MWth lead-based engineering demonstration reactor (CLEAR-II) and 1000MWth lead-based commercial prototype reactor (CLEAR-III) on each stage. To promote the CLEAR project successfully, INEST places more emphases on reactor design, reactor safety assessment, design and analysis software development, lead-bismuth experiment loop, key technologies and components R&D activities.

Detailed conceptual design of CLEAR-I has been completed and the engineering design is underway, which has subcritical and critical dual-mode operation capability for validation of ADS transmutation system and lead cooled fast reactor (LFR) technology. KYLIN series Lead-Bismuth Eutectic (LBE) experimental loops have been constructed to perform structural material corrosion experiments, thermal-hydraulics tests and safety experiments. The key components including the control rod drive and tested. In order to validate the test and key components and integrated operating technology of lead-based reactor, the lead alloy cooled non-nuclear reactor CLEAR-S, the lead-based zero power nuclear reactor CLEAR-0, the lead-based virtual reactor CLEAR-V and the high intensity neutron generator HINEG are being constructed.

In addition, HINEG and CLEAR-0 are coupled together to form a fusion neutron generator driven zero power subcritical fast reactor (FDS-0). The experiment results from FDS-0 can be used to validate the design and software in ADS and fusion-fission hybrid reactor.

Session 4: Targets and coupling experiments / 26

MegaPIE and its post-irradiation examination

The joint international MEGAPIE initiative –MegaWatt Pilot Experiment - aimed for the demonstration of designing, licensing, operating, dismantling, exploring and disposing a liquid metal spallation target at a beam power level of 1 MW. The initiative started in 1999 and resulted in the operation of the MEGAPIE target in the Swiss Intense Neutron Source (SINQ) in 2006. Thereafter, the target was dismantled in the ZWILAG facility, the interim storage facility of Swiss Nuclear Power Plants. Ten target pieces dedicated for sample production for subsequent post irradiation examination were brought to the Hot Laboratory of PSI, while the remains of the target were disposed.
From the target pieces brought to the Hot Laboratory approximately 1000 PIE samples of the lead bismuth eutectic (LBE) spallation target material and the structural materials –T91 in case of the lower liquid metal container and SS316L in case of the flow guide tube (FGT) –were fabricated. The LBE samples were analyzed at PSI with the aim of gaining information on isotope production and distribution throughout the target. Approximately one third of PIE samples from the structural materials were shipped to the international partner laboratories –CEA (France), JAEA (Japan), KIT (Germany), Los Alamos National Laboratory (USA), SCK·CEN (Belgium) –for investigation in 2013.
In this presentation we will provide an overview of the sample fabrication and show some results from the PIE investigations on the LBE and the structural material samples.

Session 4: Targets and coupling experiments / 23

The ESS target design and beam raster system

Corresponding Author: rikard.linander@esss.se

The European Spallation Source (ESS) is currently being constructed near the city of Lund in southern Sweden. When finalized and fully commissioned around 2025 it will be the world leading neutron scattering facility available to the science community. Unprecedented neutron flux and brightness will be achieved through the use of a state-of-the-art proton linear accelerator and a high-power target and a novel moderator design. Some of the unique features are the rotating and helium-cooled solid target, and the flat thermal and cold moderators. Also, the use of a set of raster scanning magnets for expansion of the proton beam onto the target, is a progressive choice. Other key objectives, parallel to the performance goal, are to make provisions for a safe, stable and reliable operation.
After a brief description of the overall configuration of ESS and a few high level nominal operating parameters for the facility, the presentation will focus on specific details of the proton beam expansion system, the target, and its cooling. Rationale for the employed design solutions will be addressed. Also, some interesting effects on the neutron output to the scientific instruments will be mentioned.

Session 4: Targets and coupling experiments / 20

Beam window design for ADS systems in JAEA

Author: Takanori Sugawara[1]

[1] *Japan Atomic Energy Agency*

To reduce the burden of the geological disposal of high-level waste (HLW), the Japan Atomic Energy Agency (JAEA) has investigated an accelerator-driven system (ADS) to transmute minor actinide (MA) included in HLW. Since the ADS is a hybrid system of an accelerator and a subcritical core,

there are various inherent issues in the research and development of the ADS. As one of the critical issues, the design of a beam window which is a boundary of the accelerator and the subcritical core, has been pointed out.
In this study, a new beam window concept was investigated by the coupled analysis of neutronics, particle transport, thermal hydraulics and structural analyses. Through these coupled analyses, feasible beam window concept was presented.

Session 4: Targets and coupling experiments / 30

Overview of high power targets for an ADS

Corresponding Author: karel.samec@gmail.com

A neutron spallation source for an Accelerator Driven System, commonly known as an ADS Target, must be able to function reliably and safely for the ADS concept to take hold as a viable option in the commercial sector. Targets operating at Megawatt level already exist but have, on the whole, been optimised with physics in mind. The "ideal" ADS target should, in addition to physics considerations, integrate inherent nuclear safety and reliability requirements borne of decades of experience in the nuclear power engineering sector.
Starting from basic nuclear safety requirements, a review of different options for ADS targetry provides an insight into the possible options for designing an ADS target. Existing designs from projects such as Megapie and Eurisol serves to illustrate the relative merits and weaknesses in specific target designs. Integrating such considerations early enough in the design stage would be of benefit to licensing an ADS operating at a power level compatible with its industrial potential, be it for waste transmutation or energy production.

Session 5: Innovative ideas and new R&D / 31

Development of high power target :dense granular flow by gravity

Session 5: Innovative ideas and new R&D / 12

CYCLADS: an EU FET proposal for high power cyclotron conceptual design.

Author: Marcello Losasso[1]

[1] *CERN*

Corresponding Author: marcello.losasso@cern.ch

It will be presented a recently submitted proposal to Horizon 2020 call FETOPEN. FET-OPEN means Future Emerging Technology, novel ideas for radically new technologies. The proposal presented, named CYCLADS, aims at designing a novel High Power Cyclotron (HPCy) as part of Accelerator Driven Systems (ADS) for innovative nuclear waste transmutation applications.

The presentation focuses on the general FET requirements and how the CYCLADS project fits these requirements. Then the project targeted breakthrough and the proposed innovative aspects are presented followed by the expected impacts on society, and the way the formed Consortia will implement the project if successfully evaluated. It is described CYCLADS ambition to combine latest advances in accelerator expertise, innovative ideas on nuclear Science & Technology and developments of HTS materials, to generate a transformative impact to EU economy and society. ADS can be a possible and effective method for incinerating the long lived component of the nuclear waste that pose longer-term radiological risks. To date no widely acceptable solution is at hand despite the technical maturity of geological disposal options. Thus, ADS may contribute to resolving the radioactive waste issue, which continues to be a major concern, because of the increasing inventory of spent nuclear fuel and the persistent public opposition to geological repositories. A special focus is devoted on the advantages of the unprecedented Single-Stage cyclotron in the MW power class proposed in CYCLADS over the current accelerators proposed for ADS. The ambition is to change the technical-economic equation for ADS alleviating most of the cost drivers identified in previous ADS designs, making it virtually adoptable by the market. The multidisciplinary group of European experts in key technological areas of accelerator, target and subcritical system, forming the Consortium is presented. The possible impact of CYCLADS on different sectors than the nuclear waste incineration is as well described, e.g. neutrino physics, isotopes production and nuclear industry, multiplying the societal and economic values of the project.

Session 5: Innovative ideas and new R&D / 13

Novelty of the LFR-AS-200 project

Author: Luciano Cinotti[1]

Co-author: Peter Briger [2]

[1] *Hydromine Nuclear Energy SARL*

[2] *Hydromine Nuclear Energy*

Corresponding Author: luciano.cinotti@gmail.com

The CYCLAD project proposed by CERN is a novelty-ADS because it couples a Single-Stage High Power Cyclotron with a sub-critical system based on the innovative lead-cooled LFR-AS-200.
LFR-AS-200 is under development by Hydromine in cooperation with ENEA. LFR stands for Lead-cooled Fast Reactor, AS stands for Amphora-Shaped, referring to the shape of the inner vessel and 200 is the electrical power in MW. The project has been carried out by a team of engineers, who had participated in the construction of SPX1.
The LFR-AS-200 exploits the peculiar, safety-relevant properties of lead, and has been conceived to enhance safety while dispensing of hitherto critical components typical of the pool-type fast reactors. In addition namely to the absence of intermediate circuits, a feature common to any other LFR project, LFR-AS-200 dispenses of (i) the in-vessel refueling machine, (ii) the above-core structure, (iii) the diagrid, (iv) the strongback, (v) the shielding elements, (vi) in-lead bearings of the pumps, (vii) flywheels to increase the mechanical inertia of the lead pumping system, (viii) the "LIPOSO"or equivalent tubular hydraulic connection between the pumps and the core and (ix) the "Deversoir" or equivalent system aimed at keeping the reactor vessel at the temperature of the cold collector.
The result is a specific volume of the primary system of less than 1 m3/MWe, i.e. about 4 times less than that of the SPX1 Sodium-cooled Fast Reactor, and also several times less than of other international LFR projects, a key-factor for cost reduction. The simplification of the primary system and the suppression of critical components reduces the required in-service inspection effort and increases the plant's mechanical robustness and availability.
These achievements are the result of the use of innovative components and of a primary system layout differing from current technology.
The steam generator features a short-height, spiral-tube bundle partially raised up to the reactor roof. It is fed from the bottom with outlet port at the lead free level of the cold collector in order to drastically reduce the reactor vessel height and the mass of displaced lead in the design case of steam generator tube rupture.
The primary pumps, with a short shaft full of lead, are installed in the hot collector in the space available inside the steam generator. The fuel assemblies are anchored at the top in gas space by means of a long stem which supports the core instrumentation and is equipped with mechanical expansors to open up the core like a flower and passively shut down the reactor, when the temperature of lead at core outlet exceeds the nominal value.
The removal of the decay heat is also ensured by passive systems in order to guarantee safety even in case of failure of protection logics, failure of operator intervention or cyber-attack.

Session 5: Innovative ideas and new R&D / 21

New thermal management technology for ADS fission in a molten salt core

Author: Peter McIntyre[None]

Session 5: Innovative ideas and new R&D / 27

the ADS-Troitsk project

Author: Stanislav Sidorkin[1]

Co-authors: A D Rogov [1]; A V Feschenko [1]; E A Koptelov [1]; E Lillestol [2]; F Carminati [2]; Frank Gerigk [2]; J-C de Mestral [2]; J-P Revol [2]; K Samec [2]; L. V. Kravchuk [1]; M Bourquin [2]; M Losasso [3]; R Gimalov [2]; V Grichine [2]; Y Kadi [2]

[1] *Institute for Nuclear Research Russian Academy of Sciences*

[2] *International Thorium Energy Committee*

[3] *CERN*

Corresponding Author: sidorkin@inr.ru

This report summarizes the results of discussions of a Research ADS Stand at the Institute for Nuclear Research (INR), to couple for the first time a proton beam to a subcritical core at a thermal power exceeding 1 MW (1 to 3 MW) for investigations in areas of nuclear transmutation and thorium fuel cycle.
The existing infrastructure provided by the INR linear accelerator and experimental area is a great asset, however, it imposes restrictions on the level of power and various technical aspects of the project, which will be discussed. The basic approaches to the design process are stated. Possible physical and design features of the Research ADS Stand, from the point of view of physical and technical safety at all stages of work, are considered.
Among other aspects, the horizontal insertion of the beam, additional barriers for safety to exclude loss of coolant, features of the tungsten and uranium targets providing the maximal neutron yield and rather long lifetimes, owing to the distributed thermal load on the beam window, will also be discussed. Results of the initial design studies will be given.
Further directions of research for the development of the neutron facility at INR will also be presented.

Session 5: Innovative ideas and new R&D / 28

An ADS irradiation facility for fast and slow neutrons

Author: Fabio Panza[1]

[1] *Istituto Nazionale di Fisica Nucleare - Sezione di Genova*

Corresponding Author: fabio.panza@ge.infn.it

We studied a flexible ADS based irradiation facility with fast neutrons inside the core and slow neutrons in the composite light reflector. A fast reactor core has been studied using MCNP-6 code with a mixed reflector formed by three concentric cylindrical layers (lead+graphite+lead) in order to have different neutron spectra to perform various types of measurements without perturbing the ADS core fast characteristics. We also included in the ADS design three irradiation channels with different neutron spectra to perform
measurements out of the reactor. We simulated different kinds of measurements to be performed in different positions, in the core, in the reflector and using the irradiation channels.

Starting from the previous design of a low-power, solid lead-based ADS system, fueled by UO2 (20% U-235), helium-cooled, with thermal power of 200 kW, intended for research, education and training purposes, we studied a possible modification of this system in order to make this machine a more flexible irradiation facility. We maintained a similar core structure, substituted the fuel with a more common MOX (22% Pu+Am), replaced helium with water as coolant and the pure lead reflector with a composite one, formed by alternate lead and graphite. The source intensity is about 8 x 10ˆ14 neutrons/sec and comprises a proton beam colliding on a beryllium target at the center of the core system. We simulated, using MCNP-6 and MCB codes, some examples of possible gamma spectroscopy measurements in different positions in.core, (CP1) out-core (RP1) and using the irradiation channels (IC2) in order to have different neutron spectra and various conditions. We considered some examples of irradiation of Medium Lived Fission Products (MLFP), Long Lived Fission Products (LLFP) and Minor Actinides (MA). Finally, we studied the effect of a simple reactor shielding and performed a preliminary thermal-hydraulics analysis of the system.

Session 5: Innovative ideas and new R&D / 38

Tram brainstorming - a dynamic beam window for ADS

Conclusions / 34

Summary of session 2: national ADS programs

Author: Jean-Pierre Revol[None]

Conclusions / 35

Summary of session 3: critical aspects of accelerators

Conclusions / 36

Summary of session 4: targets and coupling experiments

Conclusions / 37

Summary of session 5: innovative ideas and new R&D