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Euratom Contribution to the Generation IV International Forum Systems in the period 2005-2014 and future outlook

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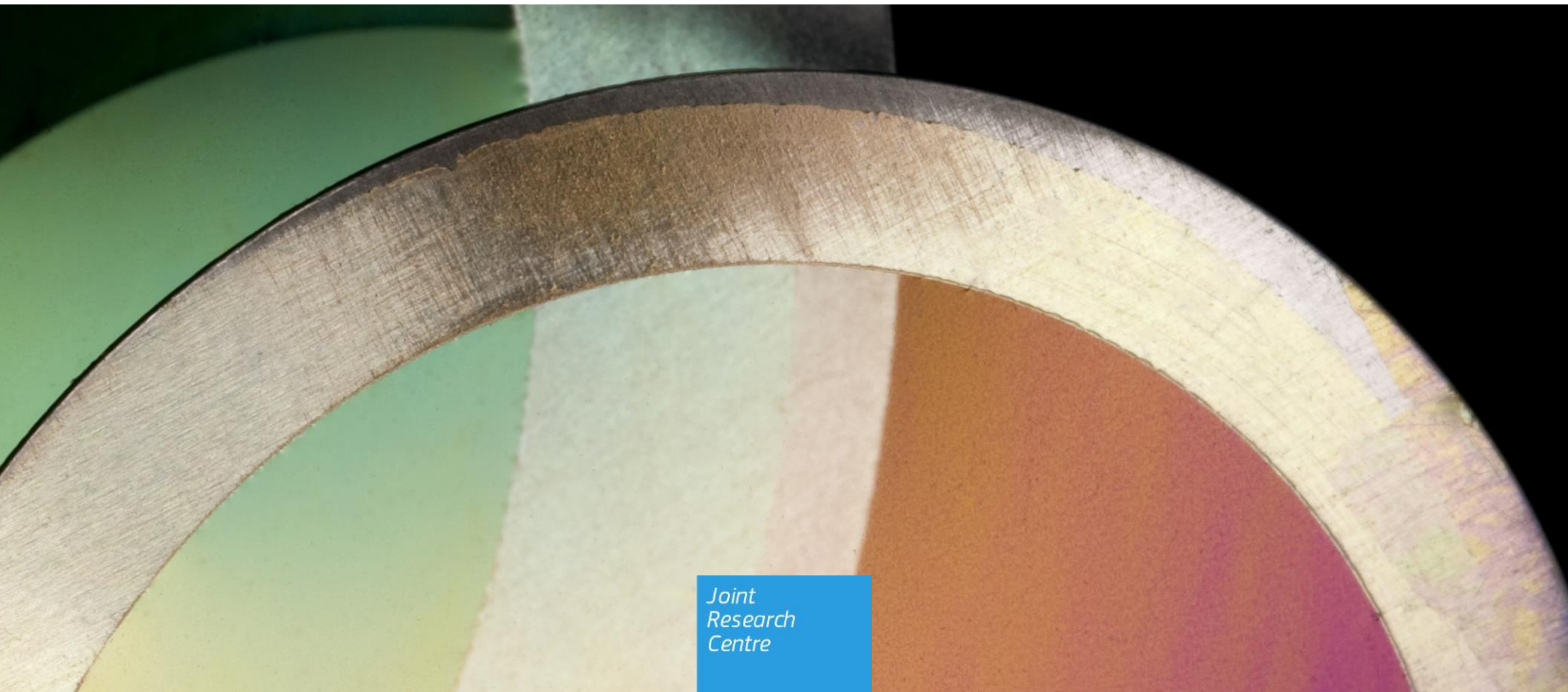

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Executive Summary

The "Generation IV International Forum" (GIF) is a nuclear-related research and development international programme launched in 2001. GIF is organized into six reactor system arrangements (SA) and within each system arrangement, specific project arrangements (PA) exist. The six reactor systems are: Sodium-cooled Fast Reactor (SFR); Lead-cooled Fast Reactor (LFR); Very High-Temperature Reactor (VHTR); Gas-Cooled Fast Reactor (GFR); Supercritical Water-Cooled Reactor (SCWR); Molten Salt Reactor (MSR). In addition, three cross-cutting methodology working groups (MWG) were created on Economic Modelling (EMWG), Proliferation Resistance and Physical Protection (PRPPWG), and on Risk and Safety (RSWG).

On the basis of an EU Commission Decision, Euratom adhered to GIF by signing in July 2003 the "Charter of the Generation IV Forum". Euratom then acceded to the International "Framework Agreement" among the Members of the Generation IV International Forum. The Joint Research Centre (JRC) of the European Commission is the Implementing Agent for Euratom within GIF. France is participating as an individual full member within GIF and only specific information will be given to complement any GIF reporting provided by France.

Euratom has been contributing to all six systems to allow all EU Member States (MS) to share research results in systems of their choice. This is necessary because EU MS are responsible of their own national energy mix strategy (e.g. by including specific nuclear systems (or not) within their energy mix).

This report analyses the best estimated contribution from Euratom over a 10years' period (2005-2014) with the objective to give an overview of the systems that have been supported together with potential future activities. The main focus of this report is on budget commitments and a summary of technical details of the activities performed in each respective system. As such, this report will not deal with a deep analysis of the "deliverables" exchanged within GIF systems that were provided to the respective system arrangements. On more technical details: (a) A special edition of the scientific review 'Progress in Nuclear Energy, vol.77', has also been published in November 2014, with a section dedicated to the 'Status of Generation IV Reactor Developments'[1], and progress made over the last decade; (b) in addition to the yearly GIF annual reports[2].

The Euratom technical contribution to the GIF systems can have three possible origins:

(1) Euratom DG RTD indirect actions,

(2) Euratom JRC direct actions,

(3) direct contributions from the EU Member States.

Data for (1) and (2) was retrieved from DG RTD/JRC co-financed projects and from MS over the past 10 years using internal projects archives together with publicly available data from the European Commission such as the European Commission R&D Information System (CORDIS[3]), the latest European Research Participant Portal[4], the European Commission Budget Financial Transparency System (FTS[5]). Data for (3) was obtained

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[1] Progress in Nuclear Energy, volume 77 http://www.sciencedirect.com/science/journal/01491970/77

[2] GIF annual reports https://www.gen-4.org/gif/jcms/c_44720/annual-reports

[3] CORDIS http://cordis.europa.eu/

[4] EU Participant Portal http://ec.europa.eu/research/participants/portal/desktop/en/home.html

[5] EU Financial Transparency System http://ec.europa.eu/budget/fts/index_en.htm

from MS feedback following a specific questionnaire survey integrating complementary information from the main stakeholders.

To summarise, in relation to all six systems supported by Euratom:

1. The share of "GIF-related projects" as compared to the "total number of Euratom RTD projects" has increased over the years, from 7 % under Framework Programme 5 (FP5), to 20 % under FP6 and 26 % under FP7. These projects selected following competitive call for proposals in the framework of the Euratom work programmes covered all six GIF systems but were mainly related to LFR (including Pb-Bi Accelerator Driven System (ADS) being MYRRHA today), then VHTR and SFR respectively. The total project budget was of around 256 MEUR (of which 136 MEUR of Euratom co-funded grants). Euratom fission work programmes are also supporting, in line with the strategy implemented by the European Commission together with EU Member States, key cross-cutting fields of nuclear safety such as: fuel developments, thermal hydraulics, materials research, numerical simulation and design activities of future reactor technologies, partitioning and transmutation, support to infrastructures, education, training and knowledge management, and international cooperation. Euratom projects dedicating only a large share (if not all) of their activities related to GIF systems have also been included in this report. Financial support to the OECD/NEA GIF secretariat is also constantly provided at a level of 120 kEUR on average on a yearly basis.

2. The JRC activity (type (2)) has complemented the EU indirect actions by contributing about 25 MEUR with its own specific funds to the six GIF systems with preference for SFR, LFR and VHTR respectively. This amount does not cover the JRC staff and infrastructure cost. An estimate of JRC 25-40 staff/year can be considered working for Generation IV activity during this period.

3. During this reporting period, EU MS have also invested through their national research programmes in several different GIF systems. France estimated its investment at 75 MEUR and increased to 102 MEUR from 2010 on a yearly basis on Generation IV R&D[6]. Belgium and Italy have been investing mainly in Lead (Lead-bismuth) system: SCK-CEN (Belgium) has also obtained a 60 MEUR grant from its government for the period 2010-2014 and an additional 30 MEUR from its budget towards MYRRHA R&D (Pb-Bi LFR and ADS). Italy has dedicated a 30 MEUR to LFR ALFRED reactor systems. Romania has also allocated around 6 MEUR for the innovative systems with a focus on LFR during the 10 years reporting period. Germany has allocated 3-4 MEUR for each of the 3 fast reactors technologies and VHTR. Finland has invested 0.5-1 MEUR for each of the 3 fast reactors, VHTR and SCWR. The Czech Republic has focused on SCWR (3 MEUR) and LFR (1 MEUR). The Netherlands invested in VHTR, SCWR, MSR and LFR with budgets of 0.4-0.8 MEUR each. Hungary has focussed on SCWR systems (0.6 MEUR) and on GFR (0.3 MEUR). Poland has invested 1.5 MEUR in the HTRPL

[6] Rapport Cour des Comptes 31/01/2012, Les coûts de la filière Électronucléaire (p.62) https://www.ccomptes.fr/content/download/1794/17981/file/Rapport_thematique_filiere_electronucleaire.pdf

project on VHTR. Spain has supported VHTR (0.5 MEUR), SFR (0.1 MEUR) and LFR (0.1 MEUR) R&D activities. Sweden has focussed on SFR (0.3 MEUR) and LFR (0.2 MEUR) and the UK on SCWR (0.5 MEUR).

4. Euratom also promotes research and training, innovation and demonstration of nuclear fission technologies to achieve the Strategic Energy Technology plan (SET Plan) objectives being:

- By 2020, (1) to maintain the safety and competitiveness in fission technology, and (2) to provide long-term waste management solutions; and
- By 2050, (3) to complete the demonstration of a new generation (Generation IV) of fission reactors with increased sustainability namely via the European Sustainable Nuclear Fission Industrial Initiative (ESNII), and (4) to enlarge nuclear fission applications beyond electricity production through the Nuclear Cogeneration Industrial Initiative (NC2I).

5. Within the European Sustainable Nuclear Industrial Initiative (ESNII), Sodium Fast Reactor (SFR) technology is considered to be the reference technology since it already has substantial technological and operations feedback in Europe. The ASTRID demonstrator (Advanced Sodium Technological Reactor for Industrial Demonstration) should be operational by 2030. Lead Fast Reactor (LFR) technology has significantly extended its technological base. MYRRHA, a Pb-Bi flexible irradiation facility supporting Fission/Fusion/radioisotope research is planned in Belgium by 2030 as a European Technology Pilot plant. LFR can be considered as the shorter-term alternative technology, supported by the FALCON consortium set up in December 2013 for the construction of a LFR demonstrator and comprising Italy's National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), ANSALDO Nucleare, the Romanian Nuclear Research Institute (RATEN ICN) and Reserch Center Řež (CV-Řež,CZ). Gas Fast Reactor (GFR) technology is considered to be a longer-term alternative option supported by the Visegrad 4 countries (CZ, SK, HU and PL). The 2015 Deployment Strategy of the Sustainable Nuclear Energy Technology Platform (SNETP) has identified these as EU priorities. The EU MS will continue to invest through their national programmes in different GIF systems. ASTRID SFR pre-conceptual design phase ended in December 2012 and approval was given by the French Government to continue all conceptual research activities - by providing a 650 MEUR grant managed by CEA. Romania will continue the research activities with at least 1MEUR/year under its National Programme on "Advanced Nuclear Reactors and Fuel Cycle" and intend to increase the efforts for the development of the experimental facilities in support of LFR and ALFRED construction. Germany, although having a 2022 phase out policy (since 2011 following Fukushima events), will continue supporting research in fast systems but also with the VHTR. Spain will continue supporting SFR, SCWR and LFR. The Czech Republic will continue its research in on SCWR and to a lesser extent MSR, GFR, VHTR and LFR systems. Finland has allocated resources for each of the 3 fast reactor systems, VHTR and SCWR. Sweden will continue supporting SFR and LFR. The Netherlands will continue investing with a similar financial effort the LFR and MSR. Hungary on the SCWR and the GFR system within ALLEGRO. Spain's focus will continue on SFR, SCWR and LFR.

6. Euratom support to all six systems is highly appreciated with a high impact as of pan-European added value. Euratom will also take into account the forthcoming Euratom Scientific and Technical Committee (STC) opinion from a sub-working group on Generation IV future Systems. FP7 Ex-post and H2020 mid-term evaluations of the Euratom framework programme will complement STC opinion.

Important to underline the potential national/European/International funding, financial and legal instruments to support the realisation of ESNII as a pan-European initiative in support to research infrastructures is being investigated taking into account the latest respective project and national investment plans, Deloitte Study from 2010, H2020 Research and Innovation, Cohesion Policy and the 2014-2020 Multi-Financial Framework programmes. The financial and legal assessment confirms that several mechanisms could provide the necessary support to upgrade existing key supporting infrastructures, to build new ones but also contribute to ESNII and its specific large scale projects, by using: (a) EIB loans, Euratom or H2020 InnovFin Risk Sharing Financial Facility (RSFF); (b) tax exemptions benefitting from a Joint Undertaking (or equivalent), or an International non-profit association (e.g. Belgian AISBL); (c) EU incentives or grants provided through Cohesion Policy funds and European Development Regional Funds (ERDF) dedicated to research infrastructures, centres of excellence and/or support from EU/Euratom Framework programmes; (d) Private investors, energy providers or research organisations; (e) National public research organisations; (f) public investments from the hosting country to support basic infrastructures as a host of a new facility; and (g) The European Fund for Strategic Investments (EFSI) so-called Juncker Plan where MYRRHA and ALLEGRO were indicated by the respective Belgian and Hungarian and Czech governments as potential projects beneficiaries on the short term.

In conclusion, a decade of GIF research has raised the technical research level of most systems significantly and Euratom has contributed to this by coordinating the effort of direct and indirect actions as well as EU MS projects. Much still needs to be done before Generation IV systems become a reality. In the coming decade, Euratom pan-European added value activities will focus on continuing R&D on Generation IV systems by: the development of advance research facilities; involving industry in the design of Generation IV systems; and developing the workforce for the future. Euratom and the EU MS will continue in the coming years to continue to invest in all six GIF systems.

The information in this document is a summary overview for EU stakeholders on Euratom and EU MS investments and commitments towards each of the six GIF systems over the 10 years’ period 2005-2014 and a future outlook. It is by no means exhaustive but provides clear indicators on the commitments on the systems of Euratom and the EU MS.

1 Introduction

The Generation IV International Forum (GIF) is a co-operative international endeavour which was set up in 2001 to carry out the research and development needed to establish the feasibility and performance capabilities of next generation nuclear energy systems.

The Generation IV International Forum has fourteen Members. The signatories of its founding document, the GIF Charter are: Argentina, Brazil, Canada, France, Japan, the Republic of Korea, South Africa, the United Kingdom and the United States signed the Charter in July 2001. Subsequently, it was signed by Switzerland in 2002, Euratom in 2003[7], and the People's Republic of China and the Russian Federation, both in 2006, and Australia in 2016. Signatories of the charter are expected to maintain an appropriate level of active participation in GIF collaborative projects.

Among the signatories to the charter, 10 members (Canada, France, Japan, the People's Republic of China, the Republic of Korea, the Russian Federation, South Africa, Switzerland, the United States and Euratom) have signed or acceded to the framework agreement (FA)[8] . Parties to the FA formally agree to participate in the development of one or more Generation IV systems selected by GIF for further research and development (R&D). Each party to the FA designates one or more implementing agents to undertake the development of systems and the advancement of their underlying technologies: the European Commission's Joint Research Centre (JRC) is the Implementing Agent for Euratom.

Argentina, Brazil and the United Kingdom have signed the GIF Charter but did not accede to the FA; accordingly, within the GIF, they are designated as "non-active members". France is an individual full member of GIF with respect to Euratom and therefore only brief information will be given to complement any specific GIF reporting provided by France.

The goals adopted by GIF provided the basis for identifying and selecting six nuclear energy systems for further development. The selected systems are based on a variety of reactor, energy conversion and fuel cycle technologies. Their designs include thermal and fast neutron spectra cores, closed and open fuel cycles. The reactors range in size from very small to very large. The six selected systems are: Sodium Fast Reactor (SFR); Lead-cooled Fast Reactor (LFR); Very High-Temperature Reactor (VHTR); Gas-Cooled Fast Reactor (GFR); Supercritical Water-Cooled Reactor (SCWR); Molten Salt Reactor (MSR). Depending on their respective degree of technical maturity, the first Generation IV systems are expected to be deployed commercially around 2030-2040.

A recent technical and strategic summary from all GIF signatories can be found in a dedicated special edition of Progress in Nuclear Energy[9]. In addition, GIF regular issues annual progress reports on its research and development activities[10].

The scope of this report is to give an overview of Euratom research and development activities in support to the six Generation IV International Forum (GIF) nuclear reactor

[7] COMMISSION DECISION C(2002)4287 of 4 November 2002 concerning the conclusion of the Technical Exchange and Cooperation Arrangement between the European Atomic Energy Community (Euratom) and the Department of Energy of the United States of America in the field of nuclear-related research and development and the adhesion of Euratom to the "Charter of the Generation IV Forum""."

[8] COMMISSION DECISION C(2006)7 of January 12 2006 concerning the accession of the European Atomic Energy Community (Euratom) to an international Framework agreement among members of the Generation IV International Forum in the field of nuclear related research.

[9] Progress in Nuclear Energy 77 (2014)

[10] www.gen-4.org

systems including estimated budgetary figures over the last 10 years (2005-2104). It will summarize from the point of view of budgetary expenditures what has been done in the past 10 years (2005-2014) and will identify the planned forthcoming work for Euratom and the EU MS.

Three extensive investigations were conducted in order to obtain the necessary data to produce this report. The first two consisted in going through all the existing Euratom Fission Projects of FP5[11], FP6[12], FP7[13] and Horizon 2020[14] - RTD indirect and JRC direct - actions during the 10 year reporting period and identifying those that had a significant contribution to the GIF Systems. Euratom fission work programmes are supporting key cross-cutting fields of nuclear safety, fuel developments, thermal hydraulics, materials research, numerical simulation and design activities of future reactor technologies, partitioning and transmutation, support to infrastructures, education, training and knowledge management, and international cooperation. A third investigation was done by carrying out a survey with the EU MS on their past and future activities within the six GIF Systems. Due to the long reporting period investigated, this information may be incomplete.

The main part of the report is focused mainly on budget resources that have been involved and extract trends based on them. The annexes deal with the technical details of the projects.

Chapter 2 deals with the types of Euratom Contribution and its estimated budget breakdown. Chapter 3 gives an overview of key EU/Euratom legislation updates, relevant initiatives, technology platforms and fora launched under FP7, committees, and potential support to investment needs. Chapter 4 gives details of the projects supporting Generation IV within Euratom RTD indirect and JRC direct actions. Chapter 5 highlights the results of EU MS 10 years' 2005-2014 survey. Chapter 6 summarises any future outlook of Euratom and its Member States in the frame of GIF. Three annexes give further summary details of the specific technical RTD – JRC – EU MS activities in contribution to GIF.

[11] COUNCIL DECISION of 25 January 1999 adopting a research and training programme (Euratom) in the field of nuclear energy (1998 to 2002) (1999/175/Euratom)

[12] - COUNCIL DECISION of 30 September2002 adopting a specific programme for research, technological development and demonstration to be carried out by the Joint Research Centre (2002-2006), (2002/836/EC)
- COUNCIL DECISION of 30 September 2002 adopting a specific programme (Euratom) for research and training on nuclear energy (2002-2006), (2002/837/EC)
- COUNCIL DECISION of 30 September 2002 adopting a specific programme for research and training to be carried out by the Joint Research Centre (2002-2006), (2002/838/Euratom)

[13] - COUNCIL DECISION of 2006/970/Euratom of 18 December 2006 concerning the Seventh Framework Programme of the European Atomic Energy Community (Euratom) for nuclear research and training activities (2007 to 2011)
- COUNCIL DECISION of 2006/975/EC of 19 December 2006 concerning the specific programme to be carried out by means of direct actions by the Joint Research Centre under the Seventh Framework Programme of the European Community for research, technological development and demonstration activities (2007 to 2011)
- COUNCIL DECISION of 19 December 2011 concerning the Framework Programme of the European Atomic Energy Community for nuclear research and training activities (2012 to 2013)
- COUNCIL DECISION of 19 December 2011 concerning the specific programme, to be carried out by means of direct actions by the Joint Research Centre, implementing the Framework Programme of the European Atomic Energy Community for nuclear research and training activities (2012-2013)

[14] COUNCIL REGULATION (EURATOM) No 1314/2013 of 16 December 2013 on the Research and Training Programme of the European Atomic Energy Community (2014-2018) complementing the Horizon 2020 Framework Programme for Research and Innovation

2 Types of contribution linked to Generation IV reactor systems

Euratom is historically present in all GIF systems in order to allow the EU Member States to participate in any specific reactor system of their choice. This report address the specific contribution of Euratom and of its MS (France and Switzerland (associated to Euratom) being stand-alone partners in addition to Euratom) for each of the six GIF systems. Careful attention was paid to avoid double accounting of any project/funding. EU contribution is provided through:

1. European Commission DG RTD projects (Euratom indirect actions)
2. European Commission's Joint Research Centre (JRC) projects (Euratom direct actions)
3. Complementary Direct contribution of an EU MS (public and private)

Contributions of type 1 and 2 are funded (respectively: partially and totally) by all the EU MS via the Euratom Research framework programmes (i.e. FP6 (2002-2006), FP7 (2007-2013), Horizon2020 (2014-2018)) following competitive call for proposals and contributions from all EU MS are automatically present in types 1 and 2 but in very different proportions.
It is important to note that Switzerland (CH), although not an EU MS, is fully associated to the Euratom framework programmes as it contributes financially to it, and benefits from its participation to DG RTD projects.

For type 1 above (see fig 1), the total allocated budget of a generic DG RTD project can be provided as follows:

1a) EU Grant (source: all EU MS + CH) - usually approx. 50% of the total budget
1b1) EU MS Consortium (public and private) that has been awarded the project (which covers a fraction of all the EU MS).
1b2) CH (if member of the consortium)
1b3) JRC (if member of the consortium)
1b4) international partners (if members of the consortium)

For type 2, the funding originates from the all EU MS + CH.

For type 3, the funding is entirely from the MS.

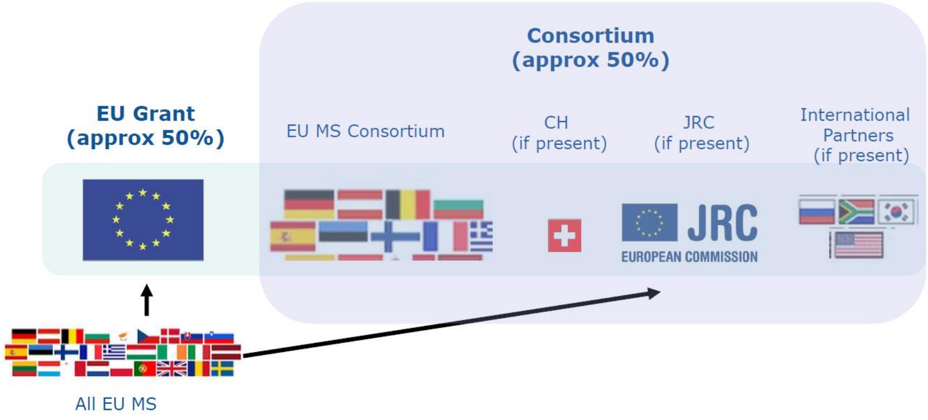

Figure 1 – Average breakdown of the total allocated budget of a generic DG RTD project co-funded

For points 1 and 2 France and Switzerland have to be considered for the appropriate breakdown of the budget as they also contribute within the framework of Euratom projects following competitive call for proposals.
For type 3 contribution, given that France is participating individually in GIF, this report will only cover indicative summary information.

3 Euratom Activity supporting Generation IV reactor systems

The European Commission promotes and facilitates through the Euratom Framework Programmes nuclear research activities in EU Member States and complements them through its specific Community research and training activities. Within this scope, the EC helps to stimulate joint funding from Member States and/or enterprises, and benefits are being capitalised from the increasing interaction between technology platforms launched during the 7th Framework Programme, namely:

- the 'Sustainable Nuclear Energy Technology Platform' (SNETP incorporating NUGENIA Generation II&III water cooled reactor technology, ESNII Generation IV fast reactors employing the closed fuel cycle, and NC2I Cogeneration of electricity and heat);
- the 'Implementing Geological Disposal of Radioactive Waste Technology Platform' (IGDTP);
- the 'Multidisciplinary European Low Dose Initiative' (MELODI),
- the European Energy Research Alliance (EERA) Joint Programme in Nuclear Materials (JPNM)

and other EU stakeholder fora (ENEF, ENSREG, WENRA, ETSON, FORATOM, etc.), as well as OECD/NEA and IAEA at the international level.

During the last 10 years Euratom activity in support to Generation IV reactor systems has been consistent, relatively modest through direct support to projects and specific GIF technologies but rather significant support is provided through cross-cutting fields namely nuclear safety, fuel developments, thermal hydraulics, materials research, numerical simulation and design activities of future reactor technologies, partitioning and transmutation, support to infrastructures, education, training and knowledge management, and international cooperation. Community legislation has been updated for current reactors but also applicable to Generation IV. Benefits from collaborative research are being capitalised. EU technology platforms have identified and prioritized Generation IV reactor systems in the framework of ESNII. Scientific and technical Committees are providing recommendations on future systems and EU Member states have clearly committed themselves in research and innovation towards specific reactor systems.

3.1 Euratom Legislation

3.1.1 Directive on Nuclear Safety from 2009 (amended in 2014)[15]

A common nuclear safety legal framework was set up in the European Union through the adoption of the Nuclear Safety Directive on 25 June 2009. With it, the EU has become the first major regional nuclear actor to provide a legally binding framework for nuclear safety, largely based on the Fundamental Safety Principles established by the International Atomic Energy Agency (IAEA) and on the obligations originating from the IAEA's Convention on Nuclear Safety. In 2014, the European Commission adopted legislative measures to further enhance nuclear safety in Europe by amending the directive and including the lessons learned from the Fukushima nuclear accident, the EU nuclear stress tests, the safety requirements of the Western European Nuclear Regulators Association (WENRA) and the International Atomic Energy Agency (IAEA). This Directive strengthens the power and independence of national regulatory

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[15] Council Directive 2014/87/Euratom of 8 July 2014 amending Directive 2009/71/Euratom establishing a Community framework for the nuclear safety of nuclear installations - http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2014.219.01.0042.01.ENG

authorities, introduces a high-level EU-wide safety objective to prevent accidents and avoid radioactive releases, sets up a European system of peer reviews by competent regulatory authorities on specific safety issues every six years, increases transparency on nuclear safety matters by informing and involving the public, and promotes an effective nuclear safety culture. The new legislative measure affects the current nuclear reactors and the development of any EU Generation IV concepts.

3.1.2 Directive on the management of spent fuel and radioactive waste 2011[16]

The directive on the management of spent fuel and radioactive waste was adopted in July 2011. With this new framework, the EU Member States have been required to submit national radioactive waste management programmes to the EC. These should include specific targets and timeframes, inventories, estimations of the cost of the programme and how they will be financed. The directive recognises the importance of deep geological repositories as the option of choice. Each Member State remains responsible for its waste management strategies and implementation. This directive is also applicable to all waste originating from Generation IV systems.

3.1.3 Directive on Basic Safety Standards 2013[17]

The Euratom Community has established a set of basic safety standards to protect workers, members of the public and patients against the dangers arising from ionising radiation. These standards also include emergency procedures that were strengthened following the Fukushima nuclear accident.

The Basic Safety Standards ensure: a) protection of workers exposed to ionising radiation, such as workers in the nuclear industry and other industrial applications, medical staff and those working in places with indoor radon or in activities involving naturally occurring radioactive material; b) protection of members of the public, for example from radon in buildings; c) protection of medical patients, for example by avoiding accidents in radio-diagnosis and radiotherapy; d) strengthened requirements on emergency preparedness and response incorporating lessons learnt from the Fukushima accident.

3.1.4 EU Research and Development framework programmes

The Euratom Framework Programme (FP) for nuclear research and training activities supports EU research in nuclear fission safety, radiation protection, safeguards and security, and fusion.

FP programmes are divided in 3 broad topics: (a) indirect actions on nuclear fusion, (b) indirect actions for nuclear fission and radiation protection; (c) direct actions including nuclear safety, safeguards and crosscutting activity implemented by the JRC. This report covers the contribution of points b) and c) towards GIF systems only.

Since the 5th Framework programme (FP5) in 1998, the global funding for EURATOM indirect actions is almost constant. As this report covers the period 2005-2014 it therefore includes: FP6 (2002-2006), FP7 (2007-2011) and FP7 extension (2012-2013), and Horizon 2020 (H2020 2014-2018). Construction of ITER is funded through the EU Multi-Financial Framework (2985 MEUR within MFF 2014-2020) but outside H2020[18]. The

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[16] COUNCIL DIRECTIVE 2011/70/EURATOM of 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste

[17] Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2014.013.01.0001.01.ENG&toc=OJ:L:2014:013:TOC

[18] ITER funding within MFF but outside H2020 http://ec.europa.eu/budget/mff/programmes/index_en.cfm#iter

following table summarises the global allocated budget in millions of EUR for each Framework Programme for indirect and direct actions.

	FP6 (2003-2006)	FP7 (2007-2011)	FP7extension (2012-2013)	Horizon 2020 (2014-2018)
Indirect Actions Fusion	824	1947	2208	727 [19]
Indirect Actions Fission	209	287	118	316
Direct Actions JRC	319	517	233	560

Table 1 – Allocated budget for Euratom FP6, FP7 and H2020 (MEUR)

In the reported period of 2005-2014, the Euratom Funding for Indirect actions Fission was in the range of 55-65 MEUR/year while the one for the JRC (direct actions) in the range of 100-115 MEUR/year. Whereas the Indirect action amount indicates the total budget available for grants, the JRC amount also includes staff and infrastructure costs. The JRC budget excluding staff and infrastructure costs for all nuclear research was in the order of 10-15 MEUR/year.

Indirect Actions Fission - Work Programme
Generation IV systems were addressed in all FPs indirect actions. In FP6 there was a sub-topic "Innovative concepts" in the domain "Other activities of nuclear technology and safety"; in FP7, the topic "Potential of advanced nuclear systems" which becomes more specific for the calls in 2011 and 2012 (extension part of FP7), with sub-topics "Generation IV nuclear systems and the European Sustainable Nuclear Industrial Initiative (ESNII)", "Crosscutting activities and ESNII", and "Advanced reactor systems". In Horizon 2020 call 2014-2015 Generation IV can be found in "Cluster A: Support Safe Operation on Nuclear Systems" with: "NFRP1-2014 Improved safety design and operation of fission reactors"; in "NFRP3-2014 New innovative approaches to reactor safety" and in NFRP9–2015: Transmutation of minor actinides (Towards industrial application)". Euratom fission work programmes are also supporting key cross-cutting fields of nuclear safety, fuel developments, thermal hydraulics, materials research, numerical simulation and design activities of future reactor technologies, partitioning and transmutation, support to infrastructures, education, training and knowledge management, and international cooperation.
The GIF programme activities within Euratom indirect actions increased over the years: 7 % under FP5, 20 % under FP6, 26 % under FP7; and 18.5% following the first call of H2020 (2014-2015).

Direct Actions JRC - Work Programme
Generation IV systems were addressed in the JRC's work programme direct actions: in FP7: "nuclear safety, in implementing research …. on new reactor design. In addition the JRC will contribute to, and coordinate, the European contribution to the Generation IV International Forum R&D initiative… ". "…. contribute to those areas that can improve safety and safeguard aspects of innovative fuel cycles, the development of safety and quality goals, safety requirements and advanced evaluation methods for systems;", in

[19] The EU contribution for ITER is not included in the Euratom Horizon 2020 Research and Training programme as it was in the previous ones.

FP7 extension: "Research will also address reactor safety of new innovative designs, safety and safeguard aspects of innovative fuel cycles, extended burn-up or of new types of fuels…. In addition the JRC will coordinate the European contribution to the Generation IV International Forum R & D initiative, by acting as integrator and disseminating research in this area" and in Horizon2020: "The JRC shall contribute to the development of tools and methods to achieve high safety standards for nuclear power reactors and fuel cycles relevant to Europe."…"As the Euratom Implementing Agent for the Generation IV International Forum (GIF), the JRC shall continue to coordinate the Community contribution to GIF".
JRC's direct actions contribution to Generation IV systems in this period has ranged in similar proportions as for the Indirect Actions (between 10-20% of the total budget). This amount does not cover JRC staff/infrastructure costs. An estimate of JRC 25-40 staff/year can be considered working for Generation IV activity during this period

3.2 Sustainable Nuclear Energy Technology Platform (SNETP)

The EU has committed for the year 2020 to: reduce by 20% its GHG emissions (compared to 1990), make 20% energy savings and include 20% share of renewable energies in its total energy mix, aiming in the long-term to attain a low-carbon economy in Europe. To reach these goals, the EU Strategic Energy Technology Plan (SET-Plan) identifies a set of competitive low-carbon energy technologies to be developed and deployed in Europe, with nuclear fission representing a key contribution.

In this frame, nuclear fission technology priority area is supported through the Sustainable Nuclear Energy Technology Platform (SNETP)[20] launched in 2007 with the support of the European Commission, and its European Sustainable Nuclear Industrial Initiative (ESNII) promoting research, development and demonstration of nuclear fission technologies. SNETP gathers European stakeholders from industry, research and academia, technical safety organisations, non-governmental organisations and national representatives. SNETP has identified three pillars: NUGENIA Gen II III water cooled reactor technology, ESNII Generation IV fast reactors employing the closed fuel cycle, and NC2I Cogeneration of electricity and heat. Latest research and innovation agendas, technology roadmaps, deployment strategies and implementation plans of stakeholder groups and organisations have been published [21] [22].

3.2.1 NUGENIA – Nuclear Generation II and III Association

NUGENIA[23] is the first pillar of SNETP. It is an association supporting research and development of nuclear fission technologies, with a focus on Generation II and III. It gathers stakeholders from industry, research, safety organisations and academia, committed to develop joint R&D projects in the field. NUGENIA integrates on the past success of a European Commission-supported network called NULIFE, and the SARNET network. The work of NUGENIA is organised in eight technical areas, within a general scope defined by the Strategic Research and Innovation Agenda published by SNETP.

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[20] SNETP http://www.snetp.eu/
[21] SNETP 2013 SRiA http://www.snetp.eu/strategic-research-and-innovation-agenda/
[22] SNETP 2015 Deployment Strategy http://www.snetp.eu/deployment-strategy/
[23] NUGENIA http://nugenia.org/

3.2.2 ESNII - European Sustainable Nuclear Industrial Initiative

The European Sustainable Nuclear Industrial Initiative[24] is the second pillar of SNETP. ESNII is devoted to R&D on fast neutron reactors with closed fuel cycles, and sustainable nuclear energy thanks to a better use of the uranium resource through plutonium breeding and recycling. The main objective of ESNII is also to maintain and enhance European leadership in fast spectrum reactor technologies.
Sodium Fast Reactor (SFR) technology is considered to be the reference technology since it already has substantial technological and operations feedback in Europe. The ASTRID demonstrator (Advanced Sodium Technological Reactor for Industrial Demonstration) should be operational by 2030. MYRRHA, a Pb Bi flexible irradiation facility supporting Fission/Fusion/radioisotope research is planned in Belgium by 2030 as a European Technology Pilot plant (not in GIF but contributing to key cross-cuttings activities within GIF such as Partitioning and Transmutation (P&T)). Lead Fast Reactor (LFR) technology has significantly extended its technological base. It can be considered as the shorter-term alternative technology, supported by FALCON consortium set up in December 2013 for the construction of a LFR demonstrator and comprising Italy's National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), ANSALDO Nucleare, the Romanian Nuclear Research Institute (RATEN ICN) and CV-Řež (CZ). Gas Fast Reactor (GFR) technology is considered to be a longer-term alternative option supported by the Visegrad 4 countries (CZ, SK, HU and PL).

ASTRID (Advanced Sodium Technical Reactor for Industrial Demonstration)[25]
ASTRID will allow Europe to demonstrate its capability to master the sodium technology with improved safety characteristics. Its 600 MWe design integrates operational feedback of past and current reactors and is a Generation IV integrated technology demonstrator to be built in France. The reactor shall provide capability for demonstration of transmutation of minor actinides, at larger scale than previously done in Phénix. An associated research and development programme led by CEA (FR) will continue to accompany and support the development of ASTRID, to increase the robustness of this technology, and allow the goals of Generation IV to be reached, not only on safety and proliferation resistance, but also related to economic and sustainability of nuclear.

MYRRHA (Multipurpose Hybrid Research Reactor for High-tech Applications)[26]
MYRRHA is a flexible fast spectrum research facility in support of the technology development (in particular for material, components and fuel irradiation tests) of the three fast reactor technologies (SFR, LFR and GFR) to be built in Mol, Belgium. Since MYRRHA will be conceived as an Accelerator Driven System (ADS), not directly linked to GIF, it will be able to demonstrate the ADS technology, thereby allowing the technical feasibility of one of the key components in the double strata strategy for high-level waste transmutation to be evaluated. Due to the fact that MYRRHA will be based on heavy liquid metal technology (namely lead-bismuth eutectic), it can serve the role of Lead Fast Reactor European Experimental Technology Pilot Plant (ETPP) as identified in the LFR roadmap.

ALFRED (Advanced Lead Fast Reactor European Demonstrator)
ALFRED is seen as a prelude to an industrial demonstration unit of about 600 MWe. The lead-cooled reactor will employ mixed-oxide (MOX) fuel and will operate at temperatures of around 550°C. It features passive safety systems. The demonstration unit will be built at ICN facility in Mioveni, Romania, where a fuel manufacturing plant is in operation for the country's two operating Candu reactors. The overall long-term plan of ALFRED

[24] ESNII http://www.snetp.eu/esnii/
[25] ASTRID http://www.cea.fr/Pages/domaines-recherche/energies/energie-nucleaire/astrid-option-quatrieme-generation.aspx?Type=Chapitre&numero=3
[26] MYRRHA http://myrrha.sckcen.be/

includes two phases: First step (2015-2025): ALFRED experimental infrastructures, experiments and design with a strong effort in technology development; Second step (2025-35) fostering the construction of ALFRED.

ALLEGRO

The ALLEGRO project started in 2010 by signing a MoU by UJV (CZ), VUJE (SK) and AEKI/EK (HU), with an scientific support from CEA. The new legal entity "V4G4 Centre of Excellence" (Visegrad 4 countries for Generation 4 reactors) was introduced in July 2013 and includes Poland. A new strategy for ALLEGRO reactor was set in April 2014 (reducing power of previous ALLEGRO designs from 75 MWth to circa 10 MWth; finding optimum core configuration; increasing main blower inertia; use UO2 pellets instead of MOX pellets).

Within the ALLEGRO project the tasks and responsibilities are shared among countries: Hungary monitors and analyses the closed fuel cycle and fuel issues; the Czech Republic performs the technological utilisation of high-temperature gas testing; Slovakia party deals with planning, security testing and the preparatory works for designing and establishing a non-nuclear mock-up of ALLEGRO; the Polish party will be responsible for the material testing. The Czech Sustainable Energy Project (SUStainable ENergy, SUSEN) is funded by the European Regional Development Fund (ERDF). It is implemented as a regional R&D centre located at the CVR, and is supporting R&D towards ALLEGRO.

ESNII priorities

The main goal of ESNII is to design, license, construct, commission and put into operation from 2030 the Sodium Fast Reactor Prototype reactor (ASTRID) and the flexible fast spectrum lead cooled ADS research facility MYRRHA. In parallel to the realisation of ASTRID and MYRRHA, activities around the Lead Fast Reactor technology and the Gas Fast Reactor technology will be continued, taking into account their specific needs. At the end of 2012, a prioritisation exercise was performed by all ESNII members based on maturity of the reactor technologies, needs for R&D including fuel cycle technologies, supporting infrastructures, resources and financial capabilities available mainly at MS level.

Sodium was considered to be the reference technology since it has more substantial technological and reactor operations feed-back. The Lead (Lead-bismuth) Fast Reactor technology had significantly extended its technological base and could be considered as the shorter-term complementary technology (with the ADS), whereas the Gas Fast Reactor technology still has to be considered as a longer-term alternative option.

The second strategic priority made within ESNII lies in the different building blocks for the fuel cycle technologies: a fuel fabrication plant for fast reactor MOX driver fuel (pelletized); a reprocessing plant; a dedicated fuel fabrication facility for transmutation fuel. The important technical choice for palletised fast reactor MOX fuel pledge for the harmonization of fast reactor fuel R&D in Europe, which is not the case in other international R&D community (GIF) – where both metallic and nitride/carbide fuel are considered.

3.2.3 NC2I - European Nuclear Cogeneration Industrial Initiative

In parallel to NUGENIA and ESNII, the European Nuclear Cogeneration Industrial Initiative (NC2I) [27] is the third pillar of SNETP. It is dedicated to demonstrate an innovative and competitive energy solution for the low-carbon cogeneration of heat and electricity based on nuclear energy.

Cogeneration technologies could extend the low carbon contribution from nuclear fission to the energy system by directly providing heat for different applications like: process

[27] NC2I http://www.snetp.eu/nc2i/

heat; sea water desalination, contribution to transportation by synthetic fuels or hydrogen production, and district heating. The main objective of nuclear co-generation is to make nuclear power present in a broader way in district heating and industrial/process heat supply thus reducing massive quantities of fossil fuel.
The best answer to market needs to nuclear co-generation is a reactor of small to medium power. VHTRs with power ranges up to 600 MWth, with attractive safety features, have the ability to provide heat at temperatures utilized by the process steam market (in EU: 87 GWth at < 600°C). For some part of the market requiring lower temperatures, Small Modular Reactors of other technologies could also be suitable.

3.3 EERA JPNM - European Energy Research Alliance – Joint Programme on Nuclear Materials

The objective of the European Energy Research Alliance Joint Programme on Nuclear Materials (EERA-JPNM)[28] is to improve safety and sustainability of Nuclear Energy by focusing on materials aspects. The main objectives are: a) Better knowledge of materials behaviour under operating conditions, seeking predictive capability, to select the most suited materials and define safe design rules, especially allowing for radiation and temperature effects, while considering the compatibility with coolants; b) development of innovative materials with superior capabilities, resistant to high temperature and aggressive environments.

The first sub-programme deals with materials R&D for ESNII demonstrators and prototypes. The early ESNII systems will rely on commercially available materials such as austenitic steels, ferritic/martensitic steels, and Ni-based alloys that need to be qualified for the harsh conditions and 60 years design life. A pre-normative R&D programme for structural and cladding materials has been initiated including: updating of Design Codes for high temperature applications, considering the new reactor coolants and 60 years design lives; test and screening procedures for material properties in heavy liquid metals; assessment of protective coatings; and test programme to improve the understanding of the involved environmental degradation mechanisms, such as liquid metal embrittlement.

3.4 The Euratom Scientific and Technical Committee (STC)

The Euratom Scientific and Technical Committee (STC) is established by the Euratom Treaty (Articles 7, 8, and 134)[29] as a consultative body to the Euratom research program. It meets on regular basis twice a year and provides opinions (or recommendations) on the activity of the Euratom direct and indirect actions (fission and fusion). FP7 Ex-post and H2020 mid-term evaluations of the Euratom framework programme also complement STC opinion on Euratom support to Generation IV systems.

The STC has recently been working on a report on "future systems". This report will include an evaluation of ESNII systems, small modular reactors, fuel cycle issues, partitioning and transmutation, thorium, Molten Salt Reactors, and Radioactive Waste management. Its main goal is to provide recommendations for Horizon 2020 Euratom research and training programmes and further

This report is due to be released by the early of 2017.

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[28] EERA-JPNM http://www.eera-jpnm.eu/
[29] CONSOLIDATED VERSION OF THE TREATY ESTABLISHING THE EUROPEAN ATOMIC ENERGY COMMUNITY, 2012/C 327/01

3.5 Potential legal and financial opportunities with (or without) EU support

Potential national/European/International funding, financial and legal instruments to support the realisation of ESNII as a pan-European initiative in support to research infrastructures is being investigated taking into account the latest respective project and national investment plans, Deloitte Study from 2010, H2020 Research and Innovation, Cohesion Policy and the 2014-2020 Multi-Financial Framework proposals. The financial and legal assessment confirms that several mechanisms could provide the necessary support to upgrade existing key supporting infrastructures, to build new ones but also contribute to the industrial initiative (ESNII) and its specific large scale projects, by using: (a) EIB loans, Euratom[30] or H2020 InnovFin[31] Risk Sharing Financial Facility (RSFF); (b) tax exemptions benefitting from a Joint Undertaking (or equivalent), or an International non-profit association (e.g. Belgian AISBL); (c) EU incentives or grants provided through Cohesion Policy funds and European Development Regional Funds[32] (ERDF) dedicated to research infrastructures, centres of excellence and/or support from EU/Euratom Framework programmes; (d) Private investors, energy providers or research organisations; (e) National public research organisations; (f) public investments from the hosting country to support basic infrastructures as a host of a new facility; and (g) The European Fund for Strategic Investments[33] (EFSI) so-called Juncker Plan where MYRRHA and ALLEGRO were indicated by the respective Belgian and Slovak governments as potential projects beneficiaries on the short term.

[30] EC DG ECFIN Euratom loans http://ec.europa.eu/economy_finance/financial_operations/investment/euratom_loans/index_en.htm

[31] EIB InnovFin http://www.eib.org/products/blending/innovfin/

[32] European Regional Development Fund http://ec.europa.eu/regional_policy/en/funding/erdf/

[33] EFSI http://ec.europa.eu/priorities/jobs-growth-and-investment/investment-plan_en and http://www.eib.org/efsi/index.htm

4 Euratom Activity in GIF Systems

This section addresses Euratom indirect and direct R&D actions contributing to each of the six GIF reactor systems including key cross-cutting projects in the fields of nuclear safety, fuel developments, thermal hydraulics, materials research, numerical simulation and design activities of future reactor technologies, partitioning and transmutation, support to infrastructures, education, training and knowledge management, and international cooperation.

4.1 Indirect Actions

The following table summarizes the Euratom indirect fission actions (or projects) originating from FP5, FP6, FP7 that are considered as contributing to the six GIF Systems [34]. Distinction in this table is made for LFR vs LFR/ADS and VHTR vs VHTR/Cogen H2 activities.

Project Name	Date	SFR	LFR	LFR/ ADS	VHTR	VHTR/ Cogen+H2	GFR	SCWR	MSR
FP5 MICANET	2001-2005				x	x			
FP6 GCFR	2005-2009						x		
FP6 RAPHAEL	2005-2010				x	x			
FP6 EUROTRANS	2005-2010		x	x					
FP6 PATEROS	2006-2008	x	x	x			x		
FP6 PUMA	2006-2009				x				
FP6 VELLA	2006-2009		x						
FP6 ELSY	2006-2010		x						
FP6 HPLWR Phase 2	2006-2010							x	
FP6 EISOFAR	2007-2008	x							
FP6 ALISIA	2007-2008								x
FP7 HYCYCLES	2008-2011				x	x			
FP7 F-BRIDGE	2008-2012	x	x				x		
FP7 CARBOWASTE	2008-2013				x				
FP7 GETMAT	2008-2013	x	x						
FP7 EUROPAIRS	2009-2011					x			
FP7 CDT	2009-2012		x	x					
FP7 CP-ESFR	2009-2013	x							
FP7 FAIRFUELS	2009-2015	x	x						
FP7 ADRIANA	2010-2011	x	x	x	x		x		
FP7 HeLiMnet	2010-2012	x	x	x					
FP7 ANDES	2010-2013	x	x				x		
FP7 LEADER	2010-2013		x						
FP7 ARCAS	2010-2013	x	x	x			x		

[34] More information can be found in annex 1 of this document or on the European Commission's CORDIS website (http://cordis.europa.eu) .

Project Name	Date	SFR	LFR	LFR/ ADS	VHTR	VHTR/ Cogen+H2	GFR	SCWR	MSR
FP7 GOFASTR	2010-2013						x		
FP7 EVOL	2010-2013								x
FP7 THINS	2010-2015	x	x	x	x		x	x	
FP7 ADEL	2011-2013				x	x			
FP7 MAX	2011-2014			x					
FP7 SILER	2011-2014	x	x		x		x	x	x
FP7 MATTER	2011-2014	x	x	x			x		
FP7 SCWR-FQT	2011-2014							x	
FP7 ARCHER	2011-2015				x	x			
FP7 JASMIN	2011-2015	x							
FP7 SEARCH	2011-2015		x	x					
FP7 FREYA	2011-2016		x	x					
FP7 ALLIANCE	2012-2015						x		
FP7 ASGARD	2012-2016	x	x				x		
FP7 SARGEN_IV	2012-2013	x	x	x			x		
FP7 PELGRIMM	2012-2015	x							
FP7 MAXSIMA	2012-2018		x	x					
FP7 NC2I-R	2013-2015				x	x			
FP7 ARCADIA	2013-2016	x	x		x		x	x	x
FP7 MARISA	2013-2016			x					
FP7 SACSESS	2013-2016	x	x				x		
FP7 ESNII PLUS	2013-2017	x	x	x			x		
FP7 MatISSE	2013-2017	x	x	x			x		

Table 2 – Main Euratom R&D indirect actions (FP5, FP6, FP7) contributing to the GIF Systems

Several indirect actions are considered cross-cutting to some GIF system so a weighing rule on their budget was used to allocate activities in support of one or the other technology. Furthermore, if the project timescale fell outside the indicative reporting period then only a fraction (corresponding to the years within reporting periods) was used. Further information concerning each project can be found in Annex 1.

4.2 Direct Actions

The JRC activities in the reporting period were organized in "Actions" during the period 2007-2013 and in "projects" in 2014. Several of these actions/projects dealt with Generation IV systems directly and/or indirectly. These were:

Name	Date	SFR	LFR	LFR/ ADS	VHTR	VHTR/ CoH2	GFR	SCWR	MSR
SAFETY-INNO	2005-2008	x	x		x		x	x	
SAFELIFE	2005-2008							x	
FANGS	2009-2011	x	x		x				

Name	Date	SFR	LFR	LFR/ ADS	VHTR	VHTR/ CoH2	GFR	SCWR	MSR
MATTINO	2009-2013	x	x		x		x	x	
NURAM	2012-2013	x	x						
ANFC	2007-2013	x	x				x		
ND-MINWASTE	2007-2013	x	x	x	x	x	x	x	x
SNF	2007-2013	x	x				x		
CAPTURE	2007-2012	x	x	x	x	x	x	x	x
IANUS	2007-2013	x	x	x	x	x	x	x	x
MaCoSyMa	2014-2016	x	x		x				
IntAG-LWR	2014-2016							x	
SAFARI	2014-2016	x							
SFR Experimental Work	2005-2015	x							
Sweep Loop Facility	2006-2015				x				
Exploratory Research	2007-2008				x				
SCWR Exploratory Research	2009-2010							x	
HLM Experimental Facility	2014-2016		x						
MSR ALISA	2007-2013								x

Table 3 – Main Euratom R&D Direct actions (FP5, FP6, FP7) contributing to the GIF Systems

The JRC has also contributed in the two crosscutting-methodology working groups of the GIF: the Risk & Safety Working Group (RSWG)[35], and the Proliferation Resistance and Physical Protection Working Group (PRPPWG)[36]. The Economic Modelling Working Group (EMWG) has been covered by EU MS.

For RSWG, resources were provided through JRC institutional projects such as FANGS, NURAM and SAFARI while for PRPPWG from JRC institutional projects such as AMENUS, IANUS and PHYMOD (for simplicity only project IANUS is referred in table 3).

More information on all the JRC projects can be found in Annex 2.

[35] Risk and Safety Working Group https://www.gen-4.org/gif/jcms/c_9366/risk-safety

[36] A complete bibliography of the PRPPWG activities and of national contributions in PR&PP related areas has been produced by PRPPWG under JRC leadership. It is available on the external web site of GIF at: https://www.gen-4.org/gif/jcms/c_71068/prpp-bibliography

4.3 Summary of the Euratom Contribution

The following table summarizes the total budgets (in MEUR) allocated towards all the GIF systems (including an additional breakdown details for LFR/ADS and VHTR/Cogeneration) during the reporting period. Indirect Actions summarise total project costs being the sum of: RTD grant, MS consortium contribution, JRC contribution if present, and international organization contribution if present. Thr JRC direct actions allocated budgets are given, but this amount does not cover the staff/infrastructure costs therefore giving a distorted view of the JRC's contribution.

GIF System	SFR	LFR	LFR/ADS	VHTR	VHTR/CoH2	GFR	SCWR	MSR	Totals
Indirect Action RTD	53,74	85,55	32,17	40,38	7,46	26,46	8,46	2,48	**256.69**
Direct Actions JRC	9,44	5,30	0,90	3,00	0,15	1,85	2,11	0,98	**23,73**

Table 4 – Main Euratom budgets for each GIF system (MEUR)

Highest system investments in the 10 years' reporting period were mainly towards LFR (+ LFR/ADS), SFR and VHTR for both indirect and direct actions. GFR plays an intermediate role while SCWR and MSR have a minor one. These results are coherent with the priorities established within SNETP/ESNII fast reactor systems and SNETP/NC2I cogeneration initiatives.

Financial support to the OECD/NEA GIF secretariat is also constantly provided at a level of 120 kEUR on average on a yearly basis.

5 EU Member States Activity in GIF Systems

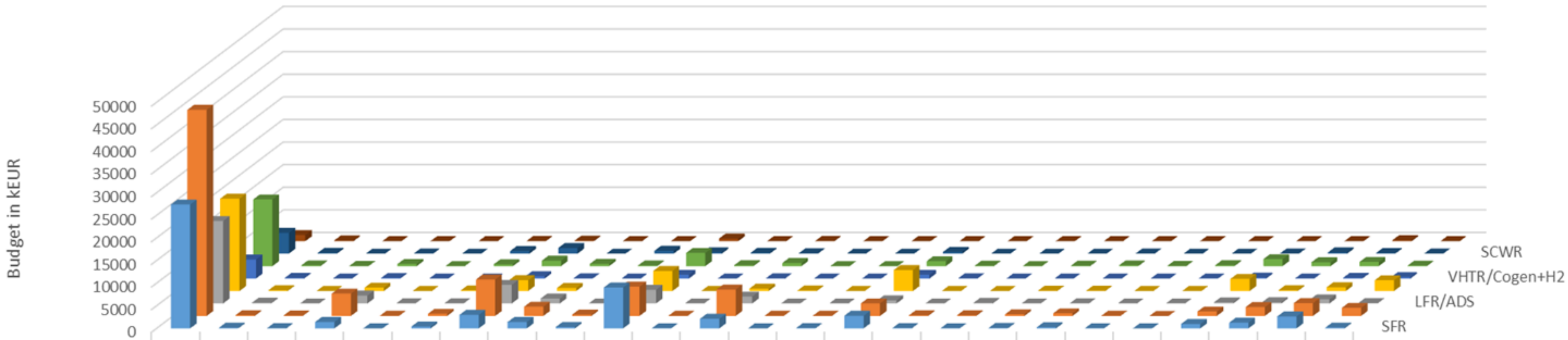
5.1 EU Member States Contribution to Indirect Actions

The following section identifies specifically the direct contribution from a Euratom MS to an indirect action project selected on a competitive basis within Euratom work programmes and related to GIF reactor systems. A member state contribution will only be indicated if a national organization was a member of the award-winning project consortium. This section does not include any member state own activity performed outside a Euratom indirect actions. As such, it avoids any double accounting of MS budget investments, being given in the following section 5.2).

The following tables and figures summarize the budgets associated by country and system in kEUR. They give also details of EU Grants; contributions from CH, JRC and International Cooperation (INCO) are given in order to be complete. More information on the Indirect Action projects can be found in Annex 1.

	SFR	LFR	LFR/ ADS	VHTR	VHTR/ Cogn+H2	GFR	SCWR	MSR	Totals
EU grant	27.403,3	45.576,7	18.227,6	20.443,5	4.214,9	14.742,4	4.579,2	1.361,3	**136.548,9**
AT	70,0	101,7	0,0	1,7	0,0	50,0	1,7	1,7	**226,7**
BE	1.431,3	4.933,5	1.750,7	747,8	131,3	465,1	55,5	5,6	**9.520,8**
BG	11,8	23,0	11,3	0,0	0,0	11,8	0,0	0,0	**57,8**
CZ	418,8	471,8	40,5	133,9	31,3	399,8	577,0	47,4	**2.120,4**
DE	3.001,8	8.053,8	4.109,1	2.390,5	500,3	1.208,0	1.253,7	136,6	**20.653,8**
ES	1.413,5	2.046,1	1.090,1	677,2	44,6	513,0	4,9	4,9	**5.794,5**
FI	300,4	300,4	0,0	3,8	9,2	146,8	641,6	0,0	**1.402,2**
FR	9.054,2	6.479,5	3.026,5	4.445,3	836,7	2.911,9	298,3	581,5	**27.633,8**
HU	34,6	35,9	3,6	0,7	6,6	199,7	193,5	15,5	**490,1**
IT	2.124,0	5.846,2	1.524,2	537,5	58,0	684,7	75,4	49,0	**10.899,0**
LT	16,1	41,3	0,0	101,2	2,3	9,1	1,3	1,3	**172,7**
LV	86,1	28,4	0,0	0,6	0,0	6,2	0,0	0,0	**121,3**
NL	2.806,1	2.763,4	692,3	4.642,7	834,2	1.086,7	376,8	23,2	**13.225,3**
PL	75,1	131,8	0,0	9,2	63,9	78,3	0,0	0,0	**358,1**
PT	26,0	154,1	143,3	0,0	0,0	15,9	0,0	0,0	**339,3**
RO	95,8	370,3	0,0	78,0	0,0	87,4	0,0	0,0	**631,4**
SE	244,3	571,8	20,2	55,1	0,0	172,0	13,6	2,3	**1.079,3**
SI	30,3	30,3	0,0	5,3	0,0	30,3	2,2	0,0	**98,3**
SK	5,9	5,1	0,0	26,3	28,0	191,5	0,0	8,2	**264,9**
UK	974,6	986,7	258,7	2.683,9	188,6	1.540,1	10,9	15,7	**6.659,2**
CH	1.276,6	1.964,6	278,6	180,3	19,6	856,5	266,0	0,0	**4.842,3**
JRC	2.650,2	2.837,1	913,1	826,3	161,1	930,8	125,6	226,3	**8.670,6**
INCO	182,6	1.790,4	73,3	2.382,1	329,1	114,6	7,8	7,4	**4.887,4**
Totals	**53.733,4**	**85.543,8**	**32.162,9**	**40.372,8**	**7.459,7**	**26.452,4**	**8.485,1**	**2.487,8**	**256.698,1**

Table 5 – EU MS, associated project partners, JRC and international cooperation total budgets for Indirect Action projects supporting GIF systems (kEUR)



	EU Projects grants	EU secretariat	AT	BE	BG	CZ	DE	ES	FI	FR	HU	IT	LT	LV	NL	PL	PT	RO	SE	SI	SK	UK	CH	JRC	INCO
SFR	27403	162.5	70	1431	11.8	418.8	3002	1414	300.4	9054	34.6	2124	16.1	86.1	2806	75.1	26	95.8	244.3	30.3	5.9	974.6	1277	2650	182.6
LFR	45577	162.5	101.7	4934	23	471.8	8054	2046	300.4	6480	35.9	5846	41.3	28.4	2763	131.8	154.1	370.3	571.8	30.3	5.1	986.7	1965	2837	1790
LFR/ADS	18228	162.5	0	1751	11.3	40.5	4109	1090	0	3027	3.6	1524	0	0	692.3	0	143.3	0	20.2	0	0	258.7	278.6	913.1	73.3
VHTR	20444	162.5	1.7	747.8	0	133.9	2391	677.2	3.8	4445	0.7	537.5	101.2	0.6	4643	9.2	0	78	55.1	5.3	26.3	2684	180.3	826.3	2382
VHTR/Cogen+H2	4215	162.5	0	131.3	0	31.3	500.3	44.6	9.2	836.7	6.6	58	2.3	0	834.2	63.9	0	0	0	0	28	188.6	19.6	161.1	329.1
GFR	14742	162.5	50	465.1	11.8	399.8	1208	513	146.8	2912	199.7	684.7	9.1	6.2	1087	78.3	15.9	87.4	172	30.3	191.5	1540	856.5	930.8	114.6
SCWR	4579	162.5	1.7	55.5	0	577	1254	4.9	641.6	298.3	193.5	75.4	1.3	0	376.8	0	0	0	13.6	2.2	0	10.9	266	125.6	7.8
MSR	1361	162.5	1.7	5.6	0	47.4	136.6	4.9	0	581.5	15.5	49	1.3	0	23.2	0	0	0	2.3	0	8.2	15.7	0	226.3	7.4

Figure 2 – Euratom, MS, JRC, CH and INCO contributions to indirect actions GIF related Projects (2005 and 2014)

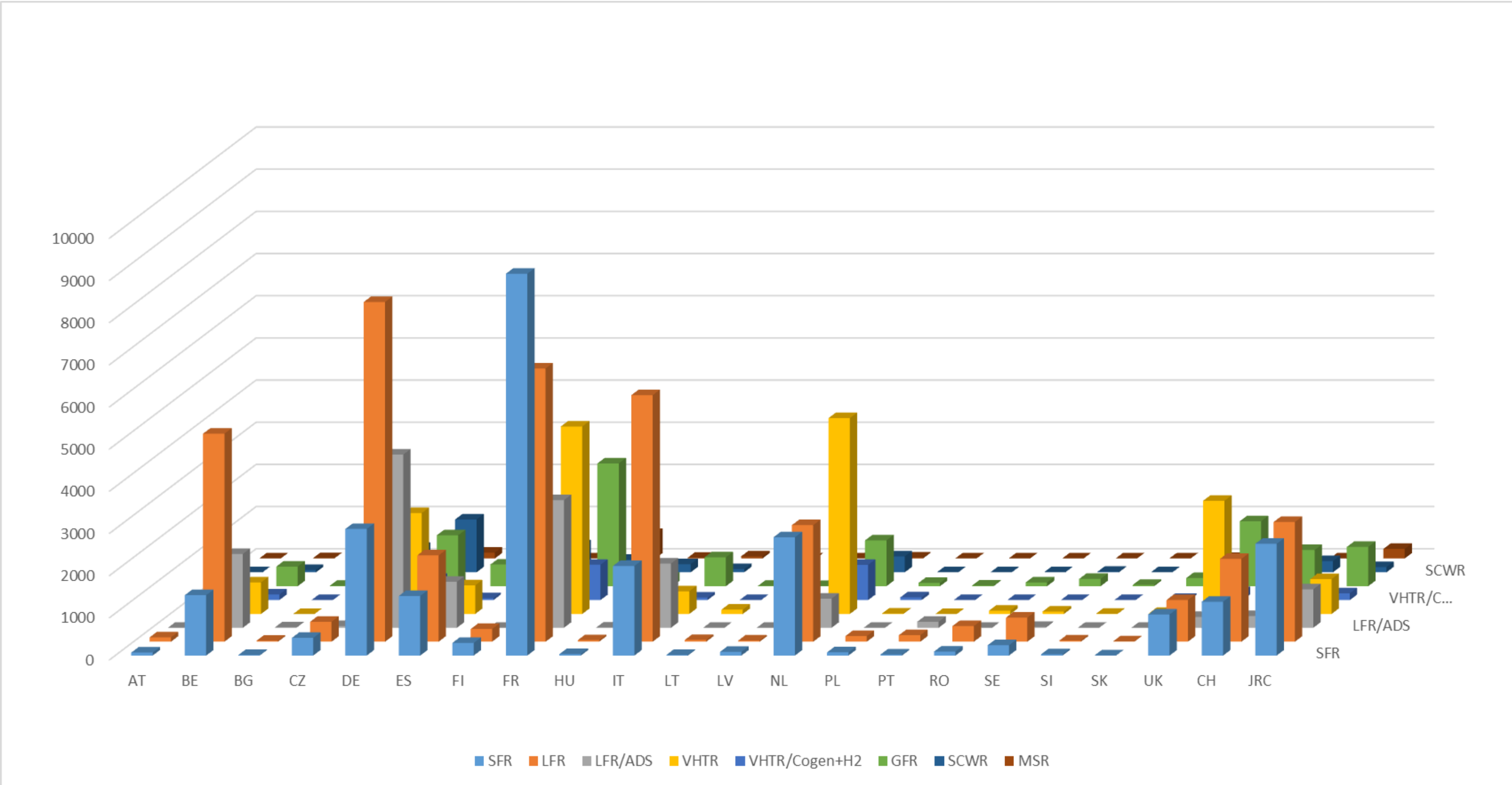
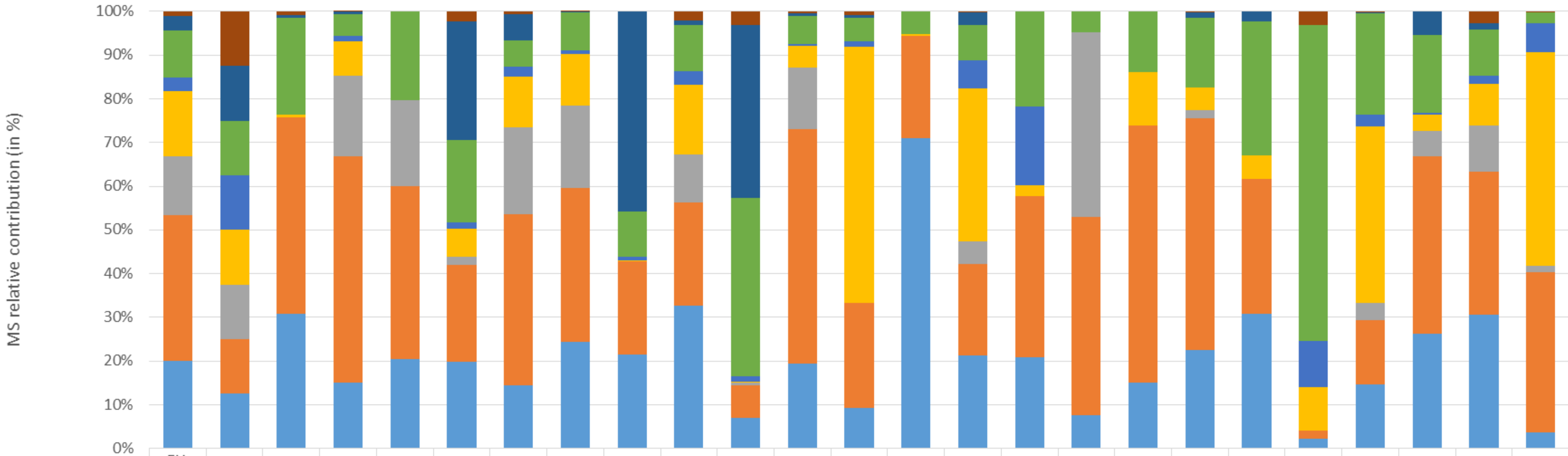


Figure 3 –Zoom: MS, JRC, CH contributions to indirect actions GIF related Projects (2005 and 2014)



	EU Projects grants	EU secretariat	AT	BE	BG	CZ	DE	ES	FI	FR	HU	IT	LT	LV	NL	PL	PT	RO	SE	SI	SK	UK	CH	JRC	INCO
MSR	1361.3	162.5	1.7	5.6	0	47.4	136.6	4.9	0	581.5	15.5	49	1.3	0	23.2	0	0	0	2.3	0	8.2	15.7	0	226.3	7.4
SCWR	4579.2	162.5	1.7	55.5	0	577	1253.7	4.9	641.6	298.3	193.5	75.4	1.3	0	376.8	0	0	0	13.6	2.2	0	10.9	266	125.6	7.8
GFR	14742	162.5	50	465.1	11.8	399.8	1208	513	146.8	2911.9	199.7	684.7	9.1	6.2	1086.7	78.3	15.9	87.4	172	30.3	191.5	1540.1	856.5	930.8	114.6
VHTR/Cogen+H2	4214.9	162.5	0	131.3	0	31.3	500.3	44.6	9.2	836.7	6.6	58	2.3	0	834.2	63.9	0	0	0	0	28	188.6	19.6	161.1	329.1
VHTR	20444	162.5	1.7	747.8	0	133.9	2390.5	677.2	3.8	4445.3	0.7	537.5	101.2	0.6	4642.7	9.2	0	78	55.1	5.3	26.3	2683.9	180.3	826.3	2382.1
LFR/ADS	18228	162.5	0	1750.7	11.3	40.5	4109.1	1090.1	0	3026.5	3.6	1524.2	0	0	692.3	0	143.3	0	20.2	0	0	258.7	278.6	913.1	73.3
LFR	45577	162.5	101.7	4933.5	23	471.8	8053.8	2046.1	300.4	6479.5	35.9	5846.2	41.3	28.4	2763.4	131.8	154.1	370.3	571.8	30.3	5.1	986.7	1964.6	2837.1	1790.4
SFR	27403	162.5	70	1431.3	11.8	418.8	3001.8	1413.5	300.4	9054.2	34.6	2124	16.1	86.1	2806.1	75.1	26	95.8	244.3	30.3	5.9	974.6	1276.6	2650.2	182.6

Figure 4 – Percentage distribution: Euratom, MS, JRC, CH and INCO contributions to indirect actions GIF related Projects (2005 and 2014)

The main results in the framework of Euratom co-funded projects in support of GIF system are – with regards to budgets invested within the respective technologies which can significantly differ from one to the other -as following:

- **Sodium Fast Reactor (SFR):** The largest contribution is from FR together with DE, NL, JRC, IT, BE, ES, CH, UK and to a lesser extent CZ, FI, SE and through International partners (INCO). France has played a key role in involving European partners in support to the development of the leading ASTRID project.

- **Lead-cooled Fast Reactor (LFR):** DE, FR, IT, and BE are the major contributors to this system together with NL, JRC, ES, UK, through International partners (INCO). There was also a relevant contribution from SE, RO, CZ and FI. R&D development in support to the MYRRHA facility (LFR/ADS) in Belgium has in complemented R&D activities by involving DE, BE, FR, IT, JRC and ES. A LFR demonstrator such as ALFRED planned in RO with an IT-RO leading consortium should see a higher contribution from RO in the future towards this technology.

- **Very High-Temperature Reactor (VHTR):** Major contributors have been NL, FR, UK, through International cooperation (INCO), DE, followed by JRC, BE, ES and IT. VHTR Cogeneration and potential of H2 production also benefitted from R&D supported by FR, NL, DE, through International cooperation, UK and JRC. Today, PL is the EU member state with a high interest in the potential of cogeneration technology and as such it is leading the NC2I industrial initiative.

- **Gas-Cooled Fast Reactor (GFR):** Major contributors have been FR, UK, DE, JRC, NL, CH but also IT, ES and BE. There is also a relevant contribution from CZ, HU, SK, SE and through International partners. Today, the Visegrad 4 countries for Generation 4 reactors group (V4G4) composed of PL, HU, CZ, and SK are further supporting GFR R&D towards a longer term demonstration of ALLEGRO.

- **Supercritical Water-Cooled Reactor (SCWR):** This system has mainly received interest from DE, FI, CZ, NL, FR, CH and JRC, then HU, IT and BE. Recently, its activity in the frame of Euratom is also supported through NUGENIA platform (second Generation II and III pillar of SNETP).

- **Molten Salt Reactor (MSR):** Research investments in this system were led by FR, JRC, DE, IT, CZ, NL and UK. Recently, a large indirect action project has been awarded in the frame of Horizon 2020 following a competitive call for 2014-2015, which will allow further research in this domain.

These EU MS Specific Programmes represent strong elements of continuity with previous framework programmes building on the demonstrated added value of European support of this type. This has also allowed a strengthened approach to the coordinating of national research programmes in the field of nuclear fission and radiation protection. EU funding was dedicated to topics where national programme priorities converge and where European added value was obvious and maximised. The joint implementation of this research at pan-European level helped to develop key infrastructures, research activities and maintain necessary competences. Interaction with non-EU organisations active in the various fields has been beneficial.

Euratom co-funded GIF related projects confirmed the strategic importance of Generation-IV reactors developments, and investments are coherent with today’s respective national European research policy roadmap encompassing the framework of ESNII but also NC2I and the Generation IV International Forum.

To summarise the Euratom GIF related projects, the research investments covered all Generation IV systems but the bulk of activities covered key cross-cutting fields of nuclear safety, fuel developments, thermal hydraulics, materials research, numerical simulation and design activities of future reactor technologies, partitioning and transmutation, support to infrastructures, education, training and knowledge management, and international cooperation. Overall, following the evaluation made over the period 2005-2014, Euratom supported mainly LFR and LFR/ADS, SFR, VHTR and GFR, then to a lesser extent SCWR, VHTR cogeneration and to a minor extent the MSR.

5.2 EU Member States Direct Contribution

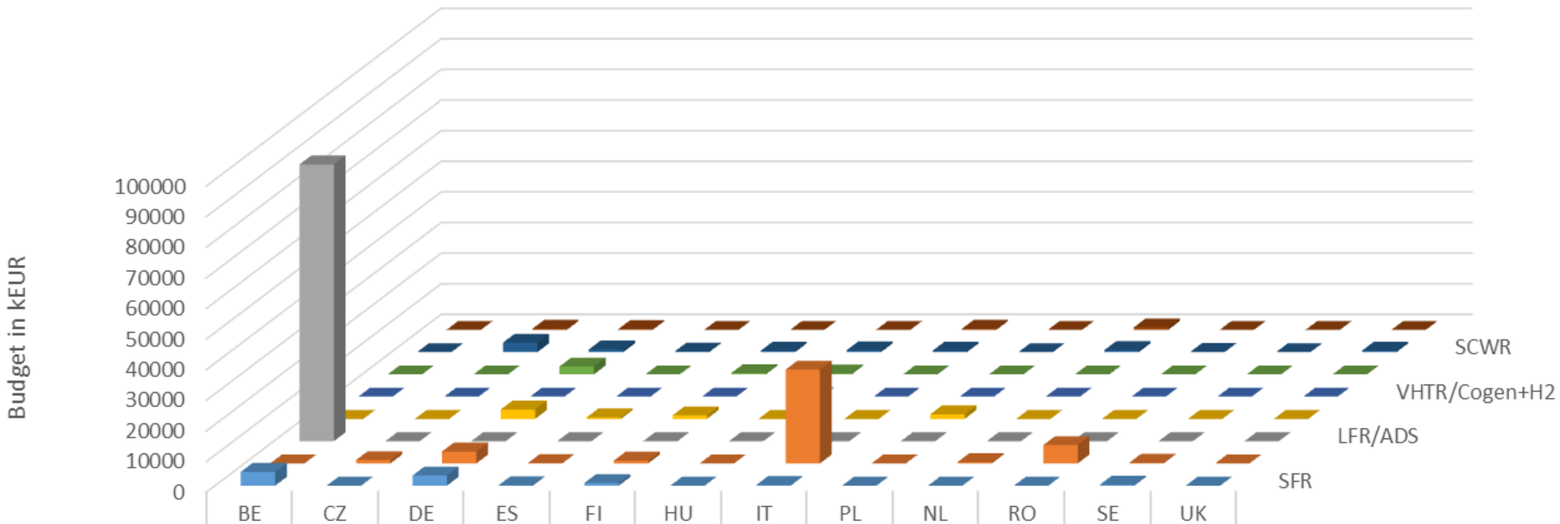
This section deals with the information provided by the MS within a dedicated survey. Careful attention was given to avoid any double accounting between national additional investments and investments made in the framework of Euratom indirect actions following competitive call for proposals as these amounts have already been accounted within the previous section 5.1.

A total of 40 institutions were approached in 14 Member States and a total of 69 answers have finally been received.

Based on a survey providing data on a voluntary basis, the methodology of allocating budgets to all different GIF systems within MS, and the long reporting period, budgets should remain indicative in the framework of this report. They can be summarised per system as follows:

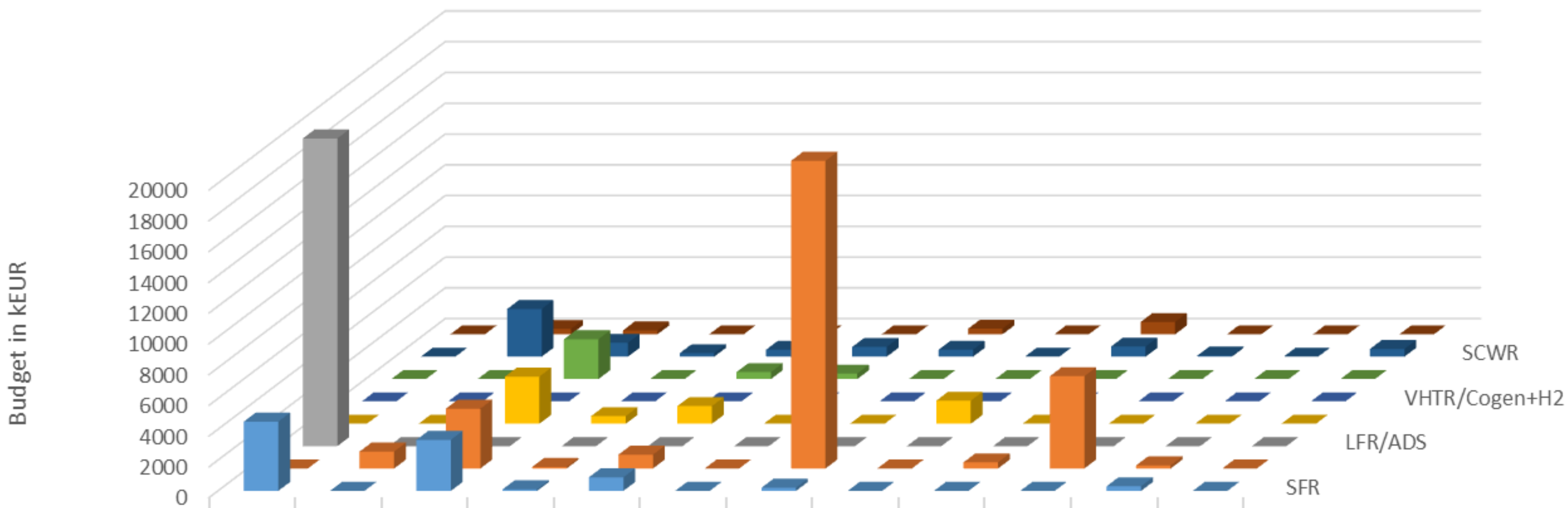
	SFR	LFR	LFR/ ADS	VHTR	VHTR/ Cogen +H2	GFR	SCWR	MSR	Totals
BE	4.5	0.0	90.4	0.0	0.0	0.0	0.0	0.0	**94.9**
CZ	0.0	1.1	0.0	0.0	0.0	0.0	3.1	0.4	**4.6**
DE	3.3	3.9	0.0	3.1	0.0	2.6	0.9	0.3	**14.0**
ES	0.1	0.1	0.0	0.5	0.0	0.0	0.2	0.0	**0.9**
FI	0.9	0.9	0.0	1.2	0.0	0.5	0.5	0.0	**3.8**
FR	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**N/A**
HU	0.0	0.0	0.0	0.0	0.0	0.4	0.6	0.0	**1.0**
IT	0.2	30.6	0.0	0.0	0.0	0.0	0.5	0.4	**31.6**
PL	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	**1.5**
NL	0.0	0.4	0.0	0.0	0.0	0.0	0.7	0.8	**1.9**
RO	0.0	6.0	0.0	0.0	0.0	0.0	0.1	0.0	**6.1**
SE	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	**0.5**
UK	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	**0.5**
Totals	9.3	43.2	90.4	6.6	0.0	3.0	7.0	1.8	**161.3**

Table 6 – EU MS estimated budgets supporting GIF systems (MEUR)



	BE	CZ	DE	ES	FI	HU	IT	PL	NL	RO	SE	UK
SFR	4500	0	3315	100	880	0	200	0	0	0	300	0
LFR	0	1100	3885	100	900	0	30625	0	400	6000	200	0
LFR/ADS	90400	0	0	0	0	0	0	0	0	0	0	0
VHTR	0	0	3065	500	1150	0	0	1500	0	0	0	0
VHTR/Cogen+H2	0	0	0	0	0	0	0	0	0	0	0	0
GFR	0	0	2585	0	450	350	0	0	0	0	0	0
SCWR	0	3100	900	225	450	630	450	0	660	70	0	500
MSR	0	350	250	0	0	0	365	0	800	0	0	0

Figure 5 –MS direct contributions to GIF related Projects (2005 and 2014)



	BE	CZ	DE	ES	FI	HU	IT	PL	NL	RO	SE	UK
SFR	4500	0	3315	100	880	0	200	0	0	0	300	0
LFR	0	1100	3885	100	900	0	30625	0	400	6000	200	0
LFR/ADS	90400	0	0	0	0	0	0	0	0	0	0	0
VHTR	0	0	3065	500	1150	0	0	1500	0	0	0	0
VHTR/Cogen+H2	0	0	0	0	0	0	0	0	0	0	0	0
GFR	0	0	2585	0	450	350	0	0	0	0	0	0
SCWR	0	3100	900	225	450	630	450	0	660	70	0	500
MSR	0	350	250	0	0	0	365	0	800	0	0	0

Figure 6 –Zoom: MS direct contributions to GIF related Projects (2005 and 2014)

The main outcome of this survey showed that:

- The case of France has to be treated separately due to the large investment made as compared to any other EU country over the reporting period (2005-2014). Large investments were provided towards SFR, LFR and LFR/ADS, VHTR, GFR, and to a lesser extent towards MSR, SCWR and VHTR cogeneration. Unfortunatley specific data was not available in due time for this report..

During the 10 year reporting period other EU MS have invested with their own national programmes in several different systems each. Specifically:

- Belgium and Italy have been the greatest investors and promoters of the Lead system: Belgium with 60 MEUR direct grant in support to MYRRHA plus a 30 MEUR budget for LFR/ADS research (but also SFR); Italy with a similar 30 MEUR budget for Generation IV systems (more specifically LFR but also SFR).

- Romania has also allocated around 6 MEUR for the innovative systems with a focus on LFR.

- Germany has allocated a budget between 3-4 MEUR for each of the three fast reactor systems (SFR, LFR, GFR) and the VHTR.

- Finland has allocated a budget between of 0.5-1 MEUR for each of the three fast reactor systems (SFR, LFR, GFR) and the VHTR and also including SCWR.

- Poland has spent 1.5 MEUR on the HTRPL project on VHTR.

- The Czech Republic has focussed on SCWR (3 MEUR) and LFR (1 MEUR) and MSR.

- The Netherlands has allocated budgets of 0.4-0.8 MEUR for each SCWR, MSR and LFR system.

- Hungary has focussed on GFR (0.35 MEUR) and SCWR (0.60 MEUR).

- Spain has supported VHTR (0.5 MEUR), SFR (0.1 MEUR) and LFR (0.1 MEUR) R&D activities

- Sweden has focussed on SFR (0.3 MEUR) and LFR (0.2 MEUR).

- The UK has focussed on SCWR (0.5 MEUR).

Euratom GIF related projects co-funded confirmed the strategic importance of Generation-IV reactors developments for a country like France, and investments are coherent with today's respective national research policy roadmaps. Belgium support to MYRRHA is also translating within such an analysis.

Overall, most EU MS are strongly benefitting from – and relying upon - Euratom collaboration to enable pan-European R&D encompassing the framework of ESNII but also NC2I and Generation IV International Forum.

More detailed technical information on the information from each member state can be found in Annex 3.

6 Future Activity in Generation IV Systems

6.1 Euratom Indirect Actions

The new 7-year EU research programme called Horizon 2020 (2014-2020), agreed and adopted by the EU Parliament and EU Council, has started its implementation phase in 2014. Within this framework, the specific "Horizon 2020 Euratom Programme for nuclear research and training activities" [37] (2014-2018 and its extension for 2019-2020), supports the EU research in nuclear fission and fusion including Generation-IV research. Its 2014-15 competitive call for proposals included a specific cluster on "Support to a Safe Operation of Nuclear Systems" that contained themes related to Generation-IV research such as "Improved safety design and operation of fission reactors" and "New innovative approaches to reactor safety". The following projects were not reported in the previous tables as they have started in 2015 (outside the reporting period) with the allocation of grants to the following Generation IV projects in the following domains:

- **SFR and LFR:** Project SESAME – Thermal hydraulics Simulations and Experiments for the Safety Assessment of MEtal cooled reactors (total budget 10.4 MEUR)
- **LFR/ADS (LFR):** Project MYRTE – MYRRHA Research and Transmutation Endeavour. (total budget 12.0 MEUR)
- **MSR**: Project SAMOFAR – A Paradigm Shift in Reactor Safety with the Molten Salt Fast Reactor (total budget 5.2 MEUR)
- **GFR:** Project VINCO – Visegrad Initiative for Nuclear Cooperation (total budget 1.1 MEUR).

The Horizon 2020 Euratom Fission Programme 2016-2017 call for proposals has been published[38] with a deadline in October 2016. It includes clusters on: Safety of existing nuclear installation; Future nuclear systems for increased safety; Fuel cycle, Partitioning and Transmutation; and Cross-cutting aspects. Subtopics within these include: safety of fast reactors, closed nuclear fuel cycle options and fuel development, research on SMR (incl. Generation IV types) and material research for Gen-IV reactors.

These projects selected on a competitive basis shall support research investments covering all Generation IV systems but the bulk of activities should cover key cross-cutting fields of nuclear safety, fuel developments, thermal hydraulics, materials research, numerical simulation and design activities of future reactor technologies, partitioning and transmutation, support to infrastructures, education, training and knowledge management, and international cooperation.
Euratom direct financial support to OECD/NEA GIF secretariat will also constantly be provided at a level of 150 kEUR on average on a yearly basis.

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[37] Council Regulation (Euratom) No 1314/2013 of 16 December 2013 on the Research and Training Programme of the European Atomic Energy Community (2014-2018) complementing the Horizon 2020 Framework Programme for Research and Innovation

[38] https://ec.europa.eu/research/participants/portal/desktop/en/opportunities/h2020/calls/nfrp-2016-2017.html

6.2 Euratom JRC Direct Actions

As Euratom implementing agent, the JRC will continue to represent Euratom at the GIF Policy Group and GIF Expert Group of Generation IV and it will coordinate the participation of Euratom representatives to the steering committees of the GIF systems.

The JRC will continue contributing to safety-related research in its own capacity and in the frame of competitive research within indirect actions in the following domains:

1. Safety of fuel development programme of the GFR, SFR, and VHTR systems. (MOX fuels are also envisaged for LFRs. The same for advanced MA-bearing fuels, especially for MYRRHA)
2. The materials R&D programme
3. Safety of Generation IV reactor designs; and
4. Cross-cutting groups with a contribution to the activities of the Risk & Safety Working Group (RSWG) and the Proliferation Resistance and Physical Protection Working Group (PRPPWG).

JRC will also organise yearly a Euratom GIF coordination meeting with MS to inform on the GIF recent developments and progress made within the respective system arrangements.

6.3 EU Member States Direct Contribution

The main outcome of the survey that was conducted showed that the MS will continue to invest with their own national programmes in several different systems each. More Specifically:

- France has chosen to lead more specifically research on sodium cooled fast reactors[39] given the knowledge and experience feedback from previous reactors such as Phoenix and Superphénix. SFR seems to be best placed to help meet the objective, if needed, of an industrial development from 2040. To meet this challenge for the future of nuclear power, the French Government has committed 650 MEUR for the period 2012-2017, CEA has designed and launched, in conjunction with industrial partners such as AREVA and EDF, a programme that should allow to have by 2030 ASTRID reactor built for industrial demonstration and integrating innovative solutions. In parallel, in order to keep access to the industry considered as a potential alternative to sodium cooled reactors, France is participating in the programs in the international framework on gas-cooled reactors.
- Belgium and Italy will remain the greatest investors and promoters of the Lead/ADS and Lead systems, Belgium with 30MEUR/year budget (plus a government endowment) for LFR/ADS while Italy with a similar 3 MEUR/y budget

[39] RAPPORT DU COMITE D'ORIENTATION et de SUIVI des RECHERCHES pour les SYSTEMES NUCLEAIRES Mars 2011

for all Generation IV systems (but especially Lead). Italy will also continue research in other fast reactors but with a lower priority.

- Romania will continue the research activities with at least 1MEUR/year under its National Programme on “Advanced Nuclear Reactors and Fuel Cycle” and intend to increase the efforts for the development of the experimental facilities in support of LFR and ALFRED construction.
- Germany, although having a 2022 phase out policy (since 2011), will continue research in fast systems and VHTR with a similar budgetary and Human resources effort.
- Spain's focus will continue on SFR, SCWR and LFR.
- Czech Republic will continue its research on SCWR (4.2 MEUR) and to a lesser extent on MSR, VHTR and LFR systems.
- Finland’s focus will continue on cross-cutting topics mainly in terms of innovative materials solution. Research on selected reactor concepts (e.g. supporting EERA JPNM activities and SCWR related work) will continue and research agenda will be updated yearly basis based on national needs.
- Sweden's focus will continue on SFRs and LFRs (4.9 MEUR).
- The Netherlands will continue with a similar financial effort focussing on LFR and MSR.
- Hungary will continue research in the ALLEGRO-GFR (2 MEUR) concept and SCWR (80kEUR).

More details can be found in Annex 3.

7 Conclusion

This report the Euratom contribution to the six GIF systems in the period (2005-2014). It addresses three types of contributions:

1) Euratom Indirect actions
2) Euratom Direct JRC actions
3) Member States direct Contribution

The analysis is based upon 47 projects of type 1), 19 of type 2), and 69 entities (research organizations, universities, etc) of type 3) within the EU MS. From the analysis of the data, it can be summarized that:

Past 10 years

- Euratom has performed research in the period of 2005-2014 on all six Generation IV International Forum Reactor Systems as well as others closely linked and not covered by GIF (e.g. LFR/ADS).

- Euratom Indirect Research contributed with around 260 MEUR, The indirect action amount is the "total project" budget and therefore includes: (a) contribution from the EU, (b) contribution from the Consortium that was awarded the grant, (c) contributions from other international partners. The Euratom total grants were estimated to around 135 MEUR. The amounts give a clear image on which GIF systems have been considered as a Euratom priority in this period. These are: LFR (86 MEUR), LFR/ADS (32 MEUR), SFR (54 MEUR), and VHTR (40 MEUR), VHTR/CoH2 (7 MEUR). The GFR (26 MEUR) can be considered as medium priority and the SCWR (8 MEUR) and MSR (2 MEUR) of a lower one. It is important to underline that especially SCWR and to a lesser extent MSR and GFR are well funded separately directly by EU MS.

- The JRC Direct Research contributed to all systems with about 25 MEUR (excluding staff/infrastructure costs). Its activity covered all systems focus was on SFR, LFR and VHTR systems. To a minor degree it also followed the remaining two systems. An estimate of JRC 25-40 staff/year can be considered working for Generation IV activity during this period

- Complementing the Euratom framework of indirect actions selected on a competitive basis, EU MS such as BE and IT have funded R&D through their national research programmes towards LFR/ADS and LFR systems (133 MEUR). SFR (9 MEUR) has benefitted from DE, NL, JRC, BE, CH, UK, ES and CZ activities support. France estimated its investment at 75 MEUR and increased to 102 MEUR from 2010 on a yearly basis on all Generation IV R&D, SFR being the reference technology and ASTRID a prototype being designed with the leadership of CEA together with EDF, AREVA and an associated industrial international consortium. SCWR (7 MEUR) was also financed by CZ, DE and NL, but also IT, FI and ES in contribution to Euratom indirect actions. VHTR and GFR benefitted from financing by DE, PL and FI, with 7 MEUR and 3 MEUR respectively. MSR activities benefitted from lesser support from by NL, CZ, DE and IT of around 1.7 MEUR.

- The SNETP/ESNII systems (SFR, LFR/ADS, LFR, GFR) and SNETP/NC2I VHTR are present and funded within Euratom. Overall this reflects the interest of EU MS in the GIF systems.

Future Activities

The Horizon 2020 Euratom Fission Programme (2014-2018) and its extension (2019-2020) will include research for all Generation IV reactor systems. The last competitive indirect call for proposals (2016-2017) has focused on safety of fast reactors, closed nuclear fuel cycle options and fuel development, research on SMR (incl. Generation IV types) and material research for Gen-IV reactors.

- The direct research will continue with similar resources/budget as in the past on: research in fuel for fast systems, material R&D and on safety of Generation IV reactor designs as well as with crosscutting topics.

- The MS will continue to invest through their own national programmes in several different systems each. Belgium and Italy will remain the greatest investors and promoters of the Lead/ADS and Lead systems, Belgium with 30 MEUR/year budget (plus a government endowment) for LFR/ADS while Italy with a similar 3 MEUR/y budget for all Generation IV systems (mainly Lead). Romania will continue to increase the budget for the research and experimental facilities in support to LFR. France estimated its investment at 75 MEUR and increased to 102 MEUR from 2010 on a yearly basis on Generation IV R&D[40]. With ASTRID, an increase of its R&D budget is being provided such as the 'Grand Emprunt' and 650 MEUR till the year 2017. Germany, despite having phase out policy by 2022 (decision dating back to 2011 following Fukushima events), will continue research in support to fast and VHTR systems. Spain's focus will continue on SFR, SCWR and LFR while the Czech Republic will continue its research in on SCWR (4.2 MEUR) and to a lesser extent MSR, VHTR and LFR systems. Finland has allocated a budget between 0.5-1 MEUR for each of the three fast reactor systems, the VHTR and the SCWR. Sweden's focus will continue on SFR and LFR (4.9 MEUR) and The Netherlands will continue with a similar financial effort focussing on LFR and MSR. Hungary will continue research in the ALLEGRO-GFR (2 MEUR) concept and SCWR (80kEUR).

Of particular importance, specific arrangements for a coordinated approach will be foreseen. More specifically:

- **International cooperation**: A strategic approach will be taken to promote actions in this respect and to address specific issues where there is a mutual interest and benefit;

- **Research infrastructures:** A close collaboration to ensure the highest support for any key nuclear research infrastructures;

- **Link with European policy:** Arrangements for an effective coordination and potential multi-annual programming to draw on the help of user groups and support policies concerned
- **Dissemination and knowledge transfer:** The need to foster the uptake of research results is a strong feature across the Specific Programmes, with a particular emphasis on transferring knowledge between countries, across

[40] Rapport Cour des Comptes 31/01/2012, Les coûts de la filière Électronucléaire (p.62) https://www.ccomptes.fr/content/download/1794/17981/file/Rapport_thematique_filiere_electronucleaire.pdf

disciplines and from academia to industry, including through the mobility of researchers;

- **<u>Potential national/European/International funding, financial and legal instruments</u>** to support the realisation of ESNII as a pan-European innovative in support to research infrastructures is being investigated taking into account the latest respective project and national investment plans, Deloitte Study from 2010, H2020 Research and Innovation, Cohesion Policy and the 2014-2020 Multi-Financial Framework programmes.

Annex 1 Euratom RTD Indirect Actions contributing to the GIF systems

FP5 MICANET

The objective of MICANET is to elaborate a European R&D strategy corresponding to the actual needs of industry for facing more and more stringent challenges of competitiveness and sustainability. It will promote innovative approaches, maybe the only solution to face such challenges. MICANET approach will be global, including all aspects, from fuel cycle front end to final disposal, from techno-economic issues to political, social and psychological dimensions of acceptance, proposing an appropriate balance of efforts between short, medium and long-term R&D, connecting in a network the various projects, which can contribute to MICANET objectives. It will lay the foundations of a long-term stable partnership between the main European organisations of nuclear industry and research, which will be the only way to support future large projects. MICANET will act for the development an effective/active European partnership to the U.S. initiative GENERATION IV.
Total cost: EUR 2 423 110
EU contribution: EUR 1 100 000
http://cordis.europa.eu/project/rcn/59918_en.html

FP6 GCFR
The Gas Cooled Fast Reactor Project

Fast Reactors have a unique capability as sustainable energy sources, for both utilisation of fissile material and minimisation of nuclear waste, due to the hard neutron spectrum. The current interest is in exploring particular advantages of the gas-cooled fast reactor (GCFR) primarily as an economic electricity generator, with good sustainability and safety characteristics, but also capable of minimising nuclear waste via transmutation of minor actinides. GCFR could also support hydrogen production. This GCFR project is directed at the ambitious long term goals of the Generation IV Gas-cooled Fast Reactor (GFR) R&D Project: self-generating cores, robust refractory fuel, high operating temperature, direct conversion with a gas turbine and full actinide recycling possibly associated with integrated on-site fuel reprocessing. The project strategy takes full advantage of technologies being developed for V/HTR but with significant extrapolations, if not breakthroughs, to reach the objectives stated above. Thus, it calls for specific R&D beyond current and foreseen work on thermal VHTRs. The R&D is structured into two technical packages specific to GCFR: System integration and Design and Safety, Fast neutron fuel, other core materials and specific fuel cycle process. A third specific package ensures the efficient interface with other FP6 projects. During its 4-year period the GCFR project will contribute a European perspective to key events of the Generation IV GFR programme, namely: the safety approach for GFR, the pre-selection of GFR reference design options and promising alternatives, the Preliminary Viability Report for GFR, selection of the Experimental Technology Demonstration Reactor (ETDR) design options, including safety design features, a contribution to the Safety Options Report, establishing the mission and contributing to the ETDR Mission Report.
Total cost: EUR 3 603 375

EU contribution: EUR 2 000 000
http://cordis.europa.eu/project/rcn/74804_en.html

FP6 RAPHAEL

The Project addresses the viability & performance of the Very High Temperature Reactor (VHTR). This innovative system is not only meant at competitive & safe power generation, but also at industrial process heat supply, in particular for hydrogen production. It offers significant advantages with its inherent safety features and the related simplification of the system, its robust fuel without significant radioactive release, its high efficiency and use of any fissile/fertile material. explored to achieve the challenging performances required for VHTR (900-1000°C, up to 200 GWd/t). The selection and qualification of materials for very high temperature components, graphite internals and vessel is a key area of the Project. The critical components (in particular the intermediate heat exchanger) are developed. The demonstration of the unique robustness of the fuel is extended to higher temperature & burn-up. The fabrication of advanced fuel with higher performances is tested. The irradiated fuel behaviour in disposal conditions is studied. Computer tools for reactor physics, safety analysis and fuel behaviour are qualified through comparison with experimental data including those resulting from tests planned in the Project. Moreover the modelling of the fuel irradiation behaviour is improved. A safety approach adapted to the specific features of modular VHTR is elaborated. Finally, an evaluation of the viability & performance of the whole system is achieved.
This programme has been set-up to compliment and support European national VHTR programmes and to contribute to the international effort on GENERATION IV VHTR projects. As the Project addresses issues raising major concerns for the future (energy and fresh water supply, climate change, natural resource preservation), it will pay special attention to education & communication.
Total cost: EUR 18 340 249
EU contribution: EUR 9 000 000
http://cordis.europa.eu/project/rcn/75830_en.html

FP6 EUROTRANS
EUROpean research programme for the TRANSmutation of high level nuclear waste in an accelerator driven system

The Integrated Project EUROTRANS was devoted to transmutation of high-level waste, focusing on transmutation in an Accelerator Driven System (ADS). The objective was the design and the feasibility assessment of an industrial ADS prototype dedicated to transmutation. The work was carried out by a consortium of 29 partners from 14 countries.
The objectives of the 5 technical domains (DM) were:

- DM1 Design: Develop a detailed design of a proton accelerator-driven, windowless 100 MW sub-critical XT-ADS (having Pb-Bi as coolant and spallation target, and MOX fuel), together with a conceptual design of a generic European Transmutation Demonstrator, ETD (having Pb as coolant and spallation target, and employing minor actinide (MA) oxide fuel); EUROTRANS also carried out an economic assessment and safety study of the two designs;

- DM2 ECATS: Provide validated experimental input from relevant experiments at sufficient power (20-100 kW) on the coupling of an accelerator, a spallation target and a sub-critical blanket;
- DM3 AFTRA: Develop U-free oxide fuels such as (Pu, MA, Zr)O2, CERCER (Pu, MA)O2+MgO or CERMET (Pu, MA)O2 + Mo, with a view to use both in XT-ADS and Generic ETD; to this end, design and modelling, safety assessment, out-of-pile fuel-property measurements, irradiation tests and fuel qualification in HFR and Phénix reactors were performed;
- DM4 DEMETRA: Develop and assess structural materials, thermal-hydraulics, and heavy-liquid metal technologies for transmutation systems with respect to spallation target material and to coolant;
- DM5 NUDATRA: Improve nuclear data evaluated files and models needed to perform the design work.

Total cost: EUR 42 926 414
EU contribution: EUR 23 000 000
http://cordis.europa.eu/project/rcn/85226_en.html

FP6 PATEROS
Partitioning and Transmutation European Roadmap for Sustainable nuclear energy

A closed fuel cycle is a prerequisite for making nuclear energy a sustainable one. This can be reached by deploying advanced partitioning and transmutation systems to reduce the burden on the geological storage. This objective is of relevance both for countries committed to nuclear energy in the future and for countries not committed to a further deployment of nuclear energy.
The Objectives of this project is to deliver a European vision for the deployment of the partitioning and transmutation technology up to the scale level of pilot plants for all its components. The project action-working programme is organised in 6 WPs:

- WP1: Rational and added value of P and T for waste management policies
- WP2: Review and selection of Relevant Fuel Cycle Strategies in Europe supplemented by Regional Context for Development and Deployment.
- WP3: Fuel Cycle Facilities related to Reprocessing.
- WP4: Fuel cycle facilities related Fuel Fabrication Demonstration.
- WP5: Fuel cycle facilities and Associated Technology (ies) for transmutation.
- WP6: Integration and Evaluation of Resources and Time Planning.

Total cost: EUR 765 615
EU contribution: EUR 600 000
http://cordis.europa.eu/project/rcn/80047_en.html

FP6 PUMA

The High Temperature gas-cooled Reactor (HTR) can fulfil a very useful niche for Pu and Minor Actinide (MA) incineration, due to its unique and unsurpassed safety features, as well as to the attractive incentives offered by the nature of the coated particle (CP) fuel.
The objective of the project is to provide additional key elements for the utilisation and transmutation of Pu and MA in current and future (high-temperature) gas-cooled reactor designs, contributing to the reduction of Pu and MA stockpiles, and to the development of safe and sustainable reactors for CO2-free multi energy generation. Earlier projects

show favourable characteristics of HTRs with respect to Pu burning. However, further steps are required to demonstrate the potential of HTRs (and GCFRs) as Pu/MA transmuters based on realistic/feasible designs of CP Pu/MA fuel. So, core physics of Pu/MA fuel cycles for HTRs will be investigated to optimise the CP fuel and reactor characteristics and to assure nuclear stability of a Pu/MA HTR core. It is envisaged to optimise actual Pu CP production and to explore feasibility for MA fuel.
New CP designs will be explored withstanding very high burn-ups and being well adapted for disposal after irradiation. It is also envisaged to irradiate existing Pu CPs in Euratom's Petten HFR. (V)HTR Pu/MA transmuters are envisaged to operate in a global system of various reactor systems and fuel cycle facilities. Fuel cycle studies are envisaged to study the symbiosis to LWR, GCFR and ADS, and to quantify waste streams and radiotoxic inventories. The technical, economic, environmental and socio-political impact shall be assessed as well. PUMA contributes to technological goals of the Generation IV International Forum. It contributes to develop and maintain competence in reactor technology, and to address European stakeholders on key issues for the future.
Total cost: EUR 3 700 566
EU contribution: EUR 1 850 000
http://cordis.europa.eu/project/rcn/80057_en.html

FP6 VELLA
Virtual European Lead LAboratory

Virtual European Lead Laboratory (VELLA) created a virtual European laboratory for Lead Technologies, establishing a network of European laboratories that operate heavy liquid metal (HLM) technology facilities. This favours integration of R&D efforts, facilitating the efficient use of the facilities, and coordination and performance of joint research activities. The activities related to VELLA have been grouped in three topics:

1. Networking Activities;
2. Transnational Access; and
3. Joint Research Activities.

The Networking Activities led to:

- The creation of a Virtual community of researchers by means of advance IT technologies (web site, video conference), thus integrating standard tools (meetings and workshops);
- The training and growth of young researchers, creating summer schools held in Italy, France, and Germany;
- The definition of common standards and protocols for facilities' use during the performance of tests; and
- Information exchange with programs/institutions operating in the field of HLM.

The goals related to Transnational Access were to:

- Favour the access to the European HLM infrastructures and knowledge; and
- Favour the mobility between laboratories.

The Joint Research Activities led to the development of the European knowledge base on:

- Lead technology as a coolant in nuclear systems (ADS, Gen-IV reactors);
- HLM components, instrumentation, design and system operation;
- HLM thermal hydraulics, incl. advanced thermal hydraulic tests in order to acquire knowledge on heat exchange, natural convection capability, and free surface behaviour; and

- Irradiation in the presence of LBE, development of a Pb system for reactor tests.

Total cost: EUR 3.913.902
EU contribution: EUR 2 300 000
Duration: From 2006-10-01 to 2009-09-30
http://cordis.europa.eu/project/rcn/80059_en.html

FP6 ELSY
European Lead-cooled System

The Gen-IV initiative considers fast reactors mandatory for a sustainable development of the Nuclear Energy. Europe has a large experience in the field of sodium-cooled fast reactors and has made a big effort in the Lead-Bismuth Eutectic (LBE) technology for use in the sub-critical reactors. The natural development is the use of pure lead since less expensive, less corrosive and of lesser radiological concern than LBE. Lead is chemically inert and has good neutronic characteristics that are unique among the coolants for a fast reactor.
The ELSY project demonstrated that it is possible to design a competitive and safe fast power reactor using simple technical engineered features. The high lead density has the advantage that, in the hypothetical case of a core disruption, it is possibly less likely to lead to core compaction scenarios which might cause the insertion of large amounts of reactivity in a short time. The use of compact in-vessel steam generators and of a simple primary circuit with possibly all internals being removable are among the reactor features for competitive electric energy generation and long-term investment protection. Europe has taken the initiative to promote this ambitious project carrying out a very innovative activity with participation of young engineers and scientists, who have learned from engineers and scientists near to retirement with large experience in fast reactors design. Gen-IV Partners outside Europe also participated in design and development of a common large-scale LFR. The activity consisted of management and technical topics subdivided into six Work-Packages:

- WP1: Design objectives, cost estimate, future R&D needs;
- WP2: Core design and performance assessment;
- WP3: Main components and systems;
- WP4: System integration;
- WP5: Safety and transient analyses; and
- WP6: Lead technology.

Total cost: EUR 6 884 590
EU contribution: EUR 2 949 645
http://cordis.europa.eu/project/rcn/80053_en.html

FP6 HPLWR
High Performance Light Water Reactor - Phase 2

The overall objective of the HPLWR Phase 2 project is to assess the critical scientific issues and the technical feasibility of the High Performance Light Water Reactor (HPLWR) system with a view to determine its future potential. To accomplish this objective, a highly qualified team of seven research centres from seven different countries, two universities and an industrial partner will substantiate the concepts and ideas from the previous HPLWR research project. The measurable results of this project can be summarized as follows:

- Conceptual layouts of the plant including core, reactor pressure vessel (RPV) components and balance-of-plant - refined economic assessment
- analysis of the thermal core for neutronic, thermalhydraulic and mechanical aspects - decision on the feasibility of the fast core option
- concept of safety system which leads to fulfil the European Utility Requirements and assessment of the safety system by simulations of several accidents and transients with improved safety codes
- selection of tested materials and data for fuel rod cladding, core and RPV materials and specifications for the water chemistry
- numerical heat transfer modelling and derived correlations
- evaluation of the concept on its environmental impact, resource utilisation and proliferation resistance
- European research agenda and industrial deployment strategy.

The assessment criteria are provided by the European Utility Requirements and the technology goals of the Generation IV International Forum. In both time frame and content, the project fits perfectly into the Generation IV roadmap, and is complementary to the international research on Supercritical Water Cooled Reactors (SCWR). A training and educational programme is carried out in course of this project.

Total cost: EUR 4 652 400

EU contribution: EUR 2 500 000

http://cordis.europa.eu/project/rcn/80035_en.html

FP6 EISOFAR

Roadmap for a European Innovative Sodium cooled Fast Reactor

Fast Reactors have a unique capability as sustainable energy source in terms of both utilization of fissile material for energy production and minimization of the nuclear waste, due to the hard neutron spectrum; Liquid Metal Fast Reactors (LMFR) are among the selected Generation IV systems to address the sustainability issues.

The SSA named "Roadmap for a European Innovative SOdium cooled FAst Reactor - EISOFAR" aims enabling the European Community to define its specific R&D strategic objectives on sodium cooled fast reactors embedded in the ongoing discussions performed within the CA on the SNE-TP; it has the ambition to be a key component of the European Strategic Research Agenda.

EISOFAR SSA is pursuing several technical objectives by:

- The identification of a comprehensive set of preliminary requirements, approaches and strategies applicable, in general, to future LMFR and in particular to a fourth generation European Sodium Fast Reactor (ESFR);
- The preliminary definition of new opportunities of viability's domains where the solutions will be found in order to meet the above requirements, and the identification of plausible design options;
- The identification of R&D topics for the ESFR and specific Euratom R&D studies;
- The preparation of a preliminary Roadmap for the ESFR It is expected that the SSA results will contribute mainly on the following items for the ESFR:
- Strategies and requirements on: Safety, and ways for possible improvements; Safeguards for PR&PP improvement and implementation; Reduction of investment and operating costs;

- Feasibility domains for: Core design with minor actinides; Advanced fuel cycle (actinide recycling, waste management, resistance to proliferation); Design options and promising alternatives.

These insights will allow helping the identification of the specific R&D needs, the objectives and content for an integrated project in FP7 and the plausible schedule for the ESFR deployment.
Total cost: EUR 489139
EU contribution: EUR 249021
http://cordis.europa.eu/project/rcn/84179_en.html

FP6 ALISIA
Assessment of Liquid Salts for innovative applications

Among other fluids like water, sodium and gases, liquid salts score high in terms of heat transport and heat transfer properties (large heat capacity, high boiling point, good conductivity).In the Generation IV programme, the MSR (Molten Salt Reactors) Steering Committee, is giving more attention to:

- Heat transport between a heat source and specific processes (hydrogen production...);
- Liquid salts as efficient coolants for solid fuel reactors, in alternative to sodium and helium in fast or thermal reactors;
- Molten salts acting both as fuel and coolant in MSR concepts operated either as breeders in thorium cycle, or as actinide burners for LWR spent fuel recycling.

Liquid salts also present a generic interest as solvents in pyrochemical techniques. Molten salts were investigated in USA in the 60's and 70's in the frame of programmes dedicated to the development of MSR breeders. US DoE/ORNL has considerable amount of results forms a reference set of data on liquid salts properties and behaviour.
The MOST project, supported by the FP5, revisited the potential of MSR technology. Since the termination of the project in 2004, the collaborative effort conducted by the MOST partners has remained vivid. This network involves today 15 partners in 9 countries and includes Russia, therefore keeping a tight link with the ISTC-1606 project.
The ISTC-1606 training programme is provided to Russian experts by scientists belonging to the European network on molten salts. The main objective of the ALISIA action is to strengthen, within an official European framework, the existing network on molten salts technologies, and to prepare future activities in FP7.
Total cost: EUR 453 867
EU contribution: EUR 248 380
http://cordis.europa.eu/project/rcn/84177_en.html

FP7 HYCICLES

HycycleS aims at the qualification and enhancement of materials and components for key steps of thermochemical cycles for solar or nuclear hydrogen generation. The focus of HycycleS is the decomposition of sulphuric acid which is the central step of the sulphur based family of those processes, especially the hybrid sulphur cycle and the sulphur-iodine cycle. Breakthrough developments are targeted for both with an accent on the hybrid sulphur cycle. Emphasis is put on materials and components for sulphuric acid evaporation, decomposition, and sulphur dioxide separation. The suitability of

materials and the reliability of the components will be shown in practice by decomposing sulphuric acid and separating its decomposition products in scalable prototypes. The final aim is to bring thermochemical water splitting closer to realisation by improving the efficiency, stability, practicability, and costs of the key components involved and by elaborating detailed engineering solutions. The activities comprise the experimental identification and evaluation of suitable materials in particular: ceramics of the SiC family, development and test of the key components evaporator, decomposer, and separator as prototypes, qualification of catalysts, construction materials and components, modelling of those components and characteristics of materials, and analysis of the techno-economic impact on the overall process. The project takes into account the activities currently performed in the US, Japan, and Australia. Therefore key partners from those countries, Westinghouse, JAEA, and CSIRO, are involved to ensure coordination of activities and information exchange with respect to sulphur based cycles in the different continents and the definition of interfaces. Beyond that, HycycleS activities will be strongly linked with international initiatives on hydrogen production under the aegis of IPHE, IEA, INERI, and Generation IV to ensure mutual benefit from different international programmes.
Total cost: EUR 5 123 432
EU contribution: EUR 3 748 823
http://cordis.europa.eu/project/rcn/85748_en.html

FP7 F-BRIDGE
Basic Research for Innovative Fuels Design for GEN IV systems

Up to now, fuel development and qualification has been a long and expensive process essentially based on an empirical approach. European experts currently have an adequate knowledge of conventional fuel manufacturing and its behaviour under operating conditions encountered during 50 years of industrial application and R&D activities. For innovative fuel systems, however, the empirical approach has reached its limit and cannot be easily extrapolated to new materials, new environments, or new operating conditions because the basic underlying mechanisms governing manufacturing, behaviour and performance remain largely poorly understood. One of the challenges for the next years is to supplement the empirical approach by a physically based description of ceramic fuel and cladding materials. To do so, the F-BRIDGE project, which stands for Basic Research for Innovative Fuels Design for GEN IV systems, intends to develop a new approach to fuel development by building a bridge (integration and transfer) between basic research activities and technological applications for the Generation IV fuel-cladding systems. Besides a general approach on ceramic materials, the project will focus on the improvement of a promising composite ceramics concept, the sphere-pac fuel, which exhibit significant advantages for Generation IV. F-BRIDGE aims at: obtaining data, mechanisms and models from basic research for an improved description of fuel and ceramic cladding materials under irradiation, in a multi-scale approach coupling separate effect experiments and modelling; ensuring the transfer between basic research and technological issues related to Generation IV systems and illustrating the integration effort through a multi-scale modelling exercise on UO2; assessing the technological implications of sphere-pac fuels for the GEN IV systems; ensuring dissemination of results, education and training in the field of R&D on fuel behaviour.
Total cost: EUR 10 204 706

EU contribution: EUR 5 450 000
http://cordis.europa.eu/project/rcn/88393_en.html

FP7 CARBOWASTE

Gas-Cooled Reactors (GCR), RBMK and some Material Test Reactors (MTR) make use of graphite as moderator of the fuel, structures of the core and/or thermal columns. During operation, the graphite and other carbonaceous materials like carbon brick, pyrocarbon and silicon carbide coatings are contaminated by fission products and neutron activation. These irradiated carbonaceous wastes are problematic due to their content of long-lived radioisotopes (e.g. Carbon-14, Chlorine-36) and due to their large volumes. About 250000 t of i-carbon are existing, worldwide. Acceptable solutions have not yet been established to handle this kind of waste. This fact also represents a significant drawback for the market introduction of graphite-moderated reactors like Very/High-Temperature Reactors (V/HTR) as a promising Generation IV system candidate. Graphite moderated reactors represent the very first generation of nuclear reactors and therefore need to be decommissioned ahead of other reactor types which evolved later. Presently, accelerated decommissioning of GCR and RBMK and subsequent disposal of i-graphite is the preferred option for not leaving this waste as a legacy for future generations. The CARBOWASTE project aims at an integrated waste management approach for this kind of radioactive wastes which are mainly characterized as Intermediate Level Waste (ILW), due to the varying content of long-lived radioisotopes. Methodologies and databases will be developed for assessing different technology options like direct disposal in adopted waste containers, treatment & purification before disposal or even recycling i-carbonaceous material for reuse in the nuclear field. The feasibility of the associated processes will be experimentally investigated to deliver data for modelling the microstructure and localization of contaminants. This is of high importance to better understand the origin of the contamination and the release mechanisms during treatment and/or disposal.
Total cost: EUR 12 292 114
EU contribution: EUR 6 000 000
http://cordis.europa.eu/project/rcn/88385_en.html

FP7 GETMAT
GEn IV and Transmutation MATerials

In FP5 and FP6, a number of projects were launched aimed at investigating innovative strategies for safe and optimised radioactive waste management. In particular, Partitioning and Transmutation (P/T) strategies based on the use of Accelerator Driven Systems were addressed within the EURATOM FP6 integrated project EUROTRANS. Moreover, during FP6, projects were also initiated to study advanced systems, as defined in the frame of the Generation-IV: VHTR, GFR, LFR, SFR, SCWR, and MSR.
Some of these innovative systems (i.e. those based on fast neutron spectra) allow also the deployment of optimised waste minimisation technologies, compatible with sustainability and increased proliferation resistance goals. New issues and challenges related to the development and qualification of structural materials for core and primary components have been recognized as crucial in all these systems to ensure their safe and reliable operation.

The objective of the GETMAT project was to integrate in a comprehensive and common effort within the European materials laboratories the R&D activities needed to select and characterize (in terms of mechanical behaviour, coolant compatibility and particle irradiation effects) structural materials with required properties for advanced nuclear reactor and transmutation systems. Specific items have been identified and selected in order to focus the proposed project on cross-cutting issues, applicable to more than one system, by taking advantage of expertise and experimental facilities operating in the area of both fission and fusion technology programmes.
Total cost: EUR 13 959 123
EU contribution: EUR 7 500 000
http://cordis.europa.eu/project/rcn/85745_en.html

FP7 EUROPAIRS

The development of GENERATION IV nuclear systems is an important objective of the FP7 Euratom work programme. The significant support given in FP5 and FP6 allowed Europe to acquire strong assets in the technology of one of the six GENERATION IV reactor types, the (V)HTR.
In line with these assets and with the recommendation of the Sustainable Nuclear Energy Technology Platform, which points out high temperature industrial process heat applications of nuclear energy as one of 3 major axes of development recommended for European nuclear R&D, the EUROPAIRS project proposes a step forward towards industrial application of (V)HTR technology: the objective of EUROPAIRS is to identify the boundary conditions for the viability of nuclear cogeneration systems connected to conventional industrial processes and to initiate the partnership of nuclear organisations and end-user industries, which would be deployed in a further step to develop a Demonstrator coupling a (V)HTR with industrial processes (the boundary condition framework defines technical, industrial, economical, licensing and safety requirements for the nuclear system, the processes that can consume the energy generated, and the coupling system).
For that purpose:

- A strong partnership of nuclear industrial and R&D organisations with process heat user industries, which is absolutely needed, will be built, based on the joint participation of nuclear and heat end-user partners. The implementation of the project will allow a better understanding of these two communities through mutual information, as well as a sharing of the objectives and of the development programme for the demonstrator.
- Boundary conditions for nuclear cogeneration will be defined from the points of view of technical feasibility, industrial practicability, licensing acceptability (with the input of Regulator and TSO partners), sustainability and economic competitiveness. The critical issues will be identified, solutions of viable coupling schemes will be proposed and R&D needs pointed out.
- A roadmap for designing and constructing a demonstrator will be elaborated, including the developments needed for the reactor, the heat transport system and the process heat applications, as well as the R&D and qualification actions required in support of this programme.

A schedule will be proposed as well as an estimation of the costs and a sketch of the business case for further industrial deployment.
Total cost: EUR 1 501 364

EU contribution: EUR 800 000
http://cordis.europa.eu/project/rcn/94416_en.html

FP7 CDT
Central Design Team for a fast-spectrum transmutation experimental facility

Besides the European Global Energy Policy, the European Council adopted an action plan that covers nuclear technologies and supports research in order to "further improve nuclear safety and the management of radioactive waste". To obtain a more efficient and sustainable management of radioactive waste and hence reduce the burden on geological storage, one can apply partitioning and transmutation independently of future commitment or not to nuclear energy. In the Strategic Research Agenda of SNETP, a need was also clearly expressed for a fast-spectrum experimental system to support the development and demonstration of an alternative technology to sodium. Within European Union many R&D organisations and industries have been conducting since late 1990s strong R&D in the Partitioning &Transmutation (P&T) field with substantial support from the European Union. As the next step after FP6 IP EUROTRANS, the design of a fast spectrum transmutation experimental facility (FASTEF), able to demonstrate efficient transmutation and associated technology through a system working in subcritical mode (ADS) and/or critical mode was therefore conducted in the CDT project.
The objectives of the CDT project were:

- to demonstrate the ADS technology and the efficient transmutation of high level waste;
- to operate as a flexible irradiation facility;
- to contribute to the demonstration of the LFR technology.

Total cost: EUR 4 029 789
EU contribution: EUR 2 000 000
http://europairs.eu
http://cordis.europa.eu/project/rcn/92883_en.html

FP7 CP-ESFR
Collaborative project on European sodium fast reactor

This Collaborative Project (CP) addresses key viability and performance issues to support the development of a fourth generation European Sodium Fast Reactor (ESFR). This innovative system is mainly developed for competitive electricity generation and offer interesting potential characteristics in terms of safety, environmental impact, resource utilization and waste minimization (e.g. potential for Minor Actinides management).
The objectives of the CP-ESFR look for the improvement, vis-à-vis of current nuclear systems, of the safety level, the guarantee of a financial risk comparable to that of the other means of energy production and a flexible and robust management of the nuclear materials. The corresponding technical requirements in terms of System's performance; Operation, maintenance and procedures; Safety design and analysis and licensing issues; Physical protection and Proliferation resistance; Functional requirements for provisions; Fuel cycle Constructability; Decommissioning; System s economy are based among others upon the results of the 6th FP Specific Support Action EISOFAR (Roadmap for a European Innovative SOdium cooled FAst Reactor).

This four years project will fit with the principle for an industrial deployment of ESFR technology around 2040 with the preliminary deployment of a demonstrator by 2020-2025.

Following the requirements above, and considering the context as it is described, the Collaborative Project is structured into six main technical sub projects (SPs):

1) Consistency and assessment and international relationships
2) Fuel, fuel element, core and fuel cycle
3) Safety and Security
4) Energy Conversion System Components and materials
5) Reactor system (including handling)
6) Education and training: A specific Management activity will insure the whole consistency.

Total cost: EUR 11865550

EU contribution: EUR 5799931

http://cordis.europa.eu/project/rcn/92070_en.html

http://www.cp-esfr.eu/

FP7 FAIRFUELS

FAbrication, Irradiation and Reprocessing of FUELS and targets for transmutation

FAbrication, Irradiation and Reprocessing of FUELS and targets for transmutation (FAIRFUELS) provides a way towards a more efficient use of fissile material in nuclear reactors with a view to reducing the volume and hazard of high level long-lived radioactive waste, closing the nuclear fuel cycle. In order to contribute to the competitiveness of Europe, the Collaborative Project FAIRFUELS will conduct appropriate studies in synergy with other fuel and actinide partitioning & transmutation projects while maintaining close links with Generation IV International Forum. In fabrication technology and assessment of transmutation performance, FAIRFUELS will focus on minor actinides. Dedicated fuels will be fabricated and a fairly comprehensive irradiation programme will be carried out to address transmutation performance. In parallel, FAIRFUELS will conduct Post Irradiation Examination (PIE) of certain previously irradiated fuels and targets to provide in-depth information on their irradiation behaviour. In support of the PIE, modelling aspects of these fuels will be developed. A training and education programme will also be implemented to share the knowledge among the community, with a link to other related projects. In accordance with the road-mapping exercise undertaken in FP6 and the SNE-TP vision report, the FAIRFUELS consortium, comprising of nuclear research bodies, industry, the European Commission Joint Research Centre, and European universities, will endeavour to improve our knowledge in the area of fuels and targets to form a basis for the development of future demonstration systems.

Total cost: EUR 7 320 810.61

EU contribution: EUR 3 000 000

http://cordis.europa.eu/project/rcn/90990_en.html

http://www.fp7-fairfuels.eu/

FP7 ADRIANA

ADvanced Reactor Initiative And Network Arrangement

The coordinating action ADRIANA (ADvanced Reactor Initiative And Network Arrangement) is proposed to setting up the network dedicated to the construction and operation of research infrastructures in support of developments for the European Industrial Initiative for sustainable nuclear fission. The project as the base for the current long-term taking place coordination activities of EURATOM under financial support of the European Commission for construction of research infrastructure in the frame of Structural funds of the European Union suggests the programme of utilization of built-up facilities for the given purpose. The project for this purpose defines in detail the new needed research infrastructures, defines and provides legal and financial structures for major refurbishment or upgrading of existing facilities, the construction of new ones and considers the trans-national access to these experimental facilities. Assurance of long-term reliable and competitive energy resources has been an indispensable request for sustainable development of EU communities and their competition s positions in the frame of the worldwide economic development and political influence in the process of global governance. The Project solves the above given objectives for reactor systems and connecting technologies: - Sodium Fast Reactor (SFR) - Lead Fast Reactor (LFR) - Gas Fast Reactor (GFR, including very high temperature technologies) - Instrumentation, diagnostics and experimental devices - Irradiation facilities and hot laboratories - Zero power reactors - Road map of research infrastructures.
Total cost: EUR 1 429 911
EU contribution: EUR 992 650
http://cordis.europa.eu/project/rcn/95953_en.html
http://adriana.ujv.cz/

FP7 HELIMNET
Heavy Liquid Metal Network

The HeLiMnet project aimed at integrating the liquid metal technology related R&D efforts on-going within and outside Europe.
In particular, HeLiMnet created a large platform for the dissemination and exchange of information on the heavy liquid metal (HLM) technologies, exploiting the capabilities of both new information technologies and the traditional tools, such as workshops, seminars, information days, etc.
HeLiMnet also contributed to the development of guidelines, protocols and standards, with particular attention to the harmonisation of operational procedures in order to have a better control over the quality and comparability of the experimental data obtained in different labs.
The project evaluated the liquid metal technology research area, through the analysis of approaches and activities on-going at national and international level in different domains (fission (LFR, ADS, SFR), neutron spallation targets and fusion), identifying possible cooperation opportunities, existing gaps, and possible future R&D activities to cover these gaps.
Total cost: EUR 718 348
EU contribution: EUR 499 984
http://cordis.europa.eu/project/rcn/94437_en.html

FP7 ANDES

Accurate Nuclear Data for nuclear Energy Sustainability

According to the "Vision report and Strategic Research Agenda" publication of the European Technological Platform for a Sustainable Nuclear Energy (SNETP), sustainability requires the combination of the present LWR, future Advanced Fast reactors and the waste minimization in closed cycles with Partitioning and Transmutation. To implement these new nuclear systems and their fuel cycles it is necessary to improve the accuracy, uncertainties and validation of related nuclear data and models, required for those systems but also for the experimental and demonstration facilities involved in the their validation. The project will include new nuclear data measurements, dedicated benchmarks, based on integral experiments, and improved evaluation and modelling specifically oriented to obtain high precision nuclear data for the major actinides present in advanced reactor fuels, to reduce uncertainties in new isotopes in closed cycles with waste minimisation and to better assess the uncertainties and correlations in their evaluation.
Total cost: EUR 5 959 674
EU contribution: EUR 2 995 000
http://cordis.europa.eu/project/rcn/95952_en.html

FP7 LEADER
Lead-cooled European Advanced Demonstration Reactor

The LEADER project dealt with the development to a conceptual level of a Lead Fast Reactor Industrial size plant (European Lead-cooled Fast Reactor, ELFR) and of a scaled demonstrator of the LFR technology (Advanced Lead Fast Reactor European Demonstrator, ALFRED). The project was based on previous achievements obtained during the FP6 in the ELSY project but took also into account priorities expressed in the Strategic Research Agenda of SNETP as well as the goals of the European Sustainable Nuclear Industrial Initiative (ESNII). The project was strongly oriented towards the conceptual design of a scaled/pilot plant to be constructed in the relatively short term.
The focus of the first part of activity of the LEADER project was the resolutions of key issues emerged in the frame of the ELSY project in order to obtain a new reference reactor configuration. This updated reactor configuration of an industrial size LFR was then used to design a low cost and fully representative scaled down prototype of a suitable size (300 MWth). The LEADER project also, from the beginning, involved End-Users, Safety Authorities and Technical Support Organisations (TSOs) in the design process to help the plant conception and to assure high safety standards. Education and Training activities were also included in a specific work package where European Universities were directly involved with the aim to grow-up the future nuclear energy designer.
The LEADER projects took strongly into account the others already proposed or on-going EU projects. All projects dedicated to R&D and material developments, projects dedicated to the development of ADS systems for transmutation or related to the development of fast reactors (EUROTRANS, VELLA, CDT, CP-ESFR, GETMAT, FAIRFUELS, ACSEPT, EUFRAT, F-BRIDGE, ACTINET-I3, THINS) have had strong synergies with LEADER toward the development of a Lead cooled fast reactor system.
Total cost: EUR 5 699 396
EU contribution: EUR 2 994 088
http://cordis.europa.eu/project/rcn/96603_en.html

FP7 ARCAS

The objective of the proposal is based on the outcome of PATEROS CA which is to assess more in depth the regional approach to P&T implementation. ARCAS will respond to one of the key-topics put forward by the Strategic Research Agenda of SNETP. The project looks at the economic aspects of the most realistic scenario for P&T with the hypothesis: limit the MA bearing fuel transport and limit the MA bearing fuel handling in and between all places such as at the reactor, at the fuel fabrication and at the reprocessing plant. The cost associated to implementing ADS's or dedicated Fast Reactors as minor actinide burning facilities will be assessed. The idea is to start from two fixed hypotheses: (1) working in double-strata approach and look only at the second ("burning" stratum); (2) assuming a certain influx of minor actinide mass per year that needs to be burned. These two hypotheses will allow the project to avoid extensive scenario studies. The economic impact will be evaluated for investment cost, associated fuel cycle and operational cost but not the needed R&D cost. A crucial parameter to be established for both reactor systems is the maximal minor actinide (MA) content in a core loading. This maximal MA value is determined by operational safety criteria to be adhered by the dedicated burner. An evaluation of a number of safety parameters for the systems will give an upper boundary for the minor actinide mass present in the core. In order to not diversify the work, the project should define a generic and representative system for the ADS approach and the FR approach.
Total cost: EUR 509 527
EU contribution: EUR 488 180
http://cordis.europa.eu/project/rcn/96861_en.html

FP7 GOFASTR
European Gas Cooled Fast Reactor

Fast reactors have the unique ability to be sustainable by, not only being able to generate their own fuel, but through being able to burn minor actinides to reduce the quantity and radiotoxicity of nuclear wastes. The latter ability enables fast reactors to not only burn the minor actinides produced by themselves but, in addition, the minor actinides arising from legacy wastes and thermal reactors in the nuclear park. This proposal concentrates on the Gas-cooled Fast Reactor (GFR) with a view to developing the GFR as a more sustainable version of the Very High Temperature Reactor (VHTR). The design goals for GFR are ambitious, aiming, initially, for a core outlet temperature of around 850 deg.C, a compact core with a power density of about 100MWth/m3, a low enough plutonium inventory to allow wide deployment, a self-sustaining core in terms of plutonium consumption, and a proliferation resistant core by not using specific plutonium breeding elements. This project will contribute Euratom's contribution to the Generation IV system research programme. As such, it is strongly aligned with the goals and structure of the latter. In addition this project fulfils an objective of the strategic research agenda of the European Sustainable Nuclear Energy Technology platform, for GFR to be developed as one of the longer-term alternatives to the sodium cooled fast reactor. The work of this project is aligned with the viability phase of the Generation IV GFR system. This three year project objective is to contribute to the demonstration of the viability of the GFR system with regard to deployment as a commercial sustainable

nuclear energy system. As well as contributing to Generation IV GFR research, this project provides the Euratom representation on the GFR System Steering Committee and the two project management boards (PMBs), namely, the Conceptual Design and Safety PMB and the Fuel and Core Materials PMB.
Total cost: EUR 5 430 276
EU contribution: EUR 3 000 000
http://cordis.europa.eu/project/rcn/96860_en.html

FP7 EVOL
Evaluation and Viability of Liquid Fuel Fast Reactor System

An innovative molten salt reactor concept, the MSFR (Molten Salt Fast Reactor) is developed by France since 2004. Based on the particularity of using a liquid fuel, this concept is derived from the American molten salt reactors (included the demonstrator MSRE) developed in the 1960s. The major drawbacks of these designs were (1) a short lifetime of the graphite blocks, (2) a reactor fuelled with 233U, not a natural fissile isotope, (3) a salt constituted of a high chemical toxic element: BeF2, and (4) a fuel reprocessing flux of 4000 liters per day required reaching a high breeding gain. However, this concept is retained by the Generation IV initiative, taking advantages of using a liquid fuel which allows more manageable on-line core control and reprocessing, fuel cycle flexibility (U or Th) and minimization of radiotoxic nuclear wastes. In MSFR, the MSR concept has been revisited by removing graphite and BeF2. The neutron spectrum is fast and the reprocessing rate strongly reduced down to 40 litres per day to get a positive breeding gain. The reactor is started with 233U or with a Pu and minor actinides (MA) mixture from PWR spent fuel. The MA consumption with burn-up demonstrates the burner capability of MSFR. The objective of this project is to propose a design of MSFR in 2012 given the best system configuration issued from physical, chemical and material studies, for the reactor core, the reprocessing unit and the wastes conditioning. By this way, demonstration that MSFR can satisfy the goals of Generation IV, in terms of sustainability (Th breeder), non-proliferation (integrated fuel cycle, multi-recycling of actinides), resources (close U/Th fuel cycle, no uranium enrichment), safety (no reactivity reserve, strongly negative feedback coefficient) and waste management (actinide burner) will be done.
Total cost: EUR 1 855 883
EU contribution: EUR 995 860
http://cordis.europa.eu/project/rcn/97054_en.html

FP7 THINS

For the long-term development of nuclear power, innovative nuclear systems such as Gen-IV reactors and transmutation systems need to be developed for meeting future energy challenges. Thermal-hydraulics is recognized as a key scientific subject in the development of innovative reactor systems. This project is devoted to important crosscutting thermal-hydraulic issues encountered in various innovative nuclear systems, such as advanced reactor core thermal-hydraulics, single phase mixed convection and turbulence, specific multiphase flow, and code coupling and qualification. The main objectives of the project are:

- Generation of a data base for the development and validation of new models and codes describing the selected crosscutting thermal-hydraulic phenomena. This data base contains both experimental data and data from direct numerical simulations (DNS).
- Development of new physical models and modelling approaches for more accurate description of the crosscutting thermal-hydraulic phenomena such as heat transfer and flow mixing, turbulent flow modelling for a wide range of Prandtl numbers, and modelling of flows under strong influence of buoyancy.
- Improvement of the numerical engineering tools and establishment of a numerical platform for the design analysis of the innovative nuclear systems. This platform contains numerical codes of various classes of spatial scales, i.e. system analysis, sub-channel analysis and CFD codes, their coupling and the guidelines for their applications.

The project will achieve optimum usage of available European resources in experimental facilities, numerical tools and expertise. It will establish a new common platform of research results and research infrastructure. The main outcomes of the project will be a synergized infrastructure for thermal-hydraulic research of innovative nuclear systems in Europe.
Total cost: EUR 10 592 854.80
EU contribution: EUR 5 941 810.80
http://cordis.europa.eu/project/rcn/94432_en.html
https://www.ifrt.kit.edu/thins/

FP7 ADEL
ADvanced ELectrolyser for Hydrogen Production with Renewable Energy Sources

The ADEL project (ADvanced ELectrolyser for Hydrogen Production with Renewable Energy Sources) proposes to develop a new steam electrolyser concept named Intermediate Temperature Steam Electrolysis (ITSE) aiming at optimizing the electrolyser life time by decreasing its operating temperature while maintaining satisfactory performance level and high energy efficiency at the level of the complete system including the heat and power source and the electrolyser unit. The relevance of this ITSE will be assessed both at the stack level based on performance and durability tests followed by in depth post-test analysis and at the system level based on flow sheets and energy efficiency calculations.
Total cost: EUR 4 155 776
EU contribution: EUR 2 043 518
http://cordis.europa.eu/project/rcn/97937_en.html
http://www.adel-energy.eu/

FP7 MAX
"MYRRHA Accelerator eXperiment, research and development programme"

"The present FP-7 proposal MAX is subsequent to the recommendations of the Strategic Research Agenda of SNETP for ADS development in Europe. Its aim is to pursue the R&D required for a high power proton accelerator as specified by the MYRRHA project. There is especially a strong focus on all the aspects that pertain to the reliability and availability of this accelerator.

This R&D effort builds on the large body of results and the clear conclusions that have been obtained during the consecutive FP5 project PDS-XADS and FP6 project EUROTRANS. MAX will investigate the key issues of redundancy and fault-tolerance by real-world experience in making maximum use of already existing or to-be-built dedicated prototypes, both on the injector side and on the main superconducting linac side.
At the end of the MAX project, it will be possible to generate an updated consolidated reference layout of the accelerator for MYRRHA with sufficient detail and adequate level of confidence in order to initiate its engineering design and subsequent construction phase.
Total cost: EUR 4 950 856
EU contribution: EUR 2 926 199
http://cordis.europa.eu/project/rcn/97423_en.html

FP7 SILER
Seismic-Initiated events risk mitigation in LEad-cooled Reactors

The SILER project aimed at studying the risk associated to seismic initiated events in Generation IV Heavy Liquid Metal reactors and developing adequate protection measures.
The attention was focused on the evaluation of the effects of earthquakes (with particular regard to beyond design basis seismic events and tsunamis) and to the identification of mitigation strategies, impacting both structures/components design as well as the design of isolation devices, which can also have beneficial impact on economics, leading to a high level of plant design standardization.
Attention was also devoted to the identification of plant layout solutions able to avoid risks of radioactive release from both the core and other structures (i.e. the spent fuel storage pools). Specific effort was devoted to the development of guidelines and recommendations for addressing the seismic issue in next generation reactor systems.
In addition, considerations were given to transfer of the knowledge developed in the project to Generation III advanced systems, in line with the objective of the Strategic Research Agenda of SNETP to support present and future Light Water Reactors and their further development.
Total cost: EUR 4 450 851
EU contribution: EUR 2 926 133
http://cordis.europa.eu/project/rcn/100587_en.html

FP7 MATTER
MATerials TEsting and Rules

The European Sustainable Nuclear Industrial Initiative (ESNII) establishes a very tight time schedule for the start of the construction of the European Gen-IV prototypes. The Gen-IV reactors pose new challenges to the designers and scientists in terms of higher operating temperature and higher irradiation damage of materials with respect to the present technologies. In this frame, the MATTER (MATerials TEsting and Rules) Project performed well-targeted research studying materials behaviour in Gen-IV operational conditions, establishing criteria for the correct use of these materials in relevant reactor applications. The MATTER project also contributed to material R&D conducted in the frame of the EERA, providing experimental data for implementation of pre-normative rules. The project investigated:

- Mature materials research focusing on testing procedures for the new reactors' conditions;
- Supporting experiments of mature materials aimed to liquid metals characterization and to pre-normative qualification;
- Pre-normative activities to revise and update the design rules;
- Preparation and starting of the EERA Joint Programme by harmonization of the structure and finalization of the preliminary programme in accordance with the Deployment Strategy of SNETP.

The project also contributed to the better coordination of expensive materials testing operations, enhancing comparability of the experimental data produced by consensual procedures.
Total cost: EUR 12 180 253
EU contribution: EUR 5 993 919
http://cordis.europa.eu/project/rcn/97428_en.html

FP7 SCWR-FQT
Supercritical Water Reactor - Fuel Qualification Test

The SCWR-FQT project is related to the HPLWR Phase 2 European project, focused on the design of the European supercritical water cooled reactor, HPLWR. The scope of the SCWR-FQT Euratom-China parallel project is to design an experimental facility for qualification of fuel for the supercritical water-cooled reactor. The facility is destined to be operated in the LVR-15 research reactor in the Czech Republic in the future. All necessary documents required for licensing of the FQT facility by the Czech regulator shall be the outcome of this project. Pre-qualification of the FQT facility will be carried out in China. Testing of a limited amount of commercially available nuclear grade materials, which are candidates for fuel cladding, will be carried out within this project as well.
Total cost: EUR 2 830 750
EU contribution: EUR 1 500 000
http://cordis.europa.eu/project/rcn/97437_en.html

FP7 ARCHER

In line with the Sustainable Nuclear Energy Technology Platform (SNETP) Strategic Research Agenda (SRA) and Deployment Strategy (DS), the ARCHER project will extend the state-of-the-art European (V)HTR technology basis with generic technical effort in support of nuclear cogeneration demonstration.
The partner consortium consists of representatives of conventional and nuclear industry, utilities, Technical Support Organisations, R&D institutes and universities. They jointly propose generic efforts composed of:

- System integration assessment of a nuclear cogeneration unit coupled to industrial processes
- Critical safety aspects of the primary and coupled system:
    - Pressure boundary integrity

- Dust
- In-core hot spots
- Water and air ingress accident evaluation

- Essential HTR fuel and fuel back end R&D
  - PIE for fuel performance code improvement and validation
  - Back end research focused on radiolysis
- Coupling component development:
  - Intermediate heat exchanger development
  - Steam generator assessment
- High temperature material R&D:
  - Completion of graphite design curves
  - Making use of the experience of state of the art metal in conventional industry
- Nuclear cogeneration knowledge management, training and communication

The activities are imbedded in the international framework via GIF; direct collaboration within the project with international partners from the US, China, Japan, and the republic of Korea; and cooperation with IAEA and ISTC.
The project proposal is a technical building block supporting nuclear cogeneration as fossil fuel alternative for industry and as such supports a high potential contribution to European energy strategy as defined in the SET-Plan. The results will be reported to SNETP, to support the strategic pillar of 'other uses of nuclear energy', and the establishment of a Nuclear Cogeneration Industrial Initiative, which shall include effective (international) nuclear cogeneration demonstration.
Total cost: EUR 9 794 363.46
EU contribution: EUR 5 400 000
http://cordis.europa.eu/project/rcn/97570_en.html
www.archer-project.eu/

FP7 JASMIN
Joint Advanced Severe accidents Modelling and Integration for Na-cooled fast neutron reactors

This project will support the ESNII (European Sustainable Nuclear Industrial Initiative) roadmap and the Strategic Research Agenda and the Deployment Strategy of SNETP (Sustainable Nuclear Energy Technology Platform) on the enhancement of Sodium-cooled Fast neutron Reactors (SFR) safety, especially towards a higher resistance to severe accidents.
In the initiation phase of SFR core disruptive accidents, it is essential to investigate the impact of new core designs that may disperse core debris and minimize risks of core compaction. The available codes today have been developed in the 80s. The objective is to develop a new European simulation code, ASTEC-Na, with improved physical models, accounting for results of recent LWR research, with modern software architecture and high flexibility to account for innovative reactor designs. It will be based on the ASTEC European code system, developed by IRSN and GRS for severe accidents in water-cooled reactors. This will allow capitalizing on the state-of-the-art knowledge on SFR severe accidents.
The code will evaluate the consequences of fuel pin failure conditions on materials relocation and primary system loads, and the source term produced by the migration

inside the reactor of activated fission products and aerosols that may be released to the environment.
The project will gather partners with strong experience on SFR safety and/or on ASTEC code. Specific SFR physical models will be developed, on the basis of outputs of the CP-ESFR FP7 project. After the elaboration of general specifications and of a validation matrix, the models will be developed, implemented into the code, validated vs. experiments (like past CABRI ones) and benchmarked with other codes. The further extension of ASTEC-Na to cover other parts of the SFR severe accidents (transition phase, fires) and to LFR will be investigated.
An Education programme will include workshops as well as the secondment of young researchers in other organizations.
Total cost: EUR 5 650 533
EU contribution: EUR 2 991 182
http://cordis.europa.eu/project/rcn/100634_en.html

FP7 SEARCH
Safe ExploitAtion Related CHemistry for HLM reactors

In accordance with the ESNII roadmap MYRRHA is expected to be the first heavy liquid metal (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 are being 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. For that, the heat transfer coefficients of a wire-spaced fuel bundle and the basic chemical behaviour of a mixture of fuel, coolant and clad materials are being studied at relevant temperatures. The compatibility experiments are being done with UO2, PuO2, and un-irradiated MOX fuel, addressing the energy release, solubility in the coolant and fuel-coolant-clad compound formation. Fuel dispersion in the coolant is 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 is addressed by studying 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 cover gas system are being examined. The evaporation of Po and Hg from lead-bismuth eutectic (LBE) is being measured to obtain a full data set for licensing. Issues related to Po management are also being 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.
Total cost: EUR 5 719 903
EU contribution: EUR 2 977 524
http://cordis.europa.eu/project/rcn/100828_en.html

FP7 FREYA
Fast Reactor Experiments for hYbrid Applications

Given the objectives for MYRRHA/FASTEF to be operated as a sub-critical as well as a critical facility, an experimental programme in support of the design and licensing of both operation modes is needed. Building up on the activities accomplished in the previous FPs, namely MUSE in FP5 and EUROTRANS in FP6, the FREYA project extends the investigations of the sub-critical configurations for validation of the methodology for on-line reactivity monitoring of ADS systems.

The investigations in the FREYA are related to the different sub-criticality levels for the nominal operation mode of ADS. In order to investigate the robustness of several proposed measurement techniques with regard to the reflector effect, experiments are being performed with different reflector materials. To complete the validation of the methodology for sub-criticality monitoring, the robustness of the reactivity indicators with regard to a change in vertical position of the neutron source are also investigated in view of possible variations of the height of the spallation source in a real ADS. The experimental programme includes also dedicated experiments for the ALFRED fuel and core configuration generating useful information for the validation of reactor computer codes for LFR development.

Total cost: EUR 5 060 978

EU contribution: EUR 2 799 992

http://cordis.europa.eu/project/rcn/97425_en.html

FP7 ALLIANCE

Preparation of ALLegro - Implementing Advanced Nuclear Fuel Cycle in Central Europe

The ALLIANCE project focuses on the preparatory phase for developing the ALLEGRO demonstrator. This is based on the Gas Fast Reactor (GFR) concept, one of the 2 alternative systems under the SET-Plan's European Sustainable Nuclear Industrial Initiative (ESNII), expected to be built in Central Europe. ALLIANCE covers a number of preliminary studies on fuel management, R&D roadmap & infrastructures needs, and siting, as well as the licensing roadmap, preliminary design and safety analysis. ALLIANCE will integrate experience and knowledge gained from the past or ongoing related initiatives.

Arguments on why GFR technology could be accepted in Europe as a complementary option of SFR will be clearly stated. Furthermore map and highlight of national or regional initiatives supporting the development of this technology and list of countries interested in the hosting of the ALLEGRO demonstrator on its territory. The conditions for the site selection should be defined within this project.

In addition the project specification on licensing and construction period will be suggested. For the R&D activities as well as for the operational and decommissioning phases specifications should be elaborated. These specifications would cover the licensing roadmap, financing and project organisation setup. According to the latest concept, a common Centre of Excellence will be created in Central Europe for GFR studies. The creation of the Centre will be the first step towards integration of fuel and reactor safety research in the region.

Total cost: EUR 1 396 860

EU contribution: EUR 850 000

http://cordis.europa.eu/project/rcn/106585_en.html

FP7 ASGARD

Advanced fuelS for Generation IV reActors: Reprocessing and Dissolution

Nuclear power issues have been attracting research interest for decades even since the actual use of power reactors using oxide fuels was considered a mature science. It has mainly been due to one of the great drawbacks of nuclear power, the waste handling. Presently, there is a high interest in nuclear power research focused on a new generation of reactor concepts utilising more of the inherent energy of the fuels. Additionally, these new concepts will also produce less radioactive waste, which is radiotoxic for a shorter time frame. If such concept succeeds, nuclear power can be considered almost sustainable bearing in mind that the waste we already have generated may be used for next generations. In order to reach these goals, there are several issues to be considered and the future nuclear fuel is one of the most important ones.
ASGARD project will conduct crosscutting studies in synergy with the current nuclear fuel and waste research projects in Europe (e.g. ACSEPT and FAIRFUELS projects), but will also extend further into the research on new innovative nuclear concepts (SFR-Prototype, MYRRHA). ASGARD will provide a structured R&D framework for developing compatible techniques for dissolution, reprocessing and manufacturing of new nuclear fuels. The fuels to be considered will mainly consist of the next generation of fuels, e.g. oxides, nitrides and carbides, since the current oxide fuels and their reprocessing is dealt within already existing projects. An educational programme will be implemented to share the knowledge between students, researchers in the fuel manufacturing and the fuel reprocessing communities. The challenging objectives of ASGARD will be addressed by a multi-disciplinary consortium composed of European universities, nuclear research bodies and major industrial stakeholders. ASGARD will be an essential contribution to the development of new sustainable nuclear fuel cycle concepts and thus pave the road to more sustainable nuclear future.
Total cost: EUR 9 689 866
EU contribution: EUR 5 493 725
http://cordis.europa.eu/project/rcn/100635_en.html

FP7 SARGEN IV

This project focusses on a harmonized European methodology for the safety assessment of innovative reactors with fast neutron spectrum planned to be built in Europe
With the objective of future assessment of these advanced reactor concepts, the SARGEN_IV Project is intended to gather safety experts from recognized European Technical Safety Organizations from Designers and Vendors as well as from Research Institutes and Universities to:

- develop and provide a tentative commonly agreed methodology for the safety assessment,
- identify open issues in the safety area, mainly addressing and focussing on assessment of relevant ones,
- detect and underline new fields for R&D in the safety area
- provide a roadmap and preliminary deployment plan for safety-related R&D, including cost estimation.

Firstly, the proposed methodology requires the identification and the ranking of the main safety issues related to these reactors which needs a strong collaboration with other European projects as CP-ESFR, GoFastR, LEADER and CDT.

Secondly, a review of the safety methodologies proposed by international organizations and those issued from national practices and European consortia in order to define the tentative commonly agreed methodology which will be therefore applied to specific safety issues relevant for the selected reactors.
The project will streamline EURATOM contribution to Generation IV International Forum in the safety field. It will also improve relations between safety assessment and research programmes efficiency in the development of new concepts.
Total cost: EUR 1 293 111
EU contribution: EUR 999 128
http://cordis.europa.eu/project/rcn/100973_en.html

FP7 PELGRIMM

PELGRIMM is a 4 year project, addressing Minor-Actinide (MA) bearing fuel developments for Generation IV Fast Reactor Systems to support the Strategic Research Agenda (SRA) of the European Sustainable Nuclear Energy Technology Platform (SNE-TP). Both options, MA homogeneous recycle in driver fuels with MA content at a few percent, and heterogeneous recycle on UO2 fuels bearing high MA contents, located in the radial core blanket, are considered. Two fuel forms (pellet and spherepac) will be investigated. Indeed, spherepac technology (that leads to production of beads that can be directly loaded in pins) is attractive regarding MA-bearing fuels as it would lead to a significant simplification of the fabrication process and to a better accommodation of solid swelling (compared to pellets) under irradiation. These developments extend Europe's leading role in this area.
A total of 12 partners from research institutions, education establishments and industries will collaborate to share and leverage their skills, progress and achievements, covering a comprehensive set of investigations: fuel fabrication, fuel behaviour under irradiation through an irradiation test and the execution of Post Irradiation Examinations, modelling and simulation of fuel behaviour and performance under irradiation, from normal operating conditions to severe accidents, and finally by providing unique education and training possibilities.
Finally, synergies will be sought with other ongoing European projects. Furthermore, the PELGRIMM project will contribute actively to the EURATOMs contribution to Generation IV International Forum (especially SFR).
Total cost: EUR 7 211 760
EU contribution: EUR 2 999 999
http://cordis.europa.eu/project/rcn/101413_en.html
www.pelgrimm.eu

FP7 MAXSIMA
Methodology, Analysis and eXperiments for the “Safety In MYRRHA Assessment”

The Strategic Research Agenda of SNETP requires new large infrastructures for its successful deployment. MYRRHA has been identified as a long term supporting research facility for all ESNII systems and as such put in the high-priority list of ESFRI. The goal of MAXSIMA is to contribute to the “safety in MYRRHA” assessment.
MAXSIMA has five technical work-packages. The first one contains safety analyses to support licensing of MYRRHA. Design-basis, design extended and severe accident events

are being studied with a focus on transients potentially leading to fuel pin failures. Fuel assembly blockage and control system failure are the least unlikely events leading to core damage. For code validation a thermal-hydraulic study of different blockage scenarios of the fuel bundle and tests of the hydrodynamic behaviour of a new buoyancy driven control/safety system are being performed. Both are supported by numerical simulations. Safety of the Steam Generator is treated by looking at consequences and damage propagation of a Steam Generator Tube Rupture (SGTR) event and by characterising leak rates and bubble sizes from typical cracks in a SGTR. Additionally, a leak detection system and the drag on bubbles travelling through liquid LBE are studied. MOX fuel segment qualification with transient irradiations is a big step in licensing. MAXSIMA also includes validation experiments for safety computer codes involving core damage scenarios with high temperature MOX-LBE interactions. Fuel-coolant-clad chemistry is studied up to 1700°C and a core melt experiment in a reactor is prepared to assess the interaction of LBE with molten fuel. Following the Fukushima accident, effort is also put on development of enhanced passive safety systems for decay heat removal and on confinement analyses for HLM systems. A separate work package is dedicated to education and training. Beside workshops, lecture series and training sessions, virtual-safety simulator software is being developed.
Total cost: EUR 10 087 542
EU contribution: EUR 5 500 000
http://cordis.europa.eu/project/rcn/106639_en.html

FP7 NC2I-R

The strategic objective of NC2I-R is to structure the European public and private R&D capabilities for delivering a nuclear cogeneration demonstrator fully meeting the market needs, in support of the Nuclear Cogeneration European Industrial Initiative.
Following the reference EUROPAIRS project and in close collaboration with the ongoing ARCHER project, national projects (e.g. Polish HTRPL, German SYNKOPE), non-EU HTR programmes (US, China, South Korea, South Africa) and Generation IV International Forum, NC2I-R will bring a decisive contribution to prepare for a successful, low-risk and rapid European nuclear cogeneration demonstration for Europe’s industry.
To this end, NC2I-R will:
1) Structure the European public and private R&D capacities towards nuclear cogeneration demonstration and identify clearly the status of Europe’s public and private R&D infrastructures and competences
2) Define the safety requirements to prepare for the future licensing process for a cogeneration demonstrator and limit the associated risk
3) Define clear and consensual specifications for the demonstrator, ensuring its economic viability, its market fit, its future replicability and its safety, in particular of the coupling scheme, and limiting all construction project risks
4) Manage the knowledge from past projects on HTR and nuclear cogeneration with a comprehensive experience feedback in order to identify potential points of attention and success factors
5) Prepare on a joint roadmap paving the way for today’s European R&D capacities towards the commissioning of the specified demonstrator and identify potential gaps
6) Prepare for and organise the cooperation with non-European similar programmes to possibly share the demonstrator risk in line with the European interest and to secure EU’s leadership position in the global competition for HTR

7) Prepare a smooth and inclusive governance for the future NC2I, engaging all stakeholders including civil society
Total cost: EUR 2 503 215.80
EU contribution: EUR 1 834 990
http://cordis.europa.eu/project/rcn/110241_en.html

FP7 ARCADIA
Assessment of Regional CApabilities for new reactors Development through an Integrated Approach.

The ARCADIA project has been conceived so as to provide a twofold support to further development of nuclear research programmes in the New Member States, targeting two major areas included in the Strategic Research and Innovation Agenda of SNETP:

- ESNII, through the support to the ALFRED LFR project towards its realization in Romania; and
- NUGENIA, tackling remaining safety aspects of Gen III/III+ concepts, that could be built in Lithuania, Poland, Czech Republic, and Slovenia.

ARCADIA focuses on the identification of primary needs for the ALFRED project, mainly what concerns Education & Training, supporting Infrastructures needs, and Regulatory aspects. It also integrates, for R&D needs, the outcomes of other research projects establishing a common inventory of National and Regional needs. ARCADIA also investigates the existing National and Regional supporting structures – with a particular attention to the ones in Romania and in all the participating New Member States – for defining a map of competences potentially eligible to satisfy the above-identified needs.
The entire work dedicated to ALFRED project is being performed within the frame of strategic orientations to be compiled for the ALFRED project, and with the scientific, technical and regulatory advice of the ALFRED consortium on one side, and of the Romanian Regulatory Body on the other side.
Finally, Networking, Cooperation and Dissemination activities provide links with the international scientific community, with the European institutional organizations and with the general public, ensuring the soundness and palatability of both Gen III/III+ and ALFRED projects in general.
Total cost: EUR 1 961 683
EU contribution: EUR 1 499 435
http://cordis.europa.eu/project/rcn/110919_en.html

FP7 MARISA
MyrrhA Research Infrastructure Support Action

The MYRRHA project aims to develop and to construct a world-class and first-of-a-kind nuclear research infrastructure. The design and the construction of the MYRRHA facility is particularly challenging since it requires the management of a large number of activities in view of achieving technical excellence in compliance with the project budget and schedule. Accordingly, state-of-the-art project management procedures and instruments have to be defined and implemented taking into account the constraints and the specifics of MYRRHA.

The MARISA proposal for a Coordination and Support Action plans to bring the MYRRHA project to a level of maturity required to enable the construction work to start. Work proposed as part of MARISA includes the following main work packages:

- Overall coordination. In this work package, management procedures and instruments to oversee the overall coordination of the MYRRHA projects will be defined and developed.
- Strategic and consortium planning. As part of this work package, a roadmap will be developed for integrating different national and international initiatives in support of the MYRRHA development.
- Legal aspects. In the framework of the MARISA project, the appropriate legal framework for the MYRRHA undertaking will be identified and implemented. The legal framework will be tailored to the composition of the consortium and initiatives will be taken aiming at the implementation of inter-governmental agreements outlining participation in MYRRHA.
- Consortium governance. In this work package, appropriate management methods and procedures will be developed and implemented taking into account the particularity and the constraints of innovative projects as MYRRHA.
- Financial aspects. In this work package, cost specificities of the project and financing and funding mechanisms will be developed.
- Technical coordination work.

Total cost: EUR 3 413 696,38
EU contribution: EUR 3 269 480,75
http://cordis.europa.eu/project/rcn/109488_en.html

FP7 SACSESS
Safety of ACtinide Separation proceSSes

"Nuclear power plays a key role in limiting EU's greenhouse gases emissions, and makes an important contribution to improve European Union's independence, security and diversity of energy supply. However, its social acceptance is closely linked to an enhanced safety in the management of long-lived radioactive waste contributing to resource efficiency and cost-effectiveness of this energy and ensuring a robust and socially acceptable system of protection of man and environment. Among the different strategies, partitioning and transmutation (P&T) allows a reduction of the amount, the radiotoxicity and the thermal power of these wastes, leading to an optimal use of geological repository sites.
In line with the Strategic Research Agenda of SNE-TP, the SACSESS collaborative project will provide a structured framework to enhance the fuel cycle safety associated to P&T. In addition, safety studies will be performed for each selected process to identify weak points to be studied further. These data will be integrated to optimise flowsheets and process operation conditions.
A training and education programme will be implemented in close collaboration with other European initiatives, addressing safety issues of nuclear energy industry.
The multidisciplinary consortium composed of European universities, nuclear research bodies, TSOs and industrial stakeholders will generate fundamental safety improvements on the future design of an Advanced Processing Unit. SACSESS will thus contribute to the demonstration of the potential benefits of actinide partitioning to the global safety of the long-lived waste management.

Total cost: EUR 10 266 535,1
EU contribution: EUR 5 550 000
http://cordis.europa.eu/project/rcn/106488_en.html

FP7 ESNII+
Preparing ESNII for HORIZON 2020

The aim of this cross-cutting project is to develop a broad strategic approach to advanced fission systems in Europe in support of the European Sustainable Industrial Initiative (ESNII) within the SET-Plan. The project aims to prepare ESNII structuration and deployment strategy, to ensure efficient European coordinated research on Reactor Safety for the next generation of nuclear installations, linked with SNETP SRA priorities.
The ESNII+ project aims to define strategic orientations for the Horizon 2020 period, with a vision to 2050. To achieve the objectives of ESNII, the project will coordinate and support the preparatory phase of legal, administrative, financial and governance structuration, and ensure the review of the different advanced reactor solutions.
The project will involve private and public stakeholders, including industry, research and academic communities, with opened door to international collaboration, involving TSOs.
Total cost: EUR 10 346 993
EU contribution: EUR 6 455 000
http://cordis.europa.eu/project/rcn/110082_en.html

FP7 MATISSE
Materials' Innovations for a Safe and Sustainable nuclear in Europe.

The European Energy Research Alliance, set-up under the European Strategic Energy Technology Plan, has launched an initiative for a Joint Programme on Nuclear Materials (JPNM). The JPNM aims at establishing key priorities in the area of advanced nuclear materials, identifying funding opportunities and harmonizing this scientific & technical domain at the European level by maximizing complementarities and synergies with the major actors of the field. The JPNM partners, through MatISSE, combine Collaborative Project and Coordination & Support Action to face the challenge of implementing a pan-European integrated research programme with common research activities establishing, at the same time, appropriate strategy and governance structure.
Focusing on cross-cutting activities related to materials used in fuel and structural elements of safe and sustainable advanced nuclear systems, the project covers the key priorities identified in the JPNM: pre-normative research in support of ESNII systems, Oxide Dispersed Strengthened steels, refractory composites for the high temperature applications, and development of predictive capacities. MatISSE fosters the link between the respective national research programmes through networking and integrating activities on material innovations for advanced nuclear systems, sharing partners best practices and setting-up efficient communication tools. It is expected that, through MatISSE, a real boost toward Joint Programming among the Member States, the European Commission and the main European research actors, will be achieved.
Total cost: EUR 8 773 428
EU contribution: EUR 4 749 993
http://cordis.europa.eu/project/rcn/110016_en.html

Annex 2 Euratom JRC Direct Actions contributing to the GIF systems

ANFC - Alternative Nuclear Fuel Cycles

The ANFC action dealt mainly with an alternative strategy where the volume and the radiotoxicity of high-level waste should be significantly reduced, thus shortening the time scales needed for safe storage and associated risks. This research in Partitioning and Transmutation (P&T) included the development of aqueous and pyrochemical processes for the separation of long-lived radionuclides and the conversion into shorter-lived or stable ones by irradiation in dedicated reactors. Research on the conditioning of high level nuclear waste was also carried out.

ND-MINWASTE - Nuclear data for radioactive waste management and safety of new reactor developments

This action was the main provider of high quality neutron data in Europe for nuclear safety applications and safety aspects of nuclear waste minimisation through recycling and transmutation of high level waste. Significantly improved nuclear data and their correlated uncertainties (covariance matrices) were used for the accurate modelling in the fields of nuclear safety and waste management and for the simulation of nuclear power installations. The cross-cutting nature of its activities made the activity of relevance to Generation-II, -III and –IV safety studies.

The research provided nuclear data to files in application libraries used by nuclear research establishments in Europe and industry (Joint Evaluated Fission and Fusion nuclear data file – JEFF –, and Evaluated Nuclear Data File, ENDF/B-VII).

FANGS - Feasibility Assessment of Next Generation nuclear energy Systems

The objective of FANGS was the assessment of the evolving technical capabilities of various next generation nuclear power systems against the energy policy goals of EU countries, specifically excellent safety and low-carbon efficiency as required by the Strategic Energy Technology Plan (SET-Plan), and also in view of European industrial competitiveness and security of energy supply. Main fields of the action were: a) feasibility and performance of reactor fuel with focus on fast reactor/transmutation fuel and high temperature reactor fuel, for which several successful irradiation tests in the HFR Petten were performed, and b) evaluation of feasibility, safety and performance of next generation nuclear reactors and fuel cycles.

MATTINO - MATerials performance assessmenT for safety and Innovative Nuclear reactOrs

MATTINO's goal was to focus JRC's structural materials research efforts on Generation IV applications. As a consequence of the Fukushima accident, to give more emphasis to severe accident, the nuclear materials related research in the Actions POS and FANGS was gathered into MATTINO. The activities performed were:

- thermo-mechanical properties, corrosion resistance, and irradiation and environmental safety performance assessment of structural materials;
- harmonisation of test methods, inspection procedures and data management tools applied in Europe for thermo-mechanical, and environmental testing;
- structural materials performance assessment under operational and accidental conditions;
- input to material design codes and standards;

- modelling with experimental validation of the materials performance in the respective conditions and environments.

NURAM - Nuclear Reactor Accident Analysis and Modelling

The Action NURAM was created in 2012 by collecting part of the contributions of the former action POS (tasks related to severe accidents especially participation to SARNET and PHEBUS networks), and FANGS (in relation with modelling and safety assessment activities for Generation IV reactors). NURAM contributions were in the area of severe accident and especially Severe Accident Management.

SNF - Safety of Nuclear Fuels and Fuel cycles

The action Safety of Nuclear Fuels was the result of the merging of two actions in 2013: Safety of Conventional Fuels (SCNF) and Safety of Advanced Nuclear Fuels (SANF).

The SCNF activity objectives went from the traditional post-irradiation techniques providing information on microstructure and fission gas release to advanced techniques providing fundamental data on the thermo-physical and thermo-mechanical properties of nuclear fuel. The action was in the forefront of studies of the in-pile behaviour of nuclear fuel, studying the fragmentation of nuclear fuel during temperature transients and the high burn-up properties of a number of LWR fuel variants.

The SANF activity started in FP7 focussing on fuels for JRC Generation IV International Forum (GIF) systems. Fuel safety aspects of the Generation IV Gas, Sodium, and Lead (GFR, SFR, LFR) fast reactor systems were covered investigating on safe synthesis of fuels containing minor actinides, on basic fuel properties, on fuel coolant and cladding interactions, and on irradiation behaviour. Efforts were being directed to complement the experimental work performed, with more theoretical support and to improve the scientific basis underpinning nuclear fuel behaviour.

CAPTURE - Knowledge and Competence Management, Training and Education in Reactor design and Operation

CAPTURE was built on three pillars:

1) Evaluation of Human Resources Trends in the Sustainable Energy Sector: collection of data and trend analyses on issues related to development and preservation of nuclear human resources and nuclear safety expertise in the EU.

2) Harmonization and standardization of nuclear skills recognition within the EU-27: open database taxonomy of commonly recognized nuclear skills and competences, and implementation of the ECVET system in the nuclear energy sector.

3) Contribution to Nuclear Education, Training and Knowledge Management: preservation of internal knowledge, contribution to nuclear training initiatives collaboration with IAEA on nuclear safety KM issues.

IANUS Information Analysis for Nuclear Security

IANUS investigated the potential of open source information for deepening the understanding of on-going nuclear security issues requiring attention and reactions by EU institutions. The action developed and used dedicated information collection and analysis tools for the acquisition and processing of the relevant open source information

Motivated by the Export Control Regulation [41] and amendments setting up a Community regime for the control of exports, transfer, brokering and transit of

[41] Council Regulation (EC) No 428/2009 of 5 May 2009 setting up a Community regime for the control of exports, transfer, brokering and transit of dual-use items

dual-use items, focus of the activity was (i) on the identification of information and trade data sources for supporting safeguards verification activities, export controls and non-proliferation studies and (ii) on the design and development of tools to analyse these data.

IANUS provided technical information on nuclear security issues to EC services and EU stakeholders, by monitoring nuclear security issues and proliferation related events. This formed the bases for producing, from open source information and technical knowledge of the nuclear fuel cycle, non-proliferation studies.

The action further contributed to the development of methodologies, software tools and methods for the evaluation of nuclear safeguards effectiveness, with regards to proliferation resistance of existing and advanced nuclear energy systems including related fuel cycles. The action was closely connected to the Generation IV International Forum (GIF) activities. (Work on PR&PP was firstly done in action AMENUS -2007-2009-, then in action PHYMOD 2009-2011 and then, from 2011 in action IANUS (for simplicity only action IANUS is here referred).

SAFARI Safety Assessment of Innovative Reactors

The project provided independent safety assessment of innovative reactors and is composed of 2 parts:

1) Using coupled multi-physics codes (US NRC CAMP) to model innovative NPP behaviour during accident sequences.

2) Support to GIF related activities (Sodium Fast Reactor System Integration & Assessment and Safety & Operation and Risk & Safety WG), IAEA on fast and innovative reactor design and within ESNII and NUGENIA TA6 (on Innovative LWR)

Annex 3 EU Member States activity contributing to the GIF systems – Past and forthcoming activity

Belgium

Belgium's participation has mainly focussed on LFR systems and more specifically on Partitioning and Transmutation activities through the development of the MYRRHA project. The main involved organisations were SCK•CEN, Bel V (Technical Support Organization), Tractebel Engineering S.A (TE), Université Catholique de Louvain (UCL), and the von Karman Institute for Fluid Dynamics (VKI).

- SCK•CEN's contributed to LFR research and development in the domains of fuels, materials, design, Thermal-Hydraulics, infrastructure, scenario studies and safety. For the reference period own budget can be estimated at 3 MEUR/year (in-cash and in-kind) with a Belgian Federal Government endowment of 60 MEUR (for the period 2010-2014).
- BELV's pre-licencing activity for MYRRHA was estimated at 1 person-month per month since 2011.
- TE participated in several indirect actions within the winning consortia. These were EUROTRANS, RAPHAEL, EUROPAIRS, and ESNII+. (Estimated Budget: 576 kEUR. Human Resources: 39 person-months).
- UCL has worked on Direct Numerical Simulations and Large Eddy Simulations of turbulent flows in liquid metals with a budget of 100 kEUR.
- VKI's DEMOCRITOS research programme has supported MYRRHA reactor licensing with emphasis given to primary loop (e.g. Design of the LBE pumps development - of MYRRHABELLE facility, a 1/5 scaled water model for thermo-hydraulic characterisation during accidental scenarios, etc.). All the experimental works were completed by extensive CFD developments. The budget has been 4.5 MEUR and Human Resources of 330 person-months in the 2011-2015 period.

Forthcoming activity:

- SCK•CEN will continue the pre-licensing phase of the MYRRHA project encompassing design, R&D and safety activities and setting-up of the MYRRHA International consortium. The pre-licensing phase is to be finalised by 2017-2018. The budget is expected to be 3 MEUR/year from SCK•CEN budget and a specific endowment from the Belgian Federal Government for MYRRHA for the period 2015-2018. The activities planned in the on-going FP7 projects (e.g. SEARCH, MAXSIMA, MARISA) as well as in the recently launched H2020 projects (SESAME and MYRTE) will be continued.
- BelV estimates 30 person-months until end of 2017 for pre-licencing assessment.
- Tractebel Engineering: A few man persons will be necessary to finish the FP7 ESNII+ project
- UCL is planning to continue research in the same domain and is has a planned budget of 130 kEUR and Human Resources of 22 person-months between 2015 and 2019.
- VKI's DEMOCRITOS 2 will be the follow-up of the previous project and will include new activities such as: coolant solidification occurrence inside the heat exchangers, modelling of water hammer phenomena in the secondary loop, of the auxiliary cooling systems (RVACS), of oxygen transport inside the primary loop by CFD. The estimated budget is 3MEUR and Human Resources of 250 person-months.

This past and forthcoming activity clearly sets Belgium as one of the leading EU countries for LFR technology, more specifically LFR/ADS.

Bulgaria
The Institute for Nuclear Research and Nuclear Energy – Bulgarian Academy of Sciences /INRNE-BAS was the main Bulgarian involved organization.

- INRNE-BAS performed LFR activities (SWOT analyses) linked to the FP7 projects NEWLANCER with budget 75kEUR and Human Resources of 14.5 person-months.

Forthcoming activity:

- INRE/BAS will continue in the frame of LFR feasibility and roadmapping, with a budget of 25KEUR in 2015-16 and Human Resources of 5.5 person-months of resources.

Czech Republic
The Centrum Výzkumu Rez (CVR) or Research Centre Rez performed numerous activities linked to the LFR, MSR, VHTR, and SCWR systems in the reporting period. More specifically:

- LFR: materials interaction with Pb and PbBi. Corrosion and Mechanical properties (tensile, fracture toughness, DBTT, etc) were studied in flowing and static environment; thermo-hydraulic studies/codes simulations (Estimated budget: 1100 kEUR for 2005-14).
- MSR: Experimental measurements focused on MSR reactor neutronics (LR-0 experimental reactor); Theoretical and experimental studies of MSR fuel cycle technology focused mainly on thorium–uranium fuel cycle (processing of liquid fuel and on-line reprocessing technology); participation in the development of structural materials (special nickel alloys) and graphite gaskets for molten fluoride salt applications (Estimated budget: 350 kEUR. Human Resources: 30-40 person-months).
- SCWR: Investments for civil constructions; PRAMEK (materials chemistry), ceramic-metal joint, ARMAT (Estimated budget: 3100 kEUR).
- VHTR: Activity linked with FP7 projects ARCHER, MATISSE and National projects dealing with R&D topics related to Technologies for gas purification and sealing for advanced applications in nuclear and non-nuclear energetic applications; Development of equipment for separation of noble gases from helium; Materials for advanced nuclear reactors and other energy applications.

Forthcoming activity:

- LFR Materials and coatings: qualification of materials for claddings, welds, pumps, steam generators; Instrumentation for LFR; Chemistry of LFR; development/validation of thermo-hydraulic codes and coordination and preparation phase of ALFRED demonstrator via FALCON Consortium (Estimated budget: 300 kEUR. Human Resources: 60 person-months 2015-20).
- MSR: Continuation in existing activities (SUSEN project) and participation in Czech–US collaborative R&D programme devoted to MSR and FHR technology (Estimated budget: 500 kEUR for the period 2015-16).
- SCWR – Participation in Ho2020 project sCO2-HERO. Regional SUSEN project – design analyses and construction of the FQT facility and support to Czech Industry (Estimated budget: 4.2MEUR. Human Resources: 72 person-months)
- VHTR: Activity linked with Ho2020 project VINCO; Research on environmentally resistant innovative Composites and ODS Steels for Advanced Energy Systems; Joint research programme on advanced materials ; Pilot project proposals EERA

JPNM: JOISIC, CREMAR, advanced materials for HTGR and LFR systems (Estimated budget: 335 kEUR . Human Resources: 45 person-months).

Finland

Finland has established different networks, contracts and projects in the frame of Generation IV. Main actors were the VTT Technical Research Centre of Finland Ltd and several universities like Lappeenranta University of Technology (LUT), Aalto University (AaU), and University of Helsinki (UoH), STUK.

- GEN4FIN: since 2004, this is a network to improve scientific and technologic expertise in the field of nuclear energy technologies and related processes through collaboration with GIF and other global forums such as EERA JPNM. Contributors are: VTT, Fennovoima, Fortum, TVO, Ministry of Employment and the Economy (TEM), Lappeenranta University of Technology (LUT), Aalto University, University of Helsinki, STUK - Radiation and Nuclear Safety Authority, TEKES – the Finnish Funding Agency for Innovation (estimated budget: 1080 kEUR)
- Nordic-Gen4: since 2009, this is a Network to spread knowledge on Generation IV issues and on-going research to different parties involved in the nuclear field in the Nordic countries. Finnish contribution is through GEN4FIN network project (estimated budget: 50 kEUR)
- NETNUC: Jan. 2008 to Dec. 2011, This was a Finnish Academy project for new type nuclear reactors. Contributors were: LUT, Aalto University, VTT, Budget was 1030 kEUR with the contribution of 465 kEUR of the Finnish Academy. Human resources were 85 person months.
- SA_IDEA: Sep. 2012 to Aug. 2016. This was a Finnish Academy project for interactive modelling of fuel cladding degradation mechanisms. VTT was a contributor. Budget was 650 kEUR with 520 kEUR from the Finnish Academy contribution - Human resources were 85 person months,
- ODS-Inno, 2012 – 2014: VTT self-financed projects "ODS manufacturing, characterizing and basic properties", the goal was to create the basic ODS facilities at VTT including conventional PM/MA manufacturing, PM manufacturing with internal oxidation, and microstructure and property characterizing. The research work focused on the internal oxidation PM process and microstructure characterizing, budget and resources - (estimated budget: 155 kEUR and Human Resources: 9 person-month)
- YTERA: 2011-2015: Doctoral Programme for Nuclear Engineering and Radiochemistry. Contributors: Aalto, LUT, UoH, VTT - (estimated budget: 2000 kEUR and Human Resources: 600 person-month)
- COUPE, Sep 2012 – Aug 2016. This was a Finnish Academy project on the development of a coupled multi-physics calculation system for three-dimensional pebble bed reactor (HTR, VHTR) core calculations. Coupling Monte Carlo reactor physics and thermal-hydraulics codes with data input from pebble bed packing simulation codes. Work performed within a national project funded by the Academy of Finland; (estimated budget: 621 kEUR and Human Resources: 66 person-month)
- UoH: UoH studied mechanisms of radiation damage generation in metals. Participated in Multiscale modelling of the response of metals in the frame or EU projects ; (estimated budget: 600 kEUR and Human Resources: 240 person-month)
- Participation in FP6 & FP7 projects HPLWR Phase2, GETMAT, SCWR-FQT, MATTER, MATISSE and THINS.
- VTT: Participation in EERA JPNM Steering Committee activities since 2011

Forthcoming activity

- VTT is involved in several pilot projects which are ongoing in EERA JPNM;
- HoU: Multiscale modelling of the response of metals, especially ferritic-martensitic and ODS steels, to hard neutron radiation ; (estimated budget: 60 kEUR/y and Human Resources: 24 person-month/y)

France [42]

The pressurized water reactors (PWR) of the French current fleet represent a mature technology. In a context of sustainable development, the weak point of this type of reactor remains not to make optimal use of the resource "uranium". The fast reactor (FBR), allows using not only the isotope uranium 235, uranium 238, but also converting it into plutonium 239. In making possible the recovery of depleted uranium, the technology of fast reactors would thus ensure resources for millennia.
The objective of the research programs in France is now ready for industrial deployment from 2040, if it is deemed necessary especially in light of the state of natural uranium resources. Internationally Generation IV reactors are also the focus of research and GIF International Forum selected six reactor concepts that have development prospects.
France has chosen to lead more specifically research on the sector of sodium cooled reactors (SFR) which, given the knowledge and experience feedback, seems to be best placed to meet the objective of potential industrial development from 2040. However, a new generation of fast reactor cooled by sodium will emerge only if they can demonstrate a design objectively showing progress as compared to previous reactors (Phoenix and Superphénix), particularly in terms of reactor safety and operation. The development and demonstration of viable solutions require different levels of validation to integration on an industrial scale.
In parallel, in order to keep access to the industry considered as a potential alternative to cooled reactors sodium, France participates in programs in the international framework on gas-cooled reactors (GFR).
Similarly, if the waste produced by the reactors are currently managed with the best available technologies, the use of FBR could help to further reduce their potential toxicity. Consideration could be subject including the results of industrial outlook studies delivered in late 2012, to transmute them in fast reactors, which would reduce the potential long-term toxicity of high level waste, and therefore would limit the amount of fission products. If such a route is confirmed, all work remains to achieve the validation of all steps (cycle technology, manufacture and irradiation), to the level of fuel assembly.
To meet this challenge for the future of nuclear power, the CEA has designed and launched in conjunction with industrial partners AREVA and EDF, a program that should allow having ASTRID reactor for industrial demonstration by 2030. This program is funded under the future investment program from the French government, 650 MEUR for the project over the period 2012-2017.

Germany

Germany has several organizations that are involved in Generation IV activities such as the Technical safety organization Gesellschaft für Anlagen- und Reaktorsicherheit (GRS); research centres as the Helmholtz-Zentrum Dresden-Rossendorf (HZDR); universities such as the Karlsruhe Institute of Technology (KIT), University of Stuttgart (UoS), the Technical university of Dresden (TUD). Focus has been set on:

- GRS has participated to FP7 projects such as SARGEN IV, JASMIN (code modelling ASTEC), THINS (LFR validation). It has also focussed on safety

[42] RAPPORT DU COMITE D'ORIENTATION et de SUIVI des RECHERCHES pour les SYSTEMES NUCLEAIRES Mars 2011

licensing issues for fast systems, HTGR, GCR and SCWR (e.g. quantification of uncertainties in licensing calculations, participating to OECD benchmarks on deterministic transport models, calculation methods for assessment of Safety, thermal-hydraulics (Estimated budget: 3850 kEUR. Human resources: 230 person-months)

- HZDR has participated to numerous FP7 projects. Focus has been on: Neutron cross section measurements: scattering, fission, total cross sections; crosscutting Fast Reactors and fusion (Materials) research (e.g. EERA JPNM - Characterisation of irradiation behaviour of steels, Fabrication and characterisation of oxide dispersion strenghtened of Fe-Cr alloys, fabrication based on spark plasma sintering, ion irradiation experiments in combination with nanoindentation, development of small specimen technology (small punch test)); Fast Reactors (Measurement technique developments for flows of sodium, lead-bismuth or lead; Thermohydraulic experiments on gas bubble behaviour in liquid metals; Steady-state neutronic analysis of MOX European SFR core with Serpent and DYN3D codes; core safety calculations for the ASTRID SFR core; shielding and monte-carlo simulations for LFR/ADS and MSR; feedback effects in SFR), VHTR (Development of HTR codes, design and safety of a VHTR core; experimental and numerical analyses for a graphite source term) (estimated budget: 8390 kEUR and Human Resources at 1126 person-months)
- KIT has several infrastructures (KALLA, KASOLA, HELOKA, KATHELO) for TH and component qualification for Fast reactors. KIT has participated in numerous FP7 projects. Its main complementary activity has been in the domain of LFR with corrosion tests of materials in liquid Pb, PbBi; chemistry of liquid metals – oxygen control in Pb alloys; Surface alloying for corrosion mitigation (GESA-process); mitigation strategies for fretting and wear improvement (estimated budget: 3000 kEUR and Human Resources: 480 person-months)
- UoS: Participation in ARCHER and GETMAT FP7 projects
- TuD: Study "Synergetic coupling of energy sources for efficient processes – Project SYNKOPE", designing a nuclear cogeneration system for the refinement of coal mined in the tri-border region of the Free State of Saxony (Germany), the Czech Republic and Poland (estimated budget: 1300 kEUR and Human Resources: 250 person-months)

Forthcoming activity:

- GRS: GRS will participate in the Ho2020 project SESAME (thermal-hydraulics of LFR). GRS is planning to continue work (2015-2018) on OECD benchmarks and uncertainty analysis assessment of Safety for Fast Reactor systems:, (estimated budget: 870 kEUR and Human Resources: 53 person-months)
- HZDR: HZDR will continue to perform: Nuclear data measurements and evaluation, transnational access to neutron beam facilities 2015-2017 ; Materials (EERA JPNM) 2015-2024: Further development of ODS alloys and of alternative ; fabrication routes, establishing of advanced microstructural and mechanical characterisation, ion irradiations as a surrogate for neutron irradiation; measurement techniques for safety of liquid metal systems; (estimated budget: 7200 kEUR and Human Resources: 1000 person-months)
- KIT: KIT is participating in several remaining FP7 projects. Forthcoming work (2015-2018) is on corrosion resistant alloy and surface alloying development, Maxphase materials for nuclear applications, corrosion, corrosion/erosion and fretting tests in liquid Pb alloys improvement
- TuD: TuD will continue project SYNKOPE in the period 2015-2019 (estimated budget: 2700 kEUR)

Germany, although having a 2022 phase out policy (since 2011), has continued research in fast systems and VHTR, both in experimental research in materials, fuels, thermal-hydraulics, neutronics, measurements, codes and licensing. Its forthcoming activity will be in the same domains (Fast + VHTR) with a similar Human Resources effort.

Hungary

The participating organisations are The Institute of Nuclear Techniques (NTI) and the Budapest University of Technology and Economics (BME) and the Centre for Energy Research of the Hungarian Academy of Sciences (MTA EK). The activity has been especially set on the SCWR and GFR Systems:

- BME NTI: NAP-NUKENERG I and II Hungarian national project ("Új nukleáris energiatermelési módszerek technológiai elemeinek fejlesztése"):CFD validation and analysis on the fuel assembly of the High Performance Light Water Reactor. Participation SCWR EU projects (Fuel qualification test loop: thermohydraulic CFD calculations and neutronic calculations ; design and analysis of the Supercritical water reactor) - (estimated budget: 83 kEUR and Human Resources: 24 person-month). Participated also in the ALLIANCE project (36 kEUR, 7person-months).
- MTA EK: NAP NUKENERG Hungarian national project: participation in the core design of the High Performance Light Water Reactor, corrosion and irradiation ageing testing of candidate materials for SCWR fuel cladding and the pressure vessel (500 kEUR including 100 person-months). MTA EK contributed to FP6 MTR I3 with the conceptual design of a Supercritical pressure loop for the Jules Horowitz Reactor (50 kEUR). MTA EK was the coordinator of the ALLIANCE project aimed at preparing the construction of the ALLEGRO reactor in the Central-European region (total budget 320kEUR, 68 person-months).
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Forthcoming activity:

- FAE TP (Sustainable Nuclear Energy Technological Platform) is a Hungarian national project to be run in 2015-2019. BME will contribute to FAE TP in many different topics and SCWR related researches are included. - (estimated budget: 80 kEUR and Human Resources: 12 person-month)
- The Hungarian National Nuclear Research Programme for the period 2015-2018 finances the ALLEGRO design activities with a total budget of about 300 person-months, 2000 kEUR. The financing agent is the National Research, Development and Innovation Office (NRDI). The participating members of the national ALLEGRO consortium are: MTA EK, BME NTI and NUBIKI Ltd.
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Italy

Italy, has been very active in the research of Generation IV systems, both with its national research agency ENEA and the universities and its consortium (CIRTEN) and smaller research institutes. The participating organisations are: ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development); Consorzio Interuniversitario per la Ricerca Tecnologica Nucleare (CIRTEN); Politecnico di Milano (POLIMI); Politecnico di Milano (POLITO); Università di Pisa (UNIPI); Università degli Studi di Genova (DIME); Ansaldo Nucleare SpA; Center for Advanced Studies, Research and Development in Sardinia (CRS4); Istituto Italiano di Technologia (IIT); Servizi Ricerche Sviluppo (SRS).

- ENEA: ENEA's main activity was in the Heavy Liquid metal Technology and more specifically for LFR. More specifically: Thermal-fluid dynamics; Structural materials; core design. These projects have been done individually (estimated budget: 30 MEUR) and in the frame of EU LFR chemistry, safety assessment, structural material development, core design, lead coolant technology projects (estimated budget: 8.8 MEUR).

- CIRTEN: CIRTEN's main topics of interest: Safety analysis, TH, Fuel, Modelling & simulation, E&T for LFR, GFR; HTGR; MSR systems. More specifically, and linked to EU projects: LFR (core TH and neutronic safety calculations, transient analysis and Education and training); GFR (MOX and ceramic core designs); Transmutation, neutronics and design issues for fast reactors; MSR (development of coupled neutronics-thermalyhdraulics codes; participation to benchmarks; core physics and fuel cycle) - (estimated budget: 1050 kEUR and Human Resources: 398 person-month). Activities not directly linked to EU projects were: MSR development of a multi-physics approach to the dynamics of graphite-moderated MSRs; modelling of the thermo-hydrodynamic behaviour of the molten salt nuclear fuel; geometric multiscale modelling approach to the analysis of graphite-moderated MSR plant dynamics; investigation of natural circulation stability with internally heated fluids; - (estimated budget: 365 kEUR; and Human Resources: 95 person-month).
- POLIMI: POLMI's Main activity was in the Lead-cooled Fast Reactors; Fuel-coolant chemical interactions, Modelling; Nuclear Fuel Cycle; Partitioning and Transmutation. It Participated in EU projects on Transmutation (estimated budget: 450 kEUR and Human Resources: 122 person-month). On its own, it participated to the Italian National project promoted by the MSE (Ministry of Economic Development) and ENEA in the field of "Nuovo nucleare da fissione", focused on the development of Lead-cooled Fast Reactors; BSc and MSc thesis works and research grants on the study of chemical interactions between nuclear fuels and coolant within LFRs, predictions of thermochemical parameters by DFT and semi-empirical methods and thermodynamic analyses; Doctoral work on theoretical studies on fuel-coolant chemical interactions within the development of Lead-cooled Fast Reactors (estimated budget: 435 kEUR and Human Resources: 220 person-month).
- UNIPI: UNIPI has focussed on SCWR Thermal-hydraulics (Heat Transfer and Stability, Modelling). Main activity was: Doctoral study on Heat transfer and stability with supercritical pressure fluids; BSc and/or MSc thesis works and research grants on heat transfer and stability with supercritical fluids; Participation in the IAEA CRP on "Heat Transfer Behaviour and Thermo-Hydraulics Code Testing for SCWRs"; heat transfer to supercritical pressure fluids); Participation in the IAEA CRP on "Understanding and Prediction of Thermal-Hydraulics Phenomena Relevant to SCWRs"; (estimated budget: 370 kEUR and Human Resources: 220 person-month). UNIPI has also participated to EU projects on SCWR.
- DIME: DIME's Activities focussed on R&D on the HTGR, GFR and LFR systems addressing: Transmutation, neutronics, thermal-fluid-dynamics (including experimental topics related to natural circulation) and, more generally, design issues. (Period: 2011-2014, estimated budget: 100 kEUR).
- ANSALDO: Ansaldo is the main italian Industrial driver of the research activities on LFR. It has participated in most of the EU projects linked to LFR and works on Design/Thermal-Hydraulics / Fuel / Materials and Balance of plant issues. It is the consortium coordinator of FALCON (Human Resources: 4 person-months/y)
- CRS4: Activity in EU projects in design evaluation, verification, validation and optimisation using and improving CFD modelling (Application to MYRRHA (FASTEF) windowless target, to MYRRHA and ALFRED (EFIT) primary coolant loop and loop components (estimated budget: 700 kEUR and Human Resources: 100 person-month);
- IIT: IIT, the Centre for Nano Science and technology develops materials for GIF systems via ENEA, MoA with the FALCON Consortium and adhesion to EERA JPNM. Main activities are linked to coating process, engineering, design, fabrication and characterisation and testing with respect to corrosion, radiation

damage and tritium permeation - (estimated budget: 210 kEUR and Human Resources: 36 person-months)

- SRS: SRS has participated in EU projects working on LFR, LFR/ADS, SFR, GFR, thermomechanical design, thermal hydraulics, seismic analysis and Balance of Plant (e.g. Design of TIEX, IELLO, HELENA, KYLIN HLM experimental facilities, T/H analyses, design for (estimated budget: 645 kEUR and Human Resources: 97 person-months)

Forthcoming Activity

- ENEA: ENEA will continue its research in the Heavy Liquid metal Technology development, (estimated budget: 10 MEUR) and in the frame of EU projects: reactor assessment and liquid metal pool thermal hydraulics (estimated budget: 1.2 MEUR).
- CIRTEN: CIRTEN, via POLIMI and POLITO will continue to participate to commitment in GEN IV Systems at International and National level. The Molten Salt Fast Reactor concept will be extensively investigated also in the future (MSFR integral safety approach and system integration; experimental proof of natural circulation dynamics for internally heated molten salt; analysis of stochasticity and uncertainties in the Molten Salt Fast Reactor; development of model for the MFSR safety analysis); CIRTEN has also adhered to the FALCON Consortium and involved in PAR2014 research activities. CIRTEN will also continue study on the potential of small modular fast reactor and deliver Training and dissemination activity; (estimated budget: 592 kEUR and Human Resource: 128 person-month)
- POLIMI: The research group is involved as participant in the Pilot Project MOLECOS (MOlten LEad and lead bismuth COrrosion of Steels), coordinated by ENEA and presented at the Call 2015 within the EERA Joint Programme for Nuclear Materials, to improve safety and sustainability of Nuclear Energy by focusing on materials aspects. POLIMI will finish its participation in an EU project (estimated budget: 198 kEUR and Human Resources: 37 person-month). There will also be the continuation of National project promoted by MSE and ENEA in the field of "Nuovo nucleare da fissione", focused on the development of Lead-cooled Fast Reactors; (estimated budget: 22 kEUR and Human Resources:15 person-month)
- UNIPI: UNIPI will continue participation in the IAEA CRP on "Understanding and Prediction of Thermal-Hydraulics Phenomena Relevant to SCWRs";
- ANSALDO: Future activity is linked to the participation in the EU SESAME project and coordination of the FALCON consortium.
- DIME: DIME will Continue work in the field of Transmutation, neutronics, thermal-fluid-dynamics (including experimental topics related to natural circulation) and, more generally, design issues.
- CRS4: In the period 2014-2018 there will be the continuation of the activity in Design evaluation, verification, validation and optimisation using and improving CFD modelling. Application will be to MYRRHA and ALFRED primary coolant loop and loop components, including control rod handling (estimated budget: 500 kEUR and Human Resources: 70 person-month);
- IIT: Continuation of coating research activities (estimated budget: 140 kEUR and Human Resources:24 person-month)
- SRS: SRS will work in the Falcon Consortium, will continue the LBE cooled small fast reactor design and continue the construction of experimental facilities supporting HLM technology (estimated Human Resources: 4 person-month/y)

<u>Lithuania</u>

The Lithuanian Energy Institute (LEI) is the main Lithuanian involved organization.

- LEI: LEI's focus was on EU projects in the domain of SFR, LFR [Materials Testing and Characterization, Testing procedures, Design rules, Pre-normative qualification, Safety assessment, Modelling, etc.]; (estimated budget: 179 kEUR and Human Resources: 30 person-month)

Forthcoming activity:

- LEI: LEI will continue the implementation of the project plan by developing roadmap to implementation of AFLRED project in Romania (estimated budget: 90 kEUR and Human Resources: 17 person-month)

<u>The Netherlands</u>
The Nuclear Research and consultancy Group (NRG) and the Technical University of Delft (TuDelft) are main Dutch involved organization. Their focus is on LFR, SCWR and MSR and MSFR. More specifically:

- NRG: NRG's research focus in recent years was on liquid metal reactors and high temperature reactors. NRG was involved in Euratom projects in the frame of HTR development and deployment, LFR and SFR thermal-hydraulics, fuel and materials and SCWR thermal hydraulics (estimated budget: 6235 kEUR and Human Resources: 305 person-month). It also pursued an own collaboration with MYRRHA on T-H support to the design team, fuel assembly T-H and above core structure modelling estimated budget: 440 kEUR).
- TuDelft: TuDelft has participated to EU programs on MSR (study on fuel cycle and safety analysis of thermal MSR design, and study on the neutronics design of the MSFR (transient and fuel cycle analysis) (estimated budget: 800 kEUR). TuDelft has performed research on: SCWR turbulent heat transfer, design of small modular supercritical reactor and the system stability of a natural circulation driven SCWR; (estimated budget: 550 kEUR and Human Resources: 114 person-month).

Forthcoming Activity

- NRG: NRG will continue to be involved in Euratom projects in the frame of LFR thermal-hydraulics (estimated budget: 2360 kEUR and Human Resources: 110 person-month). It will also contribute to the FALCON consortium with feasibility studies for core material irradiation and core thermal hydraulics. (estimated budget: 100 kEUR and Human Resources: 7 person-month). NRG will execute two SALIENT irradiations to produce data on the behaviour of molten salts during and after irradiation. This project is supported by the Dutch ministry (estimated budget: 2000 kEUR).
- TuDelft: TuDelft will continue research on the fundamental of heat transfer in systems cooled by supercritical fluids (estimated budget: 350 kEUR and Human Resources: 60 person-month). It will also lead the EU project SAMOFAR on transient analysis and safety evaluation of MSFR (estimated budget: 1000 kEUR)

<u>Romania</u>
The Institute for Nuclear Research (RATEN ICN) Pitesti is the main Romanian organization that is involved. They are performing research linked mainly to LFR.

- RATEN ICN: RATEN ICN is involved in the development and implementation of ALFRED Demonstrator being the reference site for ALFRED construction. It has participated to several EU projects in the frame of LFR (Core Design, radiological protection, materials). It is partner of the FALCON Consortium, responsible for ALFRED implementation in Romania (the reference site for ALFRED demonstrator is Mioveni, Romania) - (estimated budget: 370 kEUR and Human Resources:40 person-month). RATEN ICN has also worked on the SCWR reactor on testing of materials in supercritical conditions - (estimated budget: 70 kEUR and Human Resources: 30 person-month).

- RATEN CITON (Center of Technology and Engineering for Nuclear Power) is a subsidiary of RATEN contributing to LFR development and implementation through its expertise in design and engineering services for construction/installation, commissioning, operation and maintenance of nuclear facilities.

Forthcoming Activity

- One of the main objectives of RATEN Strategy for 2015-2025 is to support the R&D activities related to Generation IV nuclear systems with a focus on LFR technology. Most of the activities are running under the Nationally funded Programme: "Advanced Nuclear Reactors and Fuel Cycles" encompassing all the needed disciplines, including neutronics, thermal-hydraulics, materials science, engineering, safety, security, safeguards, proliferation resistance and education and training. The focus is on issues with large impact on the safety of these reactors structural materials, coolants technologies, advanced instrumentation, nuclear chemistry, waste management. The efforts are also focused on the development and implementation of ATHENA infrastructure dedicated to full-scale testing of components, fluid-structure interaction and assessment of systems behaviour in a pool configuration, as well as on setting-up ChemLab – a chemistry laboratory addressing lead coolant and cover gas chemistry and auxiliary systems development. RATEN ICN will continue its activities in the on-going EU projects, MAXSIMA (300 KEUR), ESNII+ (80 KEUR) and MATISSE (33 KEUR) and is involved in several future project proposals under HORIZON 2020.

<u>Sweden</u>

The Kungliga Tekniska Högskolan (KTH) is the main Swedish organization involved. Its research mainly focusses on the LFR and SFR systems. More Specifically:

- KTH: KTH participated to EU projects on LFR design (design and safety analysis, Thermal hydraulics, fuels development – nitrides; materials development – aluminium alloys; radiation damage;) and SFR (safety analysis, fuels and materials development – radiation damage) - (estimated budget: 4900 kEUR and Human Resources: 742 person-month). It also developed own activities in transmutation within SFR (estimated budget: 300 kEUR and Human Resources: 45 person-month)

Forthcoming Activity:

- KTH: KTH participated to EU projects on LFR design (design and safety analysis, Thermal hydraulics, fuels development – nitrides; materials development – aluminium alloys; radiation damage) and SFR (safety analysis, fuels and materials development – radiation damage) - (estimated budget: 4900 kEUR and Human Resources: 742 person-month). It also developed own activities in transmutation within SFR (estimated budget: 300 kEUR and Human Resources: 45 person-month)

<u>Slovenia</u>

The Jozef Stefan Institute (JSI) and the Regional Environmental Centre for Central and Eastern Europe (REC CO) have been involved in Generation IV activities. More Specifically

- JSI: JSI has been involved in EU projects in the frame of SFR and LFR thermal hydraulics (estimated budget: 75 kEUR and Human Resources:15 person-month)
- REC CO: Involved on EU projects on impact of Generation IV reactors impact on Radioactive waste management (Human Resources: 1.5 person-month)

Forthcoming Activity:

- JSI: JSI will continue to be involved in EU projects in the frame of SFR and LFR thermal hydraulics (estimated budget: 75 kEUR and Human Resources: 13 person-month)
- REC CO: Continue to be involved in EU project on support for LFR

<u>Spain</u>
Spain's participating organisations to Generation IV research are: ADEX SL; CIEMAT (Centro de Investigaciones Energéticas MedioAmbientales y Tecnológicas); Equipos Nucleares S. A.; Universidad Politecnica de Madrid (UPM); Universitat Politècnica de València (UPV). Focus has been set on:

- ADEX: Adex participates in the frame of EU projects, Accelerator Driven System (ADS) control and command systems, cooling system for fast-spectrum transmutation experiments; adaptive predictive control for MYRRHA (estimated budget: 320 kEUR and Human Resources: 40 person-month)
- CIEMAT: CIEMAT participates in EURATOM projects related to Reactor Design, Materials, Modelling, Fuel Cycle, Safety for Fast Reactors, ADS, Reprocessing, Closed fuel cycles including Partitioning and Transmutation. <u>Materials (EERA JPNM):</u> material characterisation in HLM; Modelling of irradiation damage on FeCr alloys; F/M steels and Oxide Dispersion Strengthened steels. <u>SFR:</u> ESFR pre-design of Steam Generators, surface treatments and associated manufacturing process applicable to the structures and components, Update of Codes & Standards in support, Feasibility and Cost inquiry study for the Inner Vessel, "Diagrid" structure and Intermediate Heat Exchanger of the Primary Circuit of ASTRID. <u>VHTR:</u> Design and Manufacture, for the main power system pressure boundary of the Pebble Bed Modular Reactor (PBMR) for Koeberg. <u>SCWR:</u> Oxidation behavior of different materials in SCWR conditions (microstructure effect in the corrosion behaviour) The estimated budget: 2160 kEUR and Human Resources:1640 person-month)
- UPM: Focus on Core design, core safety parameters and transient analysis of the European SFR concept; methodology development for safety assessment of innovative fast reactors in the frame of EU projects (estimated budget: 157 kEUR and Human Resources: 20 person-month)
- UPV: In the frame of an EU project, ASTRID core behaviour under design-basis accident conditions (system codes and 0D neutron kinetics models). Design basis accident - the unprotected loss of flow accident (ULOF) before sodium boiling - (estimated budget: 28 kEUR and Human Resources: 2 person-month)

Forthcoming activity:

- ADEX: ADEX will continue the development of optimized control cold tuning system for MYRRHA 2015 2018 (estimated budget: 118 kEUR and Human Resources: 17 person-month)
- CIEMAT: In the period 2015-2025, CIEMAT will Continue to participate in several EURATOM projects related to Reactor Design, Materials, Modelling, Fuel Cycle, Safety for Fast Reactors, ADS, Reprocessing, Closed fuel cycles including Partitioning and Transmutation and fuel. Materials: material characterisation in HLM ; Oxidation behavior and SCC of materials in SCWR conditions ; Modelling of irradiation damage on FeCr alloys; F/M steels and Oxide Dispersion Strengthened steels. SFR: Feasibility and cost enquiry study for primary circuit; welding joints and vessel; reactors. SCWR: Perform oxidation and constant extension rate tensile tests (CERT) at different temperatures, environments and pressures (estimated budget: 1700 kEUR and Human Resources: 1500 person-month)
- UPM: Continuation in the frame of EU projects - Core safety parameters of the SFR ASTRID prototype and of the LFR ALFRED demonstrator; impact of nuclear data uncertainties on core behaviour. Sensitivity and uncertainty analysis in fuel cycle and criticality calculations for MYRRHA; identification of relevant nuclear data to be improved 2018 (estimated budget: 160 kEUR and Human Resources: 36 person-month)
- UPV: Finalization of previous tasks (estimated budget: 28 kEUR and Human Resources: 2 person-month)

United Kingdom

The University of Manchester (UoM); the University of Sheffield (UoS) and MOLTEX are involved in the domain of MSR and SCWR, none of which were linked to the EU Framework Programmes.

- MOLTEX: MOLTEX has focussed on neutronic, thermal hydraulic and design costing studies
- UoS: Fundamental studies of flow and heat transfer of fluids at supercritical pressure in vertical channels, sub-channels relevant to SCWR using advanced computational fluid dynamics, including RANS, DNS and LES. Assessing and improving turbulence modelling for flows that are particularly relevant to SCWR.

Forthcoming

- UoM: University of Manchester has PhD students who are working on MSR-related projects (neutronic and thermal-hydraulic modelling, corrosion of candidate primary circuit alloys, behaviour of MAX-phase materials in molten salt environments.

References

All references are embedded in the document either as footnotes or links.

List of abbreviations and definitions

ALFRED	Advanced Lead Fast Reactor European Demonstrator
ASTRID	Advanced Sodium Technical Reactor for Industrial Demonstration
DG RTD	European Commission Directorate General for Research and Innovation
EERA JPNM	European Energy Research Alliance – Joint Programme on Nuclear Materials
ESNII	European Sustainable Nuclear Industrial Initiative
EU MS	European Union Member States
FA	GIF Framework agreement
FP5	Euratom Research Framework Programme 5
FP6	Euratom Research Framework Programme 6
FP7	Euratom Research Framework Programme 7
GFR	Gas-Cooled Fast Reactor
GIF	Generation IV International Forum
Horizon 2020	Euratom Research Framework Programme (2014-2018)
IAEA	International Atomic Energy Agency
JRC	European Commission Joint Research Centre
LFR	Lead-cooled Fast Reactor
MSR	Molten Salt Reactor
MYRRHA	Multipurpose Hybrid Research Reactor for High-tech Applications
NC2I	European Nuclear Cogeneration Industrial Initiative
NUGENIA	Nuclear Generation II and III Association
PRPPWG	GIF Proliferation Resistance and Physical Protection Working Group
RSWG	GIF Risk & Safety Working Group
SCWR	Supercritical Water-Cooled Reactor
SET-Plan	EU Strategic Energy Technology Plan
SFR	Sodium Fast Reactor
SNETP	Sustainable Nuclear Energy Technology Platform
STC	Euratom Scientific and Technical Committee
VHTR	Very High-Temperature Reactor
WENRA	Western European Nuclear Regulators Association

EU MS Organizations

Belgium

BelV	Technical Support Organization
UCL	Université Catholique de Louvain
SCK•CEN	Belgian National Nuclear Research Centre
TE	Tractebel Engineering S.A
VKI	the von Karman Institute for Fluid Dynamics

Bulgaria

INRNE-BAS	The Institute for Nuclear Research and Nuclear Energy – Bulgarian Academy of Sciences

Czech Republic

CVR	Centrum Výzkumu Rez (Research Centre Rez)

Finland

AaU	Aalto University
LUT	Lappeenranta University of Technology
STUK	Finnish Radiation and Nuclear Safety Authority
UoH	University of Helsinki

VTT	Technical Research Centre of Finland Ltd

Germany

GRS	Technical safety organization Gesellschaft für Anlagen- und Reaktorsicherheit
HZDR	Helmholtz-Zentrum Dresden-Rossendorf
KIT	Karlsruhe Institute of Technology
TUD	the Technical university of Dresden
UoS	University of Stuttgart

Hungary

BME	Budapest University of Technology and Economics
NTI	The Institute of Nuclear Techniques

Italy

CIRTEN	Consorzio Interuniversitario per la Ricerca Tecnologica Nucleare
CRS4	Center for Advanced Studies, Research and Development in Sardinia
DIME	Università degli Studi di Genova
ENEA	Italian National Agency for New Technologies, Energy and Sustainable Economic Development
IIT	Istituto Italiano di Technologia
POLIMI	Politecnico di Milano
POLITO	Politecnico di Torino
SRS	Servizi Ricerche Sviluppo
UNIPI	Università di Pisa

The Netherlands

NRG	Nuclear Research and consultancy Group
TuDelft	Technical University of Delft

Romania

RATEN ICN	The Institute for Nuclear Research, Pitesti

Sweden

KTH	The Kungliga Tekniska Högskolan

Slovenia

JSI	Jozef Stefan Institute
REC CO	Regional Environmental Centre for Central and Eastern Europe

Spain

ADEX SL	
CIEMAT	Centro de Investigaciones Energéticas MedioAmbientales y Tecnológicas Equipos Nucleares S. A.
UPM	Universidad Politecnica de Madrid
UPV	Universitat Politècnica de València

United Kingdom

MOLTEX	
UoM	The University of Manchester
UoS	the University of Sheffield (UoS)

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