VELLA

{Virtual European Lead LAboratory}

VELLA NEWSLETTER | **Year 1, issue 2**

CALENDAR OF THE EVENTS

September 9-13th, 2007 , **EUROCORR 2007**,
Konzerthaus Freiburg im Breisgau, Germany,
http://www.eurocorr.org/

September 16-19th, 2007, **ENC 2007**,
Brussels, Belgium
http://www.euronuclear.org/events/enc /enc2007/index.htm

September 24th -October 6th, 2007, **MATGEN-IV**, Carges, Corsica, France
http://www-matgen4.cea.fr

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VELLA COORDINATOR MESSAGE

These are very exciting times for the HLM-related research for nuclear applications!

Large efforts are dedicated worldwide to the HLM technologies: studies are going on in various areas of interest, from the material qualification, to thermal-hydraulic studies, component development and testing and so on.

In the fission-oriented research area, important R&D programmes are dedicated to the Generation IV LFR concept development, from the U.S. LFR Program, focused on the development of a small transportable reactor system for international deployment, to the European ELSY (*European Lead-Cooled System*) project, aimed at showing the possibility of realization and operation of a safe and competitive fast lead-cooled critical reactor.

Wide importance is given also to activities in support of the development of systems for the transmutation of radioactive waste, as can be noticed from the European Union (EU) projects, among the others, EUROTRANS (*EUROpean research programme for the TRANSmutation of high level nuclear waste in Accelerator Driven Systems*) and MEGAPIE-TEST (*MEGAwatt PIlot Experiment*).

In parallel, projects dedicated to address specific issues have been and still are carried out, as, for example, considering again the EU framework programmes, TECLA (*TEChnologies for Lead Alloys*), ASCHLIM (*ASsessment for computational Codes in Heavy LIquid Metal flows*) and SPIRE (SPallation IRradiation Effects).

Then, studies dedicated to material and component development as well as to HLM (Pb-17Li) technologies and thermal-hydraulics are going on, moreover, in the main fusion-oriented international research programmes.

In this framework take place VELLA (Virtual European Lead LAboratory), an initiative aimed at integrating the existing European HLM infrastructures, acting in a concerted way with the other EU FP6 programmes on HLM, more focused on the technological aspects.
Keywords for VELLA has to be considered **communication** and **connections**, being the main objective of the project the creation of a homogenous European “scientific community”, organized to support all the required technological challenges and the necessary research requirements.

It is a great pleasure for me, therefore, to circulate this VELLA newsletter, intended to be a point of information on the "HLM world", through thematic contributions on the different aspects of the HLM research and a window constantly open on the major events and initiatives in the field, in the pure spirit of VELLA initiative.
In this number you will find an overview of the efforts going on worldwide, passing from a brief presentation of the EU supported research activities, to the US programme, through the studies carried out in Japan.

I wish you a pleasant reading of this second issue

Gianluca Benamati

EURATOM SUPPORTED RESEARCH IN DEVELOPING HLM TECHNOLOGIES FOR NUCLEAR SYSTEMS

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Heavy liquid metals (HLM) such as lead and its eutectic alloy due to their efficient heat removal properties, high production rate of neutrons and other favourable characteristics, are expected to play an important role in the next generation of nuclear systems. These include their use as spallation targets and coolants for accelerator driven sub-critical systems (ADS) and as coolants for critical reactors. Some other characteristics will also play important role in their selection such as

- a high boiling point (permitting un-pressurized primary systems, enhancements in passive safety, good plant efficiency due to higher outlet operating temperature etc.);
- favourable neutronic characteristics (open lattice construction facilitating natural circulation of coolant, good fast neutron production etc.) and
- favourable compatibility with air/ steam/ water/ CO environment leading to plant simplifications.

Notwithstanding these good properties, lead and its eutectic are relatively corrosive for structural materials and can be contaminated by solid impurities contained in these materials during operation. Also, oxygen control is an important element in operation as it can adversely influence the efficiency of heat removal via corrosion. Moreover, an HLM system requires fairly elaborate engineering construction that includes components such as electromagnetic pumps, heat exchangers, pipelines, volume compensator, drainage tank, electric heating systems, control and instrumentation systems, support metallic structure, system of radiation shielding etc., all of which require extreme care in design and operation.

With a view to tapping the huge potential of HLMs such as lead and its eutectic for use in the nuclear systems, Euratom multi-annual Framework Programmes (FP) are supporting research in HLMs to resolve the problems mentioned above and engineer viable HLM systems for use in future nuclear systems. Starting from 1998, the European Commission (EC) has supported shared cost projects proposed by Member States in the field of HLM technologies geared towards ADS and Fast Reactors. These activities fall within the Transmutation activities (Waste management) and the investigation of the potential of Generation IV Reactors (Reactor Systems).

In the Euratom Fifth FP (1998-2002) four projects supported by the EC have been successfully completed:

- TECLA, coordinated by ENEA with a total budget of 6 M€ (EC contribution of 2.5 M€) was dedicated to assess the use of lead alloys both as a spallation target and as a coolant for an ADS;
- MEGAPIE-TEST, coordinated by FZK with a total budget of 6 M€ (EC contribution of 2.3 M€), was a first decisive step to design and operate a liquid metal spallation target at PSI, Villigen, with a high-energy proton beam SINQ. Successful completion of the project has demonstrated the feasibility, licensing and a fairly long-term operation under realistic conditions of a high power spallation target;
- ASCHLIM, coordinated by SCK-CEN and financed by the EC with a total budget of 0.12 M€ (EC contribution 0.12 M€) was aimed at sharing experience in the field of computational fluid dynamics codes applicable to HLM and their benchmarking;
- SPIRE, coordinated by CEA with a budget of 7 M€ (EC contribution of 2.4 M€) addressed the irradiation effects specific to spallation target environment on basic in-service properties (tensile, Charpy, fracture toughness, irradiation creep and swelling). It also studied the properties of selected structural steels under spallation target irradiation conditions and basic mechanisms and modelling for the phenomena observed under spallation conditions.

In the Sixth FP (2002-2006) three projects currently underway deal with HLM technologies.

- EUROTRANS – Domain 4 (Technology) coordinated by FZK with a budget 10 M€ (EC contribution of 5.2 M€) is carrying out further research in HLM to fill the gaps in research in this area with a view to its application to ADS;
- ELSY, coordinated by ANSALDO with a budget of 6.9 M€ (EC contribution of 2.9 M€) aims to show the possibility of realization and operation of a safe and competitive fast lead-cooled critical reactor;
- VELLA, coordinated by ENEA with a budget of 3.3 M€ (EC contribution of 2.3 M€) has major objectives to integrate the existing European HLM infrastructures, developing synergies and complementarities among the laboratories and the research groups across the EU.

Seventh FP (2007-2011) has just started and proposals submitted by consortia from the Member States are being evaluated by the European Commission.

In conclusion, several projects supported by Euratom are ongoing in the EU in the field of HLM technologies for sub-critical (ADS) and critical (lead-cooled fast reactor) systems to resolve the key problems of future nuclear systems using HLM technologies with a view to ensuring their safe and reliable operation.

US LFR PROGRAMME SUMMARY

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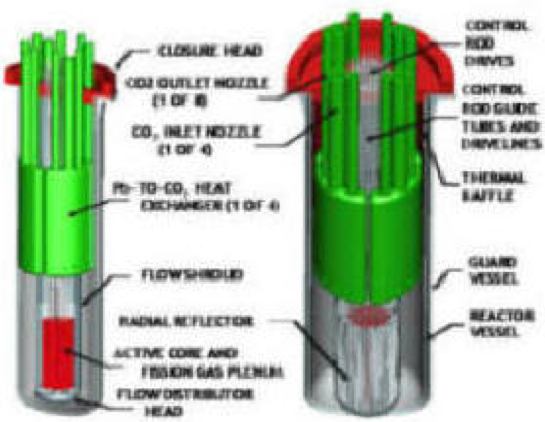
Background and Introduction. The U.S. LFR Program is focused on the development of a small transportable reactor system for international deployment known as the Small Secure Transportable Autonomous Reactor (SSTAR) with the following objectives:
Sealed or cassette core: no on-site refueling

- Transportability: entire core and reactor vessel delivered by ship or overland transport
- Long-life Core: 15-30 year core life is the target
- Autonomous load following with simple integrated controls: minimum operator intervention or maintenance required
- Local and remote observability: rapid detection/response to perturbations
- Minimum industrial infrastructure required in host location
- Very small operational (and security) footprint

Current Program Thrust. In furtherance of this goal, current system development activities are being directed toward a pre-conceptual design and viability assessment for a SSTAR 20 MWe (45 MWt) natural circulation LFR for international deployment consistent with GNEP goals.
In addition, the U.S. LFR program has been recently realigned to focus upon a concept for a near-term deployable demonstration test reactor to demonstrate successful reactor operation with a lead coolant at realistic system temperatures, provide a capability to irradiate advanced fuels and materials, and incorporating innovative engineering that will help show the economic benefits and industrial attractiveness of Pb as a primary coolant.
A sketch of the current reference concept for the SSTAR small, modular, fast reactor is shown in **the figure.**



Conceptual 20 MWe (45 MWt) SSTAR system.

This pre-conceptual design is a small shippable reactor (12 m X 3.2 m vessel), with a 30-year life open-lattice cassette core and large-diameter (2.5 cm) fuel pins held by spacer grids welded to control rod guide tubes. . The design integrates three major features: primary cooling by natural circulation heat transport; lead (Pb) as the coolant; and transuranic nitride fuel in a pool vessel configuration. The main mission of the 20MWe (45MWt) SSTAR is to provide incremental energy generation to match the needs of developing nations and remote communities without electrical grid connections, such as those that exist in Alaska or Hawaii, island nations of the Pacific Basin, and elsewhere. This may be a niche market within which costs that are higher than those for large-scale nuclear power plants are competitive. Design features of the reference SSTAR in addition to the lead coolant, 30-year cassette core and natural circulation cooling, include autonomous load following without control rod motion, and use of a supercritical CO_2 (S-CO_2) Brayton cycle energy conversion system. The incorporation of inherent thermo-structural feedbacks imparts walk-away passive safety, while the long-life cartridge core life imparts strong proliferation resistance. If these technical innovations can be realized, the LFR will provide a unique and attractive nuclear energy system that meets Generation IV goals.

Research Directions. The research priorities of the SSTAR program are organized to address system design and evaluation, fuel cycle, energy conversion and material issues.

The ongoing and planned R&D in the US is intended to address viability issues associated with the LFR leading to the design and construction of an LFR demonstration plant. Viability will be established through focused R&D tasks and with formulation of a technically defensible pre-conceptual design.

System Design and Evaluation. R&D tasks for System Design and Evaluation address the areas of core neutronics, system thermal hydraulics, passive safety evaluation, containment and building structures, in-service inspection, and assessing cost impacts. Core design is essential to establishing the necessary features of a 15- to 30-year-life core and determining core parameters that impact feedback coefficients. R&D tasks associated with this work include further optimization of the core configuration, establishing a start-up/shutdown control rod strategy, and calculating reactivity feedback coefficients.

Fuel and Fuel Cycle. Viability of both nitride fuel and whole-core cassette refuelling are to be addressed in the fuel and fuel-cycle R&D.

Energy Conversion. Use of a S-CO_2 Brayton cycle for energy conversion offers the prospect of higher thermal efficiencies with lower Pb coolant outlet temperatures and small turbo-machinery reducing the footprint and cost of the power converter.

Materials. Viability of long core lifetime, passive safety, and economic performance (both capital and operating costs) of the LFR concept will depend on identifying materials with the potential to meet service requirements.

Concluding Comment. On a worldwide basis, LFR technology is experiencing broad attention. Systems being considered include subcritical systems, central station critical systems and concepts for small transportable reactors for international deployment. These three types of systems are different in both mission and design, but there is a substantial overlap in the research and technology needed for their development. For this reason, international cooperation and collaboration in the development of LFR systems is essential.

LBE RESEARCH ACTIVITIES IN JAPAN

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The 8th meeting of "LBE Utilization Technology" Research Committee was held at Tokyo Institute of Technology on July 3, 2007. It was the final meeting of a series of three committees: the committee and the former two committees: "HLM Utilization Technology" Research Committee, in the Atomic Energy Society of Japan (AESJ) chaired by Hiroshi Sekimoto since October 2001. The programs and some presentations of HPPA5 (Mol, Belgium), ICAPP 2007 (Nice, France), IVth Int. WS on Mater. for HLM cooled Reactors and related Tech. (Rome, Italy) and SMINS (Karlsruhe, Germany) were briefly reported by Minoru Takahashi (Tokyo Tech). The prospect of future research on lead alloy technology was discussed with the speeches of topics corrosion and enrittlement subjects for ADS development, and the status and prospect of development of LFR provided by Yuji Kurata (JAEA), Kenji Kikuchi (JAEA) and Minoru Takahashi (Tokyo Tech), respectively. Then, the lectures and reports entitled "Status and Future Prospect of LBE Utilization Technology in Development of LFR and ADS" provided by the committee at the 2007 Fall Meeting of AESJ (Kitakyushu, 28 September, 2007) were discussed. Finally, it was reported that the Handbook of LBE Utilization Technology (CD-ROM) edited by the committee would be soon published by AESJ.
The contents of the Handbook of LBE Utilization Technology are as follows: Chap. 1 Introduction, Chap. 2 Research and development of ADS, Chap. 3 R & D of LFR (Properties, material corrosion, oxygen control and sensor, thermal-hydraulics, ultrasonic flowmeter and velocimeter, polonium), Chap. 4 Fundamental Studies on LBE, and Chap. 5 Concluding Remarks. It contains abstracts and viewgraphs presented at the meetings of the two committees since Oct. 2001.

Studies on conceptual design of LFR and LBE technologies were continued in Japan as follows:
Hiroshi Sekimoto (Tokyo Tech.) studied a startup of CANDLE burnup with enriched uranium at the initial core, and the effects of recladding of CANDLE burnup for LFR,and the design study on small long-life CANDLE reactor and its safety analysis. The design study on small long life CANDLE LFR (#33 and ICONE15-10873) was presented by his graduate student, M. Yang, at The 2nd COE-INES International Symposium on Innovative Nuclear Energy Systems (INES-2) held in Yokohama, Japan, 26-30 November, 2006, and ICONE-15, respectively.

Minoru Takahashi (Tokyo Tech.) studied the conceptual design of LBE-cooled direct contact boiling water fast reactor and related LBE technologies. It was found that the FeAl alloy-coated steels, refractory metals of W and Mo, and ceramics of SiC and Ti_3SiC_2 showed excellent corrosion resistance in oxygen-controlled LBE at the temperature of 700°C. Particularly, the unbalanced magnetron sputtering method could provide uniform and stable FeAl-coating layer on the steel surfaces. The studies were presented by the members of his group at INES-2 at international conferences and workshops, i. e., design study on reactor structure of LBE-cooled direct contact boiling water fast reactor (PBWFR) (#59) (by M. Takahashi); safety design of LBE-cooled direct contact boiling water fast reactor (PBWFR) (#60) (by M. Takahashi); compatibility of surface-coated steels, refractory metals and ceramics with high temperature LBE (#123) (by M. Takahashi); the performance of oxygen control system (#30) (A. K. Rivai), a rail transportable lead-bismuth coled reactor (#52) (by V. Dostal); modeling and optimization of steam dryer for removal of LBE doplets (#53) (by V. Dostal); LBE doplets generation and their removal by an electrostatic precipitator (#54) (by V. Dostal); and boiling heat transfer behavior of LBE/steam-water direct contact two-phase flow (#43) (Novitrian). The papers will be published in Progress in Nuclear Energy (Elsevier) in 2007. The results of the studies were also presented at ICONE 15, i. e., LBE droplet generation (ICONE15-10187) (by V. Dostal); numerical analysis of LBE-water direct contact boiling heat transfer (ICONE15-10153) (by Y. Yamada); visualization of LBE-water/steam direct contact boiling two-phase flow using gamma-ray radiography (ICONE15-10817) (by T. Yumura); and experimental study of molten LBE droplets impinging on surface at various angles in gas flow (ICONE15-10799) (by X. Zhi). The status and prospect of development of lead-alloy-cooled fast reactor was presented by M. Takahashi at 12th Symposium of Power and Energy Technology, Japan Society of Mech. Engineers (JSME) held in Tokyo, June 14, 15, 2007. The design study of PBWFR and corrosion test results were also presented at ICAPP 2007. In addition, the results of corrosion and oxygen sensor tests were presented by Minoru Takahashi at HPPA5, 5th Int. WS on Mater. for HLM cooled Reactors and related Tech. and SMINS.

Akihiko Kimura (Kyoto Univ.) has performed the research and development of super ODS ferritic steels for the application to LBE cooled system. It was found that the ODS steels added with 4wt.%Al showed excellent corrosion resistance in LBE at 650°C. Surveillance corrosion tests are scheduled to investigate the effects of test temperature and oxygen content in the LBE. The results were presented at ICAPP 2007 (paper No. 7374) and SMINS.

Yoshihisa Nishi (CRIEPI) performed static corrosion tests of ODS whose chemical compositions of Cr and Al differed. The test was performed during 4,000h in oxygen-controlled lead bismuth eutectic at 650°C. The test specimens were provided by JAEA, and the analysis were conducted by JAEA and CRIEPI. As the results, good corrosion resistance by aluminium oxide formation on the surface has been obtained although chromium effect on corrosion has not been observed. The results were reported in the JAEA-Research 2006-037 and presented at JSME annual meeting at Kumamoto, 2006.

Kenji Kikuchi (JAEA) studied the corrosion behavior of candidate materials of Japanese ADS beam windows, i. e., F82H and JPCA, experimentally in a circulating LBE loop under the conditions of the maximum temperature 500°C, the velocity 0.4 to 0.6 m/s, and the oxygen concentration 2 – $4x10^{-5}$ mass% for 500 to 3000 hrs. Round bar type specimens were put in the circular tube of the loop. Electron beam welded joint in the middle part of specimens were also studied. In the first 1000 hrs, corrosion rate were estimated to 10 to 20 mm at 450 and 500oC. Yuji Kurata (JAEA) conducted corrosion tests in Pb-Bi to investigate corrosion behavior of various steels for development of corrosion-resistant steels. Effects of temperature and oxygen concentration on corrosion behavior in Pb-Bi were clarified. Slow-strain rate tensile tests will be also conducted to study liquid metal embrittlement in liquid Pb-Bi. T. Furukawa (JAEA) presented the study on corrosion behavior of weld joint of high chromium alloy in flowing LBE under active oxygen control (#57) at INES-2.

SPOTLIGHT

IV workshop on Materials for HLM Cooled Reactors and Related Technologies,

Rome, Italy,

May, 21 -23rd , 2007.

The workshop on materials for HLM cooled reactors and related technologies has taken place in its fourth edition after Karlsruhe 1999, Brasimone 2001 and Roma 2003, on May 21-23rd, 2007, in Rome .
The event has been a great opportunity to share knowledge and insight on the Heavy Liquid Metal technologies for nuclear applications, promoting, in the spirit of VELLA, the exchange of the scientific results obtained in the different R&D programmes and encouraging meaningful interactions and the creation of synergies among the scientists operating in the field.
Around 90 researchers from 16 different countries participated in the workshop. The 20% of the participants came from outside Europe.
The technical program has consisted of invited plenary and specific technical sessions, organized in eight areas of technical interest, as follows.

system design and component development;
corrosion and structure protection;
mechanical behaviour in HLM;
physical/chemical properties of HLM and impurities control ;
oxygen control;
irradiation in liquid metals;
thermal-hydraulics;
safety and procedures.

A total of 51 abstracts have been submitted for review.

The contributions presented at the workshop are available on the official VELLA web site at the following page: http://192.107.58.30/HLMWORK.htm .

The proceedings of the workshop will be published on a special issue of the Journal of Nuclear Materials

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