SEVENTH FRAMEWORK PROGRAMME OF THE EUROPEAN ATOMIC ENERGY COMMUNITY

DIRECTORATE-GENERAL FOR RESEARCH & INNOVATION

SP5-Euratom

Collaborative project

Small or medium-scale focused research project

FP7-Fission-2011

Grant Agreement Number 295736

SEARCH

Safe ExploitAtion Related CHemistry for HLM reactors

SEVENTH FRAMEWORK PROGRAMME

GRANT AGREEMENT No 295736

PROJECT TITLE SEARCH

Collaborative project

Small or medium-scale focused research project

The European Atomic Energy Community ("*Euratom*"), acting under powers delegated by the European Commission (the "*Commission*"),

of the one part,

and STUDIECENTRUM VOOR KERNENERGIE, established in Herrmann Debrouxlaan 40, Brussel, 1160, Belgium represented by Eric van Walle, Director-General and/or Frank Deconinck, Chairman of the Board of Governors or their authorised representative, the *beneficiary* acting as "*coordinator*" of the *consortium* (the "*coordinator*"). ("*beneficiary no. 1*"),

of the other part

HAVE AGREED to the following terms and conditions including those in the following annexes, which form an integral part of this *grant agreement* (the "*grant agreement*").

Annex I - Description of Work
Annex II - General conditions
Annex III - Non applicable
Annex IV - Form A - Accession of *beneficiaries* to the *grant agreement*
Annex V - Form B - Request for accession of a new *beneficiary* to the *grant agreement*
Annex VI - Form C - Financial statement per funding scheme
Annex VII - Form D - Terms of reference for the certificate on the financial statements and Form E - Terms of reference for the certificate on the methodology

Article 1 - Accession to the *grant agreement* of the other *beneficiaries*

1. The *coordinator* shall endeavour to ensure that each legal entity identified below accedes to this *grant agreement* as a *beneficiary*, assuming the rights and obligations established by the *grant agreement* with effect from the date on which the *grant agreement* enters into force, by signing Form A in three originals, countersigned by the *coordinator*.

- AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE,L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE, established in Lungotevere Grande Ammiraglio Thaon di Revel 76, ROMA, 00196, Italy represented by Lelli Giovanni, ENEA Commissioner or his authorised representative ("*beneficiary no. 2*").

- Karlsruher Institut fuer Technologie, established in Kaiserstrasse 12, Karlsruhe, 76131, Germany represented by Bernhard Dasselaar, Head of Cost Account and/or Joachim Knebel, Chief Science Officer or their authorised representative ("*beneficiary no. 3*").

• NUCLEAR RESEARCH AND CONSULTANCY GROUP, established in Westerduinweg 3, PETTEN, 1755 ZG, Netherlands represented by Robert J. Stol, Managing director or his authorised representative (*"beneficiary no. 4"*),

• CENTRO DI RICERCA, SVILUPPO E STUDI SUPERIORI IN SARDEGNA, established in Via Palabanda 9, CAGLIARI, 09100, Italy represented by Paolo Zanella, President or his authorised representative (*"beneficiary no. 5"*),

• UNIVERSITEIT GENT, established in SINT PIETERSNIEUWSTRAAT 25, GENT, 9000, Belgium represented by Paul Van Cauwenberge, Rector and/or Luc Moens, Vice-Rector or their authorised representative (*"beneficiary no. 6"*),

• UNIVERSITA DI PISA, established in Lungarno Pacinotti 43/44, PISA, 56126, Italy represented by Donato Aquaro, Department Director and/or Massimo Guiggiani, Vice Department Director or their authorised representative (*"beneficiary no. 7"*),

• VON KARMAN INSTITUTE FOR FLUID DYNAMICS, established in Chaussee de Waterloo 72, RHODE-SAINT-GENESE, 1640, Belgium represented by Jean-Marie BUCHLIN, Head of EA Department or his authorised representative (*"beneficiary no. 8"*).

• REGIA AUTONOMA PENTRU ACTIVITATI NUCLEARE DROBETA TR. SEVERIN RA SUCURSALA CERCETARI NUCLEARE PITESTI, established in Cimpului 1, MIOVENI - ARGES, 0402, Romania represented by Constantin PAUNOIU , Director and/or Ilie TURCU, Scientific Director or their authorised representative (*"beneficiary no. 9"*).

• JRC -JOINT RESEARCH CENTRE- EUROPEAN COMMISSION, established in Rue de la Loi 200, BRUSSELS, 1049, Belgium represented by Thomas Fanghaenel, Director or his authorised representative (*"beneficiary no. 10"*),

• PAUL SCHERRER INSTITUT, established in Villigen, VILLIGEN PSI, 5232, Switzerland represented by Joel Mesot, Director and/or Gebhard Schertler, Department Head or their authorised representative (*"beneficiary no. 11"*).

• CHALMERS TEKNISKA HOEGSKOLA AB, established in -, GOETEBORG, 41296, Sweden represented by Ulf Carlson, Head of Department and/or Bo Albinsson, Deputy Head of Department or their authorised representative (*"beneficiary no. 12"*),

All the *beneficiaries* together form the *consortium* (the *"consortium"*).

2. The *coordinator* shall send to the *Commission* one duly completed and signed Form A per *beneficiary* at the latest 45 calendar days after the entry into force of the *grant agreement*. The two remaining signed originals shall be kept, one by the *coordinator* to be made available for consultation at the request of any *beneficiary*, and the other by the *beneficiary* concerned.

3. Should any legal entity identified above, fail or refuse to accede to the *grant agreement* within the deadline established in the previous paragraph, the *Commission* is no longer bound by its offer to the said legal entity(ies). The *consortium* may propose to the *Commission*, within the time-limit to be fixed by the latter, appropriate solutions to ensure the implementation of the *project*. The procedure established in Annex II for amendments to this *grant agreement* will apply.

4. The *beneficiaries* are deemed to have concluded a *consortium agreement* (the *"consortium agreement"*) regarding the internal organisation of the *consortium*.

Article 2 - Scope

Euratom has decided to grant a financial contribution for the implementation of the *project* as specified in Annex I, called *Safe ExploitAtion Related CHemistry for HLM reactors* (*SEARCH*) (the "*project*") within the framework of the *SP5-Euratom* and under the conditions laid down in this *grant agreement*.

Article 3 - Duration and *start date* of the *project*

The duration of the *project* shall be 36 months from 1st November 2011 (hereinafter referred to as the "*start date*").

Article 4 - Reporting periods and language of reports

The *project* is divided into reporting periods of the following duration:

- P1: from month 1 to month 18
- P2: from month 19 to the last month of the *project*.

Any report and deliverable, when appropriate, required by this *grant agreement* shall be in *English*.

Article 5 - Maximum financial contribution of *Euratom*

1. The maximum financial contribution of *Euratom* to the *project* shall be EUR 2,977,524.00 (*two million nine hundred and seventy seven thousand five hundred and twenty four EURO*). The actual financial contribution of *Euratom* shall be calculated in accordance with the provisions of this *grant agreement*.

2. Details of the financial contribution of *Euratom* are contained in Annex I to this *grant agreement* which includes:

- a table of the estimated breakdown of budget and financial contribution of *Euratom* per activity to be carried out by each of the *beneficiaries* under the *project*. *Beneficiaries* are allowed to transfer budget between different activities and between themselves in so far as the work is carried out as foreseen in Annex I.

3. The bank account of the *coordinator* to which all payments of the financial contribution of *Euratom* shall be made is:

Name of account holder: Studiecentrum voor Kernenergie - Centre d'Etude de l'Energie Nucléaire
Name of bank: ING BANK, Business Branch Institutionals
Account reference: BE92363089878523

Article 6 - Pre-financing

A *pre-financing* of EUR 2,382,019.00 (*two million three hundred and eighty two thousand nineteen EURO*) shall be paid to the *coordinator* within 45 days following the date of entry into force of this *grant agreement*. The *coordinator* shall distribute the *pre-financing* only to the *beneficiaries* who have acceded to the *grant agreement* and after the minimum number of *beneficiaries* required by the *Rules for Participation* as detailed in the call for proposals to which the *project* is related, have acceded to the *grant agreement*.

Beneficiaries hereby agree that the amount of EUR *148,876.20* (*one hundred and forty eight thousand eight hundred and seventy six EURO and twenty cents*), corresponding to the *beneficiaries'* contribution to the Guarantee Fund referred to in Article II.20 and representing 5% of the maximum financial contribution of *Euratom* referred to in Article 5.1, is transferred in their name by the *Commission* from the *pre-financing* into the Guarantee Fund. However, *beneficiaries* are deemed to have received the full *pre-financing* referred to in the first indent and will have to justify it in accordance with the *grant agreement*.

Article 7 - Special clauses

The following special clauses apply to this *grant agreement*:

Special clause 1

1. Euratom shall carry out part of the *project* through its Joint Research Centre (JRC) subject to the following conditions:

(a) For the purposes of this *grant agreement*, the JRC shall be considered as a *research organisation*.

(b) For the purposes of this *grant agreement*, the JRC shall be considered as a *beneficiary*. It shall have the same rights and same obligations as the other *beneficiaries* and shall be a member of the *consortium* identified in Article 1.1.

(c) An amount of EUR 179,200.00 (one hundred and seventy nine thousand two hundred EURO), of the *pre-financing* referred to in Article 6 shall be kept by the *Commission* for the JRC.

The JRC hereby agrees that the amount of EUR 11,200.00 (eleven thousand two hundred EURO), corresponding to the *beneficiaries* contribution to the Guarantee Fund referred to in Article II.20 and representing 5% of the maximum financial contribution of *Euratom* intended for the JRC as stated in Annex I, is transferred in its name by the *Commission* from this part of the *pre-financing* into the Guarantee Fund.

(d) In addition to the documents referred to in Article II.4, the *consortium* shall indicate to the *Commission* the amount of each of the payments referred to in Article II.6.b and II.6.c to be transferred by the *Commission* to the JRC.

(e) This *grant agreement* takes precedence over any *consortium agreement* signed by the *Commission*, represented by the JRC.

2. Relations within the *Commission* between Directorate-General for Research & Innovation and the JRC shall be regulated by an administrative arrangement as set out in Annex VIII to the *grant agreement*, without prejudice to the rights of the other *beneficiaries*.

Special clause 7

Notwithstanding Article II.16, the reimbursement rate for STUDIECENTRUM VOOR KERNENERGIE regarding research and technological development activities, may reach a maximum of 50.00%.

Notwithstanding Article II.16. the reimbursement rate for REGIA AUTONOMA PENTRU ACTIVITATI NUCLEARE DROBETA TR. SEVERIN RA SUCURSALA CERCETARI NUCLEARE PITESTI regarding research and technological development activities, may reach a maximum of 50.00% .

Notwithstanding Article II.16, the reimbursement rate for NUCLEAR RESEARCH AND CONSULTANCY GROUP regarding research and technological development activities, may reach a maximum of 50.00% .

Notwithstanding Article II.16. the reimbursement rate for CENTRO DI RICERCA, SVILUPPO E STUDI SUPERIORI IN SARDEGNA regarding research and technological development activities, may reach a maximum of 50.00% .

Notwithstanding Article II.16, the reimbursement rate for AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE,L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE regarding research and technological development activities, may reach a maximum of 50.00% .

Notwithstanding Article II.16, the reimbursement rate for JRC -JOINT RESEARCH CENTRE-EUROPEAN COMMISSION regarding research and technological development activities, may reach a maximum of 50.00% .

Notwithstanding Article II.16. the reimbursement rate for PAUL SCHERRER INSTITUT regarding research and technological development activities, may reach a maximum of 50.00% .

Special clause 30

Large Scale Research Sector, which is an integral part of beneficiary Karlsruher Institut fuer Technologie has an analytical accounting system which allows it to identify its actual indirect costs. Therefore, and notwithstanding the provisions of article II.15.3. Large Scale Research Sector may declare indirect costs in FP7 grant agreements based on its actual indirect costs, despite the fact that the beneficiary has opted for a flat rate.

Article 8 - Communication

1. Any communication or request concerning the *grant agreement* shall identify the *grant agreement* number, the nature and details of the request or communication and be submitted to the following addresses:

For the *Commission*: European Commission
Directorate-General for Research & Innovation
K.4
B-1049 Brussels, Belgium

For the *coordinator*: Ludo Veuchelen
STUDIECENTRUM VOOR KERNENERGIE
Business Support Unit
Boeretang 200
Mol 2400
Belgium

2. For information or documents to be transferred by electronic means, the following addresses shall be used:

For the *Commission*: RTD-EURATOM-PROJECTS@ec.europa.eu

For the *coordinator*: Paul.Schuurmans@sckcen.be

3. In case of refusal of the notification or absence of the recipient, the *beneficiary* or the *consortium*, as the case may be, is deemed to have been notified on the date of the latest delivery, if notification to the *coordinator* has been sent to one of the addresses mentioned in paragraphs 1 and 2 and to their legal representative. Other *beneficiaries* are deemed to have been notified if notification has been sent to the address mentioned in Article 1.1.

4. Any communication or request relating to the processing of personal data (Article II.13) shall be submitted, using the address(es) for the *Commission* identified in paragraphs 1 and 2, to the Controller responsible for the processing: Head of Unit of K.4.

Article 9 - Applicable law and competent court

The financial contribution of *Euratom* is a contribution from *the Union* research budget with the aim to implement the 7th Research Framework Programme (FP7) and it is incumbent on the Commission to execute FP7. Accordingly, this *grant agreement* shall be governed by the terms of this *grant agreement*, the *Euratom* acts related to FP7, the Financial Regulation applicable to the general budget and its implementing rules and other *Euratom* and European Union law and, on a subsidiary basis, by the law of Belgium.

Furthermore the *beneficiary* is aware and agrees that the Commission may take a decision to impose pecuniary obligations, which shall be enforceable in accordance with Article 299 of the Treaty on the Functioning of the European Union and Articles 164 and 192 of the Treaty establishing the *European Atomic Energy Community*.

Notwithstanding the *Commission's* right to directly adopt the recovery decisions referred to in the previous paragraph, the General Court, or on appeal, the Court of Justice of the European Union, shall have sole jurisdiction to hear any dispute between *Euratom* and any *beneficiary* concerning the interpretation, application or validity of this *grant agreement* and the validity of the decision mentioned in the second paragraph.

Article 10 - Application of the *grant agreement* provisions

Any provision of this part of the *grant agreement*, shall take precedence over the provisions of any of the Annexes. The provisions of Annex III shall take precedence over the provisions of Annex II, and both shall take precedence over the provisions of Annex I.

The special clauses set out in Article 7 shall take precedence over any other provisions of this *grant agreement*.

Article 11 - Entry into force of the *grant agreement*

This *grant agreement* shall enter into force after its signature by the coordinator and the *Commission*, on the day of the last signature.

Done in two originals in English.

For the *coordinator* done at Brussel

SCK·CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE
Av. Hermann Debrouxlaan 40-42
BE-1160 Bruxelles-Brussel

Name of the legal entity

Prof. Dr. Eric van Walle, director-General
Prof. Dr. Frank Deconinck, Chairman

Name of the legal representative

SCK·CEN General Management
Boeretang 200
BE-2400 Mol
Belgium
ORIGINAL

Stamp of the organisation (if applicable)

Signature of legal representative

2011-02-03

Date

For the *Commission* done at Brussels

EUROPEAN COMMISSION
Research Directorate-General

R. LIBERALI
Director

Name of the legal representative

Signature of legal representative

14/1/11

Date

FP7 GRANT AGREEMENT

ANNEX IV - FORM A - ACCESSION OF BENEFICIARIES TO THE GRANT AGREEMENT

UNIVERSITEIT GENT, represented for the purpose hereof by Paul Van Cauwenberge, Rector, and/or Luc Moens, Vice-Rector, or her/his/their authorised representative, established in SINT PIETERSNIEUWSTRAAT 25, GENT, 9000, Belgium acting as its legal authorised representative, hereby consents to become a *beneficiary* ("*beneficiary no. 6*") to *grant agreement* N° 295736 (relating to *project* "*Safe ExploitAtion Related CHemistry for HLM reactors*") concluded between the European Commission and STUDIECENTRUM VOOR KERNENERGIE established in Hermann Debrouxlaan - 40, Brussel, 1160, Belgium and accepts in accordance with the provisions of the aforementioned *grant agreement* all the rights and obligations of a *beneficiary*.

Done in 3 copies, of which one shall be kept by the *coordinator* and one by UNIVERSITEIT GENT, the third being sent to the *Commission* by the coordinator in accordance with Articles 1.1 and 1.2 and Article 8 of the grant agreement.

UNIVERSITEIT GENT

Prof. Paul Van Cauwenberge
Name of legal representative(s)

[signature]
Signature of legal representative(s)

03 AUG 2011
Date

UNIVERSITEIT GENT
Stamp of the organisation

STUDIECENTRUM VOOR KERNENERGIE

Prof. Dr. Eric van Walle
Director-General

Prof. Dr. Frank Deconinck
Chairman

Name of legal representative(s)

[signature] F. [signature]
Signature of legal representative(s)

2011-09-15
Date

Stamp of the organisation

SCK•CEN
General Management
Boeretang 200
BE-2400 Mol
Belgium
ORIGINAL

[signature]
V. VAN SPEYBROECK

SEVENTH FRAMEWORK PROGRAMME

THEME [Fission-2011-2.2.1]
[Support for ESNII]

Grant agreement for: Collaborative project

Annex I - "Description of Work"

Project acronym: SEARCH

Project full title: " Safe ExploitAtion Related CHemistry for HLM reactors "

Grant agreement no: 295736

Date of last change: 2011-06-24

Preparation of the DoW date:

Table of Contents

Part A

Workplan Tables

A1:
Project summary

Project Number [1]	295736	Project Acronym [2]	SEARCH

One form per project

General information

Project title [3]	Safe ExploitAtion Related CHemistry for HLM reactors		
Starting date [4]	The first day of the month after the signature by the Commission		
Duration in months [5]	36		
Call (part) identifier [6]	FP7-Fission-2011		
Activity code(s) most relevant to your topic [7]	Fission-2011-2.2.1: Support for ESNII		
Free keywords [8]		MYRRHA, ESNII, licensing, chemical behaviour of fuel and coolant, oxygen control, fuel-coolant compatibility, risk mitigation	

Abstract [9]

In accordance with the ESNII roadmap MYRRHA will be the first HLM cooled nuclear system to be deployed in Europe. The SEARCH project aims to support the licensing process of MYRRHA by investigating the safe chemical behaviour of the fuel and coolant in the reactor. The control of the oxygen content and the management of impurities in the melt will be studied. A second critical issue in the safety assessment of a nuclear system is the compatibility of the fuel with the coolant after fuel pin leakage or a core melt. The full analyses of these scenarios using validated codes require more experimental data on "basic" properties of the interactions between the materials involved. The basic chemical behaviour of a mixture of fuel, coolant and clad materials range will be studied at relevant temperatures. The compatibility experiments will be done with UO2 and unirradiated MOX fuel, addressing the energy release, solubility in the coolant, fuel-coolant-clad compound formation. Fuel dispersion in the coolant will be simulated by a suitable numerical approach, aiming to address the migration of the fuel and the possibility to have criticality problems due to fuel accumulation. The prevention of risks to the general public will be studied looking into the escape of radioactive materials including fission products and heavy volatile elements as Po and Hg into the environment. The kinetics and efficiency of methods to capture these elements in the covergas system will be examined. The evaporation of Po and Hg from LBE will be measured to obtain a full data set for licensing. Issues related to Po management will be also addressed by an ab initio theoretical approach, predicting its solubility in LBE, the interaction with noble metals to select possible getters and studying formation of Po-compounds.

A2:
List of Beneficiaries

Project Number [1]	295736	Project Acronym [2]	SEARCH

List of Beneficiaries

No	Name	Short name	Country	Project entry month[10]	Project exit month
1	STUDIECENTRUM VOOR KERNENERGIE	SCK-CEN	Belgium	1	36
2	AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE,L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE	ENEA	Italy	1	36
3	Karlsruher Institut fuer Technologie	KIT	Germany	1	36
4	NUCLEAR RESEARCH AND CONSULTANCY GROUP	NRG	Netherlands	1	36
5	CENTRO DI RICERCA, SVILUPPO E STUDI SUPERIORI IN SARDEGNA	CRS4	Italy	1	36
6	UNIVERSITEIT GENT	UGENT	Belgium	1	36
7	UNIVERSITA DI PISA	UNIPI	Italy	1	36
8	VON KARMAN INSTITUTE FOR FLUID DYNAMICS	VKI	Belgium	1	36
9	REGIA AUTONOMA PENTRU ACTIVITATI NUCLEARE DROBETA TR. SEVERIN RA SUCURSALA CERCETARI NUCLEARE PITESTI	INR	Romania	1	36
10	JRC -JOINT RESEARCH CENTRE- EUROPEAN COMMISSION	JRC	Belgium	1	36
11	PAUL SCHERRER INSTITUT	PSI	Switzerland	1	36
12	CHALMERS TEKNISKA HOEGSKOLA AB	Chalmers	Sweden	1	36

A3: Budget Breakdown

Project Number [1]	295736	Project Acronym [2]	SEARCH

One Form per Project

Participant number in this project [11]	Participant short name	Fund. %[12]	Ind. costs[13]	Estimated eligible costs (whole duration of the project) RTD / Innovation (A)	Demonstration (B)	Management (C)	Other (D)	Total A+B+C+D	Total receipts	Requested EU contribution
1	SCK•CEN	75.0	A	775,272.00	0.00	110,500.00	25,300.00	911,072.00	0.00	571,436.00
2	ENEA	75.0	A	702,002.00	0.00	0.00	0.00	702,002.00	0.00	351,003.00
3	KIT	75.0	T	1,255,670.00	0.00	0.00	0.00	1,255,670.00	0.00	627,835.00
4	NRG	75.0	A	96,000.00	0.00	0.00	0.00	96,000.00	0.00	48,000.00
5	CRS4	75.0	A	170,000.00	0.00	0.00	0.00	170,000.00	0.00	85,000.00
6	UGENT	75.0	T	180,000.00	0.00	0.00	0.00	180,000.00	0.00	135,000.00
7	UNIPI	75.0	T	69,020.00	0.00	0.00	0.00	69,020.00	0.00	51,765.00
8	VKI	75.0	A	113,334.00	0.00	0.00	70,386.00	183,720.00	0.00	155,386.00
9	INR	75.0	A	59,500.00	0.00	0.00	0.00	59,500.00	0.00	29,750.00
10	JRC	75.0	T	676,001.60	0.00	0.00	0.00	676,001.60	0.00	338,000.00
11	PSI	75.0	F	810,000.00	0.00	0.00	0.00	810,000.00	0.00	405,000.00
12	Chalmers	75.0	T	239,132.00	0.00	0.00	0.00	239,132.00	0.00	179,349.00
Total				5,145,931.60	0.00	110,500.00	95,686.00	5,352,117.60	0.00	2,977,524.00

Note that the budget mentioned in this table is the total budget requested by the Beneficiary and associated Third Parties.

* The following funding schemes are distinguished

Collaborative Project (if a distinction is made in the call please state which type of Collaborative project is referred to: (i) Small of medium-scale focused research project, (ii) Large-scale integrating project, (iii) Project targeted to special groups such as SMEs and other smaller actors), Network of Excellence, Coordination Action, Support Action.

1. Project number

The project number has been assigned by the Commission as the unique identifier for your project, and it cannot be changed. The project number should appear on each page of the grant agreement preparation documents to prevent errors during its handling.

2. Project acronym

Use the project acronym as indicated in the submitted proposal. It cannot be changed, unless agreed during the negotiations. The same acronym should appear on each page of the grant agreement preparation documents to prevent errors during its handling.

3. Project title

Use the title (preferably no longer than 200 characters) as indicated in the submitted proposal. Minor corrections are possible if agreed during the preparation of the grant agreement.

4. Starting date

Unless a specific (fixed) starting date is duly justified and agreed upon during the preparation of the Grant Agreement, the project will start on the first day of the month following the entry into force of the Grant Agreement (NB : entry into force = signature by the Commission). Please note that if a fixed starting date is used, you will be required to provide a detailed justification on a separate note.

5. Duration

Insert the duration of the project in full months.

6. Call (part) identifier

The Call (part) identifier is the reference number given in the call or part of the call you were addressing, as indicated in the publication of the call in the Official Journal of the European Union. You have to use the identifier given by the Commission in the letter inviting to prepare the grant agreement.

7. Activity code

Select the activity code from the drop-down menu.

8. Free keywords

Use the free keywords from your original proposal; changes and additions are possible.

9. Abstract

10. The month at which the participant joined the consortium, month 1 marking the start date of the project, and all other start dates being relative to this start date.

11. The number allocated by the Consortium to the participant for this project.

12. Include the funding % for RTD/Innovation – either 50% or 75%

13. Indirect cost model

A: Actual Costs

S: Actual Costs Simplified Method

T: Transitional Flat rate

F :Flat Rate

Workplan Tables

Project number

295736

Project title

SEARCH—Safe ExploitAtion Related CHemistry for HLM reactors

Call (part) identifier

FP7-Fission-2011

Funding scheme

Collaborative project

WT1
List of work packages

Project Number [1]	295736	Project Acronym [2]	SEARCH

LIST OF WORK PACKAGES (WP)

WP Number [53]	WP Title	Type of activity [54]	Lead beneficiary number [55]	Person-months [56]	Start month [57]	End month [58]
WP 1	Consortium Agreement	MGT	1	6.38	1	36
WP 2	Cootabiltiy of a wire spaced fuel bundle	RTD	2	51.25	1	36
WP 3	Coolant Chemistry Control	RTD	3	105.20	1	36
WP 4	Fuel Coolant Interactions	RTD	12	47.10	1	36
WP 5	Fuel Dispersion Study	RTD	5	55.65	1	36
WP 6	Release and Capture Studies for Radioisotopes	RTD	11	136.20	1	36
WP 7	Education and Training	OTHER	8	5.58	1	36
			Total	407.36		

WT2:
List of Deliverables

Project Number [1]	295736	Project Acronym [2]	SEARCH

List of Deliverables - to be submitted for review to EC

Deliverable Number [61]	Deliverable Title	WP number [53]	Lead beneficiary number	Estimated indicative person-months	Nature [62]	Dissemination level [63]	Delivery date [64]
D1.1	Project quality plan including measures of success	1	1	1.00	R	PU	2
D1.2	Minutes of the first RP general meetings complemented with indications from the ETAC	1	1	1.00	R	PU	18
D1.3	Minutes of the second RP general meetings complemented with indications from the ETAC	1	1	1.00	R	PU	36
D1.4	Report on the access to the website and information collected (newsletter, indications from ETAC)	1	1	1.00	R	PU	36
D1.5	Public and private website	1	1	0.60	R	PU	3
D1.6	Consortium agreement	1	1	0.90	R	PU	6
D1.7	Communication and dissemination plan	1	1	0.63	R	PU	6
D1.8	Project presentation	1	1	0.25	R	RE	3
D2.1	The fuel rod bundle design for the NACIE facility	2	2	2.25	R	PU	6
D2.2	8.2 mm rod bundle design and instrumentation report	2	3	8.50	R	PU	6

Deliverable Number [61]	Deliverable Title	WP number [53]	Lead beneficiary number	Estimated indicative person-months	Nature [62]	Dissemination level [63]	Delivery date [64]
D2.3	NACIE: a test facility for free and mixed convection heat transfer measurements in liquid metals for	2	2	2.25	R	PU	18
D2.4	Experimental results on free convection in heavy liquid metals using the NACIE facility	2	2	2.25	R	PU	24
D2.5	8.2 mm rod bundle experiments report	2	3	8.50	R	PU	24
D2.6	Experimental results on forced convection in heavy liquid metals using the HELENA facility	2	2	2.25	R	PU	36
D2.7	Post-test analysis on free and forced convection measurements in HLM using NACIE and HELENA faciliti	2	2	2.25	R	PU	36
D2.8	Report on pre- and post-test analyses of the NACIE and THEADES experi-mental loops and assessment of	2	4	6.00	R	PU	36
D2.9	Report on pre-test analysis	2	3	8.50	R	PU	24
D2.10	Report on post-test analysis	2	3	8.50	R	PU	36
D3.1	Report on formation of spallation	3	1	18.50	R	PU	12

Deliverable Number [61]	Deliverable Title	WP number [53]	Lead beneficiary number	Estimated indicative person-months	Nature [62]	Dissemination level [63]	Delivery date [64]
	products and neutron activation products in a MYRRHA type reactor						
D3.2	Report on expected corrosion products in a MYRRHA type reactor	3	3	23.00	R	PU	18
D3.3	Final report on the filter lifetime and efficiency	3	1	18.50	R	PU	36
D3.4	Final Report on oxygen control systems for HLM large pool system	3	2	12.00	R	PU	36
D3.5	Final Report on oxygen adsorption, entrainment of oxides and mass transport	3	3	23.00	R	PU	36
D4.1	Study of Pb-U-O and Bi-U-O phase relations	4	10	16.75	R	PU	18
D4.2	Analysis of LBE-fuel interaction : homogeneous MOX, heterogeneous MOX, BN MOX and UO2/PuO2	4	12	13.60	R	PU	36
D4.3	Study of Pb-Pu-O and Bi-Pu-O phase relations	4	10	16.75	R	PU	36
D5.1	Report on the operability of the SIMMER-III and SIMMER-IV models for the MIRRHA-FASTEF reactor	5	7	6.80	R	PU	12

WT2:
List of Deliverables

Deliverable Number [61]	Deliverable Title	WP number [53]	Lead beneficiary number	Estimated indicative person-months	Nature [62]	Dissemination level [63]	Delivery date [64]
D5.2	Single phase steady state CFD model of the MYRRHA-FASTEF primary coolant loop including all relevant	5	8	3.80	R	PU	18
D5.3	Two-phase CFD model of the MYRRHA-FASTEF primary coolant loop including all relevant thermal aspects	5	5	9.35	R	PU	18
D5.4	Report on the 3D SIMMER-IV analysis for the more representative fuel failure conditions	5	2	4.25	R	PU	24
D5.5	Report on assessment on fuel dispersion after pin failure under blockage conditions	5	3	14.00	R	PU	30
D5.6	Characterisation of long term dispersion of fuel in the coolant with CFD modelling	5	8	3.85	R	PU	36
D5.7	Characterisation of the fission gas and other species release dispersion in the coolant with CFD mod	5	5	9.35	R	PU	36
D5.8	Report on the 2D SIMMER-III analysis for the reference case and parametric study	5	2	4.25	R	PU	36

WT2:
List of Deliverables

Deliverable Number [61]	Deliverable Title	WP number [53]	Lead beneficiary number	Estimated indicative person-months	Nature [62]	Dissemination level [63]	Delivery date [64]
D6.1	Report on results of screening experiments	6	11	32.40	R	PU	15
D6.2	Report on tasks 6.3.1, 6.3.2 and 6.3.3	6	6	16.20	R	PU	22
D6.3	Final report on volatilization and deposition studies	6	11	32.40	R	PU	36
D6.4	Final report on the evaporation, release and capture of Po	6	1	19.50	R	PU	36
D6.5	Final report on the evaporation and capture of Hg	6	1	19.50	R	PU	36
D6.6	Report on tasks 6.3.4 and 6.3.5	6	6	16.20	R	PU	36
D7.1	1st Workshop lectures book	7	8	1.86	R	PU	18
D7.2	2nd Workshop lectures book	7	8	1.86	R	PU	24
D7.3	Training Course lectures book	7	8	1.86	R	PU	36
			Total	397.16			

Project Number [1]	295736	Project Acronym [2]	SEARCH

One form per Work Package

Work package number [53]	WP1	Type of activity [54]	MGT
Work package title	Consortium Agreement		
Start month	1		
End month	36		
Lead beneficiary number [55]	1		

Objectives

This WP is aimed at the general coordination of the consortium (i.e., management of legal, financial and administrative aspects) and at guaranteeing the coherence between the different work packages in order to respect the project's objectives, its overall internal coherence, time schedule, issuance of deliverables, periodic reporting to the European Commission.
Moreover, WP1 is devoted to improve the diffusion of knowledge and information utilizing the gained information on HLM technologies and on the reliability and performance components. A proper website will be implemented acting as central point of information for the partners and the overall scientific community on topics addresses in the frame of the project, highlighting the latest news.

Description of work and role of partners

WP1 is dedicated to the general management of the project, and in particular it will provide:
- general coordination of the consortium and maintenance of the consortium agreement;
- administration of project resources;
- elaboration and monitoring of project procedures including the performance indicators, the definition of the project's internal organisation, procedures, document models, etc., in detail in order also to address and solve potential conflicts among the project partners efficiently;
- preparation of the consortium agreement;
- follow-up of project planning, deliverables and milestones;
- ensuring that all partners share the same level of information on general issues concerning the project, i.e. contract and project management, work progress, communication, etc.;
- elaboration of the periodic management & activity reports to the European Commission;
- preparation, organisation and minutes of project management meetings (progress meetings, governing board meetings and technical coordination board meetings);
- follow-up of decisions and action plans;
- preparation of the project presentation.

SCK•CEN will act as project coordinator (PCO).
The coordinator is responsible for the day-to-day administration of the project to guarantee its smooth functioning. It ensures the organization and secretariat of the general meetings, of the Technical Coordination Board (TEC) meetings and of the Governing Board (GOV) meetings. Moreover it helps in the internal diffusion of information and keeps a register of all the reports produced in the project. Together with WP7 a communication and dissemination plan will be prepared.
In the frame of WP1 the support of the External Technical Advisory Committee (ETAC) will be guaranteed and the links with the other project work packages facilitated.

Finally the PCO will provide to define, a website dedicated to the main results carried out in the frame of the HLM technologies as well as the results gained in term of reliability and performance of nuclear components will be 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 is 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.

The website will be structured, therefore, in three specific areas:
1) A technical area dedicated to the main topics related with the HLM technologies (thermal hydraulics, 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 of the ESNII roadmap.

2) 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 workshop and training course 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.

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

Person-Months per Participant

Participant number [10]	Participant short name [11]	Person-months per participant
1	SCK•CEN	6.38
	Total	6.38

List of deliverables

Deliverable Number [61]	Deliverable Title	Lead beneficiary number	Estimated indicative person-months	Nature [62]	Dissemination level [63]	Delivery date [64]
D1.1	Project quality plan including measures of success	1	1.00	R	PU	2
D1.2	Minutes of the first RP general meetings complemented with indications from the ETAC	1	1.00	R	PU	18
D1.3	Minutes of the second RP general meetings complemented with indications from the ETAC	1	1.00	R	PU	36
D1.4	Report on the access to the website and information collected (newsletter, indications from ETAC)	1	1.00	R	PU	36
D1.5	Public and private website	1	0.60	R	PU	3
D1.6	Consortium agreement	1	0.90	R	PU	6
D1.7	Communication and dissemination plan	1	0.63	R	PU	6
D1.8	Project presentation	1	0.25	R	RE	3
		Total	6.38			

Description of deliverables

D1.1) Project quality plan including measures of success: A Quality Plan to be followed for the project will be produced by the PCO, containing: ☐ organisation of the working team; ☐ roles and responsibilities of each participant; ☐ control actions planned; ☐ time schedules; ☐ definition of requirement specifications and quality objectives; ☐ procedures for acceptance and quality control; ☐ performance indicators or measures of success. [month 2]

D1.2) Minutes of the first RP general meetings complemented with indications from the ETAC: The minutes of the meetings that are held at the end of the first reporting period at the midway point of the project including: • the general meeting; • the governing board meeting; • the TEC meeting; The minutes will be complemented with any indications from the ETAC. [month 18]

D1.3) Minutes of the second RP general meetings complemented with indications from the ETAC: The minutes of the meetings that are held at the end of the second reporting period at the end of the project including: • the general meeting; • the governing board meeting; • the TEC meeting The minutes will be complemented with any indications from the ETAC. [month 36]

D1.4) Report on the access to the website and information collected (newsletter, indications from ETAC): This deliverable will report on the acess of the website and the information that is collected including the newsletters published, indications from the ETAC and other general information about the project. [month 36]

D1.5) Public and private website: The deliverable will be the realisation of both the public and restricted part of the project web-site. [month 3]

D1.6) Consortium agreement: The consortium agreement will contain all agreements, rules and regulations in operation between the partners for the operation of the project. [month 6]

D1.7) Communication and dissemination plan: The communication and dissemination plan will give the roadmap for communication and dissemination of results. This roadmap includes activities like international conferences, national meetings, publications, training activities, etc. with their dates over the lifetime of the project. [month 6]

D1.8) Project presentation: The project presentation will be a 2 A4 sheet document following the template provided by the EU that presents the project goal, objectives, activities, expected outcome and impact. It will also include 2 supporting pictures. [month 3]

Schedule of relevant Milestones

Milestone number [59]	Milestone name	Lead benefi-ciary number	Delivery date from Annex I [60]	Comments
MS1	Realization of the website	1	3	M1.1
MS2	Set up of the External Technical Advisory Committee	1	6	M1.2
MS3	Submission to the EC of the first RP report	1	18	M1.3
MS4	Submission to the EC of the final report	1	36	M1.4

Project Number [1]	295736	Project Acronym [2]	SEARCH

One form per Work Package

Work package number [53]	WP2	Type of activity [54]	RTD
Work package title	Coolability of a wire spaced fuel bundle		
Start month	1		
End month	36		
Lead beneficiary number [55]	2		

Objectives

In this work package the goal is the investigation of the coolability of a wire spaced fuel assembly by the experimental analysis and numerical modelling of thermal-hydraulic behaviour of a wire wrapped rod bundle simulator. In order to meet the requirements of MYRRHA two different sized prototypical rod bundles will be investigated in a heavy liquid metal flow using LBE (lead bismuth eutectic) in the regime of forced, mixed and natural convection with a maximal attainable heat flux of 1 MW/m² by electrical heating.
Measured pressure drop and temperature profiles will give important input for the MYRRHA design.
Nevertheless, for a deeper understanding numerical support and CFD-modelling to support the experiments is indispensable.

Description of work and role of partners

This work package is divided into 3 tasks.
Task 2.1 Fuel assembly thermal-hydraulic tests (ENEA, KIT)
This task will be devoted to the experimental campaign on THEADES (KIT), NACIE (ENEA) and HELENA (ENEA) HLM loops. The experiment in the THEADES loop will study forced convection and it will be performed on a 19 pin wire wrapped rod bundle with a diameter of 8.2 mm, pitch to diameter (p/d) ratio of 1.28 and a heat flux up to 1 MW/m2. Results will be in terms of temperature measurements in the pin cladding, bulk temperatures in the subchannels, pressure drop measurements and overall temperature drop.
Information from THEADES experiment will give the base for the subsequent experiment on free and mixed convection on the NACIE loop (ENEA). A wire-spaced 19 pins hexagonal fuel bundle will be assembled in a hexagonal lattice, with pin diameter 6.55 mm, active length of 600 mm, p/d ratio of 1.28. The pins provide an azimuthally uniform heat flux up to 1 MW/m2. These values are relevant for the MYRRHA design. Free and mixed convection tests will be performed on the NACIE loop. The transient tests will simulate the transition from forced to free convection as a consequence of a loss of flow accident, and therefore the initial condition will result from the THEADES experimental tests. The following quantities will be measured during the transient: the cladding temperature through wall-embedded TCs; the integral mass flow rate through a proper flow meter; pressure losses in the FA; bulk temperature in the sub-channels; heat transfer coefficient.
The reason for using 8.2 mm pins in THEADES and 6.5 mm pins in NACIE lies in the short term availability of 8.2 mm rods from former experiments. In this way the whole campaign will save a lot of time and money without compromising on physical relevance, as the results of forced convection experiments can be transferred to the final MYRRHA-design using thermal hydraulic similarity laws and simulation tools validated using the 8.2 mm pin experimental results.
As Long Term step, the NACIE bundle will be dismantled and mounted in the horizontal HELENA loop, working with lead. The forced convection experiment above described for THEADES will be repeated on the new bundle and the coherence of the scaling laws used as Initial Conditions in the NACIE tests will be verified in HELENA. A post-test analysis will be accomplished on the whole experimental campaign.

Task 2.2 Numerical fuel assembly thermal-hydraulic analyses (NRG)
This task will provide detailed CFD analyses using appropriate turbulence modelling in support of the experiments. From these detailed analyses, input parameters will be derived for a coarse grid model of the NACIE facility to perform parameter studies at KIT. Detailed post-test CFD analyses on a section of the experimental FAs will be performed for the THEADES and NACIE experiments. These detailed analyses will provide input for LRGR and coarse grid analyses of the complete experimental FA to be performed by NRG and

KIT. These analyses will support the interpretation of the experimental results, as limited measurement data will be available due to the complex experimental environment (LBE). The validated approaches used in support of the experiments will be applied to the real 127 pin MYRRHA FA. Firstly, a detailed CFD analysis of a section of a FA will be performed. This will provide input for LRGR and coarse grid analysis of a complete MYRRHA FA or even the complete MYRRHA core. These analyses will serve to deduct heat transfer correlations to be used in less resolved numerical approaches.

Task 2.3 Numerical support to design and experiments on wire-wrap fuel assembly (KIT)
This task will be devoted to pre-test parametric and post-test numerical simulations on the rod bundle flow. Pre-test numerical simulations provide the input for the selection of parameters like axial pitch and help to choose an experimental test-program including sensor locations, error estimation and optimization of flow conditioners. Detailed interpretation of experimental data is performed based on post-test simulations. Simulations are performed with the coarse grid CFD technique with sub-grid data derived from representative simulations with fully resolved CFD (provided for NACIE-experiments by NRG and for KALLA experiments by KIT).

Person-Months per Participant

Participant number [10]	Participant short name [11]	Person-months per participant
2	ENEA	11.25
3	KIT	34.00
4	NRG	6.00
	Total	51.25

List of deliverables

Deliverable Number [61]	Deliverable Title	Lead beneficiary number	Estimated indicative person-months	Nature [62]	Dissemination level [63]	Delivery date [64]
D2.1	The fuel rod bundle design for the NACIE facility	2	2.25	R	PU	6
D2.2	8.2 mm rod bundle design and instrumentation report	3	8.50	R	PU	6
D2.3	NACIE: a test facility for free and mixed convection heat transfer measurements in liquid metals for	2	2.25	R	PU	18
D2.4	Experimental results on free convection in heavy liquid metals using the NACIE facility	2	2.25	R	PU	24
D2.5	8.2 mm rod bundle experiments report	3	8.50	R	PU	24
D2.6	Experimental results on forced convection in heavy liquid metals using the HELENA facility	2	2.25	R	PU	36
D2.7	Post-test analysis on free and forced convection measurements in HLM using NACIE and HELENA faciliti	2	2.25	R	PU	36
D2.8	Report on pre- and post-test analyses of the NACIE and THEADES experi¬mental loops and assessment of	4	6.00	R	PU	36
D2.9	Report on pre-test analysis	3	8.50	R	PU	24
D2.10	Report on post-test analysis	3	8.50	R	PU	36
		Total	51.25			

Description of deliverables

D2.1) The fuel rod bundle design for the NACIE facility: This deliverable describes the design of the 6.5 mm fuel rod bundle that will be used in the natural and mixed convection thermal-hydraulic experiments in the NACIE set-up at ENEA. [month 6]

D2.2) 8.2 mm rod bundle design and instrumentation report: Here the design and the instrumentation of the fuel rod bundle that will be used in the forced convection thermal-hydraulic experiments in the THEADES loop at KIT is described. [month 6]

D2.3) NACIE: a test facility for free and mixed convection heat transfer measurements in liquid metals for: The deliverable gives a description of the NACIE facility that is used for the free and mixed convection heat transfer experiments at ENEA. [month 18]

D2.4) Experimental results on free convection in heavy liquid metals using the NACIE facility: The deliverable will describe and discuss the experimental campaign and results from the heat transfer experiments in free convection flow as performed in the NACIE facility. [month 24]

D2.5) 8.2 mm rod bundle experiments report: The deliverable will report on the experiments performed on the 8.2 mm rod bundle in forced convection flow in the THEADES loop at KIT. [month 24]

D2.6) Experimental results on forced convection in heavy liquid metals using the HELENA facility: This report will describe the heat transfer data results on the 6.5 mm rod bundle in forced convection flow from experiments performed in the HELENA loop at ENEA. [month 36]

D2.7) Post-test analysis on free and forced convection measurements in HLM using NACIE and HELENA faciliti: In this deliverable the post-test numerical analyses of the experiments performed on the 6.5 mm fuel bundle are discussed. Both the analyses of the free convection experiments in NACIE and the forced convection experiments in HELENA are included. [month 36]

D2.8) Report on pre- and post-test analyses of the NACIE and THEADES experi¬mental loops and assessment of: In this report, a discussion is given of the pre- and post-test analyses of the experiments in the NACIE and THEADES loops using a detailed CFD analyses and a corse grid approach. Furthermore the application of this model to a full 127 pin MYRRHA fuel assembly is presented. [month 36]

D2.9) Report on pre-test analysis: This report describes the devoted to pre-test parametric simulations on the rod bundle flow that provide the input for the selection of experimental parameters. Simulations are performed with the coarse grid CFD technique with sub-grid data derived from representative simulations with fully resolved CFD. [month 24]

D2.10) Report on post-test analysis: The post-test numerical simulations on the rod bundle that are used for detailed interpretation of experimental data are discussed. Simulations are performed with the coarse grid CFD technique with sub-grid data derived from representative simulations with fully resolved CFD. [month 36]

Schedule of relevant Milestones

Milestone number [59]	Milestone name	Lead beneficiary number	Delivery date from Annex I [60]	Comments
MS5	Design and instrumentation of ENEA 6.5 mm Rod Bundle	2	6	M2.1
MS6	Design and instrumentation of KIT 8.2 mm Rod Bundle	3	6	M2.2
MS7	Flow conditioner design simulations	3	6	M2.3
MS8	Provision of detailed pre-test CFD analyses for NACIE	2	9	M2.4
MS9	Fabrication of KIT Rod Bundle Experiment	3	12	M2.5
MS10	Pre-test analysis of KALLA-experiments	3	12	M2.6
MS11	System components procurement and facility upgrade on NACIE	2	18	M2.7
MS12	Experimental results for free circulation tests in NACIE	2	24	M2.8
MS13	Pre-test analysis of NACIE-experiments	2	24	M2.9
MS14	HELENA upgrade, main system and components procurement	2	30	M2.10
MS15	Results of HELENA experiments and post-test analysis	2	36	M2.11
MS16	Provision of post-test CFD analyses for NACIE	2	36	M2.12
MS17	Assessment of a 127 pin MYRRHA FA	4	36	M2.13
MS18	Post-test analysis	3	36	M2.14

Project Number [1]	295736	Project Acronym [2]	SEARCH

One form per Work Package

Work package number [53]	WP3	Type of activity [54]	RTD
Work package title	Coolant Chemistry Control		
Start month	1		
End month	36		
Lead beneficiary number [55]	3		

Objectives

The main objectives of this work package are related to the control of the coolant chemistry and associated with that the filtering and mass transport of impurities. The objectives are summarised as follows:
• Determination and assessment of corrosion products to be expected in MYRRHA under operation. Determination and assessment of spallation products and neutron activation products to be expected in MYRRHA under operation;
• Determination of loop filter efficiency, lifetime and pressure drop for several filter types;
• Determination of feasibility and efficiency of LBE pool type filter;
• Validating an Oxygen Control System (OCS) based on solid oxide particles inside a pool type facility and measurement of PbO formation and dissolution kinetics in LBE;
• Absorption of oxygen from the cover gas under regular operating conditions and accidental ingress of oxygen into the cover gas;
• Entrainment of oxides floating on the liquid-metal surface;
• Oxygen absorption from water vapour introduced below the liquid-metal surface (HEX leak);
• Mass-transport of dissolved metals, especially nickel.

Description of work and role of partners

Work package 3 is divided in 3 tasks.
Task 3.1: Determination of Source Terms (KIT, SCK•CEN)
It is important for normal operating conditions to estimate the amount of oxidation and corrosion products that are formed. This information is needed to design and in a later stage operate the required LBE impurity control units. Oxygen control, impurity control and the cover gas handling are important issues in this field. In addition information about spallation products and neutron activation products in the LBE under operation are required, because they will interfere with the non-active impurity control handling. At KIT the expected formation of corrosion products on materials and components of a MYRRHA reactor under operation conditions will be determined and assessed. At SCK•CEN the formation of spallation products and neutron activation products of a MYRRHA reactor under operation will be evaluated and assessed using MCNPX calculations.

Task 3.2: Filtering Techniques (SCK•CEN, ENEA, INR)
Metallic and non-metallic impurities (oxides) are observed in loops and pool facilities after operation. Such impurities can aggregate and result in blockage of systems. Therefore cleaning and filtering devices are required for operation of LBE cooled systems. In loops some filter-systems were tested in the past but no final judgement could be given so far. In pool type systems different approaches not investigated in detail up to now have to be developed.
At SCK•CEN a loop type filter will be placed in a small delta T loop equipped with sacrificial rods to measure the pressure loss as a function of material loss from these sacrificial rods. Secondly, an overflow pool type filter will be developed and placed in an LBE pool to examine the applicability and efficiency of such filter to trap oxide particles from the LBE surface.
ENEA will adapt and test loop type filters based on adsorption techniques to an LBE pool environment and tested. Furthermore a detailed investigation to understand the formation of solid impurities accompanied by quantitative qualification of filtering performance will be done.

INR is a new partner in the field of heavy liquid metal technology. Their contribution will encompass the exchange of know-how and the acquirement of hands on experience by performing filter tests in the small delta T loop at SCK•CEN.

Task 3.3: Control, Mass Transport and Interaction of Oxygen, Metallic and Non-Metallic Impurities with LBE (SCK•CEN, ENEA, KIT)
Several open questions for LBE impurity control including oxygen will be addressed in this task. The use of oxygen control systems based on solid PbO oxides will be addressed from an engineering and physic-chemical point of view. Mass exchange, entrainment of solid particles (oxides), interaction, adsorption and deposition of impurities will be experimentally and theoretically investigated. Tests of oxygen sensors to be operated in a pool facility are foreseen.
At KIT vessel-type experimental device containing ~200 kg molten LBE will be developed and used for investigating mass transport and interaction phenomena. The design will be supported by CFD calculations to optimize the design and the position of oxygen sensors and cooled probes for deposition of dissolved metals. Quantitative (local oxygen activity, dissolution of metals) and qualitative (dispersion of dissolved metals) measurements of mass-transfer and transport will be done to form the basis for integrating these phenomena in the CFD code. Ultrasonic measurements of the liquid metal flow during the experiments are used for verifying these calculations. Finally a model for the absorption of oxygen from the cover gas and vapour bubbles will be developed.
A compact experiment to determine the solubility limit and the formation and dissolution kinetics of PbO in LBE will be constructed at SCK•CEN. The set-up will comprise of 2 ceramic lined pots connected by a quartz or ceramic coated transfer tube. Both pots have independent temperature and cover gas control. The PbO solubility limit and its formation and dissolution kinetics in LBE, assuming that the liquid metal transfer is not the rate limiting step, will be measured. The temperature and oxygen concentrations while be varied systematically in the closed system at high temperature.
Different oxygen control methods for a pool type facility will be investigated at ENEA. A gas/liquid systems and a solid/liquid systems (based on solid PbO) will be designed, implemented and tested in the CIRCE facility The reliability of Oxygen Sensor technology in a pool test facility (CIRCE) will be tested.

Person-Months per Participant

Participant number [10]	Participant short name [11]	Person-months per participant
1	SCK•CEN	37.00
2	ENEA	12.00
3	KIT	46.00
9	INR	10.20
	Total	105.20

List of deliverables

Deliverable Number [61]	Deliverable Title	Lead beneficiary number	Estimated indicative person-months	Nature [62]	Dissemination level [63]	Delivery date [64]
D3.1	Report on formation of spallation products and neutron activation products in a MYRRHA type reactor	1	18.50	R	PU	12
D3.2	Report on expected corrosion products in a MYRRHA type reactor	3	23.00	R	PU	18
D3.3	Final report on the filter lifetime and efficiency	1	18.50	R	PU	36

List of deliverables

Deliverable Number [61]	Deliverable Title	Lead beneficiary number	Estimated indicative person-months	Nature [62]	Dissemination level [63]	Delivery date [64]
D3.4	Final Report on oxygen control systems for HLM large pool system	2	12.00	R	PU	36
D3.5	Final Report on oxygen adsorption, entrainment of oxides and mass transport	3	23.00	R	PU	36
		Total	95.00			

Description of deliverables

D3.1) Report on formation of spallation products and neutron activation products in a MYRRHA type reactor: The deliverable discusses the neutronic assessment of the formation of spallation products and neutron activation products in a MYRRHA type reactor. From this calculation the source term for impurities originating from nuclear interactions is derived. [month 12]

D3.2) Report on expected corrosion products in a MYRRHA type reactor: On the basis of the existing understanding of corrosion of structural materials in heavy liquid metal cooled systems the amount of corrosion products that are released in the coolant of a MYRRHA type reactor is assessed. [month 18]

D3.3) Final report on the filter lifetime and efficiency: This reports gives an overall description of the activities with regard to coolant filtering. It discusses the efficiency and operational lifetime of the different filter systems that have been tested. [month 36]

D3.4) Final Report on oxygen control systems for HLM large pool system: The deliverable gives an overall report on different possibilities for oxygen control systems in a heavy liquid metal pool configuration. [month 36]

D3.5) Final Report on oxygen adsorption, entrainment of oxides and mass transport: This report describes the studies on the adsorption, entrainment of oxides in heavy liquid metals and on mass transport phenomena in liquid metals. This includes the transport of oxygen and of metal(oxide) particles. [month 36]

Schedule of relevant Milestones

Milestone number [59]	Milestone name	Lead beneficiary number	Delivery date from Annex I [60]	Comments
MS19	Commissioning of the delta T loop	1	12	M3.1
MS20	Experimental device for mass-transfer studies in molten LBE available	3	15	M3.2
MS21	OCS implementation in HLM pool facility	2	18	M3.3
MS22	Commissioning of the pool type filter	2	30	M3.4

Project Number [1]	295736	Project Acronym [2]	SEARCH

One form per Work Package

Work package number [53]	WP4	Type of activity [54]	RTD
Work package title	Fuel Coolant Interactions		
Start month	1		
End month	36		
Lead beneficiary number [55]	12		

Objectives

In this work package, the goal is to study the LBE-fuel interaction and characterize the reaction products and their potential effect on the fuel element in order to qualify the fuel for MYRRHA. In addition, a more fundamental approach is taken to understand the phase relations Pb-U-O, Bi-U-O, Pb-Pu-O and Bi-Pu-O for which there is no published available data.
The MOX fuel used in the experiments will be as close as possible to the MYRRHA specifications. In particular, the Pu fraction is set to 30% if possible, the O/M ratio representative of fresh fuel is set to 1.97 and the O/M ratio representative of irradiated fuel surface is set to 2.00.
Experiments will be done on solid pellets (or disks) to study the effect of LBE-fuel interaction on the surface. Additional experiments will be done with powders which have much higher specific surface area and show a different behaviour that the pellet (e.g. dissolution).
A temperatures range 500-800°C is chosen as representative of the fuel surface temperature in nominal operation condition. Experiment will be carried out at the limiting temperature 500°C and 800°C and possible at an intermediate temperature.
The oxygen concentration in LBE is set at [O]=1.10-6 wt.% in accordance with MYRRHA operating condition.
Additionally, two MOX manufacturing route will be investigated. One based on wet chemistry (sol-gel technique) that produces a very homogeneous solid solution of (U, Pu)O2 and one based on a dry fabrication route that consists in mixing powder of UO2 and PuO2 followed by ball milling and sintering. The latter produces a heterogeneous microstructure with Pu or U-rich agglomerates. The reason behind using two different preparation routes is to study the effect of the microstructure homogeneity on the interaction with LBE.
Complementary experiments on UO2/PuO2 pellets/powder will also be done.
Another objective of the work package is to acquire knowledge on phase relation between the different species involved in order to extent the current knowledge the phase diagrams. This work will be supported by dedicated experiments. A CALPHAD modelling of the phase diagrams is also foreseen but outside of this project.

Description of work and role of partners

Work package 4 is divided in 3 tasks.
T4.1: Fuel preparation (JRC-ITU, CHALMERS)
The objective of this task is to obtain the right materials and experimental conditions to study the LBE-fuel interactions. The manufacturing of MOX is a complex operation that can strongly influence the fuel behaviour under irradiation and also possibly, its interaction with LBE. In order to take into account the variations in microstructure in the LBE-fuel experiments, three different kind of MOX pellets/powder will be investigated. A homogeneous MOX will be prepared via the 'sol-gel' method, a heterogeneous MOX will be prepared via the powder route and a commercial MOX pellet (also heterogeneous) prepared for fast reactor by Belgonucléaire (BN) will also be studied. Existing pellets/powder of UO2 and PuO2 will also be used for additional experiments with LBE. The experimental set-up to control the oxygen potential and temperature in LBE is also described.

T4.1.1: Manufacturing of homogeneous MOX
This manufacturing route is based on wet-chemistry 'sol-gel' method. The constituent elements are dissolved in a nitric acid solution and mixed in the appropriate ratios. Then, a polymer is added to increase the viscosity and the mixture is dispersed using a rotating cup atomiser. The resulting droplets are collected in an ammonia bath where a droplet-to-particle conversion occurred via a gel supported precipitation. After ageing, the beads

are washed with water, calcined, compacted into pellets and finally sintered. The 'sol-gel' technique give a very homogeneous solid solution of (U, Pu)O2.
The obtained product is (U0.7Pu0.3)O2.00. To obtain a lower O/M ratio, it is necessary to do a heat treat the MOX in a reducing atmosphere. Part of the original (U0.7Pu0.3)O2.00 is therefore reduced to obtain (U0.7Pu0.3)O1.97 .

T4.1.2: Manufacturing of heterogeneous MOX
This manufacturing route is based on direct blending of PuO2 and UO2 powders, combined with ball milling. It is followed by forced sieving to decrease the agglomerate size, pressing and sintering. Alternatively, UO2 and PuO2 could be sieved independently before blending. An intimate mixing of U and Pu on the (sub-) micron scale is obtained. However, compared to the homogeneous MOX, heterogeneous MOX still have Pu or U-rich agglomerates.
Many variants of this direct blending process have been developed and implemented on an industrial scale. It represents today the main production route for commercial fuel MOX pellets.
The obtained product is (U0.7Pu0.3)O2.00. To obtain a lower O/M ratio, it is necessary to heat treat the MOX in a reducing atmosphere. Part of the original (U0.7Pu0.3)O2.00 is therefore reduced to obtain (U0.7Pu0.3)O1.97 .

T4.1.3: Shipping of BN MOX
A commercial MOX pellet (or pellet slice) prepared for fast reactors at Belgonucléaire (BN) with a Pu fraction of at least 20% and O/M ratio of 2.00 will be shipped from SCK•CEN to Chalmers University to study its interactions with LBE. A slice of the pellet will be heat treated in reducing atmosphere to obtain (U0.7Pu0.3)O1.97 .

T4.2: LBE/fuel interaction experiment and analysis (JRC-ITU, CHALMERS)
T4.2.1: LBE experimental set-up
The oxygen concentration in LBE is controlled by adjusting the oxygen partial pressure in the atmosphere of the furnace in which the LBE-fuel containing crucible are located, through control of the Ar-H2/H2O mixture fed to the furnace. Oxygen concentration for MYRRHA in nominal conditions is CO2=1.10-6 wt.%. Experiments will be done at this concentration. Temperature will be constantly monitored.
Analyses
Several types of analyses will be performed during or after the LBE/fuel interaction:
- Thermal analysis (DTA) to follow the reaction kinetics and its energy release
- Radiography after to check for sample integrity
- XRD to identify phase change(s)
- Ceramography/SEM-WDS/TEM/EPMA to characterize the interactions LBE/pellet
- Inductively coupled plasma mass spectroscopy (ICP-MS) for dissolved products in LBE
For each of the following tasks, 4.2.2-4.2.5 (U0.7Pu0.3)O2.00 and (U0.7Pu0.3)O1.97 pellet (or disk) and powder will be immerged in LBE under controlled atmosphere (CO2=1.10-6 wt % in LBE) using the experimental setup described above at 500°C and 800°C for minimum 50h. Analyses will be carried out to identify the properties of the reaction, its products and its effect on pellet microstructure. Similar experiment will be carried out with UO2 and PuO2.
T4.2.2: LBE - homogeneous MOX interaction

T4.2.3: LBE - heterogeneous MOX interaction

T4.2.4: LBE - BN MOX interaction

T4.2.5: LBE – UO2/PuO2 interaction

T4.3: Phase relations study (JRC-ITU)
T4.3.1: Study of Pb-U-O and Bi-U-O phase relations
The study of the phase relations in the Pb-U-O and Bi-U-O to obtain basic knowledge on the possible phases that could be formed in the system. Solid state synthesis, thermogravimetry and X-ray powder diffraction will be the main techniques used, but additional characterization techniques (e.g. MASNMR, Raman) will be employed when needed.

T4.3.2: Study of Pb-Pu-O and Bi-Pu-O phase relations
The study of the phase relations in the Pb-Pu-O and Bi-Pu-O to obtain basic knowledge on the possible phases that could be formed in the system. Solid state synthesis, thermogravimetry and X-ray powder diffraction will be the main techniques used, but additional characterization techniques (e.g. MASNMR, Raman) will be employed when needed.

Person-Months per Participant

Participant number [10]	Participant short name [11]	Person-months per participant
10	JRC	33.50
12	Chalmers	13.60
	Total	47.10

List of deliverables

Delive-rable Number [61]	Deliverable Title	Lead benefi-ciary number	Estimated indicative person-months	Nature [62]	Dissemi-nation level [63]	Delivery date [64]
D4.1	Study of Pb-U-O and Bi-U-O phase relations	10	16.75	R	PU	18
D4.2	Analysis of LBE-fuel interaction : homogeneous MOX, heterogeneous MOX, BN MOX and UO2/PuO2	12	13.60	R	PU	36
D4.3	Study of Pb-Pu-O and Bi-Pu-O phase relations	10	16.75	R	PU	36
		Total	47.10			

Description of deliverables

D4.1) Study of Pb-U-O and Bi-U-O phase relations: In this deliverable a study of the phase relations in the Pb-U-O and Bi-U-O system is described. The possible phases that could be formed in the system are investigated by solid state synthesis, thermogravimetry and X-ray powder diffraction. [month 18]

D4.2) Analysis of LBE-fuel interaction : homogeneous MOX, heterogeneous MOX, BN MOX and UO2/PuO2: In this deliverable the findings on the interaction between MOX fuel and the LBE-coolant are presented. Homogeneous MOX, heterogeneous MOX and industrial MOX pellets are discussed. In addition the interaction between the coolant and the UO2/PuO2 powders that make up the MOX fuel and the coolant is given. [month 36]

D4.3) Study of Pb-Pu-O and Bi-Pu-O phase relations: In this report an investigation of the phase relations in the Pb-Pu-O and Bi-Pu-O system is described. The possible phases that could be formed in the system are studied by solid state synthesis, thermogravimetry and X-ray powder diffraction. [month 36]

Schedule of relevant Milestones

Milestone number [59]	Milestone name	Lead benefi-ciary number	Delivery date from Annex I [60]	Comments
MS23	Manufacturing of homogeneous MOX	10	12	M4.1
MS24	Manufacturing of heterogeneous MOX	10	12	M4.2
MS25	Shipment of BN MOX	12	12	M4.3
MS26	LBE experimental set-up	10	12	M4.4
MS27	Study of Pb-U-O and Bi-U-O phase relations	10	18	M4.5

WT3:
Work package description

Schedule of relevant Milestones

Milestone number [59]	Milestone name	Lead benefi-ciary number	Delivery date from Annex I [60]	Comments
MS28	LBE - homogeneous MOX interaction & analyses	10	36	M4.6
MS29	LBE - heterogeneous MOX interaction & analyses	10	36	M4.7
MS30	LBE - BN MOX interaction & analyses	12	36	M4.8
MS31	LBE – UO2/PuO2 interaction & analyses	12	36	M4.9
MS32	Study of Pb-Pu-O and Bi-Pu-O phase relations	10	36	M4.10

Project Number [1]	295736	Project Acronym [2]	SEARCH

One form per Work Package

Work package number [53]	WP5	Type of activity [54]	RTD
Work package title	Fuel Dispersion Study		
Start month	1		
End month	36		
Lead beneficiary number [55]	5		

Objectives

The objectives are:
CFD modelling
• Realize two quite complete numerical CFD models of the MYRRHA-FASTEF facility primary coolant loop according to the latest available design and its relevant variants during the time extension of the project. The first step will be the grid generation of the primary coolant loop using CAD files of the MYRRHA reactor. The grid generation must be flexible enough to take into account the evolution of the design during the study. The first computational model (CFD) must then be foreseen for the simulation of long term events. It will be single phase with one-way coupling Lagrangian particles. The second model will be two-phase (Eulerian-Eulerian or VOF) for the simulation of short term events.
• Apply the first CFD model to the simulation of the fuel dispersion in the coolant in case of long term small rate release due to one or several pin failures. The fuel dispersion will depend on the release position and on the chemical compound released. The solid products dispersion will depend on its specific weight and size. The gaseous products dispersion will depend on the bubble size and on the product solubility. The modelling of the thermal effects and of the turbulence will be one of the challenges of the simulation.
• Apply the second CFD model to the simulation of the fuel dispersion in the coolant in case of gas release due to one or several pin failure. The gas is produced by nuclear reaction inside the fuel pin and normally trapped herein during normal operation. The impact of the gas release on the main flow will be taken into account.

SIMMER modelling
• Assessment of behaviour of fuel redistribution in heavy liquid metal nuclear systems under fuel failure conditions.
• Realize two quite complete numerical SIMMER-III models of the MYRRHA-FASTEF facility primary coolant loop according to the latest available design and its relevant variants during the time extension of the project. One model must be foreseen for the simulation of long term events. The other one must be foreseen for the simulation of relatively short term events and must be dynamically coupled with a neutronic code to capture a gas release impact of voiding on the neutronic core conditions, including the core sub-criticality status and heat release repartition.
• Apply the first SIMMER-III model to the simulation of the fuel dispersion in the coolant in case of long term small rate release due to one or several pin failure.
• Apply the first SIMMER-III model to the simulation of the fuel dispersion in the coolant in case of large core melting.
• Apply the second SIMMER-III model to the simulation of the fuel dispersion in the coolant in case of short term consistent material release due to one or several pin failure. The material would be the fission gas produced and accumulated inside the fuel pin and the simulation coupled to neutronic calculation.
• Realize a SIMMER-IV numerical model of the MYRRHA-FASTEF facility primary coolant loop according to the latest available design and its relevant variants during the time extension of the project. The model will be more precise to capture the geometry, including the core sub-criticality status and heat release repartition.. No coupling with neutronic is foreseen.
• Apply the SIMMER-IV model to the simulation of the fuel dispersion in the coolant in case of long term small rate release due to one or several pin failure.

Description of work and role of partners

WT3:
Work package description

Work package 5 is divided in 2 tasks:

Task 5.1: CFD simulation and modelling of fuel products dispersion in the MYRRHA-FASTEF primary loop coolant (CRS4, VKI)
The task is developed in two directions corresponding to the two models described in the objectives. These two models share some common aspects. They must be built in close collaboration between CRS4 and VKI and carefully cross-checked. The main shared feature is the construction of a steady-state model comprehensive of all the necessary physical modelling. This steady-state model will be frozen in the first application to concentrate on the particles Lagrangian dispersion. It will serve as initial condition for the second application.

From the CFD point of view, all the necessary features already exist. An exception may be the free-surface between LBE and cover gas having a density ratio of ten thousands while the limit of stability in CFD codes is generally only slightly above the water/air (at sea level) ratio. The cover gas density will be artificially increased to bypass this issue without sensible effect on the modelling. Also, for the gas release simulation, we expect to have only general indications.

The difficulty of the work package lies in the consistent merge of all necessary features inside a complex geometry and operating condition, subject to the computational power limitation.

VKI will focus its activity on the single phase approach with Lagrangian tracking. The mean flow field inside the primary loop of the MYRRHA reactor will be computed for the forced convection regime under nominal condition. These nominal conditions include the complete 3D, steady simulation including thermal effects. Afterwards, solid particles, of different sizes and of different densities (simulating the partial core melting) will be released inside the primary loop at different positions and with different initial conditions. The Lagrangian tracking (without coupling with the liquid phase) of the particles will allow the follow-up of the elements inside the primary loop and provide useful information on the trajectories of these particles. The Lagrangian tracking will only be valid for small objects.

This CFD approach will provide the trajectories into the primary loop of the different particles (fuel) and will localize the region of fuel accumulation. VKI has a large experience in CFD and particularly in multi-phase flows [5.1,5.2,5.3] so has to fulfil this part of the work with good confidence.

CRS4 will focus its activity on the Eulerian two-phase flow approach based on the Volume of Fluid (VOF) paradigm to capture the upper free-surface dynamics. An extension to the full Euler-Euler paradigm may be investigated in a second time if necessary to better capture the fission gas release dynamics.

To correctly describe the transport of fuel/cladding products in the MYRRHA-FASTEF primary loop flow, we need to dispose of a very accurate flow velocity field. This flow field is driven by the pumping system. It is controlled by the hydraulic resistances, the bypass flows and the level of the free surfaces. A strong influence also comes from possible thermal stratifications in different parts of the pool, therefore also from the heat transfer through the structures. The combined effect of stratification, by-pass flow and free-surface reaction is likely to result in a non-trivial flow path, mainly in the upper hot plenum. The first objective is to obtain a comprehensive description of the entire pool loop.

We will be faced with the limit imposed by the computational power available, so some mitigation strategies will have to be developed. There are two Heat-Exchanger(HE)/Pump casing, each one consisting of two HE and one pump. These casings will require specific CFD modelling. Also, the HE requires a large computational power for a reasonable description. It is priori foreseen that in the global CFD loop, only one casing will be accurately discretised, and in this casing, only one HE will be discretised at the tube level. Separate models will have to be derived to make this approach consistent. There are also two or four casing foreseen for the repository of non-active fuel assemblies, each one with its own by-pass flow required to evacuate the (essentially) decay heat. Here again, a specific modelling must be performed, but at most one of these casing will have a more precise numerical description.

While it is out of range to have a description of the FAs internals, because of the non-uniform heat release in the core, each FA (or small group of FA) must have its separate description. Some refinement on the FA where the pin failure occurs can be evaluated. The spallation beam heat release must also be consistently modelled.

The global model must be organized in such a way that the single casing discretisation can be chosen on a case by case basis.

Once the model is reasonably satisfying, we will investigate the rapid release of fission gas due to the successive failure of a pin cladding and a pin fuel. The scenario leading to this event must be carefully described. This description is part of the next task and should be available for month 12. If it involves a partial blocking of the FA, then the flow field will be modified and a corresponding initial condition must be retrieved. The released gas will be followed in its path under the combined effect on the carrier fluid and its own drift velocity. The proportion of gas directly escaping through the hot plenum free surface will be evaluated. The behaviour of the residual gas fraction, entering the heat exchangers, will also be analysed until it becomes negligible. These features are likely to depend strongly on the position of the faulty FA and on the temporal signal of gas release rate.

The modelling and simulation will be performed with Starccm+, currently version 6.02. There are about two version updates a year and we will have to regularly adapt to the latest one available.
While the foreseen simulations are very ambitious from the technical point of view, CRS4 has gained in the very recent last years some confidence that is can be successfully realized. A single phase model of the XT-ADS version or MYRRHA has already been elaborated during the FP6 IP-EUROTRANS [1]. Nominal condition steady-state and an accidental shut-down have been simulated [2], however with a much simpler geometry than the one foreseen in this project. In the framework of the FP6 THINS project, CRS4 is currently working on free-surface flows and has already ascertained the possibility to model thermal free-surface flows within Starccm+, limited however to the Boussinesq approximation.

T5.2: Simulation and modelling of fuel dispersion in the coolant with SIMMER-III (KIT, ENEA, UNIPI)
The work is articulated in two main phases.
During the first phase, KIT will assess the incidental and accidental conditions leading to fuel pin failure and successive release of fuel, fission gas and finally partial core melt. The first part is propaedeutic for all partners and KIT will lead the interaction with the other WP so as to define sound incidental and accidental scenarios.

At the same time, UNIPI, ENEA and KIT will build the SIMMER-III reference model. This reference model must have the largest possible common basis for all three organisations. UNIPI will coordinate the elaboration of the SIMMER-III model to avoid duplication of work and optimise the model quality.

In the second phase, ENEA, with the support of UNIPI, will perform 2D SIMMER-III thermo-fluid-dynamic analysis (no neutronic coupling) of fuel dispersion and redistribution in the primary circuit of LBE-cooled MYRRHA-FASTEF reactor, starting from pre-defined fuel rod failure conditions. Several parametric calculations are envisaged to evaluate the influence of important parameters such as: the fuel break-up and particle size, the amount of released fuel, forced/natural circulation in the primary system, etc.

The need and the possibility to extend the SIMMER-III analysis to hypothetical severe accident scenarios involving large core melting will be investigated.

We will extend our modelling also to the 3D SIMMER-IV thermo-fluid-dynamic analysis (no neutronic coupling) of fuel dispersion and redistribution in the primary circuit of LBE-cooled MYRRHA-FASTEF reactor for the more representative fuel rod failure conditions.

The 3D version of the SIMMER code (SIMMER-IV) is obviously not able to give the same detailed information about the fluid-dynamic aspects that can be obtained by the CFD codes. It remains a system code and its use can be justified if we recognize that we have important multidimensional effects that can't be reproduced using an axial-symmetric geometry (SIMMER-III). The use of the SIMMER-IV version code can be suitable, again, to simulate the complex phenomena involved in our problem to obtain boundary conditions that must be passed to CFD codes. Its use will be restricted to the more representative fuel failure conditions because of the very high computational power it requires.

In the second phase, KIT will focus his activity on SIMMER-III coupled neutronic/thermal-hydraulic calculations of fuel and clad redistribution after the postulated pin failures under Pb/Bi flow conditions. The work is articulated in three main parts:
• Simulation of fission gas release and impact of voiding on neutronic core conditions, depending on pin damage configuration and size;
• Assessment of release of fuel pellets, chunks, particles and impact on fuel motion behaviour in Pb/Bi and neutronic feedback on core sub-criticality status;
• Assessment of granulated fuel and clad motion behaviour within the primary system.

During the entire project, UNIPI will take care of the congruence of ENEA and KIT models with the design evolution.

Person-Months per Participant

Participant number [10]	Participant short name [11]	Person-months per participant
2	ENEA	8.50
3	KIT	14.00
5	CRS4	18.70
7	UNIPI	6.80
8	VKI	7.65
	Total	55.65

List of deliverables

Deliverable Number [61]	Deliverable Title	Lead beneficiary number	Estimated indicative person-months	Nature [62]	Dissemination level [63]	Delivery date [64]
D5.1	Report on the operability of the SIMMER-III and SIMMER-IV models for the MIRRHA-FASTEF reactor	7	6.80	R	PU	12
D5.2	Single phase steady state CFD model of the MYRRHA-FASTEF primary coolant loop including all relevant	8	3.80	R	PU	18
D5.3	Two-phase CFD model of the MYRRHA-FASTEF primary coolant loop including all relevant thermal aspects	5	9.35	R	PU	18
D5.4	Report on the 3D SIMMER-IV analysis for the more representative fuel failure conditions	2	4.25	R	PU	24
D5.5	Report on assessment on fuel dispersion after pin failure under blockage conditions	3	14.00	R	PU	30
D5.6	Characterisation of long term dispersion of fuel in the coolant with CFD modelling	8	3.85	R	PU	36
D5.7	Characterisation of the fission gas and other species release dispersion in the coolant with CFD mod	5	9.35	R	PU	36
D5.8	Report on the 2D SIMMER-III analysis for the reference case and parametric study	2	4.25	R	PU	36
		Total	55.65			

Description of deliverables

D5.1) Report on the operability of the SIMMER-III and SIMMER-IV models for the MIRRHA-FASTEF reactor: The operability of the SIMMER III and SIMMER IV models for applications to the MYRRHA reactor are investigated. This includes a review of the physical modelling used in the code. The need and the possibility to extend the SIMMER-III analysis to hypothetical severe accident scenarios involving large core melting is assessed. [month 12]

D5.2) Single phase steady state CFD model of the MYRRHA-FASTEF primary coolant loop including all relevant: This deliverable describes the construction of a single phase flow CFD model of the MYRRHA primary coolant circuit. This model will be employed to assess the long term dispersion of fuel in the coolant using CFD numerical simulations. All relevant thermal aspects will be taken into account. [month 18]

D5.3) Two-phase CFD model of the MYRRHA-FASTEF primary coolant loop including all relevant thermal aspects: This deliverable describes the construction of a two phase flow CFD model of the MYRRHA primary coolant circuit. This model will be employed to assess the release of fission gas and other elements after a fuel pin failure using CFD numerical simulations. All relevant thermal aspects are taken into account. [month 18]

D5.4) Report on the 3D SIMMER-IV analysis for the more representative fuel failure conditions: This report presents the 3D SIMMER IV analyses of a selection of the most representative fuel failure conditions. The code will be used to assess multidimensional effects that cannot be reproduced using an axial-symmetric geometry (SIMMER-III). The SIMMER-IV code will be used to simulate the complex phenomena involved in fuel failure to obtain boundary conditions for CFD codes. [month 24]

D5.5) Report on assessment on fuel dispersion after pin failure under blockage conditions: A SIMMER-III coupled neutronic/thermal-hydraulic is used to calculate fuel and clad redistribution after the postulated pin failures under Pb/Bi flow conditions. The assessment will include the simulation of fission gas release and impact of voiding on neutronic core conditions, simulation of release of fuel pellets, chunks, particles and impact on fuel motion behaviour in Pb/Bi and neutronic feedback on core sub-criticality status and an investigation of granulated fuel and clad motion behaviour within the primary system. [month 30]

D5.6) Characterisation of long term dispersion of fuel in the coolant with CFD modelling: The single phase CFD model of the MYRRHA primary coolant circuit is employed to simulate long term dispersion of MOX fuel into the heavy liquid metal coolant of MYRRHA. The distribution of released fuel over the coolant circuit is assessed. [month 36]

D5.7) Characterisation of the fission gas and other species release dispersion in the coolant with CFD mod: In this report the characterisation of the fission gas and other species dispersion in the coolant is discussed. The assessment is made by employing a two-fase CFD model of the primary coolant circuit. [month 36]

D5.8) Report on the 2D SIMMER-III analysis for the reference case and parametric study: In this deliverable 2D SIMMER-III thermo-fluid-dynamic analysis of fuel dispersion and redistribution in the primary circuit of LBE-cooled MYRRHA-FASTEF reactor is presented. The analyses starts from pre-defined fuel rod failure conditions. Parametric calculations are used to evaluate the influence of the fuel break-up and particle size, the amount of released fuel, forced/natural circulation in the primary system, etc.. [month 36]

Schedule of relevant Milestones

Milestone number [59]	Milestone name	Lead beneficiary number	Delivery date from Annex I [60]	Comments
MS33	Operability of the SIMMER models	7	12	M5.1
MS34	Establishment of relevant parameters for simulation	3	12	M5.2
MS35	Single phase steady state CFD model	8	18	M5.3
MS36	Two-phase transient CFD model	5	18	M5.4
MS37	Completion of the SIMMER-IV analysis	2	24	M5.5

WT3:
Work package description

Schedule of relevant Milestones

Milestone number [59]	Milestone name	Lead beneficiary number	Delivery date from Annex I [60]	Comments
MS38	Accident simulation analyses and documentation	3	30	M5.6
MS39	Long term fuel dispersion CFD characterisation	8	36	M5.7
MS40	Short term fuel dispersion CFD characterisation	5	36	M5.8
MS41	SIMMER-III parametric analysis	2	36	M5.9

Project Number [1]	295736	Project Acronym [2]	SEARCH

One form per Work Package

Work package number [53]	WP6	Type of activity [54]	RTD
Work package title	Release and Capture Studies for Radioisotopes		
Start month	1		
End month	36		
Lead beneficiary number [55]	11		

Objectives

The aim of this work package is to determine the key parameters that influence the volatilization of radionuclides from liquid LBE and their capture on various materials, both in order to facilitate reliable predictions of radioactivity transfer to the gas phase during MYRRHA operation and in accident scenarios as well as for the development of efficient filters for the removal of volatile radionuclides from the gas phase. These tasks will be tackled using a combination of experimental and theoretical methods:
Experiments studying the evaporation of volatiles from liquid LBE as well as their gas phase transport and their capture on suitable getter materials will be performed under variation of various experimental parameters with the following goals:
- identify those parameters that influence the evaporation, gas phase transport and deposition processes
- characterize the chemical species involved in these processes
- determine physicochemical parameters such as thermodynamic activity coefficients, saturation vapour pressure, Henry constants, deposition temperatures, adsorption enthalpies and entropies, which are necessary for the prediction of vapour phase concentrations of radionuclides in an ADS and the development of gas phase filtering systems for their removal.

In a complementary approach, quantum mechanical calculations will be used to calculate crucial properties of the evaporation and deposition processes theoretically:
- Temperature-dependent solubility and heat of solution of volatiles in solid and liquid metals, in particular LBE and potential filter materials
- Heat of adsorption of volatiles on filter material surfaces
- Heat of formation of chemical compounds of the volatiles that may precipitate from the liquid metal
- Formation energies of simple molecular compounds of the volatile elements

The results of the theoretical calculations will contribute essentially both to the interpretation and confirmation of experimental results as well as to the prediction of materials that have favourable properties for the capture of volatiles and chemical processes that can enhance or reduce evaporation. Thus, the interplay of experimental and theoretical studies will result in more reliable data, enhanced understanding of the underlying phenomena and streamlining of efforts. Because of their central importance, the focus of the proposed studies will be on polonium and mercury and their compounds and to a lesser extent their lighter chemical homologues.

Description of work and role of partners

Work package 6 is subdivided in 3 Tasks.

T6.1: Release, gas phase transport and deposition studies for volatile radionuclides (PSI)
The objective of this task is to determine the key parameters that influence the volatilization of radionuclides and their deposition on various materials. In particular, the existence of volatile chemical species and their chemical nature will be studied to obtain evidence on how and under which conditions they can be formed and captured. Thermodynamic and kinetic parameters concerning the evaporation of volatiles from LBE will be determined. The results will provide crucial input to assess the relevance of volatile chemical species of radionuclides for ADS systems and fundamental data for calculation of their gas phase concentrations and evaporation rates.
T6.1.1: Thermochromatography
To achieve these objectives, the transport of Po, Hg and their lighter chemical homologues will be studied in a temperature gradient in a carrier gas under variation of gas atmospheres (purified/moist gases, reductive, oxidizing and containing radicals), gas flows, temperature gradients, experiment duration, column material and

pre-treatment of the column material. The results will allow proving the existence of different gas phase species of the studied elements under various conditions, the identification and characterisation of their chemical nature as well as determination of their thermodynamic properties, e.g. enthalpies and entropies of adsorption.
This task will provide important input and complementary information for several other tasks within this work package: Proving the existence of different gas phase species under certain conditions will allow to systematically select relevant conditions for evaporation studies from liquid LBE (Tasks 6.1.2 and 6.2.2 and facilitate the choice of suitable filter materials through their chemical nature and the data obtained on adsorption enthalpies and entropies (Task 6.2.1). The results obtained can also provide input on which gas phase species are important to study using quantum theory (Task 6.3.4), and vice-versa the results on stability of gas phase molecules (Task 6.3.4) and adsorption enthalpies on metal surfaces (task 6.3.2) obtained by first principles calculations will be extremely valuable for the interpretation and understanding of the thermochromatography results. The comparison of experimental and theoretical results will also facilitate a validation of the reliability of first principles methods for the prediction of these properties.

T6.1.2: Evaporation studies using the transpiration method
Dynamic evaporation experiments studying the release of radionuclides, especially Po and Hg and their chemical homologues, from liquid LBE will be carried out under variation of gas phase composition (purified/moist gases, reductive, oxidizing and containing radicals), specific activity/concentration of the respective radionuclide in LBE, temperature, gas flow (saturation and non-saturated conditions) and sample geometry. Goal of this task is the determination of qualitative and quantitative effects of experimental conditions on vapour phase concentration and release rates of volatile radionuclides from LBE solution. The results will allow determining fundamental thermodynamic and kinetic parameters for the evaporation process, e.g. thermodynamic activities and Henry constants for the case of gas phase saturation as well as evaporation rates under various concentrations and gas flow conditions for unsaturated gas conditions. The latter can be compared with evaporation rate calculations of different degrees of sophistication. The thermodynamic data will be compared to those obtained by first principles calculations (Task 6.3.3-6) and independent investigations performed in Task 6.2.2 to interpret the results and to achieve a consistent data set for ADS safety assessments.

T6.2: Studies of polonium and mercury evaporation and capture on filters (SCK•CEN)
In this task, the objective is to identify and evaluate adsorbents suitable for capturing gaseous Po and Hg and to study the evaporation of Po and Hg from LBE at low (second independent data set for licensing) and elevated concentration. The two subtasks are defined as:
T6.2.1: Adsorption experiments
Po and Hg adsorption experiments under variation of adsorbent type (porous carrier material, impregnant), velocity and composition of carrier gas, adsorbate concentration and concentration of other contaminants, adsorbent bed properties (depth, temperature) will be performed. For this purpose, breakthrough and pulse chromatography experiments will be carried out using an isothermal packed bed of adsorbent particles.
Such experiments will allow determining the effective (dynamic) adsorption capacity and long-term stability of an adsorber system under conditions relevant to ADSs. To gain insight into the fundamental processes that occur in the adsorber, kinetic (mass transfer resistances) and equilibrium adsorption parameters (Henry constants, enthalpies) will be derived by matching the experimental data with appropriate mathematical models. The selection of suitable adsorbent materials will be based both on experiences reported in the literature and on experimental results produced in Tasks 6.1.1, 6.3.2 and 6.3.4 of this work package. In addition, the thermodynamic parameters determined in these Tasks will be used as input for modelling the experimental adsorption data.
From the results obtained here, optimized filtering systems for the retention of Hg and Po in ADS can be developed.
T6.2.2: Evaporation experiments
Evaporation experiments of volatile elements dissolved in LBE will be carried out using the transpiration method. Experiments at low concentrations (10-6 appm) will be performed to obtain additional, independently measured data sets for the most hazardous elements Po and Hg to support licensing of MYRRHA. Furthermore, a gradual increase up to concentrations expected in MYRRHA (0.1 appm) is envisaged. Here, the goal is to identify and characterize anomalous Po evaporation processes that may occur at elevated concentrations. Progress with the experiments at increasing Po concentration will depend on the licensing of glove box/hot cell test setup.
The results of this task will be compared with those of Task 6.1.2 and Tasks 6.3.3-5 to obtain a consistent data set concerning the extremely important volatilization data.
In addition, the data from tasks 6.1 and 6.3 will be used to assess the release of Po into the environment in various accident scenarios involving damage to the confinement structure.

T6.3: Theoretical thermochemistry of Po interacting with LBE and filter materials (UGent)
The objective of this task is the determination of fundamental properties describing the chemical interaction of polonium with components of the MYRRHA ADS, i.e. the target material LBE and impurities contained therein, promising materials for the development of filters to remove Po from the gas phase and volatile molecular Po-compounds. The task is divided in the following five subtasks:
T6.3.1: Po solubility in solid LBE
The temperature-dependent solubility of Po in solid LBE will be predicted following a computational procedure that relies on density functional theory for 0 K ground state energies and on a Debye model and/or ab initio calculated phonons for the behaviour above 0 K. The goal is to determine the solubility of Po in solid LBE to establish a lower limit on its solubility in liquid LBE.
T6.3.2: Search for most promising filter materials
The heat of solution of Po in noble metals, and the heat of adsorption of Po on noble metal surfaces will be predicted in the framework of density functional theory. Several low-index surfaces will be considered ((100), (110), (111), ...). This will allow assessing in an accurate, quantitative way which noble metal, and which specific surface type, is most effective to capture Po. This information will allow interpreting the results of thermochromatography experiments (Task 6.1.1) on a theoretical basis and performing the difficult adsorption experiments (Task 6.2.1) in a much more focused way.
T6.3.3: Predict the existence of Po-alloys
Precipitation of Po-containing alloys within liquid LBE affects the Po evaporation rate. Therefore, the stability (heat of formation) of a number of Po-X and Po-X-Y compounds will be calculated by density functional theory. Earlier simplified assessments based on the Miedema model suggest which alloys are worth to be considered. The crystal structure will be taken into account, either by examining crystal structures that are known to exist in chemically similar compounds, or by making use of unbiased crystal prediction tools. The results facilitate the interpretation of evaporation experiments (Tasks 6.1.2 and 6.2.2) where the formation of Po-compounds may play a role.
T6.3.4: Po molecules in the gas phase
The formation energies of several Po-containing molecules will be determined by density functional theory and/or quantum chemical methods: monomeric Po, Po2, PoH, PoH2, PoOH, Po(OH)2, PoBi, PoPb, PoHg,.. The results obtained by this task are important for all considerations concerning evaporation, gas phase transport and deposition processes. Thus, they will provide important input for all the experimental sub-tasks of work package 6. This information will allow eliminating molecules that are unstable at the relevant temperatures from these considerations and to assess probable volatisation paths. Several proposed/likely reaction paths will be examined by the same methodology, in order to point out the most favourable of those paths. The stability of different gas phase molecules also affects their specific adsorption properties, thus influencing the choice of filter materials (Task 6.2.1).
T6.3.5: Po solubility in liquid LBE
The solubility of Po in liquid LBE will be calculated from first principles. It has been shown in the recent literature how crucial quantities as the Henry constant can be written in terms of thermodynamic expressions that depend on a few quantities which all can be obtained from static density functional theory and/or molecular dynamics. We will apply these computational schemes to assess Po solubility in liquid LBE as a function of concentration and temperature. This will complement and expand the information that is available from experiments. In particular, the enthalpy of solution of Po in liquid LBE is one of the crucial parameters needed for interpreting the results of evaporation experiments in Tasks 6.1.2 and 6.2.2.

Person-Months per Participant

Participant number [10]	Participant short name [11]	Person-months per participant
1	SCK-CEN	39.00
6	UGENT	32.40
11	PSI	64.80
	Total	136.20

List of deliverables

Deliverable Number [61]	Deliverable Title	Lead beneficiary number	Estimated indicative person-months	Nature [62]	Dissemination level [63]	Delivery date [64]
D6.1	Report on results of screening experiments	11	32.40	R	PU	15
D6.2	Report on tasks 6.3.1, 6.3.2 and 6.3.3	6	16.20	R	PU	22
D6.3	Final report on volatilization and deposition studies	11	32.40	R	PU	36
D6.4	Final report on the evaporation, release and capture of Po	1	19.50	R	PU	36
D6.5	Final report on the evaporation and capture of Hg	1	19.50	R	PU	36
D6.6	Report on tasks 6.3.4 and 6.3.5	6	16.20	R	PU	36
		Total	136.20			

Description of deliverables

D6.1) Report on results of screening experiments: This report will present the results of the screening experiments concerning the evaporation and deposition of volatile radionuclides. The screening tests will give a first evaluation on the importance of the different physical and chemical parameters that influence the evaporation and deposition process. [month 15]

D6.2) Report on tasks 6.3.1, 6.3.2 and 6.3.3: In this report the QM calculations on three topics are presented. These include an investigation of the Po solubility in solid LBE and a search for the most promising filter materials via an assessment of the heat of solution and absorption of Po on noble metals. Finally a prediction of the existence of Po alloys in the coolant is made. [month 22]

D6.3) Final report on volatilization and deposition studies: The final results on the volatilization and deposition of selected radionuclides are presented. Both data obtained using the transpiration method as well as results from the thermochromatography are presented. [month 36]

D6.4) Final report on the evaporation, release and capture of Po: In this report the studies on the release and capture of Po are presented. Release data are based on experiments using the transpiration method for different concentrations of Po in the coolant. A parametric study of the absorption conditions : adsorbent type, velocity and composition of carrier gas, adsorbate concentration and concentration of other contaminants, adsorbent bed properties (depth, temperature) was performed. An assessment of the release of Po in accident conditions is made. [month 36]

D6.5) Final report on the evaporation and capture of Hg: In this report the studies on the release and capture of Po are presented. Release data are based on experiments using the transpiration method for different concentrations of Hg in the coolant. A parametric study of the absorption conditions : adsorbent type, velocity and composition of carrier gas, adsorbate concentration and concentration of other contaminants, adsorbent bed properties (depth, temperature) was performed. [month 36]

D6.6) Report on tasks 6.3.4 and 6.3.5: In this report the QM calculations on two topics are presented. The first is a prediction of the Po solubility in liquid LBE. The second deals with the formation of Po compounds in the gas phase. In particular the formation of monomeric Po, Po2, PoH, PoH2, PoOH, Po(OH)2, PoBi, PoPb, PoHg, is looked into. [month 36]

Schedule of relevant Milestones

Milestone number [59]	Milestone name	Lead beneficiary number	Delivery date from Annex I [60]	Comments
MS42	Setup of equipment	11	6	M6.1
MS43	Completion of the experimental set-up for Hg evaporation	1	6	M6.2
MS44	Solubility of Po in solid LBE	8	6	M6.3
MS45	Screening experiments	11	12	M6.4
MS46	Search for most promising filter materials	8	12	M6.5
MS47	Dynamic evaporation studies of Hg from LBE	1	18	M6.6
MS48	Construction and licensing of glove box set-up in controlled zone	1	18	M6.7
MS49	Predict the existence of Po-alloys	6	22	M6.8
MS50	Dynamic evaporation studies of Po from LBE at low concentrations	1	25	M6.9
MS51	Po molecules in the gas phase	6	28	M6.10
MS52	Capture studies of Hg	1	30	M6.11
MS53	Capture studies of Po at low concentrations	1	30	M6.12
MS54	Detailed thermochromatography and evaporation experiments	11	32	M6.13
MS55	Final analysis and reporting	11	36	M6.14
MS56	Dynamic evaporation studies of Po from LBE higher concentrations	1	36	M6.15
MS57	Capture studies of Po at increased concentrations	1	36	M6.16
MS58	Po solubility in liquid LBE	6	36	M6.17

Project Number [1]	295736	Project Acronym [2]	SEARCH

One form per Work Package

Work package number [53]	WP7	Type of activity [54]	OTHER
Work package title	Education and Training		
Start month	1		
End month	36		
Lead beneficiary number [55]	8		

Objectives

The objectives of this work package are fourfold:
- To coordinate the different dissemination activities of the work outcomes obtained by the SEARCH partners to guarantee strong visibility of the project at key events thus making aware the European Academia and Industry of the project;
- To initiate the preparation of technical and scientific papers for peer review journals and presentations at international conferences;
- To promote fruitful exchanges with other research projects (EC and national such as CDT, LEADER, THINS). The presence of SEARCH partners in many of these projects will facilitate this action;
- To organize educational and specialized training courses as well as practical work sessions on coolant chemistry control, fuel-coolant interaction and fuel dispersion as well as release and capture of radioisotopes, which are key issues of SEARCH project for the reliability of LFR/ADS reactors.

Description of work and role of partners

With the predominant presence of research centres and universities, the dissemination of project results will be through the traditional academic approaches such as the publication of scientific papers and participation to Scientific Conferences.

In order to ensure that the SEARCH project has a coherent approach to the way it disseminates, this work package has been defined to federate the different actions, promote the project objectives and its expected results and encourage all partners to perform both internal and external communication actions.

Aiming to build and maintain competencies in science, technology and safety issues related to nuclear fields, the Work Package will provide the following communication means,
- Project communication kit (flyer, PowerPoint presentation and project poster) for the benefit of the partners to provide coordinated messages.
- Training material, consistent with the SEARCH project objectives, to support educational and specialized training courses, e-learning and distance learning.
- Training activities or practical work, associated to courses or workshop, in research or higher technological institutes.
- Education activities in forms of open workshops and/or intensive specializing courses.

Participating students will be asked to jointly perform studies on the issues of interest for the LFR/ADS components, putting a strong relevance on MYRRHA reactor. In this framework, students at PhD, Research Master and Master Science level will be trained in the main issues of LFR nuclear reactors. Problem based learning will form the basis of the activities.

The project level dissemination of progress and results to scientific conferences and propose special sessions to well-known conferences will be ensured. Several conferences have already been identified by the Consortium as relevant opportunities (both European and International) for initial dissemination of the SEARCH objectives and baseline within the nuclear sectors.

Students will participate to intensive specializing courses (1 or 2) and/or open workshops (1 or 2), in the form of mini-symposia on lessons learned and on achieved progress, Researchers, PhD, Research Master and

Masters Science level students will participate to these workshops presenting and discussing their work, with the possibility of having feedback from SEARCH work package leaders and from the Expert Panel.

Each workshop would last 4 - 6 days, 1-2 days devoted to lectures, 1 day to student numerical simulation training, 1 day to student presentations and 1-2 practical student work in research or higher technological institute. These workshops will be included in the final review meeting of the project. The output of these workshops will be proceeding books collecting all the written documentation discussed and presented.

In the frame of the SEARCH Project partnership a Lecture Series will be selected and proposed in the intensive specializing courses that will be open to the research community all over Europe. This course will be open to the research community all over Europe. The attendance will be free of charge for the SEARCH partners and special invitation will be sent to the scientists from other running EC projects.
Moreover each SEARCH Project partnership, in collaboration with WP7, could announce masters or PhDs thesis topics related to HLM cooled nuclear systems, topics mainly related to the SEARCH Project

The work is subdivided in four Tasks as follows:
Task 7.1: Coordination and E&T/RTD organisation (VKI)
The objective of this task is to define the detailed time-table and agenda for the workshops, practical work, lectures or training course to be organised, make a list of tentative teachers for each symposia/courses and of the research centres and higher institute for practical works, a list of suitable masters thesis topics, identifying supervisors for these theses, if any, to compile workshop evaluations and produce deliverable 7.1.

Task 7.2: Workshop on LFR/ADS Objectives and Design (VKI, SCK•CEN)
The purpose of this workshop is to define a general survey of LFR/ADS science and technology development. The purpose is to provide background information to students in the field. Tools, procedure and methodology for assessing the safety and design of the components of new heavy liquid metal cooled nuclear systems, with reference to the Lead-bismuth cooled accelerator driven system MYRRHA will be introduced and applied. Moreover practical work programmes in research or higher technological Institute are foreseen jointly to the proposed learning programme.

Task 7.3: Workshop on Fuel and Coolant Chemistry (VKI, SCK•CEN)
In this workshop, the fundamental, modelling and simulating approaches of the phenomena involved in coolant chemistry control, fuel-coolant interaction and the resulting outcoming products will be dealt with. Also dispersion of these products in the coolant and release into the covergas for volatiles will be considered.
The foreseen experimental tests to analyse such mechanisms and the existing numerical approaches will be discussed with the intent to provide students with the means to identify the key features of these phenomena and the available tools to their study..
In addition the students will have also the opportunity to participate to practical sessions organized on dedicated lab facilities.

Task 7.4: Training course on Fluid Mechanics in Nuclear Technology (VKI)
This one week course will be organised within the format of VKI Lecture Series. The lecturers will be selected from the SEARCH partnership and also among world experts in the field of thermohydraulic aspects of LFRs. All the relevant physico-chemical and fluid mechanics aspects related to safety issues of LFR/ADS systems will be covered.
The output of this lecture series will include a lecture note book (with ISBN).

Person-Months per Participant

Participant number [10]	Participant short name [11]	Person-months per participant
1	SCK•CEN	1.60
8	VKI	3.98
	Total	5.58

List of deliverables

Deliverable Number [61]	Deliverable Title	Lead beneficiary number	Estimated indicative person-months	Nature [62]	Dissemination level [63]	Delivery date [64]
D7.1	1st Workshop lectures book	8	1.86	R	PU	18
D7.2	2nd Workshop lectures book	8	1.86	R	PU	24
D7.3	Training Course lectures book	8	1.86	R	PU	36
		Total	5.58			

Description of deliverables

D7.1) 1st Workshop lectures book: This deliverables collects all presentations from the first SEARCH workshop on LFR/ADS objectives and design. [month 18]

D7.2) 2nd Workshop lectures book: This deliverables collects all presentations from the second SEARCH workshop on Fuel and heavy liquid metal coolant chemistry. [month 24]

D7.3) Training Course lectures book: This deliverable consists of the notes of all lectures given during the training course on fluid mechanics in nuclear technology. [month 36]

Schedule of relevant Milestones

Milestone number [59]	Milestone name	Lead beneficiary number	Delivery date from Annex I [60]	Comments
MS59	Organization of the workshops	8	12	M7.1
MS60	Workshop on LFR/ADS objectives and design	8	18	M7.2
MS61	Workshop on Fuel and Coolant Chemistry	8	24	M7.3
MS62	Training course on Fluid Mechanics in Nuclear Technology	8	36	M7.4

WT4:
List of Milestones

Project Number [1]	295736	Project Acronym [2]	SEARCH

List and Schedule of Milestones

Milestone number [59]	Milestone name	WP number [53]	Lead beneficiary number	Delivery date from Annex I [60]	Comments
MS1	Realization of the website	WP1	1	3	M1.1
MS2	Set up of the External Technical Advisory Committee	WP1	1	6	M1.2
MS3	Submission to the EC of the first RP report	WP1	1	18	M1.3
MS4	Submission to the EC of the final report	WP1	1	36	M1.4
MS5	Design and instrumentation of ENEA 6.5 mm Rod Bundle	WP2	2	6	M2.1
MS6	Design and instrumentation of KIT 8.2 mm Rod Bundle	WP2	3	6	M2.2
MS7	Flow conditioner design simulations	WP2	3	6	M2.3
MS8	Provision of detailed pre-test CFD analyses for NACIE	WP2	2	9	M2.4
MS9	Fabrication of KIT Rod Bundle Experiment	WP2	3	12	M2.5
MS10	Pre-test analysis of KALLA-experiments	WP2	3	12	M2.6
MS11	System components procurement and facility upgrade on NACIE	WP2	2	18	M2.7
MS12	Experimental results for free circulation tests in NACIE	WP2	2	24	M2.8
MS13	Pre-test analysis of NACIE-experiments	WP2	2	24	M2.9
MS14	HELENA upgrade, main system and components procurement	WP2	2	30	M2.10

WT4:
List of Milestones

Milestone number [59]	Milestone name	WP number [53]	Lead beneficiary number	Delivery date from Annex I [60]	Comments
MS15	Results of HELENA experiments and post-test analysis	WP2	2	36	M2.11
MS16	Provision of post-test CFD analyses for NACIE	WP2	2	36	M2.12
MS17	Assessment of a 127 pin MYRRHA FA	WP2	4	36	M2.13
MS18	Post-test analysis	WP2	3	36	M2.14
MS19	Commissioning of the delta T loop	WP3	1	12	M3.1
MS20	Experimental device for mass-transfer studies in molten LBE available	WP3	3	15	M3.2
MS21	OCS implementation in HLM pool facility	WP3	2	18	M3.3
MS22	Commissioning of the pool type filter	WP3	2	30	M3.4
MS23	Manufacturing of homogeneous MOX	WP4	10	12	M4.1
MS24	Manufacturing of heterogeneous MOX	WP4	10	12	M4.2
MS25	Shipment of BN MOX	WP4	12	12	M4.3
MS26	LBE experimental set-up	WP4	10	12	M4.4
MS27	Study of Pb-U-O and Bi-U-O phase relations	WP4	10	18	M4.5
MS28	LBE - homogeneous MOX interaction & analyses	WP4	10	36	M4.6
MS29	LBE - heterogeneous MOX interaction & analyses	WP4	10	36	M4.7
MS30	LBE - BN MOX interaction & analyses	WP4	12	36	M4.8
MS31	LBE - UO2/PuO2 interaction & analyses	WP4	12	36	M4.9
MS32	Study of Pb-Pu-O and Bi-Pu-O phase relations	WP4	10	36	M4.10

WT4:
List of Milestones

Milestone number [59]	Milestone name	WP number [53]	Lead beneficiary number	Delivery date from Annex I [60]	Comments
MS33	Operability of the SIMMER models	WP5	7	12	M5.1
MS34	Establishment of relevant parameters for simulation	WP5	3	12	M5.2
MS35	Single phase steady state CFD model	WP5	8	18	M5.3
MS36	Two-phase transient CFD model	WP5	5	18	M5.4
MS37	Completion of the SIMMER-IV analysis	WP5	2	24	M5.5
MS38	Accident simulation analyses and documentation	WP5	3	30	M5.6
MS39	Long term fuel dispersion CFD characterisation	WP5	8	36	M5.7
MS40	Short term fuel dispersion CFD characterisation	WP5	5	36	M5.8
MS41	SIMMER-III parametric analysis	WP5	2	36	M5.9
MS42	Setup of equipment	WP6	11	6	M6.1
MS43	Completion of the experimental set-up for Hg evaporation	WP6	1	6	M6.2
MS44	Solubility of Po in solid LBE	WP6	8	6	M6.3
MS45	Screening experiments	WP6	11	12	M6.4
MS46	Search for most promising filter materials	WP6	8	12	M6.5
MS47	Dynamic evaporation studies of Hg from LBE	WP6	1	18	M6.6
MS48	Construction and licensing of glove box set-up in controlled zone	WP6	1	18	M6.7
MS49	Predict the existence of Po-alloys	WP6	6	22	M6.8
MS50	Dynamic evaporation studies of Po	WP6	1	25	M6.9

WT4:
List of Milestones

Milestone number [59]	Milestone name	WP number [53]	Lead beneficiary number	Delivery date from Annex I [60]	Comments
	from LBE at low concentrations				
MS51	Po molecules in the gas phase	WP6	6	28	M6.10
MS52	Capture studies of Hg	WP6	1	30	M6.11
MS53	Capture studies of Po at low concentrations	WP6	1	30	M6.12
MS54	Detailed thermochromatography and evaporation experiments	WP6	11	32	M6.13
MS55	Final analysis and reporting	WP6	11	36	M6.14
MS56	Dynamic evaporation studies of Po from LBE higher concentrations	WP6	1	36	M6.15
MS57	Capture studies of Po at increased concentrations	WP6	1	36	M6.16
MS58	Po solubility in liquid LBE	WP6	6	36	M6.17
MS59	Organization of the workshops	WP7	8	12	M7.1
MS60	Workshop on LFR/ADS objectives and design	WP7	8	18	M7.2
MS61	Workshop on Fuel and Coolant Chemistry	WP7	8	24	M7.3
MS62	Training course on Fluid Mechanics in Nuclear Technology	WP7	8	36	M7.4

WT5:
Tentative schedule of Project Reviews

Project Number [1]	295736	Project Acronym [2]	SEARCH

Tentative schedule of Project Reviews

Review number [65]	Tentative timing	Planned venue of review	Comments, if any
RV 1	18	Brussels	Mid-term project review
RV 2	36	Brussels	Final project review

WT6:
Project Effort by Beneficiary and Work Package

Project Number [1]	295736	Project Acronym [2]	SEARCH

Indicative efforts (man-months) per Beneficiary per Work Package

Beneficiary number and short-name	WP 1	WP 2	WP 3	WP 4	WP 5	WP 6	WP 7	Total per Beneficiary
1 - SCK•CEN	6.38	0.00	37.00	0.00	0.00	39.00	1.60	83.98
2 - ENEA	0.00	11.25	12.00	0.00	8.50	0.00	0.00	31.75
3 - KIT	0.00	34.00	46.00	0.00	14.00	0.00	0.00	94.00
4 - NRG	0.00	6.00	0.00	0.00	0.00	0.00	0.00	6.00
5 - CRS4	0.00	0.00	0.00	0.00	18.70	0.00	0.00	18.70
6 - UGENT	0.00	0.00	0.00	0.00	0.00	32.40	0.00	32.40
7 - UNIPI	0.00	0.00	0.00	0.00	6.80	0.00	0.00	6.80
8 - VKI	0.00	0.00	0.00	0.00	7.65	0.00	3.98	11.63
9 - INR	0.00	0.00	10.20	0.00	0.00	0.00	0.00	10.20
10 - JRC	0.00	0.00	0.00	33.50	0.00	0.00	0.00	33.50
11 - PSI	0.00	0.00	0.00	0.00	0.00	64.80	0.00	64.80
12 - Chalmers	0.00	0.00	0.00	13.60	0.00	0.00	0.00	13.60
Total	6.38	51.25	105.20	47.10	55.65	136.20	5.58	407.36

WT7:
Project Effort by Activity type per Beneficiary

Project Number [1]	295736	Project Acronym [2]	SEARCH

Indicative efforts per Activity Type per Beneficiary

Activity type	Part. 1 SCK•CEN	Part. 2 ENEA	Part. 3 KIT	Part. 4 NRG	Part. 5 CRS4	Part. 6 UGENT	Part. 7 UNIPI	Part. 8 VKI	Part. 9 INR	Part. 10 JRC	Part. 11 PSI	Part. 12 Chalmer	Total
1. RTD/Innovation activities													
WP 2	0.00	11.25	34.00	6.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	51.25
WP 3	37.00	12.00	46.00	0.00	0.00	0.00	0.00	0.00	10.20	0.00	0.00	0.00	105.20
WP 4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	33.50	0.00	13.60	47.10
WP 5	0.00	8.50	14.00	0.00	18.70	0.00	6.80	7.65	0.00	0.00	0.00	0.00	55.65
WP 6	39.00	0.00	0.00	0.00	0.00	32.40	0.00	0.00	0.00	0.00	64.80	0.00	136.20
Total Research	76.00	31.75	94.00	6.00	18.70	32.40	6.80	7.65	10.20	33.50	64.80	13.60	395.40
2. Demonstration activities													
Total Demo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3. Consortium Management activities													
WP 1	6.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.38
Total Management	6.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.38
4. Other activities													
WP 7	1.60	0.00	0.00	0.00	0.00	0.00	0.00	3.98	0.00	0.00	0.00	0.00	5.58
Total other	1.60	0.00	0.00	0.00	0.00	0.00	0.00	3.98	0.00	0.00	0.00	0.00	5.58
Total	83.98	31.75	94.00	6.00	18.70	32.40	6.80	11.63	10.20	33.50	64.80	13.60	407.36

WT8:
Project Effort and costs

Project Number [1]	295736	Project Acronym [2]	SEARCH

Project efforts and costs

Benefi-ciary number	Beneficiary short name	Estimated eligible costs (whole duration of the project)						Total receipts (€)	Requested EU contribution (€)
		Effort (PM)	Personnel costs (€)	Subcontracting (€)	Other Direct costs (€)	Indirect costs OR lump sum, flat-rate or scale-of-unit (€)	Total costs		
1	SCK•CEN	83.98	486,100.00	0.00	182,850.00	242,122.00	911,072.00	0.00	571,436.00
2	ENEA	31.75	152,592.00	0.00	425,300.00	124,110.00	702,002.00	0.00	351,003.00
3	KIT	94.00	597,800.00	0.00	315,670.00	342,200.00	1,255,670.00	0.00	627,835.00
4	NRG	6.00	43,000.00	0.00	6,000.00	47,000.00	96,000.00	0.00	48,000.00
5	CRS4	18.70	106,590.00	0.00	12,920.00	50,490.00	170,000.00	0.00	85,000.00
6	UGENT	32.40	104,130.00	0.00	8,370.00	67,500.00	180,000.00	0.00	135,000.00
7	UNIPI	6.80	34,170.00	0.00	8,967.50	25,882.50	69,020.00	0.00	51,765.00
8	VKI	11.63	84,681.00	0.00	17,748.00	81,291.00	183,720.00	0.00	155,386.00
9	INR	10.20	40,800.00	0.00	8,500.00	10,200.00	59,500.00	0.00	29,750.00
10	JRC	33.50	373,969.00	0.00	48,532.00	253,500.60	676,001.60	0.00	338,000.00
11	PSI	64.80	450,000.00	0.00	225,000.00	135,000.00	810,000.00	0.00	405,000.00
12	Chalmers	13.60	101,367.00	9,500.00	42,153.00	86,112.00	239,132.00	0.00	179,349.00
	Total	407.36	2,575,199.00	9,500.00	1,302,010.50	1,465,408.10	5,352,117.60	0.00	2,977,524.00

1. Project number

The project number has been assigned by the Commission as the unique identifier for your project. It cannot be changed. The project number **should appear on each page of the grant agreement preparation documents** (part A and part B) to prevent errors during its handling.

2. Project acronym

Use the project acronym as given in the submitted proposal. It cannot be changed unless agreed so during the negotiations. The same acronym **should appear on each page of the grant agreement preparation documents** (part A and part B) to prevent errors during its handling.

53. Work Package number

Work package number: WP1, WP2, WP3, ..., WPn

54. Type of activity

For all FP7 projects each work package must relate to one (and only one) of the following possible types of activity (only if applicable for the chosen funding scheme – must correspond to the GPF Form Ax.v):

- **RTD/INNO** = Research and technological development including scientific coordination - applicable for Collaborative Projects and Networks of Excellence
- **DEM** = Demonstration - applicable for collaborative projects and Research for the Benefit of Specific Groups
- **MGT** = Management of the consortium - applicable for all funding schemes
- **OTHER** = Other specific activities, applicable for all funding schemes
- **COORD** = Coordination activities – applicable only for CAs
- **SUPP** = Support activities – applicable only for SAs

55. Lead beneficiary number

Number of the beneficiary leading the work in this work package.

56. Person-months per work package

The total number of person-months allocated to each work package.

57. Start month

Relative start date for the work in the specific work packages, month 1 marking the start date of the project, and all other start dates being relative to this start date.

58. End month

Relative end date, month 1 marking the start date of the project, and all end dates being relative to this start date.

59. Milestone number

Milestone number:MS1, MS2, ..., MSn

60. Delivery date for Milestone

Month in which the milestone will be achieved. Month 1 marking the start date of the project, and all delivery dates being relative to this start date.

61. Deliverable number

Deliverable numbers in order of delivery dates: D1 – Dn

62. Nature

Please indicate the nature of the deliverable using one of the following codes

R = Report, P = Prototype, D = Demonstrator, O = Other

63. Dissemination level

Please indicate the dissemination level using one of the following codes:

- **PU** = Public
- **PP** = Restricted to other programme participants (including the Commission Services)
- **RE** = Restricted to a group specified by the consortium (including the Commission Services)
- **CO** = Confidential, only for members of the consortium (including the Commission Services)
- **Restreint UE** = Classified with the classification level "Restreint UE" according to Commission Decision 2001/844 and amendments
- **Confidential UE** = Classified with the mention of the classification level "Confidential UE" according to Commission Decision 2001/844 and amendments
- **Secret UE** = Classified with the mention of the classification level "Secret UE" according to Commission Decision 2001/844 and amendments

64. Delivery date for Deliverable

Month in which the deliverables will be available. Month 1 marking the start date of the project, and all delivery dates being relative to this start date

65. Review number

Review number: RV1, RV2, ..., RVn

66. Tentative timing of reviews

Month after which the review will take place. Month 1 marking the start date of the project, and all delivery dates being relative to this start date.

67. Person-months per Deliverable

The total number of person-month allocated to each deliverable.

PART B

Safe ExploitAtion Related CHemistry for HLM reactors

Acronym:

SEARCH

Type of funding scheme: **Collaborative Project**

Work programme topics addressed:
Call Identifier: **FP7-Fission-2011**
Activity/Area: ***II.2.2.3: Cross-cutting aspects for nuclear systems***
Topic: **Fission-2011-2.2.1 Support for ESNII**

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2.	ENEA	Agenzia Nazionale per le Nuove Tecnologie, l'Energia e lo Sviluppo Economico Sostenibile	Italy
3.	KIT	Karlsruher Institut fuer Technologie	Germany
4.	NRG	Nuclear Research and Consultancy Group	Netherlands
5.	CRS4	Centro di Ricerca, Sviluppo e Studi Superiori in Sardegna	Italy
6.	UGent	Universiteit Gent	Belgium
7.	UniPi	Universita di Pisa	Italy
8.	VKI	Von Karman Institute for Fluid Dynamics	Belgium
9.	INR	Regia Autonoma pentru Activitati Nucleare Drobeta Tr. Severin, Sucursala de Cercetari Nucleare Pitesti	Romania
10.	JRC-ITU	Joint Research Centre – Institute for Transuranium Elements	Germany
11.	PSI	Paul Scherrer Institut	Switzerland
12.	CHALMERS	Chalmers Tekniska Hoegskola AB	Sweden

Table of Contents

B1. Concept and objectives, progress beyond state-of-the-art, S/T methodology and work plan

B1.1 Concept and objectives

With the growing scarcity of fossil fuels and the problem of CO_2 emissions, energy is one of the critical problems society faces. Nuclear fission can be a part of a sustainable energy mix provided that due attention is given to safety aspects and waste. Presently, the European Union produces 35% of its electricity via nuclear fission in so-called second and third generation light water reactors (LWR). In this process about 2500 tons of spent fuel is generated that contains 25 tons of Pu, 3.5 tons of minor actinides (MA) like Np, Am, and Cm and 3 tons of long-lived fission products (LLFP).

Nuclear waste must be dealt with in an appropriate way. The current adapted approach is geological disposal, possibly preceded by used fuel reprocessing. The latter depends on fuel cycle choices and waste management policies of individual member states. In any case, the time scale involved in geological disposal exceeds that of the history of accumulated technological knowledge. As a result geological disposal of nuclear waste does suffer from public acceptance problems.

In various studies, partitioning and transmutation (P&T) in critical and/or sub-critical fast spectrum transmuters has been identified as a way to lessen the volume and to lower the decay time of nuclear waste. This reduces the required monitoring period to technologically feasible and manageable time scales. Also in the framework of the GEN IV initiative this approach has been put forward.

At European level a collaborative effort supported by the European commission and leading European research institutes and industries was started to bring advanced fuel cycles and the P&T strategy together in order to investigate its economic and technical feasibility. The exploratory research done in the field and the launch of the Sustainable Nuclear Energy Technology Platform (SNE-TP) in 2007 lead to a joined effort from the European nuclear fission research community to issue a Strategic Research Agenda (SRA) that describes the roadmap towards sustainable nuclear fission energy. Here, the SNE-TP community identifies the sodium fast reactor technology as the reference but also highlights the need for the development of an alternative track with lead or gas cooling. In addition, the need for R&D activities in support of accelerator driven systems (ADS) was stressed to allow the demonstration of ADS technology by the construction of the first ADS Demo facility (MYRRHA).

With regard to alternative fast reactor technologies as described in the SRA, lead cooled fast reactor (LFR) systems are very promising in meeting the Gen IV requirements in terms of sustainability, economics, safety and reliability and proliferation resistance & physical protection. This assessment is based on inherent properties of the reactor coolant and on design choices made.

In the European Strategic Nuclear Infrastructure Initiative (ESNII) Implementation plan, the roadmap for the development, design construction and operation of a lead cooled fast reactor is laid out. The conceptual design of a LFR Demonstrator (ALFRED) is foreseen for 2012. The roadmap also identifies the need for a European Technology Pilot Plant (ETPP) that should be operational by 2023. As a result a priority action must start to complete the design and to support the licencing procedure.

In this context MYRRHA (*Multi-Purpose Hybrid Research Reactor for High-Tech Applications*) will play a key role as the LFR-ETPP. MYRRHA is a flexible fast neutron irradiation facility that is designed to be able to operate as an accelerator driven sub-critical system (ADS) and as a critical liquid metal cooled reactor. In this latter mode the facility will be operated as a research and test facility to support fast neutron reactor development. All critical components of a lead cooled reactor including the core configuration, the cooling system, control system and instrumentation can be tested in this configuration. In sub-critical mode MYRRHA will serve to demonstrate the feasibility of an ADS at sizable power levels which is crucial for the development of dedicated sub-critical transmuter systems. MYRRHA is designed with a compact high flux core so that the machine can function as a fast spectrum neutron irradiation facility for tests of advanced fuel, structural materials, MA transmutation experiments and medical isotopes production. The high power density of the core dictates the use of lead bismuth eutectic (LBE) rather than pure lead as coolant because with the higher melting point of pure lead, the hot spot temperatures on the reactor fuel get too high. Because MYRRHA is primarily a research facility it is the main ESNII infrastructure that is promoted within the European Strategy Forum for Research Infrastructures (ESFRI).

In March 2010 the Belgian government decided to support the MYRRHA project with an engagement to cover 40% of the costs whereas the other 60% should be invested by a consortium of international partners to be built by 2014. In addition, the decision requires the preliminary environmental impact assessment report (EIAR), the front end engineering design (FEED) and the preliminary safety assessment report (PSAR) to be delivered to the Belgian safety and licencing authorities by 2014. The documents are a first necessary step in obtaining the construction permit and licenses. The deadline set is consistent with the ESNII goal to have the facility operational by 2023.

In particular with regard to the FEED and the PSAR there are a number of technological challenges to be met. A support R&D programme to respond to these challenges is absolutely necessary. Whereas in the past R&D work was mainly focused on feasibility studies, here there is more need for safety and reliability related R&D.

The goal of the SEARCH proposal is to group critical safety related research focussed on the coolability of the fuel with and without forced convection, the chemical behaviour of the heavy liquid metal reactor coolant and impurities, the interaction of fuel with the coolant and the behaviour of (volatile) radioisotopes in the coolant. Indeed, although information of this type is essential for the licencing process, it turns out that actual experimental data in this field are rather scarce or non-existent. The scope of SEARCH encompasses basic studies including an experimental and numerical analyses of heat transfer in the fuel bundle, the determination of the impurities source terms, the investigation of migration, deposition and release of impurities and radioisotopes and finally the development of capture and purification techniques. In particular the objectives of the project are to:

- Study the heat transfer of a wire spaced fuel bundle in forced and natural convection
- Investigate the source term for impurities in the coolant including corrosion products, spallation and activation materials and water from a possible heat exchanger leakage.
- Study the mass-transport of dissolved metals and oxides in the coolant.
- Develop filtering techniques for the coolant in both loop and pool configuration.
- Develop and validate an oxygen control system based on solid oxide particles including the influence of the cover gas, formation and dissolution kinetics and measurement techniques in a deep pool configuration.
- Study coolant-fuel interaction and characterise reaction products with their influence on fuel.

- Study the phase relations of the elements in MOX fuel and the coolant (Pb-U-O, Bi-U-O, Pb-Pu-O, Bi-Pu-O).
- Investigate the dispersion of fuel through the reactor system in case of a core melt and in case of slow fuel release by computational fluid dynamics (CFD) and SIMMER simulations.
- Identify and study the parameters that influence the evaporation, gas phase transport and deposition processes of radioisotopes from the coolant including the chemical composition of the evaporated compounds
- Determine physicochemical parameters necessary for the prediction of vapour phase concentrations of radionuclides in an ADS and the development of gas phase filtering systems for their removal.
- Use ab-initio quantum-mechanical calculations to calculate crucial properties of the evaporation and deposition processes of volatile radionuclide including the interaction with potential filter materials.

The main motivation for the selection of these specific topics is that they all are related to important operational and safety issues.

The coolability of the fuel is the most essential issue in the design and operation of a nuclear system. Both in forced convection and in natural convection which may occur after a loss of flow as happened in de Fukoshima accident coolability must be guaranteed. Another type of failure of the cooling can happen because of an assembly or channel blockage. In this respect the chemistry control of the coolant of a heavy liquid metal cooled nuclear system in normal operation is very important. The chemistry control concept for heavy liquid metal coolants can be subdivided in two major aspects. The first aspect is the specific control of the oxygen content in the coolant. This is required to protect the structural materials in the reactor from corrosion on the one hand and to avoid excessive precipitation of lead- and bismuth oxides on the other hand. The second major aspect of chemistry control deals with the management of impurities in the coolant. It is clear that uncontrolled impurities can lead to depositions in the reactor causing reduced cooling or blockages with potential disastrous consequences. The main sources of impurities are lead oxide precipitation, corrosion products but also radioactive elements originating from spallation and neutron activation reactions.

The compatibility of the fuel and the coolant is a critical issue in the safety assessment of a nuclear system. Both low probability accident scenarios involving a (partial) core melt and the high probability event of a leaking fuel pin must be considered. The full analyses of these scenarios using appropriately validated codes like e.g. Simmer III require further experimental data on basic properties of the interactions between the materials involved in scenarios mentioned above.

For licencing preparation it is important to investigate the consequences of the reference severe accident scenarios. Although the selection of the reference accident for MYRRHA is not clear at this point, it will most likely involve damage to the fuel pins. In SEARCH two scenarios will be considered: slow, long term release of fuel corresponding to a set of leaking fuel pins and a scenario involving a large, short term release of fuel which corresponds to a partial or complete core melt. We will investigate the dispersion of molten fuel in the system by means of numerical simulations.

The main concern of the safety authorities is the prevention of risks to the general public, both in normal operation of a nuclear reactor as well as in accident scenarios. The most important risk is the escape of radioactive materials to the environment. This means that the release of these elements, both from fission in the fuel and from the spallation and activation reactions in the liquid metal of an ADS system must be investigated. Furthermore, possible methods to capture these elements in the covergas conditioning system and their kinetics and efficiency should be examined. In comparison to water cooled thermal reactors, a lead-bismuth cooled ADS system such as MYRRHA has, besides fission gasses and light activation products, the additional presence of heavy volatile elements such like Po and Hg. For this reason the main focus will be put on these elements. The release of Po into the environment in various accident scenarios involving damage to the confinement structure will be assessed using the experimental data gained in the project.

In all experiments LBE is selected as the primary coolant and not pure lead. The reason for this choice is twofold. Firstly, since MYRRHA will be the first HLM cooled nuclear system to be deployed in Europe as shown in the ESNII roadmap, SEARCH will put its emphasis on LBE as it is the coolant used in MYRRHA. Secondly, because LBE is chemically more complex than pure lead, experiments performed using LBE can more readily be extrapolated to pure lead at the same temperature range whereas the reverse is not the case. In this sense using LBE is more generic than using pure lead.

SEARCH will also include a work-package on education and training. The objective is to organise a number of workshops and schools with the objective to educate and train students and PhD's in topics relevant to the project.

SEARCH will be linked to existing FP7 projects related to Gen IV system development in general and to LFR/ADS systems in particular. These include CDT (*Central Design Team*), LEADER (*Lead-cooled European Advanced Demonstration Reactor*) and THINS (*Thermal-Hydraulics of Innovative Nuclear Systems*). SEARCH will partly build on results obtained in the FP6 project EUROTRANS (*European Research Programme for the Transmutation of High Level Nuclear Waste in ADS*).

B1.2 Progress beyond the state-of-the-art

In the previous section the objectives of the SEARCH proposal have been highlighted. These can be grouped in four main research domains that each encompasses a section of the objectives. These domains are:

- Coolability of a wire spaced fuel bundle
- Coolant chemistry control
- Fuel-coolant interaction
- Fuel dispersion studies
- Release and capture studies for radioisotopes

Below, the state-of the-art and the envisaged progress beyond the state-of-the-art is described.

Coolability of a wire spaced fuel bundle

The investigation of the coolability of a wire spaced fuel bundle will encompass an experimental and numerical characterization of the heat transfer for free, mixed and forced convection in heavy liquid metal cooled rod bundles.
As in the earlier developed sodium cooled fast spectrum reactors, wire spacers are used in the current reference design for the fuel assembly of MYRRHA. The wire-wrap spacers in the hexagonal fuel assembly ensure the position of the fuel rods within the assembly, suppress mechanical vibrations, enhance mixing and provide a good heat transfer at low pressure loss.
However, existing experimental investigations of the heat transfer coefficients of fuel assemblies in heavy liquid metal coolants all focus on systems with grid spacers. Because the coolant flow

in the sub-channels of the fuel assembly differs fundamentally depending on the type of spacer that is used it is important that a detailed study is performed on heat transfer coefficient of representative fuel assembly with wire spacers in both forced and free convection.
In both scenarios the heat transfer coefficient will be crucial for the heat removal of the fuel pins and therefore for the cooling of the system under nominal conditions and accidental transients.
The foreseen activity will allow to achieve a fruitful set of experimental data and numerical overview on the thermal hydraulic behaviour of the MYRRHA's FA, making available proper tools for the FA design in HLM cooled wire-spaced fuel assembly. Indeed, one of the main objectivises of the depicted task is to improve and validate numerical tools (typically CFD codes) for supporting the innovative nuclear reactor design.

Coolant chemistry control

In the chemistry control of the coolant, the determination of the source of impurities forms essential input to design and operate the LBE impurity control units. Oxygen control, impurity control and cover gas handling are important issues in this field. In addition, information about spallation products and neutron activation products in the LBE under operation are required because they will interfere with the non-active impurity control handling.

In the past intensive corrosion and oxidation studies have been performed in the frame of several EU projects like EUROTRANS and ELSY and in international cooperation with e.g. Japan. A summary of the data is available in the OECD LBE Handbook and in open literature. The compatibility of the steels foreseen for MYRRHA (316L, T91 and 15-15Ti (1.4970)) with LBE is known to a certain extent. However, it is rather well understood which are the basic physical and chemical phenomena involved in the creation of corrosion. In addition, the formation of activation and spallation products in LBE was studied previously within EUROTRANS and for the design and operation of the MEGAPIE experiment.

In order to assess the amount of corrosion products, the specific MYRRHA conditions with respect to LBE temperature, oxygen content and flow conditions are needed. With this information, the expected formation of corrosion products on materials and components of a MYRRHA reactor under operation conditions will be determined and assessed using the available corrosion and oxidation data. Also the formation of spallation products and neutron activation products of a MYRRHA reactor under operation will be evaluated and assessed using MCNPX calculations based on the experience gained in earlier EU projects.

The accumulation of metallic and non-metallic impurities from corrosion and activation products and the formation of PbO and other oxides requires adequate filtering and cleaning technologies for the LBE to ensure continuous operation without excessive risk of blockages.

Filtering tests performed in the past in Western Europe were only done in loop type configurations. Different kinds of filters were tested and some of them showed potential. French and Russian researchers reported the formation of filter cakes and no or only limited in-depth retention for different filter types. Most filter types show good retention of impurities accompanied by a steep increase of pressure drop. Whether these pressure drops are acceptable for long term operation is one of the open questions. Overflow filters that are capable to remove oxides from LBE surfaces like those expected in pool configurations are discussed but not seriously investigated. Also the transfer of filters from loop to pool type operation is a still open task. In addition to tests that envisage to increase the knowledge about and the performance of these loop type filters, such filters will be adapted and tested in a pool type test facility. Overflow filters that are foreseen to trap oxide particles from LBE surfaces will be developed and tested as well.

Besides knowledge about the source term of the impurities and about filtering techniques to remove them, also a good understanding and control of mass transport phenomena and interactions of oxygen and metallic and non-metallic impurities with LBE is essential for the safe operation of LBE cooled nuclear facilities.

Because of its importance in corrosion protection and slag formation, this is particularly true for the understanding of the thermodynamic behaviour and chemical kinetics of oxygen in LBE. Several thermodynamic properties relevant for the behaviour of the Pb-O system in LBE are required. These include the Gibbs free energy of formation of PbO and of other relevant oxides, the activity of Pb, the oxygen solubility and diffusivity and the dissolution and precipitation kinetics of PbO. In addition, dissolution, transport and precipitation rates of metallic and non-metallic impurities in LBE are needed.

Especially during emergency shut down and abnormal working conditions the behaviour of oxygen in interaction with the coolant has to be known. In the past, significant parts of the essential information were generated, especially during some previous EU projects like EUROTRANS, ELSY and currently LEADER. Many reports and publications are available and provide reliable data. Most of them are summarized and assessed in the respective chapters of the OECD Handbook on LBE. However, although most of the fundamental thermodynamic data is available, exchange kinetics of oxygen with LBE, and the transport properties of oxygen, oxides and metallic impurities into and within LBE are still unknown.

Because of its importance for the design and safety assessment of MYRRHA, the oxidation potential or more general the reaction between water vapour and LBE (e.g. in case of small heat exchanger leak) and the contribution to oxide formation will be addressed in this proposal.

In addition, open aspects like exchange kinetics of oxygen with LBE such as absorption of oxygen from cover gas under regular conditions and accidental ingress of oxygen in the cover gas will be studied. Furthermore, mass transport of oxygen and metallic and non- metallic impurities including entrainment of oxide particles will be investigated experimentally and numerically. Adapted and optimized CFD codes are needed for realistic impurity transport simulation of a MYRRHA type reactor.

With regard to the design and operation of oxygen control systems (OCS) in Western Europe, most effort was focused on gas phase based devices which were employed for LBE loops including those with a large inventory. For pool type systems like MYRRHA such OCS were never investigated experimentally. Some preliminary calculations were performed that highlighted the necessity to explore this task. A different type of OCS system that relies on the solid PbO-LBE interaction is also possible. In the framework of the development of this solid PbO mass exchanger the kinetics of PbO dissolution in LBE has been reported as a function of temperature, flow velocity and oxygen concentration but the details of the experimental techniques used are not available.

Experimental data on the kinetics of PbO precipitation in liquid lead and LBE and the resulting size distribution of PbO particles in the liquid is very limited. Therefore, it is the aim of the current proposal to assess the PbO precipitation kinetics under MYRRHA relevant conditions and to investigate the size distribution of PbO particles formed in LBE under possible abnormal working conditions such as scrams and unexpected shut downs of the system. In addition the technological realization of a PbO based oxygen control system will be tested in pool set-up.

Fuel-coolant Interaction

In the assessment of a severe accident scenarios involving fuel pin damage or a core melt, it is important to know the interaction between the fuel and the coolant. There is significant data on sodium-fuel interaction coming from both out-of-pile and in-pile experiments done during

previous fast reactors R&D programs. Even though it is not directly applicable to LBE-fuel interaction, it shows the typical issues one has to deal with in case of cladding breach.

Sodium entering a pin with failed cladding will lead to the formation of a fuel-sodium reaction product (FSRP), Na_3MO_4, where M=U or Pu in the same ratio as in the original fuel. Na_3MO_4 has a lower density than that of the MOX fuel resulting in a volume expansion that can cause significant diametric strain of the fuel pin. Thermal conductivity of the FSRP was also significantly lower than that of the fuel. The formation of FSRP is limited by the oxygen and sodium availability and the fuel temperature.

The Na-fuel reaction requires an oxygen supply which, in case of small breach, is provided by the fuel, lowering at the same time its O/M ratio. The reaction stops when the O/M has become sufficiently low to reach equilibrium. This is why the stoichiometry at or close to the surface of the fuel in equilibrium with the FSRP is typically lower (1.93-1.96) than fresh or irradiated fuel (1.97-2.00). Higher temperatures and higher Pu fractions result in lower O/M values. The change in the stoichiometry of the fuel will lead to change in physical properties of the fuel (reduction of thermal conductivity that can increase the centreline temperature, increase in thermal expansion that can lead to cracking). Kinetics of sodium-fuel reaction depends on temperature. At 500-600°C/3500h, the reaction was confined to the pellet surfaces. At 800°C the reaction reached the pellet centre in less than 12h.

Concerning the interaction of LBE with fuel, the only existing data concerns the experiments done on liquid metal - bonded gap fuel rods containing UO_2 where helium filling the gap between fuel and cladding was replaced by a Bi-Sn-Pb alloy in order to eliminate the gap thermal resistance. After compatibility test of 3 weeks at 350°C a thin black oxide layer was observed on the fuel surface. However there was no further study on the nature and origin of this oxide layer.

The Soviet Alfa-class submarines used LBE as a coolant for their nuclear reactors and UO_2 as fuel. Russians have significant expertise in the LBE technology but data on fuel-coolant interaction is not readily available. Data concerning the interaction between MOX or PuO_2 and LBE could not be found.

From the above it is clear that knowledge on the interaction between LBE and MOX fuel is scarce to non-existent. In this project LBE-fuel interaction will be studied and the reaction products and their potential effect on the fuel element will be characterised in order to qualify the fuel for MYRRHA. In addition, a more fundamental approach is taken to understand the phase relations Pb-U-O, Bi-U-O, Pb-Pu-O and Bi-Pu-O for which there is no published available data.

The MOX fuel used in the experiments will be as close as possible to the MYRRHA specifications with a representative Pu fraction and O/M ratio. Experiments will be done on solid pellets (or disks) to study the effect of LBE-fuel interaction on the surface. Additional experiments will be done with powders which have much higher specific surface area and show a different behaviour than the pellet (e.g. dissolution). A temperatures range 500-800°C is chosen as representative of the fuel surface temperature in nominal operation condition and the oxygen concentration in LBE is set in accordance with MYRRHA operating condition.

Additionally, two MOX manufacturing routes will be investigated. One based on wet chemistry (sol-gel technique) that produces a very homogeneous solid solution of $(U, Pu)O_2$ and one based on a dry fabrication route that consists in mixing powder of UO_2 and PuO_2 followed by ball milling and sintering. The latter produces a heterogeneous microstructure with Pu or U-rich agglomerates. The reason behind using two different preparation routes is to study the effect of the microstructure homogeneity on the interaction with LBE. Complementary experiments on UO_2/PuO_2 pellets/powder will also be done.

Finally, the phase relation between the different species involved will be studied in order to extent the current knowledge of the phase diagrams. This work will be supported by dedicated experiments. A CALPHAD modelling of the phase diagrams is also foreseen but outside of this project.

Fuel dispersion studies

In conventional light water reactors and even in sodium cooled reactors there is a large difference in the density of the oxide fuel and the coolant. In the case of heavy liquid metal cooled reactors, however, the density of the oxide fuel and the coolant are rather similar. This means that the situation studied in fuel dispersion investigations that have been performed for these existing reactor types is not comparable to the case of a HLM cooled system. In this project we intend to study fuel dispersion in a HLM cooled reactor in detail for the first time by numerical simulations. Two approaches will be used. One is based on the use of CFD codes whereas in the second approach the SIMMER system code will be applied. The use and comparison of both codes will increase the overall reliability of the fuel dispersion assessment. In the calculations both the dispersion of fuel in the coolant and fuel accumulation processes will be looked into.

The thermal load on the core be calculated according to the results of neutronic simulations performed in the FP7 CDT project and related national or EU funded projects. The LBE physical properties have been gathered in the OECD LBE Handbook. In some specific cases, the system code will be dynamically coupled with a neutronic code.

In the lighter cases of normal and incidental operation, two main types of failure are foreseen. : First, a cladding failure can lead to a contact of the LBE with the fuel. Chemical reaction, as well as erosion may occur, involving the emission of fuel derived species in the primary LBE loop. This material will circulate in the primary loop. At this point, many phenomena can occur, depending on the physico-chemical properties of the species. Light species will tend to accumulate in upper bounded stagnation regions. Heavy species will tend to accumulate in lower bounded stagnation regions. Some species may attach to the structural parts. There may be preferential reattachment regions like the Heat Exchangers (HE) tubes when this property is temperature dependant. Some species may gather at the upper free surfaces, and if chemically active, they can corrode the structures at the free-surface level. This list of phenomena, a non-exhaustive list, involves small instantaneous quantities and quite long time scales, up to hours, before steady-states rates of deposition can be estimated. It requires the only one-way coupling of Lagrangian particles in an otherwise stationary carrier LBE flow.

Secondly, after clad failure, fission gas will be released from the Fuel Assembly (FA) into the plenum. This release will have an instantaneous effect on the local flow and a voiding impact on the neutronic core condition. Both effects are likely to strongly affect the local temperature field which could potentially lead to additional pin failures. The gas volume will then escape the FA. Part of it should escape through the upper free surface; another part may be carried by the main flow in the primary loop. One must check whether there are potentially damaging effects in the HE and moreover that only a negligible part of the gas re-enters the core. Simulation of this kind of events requires a coupling of the gas flow with LBE and must be fully transient. Depending on the scenario specified and the clad disruption conditions, fuel particles, fuel chunks and also disrupted clad could enter the flow. The redistribution of core materials has to be followed.

The accidental case of large core melting will be investigated in a second step, taking provision of the experience gained. It should be investigated only with SIMMER-III, according to scenarios to be developed during the first phase of the project. In effect, it is still out of realistic range for CFD.

By modelling the first type of failure, also called leaching, we will be able in the future to adapt the model for other materials such as corrosion products.

Release and capture studies for radioisotopes

In this field four major aspects are crucial in the assessment of release and capture of radioisotopes.

Vapour pressure and thermodynamic activity of volatiles over liquid metals

Data on thermodynamic activity and vapour pressure of Po, Hg, Cd, Tl, I, Cs and Rb in dilute solution in Pb, Bi and LBE have been recently reviewed. Recommendations for conservative estimates of the vapour pressure over an LBE melt were compiled. However, the data are derived from only few experiments, leading to a relatively large scatter. In many cases, data extrapolated from high temperatures have to be used, or have to be derived from binary solutions in either Pb or Bi. Thus, the accuracy of the available data is not high.

In safety assessments for ADS the question of fundamental thermodynamic data of volatile elements in diluted LBE-solutions will certainly arise. For this reason determination of the missing data within the SEARCH project is proposed, hereby applying experimental as well as theoretical methods. This will put release estimations on a sounder basis. It is particularly obligatory to study the properties of the most hazardous elements Po and Hg in LBE solution. The high radiological relevance of these elements makes independent experimental studies performed by two different laboratories mandatory. Furthermore, the experimental results are to be substantiated by ab-initio quantum mechanical (QM) calculations.

Quantum chemistry and first principles calculations have reached a level of maturity that allows predicting a variety of molecular and solid state properties. This applies even to very heavy atoms as Po, where relativistic effects play a significant role. Therefore, these theoretical methods can serve as a valuable tool to support and explain experimental results. It has been recently shown how the solubility of Mo in solid Fe can be determined from first principles. The procedure relies on density functional theory (DFT). It is tempting to apply this procedure to predict the solubility of Po in solid LBE, which puts a lower limit on its solubility in liquid LBE. Procedures to predict solubility in a liquid have been documented in recent literature as well: crucial quantities as the Henry constant depend on a few quantities which all can be obtained from static DFT and/or molecular dynamics. This method can be applied to assess Po solubility in liquid LBE as a function of concentration and temperature. This will complement and expand the information that is available from experiments.

The release of Po from liquid LBE does not only depend on its solubility. If Po would form stable compounds with Pb or Bi, or with other solutes, precipitation of solid Po compounds could occur. In a first attempt to identify possibly stable $Po_{0.5}X_{0.5}$ compounds (where X is any other element), a Miedema model has been applied recently. The regions of interest indicated by this simple model will be examined by DFT calculations. DFT has a proven record in compound prediction. The reliable formation enthalpies obtained in this way, will allow singling out a set of compounds that are likely to precipitate.

Evaporation rate data

Very few literature data of evaporation rates of volatile elements from Pb and LBE exist. The evaporation rate of Po from LBE was determined in two series of experiments only, in conditions close to saturation. The results impressively demonstrated that evaporation rates under ambient pressure are significantly lower than those obtained by simple Langmuir calculations. However, in accident scenarios, rates can be very different from those close to saturation. Therefore, experimental results under different conditions are certainly necessary.

For Hg, a series of experiments was performed studying its evaporation from Pb. Though the effects of various parameters on the evaporation rate were nicely demonstrated in a qualitative way, one is clearly far from a quantitative understanding of the evaporation process. To facilitate more reliable estimations of the evaporation rates of Po and Hg from LBE, we propose systematic studies under variation of concentration, gas flow and composition, agitation of the melt, sample size and geometry within the SEARCH project.

"Anomalous" Po-evaporation processes

Various experiments report a Po volatility higher than expected based on equilibrium vapour pressure under certain conditions, such as in presence of hydrogen and for high specific activities. Many of these reports are difficult to analyse in terms of the underlying fundamental processes, and data interpretation seems speculative on occasion. However, the observed increased gas phase concentrations are not questioned, and it remains a most urgent task to gain understanding of the fundamental processes and their importance for the safety of LBE-based systems.

The mechanism leading to increased Po gas phase concentrations can be described as a convolution of several effects: sputtering, aerosol formation and formation of volatile intermediate Po species from reactions with hydrogen containing radicals. The radiolytic formation of these radicals is facilitated by high specific activities. To gain understanding of the importance of these processes, PSI proposes dedicated experiments to study the influence of radicals on Po evaporation. Furthermore, the existence, transport and deposition of volatile Po species will be studied by thermochromatography (TC). Complementary to this, CMM proposes to calculate the formation energies of several gaseous Po compounds (e.g. PoH_2, PoOH) by DFT and/or QM. This information will allow eliminating unstable molecules. Several reaction paths will be examined, to point out the most favourable.

Removal of volatiles from the gas phase

On the basis of current knowledge, trace amounts of hazardous nuclides, most critically Po and Hg, will volatilize into the cover gas in ADS. Although still within the confinement of the reactor vessel, it is mandatory to remove and control these volatiles for safety reasons.

Mercury removal technologies based on adsorption on high surface area materials already exist in industry. Typical adsorbent materials for Hg are impregnated activated carbons. Carbons present certain disadvantages such as flammability. These limitations may be circumvented by using inorganic adsorbents such as zeolites, loaded with noble metals. The affinity of noble metals for Hg vapours over LBE was suggested by thermodynamic calculations and was demonstrated by experiment. On Po capturing, very few data are available. Carbon sorbents were reported to be capable of effective removal of gaseous Po. Calculations showed that noble metals, especially Pd, are particularly suited for capturing gaseous Po. Thus, adsorbents for Hg capturing could be effective for Po also. Although these technologies seem promising for Hg and Po control, an experimental program is needed to identify the most suitable adsorbents, and to evaluate their performance under the conditions of ADSs. Therefore, SCK•CEN proposes experiments to develop Hg and Po adsorption technologies. TC experiments at PSI will provide key thermochemical quantities, which will aid in the selection of adsorbent materials. To guide the challenging experimental work with Po, CMM proposes to calculate heats of solution of Po in noble metals, and the heat of adsorption of Po on several noble metal surfaces using DFT. This will allow assessing in a quantitative way which noble metal and surface type is most effective to capture Po.

B1.3 Scientific and technological methodology and associated work plan

B1.3.1 Overall strategy of the work plan

MYRRHA is identified in the ESNII roadmap as the LFR pilot plant and is included in the European Strategy Forum for Research Infrastructures (ESFRI) as one of the main facilities to be built. The goal of the project is to help the implementation of the roadmap by supporting the development and licencing of MYRRHA as the LFR-ETPP. SEARCH will study the behaviour of the coolant, fuel and radionuclides produced in interaction with each other by a synergetic combination of experimental, theoretical and numerical analyses. A focus is put on efforts useful in safety analyses or that will aid the design to improve safe operation of the facility. The structure and execution of the project aim to achieve the following actions:

1. Perform an investigation of the coolability of a wire spaced fuel bundle by experimental and numerical analyses of the heat transfer in a wire wrapped rod bundle in both forced convection, natural convection and the transition between these two flow regimes.
2. Study and develop methods to keep the coolant in the correct chemical composition, including oxygen control and management of impurities. Both aspects are important for corrosion protection of structural materials and to avoid possible blockage of the coolant flow. An oxygen control system in pool configuration, including pool oxygen sensors and filter techniques to remove impurities should be developed. Also, the source term of impurities and their migration mechanisms must be studied in detail.
3. Investigate the compatibility of MOX fuel and the coolant. The issue is critical in the safety assessment whereas data on the interaction is very scarce. The basic chemical behaviour of a mixture of fuel, coolant and clad materials in a relevant temperature range must be investigated. The compatibility experiments should be done with uranium oxide as reference and MOX with fuel. Data are needed on the energy release, fuel solubility in the coolant and fuel-coolant-clad compound formation. Also the influence of the interaction surface and the density and structure of the pellets should be studied
4. Perform a detailed assessment of the dispersion of fuel in the reactor in severe accident scenarios involving damage to the core. Unlike in light water reactors, the difference in density between the fuel and the coolant is small and intuitive reasoning on fuel behaviour in heavy liquid metal flows is insufficient. A detailed assessment of the dispersion of the fuel, possibly leading to criticality problems caused by fuel accumulation must be performed. Because different aspects should be looked into both system codes like SIMMER as well as CFD simulations must be applied.
5. Prevent risk to the general public by investigating possible release of radioisotopes into the environment. Detailed knowledge on evaporation and capture of radiological products including 210Po should be gained. This is essential for environmental impact studies, safety assessments and reactor design. The reliability and confidence of data interpretation must be optimised by theoretical support for the experiments. Apply the results to Po release studies in accident scenarios
6. Install education and training as well as practical work programmes to reach the necessary education level and qualifications for engineers and scientists who work in a nuclear power programme. Improvement of education and training coupled to the training dissemination of results is important to attain the technology breakthroughs and innovations needed for the deployment of the LFR/ADS nuclear systems.

SEARCH consists of seven technical work-packages, a specific work-package on education and training and a work-package to group the management of the consortium activities:

WP1: Consortium management
WP2: Coolability of a wire spaced fuel bundle
WP3: Coolant chemistry control
WP4: Fuel coolant interactions
WP5: Fuel dispersion
WP6: Release and capture studies for radioisotopes
WP7: Education and training

WP1: CONSORTIUM MANAGEMENT (SCK•CEN) .

WP1 will deal with the general coordination of the consortium including management of legal, financial and administrative aspects. It will also guard the coherence between the different work packages in order to respect the project's objectives, its overall internal coherence, time schedule, issuance of deliverables and periodic reporting to the European Commission.

In particular, WP1 will cover, a.o., the:

- general coordination of the consortium and maintenance of the consortium agreement;
- administration of project resources;
- elaboration and monitoring of project procedures, the definition of the project's internal organisation, procedures, document models, etc, in detail in order also to address and solve potential conflicts among the project partners efficiently;
- follow-up of project planning, deliverables and milestones;
- ensuring that all partners share the same level of information on general issues concerning the project, i.e. contract and project management, work progress, communication, etc;
- elaboration of the periodic management & activity reports to the European Commission;
- preparation, organisation and minutes of project management meetings (progress meetings, governing board meetings and technical coordination board meetings);
- follow-up of decisions and action plans.

In addition WP1 will ensure the support of the External Technical Advisory Committee (ETAC) and facilitate the links with the other project work packages.

WP2 : Coolability of a wire spaced fuel bundle (ENEA, KIT, NRG)

This work package will be dedicated to the experimental analysis and numerical modelling of thermal-hydraulic behaviour of a wire wrapped fuel rod bundle. In order to meet the requirements of MYRRHA two different sized prototypical rod bundles will be investigated in a heavy liquid metal flow using LBE (lead bismuth eutectic) in the regime of forced, mixed and natural convection, with a maximal attainable heat flux of 1MW/m² by electrical heating.
Measured bulk velocity, pressure drop and temperature profiles as well as determined heat transfer measurements will give important input for the MYRRHA design. The synergy between CFD-modelling and experiments appears crucial to focus on the WP goal.

Task 2.1 will be devoted to the experimental campaign on THEADES (KIT), NACIE (ENEA) and HELENA (ENEA) HLM loops. The experiment in the THEADES loop will study forced convection and it will be performed on a 19 pin wire wrapped rod bundle with a diameter of 8.2 mm, pitch to diameter (p/d) ratio of 1.28 and a heat flux up to 1 MW/m^2. Results will be in terms

of temperature measurements in the pin cladding, sub-channel bulk temperatures, pressure drop measurements and overall temperature drop measurements.

Information from THEADES experiment will give the base for the subsequent experiment on free and mixed convection on the NACIE loop (ENEA). A wire-spaced 19 pins hexagonal fuel bundle will be assembled in a hexagonal lattice, with pin diameter 6.55 mm, active length of 600 mm, p/d ratio of 1.28. The pins provide an azimuthally uniform heat flux up to 1 MW/m^2. These values are relevant for the MYRRHA design. Free and mixed convection tests will be performed on the NACIE loop. The transient tests will simulate the transition from forced to free convection as a consequence of a loss of flow accident, and therefore the initial condition will result from the THEADES experimental tests. The following quantities will be measured during the transient: the cladding temperature through wall-embedded TCs; the integral mass flow rate through a proper flow meter; pressure losses in the FA; bulk temperature in the sub-channels; heat transfer coefficient.

As Long Term step, the NACIE bundle will be dismantled and mounted in the horizontal HELENA loop, working with lead. The forced convection experiment above described for THEADES will be repeated on the new bundle and the coherence of the scaling laws used as Initial Conditions in the NACIE tests will be verified in HELENA. A post-test analysis will be accomplished on the whole experimental campaign.

Task 2.2 will provide detailed CFD analyses using appropriate turbulence modelling in support of the experiments. From these detailed analyses, input parameters will be derived for a coarse grid model of the NACIE facility to perform parameter studies at KIT. Detailed post-test CFD analyses on a section of the experimental FAs will be performed for the THEADES and NACIE experiments. These detailed analyses will provide input for LRGR and coarse grid analyses of the complete experimental FA to be performed by NRG and KIT. These analyses will support the interpretation of the experimental results, as limited measurement data will be available due to the complex experimental environment (LBE). The validated approaches used in support of the experiments will be applied to the real 127 pin MYRRHA FA. Firstly, a detailed CFD analysis of a section of a FA will be performed. This will provide input for LRGR and coarse grid analysis of a complete MYRRHA FA or even the complete MYRRHA core. These analyses will serve to deduct heat transfer correlations to be used in less resolved numerical approaches.

Task 2.3 will be devoted to pre-test parametric and post-test numerical simulations on the rod bundle flow. Pre-test numerical simulations provide the input for the selection of parameters like axial pitch and help to choose an experimental test-program including sensor locations, error estimation and optimization of flow conditioners. Detailed interpretation of experimental data is performed based on post-test simulations. Simulations are performed with the coarse grid CFD technique with subgrid data derived from representative simulations with fully resolved CFD (provided for NACIE-experiments by NRG and for KALLA experiments by KIT)

WP3: COOLANT CHEMISTRY CONTROL (KIT, ENEA, SCK•CEN, INR)

Work Package 3 will supply experimental data and technological developments with regard to the coolant chemistry control of MYRRHA. The efforts will focus on the determination of the source term of the impurities, on the investigation of transport phenomena and the development of impurity removal and oxygen control systems.

Task 3.1 will encompass the determination of the source term for impurities. At KIT the expected formation of corrosion products on materials and components of a MYRRHA reactor under operation conditions will be determined and assessed on the basis of known corrosion rates generated in previous programmes. At SCK•CEN the formation of spallation products and neutron activation products of a MYRRHA reactor under operation will be evaluated and assessed using MCNPX calculations.

Task 3.2 will include the development of filtering techniques for operation in HLM systems. At SCK•CEN a loop type filter will be placed in a small delta T loop equipped with sacrificial rods to measure the pressure loss as a function of material loss from these sacrificial rods. Secondly, an overflow pool type filter will be developed and placed in an LBE pool to examine the applicability and efficiency of such filter to trap oxide particles from the LBE surface.

ENEA will adapt and test loop type filters based on adsorption techniques to an LBE pool environment. Furthermore a detailed investigation to understand the formation of solid impurities accompanied by quantitative qualification of filtering performance will be done.

INR is a new partner in the field of heavy liquid metal technology. Their contribution will encompass the exchange of know-how and the acquirement of hands on experience by performing filter tests in the small delta T loop at SCK•CEN

Task 3.3 has the purpose to investigate several open questions for LBE impurity control including oxygen. The use of oxygen control systems based on solid PbO oxides will be addressed from an engineering and physico-chemical point of view. Mass exchange, entrainment of solid particles (oxides), interaction, adsorption and deposition of impurities will be experimentally and theoretically investigated. Tests of oxygen sensors to be operated in a pool facility are foreseen.

At KIT vessel-type experimental device containing ~200 kg molten LBE will be developed and used for investigating of mass transport and interaction phenomena. The design will be supported by CFD calculations to optimize the design and the position of oxygen sensors and cooled probes for deposition of dissolved metals. Quantitative (local oxygen activity, dissolution of metals) and qualitative (dispersion of dissolved metals) measurements of mass-transfer and transport will be done to form the basis for integrating these phenomena in the CFD code. Ultrasonic measurements of the liquid metal flow during the experiments are used for verifying these calculations. Finally a model for the absorption of oxygen from the cover gas and vapour bubbles will be developed.

A compact experiment to determine the solubility limit and the formation and dissolution kinetics of PbO in LBE will be constructed at SCK•CEN. The set-up will comprise of 2 ceramic lined pots connected by a quartz or ceramic coated transfer tube. Both pots have independent temperature and cover gas control. The PbO solubility limit and its formation and dissolution kinetics in LBE, assuming that the liquid metal transfer is not the rate limiting step, will be measured. The temperature and oxygen concentrations while be varied systematically in the closed system at high temperature.

Different oxygen control methods for a pool type facility will be investigated at ENEA. A gas/liquid systems and a solid/liquid systems (based on solid PbO) will be designed, implemented and tested in the CIRCE facility The reliability of Oxygen Sensor technology in a pool test facility (CIRCE) will be tested

WP4: FUEL COOLANT INTERACTION (Chalmers, JRC-ITU)

WP4 will yield data on the interaction between LBE and fuel including the characterisation of the reaction products and their potential effect on the fuel element. In addition, a more fundamental

approach is taken to understand the phase relations Pb-U-O, Bi-U-O, Pb-Pu-O and Bi-Pu-O for which there is no published available data.

Task 4.1 deals with the preparation of the fuel for the experiments. In subtask 4.1.1 homogeneous MOX fuel will be fabricated using the wet-chemistry sol-gel method whereas in subtask 4.1.2 heterogeneous MOX fuel will be made by direct blending of PuO_2 and UO_2 powders. The latter is the main production route for commercial fuel MOX pellets. In both sub-tasks heat treatment of the fuel pellets in a reducing atmosphere will be performed. The purpose of using two fabrication routes is to be able to study the effects of the homogeneity of the fuel pellets on the interaction with LBE. In sub-task 4.1.3 a commercially produced BelgoNucléaire MOX fuel pellet will be transported from SCK•CEN to Chalmers University. This pellet will be heat treated in a reducing atmosphere as well.

Task 4.2 involves the LBE/fuel interaction experiments and analysis. Sub-task 4.2.1 is dedicated to the set-up of the experimental apparatus at each partner institute. The set-up will consist of crucible containing LBE that will be placed in a furnace with a controlled atmosphere. The latter will be used to control the oxygen content in the LBE via the H_2/H_2O ratio in the gas phase. In subtasks 4.2.2, 4.2.3 and 4.2.4 the experiments and analyses with homogeneous, heterogeneous and BN MOX fuel will be carried out respectively. In each case the heat treated pellet and powder will be immerged in LBE under controlled atmosphere (C_{O2}=1.10^{-6} wt % in LBE) using the experimental setup from described above at 500°C and 800°C for minimum 50h. Analyses will be carried out to identify the properties of the reaction, its products and its effect on pellet microstructure. The analyses techniques will include thermal analysis (DTA) to follow the reaction kinetics and its energy release, post experiment radiography to check for sample integrity, XRD to identify phase change(s), Ceramography/SEM-WDS/TEM/EPMA to characterize the interactions LBE/pellet and inductively coupled plasma mass spectroscopy (ICP-MS) for dissolved products in LBE.

Task 4.3 focuses on the study of phase relations between Pb, Bi, U and O to obtain basic knowledge on the possible phases that are formed in the system. Pb-U-O, Bi-U-O, Pb-Pu-O and Bi-Pu-O systems will be investigated. Solid state synthesis, thermogravimetry and X-ray powder diffraction will be the main techniques used, but additional characterization techniques (e.g. MASNMR, Raman) will be employed when needed.

WP5: FUEL DISPERSION (CRS4, VKI, KIT, ENEA, UniPi)

In WP5 the dispersion of fuel under conditions relevant for a severe accident scenario involving fuel clad failure or core melt will be studied. The WP is divided into two tasks. A close contact with WP4 on fuel coolant interaction will be maintained.

Task 5.1 incorporates the study of fuel dispersion using computational fluid dynamics. As a first step two numerical CFD models of the MYRRHA primary coolant loop will be built. The first will be single phase with one-way coupling Lagrangian particles included for the simulation of long term events. The second model will be two-phase (Eulerian-Eulerian or VOF) for the simulation of short term events. The main shared feature between the two is the construction of a steady-state model including all the necessary physical modelling. This model will be frozen in the first application to concentrate on the particles Lagrangian dispersion. It will also serve as initial condition for the second application. The second step in this task is the application of the first CFD model to the simulation of the fuel dispersion in the coolant in case of long term small rate release. The modelling of the thermal effects and of the turbulence will be one of the challenges of the simulation. In parallel the second model will be used to simulate the fuel dispersion in the coolant in case of gas release due to one or several fuel pin failures. The gas is produced by nuclear reaction inside the fuel pin and normally trapped herein during normal operation. The impact of the gas release on the main flow will be taken into account.

Task5.2 will deal with the simulation of fuel dispersion using the SIMMER system code. The work will be organised in two phases. In the first phase the incidental and accidental conditions leading to fuel pin failure and successive release of fuel, fission gas and finally partial core melt will be assessed. Simultaneously the SIMMER-III reference model will be built. The efforts on this will be closely coordinated within the task to avoid duplication of work and optimise the model quality.

In the second phase a 2D SIMMER-III thermo-fluid-dynamic analysis of fuel dispersion and redistribution in the primary circuit of MYRRHA, starting from pre-defined fuel rod failure conditions will be performed. This work will include several parametric calculations but not include coupling to neutronic codes. The need and the possibility to extend the SIMMER-III analysis to hypothetical severe accident scenarios involving large core melting will also be investigated. Subsequently modelling will be extended to a 3D SIMMER-IV analyses.

In addition of the study mentioned above also SIMMER-III coupled neutronic/thermal-hydraulic calculations of fuel and clad redistribution after the postulated pin failures under Pb/Bi flow conditions will be done. This work will include firstly a simulation of fission gas release and impact of voiding on neutronic core conditions; secondly an assessment of release of fuel pellets, chunks, particles and the impact on fuel motion behaviour in Pb/Bi and neutronic feedback on core sub-criticality status and finally an analyses of granulated fuel and clad motion behaviour within the primary system.

WP6: RELEASE AND CAPTURE STUDIES OF RADIOISOTOPES (PSI, SCK•CEN, UGent)

WP6 will investigate the release and capture of radiotisotopes from the coolant in HLM cooled nuclear systems. This information is needed to assess and limit the possible release of radioisotopes from the coolant of the system into the environment. The work-package is divided into three tasks.

Task 6.1 involves a study of the release, gas phase transport and deposition of volatile radionuclides. The objective is to determine the key parameters that influence the volatilization of radionuclides and their deposition on various materials. In particular, the existence of volatile chemical species and their chemical nature will be studied to see how they can be formed and captured. Thermodynamic and kinetic parameters concerning the evaporation of volatiles from LBE will be determined. In subtask 6.1.1 the transport of Po, Hg and their lighter chemical homologues will be studied in a temperature gradient in a carrier gas under variation of gas atmospheres, flows, temperature gradients, time, column material and pre-treatment of the column material. The results will give information on the different gas phase species of the studied elements under various conditions, their chemical nature and thermodynamic properties. Subtask 6.1.2 is devoted to dynamic evaporation experiments studying the release of radionuclides, especially Po and Hg and their chemical homologues, from liquid LBE in various conditions. Data from the previous subtask will help to select the relevant conditions for the experiments. The results will yield fundamental thermodynamic and kinetic parameters such as the vapour pressure and volatisation rate for the evaporation processes.

Task 6.2 has the purpose to identify and evaluate adsorbents suitable for capturing gaseous Po and Hg and to study the evaporation of Po and Hg from LBE at low and elevated concentrations. The evaporation data are needed as second independent data set for licensing. Subtasks 6.2.1 includes Po and Hg adsoption experiments under various conditions (adsobate type, concentration, geometry, contaminants, carrier gas properties, velocity adsorbate

concentration. Breakthrough and pulse chromatography experiments will be carried out to determine the effective (dynamic) adsorption capacity and long-term stability of an adsorber system under conditions relevant to ADSs. Kinetic and equilibrium adsorption parameters will be derived by matching the experimental data with appropriate mathematical models. The selection of suitable adsorbent materials will be based both on experiences reported in the literature and on experimental results produced in Tasks 6.1.1, 6.3.2 and 6.3.4 of this work package. In subtask 6.2.2 evaporation experiments of volatile elements dissolved in LBE will be carried out using the transpiration method. Experiments at low concentrations will be performed to obtain additional, independently measured data sets for the most hazardous elements Po and Hg to support licensing of MYRRHA. Furthermore, a gradual increase up to concentrations expected in MYRRHA (0.1 appm) is envisaged to identify and characterize anomalous Po evaporation processes that may occur at elevated concentrations. Progress with the experiments at increasing Po concentration will depend on the licensing of glove box/hot cell test setup. The results of this task will be compared with those of Task 6.1.2 and Tasks 6.3.3-5 to obtain a consistent data set concerning the extremely important volatilization data.. In addition the data will be used to assess the release of Po in accident conditions including scenarios with confinement damage.

Task 6.3 will incorporate theoretical thermochemistry calculations of Po interacting with LBE and filter materials to predict fundamental properties describing the chemical interaction of these. The work is separated in five subtask. In subtask 6.3.1 the Po solubility in solid LBE will be calculated. In subtask 5.3.2 the heat of solution of Po in noble metals, and the heat of adsorption of Po on noble metal surfaces will be predicted. Subtask 6.3.3 will deal with the prediction of the existence of Po alloys in LBE. In subtask 6.3.4 the formation energies of several Po-containing molecules that are likely to enter the cover gas will be computed. These include monomeric Po, Po_2, PoH, PoH_2, PoOH, $Po(OH)_2$, PoBi, PoPb, PoHg,..Finally in subtask 6.3.5 the solubility of Po in liquid LBE will be assessed. The results of the calculations will be used to guide the experiments from tasks 6.1 and 6.2 by giving hint on which experimental parameter range and materials should be optimally covered. In addition the interpretation of the experimental data will be aided by the theoretical results.

WP7: EDUCATION AND TRAINING (VKI, SCK•CEN)

This work-package will implement and coordinate dissemination actions performed at partner level or project level to ensure a coherent approach. This will ensure that the project is correctly represented at several key events.
WP6 will promote and coordinate exchanges with research projects (EC and national such as CDT, LEADER, THINS). The presence of SEARCH partners in many of not all of these projects will facilitate this action. The dissemination of the gained knowledge and achievements will be carried out by compiling scientific and technical results for preparation of technical papers, publications in scientific journals and presentations at scientific conferences. Education and training programmes will be organized, through intensive educational and specialized training courses, with also practical work programmes in research or higher technological institute, and workshops on the technology, safety and fuel and coolant chemistry issues of LFR/ADS systems. For this WP6 will seek synergy with existing and future Euratom Fission Training Schemes such as for example ENEN III and CINCH. The ENEN network will be informed about all training activities organised within the framework of SEARCH.

Task 7.1 will define the detailed time-table and agenda for the workshops, practical work, lectures or training course to be organised, make a list of tentative teachers for each of the symposia/courses and of the research centres and higher institute for practical works, a list of suitable master thesis topics, identifying supervisors for these theses, to compile workshop evaluations and produce deliverables.

Task 7.2 will implement a workshop on LFR/ADS objectives and design. The purpose of this workshop is to define a general survey of LFR/ADS science and technology development. Tools, procedure and methodology for assessing the safety and design of the components of new heavy liquid metal cooled nuclear systems, with reference to the Lead-bismuth cooled accelerator driven system MYRRHA will be introduced and applied. Moreover practical work programmes in research or higher technological institute are foreseen jointly to the proposed learning programme.

Task 7.3 will serve to organise a workshop on fuel and coolant Chemistry In this workshop, the fundamental, modelling and simulating approaches of the phenomena involved in coolant chemistry control, fuel-coolant interaction and the resulting outcoming products will be dealt with. Also dispersion of these products in the coolant and release into the covergas for volatiles will be considered. The foreseen experimental tests to analyse such mechanisms and the existing numerical approaches will be discussed with the intent to provide students with the means to identify the key features of these phenomena and the available tools to their study. In addition the students will have also the opportunity to participate to practical sessions organized on dedicated lab facilities.

Task 7.4 will provide a training course on Fluid Mechanics in Nuclear Technology. This one week course will be organised within the format of VKI Lecture Series. The lecturers will be selected from the SEARCH partnership and also among world experts in the field of thermohydraulic aspects of LFRs. All the relevant physico-chemical and fluid mechanics aspects related to safety issues of LFR/ADS systems will be covered. The output of this lecture series will include a lecture note book with ISBN number.

B1.3.2 Timing of work packages and their components

WP	Task	Activity Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
1		Consortium management																																				
	1.1	Consortium management		D1.1	D1.5 D1.8 M1.1			D1.6 D1.7 M1.2												D1.2 M1.3						D1.3												D1.3 D1.4 M1.4
2		Coolability of wire spaced fuel bundle																																				
	2.1	Fuel assembly thermal-hydraulic tests						D2.1 D2.2 M2.1 M2.2						M2.5						D2.3 M2.7						D2.4 D2.5 M2.8						M2.10						D2.6 D2.7 M2.11
	2.2	Numerical fuel assembly thermal hydr. Analyses									M2.4																											D2.8 M2.14 M2.13
	2.3	Numerical support to design exp. On FA						M2.3									M2.6									D2.9 M2.9												D2.10 M2.14
3		Coolant chemistry control																																				
	3.1	Determination of source term												D3.1						D3.2																		
	3.2	Filtering techniques												M3.1																		M3.4						D3.3
	3.3	Control, mass transport and interaction of oxygen & impurities in LBE															M3.2			M3.3																		D3.4 D3.5
4		Fuel coolant interactions																																				
	4.1	Fuel preparation												M4.1 M4.2 M4.3																								
	4.2	LBE-fuel interaction experiments and analyses												M4.4																								D4.2 M4.6 M4.7 M4.8 M4.9
	4.3	Phase relations study																		D4.1 M4.5																		D4.3 M4.10
5		Fuel dispersion study																																				
	5.1	CFD simulation and modelling of fuel dispersion																		D5.2 D5.3 M5.3 M5.4																		D5.6 D5.7 M5.7 M5.8
	5.2	Simulation and modeling of fuel dispersion SIMMER-III												D5.1 M5.1 M5.2												D5.4 M5.5						D5.5 M5.6						D5.8 M5.9
6		Release and capture studies for radioisotopes																																				
	6.1	Release, gas phase transport and deposition of volatiles						M6.1						M6.4			D6.1																	M6.13				D6.3 M6.14
	6.2	Evaporation and capture of Po and Hg						M6.2												M6.6 M6.7						M6.9						M6.11 M6.12						D6.4 D6.5 M6.15 M6.16
	6.3	Thermochemistry from first principles						M6.3						M6.5										D6.2 M6.8						M6.10								
7		Education and training																																				
	7.1	Coordination and E&T/RTD organization												M7.1																								
	7.2	Workshop on LFR/ADS objectives and design																		D7.1 M7.2																		
	7.3	Workshop on Fuel and Coolant Chemistry																								D7.2 M7.3												
	7.4	Lecture Series on Fluid Mechanics in Nuclear technology																																				D7.3 M7.4

WP	Task	Activity	Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
2		Coolability of wire spaced fuel bundle																																					
	2.1	Fuel assembly thermal hydraulic tests																																					
	2.1.1	Design and instrumentation of ENEA 6.5 mm Rod bundle							D2.1 M2.1																														
	2.1.2	Design and instrumentation of KIT 6.2 mm Rod bundle							D2.2 M2.2																														
	2.1.3	Fabrication of KIT Rod bundle experiment													M2.5																								
	2.1.4	Experimental tests in THEADES																									D2.4												
	2.1.5	System comp. Procurement and facility upgrade on NACIE																			D2.3 M2.7																		
	2.1.6	Experimental results for free circulation experiments in NACIE																									D2.5 M2.8												
	2.1.7	Helena upgrade and comp procurement																															M2.10						
	2.1.8	Results from Helena experiments and post-test analyses																																					D2.6 D2.7 M2.11
	2.2	Numerical fuel assembly thermal hydr. Analyses																																					D2.8
	2.2.1	Provision to detailed pre-test CFD analyses for NACIE										M2.4																											
	2.2.2	Provision of post-test CFD analyses																																					
	2.2.3	Provision of post-test CFD analyses																																					M2.12
	2.2.4	Assessment of a 127 pin MYRRHA FA																																					M2.13
	2.3	Numerical support to design exp. on ...																									D2.9												D2.10
	2.3.1	Flow conditioner design simulations							M2.3																														
	2.3.2	Pre-test analyses of KALLA experiments															M2.6																						
	2.3.3	Pre-test analyses of NACIE experiments																									M2.9												
	2.3.4	Post-test analyses																																					M2.14

WP	Task	Activity	Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
3		Coolant chemistry control																																					
	3.1	Determination of source term													D3.1						D3.2																		
	3.2	Filtering techniques													M3.1																		M3.4						D3.3
	3.3	Control, mass transport and interaction of oxygen, metallic and non-metallic																M3.2			M3.3																		D3.4 D3.5

WP	Task	Activity	Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
4		Fuel coolant interactions																																					
	4.1	Fuel preparation																																					
	4.1.1	Manufacturing of homogeneous MOX													M4.1																								
	4.1.2	Manufacturing of heterogeneous MOX													M4.2																								
	4.1.3	Shipment of BN MOX													M4.3																								
	4.2	LBE-fuel interaction experiments and analyses																																					D4.2
	4.2.1	LBE experimental set-up													M4.4																								
	4.2.2	LBE-homogeneous MOX																																					M4.6
	4.2.3	LBE-heterogeneous MOX																																					M4.7
	4.2.4	LBE-BN MOX																																					M4.8
	4.2.5	LBE-UO_2/PuO_2																																					M4.9
	4.3	Phase relations study																																					D4.3
	4.3.1	Study of Pb-U-O and Bi-U-O phase relations																			D4.1 M4.5																		
	4.3.2	Study of Pb-Pu-O and Bi-Pu-O phase relations																																					M4.10

WP	Task	Activity	Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
5		Fuel dispersion study																																					
	5.1	CFD simulation and modelling of fuel																																					
	5.1.1	Single phase steady state CFD model																			D5.2 M5.3																		
	5.1.2	Two-phase transient CFD model																			D5.3 M5.4																		
	5.1.3	Long term fuel dispersion CFD characterisation																																					D5.6 M5.7
	5.1.4	Short term fuel dispersion CFD characterisation																																					D5.7 M5.8
	5.2	Simulation and modelling of fuel																																					
	5.2.1	Operability of the SIMMER models													D5.1 M5.1																								
	5.2.2	Establishment of relevant parameters for simulation													M5.2																								
	5.2.3	Completion of the SIMMER-IV analysis																									D5.4 M5.5												
	5.2.4	Accident simulation analyses and documentation																															D5.5 M5.6						
	5.2.5	SIMMER-III parametric analysis																																					D5.8 M5.9

WP	Task	Activity / Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
6		Release and capture studies for																																				
	6.1	Release, gas phase transport and																																				
	6.1.1	Set-up of equipment						MS 1																														
	6.1.2	Screening experiments												MS 4			D6.1																					
	6.1.3	Detailed thermochromography																																MS 13				
	6.1.4	Final analyses and reporting																																				D6.3 MS 14
	6.2	Evaporation and capture of Po and																																				
	6.2.1	Completion of the experimental set-						MS 2																														
	6.2.2	Dynamic evaporation studies of Hg																		MS 6																		
	6.2.3	Capture studies of Hg																														MS 11						
	6.2.4	Construction and licensing of glove																		MS 7																		
	5.2.5	Dynamic evaporation studies of Po																								MS 9												
	6.2.6	Dynamic evaporation studies of Po from LBE at increased																																				D6.4 MS 16
	6.2.7	Capture studies of Po at low concentrations																														MS 12						
	6.2.8	Capture studies of Po at increased concentrations																																				D6.5 MS 15
	6.3	Thermochemistry from first principles																																				
	6.3.1	Po solubility in solid LBE						MS 3																														
	6.3.2	Search most promising filter												MS 5																								
	6.3.3	Predict existence of ternary alloys																						D6.2 MS 8														
	6.3.4	Po molecules in the gas phase																												MS 10								
	6.3.5	Po solubility in liquid LBE																																				D6.6 MS 17

B1.3.3 Work package list

Work package No[1]	Work package title	Type of activity[2]	Lead participant No[3]	Person-months[4]	Start month[5]	End month
1	Consortium management	MGT	1 (SCK-CEN)	6.38	1	36
2	Coolabiltiy of a wire spaced fuel bundle	RTD	2 (ENEA)	51.25	1	36
3	Coolant Chemistry control	RTD	3 (KIT)	105.2	1	36
4	Fuel Coolant Interactions	RTD	12 (CHALMERS)	47.1	1	36
5	Fuel Dispersion Study	RTD	5 (CRS4)	55.65	1	36
6	Release and Capture Studies for Radioisotopes	RTD	11 (PSI)	136.2	1	36
7	Education and Training	Other	8 (VKI)	5.58	1	36
	TOTAL			407.36		

1 Workpackage number: WP 1 – WP n.
2 Please indicate one activity per work package:
RTD = Research and technological development (Collaborative Projects and Networks of Excellence only, includes coordination of research); DEM = Demonstration (Collaborative Projects only); MGT = Management of the consortium; COORD = Coordination activities (CSA-CA only); SUPP = Support activities (CSA-SA only); OTHER = Other specific activities (including training), if applicable, including any activities to prepare for the dissemination and/or exploitation of project results.
3 Number of the participant leading the work in this work package.
4 The total number of person-months allocated to each work package.
5 Measured in months from the project start date (T_0 = month 1).

B1.3.4 Deliverables list

Del. no.[6]	Deliverable name	WP n°.	Nature[7]	Dissemination level[8]	Delivery date[9]
D1.1	Project quality plan including measures of success	WP1	R	Pu	M2
D1.2	Minutes of the first RP general meetings (GOV+TEC+general management meetings) complemented with indications from the ETAC	WP1	R	Pu	M18
D1.3	Minutes of the second RP general meetings (GOV + TEC + general management meetings) complemented with indications from the ETAC	WP1	R	Pu	M36
D1.4	Report on the access to the website and information collected (newsletter, indications from ETAC)	WP1	R	Pu	M36
D1.5	Public and private website	WP1	O	Pu	M3
D1.6	Consortium agreement	WP1	O	Co	M6
D1.7	Communication and dissemination plan	WP1	R	Pu	M6
D1.8	Project presentation	WP1	R	Pu	M3
D2.1	The fuel rod bundle design for the NACIE facility	WP2	R	Pu	M06
D2.2	8.2 mm rod bundle design and instrumentation report	WP2	R	Pu	M06
D2.3	NACIE: a test facility for free and mixed convection heat transfer measurements in liquid metals for the MYRRHA reactor	WP2	R	Pu	M18
D2.4	Experimental results on free convection in heavy liquid metals using the NACIE facility	WP2	R	Pu	M24
D2.5	8.2 mm rod bundle experiments report	WP2	R	Pu	M24
D2.6	Experimental results on forced convection in heavy liquid metals using the HELENA facility	WP2	R	Pu	M36
D2.7	Post-test analysis on free and forced	WP2	R	Pu	M36

[6] Deliverable numbers in order of delivery dates. Please use the numbering convention <WP number>.<number of deliverable within that WP>. For example, deliverable 4.2 would be the second deliverable from work package 4.

[7] Please indicate the nature of the deliverable using one of the following codes:
R = Report, P = Prototype, D = Demonstrator, O = Other

[8] Please indicate the dissemination level using one of the following codes:
PU = Public
PP = Restricted to other programme participants (including the Commission Services).
RE = Restricted to a group specified by the consortium (including the Commission Services).
CO = Confidential, only for members of the consortium (including the Commission Services).

[9] Measured in months from the project start date (T_0 = month 1).

	convection measurements in HLM using NACIE and HELENA facilities				
D2.8	Report on pre- and post-test analyses of the NACIE and THEADES experimental loops and assessment of the 127 pin MYRRHA FA	WP2	R	Pu	M36
D2.9	Report on pre-test analysis	WP2	R	Pu	M24
D2.10	Report on post-test analysis	WP2	R	Pu	M36
D3.1	Report on formation of spallation products and neutron activation products in a MYRRHA type reactor	WP3	R	Pu	M12
D3.2	Report on expected corrosion products in a MYRRHA type reactor	WP3	R	Pu	M18
D3.3	Final report on the filter lifetime and efficiency	WP3	R	Pu	M36
D3.4	Final Report on oxygen control systems for HLM large pool system	WP3	R	Pu	M36
D3.5	Final Report on oxygen adsorption, entrainment of oxides and mass transport	WP3	R	Pu	M36
D4.1	Study of Pb-U-O and Bi-U-O phase relations	WP4	R	Pu	M18
D4.2	Analysis of LBE-fuel interaction : homogeneous MOX, heterogeneous MOX, BN MOX and UO_2/PuO_2	WP4	R	Pu	M36
D4.3	Study of Pb-Pu-O and Bi-Pu-O phase relations	WP4	R	Pu	M36
D5.1	Report on the operability of the SIMMER-III and SIMMER-IV models for the MIRRHA-FASTEF reactor	WP5	R	Pu	M12
D5.2	Single phase steady state CFD model of the MYRRHA-FASTEF primary coolant loop including all relevant thermal aspects	WP5	R	Pu	M18
D5.3	Two-phase CFD model of the MYRRHA-FASTEF primary coolant loop including all relevant thermal aspects	WP5	R	Pu	M18
D5.4	Report on the 3D SIMMER-IV analysis for the more representative fuel failure conditions	WP5	R	Pu	M24
D5.5	Report on assessment on fuel dispersion after pin failure under blockage conditions	WP5	R	Pu	M30
D5.6	Characterisation of long term dispersion of fuel in the coolant with CFD modelling	WP5	R	Pu	M36
D5.7	Characterisation of the fission gas and other species release dispersion in the coolant with CFD modelling	WP5	R	Pu	M36
D5.8	Report on the 2D SIMMER-III analysis for the reference case and parametric study	WP5	R	Pu	M36

D6.1	Report on results of screening experiments	WP6	R	Pu	M15
D6.2	Report on tasks 5.3.1, 5.3.2 and 5.3.3	WP6	R	Pu	M22
D6.3	Final report on volatilization and deposition studies	WP6	R	Pu	M36
D6.4	Final report on the evaporation, release and capture of Po	WP6	R	Pu	M36
D6.5	Final report on the evaporation and capture of Hg	WP6	R	Pu	M36
D6.6	Report on tasks 5.3.4 and 5.3.5	WP6	R	Pu	M36
D7.1	1st Workshop lectures book	WP7	R	Pu	M18
D7.2	2nd Workshop lectures book	WP7	R	Pu	M24
D7.3	Training Course lectures book	WP7	R	Pu	M36

B1.3.5 List of milestones

Milestone number	Milestone name	Work packages number	Lead beneficiary number	Delivery date from Annex I
M1.1	Realization of the website	WP1	1	M03
M1.2	Set up of the External Technical Advisory Committee	WP1	1	M06
M1.3	Submission to the EC of the first RP report	WP1	1	M18
M1.4	Submission to the EC of the final report	WP1	1	M36
M2.1	Design and instrumentation of ENEA 6.5 mm Rod Bundle	WP2	2	M06
M2.2	Design and instrumentation of KIT 8.2 mm Rod Bundle	WP2	3	M06
M2.3	Flow conditioner design simulations	WP2	3	M06
M2.4	Provision of detailed pre-test CFD analyses for NACIE	WP2	2	M09
M2.5	Fabrication of KIT Rod Bundle Experiment	WP2	3	M12
M2.6	Pre-test analysis of KALLA-experiments	WP2	3	M15
M2.7	System components procurement and facility upgrade on NACIE	WP2	2	M18
M2.8	Experimental results for free circulation tests in NACIE	WP2	2	M24
M2.9	Pre-test analysis of NACIE-experiments	WP2	2	M24
M2.10	HELENA upgrade, main system and components procurement	WP2	2	M30
M2.11	Results of HELENA experiments and post-test analysis	WP2	2	M36
M2.12	Provision of post-test CFD analyses for NACIE	WP2	2	M36
M2.13	Assessment of a 127 pin MYRRHA FA	WP2	4	M36
M2.14	Post-test analysis	WP2	3	M36
M3.1	Commissioning of the delta T loop	WP3	1	M12
M3.2	Experimental device for mass-transfer studies in molten LBE available	WP3	3	M15
M3.3	OCS implementation in HLM pool facility	WP3	2	M18

Milestone number	Milestone name	Work packages number	Lead beneficiary number	Delivery date from Annex I
M3.4	Commissioning of the pool type filter	WP3	2	M30
M4.1	Manufacturing of homogeneous MOX	WP4	10	M12
M4.2	Manufacturing of heterogeneous MOX	WP4	10	M12
M4.3	Shipment of BN MOX	WP4	12	M12
M4.4	LBE experimental set-up	WP4	10	M12
M4.5	Study of Pb-U-O and Bi-U-O phase relations	WP4	10	M18
M4.6	LBE - homogeneous MOX interaction & analyses	WP4	10	M36
M4.7	LBE - heterogeneous MOX interaction & analyses	WP4	10	M36
M4.8	LBE - BN MOX interaction & analyses	WP4	12	M36
M4.9	LBE – UO_2/PuO_2 interaction & analyses	WP4	12	M36
M4.10	Study of Pb-Pu-O and Bi-Pu-O phase relations	WP4	10	M36
M5.1	Operability of the SIMMER models	WP5	7	M12
M5.2	Establishment of relevant parameters for simulation	WP5	3	M12
M5.3	Single phase steady state CFD model	WP5	8	M18
M5.4	Two-phase transient CFD model	WP5	5	M18
M5.5	Completion of the SIMMER-IV analysis	WP5	2	M24
M5.6	Accident simulation analyses and documentation	WP5	3	M30
M4.7	Long term fuel dispersion CFD characterisation	WP5	8	M36
M5.8	Short term fuel dispersion CFD characterisation	WP5	5	M36
M5.9	SIMMER-III parametric analysis	WP5	2	M36
M6.1	Setup of equipment	WP6	11	M6
M6.2	Completion of the experimental set-up for Hg evaporation	WP6	1	M6
M6.3	Solubility of Po in solid LBE	WP6	6	M6
M6.4	Screening experiments	WP6	11	M12
M6.5	Search for most promising filter materials	WP6	6	M12

M6.6	Dynamic evaporation studies of Hg from LBE	WP6	1	M18
M6.7	Construction and licensing of glove box set-up in controlled zone	WP6	1	M18
M6.8	Predict the existence of Po-alloys	WP6	6	M22
M6.9	Dynamic evaporation studies of Po from LBE at low concentrations	WP6	1	M25
M6.10	Po molecules in the gas phase	WP6	6	M28
M6.11	Capture studies of Hg	WP6	1	M30
M6.12	Capture studies of Po at low concentrations	WP6	1	M30
M6.13	Detailed thermochromatography and evaporation experiments	WP6	11	M32
M6.14	Final analysis and reporting	WP6	11	M36
M6.15	Dynamic evaporation studies of Po from LBE higher concentrations	WP6	1	M36
M6.16	Capture studies of Po at increased concentrations	WP6	1	M36
M6.17	Po solubility in liquid LBE	WP6	6	M36
M7.1	Organization of the workshops	WP7	8	M12
M7.2	Workshop on LFR/ADS objectives and design	WP7	8	M18
M7.3	Workshop on Fuel and Coolant Chemistry	WP7	8	M24
M7.4	Training course on Fluid Mechanics in Nuclear Technology	WP7	8	M36

B1.3.6 Work package descriptions

Work package number	1	Start date or starting event:	Month 1
Work package title	Consortium Management		
Activity Type	MGT		
Participant number	1		
Participant short name	SCK•CEN		
Person-months per participant:	6.375		

Objectives

This WP is aimed at the general coordination of the consortium (i.e., management of legal, financial and administrative aspects) and at guaranteeing the coherence between the different work packages in order to respect the project's objectives, its overall internal coherence, time schedule, issuance of deliverables, periodic reporting to the European Commission.
Moreover, WP1 is devoted to improve the diffusion of knowledge and information utilizing the gained information on HLM technologies and on the reliability and performance components. A proper website will be implemented acting as central point of information for the partners and the overall scientific community on topics addresses in the frame of the project, highlighting the latest news.

Description of work

WP1 is dedicated to the general management of the project, and in particular it will provide:

- general coordination of the consortium and maintenance of the consortium agreement;
- administration of project resources;
- elaboration and monitoring of project procedures including the performance indicators, the definition of the project's internal organisation, procedures, document models, etc., in detail in order also to address and solve potential conflicts among the project partners efficiently;
- preparation of the consortium agreement;
- follow-up of project planning, deliverables and milestones;
- ensuring that all partners share the same level of information on general issues concerning the project, i.e. contract and project management, work progress, communication, etc.;
- elaboration of the periodic management & activity reports to the European Commission;
- preparation, organisation and minutes of project management meetings (progress meetings, governing board meetings and technical coordination board meetings);
- follow-up of decisions and action plans;
- preparation of the project presentation.

SCK•CEN will act as project coordinator (PCO).
The coordinator is responsible for the day-to-day administration of the project to guarantee its smooth functioning. It ensures the organization and secretariat of the general meetings, of the Technical Coordination Board (TEC) meetings and of the Governing Board (GOV) meetings. Moreover it helps in the internal diffusion of information and keeps a register of all the reports produced in the project. Together with WP7 a communication and dissemination plan will be prepared.

In the frame of WP1 the support of the External Technical Advisory Committee (ETAC) will be guaranteed and the links with the other project work packages facilitated.

Finally the PCO will provide to define a website dedicated to the main results carried out in the frame of the HLM technologies as well as the results gained in term of reliability and performance of nuclear components will be 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 is 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.

The website will be structured, therefore, in three specific areas:

1) A technical area dedicated to the main topics related with the HLM technologies (thermal hydraulics, 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 of the ESNII roadmap.
2) 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 workshop and training course 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.
3) A "news and events" area: a space dedicated to the main international events (conferences, workshops, and training schools) will be prepared and maintained updated, to act as a common information point for the researcher a public at large, interested in the main events in which the "HLM community" is involved. In this area the main news related to the development of LFR/ADS systems and to the HLM technologies will find place.
4)

Deliverables

D1.1: Project quality plan including measures of success (SCK•CEN) (M2)
D1.2: Minutes of the first Reporting Period general meetings (GOV+TEC+general management meetings) complemented with indications from the ETAC (SCK•CEN) (M18)
D1.3: Minutes of the second Reporting Period general meetings (GOV+TEC+general management meetings) complemented with indications from the ETAC (SCK•CEN) (M36).
D1.4: Report on the access to the website and information collected (newsletter, indications from ETAC) (SCK•CEN) (M36)
D1.5: Set-up of a public and private website (M3)
D1.6: Consortium agreement (M6)
D1.7: Communication and dissemination plan (M6)
D1.8: Project presentation (M3)

Work package number	2	Start date or starting event:	Month 1
Work package title	Coolability of a wire spaced fuel bundle		
Activity Type	RTD		

Participant number	2	3	4
Participant short name	ENEA	KIT	NRG
Person-months per participant:	11.25	34	. 6

Objectives

In this work package the goal is the investigation of the coolability of a wire spaced fuel assembly by the experimental analysis and numerical modelling of thermal-hydraulic behaviour of a wire wrapped rod bundle simulator. In order to meet the requirements of MYRRHA two different sized prototypical rod bundles will be investigated in a heavy liquid metal flow using LBE (lead bismuth eutectic) in the regime of forced, mixed and natural convection with a maximal attainable heat flux of 1 MW/m^2 by electrical heating.
Measured pressure drop and temperature profiles will give important input for the MYRRHA design. Nevertheless, for a deeper understanding numerical support and CFD-modelling to support the experiments is indispensable.

Description of work *(ENEA, KIT, NRG)*

Task 2.1 Fuel assembly thermal-hydraulic tests (ENEA, KIT)

This task will be devoted to the experimental campaign on THEADES (KIT), NACIE (ENEA) and HELENA (ENEA) HLM loops. The experiment in the THEADES loop will study forced convection and it will be performed on a 19 pin wire wrapped rod bundle with a diameter of 8.2 mm, pitch to diameter (p/d) ratio of 1.28 and a heat flux up to 1 MW/m^2. Results will be in terms of temperature measurements in the pin cladding, bulk temperatures in the subchannels, pressure drop measurements and overall temperature drop.
Information from THEADES experiment will give the base for the subsequent experiment on free and mixed convection on the NACIE loop (ENEA). A wire-spaced 19 pins hexagonal fuel bundle will be assembled in a hexagonal lattice, with pin diameter 6.55 mm, active length of 600 mm, p/d ratio of 1.28. The pins provide an azimuthally uniform heat flux up to 1 MW/m^2. These values are relevant for the MYRRHA design. Free and mixed convection tests will be performed on the NACIE loop. The transient tests will simulate the transition from forced to free convection as a consequence of a loss of flow accident, and therefore the initial condition will result from the THEADES experimental tests. The following quantities will be measured during the transient: the cladding temperature through wall-embedded TCs; the integral mass flow rate through a proper flow meter; pressure losses in the FA; bulk temperature in the sub-channels; heat transfer coefficient.
The reason for using 8.2 mm pins in THEADES and 6.5 mm pins in NACIE lies in the short term availability of 8.2 mm rods from former experiments. In this way the whole campaign will save a lot of time and money without compromising on physical relevance, as the results of forced convection experiments can be transferred to the final MYRRHA-design using thermal hydraulic similarity laws and simulation tools validated using the 8.2 mm pin experimental results.
As Long Term step, the NACIE bundle will be dismantled and mounted in the horizontal HELENA loop, working with lead. The forced convection experiment above described for THEADES will be repeated on the new bundle and the coherence of the scaling laws used as Initial Conditions in the NACIE tests will be verified in HELENA. A post-test analysis will be

accomplished on the whole experimental campaign.

Task 2.2 Numerical fuel assembly thermal-hydraulic analyses (NRG)

This task will provide detailed CFD analyses using appropriate turbulence modelling in support of the experiments. From these detailed analyses, input parameters will be derived for a coarse grid model of the NACIE facility to perform parameter studies at KIT. Detailed post-test CFD analyses on a section of the experimental FAs will be performed for the THEADES and NACIE experiments. These detailed analyses will provide input for LRGR and coarse grid analyses of the complete experimental FA to be performed by NRG and KIT. These analyses will support the interpretation of the experimental results, as limited measurement data will be available due to the complex experimental environment (LBE). The validated approaches used in support of the experiments will be applied to the real 127 pin MYRRHA FA. Firstly, a detailed CFD analysis of a section of a FA will be performed. This will provide input for LRGR and coarse grid analysis of a complete MYRRHA FA or even the complete MYRRHA core. These analyses will serve to deduct heat transfer correlations to be used in less resolved numerical approaches.

Task 2.3 Numerical support to design and experiments on wire-wrap fuel assembly (KIT)

This task will be devoted to pre-test parametric and post-test numerical simulations on the rod bundle flow. Pre-test numerical simulations provide the input for the selection of parameters like axial pitch and help to choose an experimental test-program including sensor locations, error estimation and optimization of flow conditioners. Detailed interpretation of experimental data is performed based on post-test simulations. Simulations are performed with the coarse grid CFD technique with sub-grid data derived from representative simulations with fully resolved CFD (provided for NACIE-experiments by NRG and for KALLA experiments by KIT).

Deliverables

D2.1: The fuel rod bundle design for the NACIE facility (ENEA)
D2.2: 8.2 mm rod bundle design and instrumentation report (KIT)
D2.3: NACIE: a test facility for free and mixed convection heat transfer measurements in liquid metals for the MYRRHA reactor (ENEA)
D2.4: Experimental results on free convection in heavy liquid metals using the NACIE facility (ENEA)
D2.5: 8.2 mm rod bundle experiments report (KIT)
D2.6: Experimental results on forced convection in heavy liquid metals using the HELENA facility (ENEA)
D2.7: Post-test analysis on free and forced convection measurements in HLM using NACIE and HELENA facilities (ENEA)
D2.8: Report on pre- and post-test analyses of the NACIE and THEADES experimental loops and assessment of the 127 pin MYRRHA FA (NRG)
D2.9: Report on pre-test analysis (KIT)
D2.10: Report on post-test analysis (KIT)

Work package number	3	Start date or starting event			Month 1
Work package title	Coolant Chemistry Control				
Activity Type[10]	RTD				
Participant number	1	2	3	9	
Participant short name	SCK•CEN	ENEA	KIT	INR	
Person-months per participant:	37	12	46	10.2	

Objectives

The main objectives of this work package are related to the control of the coolant chemistry and associated with that the filtering and mass transport of impurities. The objectives are summarised as follows:

- Determination and assessment of corrosion products to be expected in MYRRHA under operation
- Determination and assessment of spallation products and neutron activation products to be expected in MYRRHA under operation
- Determination of loop filter efficiency, lifetime and pressure drop for several filter types
- Determination of feasibility and efficiency of LBE pool type filter
- Validating an Oxygen Control System (OCS) based on solid oxide particles inside a pool type facility and measurement of PbO formation and dissolution kinetics in LBE
- Absorption of oxygen from the cover gas under regular operating conditions and accidental ingress of oxygen into the cover gas
- Entrainment of oxides floating on the liquid-metal surface
- Oxygen absorption from water vapour introduced below the liquid-metal surface (HEX leak)
- Mass-transport of dissolved metals, especially nickel

Description of Work (*SCK•CEN, ENEA, KIT, INR*)

Task 3.1: Determination of Source Terms (KIT,SCK•CEN)

It is important for normal operating conditions to estimate the amount of oxidation and corrosion products that are formed. This information is needed to design and in a later stage operate the required LBE impurity control units. Oxygen control, impurity control and the cover gas handling are important issues in this field. In addition information about spallation products and neutron activation products in the LBE under operation are required, because they will interfere with the non-active impurity control handling. At KIT the expected formation of corrosion products on materials and components of a MYRRHA reactor under operation conditions will be determined and assessed. At SCK•CEN the formation of spallation products and neutron activation products of a MYRRHA reactor under operation will be evaluated and assessed using MCNPX calculations.

Task 3.2: Filtering Techniques (SCK•CEN, ENEA, INR)

Metallic and non-metallic impurities (oxides) are observed in loops and pool facilities after operation. Such impurities can aggregate and result in blockage of systems. Therefore cleaning

[10] Please indicate one activity per work package:
RTD = Research and technological development (including any activities to prepare for the dissemination and/or exploitation of project results, and coordination activities – only possible for Collaborative projects and Networks of Excellence); DEM = Demonstration (only possible for Collaborative projects); MGT = Management of the consortium; COORD = Coordination activities (for Coordination Actions); SUPP = Support activities (for Support Actions); OTHER = Other specific activities (including training), if applicable.

and filtering devices are required for operation of LBE cooled systems. In loops some filter-systems were tested in the past but no final judgement could be given so far. In pool type systems different approaches not investigated in detail up to now have to be developed.

At SCK•CEN a loop type filter will be placed in a small delta T loop equipped with sacrificial rods to measure the pressure loss as a function of material loss from these sacrificial rods. Secondly, an overflow pool type filter will be developed and placed in an LBE pool to examine the applicability and efficiency of such filter to trap oxide particles from the LBE surface.

ENEA will adapt and test loop type filters based on adsorption techniques to an LBE pool environment and tested. Furthermore a detailed investigation to understand the formation of solid impurities accompanied by quantitative qualification of filtering performance will be done.

INR is a new partner in the field of heavy liquid metal technology. Their contribution will encompass the exchange of know-how and the acquirement of hands on experience by performing filter tests in the small delta T loop at SCK•CEN.

Task 3.3: Control, Mass Transport and Interaction of Oxygen, Metallic and Non-Metallic Impurities with LBE (SCK•CEN, ENEA, KIT)

Several open questions for LBE impurity control including oxygen will be addressed in this task. The use of oxygen control systems based on solid PbO oxides will be addressed from an engineering and physic-chemical point of view. Mass exchange, entrainment of solid particles (oxides), interaction, adsorption and deposition of impurities will be experimentally and theoretically investigated. Tests of oxygen sensors to be operated in a pool facility are foreseen.

At KIT vessel-type experimental device containing ~200 kg molten LBE will be developed and used for investigating mass transport and interaction phenomena. The design will be supported by CFD calculations to optimize the design and the position of oxygen sensors and cooled probes for deposition of dissolved metals. Quantitative (local oxygen activity, dissolution of metals) and qualitative (dispersion of dissolved metals) measurements of mass-transfer and transport will be done to form the basis for integrating these phenomena in the CFD code. Ultrasonic measurements of the liquid metal flow during the experiments are used for verifying these calculations. Finally a model for the absorption of oxygen from the cover gas and vapour bubbles will be developed.

A compact experiment to determine the solubility limit and the formation and dissolution kinetics of PbO in LBE will be constructed at SCK•CEN. The set-up will comprise of 2 ceramic lined pots connected by a quartz or ceramic coated transfer tube. Both pots have independent temperature and cover gas control. The PbO solubility limit and its formation and dissolution kinetics in LBE, assuming that the liquid metal transfer is not the rate limiting step, will be measured. The temperature and oxygen concentrations while be varied systematically in the closed system at high temperature.

Different oxygen control methods for a pool type facility will be investigated at ENEA. A gas/liquid systems and a solid/liquid systems (based on solid PbO) will be designed, implemented and tested in the CIRCE facility The reliability of Oxygen Sensor technology in a pool test facility (CIRCE) will be tested.

Deliverables

D3.1: Report on formation of spallation products and neutron activation products in a MYRRHA type reactor (SCK•CEN) (M12)
D3.2: Report on expected corrosion products in a MYRRHA type reactor (KIT) (M18)

D3.3: Final report on the filter lifetime and efficiency (SCK•CEN) (M36)
D3.4: Final Report on oxygen control systems for HLM large pool system (ENEA) (M36)
D3.5: Final Report on oxygen adsorption, entrainment of oxides and mass transport (KIT) (M36)

Technical Documents

T3.1: Design of an oxygen control system and filtering devices for HLM pool systems ENEA (M12)

Work package number:	4	**Start date or starting event**		Month 1
Work Package title	Fuel Coolant Interactions			
Activity Type[1]	RTD			
Participant number	10	12		
Participant short name	JRC-ITU	CHALMERS		
Person-months per participant:	33.5	13.6		

Objectives

In this work package, the goal is to study the LBE-fuel interaction and characterize the reaction products and their potential effect on the fuel element in order to qualify the fuel for MYRRHA. In addition, a more fundamental approach is taken to understand the phase relations Pb-U-O, Bi-U-O, Pb-Pu-O and Bi-Pu-O for which there is no published available data.

The MOX fuel used in the experiments will be as close as possible to the MYRRHA specifications. In particular, the Pu fraction is set to 30% if possible, the O/M ratio representative of fresh fuel is set to 1.97 and the O/M ratio representative of irradiated fuel surface is set to 2.00.

Experiments will be done on solid pellets (or disks) to study the effect of LBE-fuel interaction on the surface. Additional experiments will be done with powders which have much higher specific surface area and show a different behaviour that the pellet (e.g. dissolution)
A temperatures range 500-800°C is chosen as representative of the fuel surface temperature in nominal operation condition. Experiment will be carried out at the limiting temperature 500°C and 800°C and possible at an intermediate temperature.
The oxygen concentration in LBE is set at $[O]=1.10^{-6}$ wt.% in accordance with MYRRHA operating condition.

Additionally, two MOX manufacturing route will be investigated. One based on wet chemistry (sol-gel technique) that produces a very homogeneous solid solution of $(U, Pu)O_2$ and one based on a dry fabrication route that consists in mixing powder of UO_2 and PuO_2 followed by ball milling and sintering. The latter produces a heterogeneous microstructure with Pu or U-rich agglomerates. The reason behind using two different preparation routes is to study the effect of the microstructure homogeneity on the interaction with LBE.

Complementary experiments on UO_2/PuO_2 pellets/powder will also be done.

Another objective of the work package is to acquire knowledge on phase relation between the different species involved in order to extent the current knowledge the phase diagrams. This work will be supported by dedicated experiments. A CALPHAD modelling of the phase diagrams is also foreseen but outside of this project.

[1] Please indicate one activity per work package:
RTD = Research and technological development (including any activities to prepare for the dissemination and/or exploitation of project results, and coordination activities – only possible for Collaborative projects and Networks of Excellence); DEM = Demonstration (only possible for Collaborative projects); MGT = Management of the consortium; COORD = Coordination activities (for Coordination Actions); SUPP = Support activities (for Support Actions); OTHER = Other specific activities (including training), if applicable.

Description of work *(JRC-ITU, CHALMERS)*

Work package 3 is divided in 3 tasks.

T3.1: Fuel preparation (JRC-ITU, CHALMERS)

The objective of this task is to obtain the right materials and experimental conditions to study the LBE-fuel interactions. The manufacturing of MOX is a complex operation that can strongly influence the fuel behaviour under irradiation and also possibly, its interaction with LBE. In order to take into account the variations in microstructure in the LBE-fuel experiments, three different kind of MOX pellets/powder will be investigated. A homogeneous MOX will be prepared via the 'sol-gel' method, a heterogeneous MOX will be prepared via the powder route and a commercial MOX pellet (also heterogeneous) prepared for fast reactor by Belgonucléaire (BN) will also be studied. Existing pellets/powder of UO_2 and PuO_2 will also be used for additional experiments with LBE. The experimental set-up to control the oxygen potential and temperature in LBE is also described.

T3.1.1: Manufacturing of homogeneous MOX

This manufacturing route is based on wet-chemistry 'sol-gel' method. The constituent elements are dissolved in a nitric acid solution and mixed in the appropriate ratios. Then, a polymer is added to increase the viscosity and the mixture is dispersed using a rotating cup atomiser. The resulting droplets are collected in an ammonia bath where a droplet-to-particle conversion occurred via a gel supported precipitation. After ageing, the beads are washed with water, calcined, compacted into pellets and finally sintered. The 'sol-gel' technique give a very homogeneous solid solution of $(U, Pu)O_2$.

The obtained product is $(U_{0.7}Pu_{0.3})O_{2.00}$. To obtain a lower O/M ratio, it is necessary to do a heat treat the MOX in a reducing atmosphere. Part of the original $(U_{0.7}Pu_{0.3})O_{2.00}$ is therefore reduced to obtain $(U_{0.7}Pu_{0.3})O_{1.97}$.

T3.1.2: Manufacturing of heterogeneous MOX

This manufacturing route is based on direct blending of PuO_2 and UO_2 powders, combined with ball milling. It is followed by forced sieving to decrease the agglomerate size, pressing and sintering. Alternatively, UO_2 and PuO_2 could be sieved independently before blending. An intimate mixing of U and Pu on the (sub-) micron scale is obtained. However, compared to the homogeneous MOX, heterogeneous MOX still have Pu or U-rich agglomerates.

Many variants of this direct blending process have been developed and implemented on an industrial scale. It represents today the main production route for commercial fuel MOX pellets.

The obtained product is $(U_{0.7}Pu_{0.3})O_{2.00}$. To obtain a lower O/M ratio, it is necessary to heat treat the MOX in a reducing atmosphere. Part of the original $(U_{0.7}Pu_{0.3})O_{2.00}$ is therefore reduced to obtain $(U_{0.7}Pu_{0.3})O_{1.97}$.

T3.1.3: Shipping of BN MOX

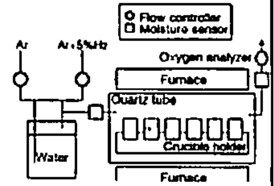
A commercial MOX pellet (or pellet slice) prepared for fast reactors at Belgonucléaire (BN) with a Pu fraction of at least 20% and O/M ratio of 2.00 will be shipped from SCK•CEN to Chalmers University to study its interactions with LBE. A slice of the pellet will be heat treated in reducing atmosphere to obtain $(U_{0.7}Pu_{0.3})O_{1.97}$.

T3.2: LBE/fuel interaction experiment and analysis (JRC-ITU, CHALMERS)

T3.2.1: LBE experimental set-up

The test apparatus is sketched in the figure. The oxygen concentration in LBE is controlled by adjusting the oxygen partial pressure in the atmosphere of the furnace in which the LBE-fuel containing crucible are located, through control of the $Ar-H_2/H_2O$ mixture fed to the furnace.

Oxygen concentration for MYRRHA in nominal conditions is $C_{O2}=1.10^{-8}$ wt.%. Experiments will be done at this concentration. Temperature will be constantly monitored.



Example of experimental set-up to control the oxygen concentration in LBE

Analyses

Several types of analyses will be performed during or after the LBE/fuel interaction:

- Thermal analysis (DTA) to follow the reaction kinetics and its energy release
- Radiography after to check for sample integrity
- XRD to identify phase change(s)
- Ceramography/SEM-WDS/TEM/EPMA to characterize the interactions LBE/pellet
- Inductively coupled plasma mass spectroscopy (ICP-MS) for dissolved products in LBE

For each of the following tasks, 4.2.2-4.2.5 $(U_{0.7}Pu_{0.3})O_{2.00}$ and $(U_{0.7}Pu_{0.3})O_{1.97}$ pellet (or disk) and powder will be immerged in LBE under controlled atmosphere ($C_{O2}=1.10^{-8}$ wt % in LBE) using the experimental setup described above at 500°C and 800°C for minimum 50h. Analyses will be carried out to identify the properties of the reaction, its products and its effect on pellet microstructure. Similar experiment will be carried out with UO_2 and PuO_2.

T4.2.2: LBE - homogeneous MOX interaction
T4.2.3: LBE - heterogeneous MOX interaction
T4.2.4: LBE - BN MOX interaction
T4.2.5: LBE – UO_2/PuO_2 interaction

T4.3: Phase relations study (JRC-ITU)

T4.3.1: Study of Pb-U-O and Bi-U-O phase relations

The study of the phase relations in the Pb-U-O and Bi-U-O to obtain basic knowledge on the possible phases that could be formed in the system. Solid state synthesis, thermogravimetry and X-ray powder diffraction will be the main techniques used, but additional characterization techniques (e.g. MASNMR, Raman) will be employed when needed.

T4.3.2: Study of Pb-Pu-O and Bi-Pu-O phase relations

The study of the phase relations in the Pb-Pu-O and Bi-Pu-O to obtain basic knowledge on the possible phases that could be formed in the system. Solid state synthesis, thermogravimetry and X-ray powder diffraction will be the main techniques used, but additional characterization techniques (e.g. MASNMR, Raman) will be employed when needed.

Deliverables

D4.1: Study of Pb-U-O and Bi-U-O phase relations
D4.2: Analysis of LBE-fuel interaction (M36)
- Homogeneous MOX (JRC-ITU)
- Heterogeneous MOX (JRC-ITU)
- BN MOX and UO_2/PuO_2 (CHALMERS)

D4.3: Study of Pb-U-O and Bi-U-O phase relations (JRC-ITU) (M18)
D4.4: Study of Pb-Pu-O and Bi-Pu-O phase relations (JRC-ITU) (M36)

Work package number:	5	Start date or starting event		Month 1	
Work package title	Fuel Dispersion Study				
Activity Type[12]	RTD				
Participant number	5	2	3	7	8
Participant short name	CRS4	ENEA	KIT	UNIPI	VKI
Person-months per participant:	18.7	8.5	14	6.8	7.65

Objectives

CFD modelling

- Realize two quite complete numerical CFD models of the MYRRHA-FASTEF facility primary coolant loop according to the latest available design and its relevant variants during the time extension of the project. The first step will be the grid generation of the primary coolant loop using CAD files of the MYRRHA reactor. The grid generation must be flexible enough to take into account the evolution of the design during the study. The first computational model (CFD) must then be foreseen for the simulation of long term events. It will be single phase with one-way coupling Lagrangian particles. The second model will be two-phase (Eulerian-Eulerian or VOF) for the simulation of short term events.
- Apply the first CFD model to the simulation of the fuel dispersion in the coolant in case of long term small rate release due to one or several pin failures. The fuel dispersion will depend on the release position and on the chemical compound released. The solid products dispersion will depend on its specific weight and size. The gaseous products dispersion will depend on the bubble size and on the product solubility. The modelling of the thermal effects and of the turbulence will be one of the challenges of the simulation.
- Apply the second CFD model to the simulation of the fuel dispersion in the coolant in case of gas release due to one or several pin failure. The gas is produced by nuclear reaction inside the fuel pin and normally trapped herein during normal operation. The impact of the gas release on the main flow will be taken into account.

SIMMER modelling

- Assessment of behaviour of fuel redistribution in heavy liquid metal nuclear systems under fuel failure conditions.
- Realize two quite complete numerical SIMMER-III models of the MYRRHA-FASTEF facility primary coolant loop according to the latest available design and its relevant variants during the time extension of the project. One model must be foreseen for the simulation of long term events. The other one must be foreseen for the simulation of relatively short term events and must be dynamically coupled with a neutronic code to capture a gas release impact of voiding on the neutronic core conditions, including the core sub-criticality status and heat release repartition.
- Apply the first SIMMER-III model to the simulation of the fuel dispersion in the coolant in case of long term small rate release due to one or several pin failure.
- Apply the first SIMMER-III model to the simulation of the fuel dispersion in the coolant in case of large core melting.
- Apply the second SIMMER-III model to the simulation of the fuel dispersion in the coolant in case of short term consistent material release due to one or several pin failure. The material would be the fission gas produced and accumulated inside the fuel pin and the simulation coupled to neutronic calculation.
- Realize a SIMMER-IV numerical model of the MYRRHA-FASTEF facility primary coolant

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loop according to the latest available design and its relevant variants during the time extension of the project. The model will be more precise to capture the geometry, including the core sub-criticality status and heat release repartition.. No coupling with neutronic is foreseen.

- Apply the SIMMER-IV model to the simulation of the fuel dispersion in the coolant in case of long term small rate release due to one or several pin failure.

Description of Work *(CRS4, ENEA, KIT, UniPi, VKI)*

Task 5.1: CFD simulation and modelling of fuel products dispersion in the MYRRHA-FASTEF primary loop coolant (CRS4, VKI)

The task is developed in two directions corresponding to the two models described in the objectives. These two models share some common aspects. They must be built in close collaboration between CRS4 and VKI and carefully cross-checked. The main shared feature is the construction of a steady-state model comprehensive of all the necessary physical modelling. This steady-state model will be frozen in the first application to concentrate on the particles Lagrangian dispersion. It will serve as initial condition for the second application.

From the CFD point of view, all the necessary features already exist. An exception may be the free-surface between LBE and cover gas having a density ratio of ten thousands while the limit of stability in CFD codes is generally only slightly above the water/air (at sea level) ratio. The cover gas density will be artificially increased to bypass this issue without sensible effect on the modelling. Also, for the gas release simulation, we expect to have only general indications.

The difficulty of the work package lies in the consistent merge of all necessary features inside a complex geometry and operating condition, subject to the computational power limitation.

VKI will focus its activity on the single phase approach with Lagrangian tracking. The mean flow field inside the primary loop of the MYRRHA reactor will be computed for the forced convection regime under nominal condition. These nominal conditions include the complete 3D, steady simulation including thermal effects. Afterwards, solid particles, of different sizes and of different densities (simulating the partial core melting) will be released inside the primary loop at different positions and with different initial conditions. The Lagrangian tracking (without coupling with the liquid phase) of the particles will allow the follow-up of the elements inside the primary loop and provide useful information on the trajectories of these particles. The Lagrangian tracking will only be valid for small objects.

This CFD approach will provide the trajectories into the primary loop of the different particles (fuel) and will localize the region of fuel accumulation. VKI has a large experience in CFD and particularly in multi-phase flows [5.1,5.2,5.3] so has to fulfil this part of the work with good confidence.

CRS4 will focus its activity on the Eulerian two-phase flow approach based on the Volume of Fluid (VOF) paradigm to capture the upper free-surface dynamics. An extension to the full Euler-Euler paradigm may be investigated in a second time if necessary to better capture the fission gas release dynamics.

To correctly describe the transport of fuel/cladding products in the MYRRHA-FASTEF primary loop flow, we need to dispose of a very accurate flow velocity field. This flow field is driven by the pumping system. It is controlled by the hydraulic resistances, the bypass flows and the level of the free surfaces. A strong influence also comes from possible thermal stratifications in different parts of the pool, therefore also from the heat transfer through the structures. The combined effect of

stratification, by-pass flow and free-surface reaction is likely to result in a non-trivial flow path, mainly in the upper hot plenum. The first objective is to obtain a comprehensive description of the entire pool loop.

We will be faced with the limit imposed by the computational power available, so some mitigation strategies will have to be developed. There are two Heat-Exchanger(HE)/Pump casing, each one consisting of two HE and one pump. These casings will require specific CFD modelling. Also, the HE requires a large computational power for a reasonable description. It is priori foreseen that in the global CFD loop, only one casing will be accurately discretised, and in this casing, only one HE will be discretised at the tube level. Separate models will have to be derived to make this approach consistent. There are also two or four casing foreseen for the repository of non-active fuel assemblies, each one with its own by-pass flow required to evacuate the (essentially) decay heat. Here again, a specific modelling must be performed, but at most one of these casing will have a more precise numerical description.

While it is out of range to have a description of the FAs internals, because of the non-uniform heat release in the core, each FA (or small group of FA) must have its separate description. Some refinement on the FA where the pin failure occurs can be evaluated. The spallation beam heat release must also be consistently modelled.

The global model must be organized in such a way that the single casing discretisation can be chosen on a case by case basis.

Once the model is reasonably satisfying, we will investigate the rapid release of fission gas due to the successive failure of a pin cladding and a pin fuel. The scenario leading to this event must be carefully described. This description is part of the next task and should be available for month 12. If it involves a partial blocking of the FA, then the flow field will be modified and a corresponding initial condition must be retrieved. The released gas will be followed in its path under the combined effect on the carrier fluid and its own drift velocity. The proportion of gas directly escaping through the hot plenum free surface will be evaluated. The behaviour of the residual gas fraction, entering the heat exchangers, will also be analysed until it becomes negligible. These features are likely to depend strongly on the position of the faulty FA and on the temporal signal of gas release rate.

The modelling and simulation will be performed with Starccm+, currently version 6.02. There are about two version updates a year and we will have to regularly adapt to the latest one available.

While the foreseen simulations are very ambitious from the technical point of view, CRS4 has gained in the very recent last years some confidence that is can be successfully realized. A single phase model of the XT-ADS version or MYRRHA has already been elaborated during the FP6 IP-EUROTRANS [1]. Nominal condition steady-state and an accidental shut-down have been simulated [2], however with a much simpler geometry than the one foreseen in this project. In the framework of the FP6 THINS project, CRS4 is currently working on free-surface flows and has already ascertained the possibility to model thermal free-surface flows within Starccm+, limited however to the Boussinesq approximation.

T5.2: Simulation and modelling of fuel dispersion in the coolant with SIMMER-III (KIT, ENEA, UNIPI)

The work is articulated in two main phases.

During the first phase, KIT will assess the incidental and accidental conditions leading to fuel pin failure and successive release of fuel, fission gas and finally partial core melt. The first part is propaedeutic for all partners and KIT will lead the interaction with the other WP so as to define sound incidental and accidental scenarios.

At the same time, UNIPI, ENEA and KIT will build the SIMMER-III reference model. This reference model must have the largest possible common basis for all three organisations. UNIPI will coordinate the elaboration of the SIMMER-III model to avoid duplication of work and optimise the model quality.

In the second phase, ENEA, with the support of UNIPI, will perform 2D SIMMER-III thermo-fluid-dynamic analysis (no neutronic coupling) of fuel dispersion and redistribution in the primary circuit of LBE-cooled MYRRHA-FASTEF reactor, starting from pre-defined fuel rod failure conditions. Several parametric calculations are envisaged to evaluate the influence of important parameters such as: the fuel break-up and particle size, the amount of released fuel, forced/natural circulation in the primary system, etc.

The need and the possibility to extend the SIMMER-III analysis to hypothetical severe accident scenarios involving large core melting will be investigated.

We will extend our modelling also to the 3D SIMMER-IV thermo-fluid-dynamic analysis (no neutronic coupling) of fuel dispersion and redistribution in the primary circuit of LBE-cooled MYRRHA-FASTEF reactor for the more representative fuel rod failure conditions.

The 3D version of the SIMMER code (SIMMER-IV) is obviously not able to give the same detailed information about the fluid-dynamic aspects that can be obtained by the CFD codes. It remains a system code and its use can be justified if we recognize that we have important multidimensional effects that can't be reproduced using an axial-symmetric geometry (SIMMER-III). The use of the SIMMER-IV version code can be suitable, again, to simulate the complex phenomena involved in our problem to obtain boundary conditions that must be passed to CFD codes. Its use will be restricted to the more representative fuel failure conditions because of the very high computational power it requires.

In the second phase, KIT will focus his activity on SIMMER-III coupled neutronic/thermal-hydraulic calculations of fuel and clad redistribution after the postulated pin failures under Pb/Bi flow conditions. The work is articulated in three main parts:

- Simulation of fission gas release and impact of voiding on neutronic core conditions, depending on pin damage configuration and size.
- Assessment of release of fuel pellets, chunks, particles and impact on fuel motion behaviour in Pb/Bi and neutronic feedback on core sub-criticality status.
- Assessment of granulated fuel and clad motion behaviour within the primary system.

During the entire project, UNIPI will take care of the congruence of ENEA and KIT models with the design evolution.

Deliverables

D5.1: Report on the operability of the SIMMER-III and SIMMER-IV models for the MYRRHA-FASTEF reactor (UniPi, KIT, ENEA) (M12)

D5.2: Single-phase CFD model of the MYRRHA-FASTEF primary coolant loop including all relevant thermal aspects (VKI) (M18)

D5.3: Two-phase CFD model of the MYRRHA-FASTEF primary coolant loop including all relevant thermal aspects (CRS4) (M18)

D5.4: Report on the 3D SIMMER-IV analysis for the more representative fuel failure conditions (ENEA, UniPi) (M24)

D5.5: Report on assessment on fuel dispersion after pin failure under blockage conditions (KIT) (M30)

D5.6: Characterisation of long term dispersion of fuel in the coolant with CFD modelling (VKI) (M36).

D5.7: Characterisation of the fission gas and other species release dispersion in the coolant with CFD modelling (CRS4) M36

D5.8: Report on the 2D SIMMER-III analysis for the reference case and parametric study (ENEA, UniPi) (M36)

Work package number:	6	Start date or starting event	Month 1		
Work package title	Release and Capture Studies for Radioisotopes				
Activity Type[13]	RTD				
Participant number	11	1	6		
Participant short name	PSI	SCK•CEN	UGent		
Person-months per participant:	64.8	39	32.4		

Objectives

The aim of this work package is to determine the key parameters that influence the volatilization of radionuclides from liquid LBE and their capture on various materials, both in order to facilitate reliable predictions of radioactivity transfer to the gas phase during MYRRHA operation and in accident scenarios as well as for the development of efficient filters for the removal of volatile radionuclides from the gas phase. These tasks will be tackled using a combination of experimental and theoretical methods:

Experiments studying the evaporation of volatiles from liquid LBE as well as their gas phase transport and their capture on suitable getter materials will be performed under variation of various experimental parameters with the following goals:

- identify those parameters that influence the evaporation, gas phase transport and deposition processes
- characterize the chemical species involved in these processes
- determine physicochemical parameters such as thermodynamic activity coefficients, saturation vapour pressure, Henry constants, deposition temperatures, adsorption enthalpies and entropies, which are necessary for the prediction of vapour phase concentrations of radionuclides in an ADS and the development of gas phase filtering systems for their removal.

In a complementary approach, quantum mechanical calculations will be used to calculate crucial properties of the evaporation and deposition processes theoretically:

- Temperature-dependent solubility and heat of solution of volatiles in solid and liquid metals, in particular LBE and potential filter materials
- Heat of adsorption of volatiles on filter material surfaces
- Heat of formation of chemical compounds of the volatiles that may precipitate from the liquid metal
- Formation energies of simple molecular compounds of the volatile elements

The results of the theoretical calculations will contribute essentially both to the interpretation and confirmation of experimental results as well as to the prediction of materials that have favourable properties for the capture of volatiles and chemical processes that can enhance or reduce evaporation. Thus, the interplay of experimental and theoretical studies will result in more reliable data, enhanced understanding of the underlying phenomena and streamlining of efforts. Because of their central importance, the focus of the proposed studies will be on polonium and mercury and their compounds and to a lesser extent their lighter chemical homologues.

[13] Please indicate one activity per work package:
RTD = Research and technological development (including any activities to prepare for the dissemination and/or exploitation of project results, and coordination activities – only possible for Collaborative projects and Networks of Excellence); DEM = Demonstration (only possible for Collaborative projects); MGT = Management of the consortium; COORD = Coordination activities (for Coordination Actions); SUPP = Support activities (for Support Actions); OTHER = Other specific activities (including training), if applicable.

Description of work *(PSI, SCK•CEN, UGent)*

Work package 6 is subdivided in 3 Tasks.

T6.1: Release, gas phase transport and deposition studies for volatile radionuclides (PSI)

The objective of this task is to determine the key parameters that influence the volatilization of radionuclides and their deposition on various materials. In particular, the existence of volatile chemical species and their chemical nature will be studied to obtain evidence on how and under which conditions they can be formed and captured. Thermodynamic and kinetic parameters concerning the evaporation of volatiles from LBE will be determined. The results will provide crucial input to assess the relevance of volatile chemical species of radionuclides for ADS systems and fundamental data for calculation of their gas phase concentrations and evaporation rates.

T6.1.1: Thermochromatography

To achieve these objectives, the transport of Po, Hg and their lighter chemical homologues will be studied in a temperature gradient in a carrier gas under variation of gas atmospheres (purified/moist gases, reductive, oxidizing and containing radicals), gas flows, temperature gradients, experiment duration, column material and pre-treatment of the column material. The results will allow proving the existence of different gas phase species of the studied elements under various conditions, the identification and characterisation of their chemical nature as well as determination of their thermodynamic properties, e.g. enthalpies and entropies of adsorption.

This task will provide important input and complementary information for several other tasks within this work package: Proving the existence of different gas phase species under certain conditions will allow to systematically select relevant conditions for evaporation studies from liquid LBE (Tasks 6.1.2 and 6.2.2 and facilitate the choice of suitable filter materials through their chemical nature and the data obtained on adsorption enthalpies and entropies (Task 6.2.1). The results obtained can also provide input on which gas phase species are important to study using quantum theory (Task 6.3.4), and vice-versa the results on stability of gas phase molecules (Task 6.3.4) and adsorption enthalpies on metal surfaces (task 6.3.2) obtained by first principles calculations will be extremely valuable for the interpretation and understanding of the thermochromatography results. The comparison of experimental and theoretical results will also facilitate a validation of the reliability of first principles methods for the prediction of these properties.

T6.1.2: Evaporation studies using the transpiration method

Dynamic evaporation experiments studying the release of radionuclides, especially Po and Hg and their chemical homologues, from liquid LBE will be carried out under variation of gas phase composition (purified/moist gases, reductive, oxidizing and containing radicals), specific activity/concentration of the respective radionuclide in LBE, temperature, gas flow (saturation and non-saturated conditions) and sample geometry. Goal of this task is the determination of qualitative and quantitative effects of experimental conditions on vapour phase concentration and release rates of volatile radionuclides from LBE solution. The results will allow determining fundamental thermodynamic and kinetic parameters for the evaporation process, e.g. thermodynamic activities and Henry constants for the case of gas phase saturation as well as evaporation rates under various concentrations and gas flow conditions for unsaturated gas conditions. The latter can be compared with evaporation rate calculations of different degrees of sophistication. The thermodynamic data will be compared to those obtained by first principles calculations (Task 6.3.3-6) and independent investigations performed in Task 6.2.2 to interpret the results and to achieve a consistent data set for ADS safety assessments.

T6.2: Studies of polonium and mercury evaporation and capture on filters (SCK•CEN)

In this task, the objective is to identify and evaluate adsorbents suitable for capturing gaseous Po and Hg and to study the evaporation of Po and Hg from LBE at low (second independent data set for licensing) and elevated concentration. The two subtasks are defined as:

T6.2.1: Adsorption experiments

Po and Hg adsorption experiments under variation of adsorbent type (porous carrier material, impregnant), velocity and composition of carrier gas, adsorbate concentration and concentration of other contaminants, adsorbent bed properties (depth, temperature) will be performed. For this purpose, breakthrough and pulse chromatography experiments will be carried out using an isothermal packed bed of adsorbent particles. Such experiments will allow determining the effective (dynamic) adsorption capacity and long-term stability of an adsorber system under conditions relevant to ADSs. To gain insight into the fundamental processes that occur in the adsorber, kinetic (mass transfer resistances) and equilibrium adsorption parameters (Henry constants, enthalpies) will be derived by matching the experimental data with appropriate mathematical models. The selection of suitable adsorbent materials will be based both on experiences reported in the literature and on experimental results produced in Tasks 6.1.1, 6.3.2 and 6.3.4 of this work package. In addition, the thermodynamic parameters determined in these Tasks will be used as input for modelling the experimental adsorption data.
From the results obtained here, optimized filtering systems for the retention of Hg and Po in ADS can be developed.

T6.2.2: Evaporation experiments

Evaporation experiments of volatile elements dissolved in LBE will be carried out using the transpiration method. Experiments at low concentrations (10^{-4} appm) will be performed to obtain additional, independently measured data sets for the most hazardous elements Po and Hg to support licensing of MYRRHA. Furthermore, a gradual increase up to concentrations expected in MYRRHA (0.1 appm) is envisaged. Here, the goal is to identify and characterize anomalous Po evaporation processes that may occur at elevated concentrations. Progress with the experiments at increasing Po concentration will depend on the licensing of glove box/hot cell test setup.

The results of this task will be compared with those of Task 6.1.2 and Tasks 6.3.3-5 to obtain a consistent data set concerning the extremely important volatilization data.

In addition, the data from tasks 6.1 and 6.3 will be used to assess the release of Po into the environment in various accident scenarios involving damage to the confinement structure.

T6.3: Theoretical thermochemistry of Po interacting with LBE and filter materials (UGent)

The objective of this task is the determination of fundamental properties describing the chemical interaction of polonium with components of the MYRRHA ADS, i.e. the target material LBE and impurities contained therein, promising materials for the development of filters to remove Po from the gas phase and volatile molecular Po-compounds. The task is divided in the following five subtasks:

T6.3.1: Po solubility in solid LBE

The temperature-dependent solubility of Po in solid LBE will be predicted following a computational procedure that relies on density functional theory for 0 K ground state energies and on a Debye model and/or ab initio calculated phonons for the behaviour above 0 K. The goal is to determine the solubility of Po in solid LBE to establish a lower limit on its solubility in liquid LBE.

T6.3.2: Search for most promising filter materials

The heat of solution of Po in noble metals, and the heat of adsorption of Po on noble metal surfaces will be predicted in the framework of density functional theory. Several low-index surfaces will be considered ((100), (110), (111), ...). This will allow assessing in an accurate, quantitative way which noble metal, and which specific surface type, is most effective to capture Po. This

information will allow interpreting the results of thermochromatography experiments (Task 6.1.1) on a theoretical basis and performing the difficult adsorption experiments (Task 6.2.1) in a much more focused way.

T6.3.3: Predict the existence of Po-alloys

Precipitation of Po-containing alloys within liquid LBE affects the Po evaporation rate. Therefore, the stability (heat of formation) of a number of Po-X and Po-X-Y compounds will be calculated by density functional theory. Earlier simplified assessments based on the Miedema model suggest which alloys are worth to be considered. The crystal structure will be taken into account, either by examining crystal structures that are known to exist in chemically similar compounds, or by making use of unbiased crystal prediction tools. The results facilitate the interpretation of evaporation experiments (Tasks 6.1.2 and 6.2.2) where the formation of Po-compounds may play a role.

T6.3.4: Po molecules in the gas phase

The formation energies of several Po-containing molecules will be determined by density functional theory and/or quantum chemical methods: monomeric Po, Po_2, PoH, PoH_2, PoOH, $Po(OH)_2$, PoBi, PoPb, PoHg,.. The results obtained by this task are important for all considerations concerning evaporation, gas phase transport and deposition processes. Thus, they will provide important input for all the experimental sub-tasks of work package 6. This information will allow eliminating molecules that are unstable at the relevant temperatures from these considerations and to assess probable volatisation paths. Several proposed/likely reaction paths will be examined by the same methodology, in order to point out the most favourable of those paths. The stability of different gas phase molecules also affects their specific adsorption properties, thus influencing the choice of filter materials (Task 6.2.1).

T6.3.5: Po solubility in liquid LBE

The solubility of Po in liquid LBE will be calculated from first principles. It has been shown in the recent literature how crucial quantities as the Henry constant can be written in terms of thermodynamic expressions that depend on a few quantities which all can be obtained from static density functional theory and/or molecular dynamics. We will apply these computational schemes to assess Po solubility in liquid LBE as a function of concentration and temperature. This will complement and expand the information that is available from experiments. In particular, the enthalpy of solution of Po in liquid LBE is one of the crucial parameters needed for interpreting the results of evaporation experiments in Tasks 6.1.2 and 6.2.2.

Deliverables

D6.1: Report on results of screening experiments (PSI) (M15)
D6.2: Report on tasks 6.3.1, 6.3.2 and 6.3.3 (UGent) (M22)
D6.3: Final report on volatilization and deposition studies (PSI) (M36)
D6.4: Final report on the evaporation, release and capture of Po (SCK•CEN) (M36)
D6.5: Final report on the evaporation and capture of Hg (SCK•CEN) (M36)
D6.6: Report on tasks 6.3.4 and 6.3.5 (UGent) (M36)

Work package number:	7	Start date or starting event	Month 1
Work package title	Education and Training		
Activity Type[14]	Other		
Participant number	8	1	
Participant short name	VKI	SCK•CEN	
Person-months per participant:	3.975	1.6	

Objectives

The objectives of this work package are fourfold:

- To coordinate the different dissemination activities of the work outcomes obtained by the SEARCH partners to guarantee strong visibility of the project at key events thus making aware the European Academia and Industry of the project.
- To initiate the preparation of technical and scientific papers for peer review journals and presentations at international conferences.
- To promote fruitful exchanges with other research projects (EC and national such as CDT, LEADER, THINS). The presence of SEARCH partners in many of these projects will facilitate this action
- To organize educational and specialized training courses as well as practical work sessions on coolant chemistry control, fuel-coolant interaction and fuel dispersion as well as release and capture of radioisotopes, which are key issues of SEARCH project for the reliability of LFR/ADS reactors.

Description of work *(VKI, SCK•CEN)*

With the predominant presence of research centres and universities, the dissemination of project results will be through the traditional academic approaches such as the publication of scientific papers and participation to Scientific Conferences.

In order to ensure that the SEARCH project has a coherent approach to the way it disseminates, this work package has been defined to federate the different actions, promote the project objectives and its expected results and encourage all partners to perform both internal and external communication actions.

Aiming to build and maintain competencies in science, technology and safety issues related to nuclear fields, the Work Package will provide the following communication means,

- Project communication kit (flyer, PowerPoint presentation and project poster) for the benefit of the partners to provide coordinated messages.
- Training material, consistent with the SEARCH project objectives, to support educational and specialized training courses, e-learning and distance learning.
- Training activities or practical work, associated to courses or workshop, in research or higher

[14] Please indicate one activity per work package:
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technological institutes.

- Education activities in forms of open workshops and/or intensive specializing courses.

Participating students will be asked to jointly perform studies on the issues of interest for the LFR/ADS components, putting a strong relevance on MYRRHA reactor. In this framework, students at PhD, Research Master and Master Science level will be trained in the main issues of LFR nuclear reactors. Problem based learning will form the basis of the activities.

The project level dissemination of progress and results to scientific conferences and propose special sessions to well-known conferences will be ensured. Several conferences have already been identified by the Consortium as relevant opportunities (both European and International) for initial dissemination of the SEARCH objectives and baseline within the nuclear sectors.

Students will participate to intensive specializing courses (1 or 2) and/or open workshops (1 or 2), in the form of mini-symposia on lessons learned and on achieved progress, Researchers, PhD, Research Master and Masters Science level students will participate to these workshops presenting and discussing their work, with the possibility of having feedback from SEARCH work package leaders and from the Expert Panel.

Each workshop would last 4 - 6 days, 1-2 days devoted to lectures, 1 day to student numerical simulation training, 1 day to student presentations and 1-2 practical student work in research or higher technological institute. These workshops will be included in the final review meeting of the project. The output of these workshops will be proceeding books collecting all the written documentation discussed and presented.

In the frame of the SEARCH Project partnership a Lecture Series will be selected and proposed in the intensive specializing courses that will be open to the research community all over Europe. This course will be open to the research community all over Europe. The attendance will be free of charge for the SEARCH partners and special invitation will be sent to the scientists from other running EC projects.

Moreover each SEARCH Project partnership, in collaboration with WP7, could announce masters or PhDs thesis topics related to HLM cooled nuclear systems, topics mainly related to the SEARCH Project

The work is subdivided in four Tasks as follows:

Task 7.1: Coordination and E&T/RTD organisation (VKI)

The objective of this task is to define the detailed time-table and agenda for the workshops, practical work, lectures or training course to be organised, make a list of tentative teachers for each symposia/courses and of the research centres and higher institute for practical works, a list of suitable masters thesis topics, identifying supervisors for these theses, if any, to compile workshop evaluations and produce deliverable 7.1.

Task 7.2: Workshop on LFR/ADS Objectives and Design (VKI, SCK•CEN)

The purpose of this workshop is to define a general survey of LFR/ADS science and technology development. The purpose is to provide background information to students in the field. Tools, procedure and methodology for assessing the safety and design of the components of new heavy liquid metal cooled nuclear systems, with reference to the Lead-bismuth cooled accelerator driven system MYRRHA will be introduced and applied. Moreover practical work programmes in research or higher technological institute are foreseen jointly to the proposed learning programme.

Task 7.3: Workshop on Fuel and Coolant Chemistry (VKI, SCK•CEN)

In this workshop, the fundamental, modelling and simulating approaches of the phenomena involved in coolant chemistry control, fuel-coolant interaction and the resulting outcoming products will be dealt with. Also dispersion of these products in the coolant and release into the covergas for volatiles will be considered.

The foreseen experimental tests to analyse such mechanisms and the existing numerical approaches will be discussed with the intent to provide students with the means to identify the key features of these phenomena and the available tools to their study..

In addition the students will have also the opportunity to participate to practical sessions organized on dedicated lab facilities.

Task 7.4: Training course on Fluid Mechanics in Nuclear Technology (VKI)

This one week course will be organised within the format of VKI Lecture Series. The lecturers will be selected from the SEARCH partnership and also among world experts in the field of thermohydraulic aspects of LFRs. All the relevant physico-chemical and fluid mechanics aspects related to safety issues of LFR/ADS systems will be covered.

The output of this lecture series will include a lecture note book (with ISBN).

Deliverables

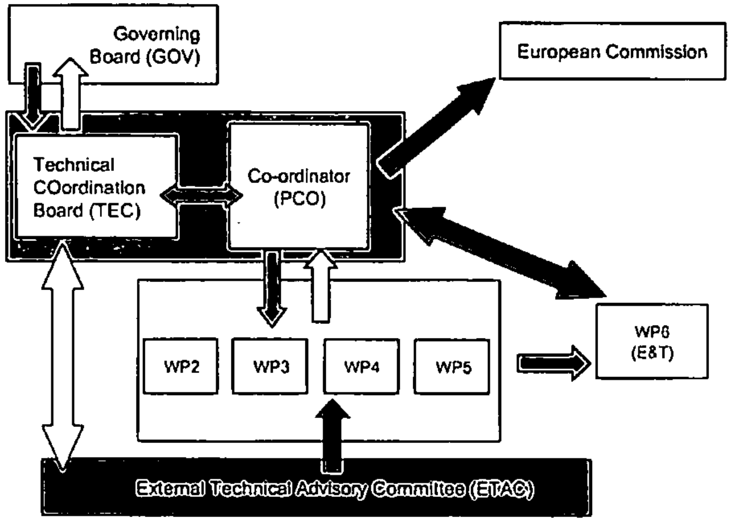
D7.1: 1st Workshop lecture book (VKI) (M18)
D7.2: 2nd Workshop lecture book (VKI) (M24)
D7.3: Lecture Series book (VKI) (M36)

B2. Implementation

B2.1 Management structure and procedures

Management Structure

In order to ensure the correct management of the project activities and to permit the fluent circulation of information among the partners and a quick individuation and solution of problems during the project life, a highly coordinated management structure is foreseen, as in the following figure.



Management Structure

The management structure is articulated in:

- a project coordinator (PCO), acting as single contact point with the Commission;
- a Governing Board (GOV), which is the ultimate decision making body;
- a Technical Coordination Board (TEC), responsible for the technical part of the project.

An External Technical Advisory Committee (ETAC) is foreseen to help the consortium in assessing the Project performance from the scientific point of view. The ETAC shall verify design needs of the LFR/ADS reactor concepts, will consider the solutions proposed in the project and will provide feedback to the work package leaders. The ETAC will give independent scientific opinions on the development made in the project.

The PCO acts as single contact point between the consortium and the commission and is responsible for:

- communicating all relevant information to the European Commission, pursuant to the terms of the grant agreement;
- establishing and maintaining effective communication between project partners, GOV, TEC and ETAC;
- reviewing the reports to verify consistency with the project tasks before transmitting them to the Commission, with the support of the TEC;
- handing the project deliverables and milestones to the European Commission;
- handing the project Periodic Activity Reports to the European Commission after prior approval by the GOV;
- administering the Community financial contribution regarding its allocation between beneficiaries and activities, in accordance with the grant agreement and the decisions taken by the consortium; in particular, the coordinator shall ensure that all the appropriate payments are made to the other beneficiaries without unjustified delay;
- keeping the records and financial accounts relevant for the Community financial contribution
- informing the Commission of the distribution of funds among the consortium members, the amounts allocated and the dates of payment to each member ;
- monitoring the compliance by beneficiaries with their obligations under the provisions of the grant agreement;
- preparing, updating and managing the Consortium Agreement between the participants;
- keeping a register of the management library (activity reports, milestones and deliverables) and of the technical library (technical reports, papers, posters, presentations, etc.);
- creating the conditions necessary for successful participation of consortium members in the Project
- ensures the organization and secretariat of the general meetings, of the TEC meetings and of the GOV meetings
- enhance the diffusion of information and keep a register of all the reports produced in the project and make them available through the website.

The **TEC** is responsible for the survey and coordination of the technical activities and their integration. It is also responsible for individuating technical problems and for indicating adequate strategies for solution, to be approved by the GOV.
The TEC is, in particular, responsible for:

- the evaluation of the progress of the technical activities;
- the evaluation of the technical-scientific results achieved in relation to the objectives of the program;
- the revision of the project periodic reports.

The TEC is composed by the work package leaders, by the chair of the ETAC, and the Coordinator. The TEC is led by the Coordinator.

The **GOV** is the ultimate decision-making body of the project. It composed by a representative from each involved institution, acting as supervising body for the project execution. The chair-person will be elected by the GOV by a simple majority from the partners represented by the consortium in a month by the project start.
The GOV is responsible for, *inter alia*:

- the supervision and evaluation of any proposed indispensable modification of the activities in progress;
- the approval of budget related issues;
- the approval of the periodic reporting to the commission;

- the resolution of any other issue that may arise during the course of the project.

The **ETAC** is composed by members of industry, academy, national and international organizations and independent experts in the frame of the HLM technologies and innovative nuclear system design and implementation. Specific attention will be paid to ensuring that the LFR/ADS programmes using the results from SEARCH such as MYRRHA, CDT, LEADER, are properly represented. The ETAC shall verify design needs of the LFR/ADS reactor concepts, will consider the solutions proposed in the project and will provide feedback to the work package leaders. The ETAC will give independent scientific opinions on the development made in the project.
Each member of the ETAC shall enter into a Non-Disclosure Agreement prior to the beginning of the membership in the Committee.
The External Advisory Committee regularly exchange information with the project through communications with the TEC by means of telephone, E-mail or specific meetings if intensive discussions is needed which cannot be achieved by the other communication means.
The ETAC participates in the project general meeting.

Collaboration with other projects

Besides via the inclusion of representatives of the programmes that will use the results of SEARCH in the ETAC, the consortium will encourage close collaboration with other EU projects in the field such as for example THINS and MATTER by including representatives of these consortia in the SEARCH kick-off and technical review meetings. In addition, SEARCH envisages to be represented at the technical meetings of the aforementioned projects whenever possible. Finally, collaboration will be ensured in an informal way because many of the scientists working for SEARCH are also involved in the other relevant EU projects.

Management Procedures

Meetings

A general meeting is foreseen at the beginning of the Project and in correspondence to the end of each reporting period (RP) as in the following:

- the kick-off meeting, to be held at latest one month after the project start;
- the first reporting period general meeting, planned during month 18;
- the final general meeting, planned during month 36;

Each general meeting will be preceded by the TEC meeting followed by a GOV Meeting.
If necessary, specific technical meetings will be held before the TEC meeting. The minutes of the meetings will be prepared by the Coordinator.

Additional TEC meetings are foreseen:

- during month 12;
- during month 24;
- during month 30.

The minutes of the meetings will be prepared by the Coordinator.

Moreover, specific technical meetings of individual bodies or a group of partners or of all partners can be held on an ad-hoc basis whenever necessary. The results have to be monitored in minutes, which will be registered and deposited at the PCO and uploaded on the website.

Information Flow

The information originated by the Project may have a technical or a managerial nature.
Concerning the technical issues, information flow will be achieved through:

- technical meetings;
- general meetings;
- distribution of minutes and periodic activity reports among the partners;
- distribution of all the technical production (reports, papers, presentations, etc.) among all the partners.

As far as managerial, administrative and financial issues are concerned, communication and information flow will be achieved through:

- general meetings;
- distribution of periodic activity reports.

Due to the importance of the documentation produced by the project (progress reports, cost statements, technical reports, deliverables, ...), the PCO will be responsible to maintain two kinds of libraries that will be available online through the website:

- management library (periodic activity reports, milestones and deliverables);
- technical library (minutes of technical meetings, reports, papers, posters, presentations, etc.).

Project Reporting

The following rules are established for **the project reporting**:
The **deliverables** and all the other **technical reports** are prepared by the concerned partners and approved by the responsible WP leader and by the project Coordinator. Each deliverable will have to report the date of submission, the number of review version, the signatures of the author and, after review, of the WP leader and the project Coordinator, as assurance of the quality of the report. The Project Coordinator will transmit the deliverable to the EC and will keep a register of all the reports produced and will made it available on the website.

The **minutes** of the general, GOV and TEC meetings, prepared by the PCO, are submitted to the GOV for approval. Once approved, are transmitted to the Commission.
The minutes of the technical meetings, prepared by the concerned partners are submitted to the PCO for approval and hence transferred to the Commission by the Coordinator.

The PCO prepares all the **activity and management reports**, to be approved by the GOV. Once approved, they are transmitted by coordinator to the Commission on behalf of the consortium following the EC project reporting rules. The progress reports (management and activity) comprise a section dedicated to outline the progress in the activity with respect to the project objective. Provide the main basis for an evaluation of progress made during the period against the objectives and milestones and constitute a basis for the payments to be made by the Commission, contain a description of progress of work towards the objectives of the project, a description of progress towards the milestones and deliverables foreseen, and the identification of problems encountered and corrective action taken. The reports contain administrative information as the distribution of resources and their use linked to the activities implemented.

A brief **Project presentation** will be prepared to inform the public on the activities of the project and will be posted on the website and distributed through the electronic newsletter.

Open publications (conferences, revues, etc.) will allow the project to spread the key results.
The Commission will be informed in advance about any publications related to public interest.

The PCO keeps a record of all the reports produced in the project and make it available for the partners in the official project website.

Management Rules for Project Quality Assurance

A **Quality Plan** to be followed for the project will be produced by the PCO, containing:

- organisation of the working team;
- roles and responsibilities of each participant;
- control actions planned;
- time schedules;
- definition of requirement specifications and quality objectives;
- procedures for acceptance and quality control
- performance indicators or measures of success

B2.2 Beneficiaries

P1 - Studiecentrum voor Kernenergie - Centre d'étude de l'Energie Nucléaire (SCK•CEN)

The Belgian Nuclear Research Centre (SCK•CEN) is a Foundation of Public Utility (FPU), with a legal status according to private law, under the tutorial of the Belgian Federal Minister in charge of energy. SCK•CEN has about 650 employees, of which one third has an academic degree. SCK•CENs main competences are found in nuclear materials research, development of innovative nuclear systems, nuclear waste research and environmental and health research in connection with nuclear radiation.

Since 1998 SCK•CEN is collaborating with European laboratories and research centres in the development of MYRRHA. MYRRHA is a heavy liquid metal cooled nuclear system that is designed to operate as Accelerator Driven sub-critical System (ADS) or as a critical fast reactor. It consists of a proton accelerator proton coupled to a liquid Pb-Bi spallation target in a Pb-Bi cooled and a sub-critical fast core. MYRRHA will serve as a basis for the European experimental ADS. It will provide protons and neutrons for various R&D applications, including transmutation studies.

SCK•CEN has participated to the European TWG on European Roadmap for ADS transmutation and coordinated the ADOPT Thematic Network. SCK•CEN has participated in several FP6 projects including among others EUROTRANS, VELLA, ELSY and MTR-I3. Presently SCK•CEN coordinates FP7 Projects CDT, FREYA and ARCAS and participates in a number of other FP7 projects including MATTER, GETMAT, MAX, LEADER, THINS, ADRIANA, and Helimnet.

Key persons in the project:

Paul Schuurmans earned his PdD in nuclear physics from the University of Leuven in 1996. After a period of Post-Doc research at CERN and Leuven he joined the Belgian nuclear research centre SCK•CEN in 2001 to work on the MYRRHA project. Between 2005 and 2010 he lead the Reactor Technology Research group in the Institute for Advanced Nuclear Systems at SCK•CEN. Presently he works as a senior scientists for MYRRHA and is responsible for the contents of the R&D programme and the international R&D collaborations.

Alexander Aerts obtained a PhD in 2007, working at the Centre for Surface Chemistry and Catalysis at the Catholic University of Leuven. Until 2010, he was postdoctoral fellow with a grant of the Flemish Research Foundation (FWO) at the same Centre, where he conducted research on the formation and characterization of porous materials for application in catalysis, adsorption and controlled release. Currently, he is researcher at SCK•CEN in the chemistry group for the MYRRHA project. He is author or co-author of 30 publications in peer-reviewed journals and 3 patents.

Jun Lim graduated in nuclear engineering at Seoul National University (SNU) in 1997 and got his PhD degree in the same university. Since 2005, he joined NUTRECK, participating in LBE cooled nuclear transmutation reactor development program. From 2010, he became a member of SCK•CEN as a research scientist. His work is to develop oxygen control and monitoring system of MYRRHA. Over the last five years, his research work has focused on lead-bismuth eutectic (LBE) coolant technologies such as corrosion of structural materials in LBE, oxygen control methods and oxygen probe development as well as new alloys development for LBE cooled nuclear systems.

Joris Van den Bosch graduated as civil engineer in material science and metallurgy at Ghent University in 2004. In 2008, he obtained his PhD in Material Science and Engineering from

Ghent University for his work at SCK•CEN, Belgium entitled: "Compatibility of Candidate Structural Materials with Liquid Metal in a Neutron Irradiation Environment".
After his PhD, Joris did a post-doc in the reactor core internals group of the Civil Nuclear Energy Program at Los Alamos National Laboratory, USA in the field of "Materials Irradiation Effects under Extreme Environments". Since December 2010, Joris is the head of the unit for chemical conditioning and purification, within the institute for Advanced Nuclear Systems at SCK•CEN, Belgium which is responsible for the chemical conditioning and purification of both the liquid LBE coolant and the reactor cover gas system for the MYRRHA ADS facility under design.

P2 – Agenzia Nazionale per le Nuove Tecnologie, l'Energia e lo Sviluppo Economico Sostenibile (ENEA)

ENEA is a public research institution operating in the fields of energy, environment and new technologies to support competitiveness and sustainable development. It conducts scientific research and technology development activities that draw on a wide range of expertise, advanced facilities and tools located at its own eleven Research Centres, operating in support of ENEA programmes and the Nation productive system. The staff is about 3300 persons out of which more than 2000 are researchers engaged in R&D activities. ENEA is member of the European Sustainable Nuclear Energy Technology Platform. ENEA has been also participating in several International Committees and Working Groups of EURATOM, NEA and IAEA in charge to develop strategies and to carry out studies, in particular in the field of innovative fast reactors and advanced nuclear fuel cycles.

Key persons involved in the project:

Dr. Mariano Tarantino received his University degree in Nuclear Engineering at the University of Pisa in 2004, and PhD degree in HLM thermal hydraulics in 2008. In the frame of the European Project IP-EUROTRANS (DEMETRA) he was mainly involved, as task leader, in the conceptual and experimental design of the Integral Circulation Experiment (ICE) aiming to characterize the thermal hydraulic behaviour of a liquid metal pool. Moreover he was involved in the design the NACIE loop, aiming to characterize the natural and gas enhanced circulation in the loop, as well as the heat exchange in heavy liquid metal loop under mixed and free convection.

In the frame of the LEADER Project (FP7) he is involved on the HLM technology assessment, as well in the frame of the THINS Project (FP7) he has been appointed as task leader for the integral test aiming to address the mixing and thermal stratification in HLM pool system.

Recently he has been appointed as coordinator for the work package "Generation IV nuclear systems" in the frame of the Italian National Programme on Nuclear Fission funded by the Italian Ministry of the Economical Development (MSE).

Alessandro Del Nevo PhD in Nuclear Safety at University of Pisa (2007); "Laurea" (MSc) in Nuclear Engineering at University of Pisa (2002). Working at ENEA CR Brasimone since January 2011. Key qualifications: Licensing of nuclear power plant. Writing Chapter 15 of FSAR. Development, verification and application of method, methodologies and computer codes for nuclear design and safety analysis. Design of experiments in thermal hydraulic experimental facilities. Coordinating service contracts. Teaching seminars on nuclear safety.

Participation in other EC projects: EC TACIS R2.03/97 Project (2004-2006): "Software Development for Accident Analysis of VVER and RBMK Reactors in Russia".EC TACIS R2.02/02 Project (2006-2008): "Development of safety analysis capabilities for VVER-1000 transient involving spatial variations of coolant proprieties (temperature or boron concentration at core inlet)". EC FP 6 NURESIM (2005-2008) "European Platform for Nuclear Reactor Simulations", EC FP 7 NURISP (2009-2010) "Nuclear reactor integrated simulation project".

Ivan Di Piazza took his Msc degree in Nuclear Engineering at the University of Palermo in 1996, and his PhD in thermo-fluid dynamics applied to nuclear systems in 2000. During the PhD, he spent a period at KIT on numerical modeling of MHD flows and at Alfa-Laval/TetraPak on CFD of compact heat exchangers. He gained a good skill in numerical modeling and CFD, developing also in-house codes at the CRS4 research centre (Cagliari, Italy). He spent a period at Ansaldo Nucleare and worked on CFD modeling of helical coiled SG for gen3+ nuclear plant. He has several publications in international journals concerning free convective heat transfer in heavy liquid metals, CFD of conjugate heat transfer problems, turbulence modeling and forced convection in helical pipes.

P3 - Karlsruher Institut fuer Technologie (KIT)

Karlsruhe Institute of Technology (KIT) is a higher education and research organisation with about 8000 employees, 18,500 students, and a total annual budget of about 700 million Euros. KIT was established on 01/10/2009 as merger of *Universität Karlsruhe* (founded in 1825), one of Germany's leading research universities, and *Forschungszentrum Karlsruhe* (founded in 1956), one of the largest research centres in the Helmholtz Association which concentrates on the five research areas of Energy, Structure of Matter, Earth and Environment, Health, and Key Technologies.

The Programme Nuclear Safety Research (NUKLEAR) within KIT is recognized as a long-term, provident research activity, studying scientific aspects of reactor safety and the safety of nuclear waste disposal. The results are applied in the public interest domain in order to contribute to the continuous improvement of the high safety standards of German nuclear installations and to provide the scientific and technical tools for the long-term safe nuclear waste disposal, including Partitioning and Transmutation. The scientific research work is performed in five academic Institutes, among which the Institute for Pulsed Power and Microwave Technology (IHM), the Institute for Nuclear and Energy Technologies (IKET) and the Institute for Applied Materials – Material Process Technology (IAM-WPT) contribute to SEARCH. The strategy and co-ordination work is performed by the Programme Management. .

KIT was or is a participant in other relevant projects such as EUROTRANS/DEMETRA, ELSY (both FP 6), ADRIANA, LEADER and THINS (all three FP 7).

In SEARCH, KIT contributes to WPs 2 and 4 and is WP leader of WP2.

Key persons involved in the project:

Prof. Dr.-Ing. Andreas G. Class got a degree in Mechanical Engineering at the University of Karlsruhe in 1989. He earned his PhD thesis on "Cellular structure of laminar premixed stagnation point flames" at the University of Karlsruhe. He did a Postdoc at the Northwestern University, IL, USA, in the Department of Engineering Sciences and Applied Math. Since 1995 he is Head of the Flow Modelling Group.

Dr. Alfons Weisenburger joined FZK in 1994. He did his PhD thesis on production of nanocrystalline materials using pulsed power methods. Since three years he is involved in surface modification of materials using pulsed electron beams and in investigations related to liquid metal corrosion. Since 2002 he is senior scientist in the electron beam and corrosion lab responsible for the investigation of material surface modification due to electron beam treatment and corrosion. Since 2006 he is Group Leader of the Section 'Surface Technologies' at FZK/IHM.

Claudia Matzerath Boccaccini holds a degree in Meteorology from the University Karlsruhe, Germany (1985). She joined KIT in 1987 in the department of applied system analysis, working on R&D of atmospheric dispersion modelling of wide area transport of smog, based on a forecasting model of Deutscher Wetterdienst (DWD). In 2001 she joined KIT's Institute for Nuclear and Energy Technologies where she worked on dynamics of Accelerated Driven Systems and modelling of reactor accident scenarios.

Dr. Donella Pellini has a MSc. Degree in Nuclear Engineering and a PhD in Energy Engineering from the University of Pisa (2011). Since 2008 she is a scientist at the Karlsruhe Institute of Technology, Germany. She is experienced in the field of liquid metal reactors, particularly in numerical simulations of heavy liquid metal-water interaction with SIMMER III code. She collaborated with ENEA Brasimone and University of Pisa in the frame of IP-EUROTRANS and ELSY programme.

Dr. Carsten Schroer received a degree in chemical engineering and a PdD in chemistry from the University of Dortmund, Germany. After working on high-temperature corrosion in municipal waste-incineration plants at the Max-Planck-Institute for Iron Research, Düsseldorf, Germany, he joined KIT in 2000. Since then, he has worked on various projects dealing with corrosion at elevated temperature, e.g., in super-critical water, sulphuric acid and lead-bismuth eutectic. He has become leader of the Liquid Metal Technology Group of the Corrosion Department in 2010.

P4 – Nuclear Research and Consultancy Group (NRG)

The Nuclear Research and consultancy Group (NRG) was established as a Partnership Firm in 1998 through the merger of ECN's and KEMA's business activities in the nuclear fields. On the first of december 2006, ECN took over KEMA's stake in NRG. NRG offices and nuclear facilities are located in the Netherlands, in Petten and Arnhem. The mission of NRG is to enable sustainable applications of nuclear technology for energy, health and environment. For these purposes, NRG provides a complete set of services and products for various sectors of industry as well as governmental bodies with a dedicated staff of about 350 employees. NRG is also a service provider for non-nuclear businesses like the chemical, oil and gas industry and the medical sectors. Furthermore, NRG is the main producer of radionuclides for the medical sectors in Europe.NRG has a complete set of nuclear facilities like a 45 MW research reactor (the HFR), hot-cell labs (HCL), laboratories for research and analyses, decontamination facilities and the radio-isotope production facilities.

One of the major research programmes of NRG focuses on the 4th generation nuclear systems. Within the 4th generation nuclear systems, NRG puts focus on three reactor systems:

- the existing Light Water Reactors and their 4th generation successor the Supercritical Water Reactor (SCWR).
- the High Temperature Reactor (HTR) and its 4th generation successor the Very High Temperature Reactor (VHTR).
- fast reactor systems (SFR, LFR, and GFR).

Research activities for other systems are also employed at NRG if these activities have a cross-cutting character. These subjects are in line with the vision of the EU presented in the Sustainable Nuclear Energy Technology Platform (SNE-TP) Vision Report. Furthermore, NRG is involved in many European projects, both as coordinator and as participant.

Ferry Roelofs is a senior consultant at NRG. He has been working on thermal-hydraulics, heat transfer and free surface modelling for most types of innovative nuclear reactors for over 10 years. He acted as workpackage coordinator of the workpackage related to "Advanced thermal-hydraulics and measurement techniques" in the EUROTRANS project. Currently, he coordinates the 'single phase turbulence workpackage' in the THINS project. Mr Roelofs holds an M.Sc. in Mechanical Engineering from Eindhoven Technical University.

Ed Komen is team leader of the CFD section of the Safety & Performance group at NRG. He has almost 20 years of experience in the numerical modelling of fluid flow, heat, and mass transfer, using thermal-hydraulic system codes as well as CFD codes. Mr. Komen is specialized in modelling of turbulence, using RANS as well as LES, two-phase flows, and combustion. Mr. Komen holds an M.Sc. (Cum Laude) in Applied Mathematics at the Delft Technical University

P5 – Centro di Ricerca, Sviluppo e Studi Superiori in Sardegna (CRS4)

CRS4 (Centre for Advanced Studies, Research and Development in Sardinia) is an interdisciplinary research centre developing advanced simulation techniques and applying them, by means of High Performance Computing, to the solution of large scale computational problems, and developing innovative applications in the field of the Information and Communications Technology.

CRS4 has developed a more than ten years of experience of CFD simulation applied to the Accelerator Driven System (ADS) cooled by heavy metals, first in National funded Programs (TRASCO), then at the European Level, contributing to the MEGAPIE experiment at PSI, the IP PDS-XADS (FP5), in the IP EUROTRANS (FP6), currently working in the IP THINS and CDT (FP6). CRS4's contributions have always been performed in close interaction with its partners, mainly ENEA, Ansaldo and SCK•CEN.

Key persons involved in the project:

Vincent Moreau senior researcher at CRS4 in the Process Engineering and Combustion Program, takes his degree in Numerical Analysis at Paris-XI University in 1990, makes his one year Scientific Service at ONERA on atmospheric lightning numerical modelling and undergoes a PhD thesis at Paris-XI, presented in 1994, on Functional Analysis applied to pseudo-Newtonian flows. In 1995, he works at ENEL-CRT of Pisa on two-phase flow simulation and modelling. He arrives at CRS4 in 1996 where he works on fluid-structure interaction. Since 1997, he works in the ADS field, making CFD simulations and analysis, participating to the FP5 PDS-XADS and FP6 EUROTRANS, THINS and CDT projects. Since 2002, he also works on turbulent combustion simulation.

Luca Massidda researcher at CRS4, graduated in Mechanical Engineering at Cagliari University in 1997. He worked for two year as a mechanical engineer for a private company, designing special valves for refinery plants. He works at CRS4 since 1999 where he gets experience in mechanical simulation and in scientific programming on parallel machines. He got involved in several projects: the design of fission fragment space propulsion system for the Italian Space Agency; the design of several equipment of the LHC and other experiments for CERN; the design and simulation of a solar power system, among others. In 2008 he worked at CERN as a scientific associate developing simulation software for beam dump studies. He develops further his software in the FP6 THINS project. He is now working at CRS4 as head of the Process Engineering and Combustion Program.

P6 – Universiteit Gent (Ugent)

Ghent University is located in Belgium, the heart of Europe. The university offers high-quality, research-based education in a wide range of academic disciplines, spread over 11 faculties. Today Ghent University attracts over 30,000 students, with a foreign student population of over 1,100 EU citizens and some 1,000 students from non-EU countries. With a view to cooperation in research and scientific service, numerous top-level research groups, centres and institutes have been founded over the years. Ghent University is recognized as one of the fastest growing universities in Western Europe. For example, in 2008, Ghent University published about 3500 research papers in the Web of Science, a 200% increase in ten years' time. Ghent University invests an annual amount of more than 187 million euro in research projects on behalf of public and private partners and appoints about 4900 scientific staff members. It has participated in around 200 research projects in the Sixth Framework Programme (2002-2006) and 140 so far in FP7. The university provides excellent training opportunities to young researchers through its five Doctoral Schools and awards around 400 PhD degrees per year, of which over 20% go to international young researchers.

The Center for Molecular Modeling (CMM) is an interfaculty research center, rooted in the Faculty of Science as well as in the Faculty of Engineering and Architecture. It has broad expertise in computational work on a.o. chemical kinetics, spectroscopic properties of solids (a.o. NMR-, EPR- and Raman calculations), ab initio molecular dynamics and classical force fields. These methods are applied to topics in the context of heterogeneous catalysis, conducting polymers, nanoporous materials (zeolites, metal-organic frameworks) and materials science. CMM aims at a close collaboration with experimental partners, in order to exploit the complementarity between theory and experiment. The CMM is currently composed of 35 researchers.

Key persons involved in the project:

Michel Waroquier is full professor in physics at the Ghent University and head of the CMM. His research field comprises theoretical physics, physical chemistry and molecular modelling in the field of heterogeneous catalysis, design of new nanomaterials, chemical kinetics, free radical polymerization reactions, ab initio determination of spectroscopic properties (EPR, IR, Raman, etc.) , molecular dynamics (development of new force fields), etc. He is currently (co-) author of 280 publications in ISI journals, has an h-index of 34 and counts more than 4800 citations.

Veronique Van Speybroeck obtained her PhD in 2001 at the Ghent University within the Faculty of Engineering. Currently she has a permanent position at the Ghent University as Research Professor. She is author or co-author of about 120 publications in peer-reviewed journals, 60 conference papers, has a h-index of 20 and has about 1300 citations. She leads the computational modelling division of the Centre for Molecular Modelling. Her current research interests primarily comprise study of the kinetics of chemical reactions with state of the art molecular modelling techniques. The applications of interest are situated in petrochemistry, catalysis and polymers. Very recently she received an ERC starting grant (Call ERC-2009-StG) on a subject on first principle chemical kinetics in nanoporous materials (KINPOR).

Stefaan Cottenier obtained his PhD in physics in 1997 from the Katholieke Universiteit Leuven (Belgium). He has a background in ab initio simulations in nuclear condensed matter physics and materials science. Stefaan Cottenier joined CMM in 2008, and supervises its expanding materials science activities.

P7 – Universita di Pisa (UniPI)

DIMNP is a research structure of the University of Pisa, with more than 50 academic and research staff members and about 30 technical-administrative staff members. Since its institution, the Department has been characterized by a strong orientation of the activities towards collaborations with Italian and European Industries in applicative research projects with wide scientific and technological significance. The main research activities regard safety analysis in nuclear and conventional fields, activities related to peaceful applications of nuclear energy, with main emphasis on plant design and safety, radiation measurements and reactor physics, management of risk and emergency in industrial plants, characterization and machining of conventional and innovative materials, design of machines and two- and four-wheel vehicles, and related studies on strength, reliability, lubrication, robotics and automation in industrial processes, and rapid prototyping technologies. Beyond these topics, several applicative studies have been carried out in many different fields. Among the most important collaborations, the following companies can be mentioned: the Italian University Ministry (MIUR), the European Union, ANPA, ENEA, ENEL, FIAT, FIAT-AVIO, PIAGGIO, NUOVO PIGNONE, BREDA, ANSALDO, AGIP, etc.

Nicola Forgione is presently Assistant Professor of Nuclear Power Plants at the University of Pisa. He has a PhD in nuclear engineering (Safety of Nuclear Plants) in 2000. Dr. Forgione performed research activities in the field of *Nuclear Reactor Safety* since his degree in Nuclear Engineering in 1996. In the following, a summary of the main achievements is reported.

- Experiments and modelling of falling film evaporation.
- Modelling of condensation in the presence of noncondensable gases.
- Measurement and statistical characterisation of falling films.
- CFD applications to heat and mass transfer of interest for Light Water Reactors, Liquid Metal Reactors and Fusion Reactors.
- Numerical analysis of heat conduction.
- Experiments and code predictions on natural and gas-injection enhanced circulation.
- Experiments on steam condensation in the presence of noncondensable gases
- Actively involved in different EC Project as INCON, DABASCO, SCACEX, EUROTRANS, ELSY and THINS.

He is teacher of the course "Elements of Applied Informatics" at the 3rd year of the "Laurea in Sicurezza Industriale e Nucleare" of the University of Pisa;

He supports the courses of "Thermodynamics and Thermal-hydraulics", "Nuclear Power Plants" and " Thermo-technical Plants" in the Degree in Nuclear and Mechanical Engineering.

Walter Ambrosini is presently Associate Professor Assistant Professor of Nuclear Power Plants at the University of Pisa. He has a PhD in nuclear engineering (Safety of Nuclear Plants) in 1988. Prof. Ambrosini performed research activities in the field of Nuclear Reactor Safety since his degree in Nuclear Engineering in 1985. In the following, a summary of the main achievements is reported.

- Application and validation of codes for safety analysis of nuclear reactors
- Development of models for basic thermal-hydraulic phenomena and plant transients: development and application of numerical methods for heat transfer and fluid-dynamic problems; proposal and application of mechanistic correlations for basic phenomena; development of codes for the analysis of plant transients; models for instabilities in single-phase loops and boiling channels
- Experimental activities: experimental studies on falling film evaporation (DABASCO Project, 4th Framework Programme); statistical characterisation of falling films; experiments on natural circulation and gas-injection enhanced circulation for ADS applications in a water loop; experiments on steam condensation in the presence of non-condensable gases

He started supports the courses of Thermal-Hydraulics and Numerical Methods for Nuclear Reactors for the Degree in Nuclear Engineering. Walter Ambrosini is President of the Teaching Board of the Research Doctorate in Nuclear and Industrial Safety (SNI) at the University of Pisa. Though not responsible, he has been de facto involved in contracts with the European Commission (DABASCO, INCON; SCACEX; THINS).

P8 - von Karman Institute for Fluid Dynamics (VKI)

The von Karman Institute for Fluid Dynamics (VKI in short), founded in 1956, is an international non-profit organization for post graduate education and research in fluid dynamics. Permanent staff of VKI is about 95 in total, spread over its 3 departments: Aeronautics and Aerospace, Environmental and Applied Fluid Dynamics, Turbomachinery and Propulsion. VKI is an associate member of EREA (European Research Establishments in Aeronautics) and is also considered as a SME according to the Commission's definition.

The research and training activities are carried out combining experimental, theoretical and numerical approaches, and span over industrial safety applications. VKI has a large number of advanced experimental facilities, in total 43 wind tunnels and test rigs, available in the domain of aerospace, aeronautical, turbomachinery and industrial fluid dynamics. They cover a large span, ranging from low speed to hypersonic. Experimental research is complemented by an important activity in the domain of Computational Fluid Dynamics (CFD) which now covers about 40% of the research activities. Four clusters of multi-processor computers are available.

Many of the research activities carried out at the VKI are supported by research contracts with industry, governmental institutions or international institutions. VKI is currently or has been involved, as partner or coordinator, in several EC projects or networks, such as JIVE, FLIE, VITAL, PROBAND, ADIGMA, IDeMAS, MESURE, CRAFT, LAPCAT, AETHER, PIVNET, FLOWnet, EUA4X, AMeGOS, VALIANT, CleanSky, ReStart,...

Key persons involved in the project:

Dr Jean-Marie Buchlin Professor at the VKI and ULB, Head of the VKI Department Environmental and Applied Fluid Dynamics. He has been the leader of the research programme on Post-Accident Heat Removal (PAHR) in Liquid Metal Fast Breeder Reactors (LMFBR) carried out at the VKI in collaboration with the SCK•CEN of Mol from 1980 to 1995.

P9 – REGIA AUTONOMA PENTRU ACTIVITATI NUCLEARE DROBETA TR. SEVERIN SUCURSALA CERCETARI NUCLEARE PITESTI - (INR)

The Institute for Nuclear Research has been established in 1971 according to IAEA recommendation, with the mission to provide the scientific and technological platform necessary for development, implementation and deployment of the national nuclear power program. Following the Romanian decision for CANDU technology in 1977, the institute contributed to the PHWR technology transfer and local manpower development, acting continuously as a scientific and technical support for the nuclear power program in the country.

The mission of the Institute has the following main components: provide the scientific and technical support for the Cernavoda NPP units during its lifetime; provide the scientific and technical support for the next NPP in Romania; develop R&D activities and programs for the advanced reactors and fuel cycles including generation IV; develop technologies for non-power nuclear application including radioisotopes production for medicine; provide services and products for the nuclear market; operate, maintain and develop the research infrastructure; international cooperation; education and training for nuclear power program. The Institute operates a complex infrastructure having as main components two TRIGA reactor cores (a steady state 14 MW and a pulsed one), hot cells, nuclear material labs, out of pile testing rigs, a radioactive waste treatment plant, radioprotection and environment laboratory.

The main activity in the SEARCH CORE on Chemistry project refer to the filtering of LBE

Key persons involved in the project:

Dumitru Oha licensed in physics-chemistry in 1972, senior researcher, PhD in advanced nuclear fuel development, head of Nuclear Materials and Corrosion department. In 1980-1995, he was involved in the development of technologies and equipment for nuclear fuel manufacturing and control. After 1995 he coordinated the activities of nuclear materials and fuel behaviour in normal, abnormal and accident conditions. Part of research activities (own and of department) was focused on candidate materials for Generation IV reactors testing in extreme conditions, especially cladding and internals. Also, he participated to FP6 Project SARNET (Severe Accident Research Network) and FP7 Projects: SARNET 2, ADRIANA and MATTER.

Vasile Viorel Ionescu Physicist, PhD and Researcher, in Nuclear Materials & Corrosion Department, in the field of Non-destructive Methods for Materials Characterization. He develops experimental methods for: ultrasonic characterization and analyses of Zr-2.5%Nb pressure tube alloy; study of the influence of hydrogen up-take on zirconium alloy elastic properties by means of ultrasonic methods; study of non-destructive methods for Steam Generator tubes examination.

Virgil Ion Cojocaru researcher, the supervisor at F/M Head and special tools testing team. The major activities: testing of Fuelling Machine Head no.4, 5 and Spare RAM Assembly for NPP Cernavoda -Unit 2, functional tests to special equipment from NPP Cernavoda – Unit 2, commissioning of the system for Fuel Handling System from NPP Cernavoda – Unit 1, elaboration of the testing documentation, set-up and calibration procedures for many of system manipulation nuclear fuel part.

P10 – Joint Research Centre – Institute for Transuranium Elements (JRC-ITU)

The **Joint Research Centre** (JRC) is a Directorate General of the European Commission, whose mission is to provide customer-driven scientific and technical support for the implementation of EU policies. One Institute of the JRC will be participating in the SEARCH Project, namely the **Institute for Transuranium Elements** (ITU) in Karlsruhe. ITU has a broad experience in the field of fuel research, and in particular for what concerns MOX, transmutation and fast reactor fuels. It can rely on highly qualified laboratories for fuel fabrication (either for Pu based fuels or its newly constructed Minor Actinide Laboratory). ITU

Laboratories are equipped with a variety of material property determination methods and post-irradiation examinations and has been a reliable partner in a large number of research projects both on MOX and Minor Actinides. Fuels have been prepared for the OECD Halden, BR2-Mol, HFR-Petten and Phenix reactors, as well as for a commercial nuclear power plant at Obrigheim. Fuels and fuel samples have also been successfully prepared and characterized for a variety of projects in the previous framework programmes, such as EFTTRA-T4, FUTURE and EUROTRANS. In addition to experimental facilities, ITU is using a variety of simulation and modelling tools. ITU has developed the TRANSURANUS fuel performance code. ITU also has a long experience in thermochemical and thermodynamic modelling, having established databases for actinide materials used in commercial packages like FACTSAGE and ThermoCalc. Finally, quantum mechanical and molecular dynamics calculations are employed to study of the fuel behaviour at the atomic scale.

Key persons involved in the project:

Rudy Konings graduated from the Utrecht University (Netherlands) in 1985. He obtained his PhD degree in chemistry from the University of Amsterdam (Netherlands) in 1990. From 1985 to 1998 he was employed by ECN and later NRG (Netherlands), working as scientific staff member and later as unit manager on various issues related to nuclear energy. Since 1999 he is employed by JRC-ITU, where he is now head of the Materials Research Unit. His main areas of expertise are thermochemical and high temperature studies of nuclear materials.

Philippo Raison has a PhD in solid state chemistry from the University Paris XI (1991). He has worked for the CEA in France before joining JRC-IE in 2002, working on various aspects on nuclear technology. In 2006 he joined JRC-ITU where he has worked on nuclear fuels and new ceramic forms for actinide containment and transmutation (pyrochlores, phosphates, zirconia-based compounds, etc.). His current activities are strongly focussed on studies on the interaction of sodium with advanced nuclear fuels for GEN-IV SFR, including investigation of phase diagrams and characterisation and structural analysis by X-ray/neutron diffraction.

Joe Somers holds a PhD in Chemistry (Trinity College Dublin, 1985) after which he spent 4 years as a post-doc in the Surface Physics Department of the Fritz Haber Institute, Berlin. Having joined the JRC-ITU in 1990, he spent several years investigating the interaction of high intensity sound fields with aerosols. For the past 12 years his research interests have been devoted to nuclear fuels with applications in LWR, HTR, ADS and fast reactor systems. He has been involved in a number of EU projects (THORIUM CYCLE, HTR-F, OMICO, PUMA) and has been responsible for fuel manufacture for irradiation testing in various reactors (HFR Petten, OECD Halden, BR2-Mol, Phénix and KWO Obrigheim).

P11 – PAUL SCHERRER INSTITUTE (PSI)

The Paul Scherrer Institute (PSI) is a multi-disciplinary research centre for natural sciences and technology. In national and international collaboration with universities, other research institutes and industry, PSI is active in solid state physics, material science, particles physics, life sciences, nuclear and non-nuclear energy research, and energy related ecology.

The institute's priorities comprise various areas of both basic and applied research, particular in fields which are relevant for sustainable development as well as for teaching and training, which are beyond the scope of a single university department. PSI develops and operates complex research installations, which call for especially high standards of know-how and experience, and is one of the world's leading user facilities for the national and international scientific community.

PSI operates a 590 MeV CW proton cyclotron with a beam current > 2 mA and the spallation neutron source SINQ receiving this beam. In 2006, the prototype liquid metal spallation target MEGAPIE using liquid lead-bismuth eutectic as target material replaced the standard solid lead SINQ-target, being the first MW-class liquid metal spallation target that was operated for a substantial period of time. Through the development, licensing, operation and dismantling of this target, PSI acquired world-wide unique knowledge in various areas related to the application of liquid metals in nuclear technology.

Key persons involved in the project:

Jörg Neuhausen acquired his PhD from Johannes Gutenberg University in Mainz, Germany in 1995 in inorganic solid state chemistry. Afterwards, he held a permanent position as research scientist at the Institute for Inorganic Chemistry and Analytical Chemistry of the Johannes Gutenberg-University in Mainz, working on high temperature synthesis, x-ray structure analysis, surface characterisation and electronic structure calculations. In 2002 he joined the Laboratory for Radio- and Environmental chemistry of the Paul Scherrer Institute, were he worked in the groups 'Targetchemistry' and 'RadWaste Analytics' on the behaviour of radionuclides in irradiated liquid metals. His interests and expertise comprise theoretical modelling of the thermochemical properties of intermetallic interactions and experimental studies of the release of volatile species from molten metals. As part of the project MEGAPIE he contributed to the successful licensing of this first-of-a-kind liquid metal spallation target. He is also member of the OECD expert group on Heavy liquid metal technology.

Robert Eichler obtained his PhD in 2000 from University of Bern, studying the chemical properties of Bohrium (Element 107). After a Post-Doc at GSI in Darmstadt, Germany, he joined the Laboratory for Radio- and Environmental Chemistry at Paul Scherrer Institute as a group leader of the 'Heavy Elements' group in 2001. His research interests are the chemical characterization of Super heavy elements including thermochemical prediction methods and the use of fast gas phase chromatographic separation techniques such as thermochromatography, isothermal gas chromatography and vacuum chromatography for the determination of thermochemical data. He has received several awards, including the Doctoral thesis Award of the Faculty of Philosophy and Natural Sciences of the University of Bern (2001), the PhD thesis award from the Nuclear Chemistry Division of the German Chemical Society (2001), a Swiss National Science Foundation (SNF) Fellowship for advanced researchers (2004) and the GSI Exotic Nuclei Community (GENCO) Membership Award for young scientists (2006).

P12 – Chalmers Tekniska Hoegskola AB (CHALMERS)

Chalmers University of Technology was founded in 1829 following a donation by William Chalmers and was transformed into an independent foundation in 1994. Chalmers' annual turnover is approximately 2 billion SEK (appr. 220 million EUR), out of which two-thirds are related to research. More than 11,000 people, including over 8,000 undergraduates, work and study in some of Chalmers' departments and divisions.

The university offers PhD and Licentiate programs as well as MScEng, MArch, BEng and nautical programmes. There are around 8,600 students taking undergraduate programs leading to 1,300 Master's degrees annually. More than 1,000 students are involved in graduate and doctoral programs leading to around 340 PhD and Licentiate of Technology degrees each year. Chalmers is involved in approximately 140 industrial and educational projects within the EU programmes.

Main tasks attributed / previous experience relevant to those tasks

Nuclear Chemistry/Industrial Recycling at Chalmers has been working for more than 50 years in the development of solvent extraction processes. During the last 30 years research has been made in many different areas but the main fields have been:

- Partitioning and transmutation,
- Actinide chemistry,
- Solvent extraction chemistry,
- Chemistry related to deep geological disposal,
- Chemical modelling and associated uncertainty and sensitivity analysis,
- Thermo dynamical data
- Recovery of precious metals from different waste streams

We have been actively participating in about 10 EU-frame work programmes on various topics. Over the years hundreds of publications concerning the special chemistry of the actinides have been published in various per-reviewed scientific publications.

The leader of the group is Professor Christian Ekberg who has more than 60 reviewed publications and about 30 reports in his publication list. His main activities have been solvent extraction, thermodynamics, statistics and geochemical modelling.

Key persons involved in the project:

Dr. Teodora Retegan published about 20 refereed publications and 5 reports. Her main research activities are solvent extraction, partitioning for transmutation, actinide chemistry. During the project she will be supported by

Professor Gunnar Skarnemark who has about 130 reviewed publications and about 100 reports in his list of publications. His main research activities are solvent extraction, actinide chemistry, chemistry of the heaviest elements, radiopharmaceutical chemistry, development of solvent extraction equipment and radioanalytical chemistry.

B2.3 Consortium as a whole

The contents of the proposal require a wide range of expertise and competences. Besides expertise in nuclear reactor and components design among others a detailed knowledge of coolant technology, fuel handling and chemistry, numerical simulations, radiochemistry, theoretical thermochemistry and safety assessment in nuclear systems is needed.

The Consortium is built up by Partners from research organisations and universities, as detailed in the list of beneficiaries, which represent various capabilities. Most of the partners have previously been involved in major projects concerning the development of Gen. IV LFR and ADS technology.

The activities planned in the project are distributed over the partners on the basis of the wide range of competencies present in the consortium.

The organizations involved have high-level profile and well proven experience in the various areas of interest. Moreover, they all have shown ability to co-operate together, gained at least partly in the other European research programmes in which they have been and still are involved. These are all important characteristics that show that the probability to accomplish all the desired objectives in the project can be considered very high.

In particular, important areas of expertise in LFR/ADS technology, (radio)-chemistry and safety are brought by the partners to the project as:

- nuclear reactor and plant design (with particular attention to LFR and ADS design);
- HLM coolant chemistry
- Fuel handling and fuel chemistry
- Advanced numerical tools modelling and validation
- HLM thermal-hydraulics
- Radiochemistry
- Theoretical thermochemistry
- Safety analysis in connection with licensing;
- Instrumentation development

The presence of institutions in the consortium with a significant pre-existing know-how, as cited above, plays a fundamental role in the overall implementation of the work to be done. The complementarity of the activities has been made evident in the tables of the work packages description. More in particular, with SCK-CEN, KIT and ENEA, the consortium includes the three most active partners in the field of LFR/ADS related R&D in Europe. In the field of fuel research JRC-ITU is the leading research institute in Europe. Moreover, Chalmers University that is also a partner in the work-package on fuel-coolant interaction is one of the few universities in Europe capable of handling quantities of Pu containing MOX. In the field of numerical modelling NRG, CRS4 and VKI have a long standing track record. With KIT, ENEA and the University of Pisa the leading players in SIMMER code simulations for HLM cooled systems have joined the consortium. With the realisation of the MEGAPIE liquid LBE spallation target project PSI, who is a key player in the work-package on release and capture of radioisotopes became one of the leading players in the field of radiochemistry of volatile elements. The CMM Institute of Gent University is a particular expertise in theoretical thermochemistry which is quite essential in support of radiochemical experiments. Finally, INR is an institute from new member state (Romania) who, because of their relative novelty in the field will play a limited role. However, INR has expressed a keen interest in developing expertise in the field of HLM technology. This interest is partly explained by the declaration of Romania of their willingness to host the LFR demo reactor ALFRED.

It may be noted that the external technical advisory committee (ETAC) can permit the involvement of industry, academy, international organization and independent experts, to support and complement the consortium if required.

B2.3.1 Sub-contracting

Sub-contracting is limited to the transport of MOX fuel as described in Task 4.1.3 because none of the partners can legally transport MOX fuel. The sub-contractors will be chosen after competitive tender based on the principle of best value for money.

The certificates on financial statements of expenditure will be issued when the sub-contractor is selected.

In addition certificates on Financial Statements of expenditure (CFS) are forecasted for any organisation requesting an EC contribution exceeding 375.000 €.

B2.3.2 Other countries

No Funding for beneficiaries from third countries is planned to be distributed. All partners are based in EU member states including CH and no partner is foreseen from other countries within the project for the time being.

B2.3.3 Additional parties

No additional beneficiaries or competitive calls are planned except for those mentioned in section 2.3.1. No specific financial resources are planned to be provided by third parties.

B2.4 Resources to be committed

The goal of the SEARCH proposal is to investigate several crucial aspects of the chemistry of the coolant, fuel and produced radioisotopes relevant to HLM cooled nuclear systems. Experiments, numerical simulations and theoretical computations will be used. The main purpose of the effort is to support the design and the licencing process of MYRRHA in its role as the LFR-ETTP since MYRRHA will be the first HLM cooled nuclear system to be deployed in the European Union as depicted in the ESNII roadmap.

As main impact on the ESNII Roadmap, SEARCH support the Front – End Engineering Design (FEED) of MYRRHA, by generating information that can be used in the engineering design of the MYRRHA and in the Preliminary Safety Assessment Report (PSAR).

In SEARCH a total of 12 partners are involved for the depicted commitments. The total effort is 407,3 person-months distributed over a period of 36 months which corresponds to the personnel costs as in forms A.3. The overall financial plan is effectively defined in order to perform the foreseen activities to reach the project objectives.

The total eligible resources necessary for carrying out the project are estimated to be 5.451.935 €, for an EC requested contribution of 2 977 525 €

The main effort will be spent in terms of person-months. These activities are mainly related to the set-up or modification of existing test rigs, running experiments, data taking an analyses and interpretation. Moreover a substantial effort is needed in project to implement the numerical simulations which are mainly found in WP2, WP5 and for the theoretical calculations of WP6.

The largest part of the effort is found in WP6 on the release and capture of radioisotopes. The main reason for this is the complexity of the problem which requires numerous experiments to determine all relevant parameters and the fact that experiments with volatile radionuclides tend

to be difficult to perform. However, because of the high radio-toxicity of the elements involved and the importance of the data for the licencing process of MYRRHA the envisaged level of detail and reliability is absolutely necessary.

In WP2 on the coolability of a wire spaced fuel bundle the costs are mainly induced by the complexity of the experimental equipment needed to do the measurements. Furthermore, a quit significant numerical support programme is envisaged.

Also in WP3 on coolant chemistry control a substantial effort is foreseen. The effort is mainly found in the development of filtering techniques which again requires a large number of tests and in the study of Control, Mass Transport and Interaction of Oxygen, Metallic and Non-Metallic Impurities with LBE. Here a dedicated set-up needs to be developed and constructed.

The justification of the costs in WP4 is found in the difficulty of properly handling MOX fuel. However since MOX will be the fuel used in MYRRHA, the fuel-coolant interaction studies will need to be performed with MOX since experiments with a homologous element are not acceptable for licencing.

Due to the complex or difficult nature of the investigations to be carried out in the project it is quite clear that the financial contribution from EC cannot completely cover all expenses of the partners that necessary to carry out the allocated activities.

Beyond the resources declared in forms A.3, a significant amount of resources are made available by the consortium to the project. This does not only refer to financial input but also to data, contacts and expertise of the partners.

The totality of these foreseen necessary resources, including the resources that will complement the EC contributions, are distributed on the different planned activities as described in section 1.3.

The activities have been organized in work packages and the resources needed to perform each activity have been evaluated and distributed over the work packages.

The resources allocated for RTD activities amount to € 5.245.749 (EC requested grant 2.771.338 €), corresponding to around 96.2% of the total costs. Beyond the resources allocated for the research and development, the management of the consortium activities and website creation and maintenance accounts for 2% of the total costs. In this percentage a budget of 15 k€ is foreseen to support the members of the ETAC for travel and accommodation costs for 3 meetings. The other activities (organization of workshops, dissemination and training) account for 1.8% of the total costs.

B3. Potential impact

B3.1 Strategic impacts

In the framework of the European study and development of more sustainable nuclear energy sources, MYRRHA has been selected as one of the high priority large research infrastructures of ESFRI, the *European Strategy Forum on Research Infrastructures.* MYRRHA is also part of the ESNII, the *European Sustainable Nuclear Industrial Initiative*, proposed to the SET-Plan, *Strategic Energy Technology Plan*, by SNETP, the *Sustainable Nuclear Energy Technology Platform* where the facility is also considered as LFR Technology Pilot plant. On the other hand, the European GENIV LFR Demonstrator ALFRED is considered as one of the two alternative technologies, together with the Gas Cooled Fast reactor, *GFR*, for the Sodium Cooled Fast reactor, *SFR*.

Following several international reviews of the MYRRHA project, the Belgian Government decided to fund MYRRHA for up to 40% of its estimated cost. It is considered of great importance for Europe to keep the leading role in this project, to extent its expertise in all innovative nuclear systems foreseen in the European nuclear energy strategy and to enable expansion of its intellectual human resources by providing an R&D basis as well as training and education on these very innovative technologies. We hence look for a major European consortium to partner in this new project which will have a direct impact on the Front End Engineering Design (FEED), the compilation of the Preliminary Safety Assessment Report, *PSAR*, and the Environmental Impact Assessment Report, *EIAR*, of MYRRHA and indirectly on the licensing and safe operation of the European LFR Demonstrator ALFRED, future LFR and industrial scale ADS.

WP2 will perform experimental analysis and numerical modelling of thermal-hydraulic behaviour of a prototypical wire-wrapped rod bundle relevant for the LFR/ADS core configuration. Different HLM flow regimes will be investigated, i.e. forced, free and mixed, with a special reference to the transition from forced to free convection. Impacts are expected in terms of thermo-hydraulic knowledge of HLM nuclear systems in operational and accidental conditions. This will realise a synergic interaction between experiments and numerical modelling with a global positive know-how both in numerical modelling and in the final quality of the experimental results. The data will be used to assess the coolability of the fuel bundle in different scenarios which form a crucial part of the safety assessment of heavy liquid metal cooled nuclear systems.

The coolant chemistry R&D foreseen in WP3 of the SEARCH project will provide the source term of impurities in the coolant created by the spallation reactions in the spallation target as well as by liquid metal corrosion of the fuel cladding and structural materials. Furthermore, WP3 will provide very valuable information on PbO formation, dissolution, mass transport of oxides and entrainment of particles in the LBE flow as well as R&D on the filtration technology to remove all these impurities and particles from the liquid metal flow. Outcome of WP2 will directly help ensure safe operation of MYRRHA and indirectly ALFRED by proving clogging prevention and mitigating erosion by avoiding particle entrainment. Furthermore, the estimation of the MYRRHA source term combined with results of filtration technology and efficiency can be directly used as input for the estimation of the MYRRHA operational solid waste stream.

In WP4, experimental verification will be made of possible fuel-coolant chemical interactions which could occur in case of a cladding breach. Although at first sight limited reactivity could be expected, this is essential safety information for several possible accident scenario impact studies of interest to all heavy liquid metal cooled irradiation facilities where fuel is envisaged to be present.

The fuel coolant dispersion studies performed by numerical calculation using SIMMER and CFD codes in WP5 combined with the experimental fuel coolant interaction studies of WP3 should provide a clear answer on how oxide fuels and MOX would behave in accident scenarios and whether localised criticality forms a realistic scenario. Unlike in light water reactors, the difference in density between the oxide fuel and the heavy metal coolant is rather limited and intuitive reasoning on fuel behaviour in heavy liquid metal flows is totally insufficient. The complementary results of WP3 and WP4 will clarify this issue for LBE and Pb cooled fast reactor systems and have a large impact on further safety assessment in accident scenario studies for MYRRHA, ALFRED, LFR and industrial scale ADS.

The impact of WP6 is clearly related to the cover gas handling of heavy liquid metal cooled nuclear systems but also of heavy liquid metal spallation targets. Detailed knowledge on evaporation and capture of radiological products are essential information for environmental impact studies, safety assessments and reactor design. Especially the highly radiotoxic Po-210 isotope release and capture is a crucial piece of know-how for all heavy metal cooled fast neutron systems. Due to the high radiotoxicity of Po-210 and the rather limited amount of scientific knowledge on the behaviour of polonium, assessment of its behaviour by minimum two independent institutes will be demanded by regulatory bodies. The complementary theoretical study foreseen in WP5 will increase the level of scientific confidence in the provided results. Apart from the knowledge on Po, WP5 will examine the volatilization and capture of mercury which is also a highly toxic element, typically related to all heavy liquid metal cooled nuclear systems. Furthermore, due to the high level of scientific work WP5 will heavily invest in PhD students providing experience and confidence on important nuclear safety related issues for Europe's future nuclear experts.

The WP7 on education and training is considered as a very important part of the project providing training to young scientists and engineers joining the project and enabling exchange of expertise and knowledge within the project but also with the international community on heavy liquid metal technology. Due to the highly innovative nature of heavy liquid metal cooled nuclear systems and the absence of a historic knowledge base on heavy liquid metal nuclear technology in Europe, education and training is key to the success of the project and the expansion and rejuvenation of the European innovative fast reactor knowledge base.

B3.2 Plan for the use and dissemination of foreground

The dissemination and exploitation of the project results is an important activity which will be carried out through different instruments.

The SEARCH project will generate relevant results in the area of liquid metal technology and safety for MYRRHA, ALFRED, GENIV LFR and heavy metal cooled transmutation systems and liquid spallation targets. In particular the results will concern essential knowledge for safe operation of heavy liquid metal cooled nuclear facilities in term of coolant quality control, effects of fuel coolant interaction and essential input for cover gas filtration and handling.

The dissemination of the results will occur via four well known instruments, which are:

1. Workshops
2. Training Courses
3. Publication in international journals and conferences.
4. Installation of a project web site

A communication and dissemination plan will be issued indicating the different activities such as workshops, international conferences, national meetings, training activites etc over the lifetime of the project. In addition a "Project Presentation" document will be prepared.

In the frame of the project , at least two international workshops will be organised with the objectives to present and discuss relevant results at international level including participants from the GenIV and Transmutation communities. The aim of the workshops is to enhance international collaborations and to network activities relevant for this area. In particular design advancement as performed by the CDT or by the GenIV systems group for coolant conditioning systems and cover gas handling.

A detailed programme of the international workshops will be discussed and proposed by the TEC and finally approved by the PCO.

One training course will be organised in order to address the different topics handled in the project. The training courses will be addressed to PhD students and researchers active inside the consortium. The program of the training courses will also be discussed and proposed by the TEC and finally approved by the PCO. The ENEN consortium will be informed about all workshops and training activities organised within SEARCH

Publications in international journals and conferences will be encouraged by the TEC. Publication rules will be determined by consortium agreement and enforced by the TEC.

An open Web site will be installed in order to disseminate knowledge and information beyond the research community of heavy liquid metal technology and towards the public as a whole. The open part of the web site will be used to present popularisation of major scientific issues.

The management of intellectual property rights is an important topic for the consortium. Indeed, a pro-active role can be envisaged in the innovation process by managing intellectual property rights with the objective to maximise the benefits of publicly funded research for society. These benefits can be measured in terms of technology transfer or spin-off with the result of new products, new companies and new jobs.

The knowledge transfer offices of the consortium partners usually address the issues on intellectual property rights and technology transfer. In addition through the consortium agreement the intellectual property rights, exclusion of pre-existing know-how will be defined. In order to maximise the benefits of the research results, the TEC will evaluate how to strengthen the collaboration between the different knowledge transfer offices of the consortium and will identify "results" which need to be managed through the intellectual property right offices.

The results of the SEARCH project will be used as input for the MYRRHA Front End Engineering design FEED, the Preliminary Safety Assessment Report, *PSAR*, and the MYRRHA Environmental Impact Assessment Report, *EIAR*. Due to the International European scientific basis of the SEARCH project and the open nature of the project's knowledge dissemination towards the public as a whole, results of SEARCH can be considered as neutral, high level safety information.

B4. Ethical Issues

Research on Human Embryo/Foetus	YES/NO	PAGE
* Does the proposed research involve human Embryos?		
* Does the proposed research involve human Foetal Tissues/ Cells?		
* Does the proposed research involve human Embryonic Stem Cells (hESCs)?		
* Does the proposed research on human Embryonic Stem Cells involve cells in culture?		
* Does the proposed research on Human Embryonic Stem Cells involve the derivation of cells from Embryos?		
I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL	YES	
Research on Humans	**YES/NO**	**PAGE**
* Does the proposed research involve children?		
* Does the proposed research involve patients?		
* Does the proposed research involve persons not able to give consent?		
* Does the proposed research involve adult healthy volunteers?		
Does the proposed research involve Human genetic material?		
Does the proposed research involve Human biological samples?		
Does the proposed research involve Human data collection?		
I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL	YES	
Privacy	**YES/NO**	**PAGE**
Does the proposed research involve processing of genetic information or personal data (e.g. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?		
Does the proposed research involve tracking the location or observation of people?		
I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL	YES	
Research on Animals	**YES/NO**	**PAGE**
Does the proposed research involve research on animals?		
Are those animals transgenic small laboratory animals?		
Are those animals transgenic farm animals?		
* Are those animals non-human primates?		
Are those animals cloned farm animals?		
I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL	YES	
Research Involving Developing Countries	**YES/NO**	**PAGE**
Does the proposed research involve the use of local resources (genetic, animal, plant, etc.)?		
Is the proposed research of benefit to local communities (e.g. capacity building, access to healthcare, education, etc.)?		
I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL	YES	
Dual use	**YES/NO**	**PAGE**
Research having direct military use		
Research having the potential for terrorist abuse		
I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL	YES	

B5. Consideration of gender aspects

The European Union has a long-standing commitment to promoting gender equality, protected in the Treaty since 1957 and the SEARCH project supports this policy.

According to the statistics of the EU of 2002, less than 35% of researchers in Europe are women and they are only 19% in Engineering science and technology. In the area of nuclear engineering this drops further down to less than 15%.

It is clear that the promotion of gender equality is an important element to be must be addressed in any organisational structure including this proposal since in R&D and especially in nuclear fields; women are underrepresented, as a consequence of the very low percentage of women graduating in nuclear engineering in the past.

The female participation in the SEARCH project in general and in the management is about 15% which corresponds to the EU average in nuclear engineering research.

Within the SEARCH project due attention will be paid to the following:

- A gender action plan will be implemented within the rules of the individual organisation of the consortium which will grant the respect of the needs of the female staff, as and when requested, related to the flexibility of hours, maternity leave requirements etc.
- The partners will encourage the gender equality in the project and take this into consideration when nominating new staff members in the frame of this project.
- Workshops and seminars organized during the SEARCH project will be accessible, whenever possible, for a wider public and give the students of various engineering disciplines the opportunity to learn more about nuclear engineering and to improve the gender balance in the long-term perspectives.

VOLGENDE BIJLAGEN BIJ GRANT AGREEMENTS IN HET ZEVENDE KADERPROGRAMMA ZIJN STANDAARDDOCUMENTEN:

Annex II - General Conditions - the same for all projects under Co-operation/Capacities, modified for ERC and Marie Curie (which both offer Single or Multi-beneficiary versions).
Annex III - Unique to the following funding schemes to provide extra conditions on finance or reporting:

- SME actions
- Integrating Activities (Research Infrastructures)
- ERA-NET Plus
- Civil Society Organisation (CSO) actions

Annex V - Form B - Request for the accession of a new beneficiary to an existing Grant Agreement, e.g. for a grant which is already up and running.
Annex VI - Form C - Financial Statement per funding scheme - used to report costs claimed at the end of reporting periods.
Annex VII

- Form D - Terms of reference of the certificate on the financial statements (known as the Audit Certificate in FP6)
- Form E - Terms of reference for the certificate on the methodology (new to FP7) to be used for beneficiaries who want to get average personnel costs certified and/or for those who are unable to calculate real indirect costs and want to have a simplified method of calculating these certified.

Alle documenten zijn te raadplegen op
http://www.ukro.ac.uk/subscriber_services/fp7/participation/grant_agreements.htm.
of op
http://cordis.europa.eu/fp7/calls-grant-agreement_en.html

A3.1: Budget

Project number [1]	295736	Project acronym [2]	SEARCH	Participant number in this project [10]	6	Participant short name [11]	UGENT

One Form per Participant

Funding % for RTD/Innovation activities (A) [40]	75.0%

Indirect costs [41]

- Actual indirect costs [42] ☐
- Simplified method [43] ☐
- Standard flat rate [44] ☐
- Special transitional flat rate [45] ☒

My legal entity is established in an ICPC [46] and I shall use the lump sum funding method **No**

	Type of Activity				
	RTD / Innovation (A)	**Demonstration (B)**	**Management (C)**	**Other (D)**	**Total A+B+C+D**
Personnel costs	104,130.00	0.00	0.00	0.00	104,130.00
Subcontracting	0.00	0.00	0.00	0.00	0.00
Other direct costs	8,370.00	0.00	0.00	0.00	8,370.00
Indirect costs	67,500.00	0.00	0.00	0.00	67,500.00
Total costs	180,000.00	0.00	0.00	0.00	180,000.00
Requested EU contribution	135,000.00	0.00	0.00	0.00	135,000.00
Receipts					0.00

WO-Fiche

WBS-Element: B/12681/01 Fonds: IV2 Gecreëerd/gewijzigd door: Nathalie VANDEPITTE 09 264 30 29

Kredietcode: 41K00111 Begindatum: 01/11/2011
Kredietnaam: SEARCH Einddatum: 31/10/2014
EC
Contractnummer: 295738 Titel: Safe ExploitAtion Related CHemistry for HLM reactors
Promotor: Prof. Veronique Van Speybroeck
Copromotor 1:
Copromotor 2: WO-Fiche: origineel
Copromotor 3: Versie: 1

Datum: 03/07/2011
Financieringsbron: 3722 BTW recuperatie
Vakgroepnummer: TW17
Gekoppelde Kredietcodes:
Gekoppelde WBS-elementen:
Promotor:

Vak Administratie

Contractueel Overhead-regime: procentueel

CTRL+N = nieuwe versie WO-fiche

CTRL+S = kopie extern budget naar SAP

Budgetdrager		EXTERN Netto-Budget (Excl. Overhead)	EXTERN OH (contract)	EXTERN Bedrag OH	INTERN Netto-Budget (Excl. Overhead)	INTERN OH (intern)	INTERN Bedrag OH	Toe te kennen budget Budget	SAP Budget	SAP WBS-element
Person		104.130,00	20,00%	20.826,00	104.130,00	17,00%	17.702,10	107.014,62		
Recuperatie OH					2.884,62	17,00%	490,39			
	RTD	104.130,00		20.826,00	104.130,00		17.702,10	104.130,00	104.130,00	B/12681/01
	2012	0,00			0,00				0,00	B/12681/01
	2013	0,00			0,00				0,00	B/12681/01
	2014	0,00			0,00				0,00	B/12681/01
	2015	0,00			0,00				0,00	B/12681/01
	2016	0,00			0,00				0,00	B/12681/01
Werking		8.370,00	20,00%	1.674,00	8.370,00	17,00%	1.422,90	8.370,00		
	RTD	8.370,00		1.674,00	8.370,00		1.422,90	8.370,00	8.370,00	B/12681/01
	2012	0,00			0,00				0,00	B/12681/01
	2013	0,00			0,00				0,00	B/12681/01
	2014	0,00			0,00				0,00	B/12681/01
	2015	0,00			0,00				0,00	B/12681/01
	2016	0,00			0,00				0,00	B/12681/01
		0,00	0,00%	0,00	0,00	0,00%	0,00	0,00		
	RTD	0,00			0,00				0,00	B/12681/01
	2012	0,00			0,00				0,00	B/12681/01
	2013	0,00			0,00				0,00	B/12681/01
	2014	0,00			0,00				0,00	B/12681/01
	2015	0,00			0,00				0,00	B/12681/01
	2016	0,00			0,00				0,00	B/12681/01
		0,00	0,00%	0,00	0,00	0,00%	0,00	0,00		
	RTD	0,00			0,00				0,00	B/12681/01
	2012	0,00			0,00				0,00	B/12681/01
	2013	0,00			0,00				0,00	B/12681/01
	2014	0,00			0,00				0,00	B/12681/01
	2015	0,00			0,00				0,00	B/12681/01
	2016	0,00			0,00				0,00	B/12681/01
		0,00	0,00%	0,00	0,00	0,00%	0,00	0,00		
	RTD	0,00			0,00				0,00	B/12681/01
	2012	0,00			0,00				0,00	B/12681/01
	2013	0,00			0,00				0,00	B/12681/01
	2014	0,00			0,00				0,00	B/12681/01
	2015	0,00			0,00				0,00	B/12681/01
	2016	0,00			0,00				0,00	B/12681/01
Netto-Inkomsten		112.500,00	20,000000%	22.500,00	115.384,62	17,000000%	19.615,39	115.384,62	Netto-Inkomsten	Moeten de inkomsten ingegeven worden in SAP? JA
Overhead financier		22.500,00			19.615,39			19.615,39	OH in SAP	
Bruto-inkomsten		135.000,00			135.000,01			135.000,01	Bruto-inkomsten	

Gem. OH-% op te nemen in SAP

17,00%

Omzetting vreemde munt

=

www.tijd.be/koersen/index.asp?page=wisselkoersen&view=

Datum:

Brutobedrag	OH-Percentage	Nettobedrag	OH
0,00	0,00%	0,0000	0,0000
0,00	0,00%	0,0000	0,0000

OH (vast bedrag)	Brutobedrag	Nettobedrag	OH-Percentage
0,00	0,00	0,0000	
0,00	0,00	0,0000	0,0000%

Aanmaak recup overhead B/12681/02 voor 2.884,62 EUR