Executive Summary:

HeLiMnet is an EURATOM FP7 Project aimed at integrating and harmonizing the research and development efforts going on within and outside Europe, in the field of Heavy Liquid Metal (HLM) technologies for nuclear applications.

At the Project, that is under the CSA-CA funding scheme, participated 13 institutions from all over the Europe, in the view to create a functional network in support to the implementation of the Strategic Research Agenda (SRA) of Sustainable Nuclear Energy Technological Platform (SNE-TP).

The HeLiMnet Project was intended to create a large and strong network for the diffusion of information on the use for nuclear applications of HLM. It was aimed at rationalizing the knowledge through the development of guidelines, protocols and standards. Specific goal was the appraisal of the liquid metal technology research area, through the analysis of approaches and activities going on at national and international level in different areas of investigation the identification of possible cooperation, the definition of existing gaps and possible future R&D activities to cover these gaps.

On the basis of the nature of the proposal, the consortium of participants in the project included institutions with different capabilities, with a significant pre-existing know-how, involved in the major projects regarding the development of HLM systems, with an high-level profile, well proven experience in the various area of interest and strong ability in cooperating.

Given the possible future extensive use of lead and lead alloys in nuclear systems, a rationalisation of results so far obtained for a deep understanding of its physical properties and engineering applications is mandatory. Large efforts both at national level as well as within the European Commission have been already dedicated to the development of HLM technologies. In this frame, specific efforts dedicated to the rationalization of the research area had a positive impact.

The project enviseged, therefore, the following specific actions:

1. Knowledge and results dissemination through the use of both advanced information technologies and traditional tools as workshops, seminars, etc..

2. Identification of operational procedures with the aim to optimize the use of experimental facilities and to improve data reliability.

3. Cooperation with LFR and ADS design teams to identify R&D priorities.

4. Survey of activities on HLM technologies ongoing worldwide and in different areas to maximize the knowledge transfer and possibly harmonize experimental and numerical approaches.

The HeLiMnet Project was expected to support the implementation of the Strategic Research Agenda, obtaining three specific results:

1. The implementation of a large and effective network for the diffusion of information on HLM technologies, thanks to the realization of an interactive website and the creation of strong links among laboratories;

2. The rationalization of the existing knowledge, thanks to the development of guidelines and recommendations for good procedures;

3. The harmonization of the EU research area in the field of HLM technologies, thanks to the identification of gaps and overlapping, to streamline efforts avoiding superposition or duplication of activities.

HeLiMnet was expected to have a strong beneficial impact in the EU research area, promoting the integration of the existing European infrastructures and developing synergies and complementarities among the laboratories and the research groups, while acting in a concerted way with the other national and international programmes and while exploiting possible shared approaches between different liquid metal systems.

It is important to underline that the Project has been structured in order to support the implementation of the SRA providing results at a time horizon compatible with the foreseen decisions and down selection of preferred future systems to be developed in several European countries.

Project Context and Objectives:

HeLiMnet is a Project funded in the 7th Framework Programme of EURATOM, aimed at integrating the R&D efforts going on within and outside Europe, in different areas of investigation. The project foresaw the participation of 13 institutions from all over the Europe, in the view to create a functional network, harmonizing the research area on HLM technologies, in support to the implementation of the Strategic Research Agenda of SNE-TP (Sustainable Nuclear Energy-Technology Platform).

In particular the Project was intended to create a large and strong network for the diffusion of information, exploiting the characteristics of both the new information technologies in order to create a virtual space for debates, focus groups and information exchanges, and the traditional tools as workshops, seminars, information days etc.

Moreover, it was aimed at rationalize the knowledge through the development of guidelines, protocols and standards, with particular attention to the homogenization of operational procedures in order to have a better control on the quality and comparability of the experimental data obtained in different labs.

Finally, one other goal was the appraisal of the liquid metal technology research area, through the analysis of approaches and activities going on at national and international level in different areas of investigation (fission (LFR, ADS, SFR),neutron spallation targets and fusion), the identification of possible cooperation, the definition of existing gaps and possible future R&D activities to cover these gaps.

In order to meet the above mentioned goals, several specific actions have been enviseged:

1. The knowledge and results dissemination through the use of advanced Information Technologies (website and electronic newsletters)
2. The knowledge and results dissemination through traditional tools as workshops, seminars, information days etc.;
3. The identification of operational procedures with the aim to optimise the use of experimental facilities and to improve data reliability
4. The cooperation with LFR and ADS design teams to identify R&D priorities and possibly promote activities in support to component design selections and validations;
5. A survey of activities on HLM technologies ongoing worldwide and in different areas (i.e. fission (LFR, ADS, SFR), neutron spallation targets and fusion oriented research), with the aim to maximise the knowledge transfer and possibly harmonise experimental and numerical approaches.

On the basis of the above described actions, the project was structured into five technical work packages, each one corresponding to a specific goal, plus a dedicated work package aimed at managing the consortium activities.

A work package was devoted (WP2) to improve the diffusion of knowledge and information exploiting the potential of the new information technologies, such as a thematic website on HLM technologies acting as central point of information and a periodic electronic newsletter, addressing different topics of interest, highlighting the latest news, etc. A website dedicated to the use of heavy liquid metals for nuclear applications has been realized and made available online with the scope to act as a common platform for exchanging information among experts and with public at large. The website was expected to act, in fact, on a double level: provide general information on HLM technologies and HLM system development to public and provide specific technical information and space of discussion to the specialists.

One other WP (WP3) was dedicated to the dissemination of knowledge and results through the organization of international workshops. The workshops were focused in the reactor systems identified by the SNE-TP SRA as the candidate to be developed: Lead Cooled Fast Reactor (LFR) as an alternative to Sodium Fast Reactor (SFR). Accelerator Driven Systems have been also considered because their technology shows a synergetic R&D with fast reactor, in particular with LFR. The workshops provided a discussion and dissemination forum on relevant topics for liquid metal reactor systems, developed in the frame of European, national and international projects. The workshops has been considered as an adequate tool to promote an active information exchange among researchers, engineers, suppliers and users.

A work package (WP4) is focused on the area of the development of protocols and standards for laboratory tests of HLM technology elements and for experimental HLM facilities operation. Overview of the up-to-date data available is the preliminary step. Afterwards, the aim is to standardize the main operational procedures to reach a production of more homogeneous data.

Work package 5 is aimed to create a direct link among the LFR/ADS design teams and the technologists involved in the frame of the HLM technologies, allowing to support the development of the Heavy Liquid Metal nuclear systems. Moreover, the contacts are extended to the ESFR (FP7) communities which evaluates an alternative coolant for the intermediate loop of a Sodium cooled Fast Reactor, the LBE (Lead Bismuth Eutectic), which has been selected as the most promising alternative coolant. The WP, starting from the identification of the 'state of the art' for the GEN-IV LFR and ADS development, defines the needs for the design and operation of a prototype for both systems. In fact, for what concerns the development of the GEN-IV LFR and ADS, the Strategic Research Agenda (SRA) foresees the construction and start-up of the prototype by 2020, the European Technology Pilot Plant (ETPP) and MYRRHA/XT-ADS respectively.

In order to support the conceptual and detailed design of these prototypes, a strong R&D effort dedicated to the development and understanding of HLM technologies is needed, ranging from system design and component development, to materials qualification, lead technology development and instrumentation development to innovative fuels and fuel cycle. The work performed in the frame of this WP have highlighted the existing gaps in the HLM technologies, delineating the main R&D effort needed in the fields above summarized.

Finally, a WP (WP6) was intended to perform a survey of activities and schedules on liquid metal technologies developed and studied in the frame of different applications (e.g. fission, neutron spallation target development, fusion, etc.). The aim was to enhance the information exchange and possibly compare experimental and numerical approaches in these different areas. This objective has been achieved through the link between initiatives taken at the level of the single EU member states or at European Community level. In particular, the R&D activities as defined and updated within the Strategic Research Agenda, prepared in the frame of the SNE-TP were taken into account. Moreover, projects supported by the European Commission especially under the EURATOM treaty were also considered. Finally, activities and initiatives, started outside the European structures as e.g. those considered in the frame of the Generation IV, OECD and IAEA were also taken into consideration.

Project Results:

The HeLiMnet project was intended to support the implementation of the Strategic Research Agenda for the ADS and LFR system development coordinating activities aimed at:

1. Creating a large and strong network for the diffusion of information on HLM technologies.
2. Rationalizing the existing knowledge.
3. Harmonizing the research area in the field of HLM technologies, to coordinate the efforts in the implementation of the SRA for the LFR and ADS development.

In order to meet the above mentioned goals, the following different actions were foreseen:

Action A.1

- Knowledge and results dissemination through the use of advanced Information Technologies (website and electronic newsletters)

Action A.2.

- Knowledge and results dissemination through traditional tools as Workshops, seminars, information days etc..

Action A.3

- 3.1-Identification of operational procedures with the aim to optimise the use of experimental facilities and to improve data reliability.
- 3.2-Cooperation with LFR and ADS design teams to identify R&D priorities and possibly promote activities in support to component design selections and validations.
- 3.3-Survey of activities on HLM technologies ongoing worldwide and in different areas (i.e. fission (LFR, ADS, SFR), neutron spallation targets and fusion oriented research), with the aim to maximise the knowledge transfer and possibly harmonise experimental and numerical approaches.

In detail:

The first action (A.1), was addressed to improve the diffusion of knowledge and information exploiting the potential of the new information technologies, such as a thematic website on HLM technologies acting as central point of information and a periodic electronic newsletter, addressing different topics of interest, highlighting the latest news, etc. A website dedicated to the use of heavy liquid metals for nuclear applications has been realized and made available online with the scope to act as a common platform for exchanging information among experts and with public at large. The website provides general information on HLM technologies and HLM system development to public and specific technical information and space of discussion to the specialists.

The second action (A.2) consisted in the dissemination of knowledge and results through traditional tools as Workshops, seminars, information days etc. In particular two international Workshops have been organised in the framework of the project. The Workshops were focused in the reactor systems identified by the SNE-TP SRA as the candidate to be developed: Lead Cooled Fast Reactor (LFR) as an alternative to Sodium Fast Reactor (SFR). Accelerator Driven Systems were also considered because their technology shows a synergetic R&D with fast reactor, in particular with LFR. The Workshops have provided a discussion and dissemination forum on relevant topics for liquid metal reactor systems, developed in the frame of European, national and international projects and have been considered as an adequate tool to promote an active information exchange among researchers, engineers, suppliers and users.

The third action (A.3) consisted in the identification of three thematic Areas:

Area 1

The first area was related to the development of protocols and standards for laboratory tests of HLM technology elements and for experimental HLM facilities operation, with the aim to optimise the use of experimental facilities and to improve data reliability.

Overview of the up-to-date data available was the preliminary step. Afterwards, the aim has been to standardize the main operational procedures to reach a production of more homogeneous data. The initial part of the work was based on the collection and review of the available documents for HLM technology elements and facilities. Each Partner specified their exact contributions in terms of which equipment would be available for the work. The tasks were divided in subtasks, of which each Partner could take responsibility.

Once the work was distributed among the Partners, each member worked on a draft version of the document. These drafts were circulated, then, among the Partners to complete and comment on the structure of the document. In most of the cases, the good networking connection and communication, worked as a base for the whole work and writing of the documents was a common effort shared by all the Partners contributing to this activity.

The results achieved in the WP4, representing this Area, have pointed out to the level of knowledge in the field of technology elements testing and experimental facilities in HLM technology. Acknowledgement of these levels gives a description of the progresses achieved in the field and the amount of work needed in future R&D.

The WP4 was particularly successful on the complex connection and networking between all the Partners, which shared their knowledge and experience in the fields of concern. Communication and exchange of ideas through technical meetings and an abundant exchange of e-mails, consolidated the connection between the various institutions and widened the possibility of collecting information.

Area 2

The second area was the area of cooperation with LFR and ADS design teams, to identify R&D priorities. A direct link among the LFR/ADS design teams and the technologists involved in the frame of the HLM technologies was created, to support the development of the Heavy Liquid Metal nuclear systems. Moreover, the contacts were extended to the ESFR (FP7) community, which evaluates an alternative coolant for the intermediate loop of a Sodium cooled Fast Reactor, the LBE (Lead Bismuth Eutectic), which has been selected as the most promising alternative coolant. Starting from the identification of the 'state of the art' for the GEN-IV LFR and ADS development, the definition of the needs for the design and operation of a prototype for both systems has been carried out. In fact, for what concerns the development of the GEN-IV LFR and ADS, the Strategic Research Agenda (SRA) foresees the construction and start-up of the prototype by 2020, the European Technology Pilot Plant (ETPP) and MYRRHA/XT-ADS respectively.

In order to support the conceptual and detailed design of these prototypes, a strong R&D effort dedicated to the development and understanding of HLM technologies is considered as necessary, ranging from system design and component development, to materials qualification, lead technology development and instrumentation development to innovative fuels and fuel cycle. The highlighting of the existing gaps in the HLM technologies, delineating the main R&D effort needed, was therefore a key activity of the project.

During the whole duration of the project, ENEA led the activities related to this Area that have been performed in the frame of the work package 5 of the Project. ENEA coordinated the WP5, by contacting and making synergies with the main European actors in the frame of the Accelerator Driven Systems (ADS) design and Led Cooled Fast Reactor (LFR) design. Among the others SCK-CEN, CEA, KIT (as members of the consortium) and ANSALDO NUCLEARE SPA (as stakeholder of the LFR) have been involved. In the frame of several technical (also bilateral) meetings several outcomes have been pointed out.

The main results achieved are:

1. The support to the implementation of the SRA for the LFR and ADS development, through a strong interaction between the ADS/LFR designer and stakeholders. The activities allowed a systematic exchange of information on component design and their validation needs (by experimental and numerical activities).

2. The identification of the main R&D needs in support to an effective implementation of the SRA to develop ADS and LFR systems.

3. A strong synergy with the IAEA - Fast Reactor Technology Development Group.

4. A contact with SFR community during the Meeting dedicated to WP5 (Bologna 2011 January 19th) and latter during the Workshop organized by CEA in October 2011.

In this frame, several synergies and commonalities have been also identified among LFR/ADS and SFR, with a strong collaboration with CEA. The main result of those interactions was the 'International Workshop on Liquid Metal Fast Reactors: Issues and Synergies' held in Aix-en-Provance on the 4th to 7th October 2011. It should be emphasized that the project Partners involved in the activity of WP5 have contributed with their competencies at the whole Workshop, also in term of definition and organization.

A report on the 'State of Development of LFR and ADS Technologies and R&D Needs' has been issued, where the European involvement in the HLM technology was described. The lead cooled reactor concepts ELSY, LEADER and ELECTRA, as well as the ADS technology (with main focus on the CDT Project, which is related to the MYRRHA design) are reported and described in the report. Moreover, besides the status of the CDT and LEADER projects (FP7 EC), several initiatives that support HLM R&D have been described, such as MATTER, THINS, ADRIANA, GETMAT and FREYA.

The overview of the activities on the HLM technology and the on-going projects worldwide has been also reported, focalizing on the critical core reactors under development in Russia, USA, Japan, South Korea, India and Indonesia.

Finally, the future R&D needs for LFR and ADS technologies have been discussed. On the basis of the state of development defined in the first year, the R&D needs have been classified in main areas and sub-areas. A specific questionnaire has been developed and submitted to the Partners and stakeholders involved in HeLiMnet. The collected answers coming from the Partners are reported into the D5.1 report.

The main final result is the availability of a complete overview related to the status of the LFR/ADS development in Europe, as well as the future R&D needs. The outcomes, carried out in collaboration with the designer of MYRRHA and ALFRED, will allow to successfully support to further implementation of the SRA for the LFR and ADS development. Moreover a strong synergy with the IAEA - Fast Reactor Technology Development Group, has been established

The exchanges with SFR community have allowed to identify topics for which clear synergies have been identified.

Area 3

The third area consisted in a survey of activities and schedules on liquid metal technologies developed and studied in the frame of different applications (e.g. fission, neutron spallation target development, fusion, etc.). The aim was to enhance the information exchange and possibly compare experimental and numerical approaches in these different areas.

This objective has been achieved through the link between initiatives taken at the level of the single EU member states or at European Community level. In particular, the R&D activities as defined and updated within the Strategic Research Agenda, prepared in the frame of the SNE-TP have been taken into account. Moreover, projects supported by the European Commission especially under the EURATOM treaty were also considered. Finally, activities and initiatives, started outside the European structures as e.g. those considered in the frame of the Generation IV, OECD and IAEA have been also taken into consideration.

The work was structured in two parts:

1)The objective of the first part was to carry out an analysis of the structure of the HLM international research area. Emphasis has been put on objectives, strategies, effort and schedule and possibly results of initiatives within the EU (e.g. SRA, EC funded projects) and within other international structures as e.g. GEN IV, OECD and IAEA. By performing this analysis understanding of common issues could be drawn and common initiatives which would strengthen the HLM research area could be identified. This work has produced a report on the initiatives on-going in the different world regions and within relevant organizations as e.g. IAEA and OECD. It turned out that Europe has a front runner position in the field of HLM technology and the networking activity performed in Europe as well as the EC funded projects have strengthened this position. Moreover, it could be shown that the other country where HLM technology is developed with a certain effort is Russia. A closer cooperation with Russia might be of advantage in this field. Within the SRA three liquid metal reactors have been identified

(LFR, ADS (MYRRHA) and SFR (ASTRID)). The aim of the work was to identify issues which are common to these reactor systems. Moreover, the ADS foresee the neutron spallation target. These components are also developed for other applications. An evaluation of needs and common approaches to identify operational items (e.g. handling, life-time, etc.) has been performed.

2)The second part of the activity has taken advantage of the second HeLiMnet Workshop organized in the frame of this project. This Workshop has addressed HLM and Na cooled reactor systems by looking on design, safety and technological aspects. It turned out that some approaches can be addressed in a common way as e.g. the strategy of ISIR. Moreover, in the frame of SFR an alternative tertiary coolant to water has been under investigation. HLM has shown potentialities to be considered as an option for this technological item.

As far as the MEGAPIE target is concerned, a list of lessons learned has been issued. These lessons might be driving for the selection of HLM as spallation neutron source. However, at present there are no teams in the area of spallation neutron sources considering seriously the option of HLM.

All the knowledge produced in the Project is available in the Project official website: http://www.HeLiMnet.eu , in the 'Thematic Areas', 'Documentation' and 'Events' sections.

The description of the structure and the main contents of the HeliMnet - official website is so an exhaustive description of the products of the Project.

Thematic Areas

On the basis of the structure of the Project, three thematic areas have been pointed out :

T.A.1: LFR and ADS Technology Development: This area is aimed at outlining the state of the art in the R&D activities and to point out the main open issues related to the LFR and ADS technology development.

T.A.2: Guidelines, protocols and standards: In this area is possible to find the protocols and standards for HLM technology elements testing developed in the project for Oxygen Sensors, Pumps, Inductive Flowmeters and Level sensors, Heat Exchangers. Moreover, the area contains the guidelines for operation of HLM experimental facilities developed in the project.

T.A.3: International Activities: The area contains an overview of:

1. the HLM activities in EU, IAEA, OECD and Generation IV.
2. the commonalities between LFR, ADS and SFR.
3. the commonalities between ADS and spallation targets.

T.A.1: LFR and ADS Technology Development

This Thematic Area is aimed at outlining the state of the art in the R&D activities and to point out the main open issues related to the LFR and ADS technology development. In particular, the optimization of the European R&D efforts in support to both LFR and ADS development, exploiting the commonalities, permitting cost-sharing actions and, also, creating new opportunities of cooperation is considered of fundamental importance.

It contains :

1. A Summary of the state of the art of the research on HLM-cooled systems;
2. The identification of R&D needs.

As for what concerns the identification of R&D needs, it has to be noticed that when considering the overall conceptual design of a ETPP as MYRRHA or a demonstrator prototype as ALFRED (that differentiate from MYRRHA from the capability to produce electricity), R&D includes a large variety of fields and disciplines. In order to set up an integrated approach the topics have been divided into areas improving the sub-division adopted in the ADRIANA Project.

The focus is devoted to LFR and MHYRRA (ADS-LBE) and the classification is in section, as follows:

1. Section A: LFR/ADS material studies and coolant physical-chemistry
2. Section B: LFR/ADS studies of core integrity, moving mechanisms, instrumentation, maintenance, in service inspection and repair
3. Section C: Steam Generator functionality and auxiliary safety systems assessment
4. Section D: Thermal-Hydraulics
5. Section E: LFR Neutronics
6. Section F: Advanced Fuel for LFR

Each section is organized in different sub-sections.

A specific questionnaire has been developed on the basis of the R&D needs classification. It has been submitted to the Partners and stakeholders involved in HeLiMnet. The questionnaire is in agreement with two main general objectives of HeLiMnet:

1. To improve, harmonize and interlink the collection of the available information to support the implementation of the Strategic Research Agenda (SRA) for the LFR and ADS development.
2. To allow systematic and fruitful knowledge exchange on HLM components and system design and their validation

The specific objectives of the questionnaire are:

1. To point out experiments to assess the open issues. Past experiments and ongoing experiments are required as database collection. New experiments is one of the main aim.
2. To point out the eventual needing of facilities (tentatively proposed).
3. To identify the computer codes required in the future for quantitative assessment of phenomena and processes that occur in LFR/ADS, such as codes required to support the design phase. To connect experiments (new, past and ongoing) to code validation (this last part of the objective is tentatively proposed).

Questionnaire development

The questionnaire addressed the topics described above (Sections A to F). An appropriate technical schedule was developed as answer format in order to allow the users to meet the specific objectives of the questionnaire.

The collected answers coming from the Partners are reported in the "questionnaire summary", downloadable from the website.

T.A.2 : Guidelines, protocols and standards

In this Thematic Area is possible to find the protocols and standards for HLM technology elements testing developed in the project for Oxygen Sensors, Pumps, Inductive Flowmeters and Level sensors, Heat Exchangers.

Moreover, the area contains the guidelines for operation of HLM experimental facilities developed in the project:

A.2.1. Protocols and standards for HLM technology elements testing

A.2.2. Guidelines for operation of HLM experimental facilities

A work plan was established, foreseeing the collection and review of the available documents for each HLM technology elements and facilities. Each Partner specified their exact contributions in terms of which equipment will be available for the work. The complete list of equipments available is listed in the following:

CNR	Oxygen Sensors - CORAL
CIEMAT	Oxygen Sensors - LINCE
UJV	Oxygen Sensors - COLONRI I&II
ENEA	Pumps, oxygen sensors, heat exchangers - LECOR, CIRCE, LIFUS V, NACIE
SCK-CEN	Pumps
CEA	Oxygen Sensors - STELLA, CICLAD, COLIMESTA
PSI	Level meters
HZDR	Elec. Flowmeters, UDV and CIFT - ELEFANT, LIMMCAST
IPUL	Pumps Loops
KTH	Heat Exchangers - TALL
IQS-URL	Oxygen Sensors

For each facility the Partners provided a technical table and a list of the most updated reports. All the reports were reviewed in order to evaluate the amount and quality of information available. In fact, most of the documents provide sufficient information for organising guidelines. After creating a list of the documents available and classifying them in subgroups, the structure of the main content of the Deliverables 4.1 (Overview of standard procedures for HLM technology testing) and 4.2 (Guidelines for HLM facilities operation) was defined. In particular, the D 4.1 is divided in 4 main chapters, corresponding to the main groups of technological elements: Oxygen sensors; Flow meters + level meters; Heat exchangers; Pumps. Moreover, the D 4.2 is divided in 3 chapters based on the characteristic flow rate of the loops: Static; Natural flow; Forced flow.

The work on the different chapters has been divided among the Partners. In particular the list of Partners responsible for each chapter is reported as follows:

Deliverable 4.1 Overview of standard procedures for HLM technology testing

Chap 1	Oxygen sensors	IQS
Chap 2	Flow and Level Meters	FZD
Chap 3	Pumps	IPUL
Chap 4	Heat Exchangers	KTH

Deliverable 4.2 Guidelines for HLM facilities operation

Chap 1	Static loops	CNR-IENI
Chap 2	Natural flow loops	UJV
Chap 3	Forced flow loops	ENEA/CIEMAT

In order to work specifically on organising the structure of the chapters, technical meetings were organised with selected Partners. The main outcome of the meetings was a complete organisation and division of subtasks and the outline for most of the chapters.

Summarising, the significant results achieved have been:

A.2.1.: Protocols and standards for HLM technology elements testing

2.1.1 Oxygen sensors:

1. Reviewed the state of knowledge
2. Discussion on issues related to position in loops
3. Summarised standard procedures (design, assembling, calibration, monitoring) for sensors
4. Highlighted differences and future needs.

2.1.2.Inductive flow meters and level meters:

1. Review of flow meters for HLM applications

2. Review of level meters for HLM applications

3. Summary of objectives achieved and open issues for future work

2.1.3 Heat Exchangers:

1. Review of theoretical principles

2. Experimental strategies in ENEA and KTH

3. Summary of commonalities and differences as a base for discussion and future development

2.1.4 Pumps:

1. Review of main characteristics of 2 different pumping systems for HLM

2. Procedures for characterising and checking the performance of pumps

A.2.2: Guidelines for operation of HLM experimental facilities

2.2.1. Categorisation of loops in static/natural/forced

1. Detailed procedures for operation of loops:
    i. Start up
    ii. Continuous operation
    iii. Anomalous operation
    iv. Shut down

2. Highlighted commonalities and differences

3. Commonalities as standard procedures

4. Differences due to the different applications of facilities

T.A.3: International Activities

This Thematic Area contains :

1. An overview of the initiatives and activities on HLM in Europe and non-European countries. The European activities can be listed by taking into account stakeholder initiatives as those from the SNETP and projects financed by the European Commission. The areas in which HLM R&D activities are pursued are Nuclear Fission, Neutron Spallation Target and Fusion. The area focuses on initiatives within the nuclear fission area;

2. An overview of the commonalities between LFR, ADS and SFR systems, that are strongly linked to the respective sodium and lead properties;

3. An overview of the commonalities between existing experience with liquid metal (LBE) target design and operation and the needs for a sustainable target concept for an ADS facility and, more specific, for the upcoming European spallation source ESS. In particular, the

experiences reported are based on the MEGAPIE experiment, conducted in the frame of an international collaboration at the Paul Scherrer Institut PSI.

Below the summary and the conclusions of any specific topic addressed:

HLM activities in EU, IAEA, OECD and Generation IV:

Europe is at the front position, together with Russia as far as the HLM technological development is concerned. Both in Europe and Russia plans to build HLM cooled reactor systems are planned. In particular, in Europe the building of MYRRHA (at SCK-CEN, Belgium) and ALFRED is under consideration and in Russia the building of SVBR 75/100 is as well treated. On the other hand, a line of thought can be recognized among the different programs, where the main key issues are addressed. These issues are related to safety, nuclear materials, chemistry, handling, thermal-hydraulics and instrumentation

Commonalities: LFR, ADS and SFR:

SFR and LFR are major options to develop systems, which satisfy Generation IV criteria: sustainability (better use of U and Pu resource, capability to perform transmutation of certain minor actinides), safety and reliability, proliferation resistance and physical protection, and economy. Gas Fast Reactor are currently studied as a quite different option, with the same Generation IV criteria, but their technology is in rupture with the Liquid Metal Fast reactors, offering potentialities of improvement for the long term ie for the periodical inspection of internal structures. SFR industrial feasibility has been demonstrated already (licensing, operation, partial decommissioning); improvements are targeted (economics, safety) based on a large experimental database existing in Europe and world-wide. This data base will be enlarged, through operation of reactors in operation or being operated in the near future. Nevertheless, several improvement with regards safety are currently investigated, in view of more stringent safety criteria (GEN IV safety goals, GENIII, WENRA objectives), with regards void effect, core monitoring, decay heat removal and sodium reactivity with air or water. LFR technology cannot rely on the same large experimental database as SFR and therefore commercial deployment of LFR will be clearly delayed in comparison with SFR. One of the major issue to tackle and preventing early deployment is the severe corrosion of unprotected steels by liquid lead and its alloys demanding major developments of corrosion-resistant materials and coatings (already under investigation), adapted components and techniques for controlling this corrosion. To reduce the technology risks and allow an early demonstration of the heavy liquid metal based technology, the LFR ETTP (MYRRHA) will be based on liquid lead-bismuth. MYRRHA is presently in the Front End Engineering Phase. LFR has a major advantage encouraging its development, i.e. the compatibility of lead (and its alloys) with water and air. This makes it possible to consider placing the steam generators directly in the primary vessel and thereby to improve the economics of the system. Several common issues and synergies have been identified which can be topics of potential collaborations to be performed through bilateral or multilateral approaches.

Commonalities ADS and Spallation Target:

With the successful licensing and operation of MEGAPIE the feasibility of a MW-scale liquid LBE spallation target was demonstrated. Target and ancillary systems were designed, qualified regarding thermo hydraulic and thermo mechanical functionality, and built to fit into the constrained space available at SINQ. Licensing in conjunction with the assessment of potential hazardous radiological issues was successfully accomplished. The target and ancillary systems worked well for 4 months of full (0.8 MW) beam power. Close and detailed investigation and analysis of the system behavior followed the operation phase. Transport, cutting and disposal of the major parts of MEGAPIE have been accomplished, again along with dedicated licensing of each single step. The conserved target pieces are waiting for sample extraction and further investigation within the MEGAPIE PIE activities.

There are a variety of commonalities with ADS target systems and a potential LBE target for ESS. An important one is the general experience and knowledge gathered with the MEGAPIE project which directly and from the very beginning can be implemented to ADS/ESS. Particular commonalities are related to special components, like sensors and instrumentation (thermocouples, level meters, flow meters, and leak detector), an LBE pumping system, and heat exchanger concepts. Even though not all concepts implemented in MEGAPIE proved to be the optimal solution, the 'negative' experiences are equally valuable for a future conceptual design. In the post-test analysis phase of the project, the data were analyzed and important information relevant to accelerator driven systems (ADS) was gained, in particular: i.) data from the thermal hydraulic measurements have offered the opportunity to validate the codes used in the design phase; ii.) Likewise, the nuclear measurements of the gas released gave the opportunity to validate the codes used during the design phase and provided indications for safe operation, and iii.) The neutronic analysis confirms the high performance of a liquid metal target and the importance of the delayed neutron measurements in an ADS target. The neutronic assessment is one of the key issues for an optimised target design for ADS/ESS since a highest neutron yield feeding the subcritical core or the moderator/reflector system, respectively, is the goal of all such facilities. From the results in these different domains recommendations to further development of ADS and heavy liquid metal targets are discussed.

Besides technical features, codes validation and neutronic optimization, the radiological issues are of paramount importance for licensing and safe operation. Compared with MEGAPIE, an ADS/ESS will produce larger total amounts of radioactivity, although it will be more diluted because of the larger volume of liquid metal used. As a consequence, similar release rates can be expected in comparable accident scenarios. For the cover gas, larger gas phase activities are predicted for ADS/ESS, mainly because of the much larger cover gas volume. With the MEGAPIE experience in mind, optimized design solutions can be found. This should include a cover gas purification unit to continually remove the gaseous radioactivity. Experience concerning such a unit exists at SNS. Furthermore, safety measures to mitigate the consequences of accidents can be included in the design from the beginning.

Concerning the polonium hazard, during normal operation no strong transfer to the gas phase is expected. However, the facility has of course to be designed to handle contamination from small scale evaporation or from sputtering accumulating over the years, e.g. during maintenance work such as target exchange. With respect to accident scenarios, to the present knowledge the hazard of an LBE-based ADS/ESS is comparable to that of MEGAPIE. However, accident scenarios may be conceivable where release of Po is more severe than in the scenarios studied for MEGAPIE, e.g. long term fire. Such scenarios must be excluded (or their consequences mitigated) by design.

Compared with other lead based alloys (LGE) or pure lead, the larger Po production in LBE is a disadvantage, which is, however, at least partly compensated by the relatively low operating temperature of LBE. The higher temperatures needed for LGE and lead in turn will increase both, release of other volatile radionuclides as well as corrosion. The availability of experimental data concerning these processes is generally much better for LBE compared to the remaining options, and the authorities will demand experimental proof rather than theoretical extrapolations.

In summary, based on the experiences of the MEGAPIE experiment and the wealth of knowledge gained in supporting studies, an LBE-based ADS or ESS is a reasonable option regarding technical solutions, control of hazardous radioactive inventory, licensing and safe operation.

In fact, several Pro's and Con's can be highlighted:

Pro's :

1. Has been tested for several months in the MW-class facility SINQ (MEGAPIE).
2. Excellent neutron production properties.
3. Physico-chemical properties well-studied (LBE-Handbook).
4. LBE is solid at room temperature and not volatile itself
5. Less chemical toxicity than mercury
6. Experimental determination of the radionuclide inventory underway (PIE)
7. Extensive corrosion studies underway (PIE) + large experiences from EUROTRANS and earlier studies
8. Experience with licensing (MEGAPIE)
9. Disposal path developed
10. Fallback options: pure lead and lead gold eutectic LGE (factor 5000 lower Po-production)

Concerns and potential drawbacks:

1. Production of highly-radiotoxic alpha-emitters (208-210Po), but:
    - Negligible release under operation conditions. After solidification no detectable release at all
    - Possibility of trapping with adsorbers (spontaneous deposition on several metals like Ag, Ni a.o.), has to be proven experimentally
    - Possibility to extract Po from the irradiated target (would need to be scaled-up to technical process)
2. Volume expansion during solidification, but:
    - In a horizontal target 'emergency' draining by gravitational forces is possible

- Safe solidification in a separate tank of suitable geometry is possible, demonstrated in the MEGAPIE project (see F&D Fill and Drain System) Operation at elevated temperatures (>200oC)
- Target system needs active heating, for filling, standby and during beam trips and beam interrupts

Documentation

In the 'Documentation' page of the official website a large number of document of general interest is present which can be easily downloaded:

1) Project Overview documents:

1. Introduction to HeLiMNet, HeLiMNet-DEMETRA Workshop, Berlin, March 2-4th, 2010
2. HeLiMNet Overview, Poster presented at the SNE-TP General Assembly, Brussels, September 14th, 2010 (see attachment)
3. HeLiMNet Overview, Megapie TRM, Luzern, September 30th, 2010
4. HeLiMNet Overview, WP5 technical meeting, Bologna, January 19th, 2011
5. Project Presentation

2) Project Newsletters.

3) Project Public Deliverables:

1. Deliverable D2.2: Collection of the newsletters sent
2. Deliverable D3.1: Report summarising the papers presented in the International Workshop on HLM technology
3. Deliverable D3.2: Report summarising the papers presented in International Workshop on Liquid Metal Fast Reactors: respective issues and synergies
4. Deliverable D4.1: Overview of standard procedures for HLM technology testing
5. Deliverable D4.2: Guidelines for HLM facilities operation
6. Deliverable D5.1: LFR and ADS nuclear system development: state of the art and future R&D activities
7. Deliverable D6.1: Critical review of international cooperation and commonalities between different liquid metal systems.

4) Technical Documentation:

1. Presentations of the 2nd HeLiMnet International Workshop, aix en Provance 4-7th October 2011

2. Presentations of the HeLiMnet WP4-WP5-WP6 Technical Meeting, Brussels, July 6-7th 2011
3. Presentations of the HeLiMnet WP5 Technical Meeting, Bologna, January 19th 2011
4. Presentations of the Open Session of the HeLiMnet First Year General meeting, Rome, March 8th 2011

Events

The 'Events' page contains quick links to the main Project as well as international events considered of interest for the HLM community.

In particular, the section contains a link to the two international Workshops organized in the frame of the Project:

E.1.) The HeLiMnet-DEMETRA Workshop (see newsletter 1), that was held on March 2-4th , 2010 at Park Inn Hotel in Berlin (Germany). This Workshop was organized by the KIT-G in the frame of the DEMETRA domain of the EUROTRANS project and co-sponsored by the EC-project HeLiMnet. The main objectives of this Workshop were to present and discuss experimental and theoretical activities performed in different international projects and in particular in the DEMETRA project during the last few years. At the Workshop 3 keynotes and 29 technical presentations were given in seven sessions and one experts panel.

E.2.) The HeLiMnet Seminar, that was organized in Aix en Provence (F), on October 4-7th, 2011 by CEA, addressed the following topics for both lead and sodium-cooled systems interaction between coolant and structural material, coolant quality control, handling operations, ISIR, operational and decommissioning issues, severe accidents etc., as well as the main design options.

E.1.) The HeLiMnet-DEMETRA Workshop started on March 2nd, 2010 with a General Session. The technical contributions were organised in 6 sessions. At the end of the technical Sessions a Panel session on the main topics related to the HLM Technologies was held.

The contents of the presentations of the Workshop are briefly summarized here below:

General Session

J. Knebel (KIT) welcomed to the participants and presented the Helmholtz Association. Enrica Ricci, coordinator of HeLiMnet, a Coordination Action of Seventh Framework Programme, presented the objectives, scope and structure of HeLiMnet. Finally, G. van Goethen from UE presented 'From knowledge creation to competence building. Euratom research and training activities in innovative materials'. The SET plan and SNE-TP (EII 'Sustainable Fission') as well as the EERA for Materials for Innovative Nuclear were introduced. The need for new skills in the nuclear field was highlighted.

1. Scenarios and design studies of HLM-cooled systems.

Five papers were presented in this session. Y. Kurata (JAEA) in his presentation 'Role of ADS in the back-end of the fuel cycle strategies and associated design activities: The case of Japan', highlighted that two fuel cycle concepts for MA transmutation are being considered in Japan: Homogeneous Cycle with FBR and Double Strata with Accelerator-Driven System (ADS). The design study on ADS is under way with J-PARC project. There is a proposal of a new experimental facility, TEF in the J-PARC project at JAEA. The ongoing effort for the development of the advanced fuel cycles and role of ADS in Europe was presented by Didier De Bruyn (SCK-CEN). Fast reactors and dedicated burners offer adequate solutions to reach sustainability objectives. Prototypes should be planned and realized. Belgium is contributing to this international endeavour through the MYRRHA research infrastructure. The Lead-cooled system design and challenges in the frame of Generation IV international forum was presented by L.Cinotti (ANSALDO). The main characteristics of the two reactor concepts included in the LFR System Research Plan, SSTAR and ELSY, were described. A list of the research topics was resolved and discussed. Mansani (ANSALDO) in his presentation on 'Pb cooled system developed in Europe' paid attention to the designs of ELSY and EFIT prototypes. The characteristics of the SVBR-100 module-type fast reactor of the IV Generation for regional power industry were presented by G.I. Toshinsky (IPPE). He highlighted the principles of actuation of the passive safety systems, the capability of the reactor to operate using different fuel types and in different fuel cycles and the multipurpose use of RF SVBR-100.

2. Structural materials characterisation in HLM

S. Gravilov (SCK-CEN) presented 'Production and characterization of T91 cladding tubes' performed in collaboration with KIT and IPPE. Information about the tubes fabrication, thermal treatment, mechanical properties, microstructure analysis, corrosion tests and creep tests were reported. A. Rusanov (IPPE) presented 'Behaviour of protective oxide barriers at long-term HLMC corrosion tests of steels'. His paper was focused in the behaviour of the cladding material for SVBR-100 Module-Type Fast Reactor. Corrosion results for long time experiments (up to 30,000 hours) were presented. Kurata (JAEA) presented an overview of the 'Corrosion experiments and materials developed for the Japanese HLM systems'. The behaviour of the Si steels and the Al coating was presented and discussed. Weisenburger (KIT) presented a summary of the work on corrosion behaviour performed in the frame of DEMETRA for several Partners, entitled 'Long-term corrosion on T91 and AISI 316L steel in flowing lead alloy and corrosion protection barrier: experiments and models'. This presentation summarised the main result achieved in long term corrosion for the reference steel and surface modified material, under 'normal conditions' (FZK; CIEMAT; ENEA; CEA; IPPE/FZK), for fast flowing experiments (CICLAD, CEA) and for exposures under abnormal conditions (COLONRI, NRI). V.I.Engelko, (NIIEFA) presented his work on 'Improvement of corrosion resistance of constructional steels in liquid Pb and Pb-Bi via steel surface modification by pulsed intense electron beams'. Technologies of Al pre-coating deposition and required parameters of e-beam treatment were presented (MIEB-SM process). Corrosion results pointed out that under optimal conditions this process ensures corrosion protection of T91 and 1.4970 steels for temperatures up to 550ºC. D. Gorse (CNRS) presented a summary of the work performed on the frame of DEMETRA for several Partners on 'Influence of liquid lead and LBE on tensile, fatigue and creep properties of ferritic/martensitic & austenitic steels for transmutation systems'. She began her presentation with a 'State of the Art and Motivations for mechanical studies of steels in HLM'. Then she presented the main results of tensile tests, fatigue tests and creep-rupture tests for the reference steels in lead and LBE. She finished with recommendations for future work. T. Auger (CNRS) presented a paper on 'Fracture mechanics behavior of ferritic/martensitic and austenitic steels in contact with liquid lead-bismuth eutectic for application in an Accelerator Driven System'. He summarised the main results on this topic obtained by several Partners in the DEMETRA project.

3. Structural materials characterisation under irradiation

Y. Dai (PSI) presented a paper on 'Neutron/proton irradiation and He effects on the microstructure and mechanical properties of ferritic/martensitic steels'. He concluded that in the low temperature regime (<350°C), at high concentrations (>~500 appm). He can induce significant hardening and embrittlement effects. At higher temperatures (>400°C), the embrittlement effects seem less pronounced. Lida Magielsen (NRG) presented the results obtained on 'HFR and BR2 Irradiation of structural materials in contact with LBE'. She presented a general description of irradiation experiments TWIN ASTIR (in the reactor BR2) and IBIS (reactor HFR), and the first results achieved from PIE. The effect of fission neutron irradiation on the tensile, impact, fracture toughness and creep properties of 316L/T91 with emphasis on the temperature range of interest for XT-ADS was presented by J. Henry (CEA). For 316, saturation of tensile properties occurs at ~10 dpa; Irradiation-induced hardening is highest in the range [300-350°C]. For T91 (& EM10), irradiation at ~330°C induces a huge hardening together with a complete loss of ductility (doses>~40 dpa). At Temperatures >400°C, there is little irradiation-induced hardening. 9Cr steels exhibit moderate DBTT shifts. 9Cr martensitic steels exhibit good dimensional stability with an irradiation creep modulus lower than that of austenitic steels. The work performed on 'Multi-scale modelling of the Fe-Cr-C system' at KTH was presented by J. Wallenius (KTH). Authors make a dissertation about 'Why does carbon matter for radiation damage?'

4. Coolant quality control

The paper entitled 'Oxygen control systems and impurity purification in LBE: Learning from DEMETRA project', performed in collaboration with NRI and KIT, was presented by L. Brissonneau (CEA). Procedures for oxygen supply and purification were presented and discussed. Finally, 'Open questions' and 'Recommendations for Sensors locations' were provided. The collaborative work performed in the frame of DEMETRA project by KIT, IQS, ENEA; UJV and CEA on 'Design and testing of electrochemical oxygen sensors for service in liquid lead alloys' was presented by C. Schroer (KIT). This paper summarised the characteristics of the oxygen sensors used by the different laboratories, the methods for the calibrations, and the main results obtained with them in the experimental facilities. L. Martinelli (CEA) presented the paper entitled 'Fundamental data: Solubility and diffusivity measurements of metals and oxygen in molten LBE'. The results obtained in the frame of DEMETRA project about the determination of nickel solubility limit in molten LBE at different temperatures and the determination of solubility and diffusivity of O2 in LBE were discussed. J. Neuhausen (PSI) presented the paper 'Behaviour of nuclear reaction products in liquid metal spallation targets'. He performed a theoretical study on solubility of metals in Pb and Bi and an exposition of the several experiments about evaporation of elements such as iodine, mercury and polonium.

5. Spallation target development

A.G. Class (KIT) presented the paper 'XT-ADS windowless spallation target: Thermohydraulic design & experimental setup'. Design evolution by close interaction between designs, experiments and numerical studies was showed. D. Buchenau (FZD) presented a paper on 'Measurement techniques developments for PbBi flows' summarising the work performed by 1. FZD on flow measurements: flow-rate and local velocities; 2. FZK on EM flow-meter and free surface sensor; and 3. SCK on laser level measurements. H. Jeanmart (UCL) presented the paper 'Characterization in water experiments of a detached flow free surface spallation target '. One of the main objectives of this work was to create reference data for the development and the evaluation of free surface models. The 'Experience from the post-test analysis of MEGAPIE' was presented by L. Zanini (PSI). Neutronic performance of an ADS target with window has been studied in great detail. Reliable THD, neutronic and nuclear tools for the design of a target have been produced in the frame of MEGAPIE project.

6. Thermal-hydraulics of the core and integral experiments, measurement techniques and safety issues.

K. Litfin (KIT) presented the work performed at KIT on 'Experimental and numerical investigation of water and heavy liquid metal cooled rod bundles'. Results from experiments with single rod, Water rod bundle and LBE rod bundle were presented and discussed. The paper entitled 'Experimental and numerical study on lead-bismuth heat transfer in a fuel rod simulator' was presented by Aram Karbojian (KTH). Experiments were performed on the TALL test facility to investigate the thermal-hydraulics of a single fuel rod simulator cooled by liquid LBE. A paper entitled 'Progresses in benchmarking of thermal-hydraulic loop models for lead-alloy cooled advanced nuclear energy systems (LACANES)' was presented by J.H. Cho (NUTRECK). Recommended practice for the application of correlations to the core region, gate valve region and orifice region were obtained by analysing the results obtained by the nine participants in the benchmarking. The results of the 'Integral system experiment: Thermal hydraulic simulator of a Heavy Liquid Metal Reactor' were presented by M. Tarantino (ENEA). The experiment was aiming to reproduce the primary flow path of a HLM pool-type nuclear reactor.

Panel session

A panel session was held with the contribution of the following speakers :P. Agostini (ENEA-Italy), J. Cho (SNU-South Korea),Y. Kurata (JAEA-Japan),S. Maloy (LANL-USA), L. Mansani (Ansaldo-Italy), A. Rusanov (IPPE-Russia), R. Stieglitz (KIT-Germany), K. Van Tichelen (SCK-CEN-Belgium) and moderated by C. Latgé (CEA-France). The main topics related to HLM technology were discussed, being the conclusion that the feasibility of the processes has been often demonstrated at the laboratory scale, in steady state conditions. But more work has to be done on the performances in realistic conditions, the operability of the systems in steady state and transient regimes and the reliability of the systems (failure mode analysis).

Conclusions

The meeting was closed by C Fazio (KIT) with a summary of the most important results and the following conclusive remarks:

1. This Workshop has pooled together experience on Materials, Thermal-Hydraulics and HLM Technologies from EU, Japan, Russia, Korea and US.
2. The DEMETRA domain has produced important results on the basis of (pre)-conceptual design information available.
3. Relevant recommendations in the field of materials temperature, stresses and irradiation dose windows, oxygen concentration and associated technologies, spallation target design/performance and heat transfer behaviour under turbulent conditions have been formulated.
4. Final summary reports have been issued as DEMETRA deliverables.

The Workshop Proceedings have been published as special issue of Journal of Nuclear Materials.

E.2.) The 2nd HeLiMnet International Workshop on Liquid Metal Fast Reactors: Issues and Synergies. was organized on October 2011 in Aix en Provence, France by the CEA. At the Workshop 3 keynotes and 33 technical presentations were given in twelve sessions and one panel of international experts. The panel of international experts closed the Workshop summarizing the identification of synergies and common developments both Sodium fast Reactors (SFR) and lead Fast Reactors (LFR).

The main contents of the Workshop are briefly summarized here below:

1. Safety approach, codes and standards, In Service Inspection & Repair

Safety and reliability are key points for the design of Liquid metal fast reactors. More detailed goals are the following ones: improved and robust safety demonstration with regard to former fast Reactors, enhanced prevention of whole core melting accidents, exclusion in a credible way of the energetic accident sequences, robustness to external hazards, safety level at least equivalent to 3rd generation reactors, and of course taking into account lessons learnt from Fukushima accident. In addition, for SFR, it is necessary to prevent and mitigate risks due to sodium chemical reactivity and for both SFR and LFR to prevent from physical interaction between coolant and water in the Steam Generators. The required high level of prevention has to be achieved by an extensive and deep use of the defence in depth and by several provision that shall be specified at the level of plant safety approach: implementation of two redundant and diverse shutdown systems (a third innovative device is under investigation for ASTRID), demonstration of the safe behaviour of the reactor (i.e., maintain sub-criticality) by inherent core characteristics and passive devices, requirements of redundancy and diversification for DHRS. There is the need to have a large capability to operate in natural convection, to demonstrate that there is a high grace time for operating the systems allowing the correction of their failure. In any case the failure of decay heat removal has to be 'practically eliminated'. The development of seismic protection devices is also a topic of potential synergies.. In case of 'severe accident', namely core melting, there is the necessity to confirm the corium relocation in case of SFR and the fuel dispersion for LFR in order to evaluate with high reliability the residual risk of recriticality and to suggest mitigation systems (recuperator).The others radiological source terms other than the core have to be considered also, especially for handling and storage of spent fuel (feedback from Fukushima). There is the necessity to demonstrate that, in case of accident, the neighbouring population has not to be evacuated. For codes and standards, there is need to improve the qualification of neutronics tools, system codes for transient scenario, thermal-hydraulics more particularly for natural convection in primary vessel and DHRS. In addition, RCC-MR has to be adapted for LFR.

The development of advanced instrumentation for core control and detection of local fuel damage is mandatory for the fast reactors. It is important to be to be able to distinguish fuel assembly melting from fuel cladding rupture. The characterization of gas bubbles in coolant is also a very important issue, common to Na and Pb systems.

For In Service Inspection and Repair (ISIR), a common strategy, based on the definition of the structures to be controlled, periodicity, accessibility for control or repair has to be shared. The requirements for ISI have to be exchanged and discussed i.e. the definition of minimum size for the cracks, defaults, the resolution for long distance telemetry. The US detectors for both reactors have to be developed and their reliability to be assessed following similar standards.

In conclusion the safety approach of the two reactors should be harmonized and several point of contacts and synergies have been identified.

2. Components and system: development and qualification

1. Due to the fact that both coolants are liquid metals, several components have similar requirements. Therefore it is possible to foresee some common developments, ie:

2. Shut down system, design of self actuated systems;

3. Steam generators Unit (SGU): development of concepts with double wall for both coolants.

4. Activated or contaminated component handling : development of similar handling systems,

5. DHRS: to be based on passive systems; development of compact and reliable air cooled systems; optimization of finned tube HX and air chimney (e.g. resistant to atmospheric perturbations and sabotage)

6. Seismic protection devices: optimization, qualification .

3. Structural materials and corrosion

The material for the LFR fuel cladding, at least for the short term developments, strongly rely on previous materials already qualified in the sodium reactors. The appropriate material will be protected by a suitable coating against the corrosive effect. This fact offers a strong element of collaboration between the sodium and the lead design groups. Moreover, it is recognized a common interest towards austenitic steels such as AISI 316L and 15-15Ti and ferritic-martensitic steels having higher thermal conductivity and rupture strength such as P91 and T91. The collaboration on corrosion mechanisms, cyclic load resistance, creep resistance and welding of these steels could be envisaged. Moreover, the development of ODS steels, foreseen for the claddings, could be also a topic of collaboration. Corrosion in liquid alloys which are involved in nuclear systems (Na, pure Pb or Pb alloys) follows two main processes:

a) Dissolution of the steel constitutive elements (can lead to preferential dissolution of some elements)

b) Oxidation of the steel constitutive elements

Even if the liquid metals are very different, the elementary processes for corrosion phenomena and the methodologies to reach the corrosion mechanism are identical and some corrosion mechanisms are similar. Therefore, it is possible to develop common models and methodologies for validation of them. It is also necessary to develop and qualify coatings like aluminization which are investigated for both coolants and, for some of them, to qualify them with regards their tribological behaviour. For several other topics related to material science, such as behaviour under irradiation, fabricability, joining technologies, there are surely potential synergies. For SFR, DHRS with intermediate coolant such as Pb-Bi could be developed.. The selected materials need to be qualified in relevant conditions, similar to those of some circuits of LFR.

4. Coolant technologies, quality control and tritium

The chemistry control procedures of lead and sodium are quite different and have different purposes:

1. for Na: obtain as low as achievable oxygen and/or hydrogen content, in a cold trap (crystallization of Na2O and/or NaH)
2. for Pb, monitor O content in a given range, to maintain stability of oxides on structural material to protect them (if they are not previously coated), but to prevent from PbO precipitation.

Nevertheless, a strategy very similar to the low oxygen content already used for sodium is also under investigation for lead, in case of protected structures by coatings. This may enhance the possible synergies between the two systems.

Mutual exchanges of knowledge of the existing technologies could be activated; and more particularly for chemical sampling systems & measurements, on-line chemical instrumentation in metal bulk, such as O-meters, H-meters, purification strategies, operational feedback, waste management... The measurement of particles (amount, distribution) and their filtering is also of mutual interest, even if for sodium, this operation is carried out only during the start-up operations. For ISI, the wetting phenomena are key point for the good accuracy of measurements by US technologies, and basic studies could be shared on this topic, even if there are significant differences between Na and Pb. Tritium is produced from ternary fissions and boron carbide irradiation. For Na, the tritium behaviour (tritium accumulation, transfer and release) is well mastered if the Energy Conversion system is based on Rankine cycle, thanks to continuous co-trapping of hydrogen due to aqueous corrosion in SGU, but for Brayton cycle, this is not the case. The tritium permeation and dissolution in Pb-Li have been studied in the frame of the Fusion activities For lead, this issue has to be analysed. In both cases, it is quite important to have a better evaluation of the source term. Another issue is the possible trapping of activated corrosion products, to limit the dosimeter of primary components. The development of dedicated trapping devices may be of common interest. The components cleaning technologies for

LFR have to be demonstrated at industrial scale, with demonstration of the reuse of the component (re-qualification). The methodology of requalification is a potential topic of exchange.The use of Lead-Bismuth eutectic as intermediate coolant between primary sodium and air is of interest for innovative options in SFR DHRS, but it is necessary to investigate several related issues. Thus, mutual exchanges of knowledge on this topic could be activated.

5. Simulation and modelling, and code V&V

Simulation is a fundamental part of the activities to be carried out in the frame of the development of a new generation of nuclear reactors and plays a very important role for both design and safety evaluations.

SFR and LFR systems share the fast neutron spectrum that permits the recycling of all the uranium and transuranic isotopes (actinide management mission).

They also share common attributes or issues: i) as the oxide fuel is selected for both, the developments of fuel manufacturing and fuel reprocessing are applicable to both systems; ii) the needs in term of fuel behavior modeling are somewhat similar; iii) the neutron physics calculation tools are similar (but validation is somewhat specific). For thermal-hydraulics, several commonalities and synergies exists between LFR and SFR: mixing and stratification phenomena, fuel bundle behaviour under mixed convection, forced to natural circulation transition, The design of some systems operating in natural convection, ie main vessel and internal structures, Decay Heat Removal Systems... should be reviewed to highlight their behaviour, aiming to demonstrate their reliability particularly in case of a long-term station black-out (Fukushima). The introduction of these passive safety systems, is challenging strongly the numerical simulation tools (very small pressure difference, low turbulence levels etc.), which strongly need detailed and dedicated experiments for their V&V. After validation, these tools will be very helpful for the configuration of the experimental facility, instrumentation position, reduction of the number of experiments Most of the computer codes available may handle both fluids and the codes V&V process is further enhanced by the possibility to use a wider set of experiments including both sodium and lead. In addition, with the fundamental aim to involve well experienced and trained users, it is mandatory to organize benchmarking studies. For both SFR and LFR, in case of severe accident, even if the scenarii are different due to the differences of coolant melting temperatures and respective densities, specific developments are necessary for the description of fuel distribution inside the primary system and relocation, which should demonstrate the absence of possible re-criticality scenario and whole core damage.

6. Experimental facilities and needs

Both sodium and lead are Low Prandtl number fluids, therefore present similar peculiarities related with thermal stratification, thermal striping, natural circulation and height of thermal boundary layer. The thermo fluid dynamic calculations performed so far still need suitable qualification experiments which should be conducted by non intrusive devices. Moreover, due to the high thermal conductivity of both fluids, specific thermo-mechanical effects on the structural materials, such as thermal shocks, ratcheting and thermal cycling must be dealt with. Considering the synergies between the two liquid metals with regards the previous phenomena, a large range of collaborations in experimental fluid dynamics and thermo-mechanics could be envisaged by performing tests based on the use of chemically inert liquid metals in several configurations of interest. Finally the experimental studies of the mechanical effects of the Steam Generator Tube Rupture (SGTR) could be commonly defined and performed. The lead effect is only physical, while the sodium effect is a sum of the physical and of the chemical effects. The experimental study of the physical effects in lead, gives the possibility to separate the effects in the sodium case. These analyses are preliminary to the development of common calculation tools or evolution of existing ones.

7. System approach including fuel and fuel cycle approach

SFR and LFR systems have selected a pool type primary system which raises a number of common design and modeling issues (seismic behavior, gas entry, thermal-hydraulics and thermo-mechanics in large plenum). As it has been seen in previous 3-5 chapter, potential synergies exist in term of neutron physics, thermal-mechanical and thermal-hydraulics modeling. Moreover, synergies could be developed in core and fuel design activities: design optimization techniques are being developed for both systems; exchanging on design criteria and targeted performances would be profitable for a better understanding. Very relevant progress has been done for SFR to limit the sodium void worth; these new tracks should be potentially investigated for the LFR, if needed. For both reactors the fuel and fuel-cladding interaction may share common studies or developments. Fuel fabrication is developed in France for SFR and the LFR community could benefit from these developments. Dismantling which is not an issue for SFR can be assessed for LFR using the experience obtained for SFR. The proliferation is also a common issue for control and fuel cycle. On all these items, fruitful exchanges could be helpful to improve both systems, with regards the main Generation IV criteria.

Conclusions

SFR and LFR are major options to develop systems, which satisfy Generation IV criteria: sustainability (better use of U and Pu resource, capability to perform transmutation of certain minor actinides), safety and reliability, proliferation resistance and physical protection, and economy. Gas Fast Reactor are currently studied as a quite different option, with the same Generation IV criteria, but their technology is in rupture with the Liquid Metal Fast reactors, offering potentialities of improvement for the long term ie for the periodical inspection of internal structures.

-SFR industrial feasibility has been demonstrated already (licensing, operation, partial decommissioning); improvements are targeted (economics, safety) based on a large experimental database existing in Europe and world-wide. This data base will be enlarged, through operation of reactors in operation or being operated in the near future. Nevertheless, several improvement with regards safety are currently investigated, in view of more stringent safety criteria (GEN IV safety goals, GENIII, WENRA objectives), with regards void effect, core monitoring, decay heat removal and sodium reactivity with air or water.

-LFR technology cannot rely on the same large experimental database as SFR and therefore commercial deployment of LFR will be clearly delayed in comparison with SFR. One of the major issue to tackle and preventing early deployment is the severe corrosion of unprotected steels by liquid lead and its alloys demanding major developments of corrosion-resistant materials and coatings (already under investigation), adapted components and techniques for controlling this corrosion. To reduce the technology risks and allow an early demonstration of the heavy liquid metal based technology, the LFR ETTP (MYRRHA) will be based on liquid lead-bismuth. MYRRHA is presently in the Front End Engineering Phase. LFR has a major advantage encouraging its development, i.e. the compatibility of lead (and its alloys) with water and air. This makes it possible to consider placing the steam generators directly in the primary vessel and thereby to improve the economics of the system.

Several common issues and synergies have been identified which can be topics of potential collaborations to be performed through bilateral or multilateral approaches.

This HeLiMnet Seminar has given to the sodium and heavy liquid metal communities the opportunity to share structured knowledge and identify several tracks of potential exchanges and dedicated collaborations. This result illustrates the great interest of networking activities in general and the benefit which can be obtained from HeLiMnet network and future similar initiatives.

Education and training initiatives, organized by national or European or IAEA are also key tools to share and develop knowledge with new students, researchers and engineers involved in the development of Liquid Metal Fast Reactors.

Potential Impact:

The HeLiMnet action saw different activities aimed at harmonizing the European Research Area in the field of HLM technologies for nuclear applications, in order to maximize the cooperation and the coordination of efforts of the different EU laboratories, to offer a valid support to the implementation of the Strategic Research Agenda for the development of LFR and ADS nuclear systems.

The project has been, then, expected to have a strong beneficial impact in the EU research area, promoting the integration of the existing European infrastructures and developing synergies and complementarities among the laboratories and the research groups, while acting in a concerted way with the other national and international programmes and while exploiting possible shared approaches between different liquid metal systems.

The structure of the project has been certainly permitted to play a positive role in the implementation on the SRA from one hand and will consent to contribute to the competitiveness of European key players (e.g. Industries, Research Associations, etc.) in this field facilitating cooperation, coordination of actions, spread of results and dissemination of information.

The impact of the approach adopted in the project, thanks to the continuous exchange of information within and outside the project, allowed to focus the activities on the most relevant issues and to support the identification of research priorities to answer the most relevant questions arising from design, and will therefore contribute to the timely development of LFR and ADS systems as foreseen in the SRA.

The exploitation of results and dissemination of knowledge have been important activities which have been carried out through different instruments.

Communication, in fact, has been considered as a fundamental keyword of the project, which acts in a concerted way with the other international R&D programmes related to the development of heavy liquid metal systems.

The project intended to turn strategies into dedicated actions and ensure coherency and consistency in all the communications, in particular for what concerns the knowledge dissemination.

The communication strategy proposed had, then, the intent to be accessible, accurate, coordinated and frequent and to reach the entire community of people involved or simply interested in the lead technologies.

It is clear, in this framework, that the community of researchers active in the area of heavy liquid metal systems was considered as the main target audience, but also the lead industry or, more in general, the whole nuclear industry as well as the governing institutions involved in technological and energy-related fields, have been taken into account.

Well-planned communications have been, then, the heart of a successful public information effort, considering the fact that to be effective, a communication has to:

a) use varied dissemination methods, including written information, electronic media, and person-to-person contact;

b) draw upon existing resources, relationships, and networks to the maximum extent possible while building new resources as needed by users;.

c) include effective quality control mechanisms to assure that information to be included in the system is accurate, relevant, and representative.

To meet the three abovementioned requirements, in the project the diffusion of information exploited the potentialities of all the communication tools (website, newsletter, organization of workshops, etc), to enlarge the community created in the previous EURATOM projects (especially the VELLA Initiative).

In more detail, the project developed a dedicated website to inform the public at large on the project objectives and activities. The website will contain all the information on the project objectives, on the status of the activities, news and events. It will have the scope to act as a common platform for exchanging information among experts and with public at large.

The website acted on a double level: provide general information on HLM technologies and HLM system development to public and provide specific technical information and space of discussion to the specialists.

The website has been structured, therefore, in three specific areas:

a) A technical area dedicated to the main topics related with the HLM technologies (materials, thermal hydraulics, coolant chemistry control and monitoring, component and system development), outlining the state of the art and the main results. In this section it will be possible to find data and exchange information through a dedicated space of discussion. Actions to encourage the fruition of the website area by the other project teams as well as by public at large will be carried out in order to have the website acting as a platform of information and discussion on HLM technologies and on the ADS/LFR development, for an effective support to the implementation of the SNE-TP SRA.

b) A project presentation area: part of the website will be dedicated to the description of the project, presenting the structure and the outcomes of the work packages (i.e. the outcomes of the two workshop organized in the project, the links with other projects and national/international activities, etc.). In particular, an internal area restricted to the project consortium where all the documentation related to the project will be made available for an easy consultation to the consortium partners and the commission will be created.

c) A 'news and events' area: a space dedicated to the main international events (conferences, workshops, training schools) will be prepared and maintained updated, to act as a common information point for the researcher an public at large, interested in the main events in which the 'HLM community' is involved, to enlarge and strengthen the network. In this area the main news related to the development of LFR/ADS systems and to the HLM technologies will find place, as well as a collection of the newsletter sent.

A co-ordinated and united global image (project logo) supported by informative brochures or posters has been realized;

A mailing list, constantly updated with suggestion by each partner, has been centralised and used for the initiative, to disseminate information in the shape of an electronic newsletter;

The documents produced in the project have been presented during key events and will be further promoted through scientific papers.

Events organized by HeLiMnet Project, as well as the presentation of the Project-related activities during events organized outside HeLiMnet had a sensible communication dimension. In particular, two workshops have been organized:

a) an International Workshop on HLM technology with the objective to review and discuss experimental and modelling results obtained in the frame of relevant EU, national and international projects on the main technological issues related to the use of HLM in nuclear systems;

b) an International Workshop on Liquid Metal Fast Reactors: respective issues and synergies aimed to deal with relevant topics for fast reactor systems, such as interaction between coolant and structural material, coolant quality control, handling operations, ISIR, operational and decommissioning issues, etc.;

Initiatives (as training course, summer school) taken by other institutions, in other programmes have been supported, to enhance the diffusion of the information on the project itself and its objectives;

Meeting with the industries, to have a feedback on the needs of the users, as well as contacts with the universities, to take into account the interests of the academic world, have been carried out.

Moreover, to favour the dissemination of information, an External Advisory Committee is created, to help the consortium in the contacts with ADS/LFR design teams, with GIF and other international forums, with other EU, national and international programmes.

The EAC was composed by members of industry, academy, national and international organizations and independent experts.

The EAC:

1. regularly exchanged information with the project through communications by means of telephone, E-mail or specific meetings if intensive discussions is needed which cannot be achieved by the other communication means;

2. participated in the project general meeting.

It this way, the EAC acted as a channel of information and consultancy, linking technicians, stakeholders and public at large.

List of Websites:

http://www.helimnet.eu